

# **FINAL SUPPLEMENTAL BASELINE ECOLOGICAL RISK ASSESSMENT**

## **Volume 1: Sections 1 - 5**

### **Nyanza OU4 Chemical Waste Dump Superfund Site Operable Unit 4 – Sudbury River Ashland, Massachusetts**

Remedial Investigation/ Feasibility Study  
EPA Task Order No. 0026-RI-CO-0115

## **REMEDIAL ACTION CONTRACT**

### **No. EP-S1-06-03**

FOR

**U.S. Environmental Protection Agency  
Region 1**

BY

**Nobis Engineering, Inc.**

And

**Avatar Environmental, LLC.**

**Nobis Project No. 80026**

**December 2008**

**U.S. Environmental Protection Agency**

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Nyanza OU4 Chemical Waste Dump Superfund Site  
Operable Unit 4 – Sudbury River  
Ashland, Massachusetts  
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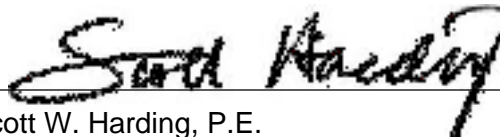
And  
Avatar Environmental, LLC.

Nobis Project No. 80026

December 2008

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## GLOSSARY

**Abiotic:**

Not associated with living organisms.

**Absorption:**

Penetration of a substance into an organism by various processes, including active and passive transport.

**Acute:**

Responses accruing within a short period in relation to the life span of the organism. It can be used to define either the exposure, or the response to an exposure.

**Acute exposure:**

Exposure to a chemical for a short period of time.

**Adsorption:**

An increase in the concentration of a dissolved substance at the interface of a condensed and a liquid phase due to the operation of surface forces.

**Adverse effect:**

Any effect that causes harm to the normal functioning of plants or animals due to exposure to a substance (i.e., a chemical contaminant).

**Antagonism:**

The effect created when the combined effect of two or more substances is smaller than the combined individual effects of the substances.

**Anthropogenic:**

Something that is caused or produced by humans: *anthropogenic air pollution*.

**Assessment endpoint(s):**

Part(s) of an ecosystem that should be protected at a particular site; this is generally some characteristic(s) of a species of plant or animal, such as reproduction, that can be described numerically.

**Average daily dose (ADD):**

Dose rate averaged over a pathway-specific period of exposure expressed as a daily dose on a per-unit-body-weight basis. The ADD is used for exposure to chemicals with non-carcinogenic non-chronic effects. The ADD is usually expressed in terms of mg/kg-day or other mass/mass-time units.

**Background concentration:**

The concentration of a substance in environmental media that is not contaminated by the sources being assessed or any other local sources. Background concentrations are due to regional contamination or natural occurrence.

**Benthic community:**

The group of plants and animals that live at the bottom of a pond, river, lake, or ocean.

**Benthic invertebrates:**

Those animals without backbones that live on or in the sediments of a lake, pond, river, etc.

**Bioaccumulation:**

Bioaccumulation is the general term describing a process by which chemicals are taken up by a plant or animal either directly from exposure to a contaminated medium (soil, sediment, water) or by eating food containing the chemical.

**Bioconcentration:**

Bioconcentration describes the process in which chemicals are absorbed by an animal or plant to levels higher than the surrounding environment.

**Bioconcentration factor (BCF):**

Ratio between the concentration of a substance in an organism or tissue and the concentration in the environmental matrix at apparent equilibrium during the uptake phase.

**Biomagnification:**

Biomagnification describes the process in which chemical levels in plants or animals increase from transfer through the food web (e.g., predators have greater concentrations of a particular chemical than their prey).

**Bioassay:**

A laboratory test which determines the strength or biological effects of a unknown or experimental substance, such as a drug, hormone or chemical; the test is done by comparing the experimental substance's effects with those of a known substance on a culture of living cells or a test organism.

**Bioavailability:**

How easily a plant or animal can take up a particular contaminant from the environment.

**Biomarker:**

Indicator signaling an event or condition in a biological system or sample and giving a measure of exposure, effect, or susceptibility. Such an indicator may be a measurable chemical, biochemical, physiological, behavioral, or other alteration within an organism.

**Biomass:**

The total mass (or weight) of plants and animals in a particular area; can be a particular group of plants or animals or a single species. This measurement can be used instead of counting individuals to help determine abundances in an area.

**Biomonitor:**

A species that is sensitive to, and shows measurable responses to, changes in the environment, such as changes in pollution levels.

**Carnivore:**

Animals that eat other animals.

**Chronic:**

Responses occurring after an extended time relative to the lifespan of an organism.

**Chronic Toxicity:**

The harmful effects of a substance or mixture of substances occurring after an extended exposure.

**Complete exposure pathway:**

A complete exposure pathway is how a chemical can be traced, or expected to travel, from a source to a plant or animal that can be affected by that chemical.

**Composite sample:**

A composite sample is a collection of individual samples. Each individual sample is combined with the others. The resulting mixture (composite sample) forms a representative sample and is analyzed to determine the average conditions in a specific area.

**Conceptual model:**

A model that shows the relationship between historical sources of pollution, transport pathways, and media affected by the pollution.

**Conservative:**

A conservative risk assessment estimates high-end risk rather than low-end risk. A conservative risk assessment should not underestimate risk and, therefore, will indicate risk to most species of plants and animals.

**Contaminant:**

Any physical, chemical, biological, or radiological substance found in air, water, soil or biological matter that has a harmful effect on plants or animals; harmful or hazardous matter introduced into the environment.

**Cumulative distribution functions (CDF)**

A function expressing the probability that a random variable is less than or equal to a certain value.

**Cumulative effect:**

Overall change that occurs after repeated doses or exposures to a substance or physical stressor.

**Deposition:**

The removal of airborne substances to available surfaces that occurs as a result of gravitational settling and diffusion, as well as electrophoresis and thermophoresis; substances at low concentrations in the vapor phase are typically not subject to deposition in the environment

**Direct effect:**

An effect resulting from an agent acting on the assessment endpoint or other ecological component of interest itself, not through effects on other components of the ecosystem.

**Discrete data:**

Data collected from a single point in space and time

**Distribution:**

A set of values derived from a specific population or set of measurements that represents the range and array of data for the factor being studied.

**Dose:**

The amount of a substance available for interaction with metabolic processes or biologically significant receptors after crossing the outer boundary of an organism.

**Ecological risk assessment (ERA):**

A process that evaluates the likelihood that adverse ecological effects may occur or are occurring as a result of exposure to 1 or more stressors.

**Ecology:**

The scientific study of the relationship of organisms to each other and to their environment.

**Ecosystem:**

The sum of all the living plants and animals, their interactions, and the physical components in a particular area.

**Effects range – low (ERL):**

The concentration of a contaminant above which harmful effects may be expected to occur.

**Exposure:**

How a biological system (i.e., ecosystem), plant, or animal comes in contact with a chemical.

**Exposure characterization:**

The component of an ecological risk assessment that estimates the exposure resulting from release or occurrence in a medium of a stressor. It includes estimation of transport, fate, and uptake.

**Exposure concentration:**

The concentration of a chemical in its transport or carrier medium at the point of contact.

**Exposure duration (ED):**

Total time an individual is exposed to the chemical being evaluated.

**Exposure pathway:**

The physical course a chemical or pollutant takes from the source to the organism exposed.

**Exposure route:**

The way a chemical or pollutant enters an organism after contact (e.g., by ingestion, inhalation, or dermal absorption).

**Exposure scenario:**

A set of facts, assumptions, and inferences about how exposure takes place that aids the exposure assessor in evaluating, estimating, or quantifying exposures.

Extrapolation:

1) An estimation of a numerical value of an empirical function at a point outside the range of data that were used to calibrate the function. 2) The use of data derived from observations to estimate values for unobserved entities or conditions.

Field duplicate sample:

Two samples taken from and representative of the same population and carried through all steps of the sampling and analytical procedures in an identical manner. Duplicate samples are used to assess variance of the total method, including sampling and analysis.

Food web:

Interrelationships between the individual populations of species related to the transfer of energy.

Frequency distribution:

The organization of data to show how often certain values or ranges of values occur.

Habitat:

The place where a population of plants or animals and its surroundings are located, including both living and non-living components.

Hazard quotient:

The ratio of an exposure level by a contaminant (e.g., maximum concentration) to a screening value selected for the risk assessment for that substance (e.g. LOAEL or NOAEL). If the exposure level is higher than the toxicity value, then there is the potential for risk to the receptor.

Herbivore:

Plant-eating animal.

Home range:

The undefended area in which an animal performs its daily activities: primarily foraging, but also finding shelter, mating, etc.; this is opposed to a territory which is defended and is generally smaller than a home range.

Incidental ingestion:

Amount of substance (e.g. soil) oral ingested unintentionally.

Indirect effect:

An effect resulting from the action of an agent on some components of the ecosystem, which in turn effects the assessment endpoint or other ecological component of interest.

*In-situ*:

Assessments or tests that involve evaluating plants or animals in locations that might be affected by site contaminants and in reference locations, rather than laboratory tests done using generic materials and organisms. *In-situ* assessments and tests can provide more realistic evidence of adverse effects than laboratory tests; however, there is little control over many environmental factors and experimental organisms can be lost to adverse weather or other events.

Insectivore:

Insect-eating animal.

Intake:

The process by which a substance crosses the outer boundary of an organism without passing an absorption barrier (e.g., through ingestion or inhalation).

Intake rate (IR):

Rate of inhalation, ingestion, and dermal contact depending on the route of exposure. For ingestion, the intake rate is simply the amount of food containing the contaminant of interest that an individual ingests during some specific time period (units of mass/time). For inhalation, the intake rate is the inhalation rate (i.e., rate at which air is inhaled). Factors that can affect dermal exposure are the amount of material that comes into contact with the skin, the rate at which the contaminant is absorbed, the concentration of contaminant in the medium, and the total amount of the medium on the skin during the exposure duration.

Invertebrates:

Animals without backbones: e.g. insects, spiders, crayfish, worms, snails, mussels, clams, etc.

Lipophilic:

Substances having an affinity for fats.

LOAEL:

Lowest Observable Adverse Effect Level. The lowest level of a chemical stressor evaluated in a toxicity test that shows harmful effects on a plant or animal.

Lowest-observed-effect concentration (LOEC):

The lowest concentration of a test substance to which organisms are exposed that causes an observed and statistically significantly different effect (adverse or not) on the organism as compared with the controls.

Mean value:

The arithmetic average of a set of numbers.

Measurement endpoints and measures of effect:

A measurable ecological characteristic that is related to the valued characteristic chosen as the assessment endpoint and is a measure of biological effects (e.g., death, reproduction, growth) of particular species, and they can include measures of exposure as well as measures of effects. Measures of effect often are expressed as the statistical or numerical assessment endpoint summaries of the observations that make up the measurement.

Model:

A formal representation of some component of the world, or a mathematical function with parameters that can be adjusted so that the function closely describes a set of empirical data.

Moisture content:

The portion of foods made up by water. The percent water is needed for converting food intake rates and residue concentrations between whole weight and dry weight values.

Monte Carlo simulation:

An iterative resampling technique frequently used in uncertainty analysis in risk assessments to estimate the distribution of a model's output parameter.

NOAEL:

No Observed Adverse Effects Level. The highest level of a chemical stressor in a toxicity test that did not cause a harmful effect in a plant or animal.

No-observed-effect concentration (NOEC):

Greatest concentration or amount of a substance, found by experiment or observation, that causes no alterations (adverse or otherwise) of morphology, functional capacity, growth, development, or life span of the target organisms distinguishable from those observed in control organisms of the same species and strain under the same conditions of exposure.

Normal distribution:

The classical statistical bell-shaped distribution that is symmetric and parametrically simple in that it can be fully characterized by 2 parameters: its mean and variance.

Normalization:

Alteration of a substance concentration or other property to reduce variance due to some characteristic of an organism or its environment.

Omnivorous:

An omnivorous animal is one that eats both plants and other animals.

Palustrine wetlands:

Palustrine wetlands include nontidal wetlands dominated by trees, shrubs, persistent emergents, emergent mosses, or lichens.

PAHs/Polycyclic aromatic hydrocarbons:

Group of organic chemicals.

PEC/Probable effects concentration:

The level of a concentration in the media (surface water, sediment, soil) to which a plant or animal is directly exposed that is likely to cause an adverse effect.

Physiology/Physiological:

(The study of) the biological processes of a plant or animal; how things work and interact within a body, rather than just the organs and tissues themselves.

Piscivore:

A fish-eating animal (bird, mammal, reptile, amphibian, or other fish).



**Plankton:**

Free-swimming (as opposed to rooted/stationary) microscopic plants (phytoplankton) or animals (zooplankton) that live in water; they can be larval forms of other animals such as fish or crustaceans, or adult forms of plants and animals.

**PCBs/Polychlorinated biphenyls:**

A type of organic chemical with chlorine atoms that was extensively used in industry for a variety of purposes, but is now banned. Studies have shown that PCBs can cause cancer in rats and possibly in humans.

**Population:**

An aggregate of interbreeding individuals of a species, occupying a specific location in space and time.

**Receptor:**

The species, population, community, habitat, etc. that may be exposed to contaminants.

**Reference areas:**

Often incorrectly referred to as a control, this is a comparatively uncontaminated site used for comparison to contaminated sites in environmental monitoring studies. It can be the least impacted (or unimpacted) area of the site or a nearby site that is ecologically similar, but not affected by the contaminants at the site under investigation.

**Remediation:**

Cleanup or other methods used to remove or contain a toxic spill or hazardous materials from a Superfund site.

**Replicate sample:**

Two or more representative portions taken from the same sample and analyzed by different laboratories to estimate the interlaboratory precision or variability and the data comparability.

**Risk assessor:**

The person who analyzes information from a cleanup/site to determine if there is the possibility of harm to the local ecosystem.

**Risk manager:**

The person who makes decisions concerning how to proceed with the cleanup process in response, in part, to ecological risk studies.

**Risk calculation:**

A way of numerically estimating the possibility of risk to the environment.

**Risk characterization:**

A phase of ecological risk assessment that integrates the exposure and stressor response profiles to evaluate the likelihood of adverse ecological effects associated with exposure to the contaminants.

**Risk management:**

The process of deciding what regulatory or remedial actions to take, justifying the decision, and implementing the decision.

**Riverine wetlands:**

Riverine wetlands include wetlands and deepwater habitats contained within a channel, except those areas dominated by trees, shrubs, persistent emergents, emergent mosses, or lichens.

**Scientific management decision point (SMDP):**

A point during the Ecological Risk Assessment (ERA) process when the risk assessor communicates results of the assessment at that stage to a risk manager. Decisions on the next action(s) are made by the risk assessor and risk manager.

**Sediment:**

The material of the bottom of a body of water (i.e., pond, river, stream, etc.)

**Speciation:**

Determination of the exact chemical form or compound in which an element occurs in a sample.

**Stressors:**

Any factor that may harm plants or animals; includes chemical (e.g. metals or organic compounds), physical (e.g. extreme temperatures, fire, storms, flooding, and construction/development) and biological (e.g. disease, parasites, depredation, and competition).

**Surface water:**

All water naturally open to the atmosphere (rivers, lakes, reservoirs, streams, seas, etc.) and all springs, wells, or other collectors that are directly influenced by surface water.

**Susceptibility:**

The relative condition of an organism or other ecological component lacking the power to resist a particular stressor. It is inversely proportional to the magnitude of the exposure required to cause the response.

**Synergism:**

Toxicological interaction in which the combined effect of 2 or more substances is greater than the simple sum of the effects of each substance.

**TEC/Threshold effects concentration:**

A concentration in media (surface water, sediment, soil) to which a plant or animal is exposed, above which some effect (or response) will be produced and below which it will not.

**TEL/Threshold effects level:**

A chemical concentration in some item (dose) that is ingested by an organism, above which some effect (or response) will be produced and below which it will not. This item is usually food, but can also be soil, sediment, or surface water that is incidentally (accidentally) ingested as well.

**Toxic:**

Capable of causing injury or harm to an organism.

Toxicity testing:

A type of test that studies the harmful effects of chemicals on particular plants or animals.

Trophic level:

This term refers to the position of a species (or in some cases, types of species with similar feeding habitats) within a food chain or food web.

Uncertainty:

A lack of knowledge about certain factors in a study which can reduce the confidence in conclusions drawn from data in that study; it is opposed to variability which is a result of true variation in characteristics of the environment.

Uptake:

The process by which a substance crosses an absorption barrier and is absorbed into the body.

Vertebrates:

Animals with a backbone, such as fish, birds, and mammals.

## EXECUTIVE SUMMARY

The results of the 1999 BERA (Weston, 1999a) suggested that ecological risk might be present in Sudbury River Reaches 2, 3, 5, 6, 7, 8 and 9 due to mercury contamination in sediment and subsequent bioaccumulation in aquatic organisms. However, internal review comments to this BERA identified many data gaps that resulted in much uncertainty with the findings. Region 1 EPA developed a scope of work in March 2003 that identified an approach to address existing data gaps and reduce uncertainty when developing the final SBERA for Nyanza OU IV – Sudbury River. The primary objectives of the scope of work were to:

- accurately identify environmental bioaccumulation for mercury
- indicate where and what magnitude risks apply to what environmental receptors for which media, and
- otherwise provide data that is useful to the risk manager.

The scope of work for this SBERA broke the Sudbury River Reaches into 4 major decision target areas:

### Primary target areas

- Reaches 2, 3, and 4 (primary reservoirs – note: Reach 2 is impounded at Mill Pond, but is not strictly a reservoir)
- Reach 8 – Great Meadows National Wildlife Refuge

### Secondary target areas

- Reaches 5, 6, and 7 (flowing reaches)
- Reaches 9 and 10 (Fairhaven Bay and remainder of river)

For most reaches, all six assessment endpoints for this SBERA (see Table 2-68) were evaluated with two or more lines of evidence to assess risk using a WOE approach. Using a systematic WOE process integrated both the quality of the assessment and the magnitude of response for each line of evidence.

Using the risk criteria from Section 4.3 and comparing to concentrations at local reference areas and from regional data sources, only four lines of evidence showed a likelihood of adverse ecological effects above baseline: sediment mercury concentrations compared to benthic community TEC and PEC benchmarks; mercury levels in TL >20 cm fish compared with LEL reproductive CBRs, mercury levels in Reach 8 red-winged blackbird blood (collected in 2005) compared to a generic avian blood effect level, and mercury levels in hooded merganser

eggs from Reaches 4 and 8 in 2005. The following discussion evaluates the confidence and uncertainty with these four lines of evidence and assesses the risks associated with the assessment endpoints related to these lines of evidence.

Mercury concentrations in sediment were compared to consensus-based sediment quality guidelines (TEC and PEC) by MacDonald et al. (2000). In the uncertainty analysis, many concerns were identified by using co-occurrence sediment quality benchmarks to assess specific sediment sample toxicity (O'Connor et al, 1998; O'Connor, 1999; Lee and Jones-Lee, 2002). Note also that the mercury TEC did not meet the authors' criteria of predicting no toxic effect in 75% of the samples evaluated (the mercury TEC was successful 34% of the time). The PEC was more successful in predicting toxic effects in test samples; however, the data set used for the PEC development only had 4 toxic samples. Also, this SBERA has cited many studies showing that total mercury in sediments do not correlate strongly with mercury bioavailability and subsequent trophic transfer. The *Elliptio* study showed lower growth, but no effect on survival, in Reaches 2 and 3. However, growth was not reduced in Reaches 9 and 10, which were used as surrogate reference areas. The two other lines of evidence used to evaluate impacts to the benthic community (i.e., the *Hexagenia* [Reaches 3, 4, 8, and 9] and crayfish tissue levels [Reaches 2 through 7]) did not show risk to the benthic community. Therefore, we believe it is wise to follow the advice of Chapman (1995) and others that these benchmarks should not be used for stand-alone decision making. It is concluded that risk to the benthic community in the Sudbury River is limited, given the lack of concurrence between measurement endpoints, the high degree of uncertainty associated with sediment benchmarks and the surface water data that indicate that methylation is mostly associated with the wetland areas bordering Reaches 7 and 8.

Except for 4 largemouth bass (size class D, > 20 cm) samples; one each from Reaches 8 and 9, and two from Reach 10, there were no exceedances of the reproductive LEL. In general, over 90% of all fish samples were less than the reproductive NEL. While mercury concentrations were typically higher in impacted reaches when compared to reference areas and regional background, it appears that potential adverse effect levels are limited to larger, older fish at a higher trophic level. These results are consistent with previous studies describing the biomagnification potential of mercury in aquatic systems; however, the data do not support a conclusion of population-level risk for fish based on reproductive impairment.

Redwing blackbird blood evaluated in this assessment was limited to 10 samples (4 juvenile and 6 adult) collected in August of 2005. All 10 samples exceeded the conservative avian blood CBR derived from field observations of loon chick behavior, where a strong correlation was found between higher blood mercury levels in chicks and less time riding parents' backs but more time spent preening. These behavioral changes resulted in increased energy expenditures which were not compensated for with a higher feeding rate or more begging to parents for food; suggesting a reduction in the overall fitness of the affected chicks.

A key factor to consider in the interpretation of the redwing blackbird data is that these birds were sampled well beyond the point in the season when reproduction and chick rearing occur. Most of the other insectivorous bird blood samples collected for this assessment were obtained in the spring and early summer (only 25% of the 235 insectivorous bird blood samples were collected as late as August). Such early-season blood samples may not reflect long-term, site-specific exposures; however, these samples do reflect exposure during nesting and are expected to be the best indicators of survival, growth, and reproductive effects. The results of the CBR comparisons to other insectivorous bird tissue data do not suggest much concern with this assessment endpoint. Blood samples collected later in the summer reflect long-term site exposure which would include periods of lower river flow and higher water temperatures when both methylmercury concentrations in surface waters and bioaccumulation increase. Without nesting season or reference data available there is no information that would indicate adverse impacts to the assessment endpoint resulting from the blackbird blood data. However, blackbird blood results do show mercury accumulation which may indicate potential late season effects after the blackbirds leave the study area. Any effects after the nesting season and their implications for bird population dynamics are unknown, because the state of the science offers little insight on the effects of high mercury on the ability of adults to successfully nest the following year. Re-sampling of the same birds between May and July have shown that adult mercury blood concentrations often increase during the summer in contaminated areas (Oksana Lane, BRI, November 21, 2007, Personal Communication). It is therefore possible that tree swallows follow the redwing blackbird pattern by further increasing their blood mercury levels later in the summer. This theory cannot be verified because it is unfeasible to capture adult swallows after their chicks have fledged. Overall, the available evidence does not suggest a population-level risk based on effects to reproductive endpoints.

Most of the hooded merganser eggs from Reaches 4 and 8 (n=2 and 21, respectively) in 2005 exceeded the no-effect level CBR (500 µg/kg). These results alone indicate that adverse

reproductive effects are possible for this piscivorous avian species. However, three of the four merganser egg samples collected at reference locations (Delaney Wildlife Management Area and Whitehall Reservoir) in 2005 also exceeded the no-effect CBR. These findings, while limited by a small sample size for the reference areas, suggest that mercury accumulation in merganser eggs may be a regional phenomenon and not strictly associated with Nyanza site-related discharges. Reference area data must be given a great deal of weight in this context because of the widely recognized regional problem of high fish tissue mercury caused by atmospheric deposition.

Overall, the results of this SBERA do not indicate that mercury contamination resulting from Nyanza Site discharges are likely to result in population-level risk to ecological receptors residing in or using the Sudbury River. The conservative assumptions built into this approach support this conclusion, even though there is an acknowledged amount of uncertainty with several of the lines of evidence used to evaluate the six assessment endpoints.

## **SECTION 1**

### **INTRODUCTION**



## 1.0 INTRODUCTION

### 1.1 Purpose and Approach

Nobis Engineering, Inc. (Nobis), and its Team Subcontractor, Avatar Environmental, LLC has prepared this Supplemental Baseline Ecological Risk Assessment (SBERA) for the Nyanza Chemical Waste Dump Superfund Site, Operable Unit IV (OU IV SBERA) – Sudbury River (Site). This work was performed in accordance with the United States Environmental Protection Agency (EPA) Region I Remedial Action Contract 2 (RAC 2) No. EP-S1-06-03, Task Order No. 0026-RI-CO-0115. The SBERA documents the potential exposure and consequent risk to ecological receptors exposed to mercury contamination in the Sudbury River. This *SBERA* represents an addendum to a previous report, *Nyanza Chemical Waste Dump Superfund Site, Supplemental Baseline Ecological Risk Assessment*, prepared by Roy F. Weston, Inc. in 1999 (Weston, 1999a).

The *Supplemental Baseline Ecological Risk Assessment* (BERA) prepared in 1999 by Weston supplemented the original risk assessment prepared by NUS in its *Final Remedial Investigation Report: Nyanza Operable Unit III-Sudbury River Study* (OU III RI) (NUS, 1992). The findings presented in the NUS assessment determined that the potential risks to both human and ecological receptors were attributed principally to mercury contamination in the Sudbury River. To further evaluate the nature, extent, and potential impacts of the mercury contamination in the Sudbury River, EPA organized a multi-disciplinary task force (hereafter, Task Force) in 1994. The Sudbury River Task Force included representatives from EPA-New England, the U.S. Fish and Wildlife Service (USFWS), the U.S. Geological Survey (USGS), the Army Corps of Engineers (ACOE), the National Oceanic and Atmospheric Administration (NOAA), and the Framingham Advocates for the Sudbury River, as well as members of several academic and private research concerns.

Based on a review and ‘information gaps’ evaluation of the 1992 assessment related to the nature and extent of contamination in the Sudbury River, the Task Force was directed to develop information necessary to produce a scientifically defensible ecological risk assessment (ERA) associated with mercury contamination in the Sudbury River. In an effort to facilitate this investigation, EPA established Operable Unit IV – “Sudbury River” specifically to address mercury contamination within the river proper. The primary objectives of the Sudbury River Task Force were to:

- 1) Establish the extent of mercury contamination within the Sudbury River;
- 2) Determine the contribution of the Nyanza Site to any identified mercury contamination; and
- 3) Provide information necessary to refine remediation objectives for ecological and human health.

With the additional data collected by the Task Force, the Weston report further refined the previous risk estimates, and more importantly, focused the assessment of the ecological risk on exposure to mercury in the Sudbury River through several pathways including:

- 1) Bioconcentration and bioaccumulation of mercury in the benthic and pelagic communities in the Sudbury River and selected adjacent wetlands; and
- 2) Bioaccumulation and biomagnification of mercury in select prey species and consequent exposure to piscivorous birds and carnivorous mammals foraging the Sudbury River and selected adjacent wetlands.

The reader is referred to the 1999 BERA (Weston, 1999a) for a comprehensive treatment of the technical approach, concomitant data, and the evaluation of the risk posed through these pathways. In summary, the Weston report concluded mercury may result in risks to organisms exposed to sediment and foraging prey within the study area, except for the wetlands adjacent to Reach 4 and in Reach 10, although the data sets for each of these reaches were quite limited and the uncertainty associated with several endpoints was considered moderate to high, therefore, the conclusions were considered tenuous. The report also concluded that methylation is occurring in the wetland areas; bioaccumulation of methylmercury is occurring; and avian piscivores might be adversely affected by methylmercury.

Subsequent evaluation of the Weston report by EPA concluded that there were insufficient abiotic (e.g., sediment, surface water) and biotic (e.g., fish, invertebrate tissue) data for a number of reaches to adequately assess the ecological risk associated with the entire 60 km of the Sudbury River, beginning at the headwaters (upgradient of the Nyanza Site) and extending to the confluence of the Sudbury and Assabet Rivers.

To address these data limitations, during the period between Spring 2003 and Fall 2005, several government agencies and contractors collected sediment, surface water, and biota from each of ten reaches of the Sudbury River (Figure 1-1) for subsequent total mercury and methylmercury analyses. These data included:

- Sediment data collected from each of ten reaches in the Sudbury River as well as the reference areas;

- Surface water data collected from each of ten reaches in the Sudbury River as well as the Charles River reference area;
- Crayfish collected from each of the reaches in the Sudbury River inhabited by crayfish as well as the reference areas;
- Fish tissue data from several species and size classes collected from each of ten reaches in the Sudbury River as well as the reference areas;
- Avian blood, egg, and feather data from several species of piscivorous predators (i.e., belted kingfisher) and waterfowl (i.e., hooded mergansers) as well as insectivorous marsh birds from select reaches in the Sudbury River as well as reference areas; and
- Mammalian blood and tissue data from mink captured at select reaches in the Sudbury River.

These data were used to revise the previous assessment and to address several objectives:

- 1) Evaluate bioaccumulation risks for mercury;
- 2) Identify receptors and media for which the risks apply; and
- 3) Provide other data useful to risk managers.

This SBERA was conducted based on the general approach outlined in the *Final Risk Assessment Work Plan, Nyanza Superfund Site, Operable Unit IV, Sudbury River Mercury Contamination* (Avatar, 2005) and attendant comment documents. This assessment supplements the previously performed BERA by using reach-specific abiotic and biotic concentration data to estimate exposure. Consequently, the methodology used in the prior assessment has been followed to maintain consistency. However, where more recent data suggest the need to modify the approach (e.g., use of recent risk assessment conventions), these changes have been made.

Note also that discussions of the results of previous assessments are incorporated by reference in this document. As such the reader is referred to those earlier documents for a comprehensive discussion of those studies.

## 1.2 Ecological Risk Assessment Guidance

The Nyanza Chemical Waste Dump Site was placed on the National Priorities List (NPL) in 1982; therefore, this investigation is being performed under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) of 1980 as amended by the Superfund Amendments and Reauthorization Act (SARA) of 1986 under the authority of EPA Region 1.

The objective of the ERA is to characterize and quantify, where appropriate, the current impact and the potential ecological risks that would occur should no further remedial action be taken. This SBERA does not recommend remedial alternatives; rather, it provides one of the bases for risk management decisions for the Nyanza Site. The decisions regarding which remedial alternatives (if any) are appropriate to address the baseline risk will be made in the Feasibility Study (FS) process.

EPA's *Ecological Risk Assessment Guidance for Superfund: Process for Designing and Conducting Ecological Risk Assessments* (hereafter, referred to as the Guidance) (EPA, 1997a) will serve as the primary source of guidance in developing this SBERA. This Guidance describes a progressive and iterative process that is consistent with and incorporates the basic and fundamental approach to performing ERAs outlined by EPA's Risk Assessment Forum in its *Framework for Ecological Risk Assessment* (Framework) (EPA, 1992a) and *Guidelines for Ecological Risk Assessment* (Guidelines) (EPA, 1998). This Guidance outlines an 8-step process and several scientific/management decision points (SMDPs). An SMDP represents a significant communication point in the conduct of the ERA requiring the interaction of the risk manager and the risk assessment team. The purpose of the SMDP is to evaluate the relevant information and to re-evaluate the scope, focus, and direction of the ERA.

Although this SBERA does not explicitly require the six SMDPs outlined in the Guidance, meetings between EPA's risk managers and the risk assessment team have occurred and will continue to occur formally and informally on a regular basis to evaluate and approve or redirect the work up to that point (analogous to the SMDPs).

Several of the steps in the process (e.g., the screening level assessment – Steps 1 and 2) have already been addressed or are incorporated in the existing BERA (Weston, 1999a).

In addition to and incorporated within the framework of the guidance discussed previously, the following documents also were used in the development of this SBERA:

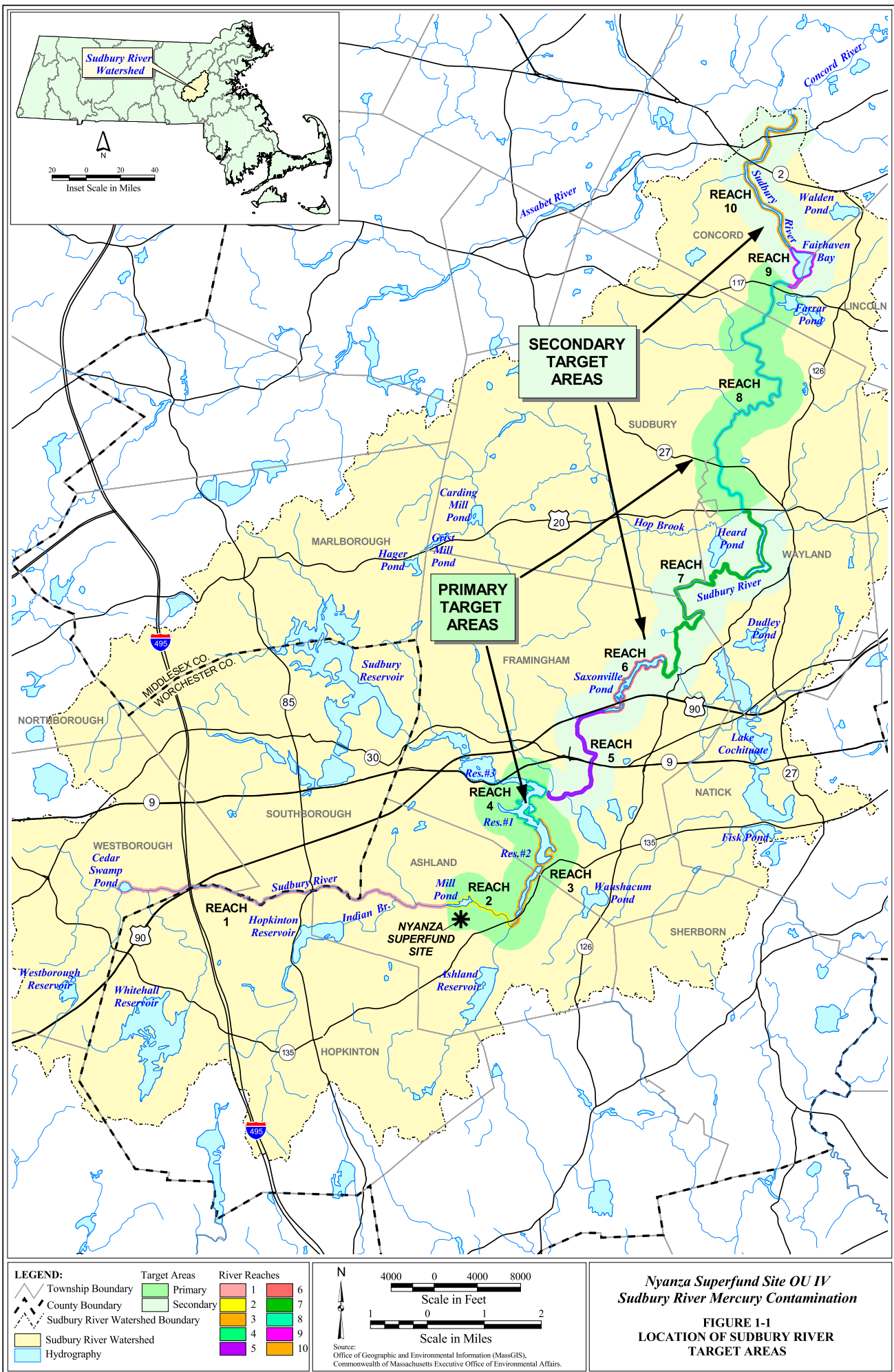
- *Guidelines for Ecological Risk Assessment* (EPA, 1998).
- *Framework for Ecological Risk Assessment* (EPA, 1992a).
- *Wildlife Exposure Factors Handbook, Volumes I and II* (EPA 600R-93/187a and 187b) (EPA, 1993a).
- *Risk Assessment Guidance for Superfund (RAGS), Volume II: Environmental Evaluation Manual* (EPA 540/1-89/001) (EPA, 1989).
- *Ecological Assessment of Hazardous Waste Sites: A Field and Laboratory Reference Document* (EPA 600/3-89/013) (Suter, 1989).
- *Ecological Risk Assessment Issue Papers* (EPA/630R-94/009) (Suter et al., 1994).
- ECO Updates, Volumes 1-4 (EPA Office of Solid Waste and Emergency Response) (EPA, 1991-1994).
- *Screening Level Ecological Risk Assessment Protocol for Hazardous Waste Combustion Facilities* (EPA 530-D-99-001A) (EPA, 1999).

### 1.3 Report Overview

The remainder of this report describes the comprehensive ERA process, which includes a number of technical components. A summary of each key component is provided below:

- Problem Formulation (Section 2)—This subsection describes ecosystems potentially at risk, assessment and measurement endpoint selection, the approach used for the weight-of-evidence (WOE), conceptual model development, as well as an analysis plan.
- Analysis Phase (Section 3)—This subsection is based on the conceptual model developed during the Problem Formulation and consists of two primary components: 1) Characterization of Exposure and 2) Characterization of Ecological Effects.
- Risk Characterization (Section 4)—This subsection is divided into two stages: risk estimation and risk description. The risk estimation integrates exposure and toxicity information from the Analysis Phase; estimates the likelihood of adverse effects on the assessment endpoint of concern; and addresses the uncertainty, assumptions, and limitations. The risk description provides a complete and informative synthesis of the overall conclusions regarding risk estimates; and can be used to make risk management decisions.

## SECTION 1 FIGURES



## **SECTION 2**

### **PROBLEM FORMULATION**



## **2.0 PROBLEM FORMULATION**

### **2.1 Introduction**

The problem formulation is the first stage in the development of an ERA. In the problem formulation stage, the risk assessment objectives are stated, the problem is defined in the form of a conceptual model, and the approach for analyzing and characterizing the ecological risk(s) is determined. The problem formulation typically results in several primary products that include: (1) assessment endpoints that adequately reflect the risk management goals and the ecosystems under investigation; (2) complete exposure pathways that incorporate fate and transport information with potential ecological receptors; (3) a conceptual model that describes key relationships between the contaminant(s) and assessment endpoints; and (4) the risk questions that the site investigation will address.

The discussion that follows presents an overview of the site history, site description, chemicals of concern, the conceptual model development, the assessment and measurement endpoint selection, and the weight-of-evidence (WOE) approach.

### **2.2 Site History**

#### **2.2.1 History of Operations**

The Nyanza Chemical Waste Dump Superfund Site (hereafter Nyanza Site) was occupied from 1917 through 1978 by several companies that manufactured textile dyes and dye intermediates. Additional products manufactured on-site included various colloidal solids and acrylic polymers. During the period of operation, large volumes of chemical waste were disposed in burial pits, below ground containment structures, and various lagoons scattered throughout the “Hill” section of the Site. Wastes contained in these disposal areas included partially treated process water, chemical sludge, solid process wastes (chemical precipitate and filter cakes), solvent recovery distillation residue, numerous organic and inorganic chemicals (including mercury), and off-specification products. Process chemicals that could not be reused or recycled, such as phenol, nitrobenzene, and mercuric sulfate, were also disposed of on-site or discharged into the Sudbury River mainly through a small stream referred to as Chemical Brook.

Mercury and chromium were used as catalysts in the production of textile dyes from 1917 to 1978. Approximately 2.3 metric tons (2,300 kg) of mercury were used per year from 1940 to

1970 (JBF Scientific Corp., 1972), with approximately 45 to 57 metric tons of mercury released to the Sudbury River during this period (JBF Scientific Corp., 1973). From 1970 until the facility closed in 1978, wastes were treated on-site and wastewater was discharged to Ashland's town sewer system. These revised treatment practices reduced the quantity of mercury released to the Sudbury River to between 23 and 30 kg per year or about 0.2 metric tons during that eight-year period.

Nyanza, Inc. was cited for several waste disposal violations by the Massachusetts regulatory agencies from 1972 to 1977. In 1981, most of the property was acquired by MCL Development Corporation, which leased a large portion of the Site to Nyacol Products, Inc. In 1982, the Nyanza Site was placed on the National Priorities List (NPL) by the U.S. EPA. Four other small property owners currently operate or lease facilities to various light industries and commercial concerns including, Ashland Excavating Co., Ashland Auto Body, A & J Air Conditioning and Gas Heating Service, and Middlesex Screw Machine.

### **2.2.2 History of Site Investigations**

To expedite remediation, the RI/FS for the Nyanza Site was originally divided into the following three Operable Units (OUs):

- OU I — addressed on-site surficial soil, sediment and sludges (Record of Decision signed and most remedial construction activities have been completed).
- OU II — “Nyanza II - Groundwater Study” — addresses groundwater contamination from the Site and determines the presence of off-site migration. The investigation is ongoing.
- OU III — “Nyanza III - Sudbury River” — originally addressed contamination of the Sudbury River by discharges of wastewater and sludge from the Site; OU III has since been additionally focused on addressing mercury contamination in soils and surface water in the continuing source areas, which are the Eastern Wetlands, Trolley Brook, Outfall Creek, and the Lower Raceway. In 1993, a decision was made to excavate and landfill contaminated sediments from these wetlands. The design of the remedy was completed in 1998 and cleanup activities began in March 1999. Over 45,000 cubic yards of mercury-contaminated sediments were excavated from four areas (Eastern Wetland, Trolley Brook, Outfall Creek, and Lower Raceway) and disposed of in the on-site landfill. EPA completed all remedial and restoration activities by August 2001.

Table 2-1 presents a chronology of key activities that have occurred at the Site prior to and since its placement on the NPL. A more detailed presentation of the OU I, II, and III investigations conducted at the Site and their findings can be found in the *Final Remedial Investigation Report: Nyanza Operable Unit III-Sudbury River Study* (NUS, 1992).

As a result of the findings in the OU III RI, EPA determined that the potential risk to both human health and ecological receptors could be attributed principally to mercury contamination of the Sudbury River. To further evaluate the nature, extent, and potential impacts of mercury contamination in the river, EPA established an additional operable unit (Operable Unit IV - Sudbury River) specifically to address mercury contamination within the river proper. Table 2-2 presents a list of studies, including their researchers and objectives, which have been conducted as part of the OU IV assessment.

### **2.3 Site Description**

The Nyanza Site is located in Ashland, Massachusetts, approximately 35 km west of Boston. The Nyanza Site, which covers approximately 35 acres, is situated in an industrial area 0.4 km south of the Sudbury River. Surface water runoff and groundwater discharged from the Site drains to Trolley Brook, Chemical Brook, and the Eastern Wetland (Figure 2-1). Trolley Brook, which drains the Eastern Wetlands, and Chemical Brook are the primary site drainages. Trolley Brook merges with Chemical Brook and continues through a culvert that discharges to Outfall Creek, a small man-made channel approximately 60 m long. Outfall Creek flows to the Lower Raceway, which joins the Sudbury River 240 m downstream from the Site.

Whereas the OU III RI (NUS, 1992) included the wetlands and surface water drainages of the Nyanza Site and the Sudbury River, for this SBERA, the study area (OU IV) consists of the Sudbury River proper, selected drainage areas that provide input to the Sudbury River, and reference areas that provide information regarding reference levels of mercury in surface waters proximate to the Sudbury River and in the biota inhabiting those waters. The study area consists of an approximately 60 km stretch of river that begins in the river's headwaters and extends to the confluence of the Sudbury and the Assabet Rivers to form the Concord River (Figure 1-1).

The Sudbury River flows northerly through rolling, hilly terrain and consists of a series of impoundments, flowing reaches, and extensive fringing wetlands. A large portion of the land surrounding the study area is suburban residential, consisting of several closely spaced urban centers connected by arterial commuting routes. The watershed area of the Sudbury River is approximately 165 square miles. In the OU III RI (NUS, 1992), the Sudbury River was divided into ten reaches (i.e., river segments) that were based on changes in river configuration, impounding structures, and stream junctures (Figure 1-1). The same geographical convention, i.e., reaches, was also used in the more recent investigations conducted specifically to evaluate potential mercury impacts within OU IV and continues to be used as part of this SBERA. A detailed description of reaches, boundaries, and characteristics is provided in the OU III RI (NUS, 1992).

### **2.3.1 Sudbury River Reach Descriptions**

The following discussion presents a brief description of each reach and any identified subreaches. Note that because of their size and, in some cases, distinct intra-reach hydrography, a number of the reaches were subdivided into subreaches. The purpose of this additional segmentation was to provide greater resolution for investigating the relationship between levels of mercury in sediment in a specific area with the levels of mercury in biota (e.g., crayfish, fish) collected from that same area. (See Figures 2-2 through 2-9). Because of their habitat type and the likelihood of target species presence, several of these subreaches throughout the river were selected for detailed investigations and were termed focus areas. For example, a preliminary investigation of the Sudbury River below the Winter Street dam (i.e., Subreaches 5.1 and 5.2) indicated the presence of a sizeable population of crayfish. To better understand the relationship between the mercury in sediment and the mercury in crayfish inhabiting those sediments, a detailed investigation of this relationship was conducted in this focus area. Similar investigations were conducted at focus areas in the vicinity of the railway bridge at the upper end of Reservoir No.2 (Subreach 3.1) and in Reach 7 (Subreach 7.1) below the Saxonville dam.

- Reach 1— this reference area extends from the headwaters of the Sudbury River in Cedar Swamp to the Pleasant Street Impoundment.

- Reach 2—extends from the Pleasant Street Impoundment to the Union Street Bridge (Route 135) in Ashland. Reach 2 is directly impacted by site discharges in and downstream of Mill Pond, the only impoundment located in this reach. The OU III surface water bodies (i.e., Trolley Brook, Chemical Brook, Outfall Creek, and Lower Raceway) and wetlands (i.e., Eastern Wetlands) discharge into the Sudbury River within Reach 2. Again, note that remediation of the surface drainages from the Site and the Eastern Wetlands was completed in August 2001 – approximately 2 years prior to this latest round of data collection. In addition, contaminated groundwater underlying the Site discharges to Mill Pond. Subreach 1 encompasses an approximately 500 meter (m) stretch, beginning immediately below the joining of the two raceways of the Mill Pond dam. The area is characterized as shallow (<0.46 m deep) with fairly high stream velocities, and bottom sediments that are dominated by pebbles. Sand and finer grained sediments are dominant in the vicinity of stream eddies. Subreach 2 extends from the end of Subreach 1 to the end of Reach 2, a distance of about 800 m (~ ½ mile). As with the upper reach, the river in Subreach 2 is narrow and shallow. A portion of the river in the subreach (approximately 200 m) has been culverted below ground before re-surfacing about 300 m from the mouth of Reservoir No.2.
- Reach 3—extends from the Union Street Bridge to the Reservoir No. 2 dam. Reach 3 contains Reservoir No. 2 (116 acres, mean depth 3.1 m, maximum depth 4.9 m) and receives discharge from Cold Spring Brook. Reservoir No. 2 is the first major sediment depositional area downstream of the Site. This reservoir was developed in 1879 to supply water to Boston. Because of its size, Reach 3 was subdivided into 3 distinct areas. Subreach 1 is located at the uppermost portion of Reach 3 and includes that area from the point of discharge of Reach 2 near Chestnut Street to the bridge supporting the Massachusetts Commuter Rail Service over the Sudbury River. This area represents a quiescent headwater of the reservoir and a depositional area for sediments transported from the more dynamic Reach 2. Subreach 2 of Reach 3 includes the lobed portion of Reservoir No.2 located between the commuter bridge and the Fountain Street Bridge. Subreach 3 includes that portion of Reservoir No. 2 between the Fountain Street Bridge and the Reservoir No.2 dam. Subreach 3 has historically had some of the highest mercury levels in sediments. This lower lobe of the reservoir is on the order of 3 to 4.5 m deep, and is steep-sided, i.e., the drop off along the shoreline is fairly sharp. Sediments in the reservoir are predominantly fine-grained.
- Reach 4—extends from the Reservoir No. 2 dam to the Reservoir No. 1 dam at Winter Street. Reservoir No. 1 comprises Reach 4 (121 acres, mean depth 2.2 m, maximum depth 4.0 m) and is the second principal impoundment downstream from the Site. Reach 4 was also divided into 2 subreaches and includes the portion of Reservoir No.1 from the upstream dam to the end of the peninsula in the vicinity of Fenelon Road (Subreach 1) and the remainder of the reservoir (Subreach 2). In addition to discharges from the

upstream portion of the Sudbury River, Reservoir No. 1 receives discharge from the Framingham Reservoir No. 3 reference impoundment which, in turn, receives source water from the Sudbury Reservoir. Neither the Sudbury Reservoir nor Reservoir No. 3 receives surface drainage from the Site. Reaches 3 and 4 are similar in that they consist primarily of impounded areas with slow moving water. As with Reservoir No. 2, this reservoir was also developed as a water supply for Boston.

- Reach 5—extends from the Reservoir No. 1 dam at Winter Street to the Massachusetts Turnpike (Interstate 90) overpass, where the Sudbury River widens. The upper portion of this reach is typically narrow with high stream velocity and only minor depositional areas. In the lower portion of this reach, the river broadens as a result of water retention in Saxonville Reservoir and the water velocity diminishes. Sediment deposition is expected to occur in this portion of the reach. Subreach 1 encompasses an approximately 500-m stretch, beginning immediately below the pooled area below the Reservoir 1 dam at Winter Street to the old railroad overpass. This area was the location designated as a focus area for evaluating the relationship between mercury levels in sediments and in crayfish collected from this area. With the exception of a pool about 0.9 to 1.2 m deep just below the Winter Street Bridge, this stretch of river is characterized as shallow (0.6 m) with moderate velocity. The flow in this section of stream reflects riffle-glide characteristics with fairly steep riparian border and dense overhanging canopy. Sediments in this subreach are characterized by sand, pebbles, and silt. Subreach 2 extends approximately 1.6 km from the end of Subreach 1 to the Massachusetts Route 9 Bridge (Worcester Road). This area also was used to evaluate the mercury sediment/crayfish relationship. Although similar in stream hydrography to Subreach 1, this reach has a much higher proportion of glides with a few pools. As such, the sediments in this area are siltier. Subreach 3 extends from the Route 9 Bridge to the Massachusetts Turnpike bridge (Interstate 90), a distance of about 2.7 km. The subreach begins as a moderate flowing stream that eventually widens as it borders the Massachusetts Turnpike. This section of the river is essentially a shallow ponded area of low velocity and supports both open water and a vegetated aquatic habitat.
- Reach 6—extends from the Turnpike overpass to the Saxonville Dam. This reach includes a small section of flowing river and a ponded depositional area behind the Saxonville Dam (Saxonville Reservoir). Saxonville Reservoir supports both open water and vegetated aquatic habitat. Rooted macrophytes occur primarily at the shallower head of the reservoir and along the shoreline. Because of the similarity of the hydrography of Saxonville Reservoir, no subreaches were assigned to Reach 6. Sediments in the reservoir are dominated by mud and fine silts with some sand near the top of the reservoir in the vicinity of the Massachusetts Turnpike Bridge where the river narrows.

- Reach 7—extends from the Saxonville Dam downstream to the Route 20 overpass in Wayland. Because of its size, Reach 7 was divided into 3 subreaches. Subreach 1 extends from just below the Saxonville Dam to about the Stone Bridge Road, a distance of nearly 3.2 km. The upper portion of this stream has been engineered for flood control and is bordered by flood control revetments. Because of the higher water velocities in this segment, the bottom is predominantly rock and pebble. At the time of the survey, this section of the stream was also littered with extensive debris from the adjacent urbanized area. Subreach 2 extends from Stone Bridge Road to that portion of the river adjacent Heard Pond. Subreach 3 is Heard Pond, which, although not an impoundment of the Sudbury River, lies within the Sudbury's floodplain and at times of high water receives overflow from the river. The lower segments of Reach 7 reflect a low stream gradient (<1 foot per mile or 19 cm per km) resulting in a slow, meandering river with increased potential for deposition. This area is bordered by extensive sedge meadows that receive and sequester transported sediment during periods of high flow.
- Reach 8—Reach 8 includes the Great Meadows National Wildlife Refuge (GMNWR) and extends from the Route 20 overpass to the Route 117 overpass just upstream of the Fairhaven Bay inlet. The river channel within Reach 8 meanders through an extensive wooded and emergent wetland complex that has a high depositional potential. The sedge meadows of Reach 8 are completely inundated in spring during high seasonal flow and also during other periods of heavy precipitation. The area is characterized by moderate depth (~1.5 m) with low velocity. Sediments in this portion of the Sudbury River are characterized by silt and sand. As with much of the Sudbury River, the Great Meadows area is iced-over during most winters. Subreach 1 of Reach 8 extends from Rte 20 (Boston Post Road) to Rte 27 (Old Sudbury Road), a distance of 1.6 km. Subreach 2 includes that portion of the Sudbury River from the Rte. 27 Bridge to Sherman's Bridge; a distance of a little less than 4.8 km. Subreach 3 includes the 4 km segment of the river from Sherman's Bridge to Route 117 (South Great Road).
- Reach 9—extends from the inlet area to Fairhaven Bay to the Fairhaven Bay outlet. Fairhaven Bay is a large pond-like feature in the Sudbury River (67 acres, mean depth 1.5 m, maximum depth 3.4 m) that is the last major depositional area before the Sudbury/Assabet River confluence. The area supports shallow open-water habitat and areas of rooted aquatic vegetation. The substrate is primarily mud and fine silt. There were no subreaches designated for Reach 9.
- Reach 10—extends about 5.6 km from the Fairhaven Bay outlet to the Sudbury/Assabet River confluence at Egg Rock in Concord. This portion of the Sudbury River has a flow regime similar to that of Reach 8, with slightly less meander. There were no subreaches designated for Reach 10.

### **2.3.2 Reference Area Descriptions**

Portions of the Sudbury River lie within the Boston-Sudbury Lowland and Eastern Plateau hydrologic provinces of eastern Massachusetts (Motts and O'Brien, 1981). Reference areas located within these provinces were used to provide data on reference levels of mercury for the field investigations.

In establishing reference areas for the Sudbury River, several areas were chosen to represent three types of riverine characteristics:

- 1) a lotic environment characterized by shallow water (i.e., < 3 ft) segments of moderate to fast flowing water;
- 2) a lotic environment characterized by somewhat deeper water segments (i.e., > 3 ft) of relatively slow flowing water; and
- 3) a lacustrine environment characterized by reservoirs and ponds.

The primary reference areas include Reach 1 (headwaters of the Sudbury River), the Charles River in the vicinity of Millis, and the Sudbury Reservoir west of Framingham.

#### **2.3.2.1 Reach 1 – Headwaters of the Sudbury River**

Reach 1 (Figure 2-10) extends from the headwaters of the Sudbury River in Cedar Swamp to a small dam (referred to as the Pleasant Street Impoundment), just upstream of Mill Pond in Ashland. The flowing portion of Reach 1 serves as a reference area for Reaches 2 (Pleasant Street Impoundment to Union Street Bridge), 5 (Winter Street Dam to Massachusetts Turnpike), 7 (Saxonville Dam to Rte 20 overpass), and 10 (Fairhaven Bay Outlet to Assabet confluence).

#### **2.3.2.2 Charles River**

The Charles River reference area lies within the Boston-Sudbury Lowland hydrologic province (Figures 2-11 and 2-12). This province represents a small irregularly-shaped area of low relief in eastern Massachusetts. It consists mainly of broad plains interrupted by numerous low hills and ridges. The lowland in the vicinity of the Site and reference areas is drained by the Charles and Sudbury Rivers. The surficial geology of the region consists mostly of stratified drift surrounding drumlins and isolated till-covered bedrock hills. Glaciolacustrine sediments occupy much of the lowland around the Sudbury River (Motts and O'Brien, 1981). The habitat of the Charles River near Millis is similar to that of the Sudbury River especially in the vicinity of the GMNWR. Flow



characteristics, open water, emergent wetlands and adjacent scrub-shrub areas are similar and are expected to support fish and wildlife species that have been observed in the Great Meadows and other meandering portions of the Sudbury River watershed. The Charles River was selected to serve as a reference for portions of the slower flowing areas of the Sudbury River, including Reach 8 (GMNWR) and Reach 9 (Fairhaven Bay).

#### **2.3.2.3 Sudbury Reservoir**

The Sudbury Reservoir is a man-made impoundment located within the Eastern Plateau province (Figures 2-13 and 2-14). This province is characterized as a low-lying region, sloping gently seaward. Elevations in this province are generally less than 500 ft above sea level. In addition to the Sudbury River, this region is drained by the Concord, Charles, and Assabet Rivers, among others. Surface waters reflect poorly-integrated drainage due to disruption by glaciation. Surface topography in the province reflects stratified drift of sand and gravel deposits (Motts and O'Brien, 1981). The Sudbury Reservoir was selected to serve as a reference for the impounded areas of the Sudbury River, including Reach 2 (Mill Pond), Reaches 3 and 4 (Reservoirs 2 and 1, respectively), and Reach 6 (Saxonville Reservoir). Although lacking the substantial industrial, commercial and residential development surrounding many of the Sudbury River reservoirs, it is, nevertheless, expected to provide a suitable reference area for ambient mercury levels in biota.

#### **2.3.2.4 Delaney Wildlife Management Area**

The Delaney Wildlife Management Area is located on the Assabet River in Stowe, Massachusetts and was selected as a reference area for mercury levels in blood and egg samples of waterfowl (specifically, hooded mergansers) collected from the Sudbury River (Figure 2-15). The Delaney Wildlife Management Area encompasses 514 acres of diverse habitat including 3 ponds that are utilized by mergansers, wood duck, and other waterfowl for nesting. It is in the Assabet River drainage which has no known concern for mercury contamination other than that associated with atmospheric deposition reflected by the regional levels of mercury in waterbodies throughout Massachusetts and the rest of New England.

### **2.3.2.5 Whitehall Reservoir**

Early in the monitoring program, Whitehall Reservoir was chosen to represent a reference area for mercury levels in blood and egg data for waterfowl, tree swallows, and possibly other insectivorous birds (Figure 2-16). Whitehall Reservoir is at the top of the Sudbury River watershed and is approximately 580 acres (mean depth 2.0 m, maximum depth 9.8 m). It had been previously sampled to assess background conditions in fish. Subsequent efforts to collect swallows in this area indicated that the riparian habitat adjacent the reservoir was not altogether favorable for nesting of these birds. As such, collection of tree swallow data from Whitehall Reservoir was discontinued after the first season of sampling. It was also decided that the Sudbury Reservoir was a more appropriate background location for the other avian species than Whitehall Reservoir. Therefore, no samples were submitted from Whitehall Reservoir for collection years after 2003.

### **2.3.3 Ecological Setting**

Part of the problem formulation is to assess whether the COECs and ecological receptors co-occur, resulting in exposure and the potential for adverse effects. A principal component in making this determination is the evaluation of the ecological setting. This task was addressed in the 1999 BERA (Weston, 1999a), where it was determined that upper trophic level organisms were at risk to adverse effects as a result of mercury exposure through food chain transfer.

Due to the length and complexity of the Sudbury River ecosystem, it would be impractical to attempt to describe this ecosystem in anything but general terms. In an effort to describe key ecological characteristics of the Sudbury watershed, the following state, federal, and private agencies were contacted: Massachusetts Division of Fisheries and Wildlife, USGS, USFWS, Great Meadows National Wildlife Refuge, and the Massachusetts Audubon Society. Specific information requested included habitat descriptions, population surveys and inventories, threatened and endangered species accounts, localized habitats of special concern, and any general information pertaining to the ecological communities directly or indirectly associated with the Sudbury River.

The purpose of this ecological setting subsection is to present the key findings of previous biological assessments conducted within the Sudbury River drainage. This information, in

conjunction with information provided in the site contaminant characterization, is integrated so that the reader can follow the problem formulation development process that ultimately results in the selection of assessment endpoints. The ecological setting description has been divided into the following subsections: general habitat description; common wildlife and aquatic life; and threatened and endangered species, and species and habitats of special concern.

#### **2.3.3.1 General Habitat Description**

The Sudbury River is a relatively low gradient stream with faster flowing areas and associated riffle and pool complexes limited primarily to the headwater regions of the river and directly downgradient of impoundment dams (e.g., below Saxonville dam). Throughout its course, the river flows through a series of alternating small woodlots, emergent and forested wetlands, and urban areas. Vegetation along the river banks is dominated by red maple (*Acer rubrum*), black willow (*Salix nigra*), button bush (*Cephalanthus accidentalis*), sweet pepperbush (*Clethra alnifolia*), smartweed (*Polygonum spp*), river birch (*Betula nigra*), and arrowwood (*Viburnum recognitum*).

Some of the more common herbaceous plants identified within the floodplain, especially in or adjacent to impounded areas include: bittersweet nightshade (*Solanum dulcamara*), jewelweed (*Impatiens capensis*), purple loosestrife (*Lythrum salicaria*), swamp smartweed (*Polygonum coccineum*), arrowhead (*Sagittaria latifolia*), arrow arum (*Peltandra virginica*), Joe-pye weed (*Eupatorium maculatum*), and water hemlock (*Cicuta maculata*).

Perhaps the most sensitive and diverse natural habitats associated with the Sudbury River are the extensive emergent and forested wetland areas which border the river and the tributaries of several locations along its course. The most extensive wetland areas associated with the Sudbury are found in the headwater region of Reach 1 near Cedar Swamp Pond where the river meanders for several kilometers before reaching Hopkinton wetland complex, which borders the river at the end of Reach 7; the beginning of Reach 8 where Hop Brook discharges into the Sudbury; and where the GMNWR begins. The Sudbury River meanders through the GMNWR for the majority of Reach 8 before discharging into Fairhaven Bay, a lake-like waterbody of the Sudbury River. The GMNWR consists of approximately 3,000 acres of prime wetland wildlife habitat. Dominant vegetation associated with these wetland areas include: button bush,

common cattail (*Typha latifolia*), tussock sedge (*Carex stricta*), soft rush (*Juncus effusus*), reed canarygrass (*Phalaris arundinacea*), burreed (*Sparaganium americanum*), great bulrush (*Scirpus validus*), and marsh mermaid weed (*Proserpinaca palustris*).

Partially submerged aquatic vegetation typically found within ponded and slow-moving portions of the river include: yellow pond lily (*Nuphar variegatum*), white water lily (*Nymphaea odorata*), duckweed (*Lemna minor*), water-meal (*Wolffia columbiana*), water clover (*Marsilea quadrifolia*), water chestnut (*Trapa natans*), coontail (*Ceratophyllum demersum*), low watermilfoil (*Myriophyllum humile*), water celery (*Vallisneria americana*), and pondweed (*Potamogeton natans*).

#### **2.3.3.2 Common Wildlife and Aquatic Life**

As a result of numerous contacts with the USFWS, the Massachusetts Division of Fisheries and Wildlife, Massachusetts Audubon Society, and Great Meadows National Wildlife Refuge, lists of the dominant wildlife and aquatic species associated with the Sudbury River were developed (Tables 2-3 and 2-4). These tables should not be considered comprehensive wildlife and aquatic life inventories; rather, they reflect key species that may come in direct or indirect contact with mercury contamination within the river. In addition, the species listed on these tables provide a general overview of the community structure and diversity found along the course of the river. In addition to the agencies, the following primary references were used to develop species lists: *Birds of the Sudbury River Valley: An Historical Perspective* (Walton, 1984); *The Concord, Sudbury and Assabet Rivers: A Guide to Canoeing, Wildlife and History* (McAdow, 1990); *Fish of the Concord and Sudbury River and Other Waters in Great Meadow National Wildlife Refuge* (USFWS, 1979a); *Great Meadows National Wildlife Refuge; Amphibians and Reptiles* (USFWS, 1979b); *Bird Checklists of the United States; Great Meadow Wildlife Refuge* (USGS, 1997); and *New England Wildlife: Habitat, History, and Distribution* (DeGraaf and Rudis, 1986).

#### **2.3.3.3 Threatened and Endangered Species, and Species and Habitats of Special Concern**

The Massachusetts Natural Heritage and Endangered Species Program (MNHESP) database was searched to determine the potential presence of any endangered, threatened, or rare plant,

animals or communities within the Sudbury River watershed. This database is the most extensive information source currently available. The report generated (July 2008) summarized data collected from literature sources, herbaria, museums, universities, and field surveys by staff and cooperating biologists. The information provided by MNHESP is the most comprehensive database available for assessing the presence of threatened or endangered species or species and communities of special concern; however, this database is constantly being expanded and updated and cannot be interpreted as the definitive word on the presence of critical species and habitats within a given locale. The results of the Heritage Program database search for the Sudbury River watershed are presented in Table 2-5.

In addition, the US Fish and Wildlife “Federally Listed Endangered and Threatened Species in Massachusetts” (September 2007) was obtained. Of the 14 species FWS T&E species listed for Massachusetts, only three have the potential to be present in counties within the study area: eastern cougar (*Felis concolor cougar*); bald eagle (*Haliaeetus leucocephalus*) and small-whorled pogonia (*Isotria medeoloides*). The cougar is a historic resident of the entire state and is listed as endangered. The bald eagle is delisted as a FWS T&E species, but is protected under the Bald and Golden Eagle Protection Act and the Migratory Bird Treaty Act. Worcester County, among others, is listed as part of the eagle’s distribution area. Reach 1, a reference area, is the only portion of the Sudbury River in Worcester County. Lastly, the small whorled pogonia is listed as threatened by FWS and has Middlesex and Worcester counties included in its distribution area. It is unlikely that the pogonia (an orchid) would be found in the study areas because it:

... occurs on upland sites in mixed-deciduous or mixed-deciduous/coniferous forests that are generally in second- or third-growth successional stages. Characteristics common to most *Isotria medeoloides* sites include sparse to moderate ground cover in the species’ microhabitat, a relatively open understory canopy and proximity to features that create long-persisting breaks in the forest canopy. (USFWS, 2001)

Complete documentation provided by the MNHESP and USFWS are presented in Appendices B and C, respectively.

## 2.4 Chemicals of Concern

This portion of the problem formulation phase is to provide a discussion of contaminant identification, fate and potential effects associated with the contaminants, potential ecological exposure pathways; and contaminant distribution, concentration, and frequency of detection. This process typically culminates in an identification of what chemicals of ecological concern (COECs) will be used throughout the remainder of the SBERA to evaluate ecological risks.

However, after a review of the historical data and the results of the *Final Remedial Investigation Report: Nyanza Operable Unit III – Sudbury River Study* (NUS, 1992), which included a complete suite of chemicals, it was determined that the primary COECs for the remaining evaluation of the Site were mercury and methylmercury.

Mercury is a dynamic pollutant because of its unique physical, chemical and bioaccumulative properties. The volatility of elemental mercury and several organic forms, in conjunction with its ability to transform under different environmental conditions, allows mercury to readily pass from one medium to the next. The fate of mercury in the biosphere is of particular concern because it is frequently bioavailable to organisms and can subsequently bioaccumulate and biomagnify within the food chain.

Mercury is released into the environment from both anthropogenic and natural sources. Because of its unique chemical and physical properties, mercury is readily transported through different types of environments while frequently changing its chemical form in the process (EPA, 1997b). Mercury enters the environment, in particular freshwater aquatic systems such as lakes, reservoirs, rivers, and wetlands, from three primary sources:

- Atmospheric deposition
- Point and non-point pollution sources
- Erosion of soils and sediments within a watershed.

The majority of mercury emitted into the atmosphere, and thus subject to deposition, is from a number of well-documented, man-made sources (e.g., combustion of fossil fuels and municipal waste incineration). Other substantial anthropogenic sources of mercury include smelting, biomedical waste incineration, chlor-alkali production, base metal mining, and mercury use in gold mining (Chan et al., 2003). These additional sources of mercury not only contribute to the

global mercury pool, they also frequently create local point sources that result in localized acute mercury contamination. There are some natural sources of mercury (e.g., volcanic activity), but the emissions from these sources do not compare to those from man-made sources (ATSDR, 1999). Atmospheric deposition is the primary source of mercury contamination for the majority of aquatic ecosystems (EPA, 1997b; Krabbenhoft et al., 1999). The northeastern United States receives some of the highest levels of mercury deposition in the country (Chen et al., 2005). Non-point sources are not as easily identifiable as point sources, but constitute a significant source of mercury. The natural weathering and erosion of soil and sediment can also release mercury. This can include the erosion of soil and sediment contaminated as a result of human activity as well as the weathering of natural deposits in soil and sediment.

Mercury in the environment can occur as a gas or liquid, or it may be associated with particulates. Mercury is very persistent, remaining in the environment for decades following removal of the source (NOAA, 1996). There are three oxidation states of mercury typically found in the environment. The oxidation state strongly influences the properties and behavior of mercury (EPA, 1997b).

- 1)  $\text{Hg}^0$  – elemental mercury; the most reduced form of mercury, is a liquid at ambient temperatures, but extremely volatile. The vast majority (95%) of mercury found in the atmosphere is in the elemental state (Jackson, 1997; ATSDR, 1999). Some of the elemental form can be oxidized and transformed while in the atmosphere before being deposited on land or in water.  $\text{Hg}^0$  is oxidized into inorganic Hg, primarily in the mercuric  $\text{Hg}^{+2}$  form and to a lesser extent, the mercurous ( $\text{Hg}^{+1}$ ) state. Elemental mercury is not likely to be found in environmental media, except for air.
- 2)  $\text{Hg}^{+2}$  – mercuric; can form many different types of inorganic salts (mercuric chloride) and organomercuric compounds ( $\text{MeHg}$ ). This is the most common form found in surface water, sediments, and biota (ATSDR, 1999). Mercuric mercury enters the environment by atmospheric deposition as well as from point and non-point sources and erosion. About 5% of the mercury in the atmosphere is in this form and can bind with particulates and settle out of the atmosphere by dry and wet deposition.
- 3)  $\text{Hg}^{+1}$  – mercurous; a form of mercury that is unstable and not likely to occur under typical environmental conditions (EPA, 1997b).

Because the COECs (i.e., inorganic and organic mercury) have already been determined, the emphasis of this section is on the distribution of mercury contamination within the Sudbury River

and the potential fate and effects associated with mercury contamination in aquatic environments.

#### **2.4.1 Site Characterization Data**

The Site Characterization presents the mercury data used in this SBERA to assess risks to ecological receptors from mercury exposure. Mercury data for a variety of media have been compiled in a comprehensive database to support both the HHRA and this SBERA. This database interfaces with a geographical information system and contains information on the physical and chemical properties of the media.

The objectives of the site characterization for this assessment include:

- Review and summarize the analytical data for media sampled in the Sudbury River reaches potentially impacted by the migration of mercury from past operations and activities at the Nyanza Site.
- Select the chemicals of ecological concern (COECs) to be evaluated in the ERA. Note that for this SBERA, the focus is solely on mercury (as total mercury and methylmercury) as the chemical of concern.
- Select the data and data treatment approach(es) to be used in this SBERA.

##### **2.4.1.1 Available Data**

This section presents a summary of existing information relating to the nature and extent of mercury contamination within the Sudbury River drainage. It describes the primary sources of data and presents an overview of data collection and handling procedures.

Data were collected for the OU III RI (NUS, 1992), for the Task Force studies (see Table 2-2), and during 2003-2005 Supplemental Investigation field efforts. Each data set is discussed below.

##### **2.4.1.1.1 OU III RI Data Set**

Due to differences in handling techniques and analytical procedures, EPA determined that analyses conducted for the OU III RI lacked the analytical precision of data collected for the Task Force studies and the 2003-2005 supplemental investigation (e.g., the detection limits for



OU III RI data were not sufficiently low to detect mercury at the concentrations present in fish because of sample dilution necessary to correct for matrix interference). In addition, questions were raised regarding the ability to meet data quality objectives (DQOs) in the analytical procedures. Consequently, mercury data collected prior to 1992 were excluded from the analysis of risk in this SBERA.

#### **2.4.1.1.2 Task Force Studies Data Sets**

As noted in Section 1, the Task Force was directed to develop information necessary to produce a scientifically defensible ERA associated with mercury contamination in the Sudbury River. Numerous studies were undertaken from 1993 to 1995 (see Table 2-2), resulting in the collection of mercury data for surface water, sediment, and tissue (mussel, mayfly, dragonfly, crayfish, and fish). Because of the temporal differences (8-10 years) between the Task Force and Supplemental Investigation data, these data were not combined in this SBERA. In the instances where biota with concentration data available from Task Force studies were not targeted for collection in the Supplemental Investigation, but were needed to estimate exposure and/or effects for this SBERA, the reader is referred to the 1999 BERA (Weston, 1999a) to obtain data summary tables. However, all data used to estimate exposure, including those of the Task Force where needed, are presented in Section 3.2 – Exposure Characterization, of this report.

#### **2.4.1.1.3 2003-2005 Supplemental Investigation Data Set**

The *Supplemental Investigation Work Plan Addendum, Nyanza Superfund Site, Operable Unit IV, Sudbury River Mercury Contamination* (Avatar, 2003a) and the *Field Sampling Plan, Nyanza Superfund Site, Operable Unit IV, Sudbury River Mercury Contamination* (September 2003b) present the data collection and analytical requirements for the supplementary investigation conducted in 2003. The reader is referred to the *Field Sampling Plan* (FSP) for details of the sampling methodology and the sample requirements.

While the approach for this SBERA is similar to, and in tandem with the work performed in the 1999 BERA (Weston, 1999a), there are some distinct diversions of tactic and analysis. In addition to collecting data from each of the ten reaches, the river study was divided into 4 major decision target areas:

- Primary target areas:
  - Reservoirs (Reaches 2, 3, and 4)
  - GMNWR (Reach 8)
- Secondary target areas:
  - River flowing reaches (Reaches 5, 6, and 7)
  - Fairhaven Bay and remainder of river (Reaches 9 and 10)

The two primary study areas were selected for more intensive study based on the findings of the 1999 BERA (Weston, 1999a). The secondary target areas, flowing reaches and Fairhaven Bay, have been less of a focus in the past and more interpretation of data may be required to resolve the potential risks posed by those areas. The more intensive study includes further direct measurement of mercury food web transfer. For each habitat type (e.g., impoundment and wetland), there is both a contaminated area and an associated reference area as noted above.

Sediment, surface water, and several different biological tissues were analyzed to support this SBERA. These tissue types include: crayfish, fish of various size and age classes, waterfowl (eggs, blood, and feathers), tree swallows (eggs, blood, and feathers), eastern kingbird (eggs), red-winged blackbird (blood), belted kingfisher (eggs, blood, and feathers), marsh bird (eggs, blood, and feathers), and mink (blood, fur, liver, and brain). Fish tissue and sediment were collected from all reaches of the river. Crayfish were collected from those reaches where they were found. Tissue samples from higher trophic-level organisms (birds and mammals) were measured only in the primary target areas. Biological tissue was collected to provide empirical data to verify mercury residue estimates based on models for transfer of methylmercury through the food web in the different habitat types. Figures 2-17 through 2-23 present the sampling locations for sediment, surface water, and crayfish; and Figures 2-24 through 2-31 present the sampling locations for birds and mammals.

Comprehensive discussions of the analytical procedures used to obtain the data for the Supplemental Investigation can be found in the *Quality Assurance Project Plan, Nyanza Superfund Site, Operable Unit IV, Sudbury River Mercury Contamination* (Avatar, September 2003c).

#### **2.4.1.2 Data Evaluation and Reduction**

The following narrative provides a discussion of the data evaluation and data reduction procedures that were used to summarize media-specific data. The database used containing the supplemental investigation analytical results is presented in Appendix D.

The objectives of the data evaluation and reduction are as follows:

- Review and organize mercury data into spatially relevant groups for each medium and for each target species analyzed.
- Discuss the origin and quality of the mercury data that are incorporated into the ERA.
- Provide a discussion of data treatment as it pertains to qualified data, duplicate samples, and multiple sampling rounds.
- Summarize data statistically so that appropriate exposure information is readily available and in a form that permits effective comparisons between data groups.

As noted previously, comprehensive discussions of the sampling methodologies and analytical procedures that will be used for the data are presented in the FSP, *Quality Assurance Project Plan* (QAPP), and individual reports referenced throughout the *Supplemental Investigation Work Plan*.

#### **2.4.1.2.1 Data Usability and Data Validation**

EPA Region 1 discusses data usability issues that should be considered in the risk assessment process in its Risk Update 3 (EPA Region 1, 1995). Data usability is defined as the process of ensuring that the quality of the data meets the intended uses and satisfies the DQOs established for sampling and analysis. Data usability involves assessing both the analytical quality, sampling methodology, and field errors that may be inherent in the data. Factors evaluated include the level of validation (data validation tier) and data quality indicators such as completeness, comparability, precision and accuracy, and analytical detection limits.

EPA Region 1 recommends that all data used in the risk assessment process be validated using Tier II or Tier III validation procedures. In a Tier II validation, quality control (QC) checks are conducted, analytical procedures are assessed, and data are qualified accordingly. In a Tier III validation, in addition to meeting the Tier II requirements, the raw laboratory data are examined to check for calculation errors, compound misidentification, and transcription errors. A Data Validation report is produced for both Tier II and Tier III validations. All sediment, surface water,

fish, and crayfish data and much of the bird blood data collected for the supplemental investigation were validated to at least a Tier II level. Since no issues were found in those approximately 1900 results, to expedite the validation process, only 10% of the mammal data and remaining bird data submitted for analysis in 2004 were evaluated at a Tier II level with the rest evaluated at Tier I. Data submitted for analysis in 2005 were not validated.

#### **2.4.1.2.2 Data Reduction**

The analysis of the data contained in this SBERA was based on guidance presented in *Guidance for Data Usability in Risk Assessment, Part A* (EPA, 1992b). The guidelines listed below were used when evaluating data qualifiers, sample quantitation limits (SQLs), duplicate samples, and multiple sampling rounds, prior to the data summarization.

- All U-qualified data represents a non-detect for the parameter evaluated. The concentration was assumed to be present in the sample at one-half the SQL.
- All mercury data with “J” qualifiers were assumed to be positive identifications. “J” indicates that the numerical value is an estimated concentration (e.g., is reported below the minimum confident SQL).
- All mercury data with “R” qualifiers were eliminated from use as the results were rejected based upon non-adherence to standards set by the laboratory or data validator.
- If a sample duplicate is collected and analyzed, the average of the two reported concentrations will be used for subsequent calculations unless there is a greater than 30% difference in surface water concentrations or a greater than 50% difference in soil, sediment, or tissue concentrations, in which case the higher of the two concentrations was used.
- Data from multiple sampling rounds will be treated as individual, discrete data points.

In general, summary information provided for each data group includes frequency of detection, range of detected concentrations, range of SQLs, mean concentration, median, and standard deviation. Data are presented by medium in the subsections that follow.

#### **2.4.1.2.3 Data Evaluation**

The objectives of the data evaluation are to summarize the data by medium and exposure scenario and to evaluate the usability of the data for this SBERA. For this SBERA, mercury

concentrations were summarized by medium within each river reach to provide information on the geographic distribution of mercury throughout the river.

Since this section presents the site characterization, data is presented on a per reach basis. For the exposure characterization (Section 3.2), analytical data may be organized into spatially relevant exposure groups for each of the media, depending upon the receptor. The term “spatially relevant group” refers, in large part, to how a representative exposure of a target species to mercury in a specific medium will be defined.

#### **2.4.1.2.3.1 Sediment**

Both surficial sediment (0-5 cm) data and sediment core (0-3 cm, 3-6 cm, 6-9 cm, and 9-12 cm) data were collected for the supplemental investigation in 2003. In addition to the 2003 data, both surficial sediment (0-5 cm) data and sediment core (0-5 cm, 5-10 cm, 10-15 cm, and 15-20 cm) data were also collected for the supplemental investigation in 2005. Surficial data (i.e., all sediment collected to a depth of 5 cm) are summarized in Table 2-6. Sediment core data are presented in Table 2-7. In addition to the tabular presentation of data, Figures 2-32 and 2-33 present box-plots of the mercury distribution in sediment.

Note that for Reaches 3 and 5, sediment samples were collected in what was called a focus area. The purpose of collecting data in each of the focused study areas is to identify and quantify, if possible, the mechanisms, various controlling factors, and transfer rates by which mercury and methylmercury in sediment accumulate in fish and invertebrates (with crayfish as the representative species). The focused areas were selected from those subreaches in which small fish (5 to 15 cm total length) were obtained by the USFWS. In order to provide an overview of the entire reach (i.e., not weight the statistics towards the characteristics of the microcosm of the focus area), summary statistics are presented that include the average of the focus area samples as a single point within the reach. Summary statistics for the focus areas alone are also presented.

Floodplain data collected in 2005 are not included in this SBERA as their locations/depths were selected for fate and transport modeling purposes.

Surficial sediment mercury and methylmercury concentrations are available for each reach. Reach 3 (Reservoir 2) reported the highest level of mercury in sediment (44.9 mg/kg), followed by Reach 4 (Reservoir 1 - 15.6 mg/kg), Reach 6 (Saxonville Reservoir - 9.76 mg/kg), and Reach 2 (Mill Pond - 9.65 mg/kg). The highest median concentration of mercury was observed in the sediments of Reach 3 followed by Reach 4, Reach 7-Heard Pond, and Reach 6. In general, methylmercury concentrations follow a similar trend with higher concentrations observed in low flowing reaches and in reaches receiving discharge from larger wetland complexes. For the sediment reference data (i.e., Reach 1, Charles River, and Sudbury Reservoir), the sample concentrations range from 0.0576 (Sudbury Reservoir) to 3.15 mg/kg (Reach 1).

A summary of total mercury and methylmercury sediment core data is presented in Table 2-7. Core samples are only available for Reach 3 and Charles River. Reach 3 mercury levels range from 1.24 mg/kg (2005 core 1; 15-20 cm) to 48.1 mg/kg (2005 core 2; 5-10 cm). Reach 3 methylmercury levels range from 0.000119 mg/kg (2005 core 4; 15-20 cm) to 0.034 mg/kg (2005 core 5; 5-10 cm), Charles River mercury levels range from 0.051 mg/kg (core 2; 6-9 cm) to 0.531 mg/kg (core 1; 6-9 cm). Charles River methylmercury levels range from 0.000166 mg/kg (core 2; 6-9 cm) to 0.0021 mg/kg (core 2; 0-3 cm).

Alkalinity, percent solids, and total organic carbon (TOC) were also tested for sediment samples (Table 2-8). Alkalinity in the impacted areas of the Sudbury River ranged from 15 to 34.5 mg/L, percent solids ranged from 11.5 to 86.6%, and TOC ranged from 0.6 to 20%. Reference area values were as follows: alkalinity 18 to 41 mg/L (Reach 1 and Charles River, respectively); percent solids 12.3 to 51.2% (Reach 1 and Sudbury River, respectively); and TOC 1.6 to 20% (Sudbury Reservoir and Reach 1, respectively).

A comparison of total mercury and methylmercury concentrations analyzed in the same sediment sample and for which comparative data were available indicate that methylmercury represents generally less than 1 percent (average of 0.4%) of the total mercury detected in sediments (Table 2-9).

#### **2.4.1.2.3.2 Surface Water**

Surface water data were collected by USGS for the supplemental investigation. Data are summarized in Table 2-10. In addition to the tabular presentation of data, Figures 2-34 and 2-35 present box-plots of the mercury distribution in surface water.

Surface water mercury and methylmercury concentrations are available for each reach except for Reach 6 (Saxonville Reservoir) and the Sudbury Reservoir reference area, where there were no analyses performed; and for Reaches 9 (Fairhaven Bay) and 10 (Fairhaven Bay outlet to the Assabet River). Reach 2 (Pleasant Street Impoundment to the Union Street Bridge) reported the highest level of mercury in surface water ( $4.18\text{E}+01$  ng/L), followed by Reach 7 (Saxonville Dam to the Route 20 overpass –  $2.30\text{E}+01$  ng/L), and Reach 8 (GMNWR –  $1.50\text{E}+01$  ng/L). The highest median concentration of mercury was observed in the surface water from Reach 8, followed by Reach 3 (Reservoir 2), and Reach 7. In general, methylmercury concentrations follow a similar trend with higher concentrations observed in low flowing reaches and in reaches receiving discharge from larger wetland complexes. For the reference data (i.e., Reach 1 and Charles River), the sample concentrations range from  $1.73\text{E}-00$  (Reach 1) to  $2.85\text{E}-00$  ng/L (Charles River).

A comparison of total mercury and methylmercury concentrations analyzed in the same surface water sample and for which comparative data were available indicate that methylmercury represents generally less than 27 percent (average of 7.2%) of the total mercury detected in surface water (Table 2-11).

#### **2.4.1.2.3.3 Crayfish**

Crayfish represent a substantial forage base for a number of birds, mammals, fish, and reptiles that use the Sudbury River as habitat. As omnivores, in addition to their close association with sediments, crayfish may serve as an important vector of mercury transfer to higher trophic level organisms. The crayfish tissue analyses results are used to support this SBERA and to potentially elucidate mechanisms of food chain transfer in the Sudbury River.

Both whole body (for the most part individual whole body, but some composited whole body) crayfish and crayfish tails were submitted for chemical analyses. These data are summarized in

Table 2-12. In addition to the tabular presentation of data, Figures 2-36 and 2-37 present box-plots of the mercury distribution in whole body crayfish. Information regarding which samples are whole body versus whole body composite samples are noted in the table and figures.

Mercury and methylmercury concentrations are available for individual whole body samples only; whereas only total mercury was analyzed for in the composite and tail samples. Crayfish data are only available for Reaches 1 through 7, the Charles River, and Sudbury Reservoir. Although crayfish collection was attempted in the lower reaches (Reaches 8 through 10), the collection effort from Reaches 8 through 10 (i.e., GMNWR to the confluence with the Assabet River) was not successful.

Crayfish collected from Reach 3 (Reservoir 2) exhibited the highest mercury level in a whole body crayfish sample (210 µg/kg) followed by Reach 5 (between Reservoir 1 and the Saxonville Reservoir - 192 µg/kg), and Reach 7 (between the Saxonville Reservoir and the GMNWR 86.1 µg/kg). Reach 5 has the highest whole body median concentration (88.6 µg/kg) followed by Reach 7 and Reach 3. For the crayfish reference data (i.e., Reach 1, Charles River, and Sudbury Reservoir), the concentrations range from 4.57 (Sudbury Reservoir) to 47.2 µg/kg (Reach 1).

Analytical data specific to this most recent crayfish collection indicate that, among reaches, the mean methylmercury to total mercury ratio is 0.88 (Table 2-13). For this assessment, it is conservatively assumed that all total mercury detected in crayfish tissue is methylmercury.

#### **2.4.1.2.3.4 Fish**

Species targeted for mercury analysis spanned a variety of feeding guilds and included yellow perch (*Perca flavescens*), largemouth bass (*Micropterus salmoides*), and brown and yellow bullhead (*Ameiurus nebulosus* and *A. natalis*, respectively). The mercury analysis for bass and bullhead was primarily collected for the human health risk assessment, but these data were also used in this SBERA. Yellow perch of different size classes were targeted for collection. The following describe the 4 size classes: >5 to ≤ 10 cm (size class A), >10 to ≤ 15 cm (size class B), >15 to ≤ 20 cm (size class C), >20 cm (size class D). Different size classes were primarily collected to provide appropriate dietary inputs for upper trophic level target receptors. Surrogate species for yellow perch and brown bullhead (see below) were collected when



sufficient numbers of these species (and within a size class for yellow perch) could not be collected. Because all fish were measured for length, all samples could be categorized into a size class; however, only yellow perch and its surrogates had specific collection requirements within a size class.

Surrogate species for yellow perch were predominantly bluegill sunfish (*Lepomis macrochirus*); however, pumpkinseeds (*Lepomis gibbosus*) were also collected in all Reaches except 4, 9 and 10. Centrarchids (i.e., sunfish) in these size classes are expected to be similar in prey selection and foraging behavior to those of similar-sized yellow perch; it was therefore hypothesized that mercury residue levels in sunfish would be similar to comparable size yellow perch. To test this hypothesis, sunfish and yellow perch of both the  $\geq 5$ -10 cm (class A) and  $\geq 10$ -15 cm (class B) size classes were collected from the same area in Reach 8 (GMNWR). Any observed concentration differences between these species may reflect differences in uptake dynamics.

T-tests (Equal-Variance T-Test at  $\alpha = 0.05$ ; variances checked using Variance-Ratio Equal-Variance Test and Modified-Levene Equal-Variance Test) were used to compare mercury concentrations between yellow perch and sunfish of the same size class. The results of this analysis indicated that size class A sunfish had significantly higher concentrations than similar size yellow perch ( $p=0.008$ ) and the size class B fish were not significantly different ( $p=0.90$ ) (see Table 2-14 for summary statistics). These results, in general, agree with EPA's independent analysis (see Appendices E and F). However, it should be noted that there were only 3 size class A yellow perch available for comparison and the resulting power of this test was low.

A confounding factor to these analyses is that sunfish overall are smaller fish than perch, and presumably have a smaller growth-rate than the perch. Therefore, if they are of the same size, sunfish concentrations may be higher because they are older and have had more time to bioaccumulate methylmercury. In addition, small fish collection occurred during summer and fall. All of the Reach 8 size class B sunfish were collected in fall, as opposed to the perch which were all collected in the summer. This would also tend the sunfish towards higher concentrations than the perch. Considering the confounding factors it was determined that

sunfish concentrations as a surrogate for yellow perch concentration in size classes A and B serves as good to conservative approximations.

Brown and yellow bullheads were collected in all reaches and reference locations. However, when a sufficient number of bullhead could not be collected within a reach, white suckers (*Catostomus commersoni*) were collected as a surrogate for bullheads because of their similar feeding habits and the lack of bullheads from those reaches. Reach-specific sample sizes of co-located bullheads and white suckers were inadequate for statistical comparison and it was assumed that white suckers could be used as a bullhead surrogate for subsequent analyses.

All targeted species size classes were collected from each of the 9 site-impacted reaches and 3 reference areas. A summary of all the fish that were collected during the supplemental investigation are presented in Table 2-15.

#### **2.4.1.2.3.4.1                      Developing Whole Body Fish Total Mercury Residue Datasets**

Three different types of fish samples were obtained from the ten Sudbury River Reaches and the two external reference locations. Those samples represented the following tissue types:

- Whole body fish: Sunfish (size classes A and B), yellow perch (size classes A, B, and C), and a handful of bullheads were analyzed as whole body fish.
- Fillet and offal: About 30% of all of the largemouth bass, bullheads, and size class D yellow perch were analyzed as fillet and offal. Both tissue types were weighed separately before they were processed for chemical analysis to allow for the calculation of reconstructed whole body fish total mercury concentrations.
- Fillet only: About 70% of all largemouth bass, bullhead, and size class D yellow perch were analyzed as fillet only. The fillets and whole body fish were weighed separately before the fillets were processed for chemical analysis. Fish for which only fillet samples were collected were not included in the total mercury residue dataset used in this SBERA. However, additional analysis conducted by EPA (see Section 2.4.1.2.3.4.2) indicates the whole body fish total mercury residue dataset could be expanded if future evaluations appear warranted.

The goal of the data consolidation process discussed below is to use all of the available tissue residue data to generate species and sampling location-specific whole body fish total mercury data sets.

Only whole body fish concentrations were used for modeling wildlife exposures and comparisons with CBRs in this SBERA. The whole body fish data sets consist of all whole body fish and of “reconstructed” whole body fish concentrations. Many of the larger fish were filleted and oftentimes analyzed with the associated offal sample. To obtain a “reconstructed” whole body fish concentration, the following equation was used:

$$C_{wb} = \frac{C_f \times W_f + C_o \times W_o}{W_f + W_o}$$

Where:

$C_{wb}$  = Concentration in whole body fish  
 $C_f$  = Concentration in fillet  
 $W_f$  = Weight of fillet  
 $C_o$  = Concentration in offal  
 $W_o$  = Weight of offal

Note: If a fillet was split and analyzed as a primary and duplicate sample (instead of analyzing both the left and right fillets together as a primary), the fillet concentration was determined using the averaging technique noted above and the fillet weight equaled the sum of the primary and duplicate samples.

Tables 2-16 through 2-28 present summaries of the total- and methylmercury concentrations of the whole body and reconstructed whole body samples from the Sudbury River and reference locations by fish species. In addition to the tabular presentation of data, Figures 2-38 through 2-46 present box-plots of the mercury distribution in whole body fish tissue. In order to facilitate interpretations of upstream to downstream patterns in mercury and methylmercury distribution, average total mercury concentrations in whole body (i.e., whole body plus whole body reconstructed) fish by reach are presented in Figure 2-47. In addition, Figures 2-48 and 2-49 depict average total and methylmercury concentrations, respectively, in whole body largemouth bass, sediment, and surface water.

For the site-related data, the concentrations in largemouth bass range from 119 (Reach 7-Heard Pond) to 1,270 µg/kg wet weight (WW) (Reaches 9 and 10). The concentrations in bullheads and white sucker range from 59.1 (Reach 8, bullhead) to 465 µg/kg WW (Reach 8, bullhead). (Note: white sucker were only collected in Reach 2 and comprised four of the seven samples for the feeding guild.) The yellow perch and bluegill concentrations range from 9.8 (Reach 7-Heard Pond) to 477 µg/kg WW (Reach 3) for size class A; 15.7 (Reach 7-Heard Pond) to 363 µg/kg WW (Reach 2) for size class B; 21.2 (Reach 7-Heard Pond) to 350 µg/kg WW (Reach 3) for size class C; and 56.3 (Reach 7-Heard Pond) to 606 µg/kg WW (Reach 3) for size class D (size class D dataset included perch only).

For the whole body fish reference data, the largemouth bass concentrations range from 155 (Sudbury Reservoir) to 414 µg/kg WW (Charles River). The bullheads and white sucker concentrations range from 40 (Reach 1, white sucker) to 555 µg/kg WW (Reach 1). (Note: white sucker comprised eight of the ten samples for the feeding guild.) The yellow perch and bluegill concentrations range from 21.7 (Sudbury Reservoir) to 252 µg/kg WW (Reach 1) for size class A; 22.5 (Sudbury Reservoir) to 167 µg/kg WW (Reach 1) for size class B; 33.2 (Sudbury Reservoir) to 123 µg/kg WW (Reach 1 and Charles River); and 63.4 (Sudbury Reservoir) to 169 µg/kg WW (Charles River) for size class D.

Note that fish tissue collected as part of this study was analyzed for total mercury, with a subset analyzed for methylmercury. Numerous studies have indicated that the predominant form of mercury in biological tissue is methylmercury. The proportion of total mercury in biota that exists as methylmercury has been shown to increase with trophic level as well as with age and size of fish within a given trophic level, e.g., tertiary consumer such as largemouth bass (EPA, 1996). It is estimated that 95 to 99 percent of the mercury contained in fish exists as methylmercury (Huckabee et al., 1979; Bloom and Effler, 1990; EPA, 1996). Analytical data specific to this most recent fish collection indicate that, within a species, the mean methylmercury to total mercury ratio ranges from 0.89 to 0.99 (Tables 2-29 through 2-31). For this assessment, it is conservatively assumed that all total mercury detected in fish tissue is methylmercury.

#### **2.4.1.2.3.4.2**

#### **Additional Fish Residue Analysis**

Region 1 EPA's Environmental Services Assistance Team (ESAT) contractor performed additional analysis of the fish tissue data set (see Appendices E and F). Their analyses looked more closely at the relationship between total mercury concentrations in fillets and reconstructed whole body fish concentrations. The results of these analyses were species-specific linear regression equations for largemouth bass, yellow bullhead, brown bullhead, and yellow perch (size class D):

- Largemouth bass:  $y = -9.70 + 0.70(x)$  ( $r^2=0.97$ ;  $p<0.0001$ )
- Yellow bullhead:  $y = 26.91 + 0.578(x)$  ( $r^2=0.93$ ;  $p<0.0001$ )
- Brown bullhead:  $y = -0.99 + 0.6733(x)$  ( $r^2=0.94$ ;  $p<0.0001$ )
- Yellow perch (Class D):  $y = 19.72 + 0.61(x)$  ( $r^2=0.94$ ;  $p<0.0001$ )

Where:

- x = total mercury concentration in fillet
- y = total mercury concentration in reconstructed whole body fish

These equations were then used to derive whole body fish concentrations for those fish for which only total mercury fillet data were available. Concentrations resulting from this exercise were not used in the risk assessment modeling effort, but for comparisons with regional data.

#### **2.4.1.2.3.5**

#### **Birds**

In order to facilitate interpretations of upstream to downstream patterns in mercury distribution in birds, average total mercury concentrations in blood are presented for each sampling year by reach in Figures 2-50 through 2-52. Concentrations found in individual species are discussed below.

#### **2.4.1.2.3.5.1**

#### **Waterfowl**

Blood, feather, and egg samples were submitted for hooded mergansers and wood ducks from 4 locations in 2003 – Reach 1 (Whitehall Reservoir), Reach 8, Delaney Wildlife Management Area, and Sudbury Reservoir; 3 locations in 2004 – Reach 7, Reach 8, and Sudbury Reservoir; and 3 locations in 2005 – Reach 4, Charles River, and Sudbury Reservoir. Samples were analyzed for only total mercury. These data are summarized in Tables 2-32 through 2-42. In addition to the tabular presentation of data, Figures 2-53 through 2-56 present box-plots of the

mercury distribution in waterfowl tissue. Note that some of the data represent blood concentrations from the same bird (i.e., samples were obtained from birds that were recaptured later in the season). These data were not segregated from data collected from birds captured only once, as this characterization section provides the approximate range of concentrations in hooded mergansers during the breeding season and insufficient data were available to determine temporal trends in mercury concentrations.

From the 2003 sampling, site-related data were available for wood ducks in Reach 8 only. The mercury concentrations in blood range from 21.1-499 µg/kg and the concentrations in eggs range from 25-221 µg/kg. For the waterfowl reference data (i.e., Reach 1 – Whitehall Reservoir, Delaney Wildlife Management Area, and Sudbury Reservoir), the concentrations in hooded merganser range from 70.7 (Delaney) to 1,130 µg/kg (Whitehall Reservoir) in blood, 6,250-17,500 µg/kg (Delaney) in feathers, and 147-726 µg/kg (Delaney) in eggs. Only blood and egg data were available for reference wood duck tissue. Blood concentrations range from 12.1 (Delaney) to 82 µg/kg (Sudbury Reservoir) and egg concentrations range from 11.2-73.7 µg/kg (Delaney).

From the 2004 sampling, site-related data were available for hooded merganser in Reach 8 and wood duck in Reaches 7 and 8 only. For the one hooded merganser captured, the blood concentration is 21.2 µg/kg and the feather concentration is 7,590 µg/kg. For the two wood ducks captured, the blood concentrations range from 52.2 (Reach 7) to 421 µg/kg (Reach 8) and the feather concentrations range from 442 (Reach 8) to 541 µg/kg (Reach 7). For the waterfowl reference data (i.e., Sudbury Reservoir), the concentrations from the one captured wood duck are 25.3 µg/kg in blood and 298 µg/kg in feathers.

From the 2005 sampling, site-related data were available for hooded merganser blood and feathers in Reach 8 only, and eggs in Reaches 4 and 8. The mercury concentrations in blood from Reach 8 range from 167-1,880 µg/kg and the concentrations in feathers range from 899-7,480 µg/kg. In eggs, the concentrations range from 257-1,950 µg/kg (both concentrations were found in Reach 8). For the waterfowl reference data (i.e., Charles River and Sudbury Reservoir), the concentrations in hooded merganser eggs range from 288 (Sudbury Reservoir) to 2,420 µg/kg (Charles River). Blood concentrations were available from the Charles River

(614-4,270 µg/kg) and feather concentrations were available from both reference areas (range 6,440 µg/kg in Sudbury Reservoir to 8,920 µg/kg in the Charles River).

#### **2.4.1.2.3.5.2 Kingfisher**

Kingfisher tissue collection occurred from April 2003 to July 2003. Blood, feather, and egg samples were submitted for belted kingfishers from 6 locations – Reach 1 (Whitehall Reservoir), Reach 7, Reach 8 (Transfer Station Pit, Macone's Pile, and Route 117 Pit), and Charles River. Samples were analyzed for only total mercury. These data are summarized in Tables 2-43 through 2-48. In addition to the tabular presentation of data, Figures 2-57 and 2-58 present box-plots of the mercury distribution in kingfisher tissue. Note that some of the data represent blood concentrations from the same bird (i.e., samples were obtained from birds that were recaptured later in the season). These data were not segregated from data collected from birds captured only once, as this characterization section provides the approximate range of concentrations in kingfisher during the breeding season and insufficient data were available to determine temporal trends in mercury concentrations.

For the site-related data, the maximum blood concentration was observed in Reach 8 at Macone's Pile (1,330 µg/kg). The maximum feather concentration was observed in Reach 8 at the Transfer Station Pit (12,400 µg/kg). The Reach 8 Route 117 Pit was the only area with available egg data with concentrations of the one sample and its duplicate ranging from 150 to 152 µg/kg. The highest median blood and feather concentrations were found in Reach 8 at the Route 117 Pit (701 µg/kg) and at the Transfer Station Pit (12,400 µg/kg), respectively. For the belted kingfisher reference data (i.e., Whitehall Reservoir and Charles River), the blood concentrations range from 130 to 398 µg/kg (Whitehall) and the only feather concentration is 7,180 µg/kg (Charles River).

#### **2.4.1.2.3.5.3 Tree Swallow**

Blood, feather, and egg samples were submitted for tree swallows from 6 locations in 2003 – Reach 3 (Reservoir 2), Reach 4 (Reservoir 1), Reach 7, Reach 8 (GMNWR), Sudbury Reservoir, and Charles River; and 5 locations in 2004 – Reach 3 (Reservoir 2), Reach 4 (Reservoir 1), Reach 7-Heard Pond, Reach 8 (GMNWR), and Charles River. For the 2003 data Reaches 7 and 8 were combined for tree swallow location designations because of the

proximity of the nest boxes. These data were not combined for the 2004 data set as the Reach 7 samples were collected from the periphery of Heard Pond, where the habitat differs from the flowing reaches through the GMNWR. Samples were analyzed for only total mercury. These data are summarized in Tables 2-49 through 2-58. In addition to the tabular presentation of data, Figures 2-59 through 2-64 present box-plots of the mercury distribution in tree swallow tissue. Note that some of the data represent blood concentrations from the same bird (i.e., samples were obtained from birds that were recaptured later in the season). These data were not segregated from data collected from birds captured only once, as this characterization section provides the approximate range of concentrations in tree swallows during the breeding season and insufficient data were available to determine temporal trends in mercury concentrations.

From the 2003 sampling, for the site-related data, the maximum blood concentration was observed in Reaches 7 and 8 combined (917 µg/kg). The maximum feather concentration was observed in Reach 3 (2,690 µg/kg). Reaches 7 and 8 combined had the highest observed tree swallow egg concentration (212 µg/kg). The highest median concentrations were observed in Reaches 7 and 8 combined for each of the tissue types (blood – 338 µg/kg, feather – 1,260 µg/kg, and egg – 121 µg/kg). For the tree swallow reference data (i.e., Charles River and Sudbury Reservoir), the blood concentrations range from 2.65 (Sudbury Reservoir) to 996 µg/kg (Charles River). The reference feather concentrations range from 591 (Charles River) to 2,270 µg/kg (Sudbury Reservoir). The reference tree swallow egg concentrations range from 26.5 (Sudbury Reservoir) to 257 µg/kg (Charles River).

From the 2004 sampling, for the site-related data, the maximum blood concentration was observed in Reach 8 (1,310 µg/kg). The maximum feather concentration was observed in Reach 3 (8,560 µg/kg). Reach 8 had the highest observed tree swallow egg concentration (464 µg/kg). The highest median concentrations were observed in Reach 8 for each of the tissue types (blood – 611 µg/kg, feather – 2,180 µg/kg, and egg – 273 µg/kg). For the tree swallow reference data (i.e., Charles River), the blood concentrations range from 305-594 µg/kg. The reference feather concentrations range from 181-6,030 µg/kg. The reference tree swallow egg concentrations range from 82-151 µg/kg.



#### **2.4.1.2.3.5.4**

#### **Eastern Kingbird**

Kingbird tissue collection occurred from April 2003 to July 2003. Kingbird egg samples were submitted from 5 locations – Reach 7 (river adjacent to Heard Pond), Reach 8 (GMNWR), Reach 9 (Fairhaven Bay), Reach 10 (Fairhaven Bay outlet to the confluence with the Assabet River), and the Charles River. Samples were analyzed for only total mercury. These data are summarized in Table 2-59. In addition to the tabular presentation of data, Figure 2-65 presents box-plots of the mercury distribution in kingbird eggs.

For the site-related data, the maximum egg concentration was observed in Reach 8 (210 µg/kg). The highest median concentration also was observed in Reach 8 (135 µg/kg). For the kingbird reference data (i.e., Charles River), the egg concentrations range from 156 to 170 µg/kg.

#### **2.4.1.2.3.5.5**

#### **Red-winged Blackbird**

Blood samples were submitted for red-winged blackbird from 1 location in 2005 – Reach 8 (GWNWR). Samples were analyzed for only total mercury. These data are summarized in Table 2-60. In addition to the tabular presentation of data, Figure 2-66 presents box-plots of the mercury distribution in red-winged blackbird tissue.

The maximum blood concentration observed in Reach 8 was 9,420 µg/kg. The median blood concentration was 2,650 µg/kg.

#### **2.4.1.2.3.5.6**

#### **Marsh Birds**

Both blood and feather samples were submitted for marsh birds from 3 locations in 2003 – Reach 7 (river adjacent to Heard Pond), Reach 8 (Middle Reach), and the Charles River; and 3 locations in 2004 – Reach 7-Heard Pond, Reach 8 (Middle Reach), and the Charles River. Samples were analyzed for only total mercury. These data are summarized in Tables 2-61 through 2-66. In addition to the tabular presentation of data, Figures 2-67 through 2-69 present box-plots of the mercury distribution in marsh bird tissue.

In 2003, swamp sparrows had the maximum blood concentrations in both site-related reaches (431 µg/kg in Reach 7 and 1,450 µg/kg in Reach 8). For feathers, maximum concentrations were observed in a song sparrow from Reach 7 (8,570 µg/kg) and a yellow warbler from Reach 8 (11,700 µg/kg). The highest median concentrations in blood are for swamp sparrows in

Reach 7 (228 µg/kg) and song sparrows in Reach 8 (448 µg/kg). The highest median concentrations in feathers are for swamp sparrows in Reach 7 (2,730 µg/kg) and yellow warblers in Reach 8 (11,700 µg/kg). For the marsh bird reference data (i.e., Charles River), the maximum concentrations were observed in swamp sparrow blood (423 µg/kg) and song sparrow feathers (13,600 µg/kg).

In 2004, the maximum blood concentrations are from a song sparrow in Reach 7-Heard Pond (845 µg/kg) and a swamp sparrow in Reach 8 (957 µg/kg). The highest median concentrations in blood are for swamp sparrows in Reach 7-Heard Pond (329 µg/kg) and song sparrows in Reach 8 (407 µg/kg). For the marsh bird reference data (i.e., Charles River), only song sparrows were caught, with the concentrations in blood ranging from 59-209 µg/kg. (Feathers were not analyzed for the 2004 samples.)

#### **2.4.1.2.3.6 Mammals**

Blood, fur, liver, and brain samples were submitted for mammals from 4 locations – Reach 3 (Reservoir 2), Reach 4 (Reservoir 1), Reach 5, and Reach 7. Five animals were trapped for sampling. Liver and brain samples were collected only from specimens that were found dead or that succumbed subsequent to sampling but prior to release. Samples were analyzed for only total mercury. These data are presented in Table 2-67. In addition to the tabular presentation of data, Figure 2-70 presents box-plots of the mercury distribution in mammal tissue.

The maximum blood concentration was observed for a mink in Reach 3 (177 µg/kg). The maximum fur concentration was observed for a mink in Reach 3 (58,600 µg/kg). Liver and brain samples were available only for mink from Reach 5. Concentrations in liver ranged from 1,130 to 1,210 µg/kg. Brain concentrations ranged from 118 to 215 µg/kg.

#### **2.4.2 Mercury Fate and Transport**

This section presents a brief discussion of environmental fate and transport mechanisms associated with mercury in environmental media with a specific focus on freshwater aquatic ecosystems. The fate of mercury depends on the form released into the environment, the potential transformation from one form to another, and the environmental conditions present (NOAA, 1996; Morel et al., 1998). The primary objectives of this section are to present

overviews of mercury cycling and of the methylation process and partitioning of mercury that occurs in the environment, and discuss the bioaccumulation potential and the likely exposure pathways within the Sudbury River drainage. It should be noted that while our general understanding of mercury fate and transport has increased substantially over the past decade, there remain substantial gaps in our understanding that limit our ability to confidently predict the disposition of mercury within a specific ecosystem.

#### **2.4.2.1 Fate in Aquatic Systems**

Once mercury has entered an aquatic system, it is subject to an array of chemical and biological reactions, including:

- Binding to sediments and undergoing a conversion to immobile compounds.
- $\text{Hg}^{+2}$  in surface water can be reduced to  $\text{Hg}^0$  and reemitted to the atmosphere by a process known as evasion.
- $\text{Hg}^0$  in the atmosphere may be oxidized (via photocatalytic reactions) to form  $\text{Hg}^{+2}$  and re-deposited to surface water.
- $\text{Hg}^{+2}$  can be methylated in sediments, water column or in biota to form methylmercury (EPA, 1996). Methylated mercury can then be volatilized from water; bound to particulates; or, as will be discussed later, incorporated into biological tissue.
- Methylmercury can be demethylated to elemental mercury which can be reemitted to the atmosphere.

A variety of complexation/dissociation, precipitation/dissolution, adsorption/desorption and methylation/demethylation reactions affect the speciation and partitioning of mercury in the water column and sediment (Fitzgerald et al., 1994; ALCOA, 1996). Each of the reactions listed above are determined by numerous controlling environmental factors such as: temperature, pH, ozone concentration, microbial activity, dissolved organic carbon (DOC), alkalinity, sulfate availability, sediment characteristics, and others. Most of the mercury in the water column is bound to organic matter; either dissolved carbon or suspended particulate matter. Typically 25-60% of the mercury present in the water column is particulate-bound with the remainder in the dissolved or DOC-bound phase.

$\text{Hg}^0$  is produced in freshwater by humic acid reduction of  $\text{Hg}^{+2}$  or the demethylation of methylmercury mediated by sunlight (EPA, 1997b.) Once in a water body, mercury can remain in the water column, volatilize into the atmosphere, settle in to the sediment or be taken up by aquatic biota. In general, mercury in aquatic environments has a strong affinity to remain bound to bottom sediment or suspended matter. For most aquatic environments, sediments serve as a sink and subsequent reservoir for mercury contamination and recycling, with as much as 90 percent of the total mercury in aquatic systems found in sediments (Faust and Aly, 1981)

#### **2.4.2.2 Mercury Methylation and Partitioning**

In aquatic systems,  $\text{Hg}^{+2}$  is converted to methylmercury by a process known as methylation. Methylation is a key step in the introduction of mercury into the food chain. Methylmercury is the form of mercury of greatest concern from both an ecological and human health based risk perspective because methylmercury has been shown to accumulate in the food chain, magnify in successive trophic levels, and because it is the most toxic form of mercury (Eisler, 1987; EPA, 1996; Weiner et al., 2003). In aquatic environments, the percent of total mercury in surface water that exists as methylmercury varies. In general, methylmercury makes up less than 10 percent of the total mercury in oxic surface water (Babiarz et al., 1998). The highest relative methylmercury surface water concentrations are detected in anoxic surface waters associated with wetland areas (EPA, 1997b; Krabbenhoft et al., 1998). The density of wetland complexes within a water body or river system may be the single most important factor governing the methylation process (Krabbenhoft et al., 1999). This fact is typically attributed to the high degree of methylation occurring in sediments where sulfate-reducing bacteria are found in high densities (Rudd, 1995). In general, sulfate-reducing bacteria are considered to be the primary methylating agent in aquatic environments (Winfrey and Rudd, 1990; Gilmour et al., 1992; Wiener et al., 2003), with most methylation occurring at the oxic-anoxic interfaces in sediment and wetlands (Pak and Bartha, 1998; Branfireon et al., 1996). However, it is recognized that there is a large degree of uncertainty and variability among water bodies concerning the dominant processes regulating mercury methylation (EPA, 1997b).

Most of the mercury in the water column is expected to bind to organic matter (EPA, 1997b). In aquatic biota such as phyto- and zooplankton, methylmercury comprises 10 to 90 percent of the total mercury present (May et al., 1987; Watras and Bloom 1992; Huckabee et al., 1979).

However, in fish, methylmercury generally comprises 90-99 percent of the total body burden (Bloom, 1992; Wiener and Spry, 1996). Analytical data specific to the most recent fish collection effort within the Sudbury River drainage indicate that, within a species, the mean methylmercury to total mercury ratio ranges from 0.89 to 1.0 (Tables 2-29 through 2-31). For this assessment, it is conservatively assumed that all total mercury detected in fish tissue is methylmercury.

Both methylation and demethylation of mercury takes place in aquatic environments. Most research indicates that biological processes are more important in the production and breakdown of methylmercury than abiotic chemical reactions. As previously discussed, biotic methylation of mercury is principally mediated by anaerobic sulfate-reducing bacteria at the sediment-water interface (Regnall and Tunlid, 1991; Gilmour and Henry, 1991), although aerobic bacteria and fungi can also contribute to the methylation process (Yannai et al., 1991). Methylation is the greatest at the sediment-water interface, but it also occurs, to a lesser degree within the water column (NOAA, 1996). In addition to biotic methylation processes, abiotic methylation can be an important process within wetland complexes (Lee et al., 1985; Weber, 1993). Metals acting as catalysts and humic and fulvic acids are all that is required for abiotic methylation of  $\text{Hg}^{+2}$ .

Physico-chemical factors, such as low oxygen conditions, increased temperature, reduced pH, sulfate enrichment, and dissolved organic matter have also been shown to accelerate the production of methylmercury at the sediment-water interface and within the water column (Winfrey and Rudd, 1990; Bodaly et al., 1993; Scheuhammer and Graham, 1999; Chen et al., 2005). The acidification of aquatic environments resulting from sulfate deposition plays an important role in the increased presence of methylmercury in aquatic biota. In acidified lakes there is often a clear inverse correlation between pH and concentration of methylmercury in zooplankton and fish (Wren and MacCrimmon, 1983; Westcott and Kalff, 1996). However, increased sulfide concentrations in sediments are often correlated with decreasing methylmercury concentrations in biota (Benoit et al., 1999; Winfrey and Rudd, 1990). Apparently low concentrations of sulfide enhance the methylation process because  $\text{Hg-S}$  is a neutral complex that has a high formulation constant and diffusion rate; as sulfide concentrations in sediment increase, the speciation of mercury goes from predominantly neutral

$\text{HgS}^0$  to charged  $\text{HgHS}_2^{-1}$  and  $\text{HgS}_2^{-2}$ , which cannot diffuse across microbial cell membranes and are therefore unavailable for methylation (Benoit et al., 1999). Elevated levels of chlorides have also been observed to inhibit methylation in sediments in a similar fashion (Winfrey and Rudd, 1990; ATSDR, 1999; Benoit et al., 1999).

Environmental factors that influence the enhancement of methylation indirectly influence the bioavailability and accumulation potential. Human activities that alter the biogeochemical character of aquatic systems have been shown to greatly influence the rate of mercury methylation and subsequent availability (Gilmour and Henry, 1991). A prime example of this type of action occurs when soils are flooded for the creation of reservoirs; flooding increases the decomposition of vegetation and dissolution of organic carbon, which in turn increases the release of mercury bound to organic material in water and results in increased mercury methylation rates (Chan et al., 2003). Kelly et al. (1997) also showed that after flooding, the methylmercury concentration in surface water was increased 39-fold. Given the conditions that seem to favor the production of methylmercury, it is not surprising that drainage areas with high concentrations of wetland complexes typically have the highest relative concentrations of methylmercury in surface waters and in the fauna inhabiting those waters (Zillioux et al., 1993).

#### **2.4.2.3 Bioaccumulation and Exposure Pathways**

The most significant mercury exposure pathway is an aquatic food chain pathway in which mercury is biomagnified and exposure to upper level aquatic and terrestrial receptors may result in significant toxic effects.

The conversion of inorganic or complexed mercury to methylated forms is the initial step in the mercury bioaccumulation process. Methylmercury is soluble, mobile, and rapidly enters the food chain (Mason et al., 1995; ATSDR, 1999; Weiner et al., 2003). There is more accumulation of methylmercury in biological tissue than accumulation of inorganic forms of mercury (Wiener and Spry, 1996; ATSDR, 1999). Within aquatic systems, methylmercury can enter the food chain immediately via diffusion, is subsequently tightly bound to biological organics such as proteins, and is stored in tissues rather than excreted (Eisler, 1987; TCI, 1992). As such, plants and animals may absorb mercury from direct exposure to contaminated media (i.e., water) and animals may further accumulate mercury through the ingestion of

contaminated food. While inorganic forms of mercury may also be absorbed or ingested, these compounds are typically not absorbed through cell membranes into muscles and organs and are eliminated from organisms relatively quickly (TCI, 1992; Weiner et al., 2003). Methylmercury on the other hand, tends to be tightly bound to sulfhydryl groups in proteins found in many cellular components, and is stored in skeletal muscle and organ tissues rather than excreted (Spry and Wiener, 1991; Harrison et al., 1990; Ribeyre and Boudou, 1984), where the demethylation process tends to be very slow. Even if concentrations of mercury in sediment and surface water decrease over time, levels in fish may not decrease because of the slow rate of elimination of methylmercury (NOAA, 1996).

Three terms are used to describe the mechanisms by which mercury (primarily methylmercury) accumulates in biological tissues:

- Bioconcentration – uptake and retention of chemical directly from an organism's surrounding media (e.g., fish take up mercury from the water column through gill membranes and other external surface tissues).
- Bioaccumulation – uptake and retention of a chemical from the environment into biological tissue from all possible pathways (including diet).
- Biomagnification – increase in chemical concentrations in organisms at successively higher trophic levels as a result of the ingestion of contaminated organisms at lower trophic levels. Biomagnification has been demonstrated by elevated levels in higher trophic level fish compared with fish lower in the food chain (ATSDR, 1999). Some estimates indicate that levels of methylmercury in carnivorous fish are biomagnified between 10,000 – 100,000 times the concentration detected in water (EPA, 1996).

Mercury is unique in that it is one of the few metals that is known to bioconcentrate, bioaccumulate and biomagnify.

In aquatic systems, aquatic plants (e.g., phytoplankton, algae, duckweed) and aquatic animals at all levels of the food chain (e.g., zooplankton → benthic invertebrates → fish) can all be directly exposed to mercury. Sediments, which serve as a sink for contaminated mercury, may be a primary source of exposure to rooted aquatic macrophytes (e.g., hyacinth, *Spartina* spp, common reed) via root uptake and translocation and benthic invertebrates via sediment ingestion. Sediments are also known to be a major long-term source of mercury contamination

in surface water via mobilization reactions previously discussed. The entry of mercury into the base of the aquatic food web and subsequent trophic transfer at the lower trophic levels is not completely understood (Weiner et al., 2003). However, as was previously discussed, the conversion of inorganic mercury to methylmercury by sulfate-reducing bacteria is the essential first step in the aquatic food chain bioaccumulation process. The abundance of methylmercury in lower trophic levels is directly linked to the supply (i.e., net production) of methylmercury. The accumulation of methylmercury by the planktonic community is the next critical step in the bioaccumulation and biomagnification process. Recent studies in lakes by Chen and Folt (2005) have shown that planktonic densities are negatively correlated with the biomagnification potential of mercury within a given aquatic system; they have labeled these correlations they observed: algal bloom dilution and zooplankton density dilution. One factor that remains supported by recent studies on mercury cycling is that methylmercury concentrations in surface water are strongly correlated with concentrations in subsequent trophic levels.

The food-chain structure and feeding habits of its constituents can also have a substantial influence on the bioaccumulation and magnification of methylmercury (MacCrimmon et al., 1983; Phillips et al., 1980; Cabana and Rasmussen, 1994; Cabana et al., 1994), with the fraction of total mercury that exists as methylmercury in aquatic organisms increasing sequentially from lower trophic level producers to piscivorous fish (May et al., 1987; Watras and Bloom, 1992). In addition, the size and age of exposed fish are positively correlated to the methylmercury content of fish tissue (Huckabee et al., 1979; Lange et al., 1993). Several studies have also concluded that approximately 90% of the total methylmercury present in fish tissue results from dietary uptake (Hall et al., 1997; Harris and Bodaly, 1998).

### **2.4.3 Mercury Toxicity and General Toxicokinetics**

Elemental mercury has no known metabolic function, and its presence in living organisms is undesirable and potentially hazardous (Eisler, 1987). Elemental mercury as vapor is most often absorbed through the lungs, although small amounts may be absorbed through the skin. Elemental mercury as a liquid can be absorbed through the skin and gastrointestinal tract; however, only 0.01 percent of liquid mercury ingested is absorbed (Goyer, 1986). Elemental mercury is insoluble in water, but is extremely lipophilic. Much of the  $\text{Hg}^0$  entering the lung is taken up by red blood cells where a majority of it is oxidized to a mercuric form. The  $\text{Hg}^0$



remaining in the blood is able to cross the blood-brain barrier and placenta because of its high lipid solubility. Once in the brain,  $\text{Hg}^0$  is also oxidized and tends to bind with different proteins and accumulates at a rate 10 times faster than in other tissues.

Mercuric chloride ( $\text{HgCl}_2$ ) is the most commonly encountered naturally occurring mercuric form.  $\text{HgCl}_2$  exposure is typically through the oral exposure route; however, only 7-15% of the  $\text{HgCl}_2$  ingested is absorbed through the gastrointestinal tract. Mercuric mercury can also cross the blood-brain barrier and can cross into the placenta in mammals or eggs in birds, but not as effectively as  $\text{Hg}^0$  or methylmercury. The cortex of the kidney is where most mercuric mercury is accumulated. Mercuric mercury is excreted primarily through the feces although urine and fur (in mammals) act as minor excretion routes.

Organic mercury (primarily methylmercury) is more toxic than inorganic mercury, most likely due to its greater lipid solubility, leading to greater bioavailability. Methylmercury and other organic mercury compounds are readily absorbed by inhalation (nearly 100% absorption) and through the gastrointestinal tract (80-90% absorption). Organomercurial can also be absorbed through the skin. Methylmercury is distributed primarily by red blood cells to the brain and to a lesser extent to the liver and kidney. Once inside cells, organic mercury tends to form unique bonds with proteins and is more readily transported across the blood-brain barrier and to the placenta or to eggs than the inorganic form. The major route of excretion for methylmercury is in feces, with hair and feathers acting as minor routes of excretion for mammals and birds, respectively. Organomercury is also more biologically stable and resistant to degradation than inorganic mercury, the form that can be more readily eliminated from the body (NAS, 1980). As previously discussed, bioaccumulation and biomagnification of methylmercury along food chains is well documented (Eisler, 1987).

Although organomercury is more easily absorbed and more toxic, inorganic forms present in the environment are also of concern since inorganic forms can be microbially methylated in aquatic media (Hill and Shaffner, 1976).

Mercury seems to affect all classes of vertebrates in a like manner. Mercury is also a mutagen, teratogen, and carcinogen. It has the potential to produce severe neurological, embryocidal, cytochemical, and histopathological effects in exposed wildlife (Eisler, 1987).

The following subsections present an overview of mercury toxicity in mammals, birds, and aquatic life. Primary emphasis is placed on toxic effects specifically attributed to methylmercury.

#### **2.4.3.1 Mammals**

Larger mammals seem to be more resistant to mercury than small mammals. Mercury concentrations in mammals are usually higher in fish-eating furbearers than in herbivorous species; seemingly reflecting the amounts of fish and other aquatic organisms in the diet. In river otter and mink exposed to high mercury levels, the residues were highest in the fur, followed by the liver, kidney, muscle, and brain (Eisler, 1987). A similar relationship was observed by Yates et al. (2005) for river otter and mink samples collected in the northeast from 1982-2003. Lake et al. (2007) also observed that mercury concentrations in mink livers collected from 1999-2004 in Rhode Island were higher than corresponding muscle concentrations; however, their analysis also noticed a substantial difference in mercury levels in mink sampled in freshwater and saltwater environments, with higher levels generally associated with freshwater habitats.

Symptoms of methylmercury poisoning generally do not occur immediately upon exposure, with a substantial latent period (weeks to years) passing between cessation of exposure and the onset of symptoms (Eisler, 1987).

The primary endpoint of concern with mammalian exposure to methylmercury is neurotoxicity (EPA, 1996). Methylmercury irreversibly destroys the neurons of the central nervous system (Eisler, 1987). In studies with laboratory rats, pathological changes in the cerebellum were evident in methylmercury treated rats. Toxicological studies with small mammals indicate that when methylmercury concentrations in the brain exceed 12,000 to 20,000 µg/kg WW, frequently observed effects include blindness, spasticity, and seizures (Burbacher et al., 1990). Other potential sites of damage include the posterior spinal roots, peripheral nerves, and peripheral sensory fibers (Suzuki, 1979). Other frequently observed signs of methylmercury intoxication include lethargy, weakness, ataxia, paralysis, tremors, convulsions, and visual impairment (Wiener et al., 2003). Many of the neurological effects reported for mammals exposed to

methylmercury could be life-threatening in the wild, with local population level impacts a real concern if exposure is widespread.

Aside from nervous system damage, chronic mercury toxicosis causes digestive, genitourinary, respiratory, and muscular dysfunction; and skin, visual (NAS, 1980), auditory, and sensory (EPA, 1996) problems.

The kidney is a target organ for inorganic mercury toxicity. Inorganic mercury exposures in rats have resulted in several forms of glomerular nephritis. Inorganic mercury also, through differing mechanisms including autoimmunity, causes changes in the renin angiotensin system (RAS) and kallikrein-kinin system (Carmignani et al., 1992). Renin is an enzyme produced by the kidney that acts on angiotensinogen to form angiotensin, a powerful vasopressor and stimulator of aldosterone production and secretion. Kallikrein is an enzyme present in the blood, plasma, urine, and body tissue that forms kinin. Kinin is a potent vasodilator that influences smooth muscle contraction, inducing hypotension (Thomas, 1985). The kallikrein-kinin system also influences the synthesis and release of aldosterone (Carmignani et al., 1992). Aldosterone affects the regulation of sodium, chloride, and potassium metabolism (Thomas, 1985). Therefore, inorganic mercury modifies systemic hemodynamics (Carmignani et al., 1992).

Dose-response studies of mink (Wobeser and Swift, 1976) and otter (O'Connor and Neilson, 1980) have shown that total mercury concentrations of 20,000-25,000 µg/kg WW in liver and 15,000-19,000 µg/kg WW in brain tissue may result in mortality. These concentration ranges also appear to be appropriate benchmarks for lethal effects, observed in fox (*Vulpes vulpes*), marten (*Martes martes*), the Florida panther (*Felix concolo*), and feral cats (Wiener et al., 2003). Dietary concentrations of methylmercury >1,800 µg/kg WW are sufficient to cause mercury intoxication in piscivorous mammals (Wobeser and Swift, 1976; Thompson, 1996). An Ontario study considered otter populations to have reduced survivorship when mercury concentrations in fur exceeded 20,000 µg/kg (Mierle et al., 2000). It is also worth noting that fur mercury levels in mink and otter are strongly correlated with corresponding brain mercury levels (Evers et al., 2002).

#### **2.4.3.2 Avian**

As with mammals, the threat of mercury to birds is largely an aquatic one (Wiener et al., 2003). In avian species, mercury intoxication causes muscular incoordination, falling, slowness, fluffed feathers, calmness, withdrawal, hypoactivity, hyperactivity, and eyelid drooping. Subtle effects of mercury include adverse effects on growth, development, reproduction, blood and tissue chemistry, metabolism, behavior, and histopathology (Eisler, 1987).

The most sensitive toxic endpoints for avian exposure to methylmercury are reproductive effects. Avian species exposed to methylmercury experienced a reduction in fertility, egg number, and survival; and defective shells (EPA, 1996). When methylmercury chloride was given to hens, 55% of the absorbed dose accumulated in the egg, with 80% of that associated with albumin (NAS, 1980). Mercury levels in eggs are a good indicator of avian exposure within the bird breeding territory (Heinz and Hofman, 2003).

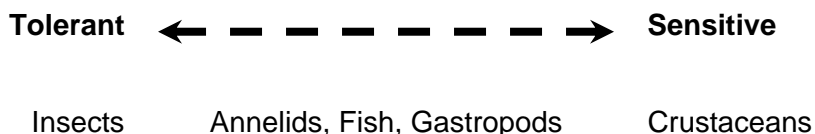
Studies have also shown that when exposed to methylmercury, a decreased number of ducklings approach maternal calls (EPA, 1996). Behavioral alterations noted in pigeons exposed to methylmercury were changes in posture and motor coordination, with "spastic paralysis" (Eisler, 1987).

Mercury levels in avian blood are the best tissue for evaluating short-term dietary uptake (Evers et al., 2005). Evers et al. (2003) observed that blood mercury levels of >3,000 µg/kg in territorial loons resulted in 40% fewer young than pairs below the no observed adverse effect level (NOAEL) of approximately 1,000 µg/kg in blood. Evers et al. (2003) also observed that loons with high mercury blood levels have higher ratios of chronic stress and may therefore have compromised immune systems. This study also found several atypical behaviors, such as reduced nest brooding and foraging, associated with increased mercury blood levels.

High inorganic mercury levels in drinking water decreased growth rate; decreased food and water consumption; and elevated hemoglobin, hematocrit, and erythrocyte content in chickens (Eisler, 1987).

### 2.4.3.3 Aquatic Life

The potential toxicity of mercury to aquatic life is higher in surface waters exhibiting elevated temperatures, lower oxygen content, and the presence of other metals (NOAA, 1996). Freshwater invertebrates are relatively tolerant of mercury, except in the larval stages. In general, mercury tolerance and sensitivity is reflected in the following scale:



As with most organisms, methylmercury is the most toxic form to freshwater invertebrates. Bottom feeders accumulate more methylmercury than other invertebrates, but methylmercury generally represents less than 60% of the organisms' total mercury burden. The kinetics and associated effects of mercury contamination of freshwater benthic organisms has received relatively little study; however several studies exist that have been able to demonstrate a relationship between total mercury concentrations in tissue and adverse effects on growth and behavior (Wiener et al., 2006). Water concentrations from 1E+06-10E+07 ng/L can be acutely toxic or lethal to some invertebrate larval stages. Calculated LC<sub>50</sub> ranges from 200 µg/kg for a sensitive crayfish (*Procambarus clarkia*) to 2.1E+06 µg/kg for the freshwater snail *Amnicola* were reported by Wren and Stepheson (1991).

Higher residues of mercury were found in piscivorous game fish than in herbivorous, insectivorous and omnivorous species. The highest mercury concentrations in fish occur in the blood, spleen, kidney, and liver (EPA, 1996). Body burdens in fish vary greatly depending on age, weight, length, species, temperature and local physical/chemical properties of the water. Exposure occurs through two principal mechanisms: Adsorption at the gill and ingestion of prey species. Comparisons of toxicity tests have indicated that methylmercury is 30 times more acutely toxic than inorganic mercury to freshwater species. Chronic exposure to low concentrations of mercury may result in fish populations tolerant to toxic effects of the contamination (NOAA, 1996).

Fish are more sensitive to sublethal effects from chronic exposure to inorganic and organic mercury than invertebrates, but are less sensitive to acute effects. Fish early life stages (especially in salmonids) are generally the most sensitive. Mercury can be transferred from adult female fish to the developing eggs (NOAA, 1996).

In fish species, acute lethality is preceded by flaring of gill covers, increased frequency of respiratory movements, loss of equilibrium, and sluggishness. Death from chronic exposure to mercury is preceded by emaciation from appetite loss, cataracts, and various erratic behaviors. Spry and Wiener (1991) reported  $LC_{50}$  values ranging from  $3.3E+07$  ng/L to  $6.87E+08$  ng/L for two-month old rainbow trout and adult white suckers, respectively. At sublethal doses, mercury adversely affects reproduction, growth, behavior, metabolism, blood chemistry, osmoregulation, and oxygen exchange (Eisler, 1987).

As with many terrestrial vertebrates, methylmercury is lipid soluble and penetrates the blood-brain barrier. Neurotoxicity results from the accumulation of methylmercury in the cerebellum and cerebral cortex, where it binds to sulfhydryl groups, causing pathological changes. Inside cells, methylmercury inhibits protein and RNA synthesis. Neurotoxicity is observed in adult fish as incoordination, inability to feed, lethargy, diminished responsiveness, abnormal movement, and brain lesions (NOAA, 1996).

Inorganic mercury has a high affinity for binding to thiol and sulfhydryl groups of proteins; thereby altering protein production or synthesis. This results in reproductive impairment, growth retardation/inhibition, and teratogenicity. Olfactory and chemoreceptor impairment in salmonids and other fish have also been noted from inorganic mercury exposure. This may interfere with normal migratory behavior, and disruption of simple upstream movement (NOAA, 1996).

## **2.5 Conceptual Model**

The conceptual model provides a description and visual representation of the fate, transport, and effects that mercury may have on the environment and as such, helps identify appropriate measures (measurement endpoints) that can be used to evaluate the assessment endpoints. In essence, the conceptual model presents a series of working hypotheses regarding how the contaminants (in this case, mercury) might affect ecological components of the natural environment. Risk hypotheses are specific assumptions about potential risk to assessment

endpoints and may be based on theory and logic, empirical data, or mathematical or probability models (EPA, 1998). The hypotheses are formulated using professional judgment and available information of the ecosystem at risk, potential mercury sources and characteristics, and observed or predicted effects on assessment endpoints. As with the entire ERA process, the development of a conceptual model is a complex, non-linear process, with many parallel activities that may result in modifications to the conceptual model as additional information becomes available.

Conceptual model diagrams are visual representations of the multiple relationships between mercury and receptors and the pathways of exposure at a site. Evaluation and inclusion of each relationship in the conceptual model diagram are based on several criteria:

- Data availability.
- Strength of relationship between mercury and effects.
- Endpoint significance.
- Relative importance or influence of mercury.
- Importance of effects to ecosystem function.

Information used to develop the conceptual model is often one of the most significant sources of uncertainty in a risk assessment. This uncertainty arises from lack of knowledge of how ecosystems function in general, and how the system being evaluated functions specifically; how mercury moves through the environment and causes adverse effects; and how the confounding variables associated with multiple contaminants interact. The availability of historical data on mercury and receptors, and a comprehensive ecological characterization reduces the uncertainty associated with the development of the conceptual model at this Site. Although general uncertainties associated with assumptions are addressed throughout this SBERA, a detailed discussion of specific uncertainties and their implications for the interpretation of risk results is reserved for the Risk Characterization.

The conceptual model discussed below addresses the relationship of mercury and methylmercury to key receptors selected for assessment. For each key receptor, the mechanisms of exposure and associated assessment attributes are presented. When possible, potential effects to other organisms that may result from a decline in the receptor population are introduced. For example, a decline in an organism population could result in a decrease in the food base for predatory organisms.

Biota inhabiting contaminated sediments and surface waters may be exposed and adversely impacted as a result of direct contact with sediments and surface water, ingestion of contaminated sediments, or consumption of contaminated organisms.

A large portion of the benthic macroinvertebrate community in aquatic systems is composed of the early life stages of insects. Because benthic macroinvertebrates are exposed to contaminated sediments and mercury bioaccumulates in these organisms, insectivorous birds can be exposed to contamination through the ingestion of emerging, adult insects.

Given that the existence of sediment-bound contaminants and the potential for release of contaminants into the overlying water may result in the pelagic community bioaccumulating contaminants, piscivores (both birds and mammals) may be exposed to contaminants in their diet. In addition, these species may be exposed to contamination through the incidental ingestion of sediment and floodplain soils and surface water that occurs during foraging activities, and through the deliberate ingestion of surface water.

Figure 2-71 provides a simple graphical representation of the pathways of exposure to stressors through the aquatic and semi-aquatic environments at the Sudbury River, and identifies key ecological components that have been selected for further analysis. This flow diagram provides a working, dynamic representation of the relationships that exist between mercury and key ecological receptors that may be modified as additional information becomes available, and is not meant to characterize all possible mechanisms of exposure or potentially impacted species.

## **2.6 Assessment Endpoint Selection**

A critical early step when conducting an ERA is deciding which aspects of the environment will be selected for evaluation, because not all organisms or ecosystem feature can be studied (EPA, 2003). It is therefore, essential that risk assessors understand the potential relationship of site-related contamination to ecological endpoints so that well informed risk management decisions can be made at the end of the ERA process (Suter, 1989). In general, endpoints are defined as ecological characteristics (e.g., fish survival) that may be adversely affected by site contaminants (EPA, 1992a). In the ERA process, two distinct types of endpoints are identified: assessment endpoints and measurement endpoints. The following discussion provides definitions and criteria used to develop the assessment endpoints that are used to evaluate



potential ecological risks in the Sudbury River. A discussion of measurement endpoints that are used to evaluate assessment endpoints is provided in Section 2.10.

Assessment endpoints are “explicit expressions of environmental values to be protected, operationally defined as an ecological entity and its attributes” (EPA, 1998). Valued ecological entities can be categorized by their level of organization (e.g., organism, population, community or ecosystem) and can include such varied ecological components as a species of specific concern (e.g., the endangered piping plover), a functional group of species (e.g., piscivorous mammals), a community (e.g., benthic invertebrates), a unique ecosystem (e.g., forested wetland), or other entities of concern. Attributes are characteristics of the entity selected that are important to protect, are potentially at risk, and are tied directly to site-specific management goals determined by regulatory and programmatic objects (EPA, 2003).

Assessment endpoints determine the foundation for an ERA because they:

- Provide guidance for evaluating the site and the extent of contamination.
- Establish a basis for assessing the potential risks to identified receptors.
- Assist in the identification of the ecological structure and function at the site.

Each site or area evaluated in an ERA has the potential to be biologically unique; therefore, there is no universal list of assessment endpoints (Suter, 1993). However, EPA (2003) has developed a set of generic ecological assessment endpoints (GEAEs) that provides examples of endpoints applicable to a wide variety of assessment scenarios and also provides guidance for using GEAEs to develop robust assessment-specific endpoints. When selecting site-specific assessment endpoints, EPA has provided the three principal criteria that should be followed: ecological relevance, susceptibility and relevance to management goals (EPA, 1998). Of these criteria, ecological relevance and susceptibility are essential for selecting assessment endpoints that are scientifically defensible and relevance to management goals is critical for the translation of risk results into effective management decisions. According to Guidance (EPA, 1997a):

“Assessment endpoints for the baseline ERA must be selected based on the ecosystems, communities, and/or species potentially present at the site. The selection of assessment endpoints depends on:

- The contaminants present and their concentration;
- Mechanisms of toxicity of the contaminants to different groups of organisms;

- Ecologically relevant receptor groups that are potentially sensitive or highly exposed to the contaminant and attributes of their natural history; and
- Potentially complete exposure pathways.”

In addition, specific assessment endpoints should define the ecological value in sufficient detail to identify measures (measurement endpoints) that can be used to evaluate potential impacts to the assessment endpoint (EPA, 1997a). For practical reasons, it is helpful to use assessment endpoints that have well-developed test methods, field measurement techniques, and predictive models (Suter, 1993). Ultimately, the true value and success of any ecological risk assessment depends on whether it can be used to make appropriate management decisions. Therefore, the careful selection of well-defined assessment endpoints is crucial in determining the success or failure of the risk assessment process. Once assessment endpoints have been selected and the conceptual model of exposure has been adequately developed, testable hypotheses and measurement endpoints can be selected to determine whether or not a potential threat to the assessment endpoints exists (EPA, 1997a). Assessment endpoints specific to this study are presented in Table 2-68. The application of assessment and associated measurement endpoints are made on reach or target-area basis. Decisions regarding the extrapolation of data collected between reaches or target areas were made after consultation with the ERA team.

## **2.7 Measurement Endpoint Selection**

A measurement endpoint is defined as “a measurable ecological characteristic that is related to the valued characteristic chosen as the assessment endpoint.” Measurement endpoints link the conditions existing on-site to the goals established by the assessment endpoints through the integration of modeled, literature, field, or laboratory data (Maughan, 1993).

“Measurement endpoints are frequently numerical expressions of observations (e.g., toxicity test results, community diversity measures) that can be compared statistically to a control or reference site to detect adverse responses to a site contaminant” (EPA, 1997a). Measurement endpoints can include measures of exposure (e.g., contaminant concentrations in water or tissues) as well as measures of effect.

It is desirable to have more than one measurement endpoint for each assessment endpoint (if the assessment cannot be measured directly), thereby providing multiple lines of evidence for

the evaluation. When direct measurement of assessment endpoint responses is not possible, the selection of surrogate measures is necessary (e.g., effects to tree swallow are measured to assess potential affects to insectivorous birds in general). However, the primary consideration for selecting measurement endpoints should always be how many and which lines of evidence are needed to support risk management decisions at the site. Once it has been determined which lines of evidence are required to answer questions concerning the assessment endpoint, the measurement endpoints by which the questions or test hypotheses are examined are selected (EPA, 1997a).

In selecting an appropriate measurement endpoint to represent an assessment endpoint, the following criteria are considered (Suter, 1989):

- Corresponds to or is predictive of an assessment endpoint.
- Readily measurable.
- Appropriate to site scale, exposures pathways, and temporal dynamics.
- Diagnostic.
- Broadly applicable.
- Standard.

With the selection of measurement endpoints, the conceptual model development is essentially completed. The conceptual model, which is discussed in Subsection 4.2.5, then is used to develop the study design and DQOs, which are presented in the QAPP.

The assessment and associated measurement endpoints that are used to evaluate potential ecological risks resulting from mercury and methylmercury exposure in the Sudbury River were presented in Table 2-68 with their corresponding assessment endpoints. Many studies conducted as part of this investigation include multiple measurement endpoints (e.g., the tree swallow field investigation collected blood, feather, and egg residue data) in their design. Rather than list these individual measurement endpoints separately, the assessment endpoint and principal measurement endpoints are presented. This approach will allow interrelated measurement endpoints to be evaluated concurrently when assessing the associated assessment endpoint.

Initial evaluations conducted during the 1999 BERA (Weston, 1999a) identified the potential for bioaccumulation and adverse impacts to benthic organisms (i.e., mayflies, freshwater mussels,

and the benthic community). Specific impacts to mayflies and freshwater mussels are evaluated using site-specific bioaccumulation and toxicity studies (Salazar et al., 1996; Naimo et al., 1997). Potential effects to the benthic community inhabiting the site are assessed by comparing sediment concentrations to appropriate benchmarks. Previous sediment studies that were included in the 1999 BERA are summarized and included as independent lines of evidence for the benthic community evaluation. Also, crayfish tissue residue data, collected in several reaches and target areas are evaluated by comparing crayfish tissue concentrations with literature-based benchmarks.

Although fish tissue concentrations used in the 1999 BERA did indicate the potential for adverse impacts to fish, the original fish data set was limited in composition and spatial representation. Therefore, any new fish tissues residue information collected are included in the baseline risk assessment and are evaluated using appropriate fish tissue residue benchmarks.

The survival, neurological effects, and reproduction of insectivorous birds are assessed using site-specific tree swallow, eastern kingbird, and marsh bird data including the comparison of tissue (i.e., egg, blood, and feather) concentrations with residue effects levels from literature. Site-specific exposure and effects modeling is also conducted for tree swallows as an independent line of evidence for evaluating potential impacts to this foraging guild.

In addition, survival, neurological effects, and reproduction of herbivorous birds (e.g., wood duck), piscivorous birds (e.g., kingfisher and hooded merganser) and mammals (e.g., mink) are assessed by comparing site-specific tissue concentrations (blood, feather, and egg for birds; and blood, fur, liver, and brain for mammals) with residue effect levels from the literature. Site-specific exposure and effects modeling is also conducted for kingfisher, great blue heron, and mink as independent lines of evidence for evaluating potential impacts to piscivores.

Although many of the endpoints presented here are linked to organism-level effects (e.g., survival and reproduction), these endpoints are in fact strong indicators of potential population-level effects (e.g., viability of the tree swallow population within the Sudbury River study area). Extrapolation from organism-level to population-level effects may be logically achieved based on the predictive nature of the endpoint and/or through the use of process-based models. A general description of these models is discussed in Subsection 4.3.2.2.

## 2.8 Weight-of-Evidence Approach

The assessment methods that are used in this SBERA consider a wide variety of endpoints and effects that differ in their suitability for, and sensitivity to, assessing the potential risks at the site. In assessing ecological risk, not all measurement endpoints are equivalent in their ecological significance or in their ability to predict risk. For example, it can be argued that comparison of chemical concentrations in sediments to benchmark values is less compelling than the results derived from chronic sediment toxicity testing.

To account for the strengths and weaknesses of different measurement endpoints that will be used in this assessment and to provide a framework for evaluating multiple lines of evidence, a WOE approach will be used. The objective of this WOE framework is to provide a more rigorous consideration of the strengths and weaknesses of various measurements, the nature of uncertainty associated with them, and their potential utility in the ERA. The framework for the approach used in this assessment was developed by the Massachusetts Weight-of-Evidence Workgroup (the Workgroup) and is detailed in the *Special Report of the Massachusetts Weight-of-Evidence Workgroup: A Weight-of-Evidence Approach for Evaluating Ecological Risks* (Menzie et al., 1996). In this paper, the Workgroup defines the WOE approach as:

...the process by which measurement endpoints are related to an assessment endpoint to evaluate whether a significant risk of harm is posed to the environment. The approach is planned and initiated at the problem formulation stage, and results are integrated at the risk characterization stage.

According to Menzie et al. (1996), WOE is reflected in three characteristics of measurement endpoints: (1) the weight assigned to each measurement endpoint; (2) the magnitude of response observed in the measurement endpoint; and (3) the degree of concurrence among outcomes of multiple measurement endpoints for a given assessment endpoint. The approach provides the option of performing either a quantitative or qualitative WOE evaluation. Regardless of what form the WOE takes, it should provide clear and transparent documentation of the thought processes used when determining potential ecological risk. For this assessment, a more qualitative approach using a low-medium-high significance rating is used to assign

weights to different measurement endpoints. The discussion that follows provides a detailed description of the steps taken to conduct the WOE for this SBERA.

First, weights are assigned to measurement endpoints based on 10 attributes (summarized in Table 2-69) related to: (1) strength of association between assessment and measurement endpoints; (2) data and study quality; and (3) study design and execution. In either a quantitative or qualitative WOE analysis, the process of assigning weights to measurement endpoints can incorporate two elements:

- 1) The relative importance assigned to each attribute, a process referred to as “attribute scaling.”
- 2) The score that each measurement endpoint receives with respect to each attribute, typically referred to as “attribute weighting.”

For this SBERA, it was assumed that all attributes were of equal importance so there was no “attribute scaling” conducted. The second element of the measurement endpoint weighting process, “attribute weighting,” was performed for measurement endpoints using a qualitative scale ranging from low to high and following “attribute weighting” guidelines provided in Menzie et al. (1996; Table 2). This process, even when following the guidelines, is somewhat subjective and was accomplished using the combined professional judgment of the ecological risk assessors.

After assigning a weight for each of the 10 attributes, a total measurement endpoint value was determined by averaging the 10 attribute weights. Consistency in the weighting process was ensured by assigning each attribute weight a numerical score of 1 (low) through 5 (high). The final qualitative measurement endpoint value was determined by applying the following classification scale to the arithmetic average of the attribute weights: 1-1.49 (Low), 1.50-2.49 (Low/Moderate), 2.50-3.49 (Moderate), 3.50-4.49 (Moderate/High), and  $\geq 4.5$  (High).

This process is further described in the Risk Characterization (Section 4) for each assessment endpoint. Figure 2-72 provides a generic example of the measurement endpoint weighting process used to evaluate each assessment endpoint.

To ensure that the selected measurement endpoints would result in the achievement of the study objectives, the first step in the WOE process was conducted in preparing the work plan;

however, so that the complete WOE can be easily followed and clearly understood, the entirety of the WOE process is presented in the risk characterization. Because a preliminary WOE was conducted during the problem formulation phase, it is expected that low attribute weights will not typically be assigned if the study was conducted as planned, and total endpoint values will typically be in the moderate to high range. In general, overall endpoint weights developed using the aforementioned approach follow a basic hierarchy:

- Low = generic benchmarks, food chain modeling using estimated tissue concentrations;
- Moderate = laboratory toxicity testing, food chain modeling using measured tissue concentrations; and
- Moderate-high = field toxicity testing, comparing measured tissue concentrations to CBRs.

The second step of the WOE approach is to evaluate the magnitude of response in the measurement endpoint. This is accomplished by considering the potential risk to the population/community being evaluated and the level of confidence associated with that risk determination.

The third step of the WOE process evaluates the degree of concurrence among measurement endpoints. This is accomplished by presenting the risk results for each line of evidence, their associated weights, and key uncertainties together. Since the study area has been divided by reach, the concurrence of measurement endpoints are presented in the risk characterization on a reach-by-reach basis.

## SECTION 2 TABLES



**Table 2-1**

**Chronology of Primary Evaluations and Investigations Conducted  
Nyanza Chemical Dump Superfund Site  
Middlesex County, Massachusetts**

<b>Investigation</b>	<b>Investigator and Date</b>	<b>Key Findings</b>
Waste disposal violations	Massachusetts Departments of Public Health (DPH) and Massachusetts Department of Water Pollution Control, 1972-1977	Identified several waste disposal violations.
Investigation of Mercury Problems in Massachusetts	JBF Scientific Corp. 1972	Identified elevated levels of mercury in water, sediments and biota in the Sudbury River, and qualitatively linked mercury contamination in the Sudbury River to the Nyanza Site.
Environmental Site Investigation	Camp, Dresser and McKee, 1974	Determined on- and off-site contamination sources and developed a groundwater contamination control plan.
Sudbury River Fish Monitoring Study	U.S. Fish and Wildlife Service (USFWS) 1977-1987	Detected elevated mercury concentrations in several fish species and sediment collected in the Sudbury River.
Preliminary Site Assessment	Massachusetts Department of Environmental Quality and Engineering (DEQE) 1980	Performed a site assessment and review of previous studies that identified off-site migration of several metal (including mercury) and organic contaminants.
Environmental Investigations of Sudbury River	Massachusetts DEQE Metropolitan District Commission (MDC), 1980-1987	Identified metal and organic contamination in surface water, sediment, and fish collected in the Sudbury River near the site.
Remedial Action Master Plan	Camp, Dresser and McKee 1982	Remedial action plan emphasizing on-site source control is developed.
Operable Unit I (on-site surficial soil, sediment, and sludge) RI/FS	NUS Corporation, 1984	Characterized the extent of on-site inorganic and organic contamination and recommended source removal and stabilization activities. ROD based on findings signed in 1985.

**Table 2-1, Continued**

**Chronology of Primary Evaluations and Investigations Conducted  
Nyanza Chemical Dump Superfund Site  
Middlesex County, Massachusetts**

<b>Investigation</b>	<b>Investigator and Date</b>	<b>Key Findings</b>
Sludge Removal Action	EPA Region 1 Environmental Service Division (ESD), 1987	The “vault,” or major source of organic groundwater contamination is removed. E.C. Jordan begins RI/FS activities on Operable Unit II (groundwater).  On-site sludges were excavated, solidified and buried on Mejunko Hill, then covered with a cap.
Off-site Groundwater Control, OU II	EPA, 1991	Activities involved in the groundwater study included installation of monitoring wells, topographic and geophysical studies, aquifer testing, and groundwater, surface water, sediment, and subsurface sampling. As a result, it was concluded that a contaminated groundwater plume containing VOCs and metals was traveling north, east, and northeast toward the Sudbury River. It was concluded that there were minimal human health risks due to groundwater in basements or drinking water. The minimal risk is attributed to the lack of known public or private drinking wells. It was concluded that if individuals began to utilize the groundwater for future household use or if groundwater was not properly addressed, potential human health and environmental risks exists.
Sudbury River Study, OU III	NUS Corporation, 1992	Following Phase I sampling, surface water had minimal contamination; mercury, chromium, and lead contamination found in sediments; and mercury, PCB, and pesticide contamination found in fish. Following Phase II activities, minimal surface water contamination confirmed Phase I findings, high levels of mercury contamination found in sediments downstream of site, high mercury levels in fish found in entire river stretch, and PCB and pesticide contamination found not related to Nyanza site.
Additional On-site Investigations	Camp, Dresser and McKee, 1996	Identified additional on-site source areas in support of remedial design.

**Table 2-1, Continued**

**Chronology of Primary Evaluations and Investigations Conducted  
Nyanza Chemical Dump Superfund Site  
Middlesex County, Massachusetts**

<b>Investigation</b>	<b>Investigator and Date</b>	<b>Key Findings</b>
Final Extent of Contamination Report for Pre-Design Investigations, OU III	Ebasco Services, Inc., 1995	Determined the extent of mercury contamination in the Continuing Sources Area soils and excluded both TCL and TAL chemicals in surface water. Most soil mercury levels below 1-foot depth were less than 1.0 mg/kg. Mercury contamination in soils in the Eastern Wetlands was present to depths of at least 0.5 feet. Trolley Creek had mercury contamination as high as 126 mg/kg at depths of 2 to 3 feet. Study estimated that approximately 18,750 cubic yards of soil would require excavation. Surface water sampling was limited; however, no VOC, SVOC, pesticides or PCB's were present. Mercury in surface waters was detected at levels ranging from 2.2E+05 to 1.69E+07 ng/L.
Ecological Task Force Findings	Task Force Members, 1997	Following initial site investigations of the Sudbury River, it was concluded that additional studies were necessary. Sediments and fish were contaminated with mercury and other heavy metals.
Baseline Human Health Risk Assessment	Roy F. Weston, Inc. 1999b	Evaluation showed human health effects from mercury due to fish consumption. Risks to recreational anglers and subsistence fishermen due to exposure from fish consumption were above a hazard quotient of 1. Routine monitoring of mercury in fish in the Sudbury River was recommended to evaluate the need for continued fish advisories due to mercury contamination.
Baseline Ecological Risk Assessment	Roy F. Weston, Inc., 1999a	Evaluation showed sediment contamination effects on benthic communities within Sudbury River and nearby wetlands and tributaries; methylation of inorganic mercury occurring in wetlands, bioaccumulation of methylmercury occurring within study area, and reproductive/developmental and neurotoxic/behavioral effects occurring on avian receptors. Recommended need for continued monitoring and data collection and potential remediation.
Supplemental Baseline Human Health Risk Assessment	Avatar Environmental, 2006	HQs ranged from 0.3 (Child of a recreational angler – Heard Pond) to 15 (Child of an ethnic angler – Reach 3). HQs for site-impacted areas were 0.5 to 4.5 times those found in the reference areas.

**Table 2-1, Continued**

**Chronology of Primary Evaluations and Investigations Conducted  
Nyanza Chemical Dump Superfund Site  
Middlesex County, Massachusetts**

<b>Investigation</b>	<b>Investigator and Date</b>	<b>Key Findings</b>
Tree Swallow Study	Biodiversity Research Institute (BRI), 2007a; See Appendix A	Presented in Section 4 and Appendix A.1 of this report.
Marsh Bird Study	BRI, 2007b; See Appendix A	Presented in Section 4 and Appendix A.2 of this report.
Hooded Merganser Study	BRI, 2007c; See Appendix A	Presented in Section 4 and Appendix A.3 of this report.
Kingfisher Study	BRI, 2007d; See Appendix A	Presented in Section 4 and Appendix A.4 of this report.
Mink and Otter Study	BRI, 2007e; See Appendix A	Presented in Section 4 and Appendix A.5 of this report.
Supplemental Baseline Ecological Risk Assessment	Avatar Environmental, 2008 (Under Contract to Nobis Engineering, Inc.)	Presented in this report.

**Table 2-2**

**Mercury Assessment Studies  
Operable Unit IV - Nyanza Chemical Dump Superfund Site  
Middlesex County, Massachusetts**

<b>Title</b>	<b>Researchers and Date</b>	<b>Affiliation</b>	<b>Objectives</b>
An in-situ assessment of mercury contamination in the Sudbury River, Massachusetts, using bioaccumulation and growth in transplanted mussels	Salazar, S.M., Beckvar, N, Salazar, M.H. and K. Finkelstein, 1996	National Oceanic and Atmospheric Administration and E.V.S. Consultants	Demonstrate the extent of bioavailable mercury within the downstream reaches of the Sudbury River resulting from operations at the Nyanza site. Identify areas that could act as sources of mercury for transport downstream. Determine the effect of mercury exposure on a resident species.
Artifact formation of methyl mercury during aqueous distribution and alternative for the extraction of methyl mercury environmental samples	Bloom, N.S., Colman, J.A. and L. Barber, 1997	Frontier Geo-Sciences, Inc., U.S. Geological Survey, Duke University	Determine the relative proportion of methyl mercury generated during standard pre-extraction distillation procedures and identify method modifications that may result in the elimination or reduction in pre-extraction methyl mercury production.
Estimating historical mercury concentrations and assessing fish exposure to mercury in a contaminated reservoir on the Sudbury River, East-Central Massachusetts, using a constant settling-velocity model and accumulation rates of mercury in sediment cores	J.A. Colman, 1997	U.S. Geological Survey	Estimate historical mercury concentrations in the first reservoir downstream from the Nyanza Superfund site for use in assessing exposure of fish to mercury.
Stratigraphy and historic accumulation of mercury in recent depositional sediments in the Sudbury River	Frazier, B.E., Wiener, J.G., Rada, R.G., and D.E. Engstrom, 1997	University of Wisconsin-La Crosse, U.S. Geological Survey, Biological Resources Division, and Science Museum of Minnesota	Determine the vertical distribution of mercury in sediments from the Sudbury River. Estimate the recent inputs of mercury to depositional environments in the Sudbury River, as reflected by the temporal pattern in accumulation rates of mercury in the sediments.

**Table 2-2, Continued**

**Mercury Assessment Studies  
Operable Unit IV - Nyanza Chemical Dump Superfund Site  
Middlesex County, Massachusetts**

Title	Researchers and Date	Affiliation	Objectives
Factors affecting food chain transfer of mercury in the vicinity of the Nyanza Site, Sudbury River, Massachusetts	Haines, T.A., May, T.W., Finlayson, R.T., Mierzykowski, S.E. and M.W. Powell, 1997	U.S. Geological Survey-Biological Resources Division, University of Maine, U.S. Fish and Wildlife Service	<p>Characterize total mercury content of the most important predator fish species in reference and contaminated sites in the Sudbury River, considering both impounded and free-flowing reaches and three seasons (spring, summer and fall).</p> <p>Characterize total and methyl mercury concentrations in invertebrates and forage fish in reference and contaminated sites in the Sudbury River, in order to assist in the determination of the importance of food chain pathways of mercury in the continuing contamination of fish and wildlife resources in the river.</p> <p>Construct a computer model that represents the major pathways of methyl mercury into the food chain leading to predatory fish and develop forecast models that predict biota mercury accumulation from environmental variables and can be used to evaluate remediation strategies.</p>
Sudbury River Sediment Transport Model	Nail, G.H. and D.D. Abraham, 1997	U.S. Army Corps of Engineers	Determine the extent of mercury contamination in existing river sediment, and the potential for resuspension and movement of these sediments.
Bioavailability of sediment associated mercury in <i>Hexagenia</i> mayflies in a contaminated floodplain river	Naimo, T.J. Wiener, J.G., Cope, W.G., and N.S. Bloom, 1997	U.S. Geological Survey, Biological Resources Division, and Frontier Geosciences	<p>Determine if <i>Hexagenia</i> mayfly nymphs exposed to mercury-contaminated surficial sediment from the Sudbury River accumulate MeHg.</p> <p>Determine if the accumulation of MeHg in mayflies is a function of the <math>\Sigma</math>Hg concentration in sediment.</p> <p>Assess which contaminated areas on the Sudbury River have the greatest potential for MeHg transfer into the benthic food chain.</p>

**Table 2-2, Continued**

**Mercury Assessment Studies  
Operable Unit IV - Nyanza Chemical Dump Superfund Site  
Middlesex County, Massachusetts**

<b>Title</b>	<b>Researchers and Date</b>	<b>Affiliation</b>	<b>Objectives</b>
Distribution and transport of total mercury and methylmercury in mercury-contaminated sediments in reservoirs and wetlands of the Sudbury River, east-central Massachusetts	Colman, J.A., M.C. Waldron, R.F. Breault, and R.M. Lent, 1999	U.S. Geological Survey	Determine the effect of Hg contaminated-Sudbury River sediment on net MeHg generation as determined by the presence, distribution, and correlation of $\Sigma$ Hg and MeHg in the bed sediments.
Sampling for mercury at sub-nanogram per liter concentrations for load estimation in rivers.	Colman, J.A. and R.F. Breault, 2000	U.S. Geological Survey	Collect and analyze Hg water concentrations at subnanogram/liter concentrations of stream cross-sections so that constituent load estimates could be calculated.
Distribution, hydrologic transport, and cycling of total mercury and methyl mercury in a contaminated river-reservoir-wetland system (Sudbury River, eastern Massachusetts)	Waldron, M.C., Colman, J.A. and R.F. Breault, 2000	U.S. Geological Survey	<p>Determine occurrence and distribution of Hg in the water column.</p> <p>Determine current sources of Hg in the Sudbury River.</p> <p>Determine how Hg from the Superfund site moves downstream through the system.</p> <p>Determine if the reservoirs affect Hg transport and sedimentation.</p> <p>Determine if contaminated sediment beds are sites of elevated MeHg production.</p> <p>Determine how much the wetland associated reaches contribute to the river's MeHg load.</p> <p>Determine if transport of MeHg from <math>\Sigma</math>Hg contaminated sites is an important source of MeHg to food chains at downstream sites.</p>

**Table 2-2, Continued**

**Mercury Assessment Studies  
Operable Unit IV - Nyanza Chemical Dump Superfund Site  
Middlesex County, Massachusetts**

<b>Title</b>	<b>Researchers and Date</b>	<b>Affiliation</b>	<b>Objectives</b>
Kingfisher Study	Biodiversity Research Institute (BRI), 2007d; see Appendix A	Not Applicable	Determine the extent to which mercury has accumulated in the blood and feathers of adult kingfisher foraging the Sudbury River for comparison with existing data on effects levels (i.e., critical residue levels); Determine the extent to which mercury has accumulated in the eggs of kingfisher for comparison with existing data on effects levels; and Obtain data on the ambient levels of mercury in eggs and in blood and feathers of adult kingfisher inhabiting reference surface waters including Sudbury Reservoir and the Charles River.
Marsh Bird Study	BRI, 2007b; see Appendix A	Not Applicable	Determine the extent to which mercury has accumulated in the blood and feathers of adult marsh birds inhabiting the floodplains of the Sudbury River for comparison with existing data on effects levels (i.e., critical residue levels); Determine the extent to which mercury has accumulated in the eggs of marsh birds for comparison with existing data on effects levels; and Obtain data on the ambient levels of mercury in eggs and in blood and feathers of marsh birds inhabiting reference floodplains including Sudbury Reservoir and the Charles River.



**Table 2-2, Continued**

**Mercury Assessment Studies  
Operable Unit IV - Nyanza Chemical Dump Superfund Site  
Middlesex County, Massachusetts**

<b>Title</b>	<b>Researchers and Date</b>	<b>Affiliation</b>	<b>Objectives</b>
Hooded Merganser Study	BRI, 2007c; see Appendix A	Not Applicable	Determine the extent to which mercury has accumulated in the blood and feathers of adult mergansers inhabiting the Sudbury River for comparison with existing data on effects levels (i.e., critical residue levels);  Determine the extent to which mercury has accumulated in the eggs of mergansers for comparison with existing data on effects levels; and  Obtain data on the ambient levels of mercury in eggs and in blood and feathers of adult mergansers inhabiting reference surface waters including Sudbury Reservoir and the Charles River.
Tree Swallow Study	BRI, 2007a; see Appendix A	Not Applicable	Determine the extent to which mercury has accumulated in the blood and feathers of adult tree swallows for comparison with existing data on effects levels (i.e., critical residue levels);  Determine the extent to which mercury has accumulated in the eggs of tree swallows for comparison with existing data on effects levels; and  Obtain data on the ambient levels of mercury in eggs and in blood and feathers of adult tree swallows inhabiting reference surface waters including Sudbury Reservoir and the Charles River.
Mink and Otter Study	BRI, 2007e; see Appendix A	Not Applicable	Determine the extent to which mercury has accumulated in the blood and fur of mink and otter inhabiting the Sudbury River for comparison with existing data on effects levels (i.e., critical residue levels); and  Obtain data on the ambient levels of mercury in blood and fur in mink and otter inhabiting reference surface waters including Sudbury Reservoir and the Charles River.

Table 2-3

**Potential Wildlife Species**  
**Operable Unit IV – Nyanza Chemical Dump Superfund Site**  
**Middlesex County, Massachusetts**

Common Name	Scientific Name	Seasonal Presence			
		W	Sp	Su	F
BIRDS					
Blue-winged teal	<i>Anas discors</i>		X	X	X
American black duck	<i>Anas rubripes</i>		X	X	X
Mallard	<i>Anas platyrhynchos</i>	X	X	X	X
Wood duck	<i>Aix sponsa</i>		X	X	X
Ring-necked duck	<i>Aythya cottaris</i>		X		X
Common merganser	<i>Mergus merganser</i>			X	X
American bittern	<i>Botaurus lentiginosus</i>		X	X	X
Great blue heron	<i>Ardea herodias</i>		X	X	X
Black-crowned night heron	<i>Nycticorax nycticorax</i>		X	X	X
Green-backed heron	<i>Butorides striatus</i>		X	X	X
Killdeer	<i>Charadrius vociferus</i>		X	X	X
Osprey	<i>Pandion haliaetus</i>		X	X	X
Red-tailed hawk	<i>Buteo jamaicensis</i>	X	X	X	X
Northern harrier	<i>Circus cyaneus</i>	X	X	X	X
American kestrel	<i>Falco sparverius</i>	X	X	X	X
Belted kingfisher	<i>Ceryle alcyon</i>	X	X	X	X
Downy woodpecker	<i>Picoides pubescens</i>	X	X	X	X
Eastern kingbird	<i>Tyrannus tyrannus</i>		X	X	X
Barn swallow	<i>Hirundo rustica</i>		X	X	X
Tree swallow	<i>Tachycineta bicolor</i>		X	X	X
Tufted titmouse	<i>Parus bicolor</i>	X	X	X	X
Black-capped chickadee	<i>Parus atricapillus</i>	X	X	X	X
White-breasted nuthatch	<i>Sitta carolinensis</i>	X	X	X	X
Gray catbird	<i>Dumetella carolnensis</i>	X	X	X	X
Marsh wren	<i>Cistothorus palustris</i>		X	X	X

Table 2-3, Continued

**Potential Wildlife Species**  
**Operable Unit Iv – Nyanza Chemical Dump Superfund Site**  
**Middlesex County, Massachusetts**

Common Name	Scientific Name	Seasonal Presence			
		W	Sp	Su	F
BIRDS (Continued)					
Yellow warbler	<i>Dendroica petechia</i>		X	X	X
Common yellowthroat	<i>Geothlypis trichas</i>		X	X	X
Red-winged blackbird	<i>Agelaius phoeniceus</i>		X	X	X
Common grackle	<i>Quiscalus quiscula</i>	X	X	X	X
Song sparrow	<i>Melospiza melodia</i>	X	X	X	X
MAMMALS					
Virginia opossum	<i>Didelphis virginiana</i>	X	X	X	X
Raccoon	<i>Procyon lotor</i>	X	X	X	X
Long-tailed weasel	<i>Mustela frenata</i>	X	X	X	X
Mink	<i>Mustela vison</i>	X	X	X	X
River otter	<i>Lutra canadensis</i>	X	X	X	X
Striped skunk	<i>Mephitis mephitis</i>	X	X	X	X
Masked shrew	<i>Sorex cinereus</i>	X	X	X	X
Water shrew	<i>Sorex palustris</i>	X	X	X	X
Short-tailed shrew	<i>Blarina brevicauda</i>	X	X	X	X
Little brown myotis	<i>Myotis lucifugus</i>		X	X	X
Eastern pipistrelle	<i>Pipistrellus subflavus</i>		X	X	X
Beaver	<i>Castor canadensis</i>	X	X	X	X
Southern bog lemming	<i>Synaptomys cooperi</i>	X	X	X	X
Meadow vole	<i>Microtus pennsylvanicus</i>	X	X	X	X
Eastern cottontail	<i>Sylvilagus floridanus</i>	X	X	X	X
New England cottontail	<i>Sylvilagus transitionalis</i>	X	X	X	X
Eastern chipmunk	<i>Tamias striatus</i>	X	X	X	X
White-tailed deer	<i>Odocoileus virginianus</i>	X	X	X	X
REPTILES AND AMPHIBIANS					
Northern dusky salamander	<i>Desmognathus fuscus</i>		X	X	X
Northern two-lined salamander	<i>Eurycea bislineata</i>		X	X	X

**Table 2-3, Continued**

**Potential Wildlife Species  
Operable Unit Iv – Nyanza Chemical Dump Superfund Site  
Middlesex County, Massachusetts**

Common Name	Scientific Name	Seasonal Presence			
		W	Sp	Su	F
REPTILES AND AMPHIBIANS, Continued					
Red-spotted newt	<i>Notophthalmus viridescens</i>		X	X	X
Eastern pointed turtle	<i>Chrysmys picta</i>		X	X	X
Spotted turtle	<i>Clemmys guttata</i>		X	X	X
Blanding's turtle	<i>Emydoidea blandingi</i>		X	X	X
Common snapping turtle	<i>Chelydra serpentine</i>		X	X	X
Stinkpot	<i>Sternotheracrus odoratus</i>		X	X	
Bullfrog	<i>Rana catesbeiana</i>		X	X	
Northern leopard frog	<i>Rana pipiens</i>		X	X	
Eastern American toad	<i>Bufo americanus</i>		X	X	
Northern spring peeper	<i>Hula crucifer</i>		X	X	
Green frog	<i>Rana clamitans</i>		X	X	
Wood frog	<i>Rana sylvatica</i>		X	X	
Pickerel frog	<i>Rana palustris</i>		X	X	
Eastern garter snake	<i>Thamnophis s. sirtalis</i>		X	X	
Eastern milk snake	<i>Tampropeltis treangulum</i>		X	X	X
Northern water snake	<i>Nerodia sipedon</i>		X	X	X
Eastern smooth green snake	<i>Opheodrys vernalis</i>		X	X	X
Northern ringneck snake	<i>Diadophis punctatus</i>		X	X	X
Northern brown snake	<i>Storeria dekayi</i>		X	X	X

W = Winter

Sp = Spring

Su = Summer

F = Fall

Note: All reptiles and amphibians listed are winter hibernators and are not considered active during the winter months.

Table 2-4

**General List of Potential Aquatic Life  
Operable Unit IV – Nyanza Chemical Dump Superfund Site  
Middlesex County, Massachusetts**

Fish		Invertebrates	
Common Name	Scientific Name	Common Name	Scientific Name
American eel	<i>Anguilla rostrata</i>	Crayfish	<i>Orconectes spp.</i>
Brook trout	<i>Salvelinus fontinalis</i>	Stoneflies	<i>Plecoptera</i>
Brown trout	<i>Salmo trutta</i>	Backswimmers	<i>Notonecta undulata</i>
Rainbow trout	<i>Oncorhynchus mykiss</i>	Water boatmen	<i>Corixa spp.</i>
Chain pickerel	<i>Esox niger</i>	Giant water bugs	<i>Belostoma spp.</i>
Redfin pickerel	<i>Esox americanus americanus</i>	Water striders	<i>Gerris remigis</i>
Carp	<i>Cyprinus carpio</i>	Whirligig beetles	<i>Dineutus spp; Gyrimus spp.</i>
Fallfish	<i>Semotilus corporalis</i>	<b>Dragonflies</b>	
Golden shiner	<i>Notemigonus crysoleucas</i>	<b>Common Name</b>	<b>Scientific Name</b>
Common shiner	<i>Notropis cornutus</i>	Green darner	<i>Anax junius</i>
Bridle shiner	<i>Notropis bifrenatus</i>	Cherry-faced meadowhawk	<i>Sympetrum internum</i>
White sucker	<i>Catostomus commersoni</i>	Twelve-spotted skimmer	<i>Libellula pulchella</i>
Lake chubsucker	<i>Erimyzon sucetta</i>	Whitetail	<i>Plathemis lydia</i>
Brown bullhead	<i>Ameiurus nebulosus</i>	<b>Damselflies</b>	
Yellow bullhead	<i>Ameiurus natalis</i>	<b>Common Name</b>	<b>Scientific Name</b>
White perch	<i>Morone americana</i>	Ebony jewelwing	<i>Calopteryx maculata</i>
Largemouth bass	<i>Micropterus salmoides</i>	Violet dancer	<i>Argia fumipennis</i>
Smallmouth bass	<i>Micropterus dolomieu</i>	Stream bluet	<i>Enallagma exulans</i>
Pumpkinseed	<i>Lepomis gibbosus</i>	Eastern forktail	<i>Ischnura verticalis</i>
Redbreast sunfish	<i>Lepomis auritus</i>		
Bluegill	<i>Lepomis macrochirus</i>		
Banded sunfish	<i>Enneacanthus obesus</i>		
Black crappie	<i>Pomoxis nigromaculatus</i>		
Yellow perch	<i>Perca flavescens</i>		
Tessellated darter	<i>Etheostoma olmsted</i>		

Table 2-5

**Massachusetts Threatened and Endangered Species and Habitats of Special Concern  
within the Sudbury River Watershed  
Operable Unit IV – Nyanza Chemical Dump Superfund Site  
Middlesex County, Massachusetts**

Common Name	Scientific Name	State Status	Reach Potentially Inhabiting				
			1	7	8	9	10
VERTEBRATES							
Amphibians							
Blue-spotted salamander	<i>Ambystoma laterale</i>	SC		√	√	√	√
Reptiles							
Blanding's turtle	<i>Emydoidea blandingii</i>	T					√
Eastern box turtle	<i>Terrapene carolina</i>	SC			√		
Birds							
American bittern	<i>Botaurus lentiginosus</i>	E		√	√		
Common moorhen	<i>Gallinula chloropus</i>	SC		√	√		
Least bittern	<i>Ixobrychus exilis</i>	E		√	√		
Pied-billed grebe	<i>Podilymbus podiceps</i>	E			√		
INVERTEBRATES							
Butterflies							
Hessel's hairstreak	<i>Callophrys hesseli</i>	SC	√				
Dragonflies							
Umber shadowdragon	<i>Neurocordulia obsoleta</i>	SC					√
Clubtail dragonfly	<i>Stylurus spiniceps</i>	T					√
PLANTS							
River Bulrush	<i>Bolboschoenus fluviatilis</i>	SC		√	√		
Long's Bulrush	<i>Scirpus longii</i>	T			√		
Britton's Violet	<i>Viola brittoniana</i>	T					√

E—"Endangered" species are native species which are in danger of extinction throughout all or part of their range, or which are in danger of expiration from Massachusetts.

SC—"Special Concern" species are native species which have been documented to have suffered a decline that could threaten the species if allowed to continue unchecked, or which occur in such small numbers or with such restricted distribution or specialized habitat requirements that could easily become threatened within Massachusetts.

T—"Threatened" species are native species which are likely to become endangered in the foreseeable future, or which are declining or rare.

Table 2-6

**Summary of Chemicals Detected in Sediment  
Operable Unit IV - Nyanza Chemical Dump Superfund Site  
Middlesex County, Massachusetts**

Chemical	Frequency of Detection <sup>a</sup>	Range of Detected Concentrations (mg/kg)	Range of Sample Quantitation Limits (mg/kg)	Arithmetic Mean Concentration (mg/kg)	Median (mg/kg)	Standard Deviation (mg/kg)
<b>Reach 1</b>						
Total Mercury	5 / 5	1.29E-01 - 3.15E+00	NA	8.43E-01	3.22E-01	1.29E+00
Methylmercury	5 / 5	1.38E-03 - 5.98E-03	NA	2.77E-03	1.79E-03	2.03E-03
<b>Reach 2</b>						
Total Mercury	12 / 12	5.17E-03 - 9.65E+00	NA	2.03E+00	4.34E-01	3.21E+00
Methylmercury	10 / 12	4.30E-05 - 1.75E-02	2.30E-05 - 4.10E-05	4.68E-03	1.79E-03	5.38E-03
<b>Reach 3<sup>b</sup></b>						
Total Mercury	40 / 40	1.32E+00 - 4.49E+01	NA	1.50E+01	1.26E+01	1.16E+01
Methylmercury	40 / 40	2.06E-03 - 2.07E-02	NA	6.66E-03	5.60E-03	3.73E-03
<b>Focus Area</b>						
Total Mercury	15 / 15	2.40E-01 - 8.96E+00	NA	2.74E+00	2.36E+00	2.40E+00
Methylmercury	15 / 15	3.96E-04 - 1.05E-02	NA	4.89E-03	6.34E-03	3.61E-03
<b>Reach 4</b>						
Total Mercury	11 / 11	8.22E-01 - 1.56E+01	NA	6.59E+00	7.55E+00	4.66E+00
Methylmercury	11 / 11	6.86E-04 - 4.05E-03	NA	2.09E-03	2.15E-03	1.04E-03
<b>Reach 5<sup>b</sup></b>						
Total Mercury	11 / 11	4.33E-02 - 3.20E+00	NA	1.05E+00	9.41E-01	1.02E+00
Methylmercury	11 / 11	2.14E-04 - 8.12E-03	NA	2.66E-03	1.63E-03	2.54E-03
<b>Focus Area</b>						
Total Mercury	15 / 15	3.47E-02 - 1.99E+00	NA	2.94E-01	9.78E-02	5.10E-01
Methylmercury	11 / 15	3.40E-05 - 5.29E-03	2.50E-05 - 3.60E-05	1.10E-03	7.60E-05	1.90E-03
<b>Reach 6</b>						
Total Mercury	12 / 12	3.21E-02 - 9.76E+00	NA	2.53E+00	1.90E+00	2.77E+00
Methylmercury	12 / 12	4.90E-05 - 1.13E-02	NA	2.51E-03	1.85E-03	2.96E-03
<b>Reach 7</b>						
Total Mercury	16 / 16	1.18E-02 - 1.55E+00	NA	2.96E-01	1.32E-01	4.24E-01
Methylmercury	15 / 16	5.30E-05 - 3.95E-03	2.40E-05 - 2.40E-05	9.27E-04	3.82E-04	1.25E-03
<b>Reach 7 - Heard Pond</b>						
Total Mercury	4 / 4	1.75E+00 - 3.00E+00	NA	2.50E+00	2.47E+00	3.85E-01
Methylmercury	4 / 4	4.62E-03 - 5.39E-03	NA	5.05E-03	5.12E-03	3.40E-04
<b>Reach 8</b>						
Total Mercury	13 / 13	7.30E-02 - 1.19E+00	NA	4.73E-01	3.89E-01	3.90E-01
Methylmercury	13 / 13	6.60E-05 - 6.20E-03	NA	2.59E-03	2.41E-03	2.38E-03
<b>Reach 9</b>						
Total Mercury	10 / 10	4.35E-01 - 1.90E+00	NA	1.21E+00	1.23E+00	4.22E-01
Methylmercury	10 / 10	1.74E-03 - 4.65E-03	NA	2.93E-03	3.03E-03	7.86E-04
<b>Reach 10</b>						
Total Mercury	10 / 10	5.35E-02 - 1.51E+00	NA	5.34E-01	4.13E-01	4.83E-01
Methylmercury	10 / 10	1.61E-04 - 5.43E-03	NA	2.25E-03	1.93E-03	1.78E-03
<b>Charles River</b>						
Total Mercury	7 / 7	1.39E-01 - 3.41E-01	NA	2.37E-01	2.20E-01	7.29E-02
Methylmercury	7 / 7	1.03E-03 - 2.10E-03	NA	1.57E-03	1.55E-03	3.86E-04
<b>Sudbury Reservoir</b>						
Total Mercury	6 / 6	5.76E-02 - 4.02E-01	NA	1.99E-01	1.86E-01	1.36E-01
Methylmercury	6 / 6	1.96E-04 - 9.09E-04	NA	3.98E-04	3.22E-04	2.60E-04

<sup>a</sup> Number of sampling locations at which chemical was detected compared with total number of sampling locations; duplicates at a location were averaged and considered one sample.

<sup>b</sup> Focus area samples were averaged and were included as one sample.  
mg/kg = Milligrams per kilogram  
NA = Not applicable.

Table 2-7

**Sediment Core Data**  
**Operable Unit IV - Nyanza Chemical Dump Superfund Site**  
**Middlesex County, Massachusetts**

Reach/Core #	Depth (cm)	Concentration (mg/kg)	
		Total Mercury	Methylmercury
Reach 3 - 2003			
1	0 - 3	3.45E+00 J	7.77E-03 J
	3 - 6	2.70E+00 J	7.38E-03 J
	6 - 9	2.97E+00 J	8.29E-03 J
	9 - 12	8.26E+00 J	9.72E-03 J
Reach 3 - 2005			
1	0 - 5	2.33E+01	1.11E-02
	5 - 10	1.01E+01	7.45E-03
	10 - 15	2.58E+00	2.10E-03
	15 - 20	1.24E+00	1.81E-03
2	0 - 5	2.98E+01	7.60E-03
	5 - 10	4.81E+01	1.94E-02
	10 - 15	3.83E+00	4.45E-03
	15 - 20	5.27E-01	4.35E-04
3	0 - 5	3.47E+01	1.63E-02
	5 - 10	8.68E+00	5.65E-03
	10 - 15	1.48E+00	1.18E-03
	15 - 20	7.01E+00	3.59E-03
4	0 - 5	1.39E+01	7.89E-03
	5 - 10	4.84E-01	8.85E-04
	10 - 15	1.93E-01	2.36E-04
	15 - 20	8.54E-02	1.19E-04
5	0 - 5	2.27E+01	1.32E-02
	5 - 10	1.85E+01	3.40E-02
	10 - 15	1.46E+01	2.01E-02
	15 - 20	9.89E-01	2.00E-03
6	0 - 5	2.43E+01	1.11E-02
	5 - 10	3.28E+01	1.94E-02
	10 - 15	1.15E+01	1.94E-02
	15 - 20	5.17E+00	7.67E-03
7	0 - 5	1.55E+01	7.26E-03
	5 - 10	4.22E+01	1.26E-02
	10 - 15	3.29E+01	1.25E-02
	15 - 20	1.50E+01	1.72E-02
8	0 - 5	4.07E+00	5.17E-03
	5 - 10	1.30E+01	7.55E-03
	10 - 15	2.08E+01	6.51E-03
	15 - 20	2.85E+01	1.24E-02
Charles River			
1	0 - 3	3.15E-01 J	1.89E-03 J
	3 - 6	4.29E-01	1.69E-03
	6 - 9	5.31E-01 J	1.25E-03 J
	9 - 12	3.98E-01	8.05E-04
2	0 - 3	1.91E-01	2.10E-03
	3 - 6	1.54E-01	1.03E-03
	6 - 9	5.10E-02	1.66E-04
	9 - 12	8.11E-02	3.51E-04



Table 2-8

**Summary of Sediment Conventional  
Operable Unit IV - Nyanza Chemical Dump Superfund Site  
Middlesex County, Massachusetts**

Chemical	Frequency of Detection <sup>a</sup>	Range of Detected Concentrations	Range of Sample Quantitation Limits	Arithmetic Mean Concentration	Median	Standard Deviation
<b>Reach 1</b>						
Alkalinity	2 / 2	1.80E+01 - 1.90E+01	NA	NA	NA	NA
Percent Solids	5 / 5	1.23E+01 - 3.84E+01	NA	2.51E+01	2.68E+01	1.04E+01
TOC	5 / 5	8.00E+04 - 2.00E+05	NA	1.12E+05	1.00E+05	5.02E+04
<b>Reach 2</b>						
Alkalinity	2 / 2	1.60E+01 - 1.80E+01	NA	NA	NA	NA
Percent Solids	12 / 12	1.64E+01 - 8.52E+01	NA	4.50E+01	4.21E+01	2.61E+01
TOC	11 / 12	6.20E+03 - 9.81E+04	6.41E+03 - 6.41E+03	4.43E+04	3.60E+04	3.07E+04
<b>Reach 3<sup>b</sup></b>						
Alkalinity	3 / 3	1.60E+01 - 2.15E+01	NA	NA	NA	NA
Percent Solids	23 / 23	1.28E+01 - 5.19E+01	NA	1.93E+01	1.66E+01	8.73E+00
TOC	23 / 23	4.00E+04 - 1.00E+05	NA	8.85E+04	1.00E+05	1.86E+04
<b>Focus Area</b>						
Alkalinity	2 / 2	1.50E+01 - 1.70E+01	NA	NA	NA	NA
Percent Solids	15 / 15	1.16E+01 - 7.55E+01	NA	3.75E+01	2.86E+01	2.29E+01
TOC	14 / 15	1.54E+04 - 2.04E+05	6.37E+03 - 6.37E+03	5.27E+04	4.05E+04	5.18E+04
<b>Reach 4</b>						
Alkalinity	2 / 2	2.10E+01 - 2.30E+01	NA	NA	NA	NA
Percent Solids	11 / 11	1.45E+01 - 4.87E+01	NA	2.61E+01	2.47E+01	9.35E+00
TOC	11 / 11	2.07E+04 - 1.11E+05	NA	6.57E+04	6.69E+04	2.74E+04
<b>Reach 5<sup>b</sup></b>						
Alkalinity	3 / 3	2.08E+01 - 2.55E+01	NA	NA	NA	NA
Percent Solids	11 / 11	1.92E+01 - 7.35E+01	NA	4.25E+01	4.12E+01	1.91E+01
TOC	11 / 11	9.20E+03 - 8.83E+04	NA	4.20E+04	4.07E+04	2.53E+04
<b>Focus Area</b>						
Alkalinity	2 / 2	2.05E+01 - 2.10E+01	NA	NA	NA	NA
Percent Solids	15 / 15	2.51E+01 - 8.66E+01	NA	6.95E+01	8.00E+01	2.12E+01
TOC	8 / 15	6.79E+03 - 3.51E+04	6.29E+03 - 7.04E+03	1.01E+04	6.79E+03	9.70E+03
<b>Reach 6</b>						
Alkalinity	2 / 2	2.50E+01 - 2.55E+01	NA	NA	NA	NA
Percent Solids	12 / 12	1.29E+01 - 6.96E+01	NA	2.94E+01	2.29E+01	1.65E+01
TOC	12 / 12	1.24E+04 - 1.03E+05	NA	6.51E+04	7.59E+04	3.28E+04
<b>Reach 7</b>						
Alkalinity	2 / 2	2.80E+01 - 3.00E+01	NA	NA	NA	NA
Percent Solids	16 / 16	1.15E+01 - 8.33E+01	NA	5.65E+01	6.29E+01	2.32E+01
TOC	10 / 16	6.00E+03 - 2.00E+05	6.00E+03 - 7.00E+03	3.15E+04	8.50E+03	5.27E+04
<b>Reach 8</b>						
Alkalinity	3 / 3	2.50E+01 - 3.45E+01	NA	NA	NA	NA
Percent Solids	13 / 13	1.39E+01 - 7.55E+01	NA	3.72E+01	2.67E+01	2.23E+01
TOC	12 / 13	6.56E+03 - 1.22E+05	6.80E+03 - 7.25E+03	3.89E+04	2.59E+04	3.77E+04
<b>Reach 9</b>						
Alkalinity	2 / 2	3.20E+01 - 3.35E+01	NA	NA	NA	NA
Percent Solids	10 / 10	1.24E+01 - 2.71E+01	NA	1.58E+01	1.36E+01	4.50E+00
TOC	10 / 10	1.72E+04 - 1.14E+05	NA	8.84E+04	9.73E+04	2.56E+04
<b>Reach 10</b>						
Alkalinity	2 / 2	3.05E+01 - 3.20E+01	NA	NA	NA	NA
Percent Solids	10 / 10	1.28E+01 - 6.66E+01	NA	3.36E+01	3.01E+01	1.72E+01
TOC	10 / 10	6.20E+03 - 1.18E+05	NA	5.65E+04	4.10E+04	4.45E+04
<b>Charles River</b>						
Alkalinity	2 / 2	3.90E+01 - 4.10E+01	NA	NA	NA	NA
Percent Solids	7 / 7	2.35E+01 - 4.59E+01	NA	3.46E+01	3.65E+01	8.04E+00
TOC	7 / 7	1.74E+04 - 5.26E+04	NA	3.40E+04	2.51E+04	1.36E+04
<b>Sudbury Reservoir</b>						
Alkalinity	2 / 2	1.85E+01 - 1.85E+01	NA	NA	NA	NA
Percent Solids	6 / 6	1.39E+01 - 5.12E+01	NA	3.28E+01	3.25E+01	1.63E+01
TOC	6 / 6	1.63E+04 - 7.63E+04	NA	3.94E+04	3.38E+04	2.44E+04

Note: alkalinity units presented in mg/L as CaCO<sub>3</sub> and TOC units presented in mg/kg.

<sup>a</sup> Number of sampling locations at which chemical was detected compared with total number of sampling locations; duplicates at a location were averaged and considered one sample.

<sup>b</sup> Focus area samples were averaged and were included as one sample.

mg/kg = Milligrams per kilogram

NA = Not applicable.

Table 2-9

**Sediment Methylmercury to Total Mercury Comparison  
Operable Unit IV - Nyanza Chemical Dump Superfund Site  
Middlesex County, Massachusetts**

Reach	Total Samples	Range of Concentrations		Mean of Concentrations		Range of MeHg to Total Hg Ratios	Mean MeHg to Total Hg Ratios
		Total Hg	MeHg	Total Hg	MeHg		
1	5	1.30E-01 - 3.15E+00	1.38E-03 - 4.86E-03	8.43E-01	2.77E-03	0.001 - 0.04	0.01
2	12	5.17E-03 - 9.65E+00	1.15E-05 - 1.75E-02	2.03E+00	4.68E-03	0.001 - 0.01	0.004
3	54	2.40E-01 - 4.49E+01	3.96E-04 - 2.07E-02	1.18E+01	6.20E-03	0.0002 - 0.004	0.001
4	11	8.22E-01 - 1.50E+01	6.86E-04 - 4.05E-03	6.59E+00	2.09E-03	0.0002 - 0.002	0.0005
5	25	3.47E-02 - 3.20E+00	1.30E-05 - 8.12E-03	6.28E-01	1.79E-03	0.0001 - 0.01	0.003
6	12	3.34E-02 - 9.76E+00	5.05E-05 - 1.13E-02	2.53E+00	2.51E-03	0.0003 - 0.005	0.002
7	16	1.18E-02 - 1.55E+00	1.20E-05 - 3.95E-03	2.96E-01	9.27E-04	0.0004 - 0.02	0.004
7 - Heard Pond	4	2.06E+00 - 3.00E+00	4.62E-03 - 5.34E-03	2.50E+00	5.05E-03	0.002 - 0.003	0.002
8	13	7.30E-02 - 1.19E+00	6.60E-05 - 6.20E-03	4.73E-01	2.59E-03	0.0005 - 0.01	0.005
9	10	4.66E-01 - 1.90E+00	1.88E-03 - 4.65E-03	1.21E+00	2.93E-03	0.002 - 0.004	0.003
10	10	5.36E-02 - 1.51E+00	1.72E-04 - 5.43E-03	5.34E-01	2.25E-03	0.003 - 0.01	0.005
Charles River	7	1.54E-01 - 3.41E-01	1.03E-03 - 2.10E-03	2.37E-01	1.57E-03	0.004 - 0.01	0.007
Sudbury Reservoir	6	5.76E-02 - 3.92E-01	1.96E-04 - 8.97E-04	1.99E-01	3.98E-04	0.001 - 0.004	0.002
<b>All Data</b>						<b>0.0001 - 0.04</b>	<b>0.004</b>

\* All concentrations are presented in mg/kg. Duplicates averaged.

Table 2-10

**Summary of Chemicals Detected in Surface Water  
Operable Unit IV - Nyanza Chemical Dump Superfund Site  
Middlesex County, Massachusetts**

Chemical	Frequency of Detection <sup>a</sup>	Range of Detected Concentrations (ng/L)	Range of Sample Quantitation Limits (ng/L)	Arithmetic Mean Concentration (ng/L)	Median (ng/L)	Standard Deviation (ng/L)
<b>Reach 1</b>						
Total Mercury	4 / 4	1.73E+00 - 2.26E+00	NA	2.05E+00	2.10E+00	2.27E-01
Methylmercury	4 / 4	1.84E-01 - 3.10E-01	NA	2.60E-01	2.72E-01	5.66E-02
<b>Reach 2</b>						
Total Mercury	3 / 3	3.81E+00 - 4.18E+01	NA	1.66E+01	4.25E+00	2.18E+01
Methylmercury	3 / 3	2.38E-01 - 3.92E-01	NA	3.06E-01	2.72E-01	7.87E-02
<b>Reach 3</b>						
Total Mercury	1 / 1	5.89E+00 - 5.89E+00	NA	5.89E+00	5.89E+00	NC
Methylmercury	1 / 1	3.61E-01 - 3.61E-01	NA	3.61E-01	3.61E-01	NC
<b>Reach 4</b>						
Total Mercury	1 / 1	2.70E+00 - 2.70E+00	NA	2.70E+00	2.70E+00	NC
Methylmercury	1 / 1	1.42E-01 - 1.42E-01	NA	1.42E-01	1.42E-01	NC
<b>Reach 5</b>						
Total Mercury	1 / 1	1.59E+00 - 1.59E+00	NA	1.59E+00	1.59E+00	NC
Methylmercury	1 / 1	1.25E-01 - 1.25E-01	NA	1.25E-01	1.25E-01	NC
<b>Reach 7</b>						
Total Mercury	10 / 10	1.33E+00 - 2.30E+01	NA	5.88E+00	4.35E+00	6.36E+00
Methylmercury	10 / 10	9.20E-02 - 5.18E-01	NA	2.05E-01	1.69E-01	1.24E-01
<b>Reach 8</b>						
Total Mercury	14 / 14	5.22E+00 - 1.50E+01	NA	9.61E+00	9.20E+00	3.04E+00
Methylmercury	14 / 14	1.69E-01 - 3.23E-01	NA	2.58E-01	2.68E-01	5.08E-02
<b>Charles River</b>						
Total Mercury	10 / 16	1.96E+00 - 2.85E+00	9.14E-01 - 2.81E+00	1.87E+00	2.14E+00	7.15E-01
Methylmercury	14 / 16	9.40E-02 - 3.62E-01	7.00E-02 - 7.00E-02	2.49E-01	2.77E-01	1.09E-01

<sup>a</sup> Number of sampling locations at which chemical was detected compared with total number of sampling locations; duplicates at a location were averaged and considered one sample.

ng/L = nanograms per liter

NA = Not applicable.

Table 2-11

**Surface Water Methylmercury to Total Mercury Comparison  
Operable Unit IV - Nyanza Chemical Dump Superfund Site  
Middlesex County, Massachusetts**

Reach	Total Samples	Range of Concentrations		Mean of Concentrations		Range of MeHg to Total Hg Ratios	Mean MeHg to Total Hg Ratios
		Total Hg	MeHg	Total Hg	MeHg		
1	4	1.73E+00 - 2.26E+00	1.84E-01 - 1.84E+05	2.05E+00	2.60E-01	0.11 - 0.14	0.13
2	3	3.81E+00 - 4.18E+01	2.38E-01 - 2.38E+05	1.66E+01	3.06E-01	0.009 - 0.075	0.047
3	1	5.89E+00 - 5.89E+00	3.61E-01 - 3.61E+05	5.89E+00	3.61E-01	0.061 - 0.061	0.061
4	1	2.70E+00 - 2.70E+00	1.42E-01 - 1.42E+05	2.70E+00	1.42E-01	0.053 - 0.053	0.053
5	1	1.59E+00 - 1.59E+00	1.25E-01 - 1.25E+05	1.59E+00	1.25E-01	0.079 - 0.079	0.079
7	10	1.33E+00 - 2.30E+01	9.20E-02 - 9.20E+04	5.88E+00	2.05E-01	0.012 - 0.27	0.064
8	14	5.22E+00 - 1.50E+01	1.69E-01 - 1.69E+05	9.61E+00	2.58E-01	0.015 - 0.041	0.029
Charles River	10	1.96E+00 - 2.85E+00	9.40E-02 - 9.40E+04	2.35E+00	2.83E-01	0.044 - 0.16	0.12
<b>All Data</b>						0.009 - 0.27	0.072

## Notes:

All concentrations are presented in ng/L.

Ratios calculated only for samples with detected concentrations of both tHg and MeHg.

Duplicates averaged.

Reaches 9 and 10 had no detected mercury in surface water.

Table 2-12

**Summary of Chemicals Detected in Crayfish  
Operable Unit IV - Nyanza Chemical Dump Superfund Site  
Middlesex County, Massachusetts**

Chemical	Frequency of Detection <sup>a</sup>	Range of Detected Concentrations (µg/kg WW)	Arithmetic Mean Concentration (µg/kg WW)	Median (µg/kg WW)	Standard Deviation (µg/kg WW)
<b>Reach 1</b>					
<b>Whole Body<sup>b</sup></b>					
Total Mercury	3 / 3	4.21E+01 - 4.72E+01	4.38E+01	4.21E+01	2.94E+00
<b>Reach 2</b>					
<b>Whole Body</b>					
Total Mercury <sup>c</sup>	11 / 11	2.81E+01 - 7.45E+01	4.57E+01	3.45E+01	1.82E+01
Methylmercury	8 / 8	2.47E+01 - 7.10E+01	4.69E+01	4.68E+01	2.01E+01
<b>Reach 3</b>					
<b>Whole Body</b>					
Total Mercury	19 / 19	2.74E+01 - 2.10E+02	5.52E+01	4.17E+01	4.11E+01
Methylmercury	19 / 19	5.77E+00 - 7.74E+01	3.63E+01	3.30E+01	1.68E+01
<b>Reach 4</b>					
<b>Whole Body</b>					
Total Mercury	4 / 4	1.44E+01 - 3.62E+01	2.31E+01	2.13E+01	9.93E+00
Methylmercury	4 / 4	1.32E+01 - 3.89E+01	2.46E+01	2.31E+01	1.32E+01
<b>Reach 5</b>					
<b>Whole Body</b>					
Total Mercury <sup>d</sup>	17 / 17	4.85E+01 - 1.92E+02	9.83E+01	8.86E+01	3.67E+01
Methylmercury	15 / 15	1.75E+01 - 2.32E+02	9.15E+01	7.50E+01	5.50E+01
<b>Tail</b>					
Total Mercury	2 / 2	7.21E+01 - 3.90E+02	2.31E+02	2.31E+02	2.25E+02
<b>Reach 6</b>					
<b>Whole Body<sup>e</sup></b>					
Total Mercury	1 / 1	2.97E+01 - 2.97E+01	2.97E+01	2.97E+01	NC
<b>Reach 7</b>					
<b>Whole Body</b>					
Total Mercury <sup>f</sup>	7 / 7	2.58E+01 - 8.61E+01	4.96E+01	4.72E+01	2.01E+01
Methylmercury	5 / 5	2.64E+01 - 7.30E+01	4.91E+01	4.92E+01	1.73E+01
<b>Tail</b>					
Total Mercury	4 / 4	2.35E+01 - 2.17E+02	1.37E+02	1.53E+02	8.30E+01
<b>Charles River</b>					
<b>Whole Body<sup>g</sup></b>					
Total Mercury	2 / 2	3.41E+01 - 4.57E+01	3.99E+01	3.99E+01	8.20E+00
<b>Sudbury Reservoir</b>					
<b>Whole Body</b>					
Total Mercury	3 / 3	4.57E+00 - 1.31E+01	1.01E+01	1.27E+01	4.81E+00
Methylmercury	3 / 3	3.50E+00 - 9.01E+00	6.68E+00	7.54E+00	2.85E+00

<sup>a</sup> Number of sampling locations at which chemical was detected compared with total number of sampling locations; duplicates at a location were averaged and considered one sample.

<sup>b</sup> All three samples were whole body composites. Two consisted of five individuals and one consisted of six individuals.

<sup>c</sup> Three samples were whole body composites. Two consisted of seven individuals and one consisted of six individuals.

<sup>d</sup> Two samples were whole body composites. One consisted of seven individuals and one consisted of eight individuals.

<sup>e</sup> The one sample from Reach 6 was a whole body composite consisting of two individuals.

<sup>f</sup> Two samples were whole body composites. Both consisted of five individuals.

<sup>g</sup> Both samples were whole body composites. One consisted of five individuals and one consisted of 18 individuals.

µg/kg = Micrograms per kilogram

NC = Not calculated due to insufficient sample size.

Note: Whole body samples include individual whole body and whole body composites.

**Table 2-13**  
**Crayfish Methylmercury to Total Mercury Comparison**  
**Operable Unit IV - Nyanza Chemical Dump Superfund Site - Middlesex County, Massachusetts**

Reach	Total Samples	Range of Concentrations		Mean of Concentrations		Range of MeHg to Total Hg Ratios	Mean MeHg to Total Hg Ratios	Range of RPD	Mean of RPD
		Total Hg	MeHg	Total Hg	MeHg				
2	8	2.81E+01 - 7.29E+01	2.47E+01 - 6.84E+01	4.94E+01	4.69E+01	0.782 - 1.19	0.945	2% - 25%	12%
3	19	2.74E+01 - 2.10E+02	5.77E+00 - 7.74E+01	5.52E+01	3.63E+01	0.1767 - 1.230	0.744	7% - 140%	42%
4	4	1.44E+01 - 3.55E+01	1.32E+01 - 3.89E+01	2.31E+01	2.46E+01	0.8354 - 1.457	1.0377	6% - 37%	17%
5	15	4.85E+01 - 1.92E+02	1.75E+01 - 2.32E+02	1.01E+02	9.15E+01	0.2121 - 1.21	0.862	0% - 130%	25%
7	5	2.58E+01 - 8.61E+01	2.64E+01 - 7.30E+01	5.16E+01	4.91E+01	0.8479 - 1.26	0.996	2% - 23%	11%
Sudbury Reservoir	3	4.57E+00 - 1.31E+01	3.50E+00 - 9.01E+00	1.01E+01	6.68E+00	0.594 - 0.766	0.682	27% - 51%	38%
All Data						0.1767 - 1.46	0.878		

\* All concentrations are presented in µg/kg. Duplicates averaged. All samples individual whole body.

**Table 2-14**

**Summary of Size Class A and B Total Mercury Statistics from Reach 8-2<sup>a</sup>  
Operable Unit IV - Nyanza Chemical Dump Superfund Site  
Middlesex County, Massachusetts**

<b>Size Class/Species</b>	<b>Frequency of Detection<sup>b</sup></b>	<b>Range of Detected Concentrations (µg/kg)</b>	<b>Arithmetic Mean Concentration (µg/kg)</b>	<b>Median (µg/kg)</b>	<b>Standard Deviation (µg/kg)</b>
<b>Class A</b>					
Sunfish	23 / 23	1.87E+02 - 3.03E+02	2.29E+02	2.29E+02	2.94E+01
Yellow Perch	3 / 3	1.31E+02 - 2.01E+02	1.75E+02	1.94E+02	3.86E+01
<b>Class B</b>					
Sunfish	6 / 6	1.76E+05 - 2.16E+05	1.97E+05	1.99E+05	1.34E+04
Yellow Perch	18 / 18	1.51E+05 - 2.39E+05	1.96E+05	1.93E+05	2.45E+04

<sup>a</sup>Except for size class A yellow perch, which includes all samples collected in Reach 8 (i.e., 2 from 8-1 and 1 from 8-2).

<sup>b</sup>Number of sampling locations at which chemical was detected compared with total number of sampling locations;  
duplicates at a location were averaged and considered one sample.

Table 2-15

**Fish Summary**  
**Operable Unit IV - Nyanza Chemical Dump Superfund Site**  
**Middlesex County, Massachusetts**

Reach	Subreach	Species	Size Class	# Samples Analyzed		
				Fillet	Offal	Whole Body
1	0	Bluegill	A	-	-	5
			B	-	-	5
		Largemouth Bass	-	11	3	-
		Pumpkinseed	A	-	-	6
			B	-	-	5
		White Sucker	-	-	-	8
		Yellow Bullhead	-	2	2	2
		Yellow Perch	C	-	-	5
			D	14	3	-
2	0	Bluegill	A	-	-	2
			B	-	-	1
		Largemouth Bass	-	3	2	-
		Pumpkinseed	A	-	-	2
			B	-	-	1
		White Sucker	-	-	-	2
		Yellow Perch	B	-	-	4
			C	-	-	6
			D	7	3	-
	1	Bluegill	A	-	-	5
		Brown Bullhead	-	-	-	3
		Largemouth Bass	-	3	2	-
		Pumpkinseed	A	-	-	2
		Yellow Perch	B	-	-	2
			C	-	-	2
			D	1	1	-
	2	Largemouth Bass	-	4	2	-
		White Sucker	-	-	-	2
		Yellow Perch	B	-	-	5
			C	-	-	5
			D	5	2	-
3	0	Bluegill	A	-	-	3
		Pumpkinseed	A	-	-	3
	1	Bluegill	A	-	-	3
		Brown Bullhead	-	3	1	-
		Largemouth Bass	-	3	1	-
		Yellow Perch	B	-	-	6
			C	-	-	6
			D	6	1	-
	2	Bluegill	B	-	-	1
		Brown Bullhead	-	1	1	-
		Largemouth Bass	-	3	1	-
		Yellow Bullhead	-	2	-	-
		Yellow Perch	B	-	-	1
			D	5	1	-
	3	Bluegill	A	-	-	3
		Brown Bullhead	-	3	1	-
		Largemouth Bass	-	4	2	-
		Yellow Bullhead	-	1	1	-
		Yellow Perch	B	-	-	6
			C	-	-	7
			D	2	1	-



Table 2-15

**Fish Summary**  
**Operable Unit IV - Nyanza Chemical Dump Superfund Site**  
**Middlesex County, Massachusetts**

Reach	Subreach	Species	Size Class	# Samples Analyzed		
				Fillet	Offal	Whole Body
4	0	Bluegill	A	-	-	13
	1	Largemouth Bass	-	5	2	-
		Yellow Bullhead	-	1	1	-
		Yellow Perch	B	-	-	4
			C	-	-	5
			D	6	2	-
	2	Brown Bullhead	-	5	1	-
		Largemouth Bass	-	5	1	-
		Yellow Bullhead	-	4	2	-
		Yellow Perch	B	-	-	9
			C	-	-	8
			D	9	2	-
5	0	Bluegill	A	-	-	2
	1	Bluegill	A	-	-	8
			B	-	-	2
		Pumpkinseed	A	-	-	3
			B	-	-	1
		Yellow Bullhead	-	-	-	3
	2	Largemouth Bass	-	6	2	-
		Yellow Bullhead	-	1	1	-
		Yellow Perch	C	-	-	2
			D	6	1	-
	3	Bluegill	B	-	-	8
		Brown Bullhead	-	10	2	-
		Largemouth Bass	-	5	2	-
		Yellow Perch	C	-	-	1
			D	8	2	-
6	0	Bluegill	A	-	-	8
			B	-	-	7
		Brown Bullhead	-	1	1	-
		Largemouth Bass	-	11	3	-
		Pumpkinseed	A	-	-	4
			B	-	-	1
		Yellow Bullhead	-	9	2	-
		Yellow Perch	A	-	-	1
			B	-	-	2
			C	-	-	13
			D	14	3	-
7	1	Brown Bullhead	-	2	1	-
		Largemouth Bass	-	6	2	-
		Yellow Bullhead	-	2	1	-
		Yellow Perch	A	-	-	2
			B	-	-	7
			C	-	-	6
			D	9	2	-

Table 2-15

**Fish Summary**  
**Operable Unit IV - Nyanza Chemical Dump Superfund Site**  
**Middlesex County, Massachusetts**

Reach	Subreach	Species	Size Class	# Samples Analyzed		
				Fillet	Offal	Whole Body
7 - cont'd.	2	Bluegill	A	-	-	6
		Brown Bullhead	-	2	1	-
		Largemouth Bass	-	7	2	-
		Pumpkinseed	A	-	-	1
		Yellow Bullhead	-	4	-	-
		Yellow Perch	A	-	-	1
			B	-	-	6
			C	-	-	7
			D	5	2	-
	3	Largemouth Bass	-	10	3	-
		Yellow Bullhead	-	10	3	-
		Yellow Perch	A	-	-	13
			B	-	-	13
			C	-	-	13
			D	10	3	-
	X	Bluegill	A	-	-	1
		Brown Bullhead	-	-	-	-
		Golden Shiner	A	-	-	1
			B	-	-	1
		Largemouth Bass	-	-	-	-
		White Crappie	B	-	-	1
		Yellow Bullhead	-	-	-	-
		Yellow Perch	A	-	-	-
			B	-	-	-
			C	-	-	-
			D	-	-	-
8	1	Bluegill	A	-	-	11
		Largemouth Bass	-	4	2	-
		Yellow Bullhead	-	3	2	-
		Yellow Perch	A	-	-	2
			B	-	-	20
			C	-	-	10
			D	6	3	-
	2	Bluegill	A	-	-	21
			B	-	-	3
			C	-	-	5
		Brown Bullhead	-	2	2	-
		Largemouth Bass	-	4	2	-
		Pumpkinseed	A	-	-	2
			B	-	-	3
		Yellow Bullhead	-	4	-	-
		Yellow Perch	A	-	-	1
			B	-	-	18
			C	1	-	10
			D	10	4	-
	3	Brown Bullhead	-	5	2	-
		Largemouth Bass	-	3	2	-
		Yellow Perch	B	-	-	12
			C	-	-	10
			D	6	3	-

Table 2-15

**Fish Summary**  
**Operable Unit IV - Nyanza Chemical Dump Superfund Site**  
**Middlesex County, Massachusetts**

Reach	Subreach	Species	Size Class	# Samples Analyzed		
				Fillet	Offal	Whole Body
8 - cont'd.	X	Bluegill	A	-	-	1
		Brown Bullhead	-	-	-	-
		Chain Pickerel	A	-	-	2
		Golden Shiner	A	-	-	1
			B	-	-	1
		Largemouth Bass	-	-	-	-
		Yellow Bullhead	-	-	-	-
		Yellow Perch	A	-	-	-
			B	-	-	-
			C	-	-	-
D	-		-	-		
9	0	Bluegill	A	-	-	7
			B	-	-	7
		Brown Bullhead	-	10	3	-
		Largemouth Bass	-	11	3	-
		Yellow Perch	B	-	-	4
			C	-	-	13
			D	14	3	-
10	0	Bluegill	A	-	-	12
		Brown Bullhead	-	7	1	-
		Largemouth Bass	-	11	3	-
		Yellow Bullhead	-	4	2	-
		Yellow Perch	A	-	-	1
			B	-	-	13
			C	1	-	13
			D	13	3	-
Charles River	0	Bluegill	A	-	-	3
		Brown Bullhead	-	2	2	-
		Largemouth Bass	-	10	3	-
		Pumpkinseed	A	-	-	9
		Yellow Bullhead	-	8	1	-
		Yellow Perch	B	-	-	13
			C	-	-	13
			D	13	3	-
Sudbury Reservoir	0	Bluegill	A	-	-	6
		Brown Bullhead	-	2	1	-
		Largemouth Bass	-	9	2	-
		Pumpkinseed	A	-	-	1
		Yellow Bullhead	-	7	2	-
		Yellow Perch	A	-	-	6
			B	-	-	13
			C	1	-	13
			D	13	3	-

## Notes:

Numbers include duplicate samples.

Fish from subreaches noted "X" are kingfisher prey.

Table 2-16

**Summary of Chemicals Detected in Fish**  
**Operable Unit IV - Nyanza Chemical Dump Superfund Site - Reach 1**  
**Middlesex County, Massachusetts**

Chemical	Frequency of Detection <sup>a</sup>	Range of Detected Concentrations (µg/kg WW)	Arithmetic Mean Concentration (µg/kg WW)	Median (µg/kg WW)	Standard Deviation (µg/kg WW)
<b><i>Sunfish (Bluegill and Pumpkinseed)</i></b>					
<b><i>Whole Body</i></b>					
<b><i>Size Class A</i></b>					
Total Mercury	11 / 11	7.17E+01 - 2.52E+02	1.37E+02	1.30E+02	4.61E+01
<b><i>Size Class B</i></b>					
Total Mercury	10 / 10	6.35E+01 - 1.67E+02	1.12E+02	1.12E+02	3.02E+01
<b><i>Bullhead</i></b>					
<b><i>Whole Body</i></b>					
Total Mercury	2 / 2	5.70E+01 - 2.07E+02	1.32E+02	1.32E+02	1.06E+02
<b><i>Reconstructed Whole Body</i></b>					
Total Mercury	2 / 2	2.44E+02 - 5.55E+02	3.99E+02	3.99E+02	2.20E+02
Methylmercury	2 / 2	2.05E+02 - 4.02E+02	3.04E+02	3.04E+02	1.39E+02
<b><i>Largemouth Bass</i></b>					
<b><i>Reconstructed Whole Body</i></b>					
Total Mercury	3 / 3	1.96E+02 - 2.55E+02	2.24E+02	2.23E+02	2.95E+01
Methylmercury	3 / 3	1.24E+02 - 2.62E+02	1.85E+02	1.69E+02	7.04E+01
<b><i>White Sucker</i></b>					
<b><i>Whole Body</i></b>					
Total Mercury	8 / 8	4.00E+01 - 2.40E+02	9.65E+01	7.91E+01	6.32E+01
<b><i>Yellow Perch</i></b>					
<b><i>Whole Body</i></b>					
<b><i>Size Class C</i></b>					
Total Mercury	5 / 5	9.85E+01 - 1.23E+02	1.13E+02	1.17E+02	1.01E+01
<b><i>Reconstructed Whole Body</i></b>					
<b><i>Size Class D</i></b>					
Total Mercury	3 / 3	8.93E+01 - 1.64E+02	1.26E+02	1.24E+02	3.76E+01
Methylmercury	3 / 3	6.88E+01 - 1.44E+02	1.12E+02	1.24E+02	3.90E+01

<sup>a</sup> Number of sampling locations at which chemical was detected compared with total number of sampling locations; duplicates at a location were averaged and considered one sample.

µg/kg = Micrograms per kilogram

Table 2-17

**Summary of Chemicals Detected in Fish**  
**Operable Unit IV - Nyanza Chemical Dump Superfund Site - Reach 2**  
**Middlesex County, Massachusetts**

Chemical	Frequency of Detection <sup>a</sup>	Range of Detected Concentrations (µg/kg WW)	Arithmetic Mean Concentration (µg/kg WW)	Median (µg/kg WW)	Standard Deviation (µg/kg WW)
<b><i>Sunfish (Bluegill and Pumpkinseed)</i></b>					
<b><i>Whole Body</i></b>					
<b><i>Size Class A</i></b>					
Total Mercury	11 / 11	1.36E+02 - 2.65E+02	1.87E+02	1.90E+02	4.04E+01
<b><i>Size Class B</i></b>					
Total Mercury	2 / 2	1.96E+02 - 3.63E+02	2.80E+02	2.80E+02	1.18E+02
<b><i>Bullhead</i></b>					
<b><i>Whole Body</i></b>					
Total Mercury	3 / 3	8.88E+01 - 1.63E+02	1.14E+02	8.98E+01	4.26E+01
Methylmercury	3 / 3	7.66E+01 - 1.63E+02	1.11E+02	9.19E+01	4.61E+01
<b><i>Largemouth Bass</i></b>					
<b><i>Reconstructed Whole Body</i></b>					
Total Mercury	6 / 6	2.40E+02 - 5.65E+02	3.92E+02	3.85E+02	1.61E+02
Methylmercury	3 / 3	2.74E+02 - 4.50E+02	3.34E+02	2.77E+02	1.01E+02
<b><i>White Sucker</i></b>					
<b><i>Whole Body</i></b>					
Total Mercury	4 / 4	8.84E+01 - 1.60E+02	1.18E+02	1.13E+02	3.14E+01
<b><i>Yellow Perch</i></b>					
<b><i>Whole Body</i></b>					
<b><i>Size Class B</i></b>					
Total Mercury	11 / 11	1.64E+02 - 2.59E+02	2.22E+02	2.27E+02	3.13E+01
<b><i>Size Class C</i></b>					
Total Mercury	13 / 13	7.43E+01 - 3.24E+02	1.89E+02	1.74E+02	8.73E+01
<b><i>Reconstructed Whole Body</i></b>					
<b><i>Size Class D</i></b>					
Total Mercury	6 / 6	2.44E+02 - 5.84E+02	3.52E+02	3.31E+02	1.27E+02
Methylmercury	3 / 3	1.86E+02 - 7.45E+02	3.88E+02	2.33E+02	3.10E+02

<sup>a</sup> Number of sampling locations at which chemical was detected compared with total number of sampling locations; duplicates at a location were averaged and considered one sample.

µg/kg = Micrograms per kilogram

Table 2-18

**Summary of Chemicals Detected in Fish**  
**Operable Unit IV - Nyanza Chemical Dump Superfund Site - Reach 3**  
**Middlesex County, Massachusetts**

Chemical	Frequency of Detection <sup>a</sup>	Range of Detected Concentrations (µg/kg WW)	Arithmetic Mean Concentration (µg/kg WW)	Median (µg/kg WW)	Standard Deviation (µg/kg WW)
<b><i>Sunfish (Bluegill and Pumpkinseed)</i></b>					
<b><i>Whole Body</i></b>					
<b><i>Size Class A</i></b>					
Total Mercury	13 / 13	1.42E+02 - 4.77E+02	2.19E+02	2.01E+02	8.42E+01
<b><i>Bullhead</i></b>					
<b><i>Reconstructed Whole Body</i></b>					
Total Mercury	4 / 4	1.20E+02 - 4.87E+02	3.25E+02	3.46E+02	1.53E+02
Methylmercury	3 / 3	9.02E+01 - 3.60E+02	2.65E+02	3.44E+02	1.51E+02
<b><i>Largemouth Bass</i></b>					
<b><i>Reconstructed Whole Body</i></b>					
Total Mercury	4 / 4	4.26E+02 - 8.95E+02	6.58E+02	6.56E+02	2.01E+02
Methylmercury	3 / 3	5.22E+02 - 8.99E+02	6.95E+02	6.64E+02	1.91E+02
<b><i>Yellow Perch</i></b>					
<b><i>Whole Body</i></b>					
<b><i>Size Class B</i></b>					
Total Mercury	13 / 13	1.45E+02 - 2.53E+02	1.95E+02	1.97E+02	2.86E+01
<b><i>Size Class C</i></b>					
Total Mercury	13 / 13	1.12E+02 - 3.50E+02	2.60E+02	2.77E+02	6.83E+01
<b><i>Reconstructed Whole Body</i></b>					
<b><i>Size Class D</i></b>					
Total Mercury	3 / 3	2.82E+02 - 6.06E+02	4.23E+02	3.80E+02	1.66E+02
Methylmercury	3 / 3	3.22E+02 - 5.17E+02	4.19E+02	4.19E+02	9.72E+01

<sup>a</sup> Number of sampling locations at which chemical was detected compared with total number of sampling locations; duplicates at a location were averaged and considered one sample.

µg/kg = Micrograms per kilogram

NC = Not calculated due to insufficient sample size.

Table 2-19

**Summary of Chemicals Detected in Fish**  
**Operable Unit IV - Nyanza Chemical Dump Superfund Site - Reach 4**  
**Middlesex County, Massachusetts**

Chemical	Frequency of Detection <sup>a</sup>	Range of Detected Concentrations (µg/kg WW)	Arithmetic Mean Concentration (µg/kg WW)	Median (µg/kg WW)	Standard Deviation (µg/kg WW)
<b><i>Sunfish (Bluegill and Pumpkinseed)</i></b>					
<b><i>Whole Body</i></b>					
<b><i>Size Class A</i></b>					
Total Mercury	13 / 13	9.80E+01 - 3.53E+02	2.20E+02	2.03E+02	7.43E+01
<b><i>Bullhead</i></b>					
<b><i>Reconstructed Whole Body</i></b>					
Total Mercury	4 / 4	9.98E+01 - 3.12E+02	2.08E+02	2.11E+02	9.36E+01
Methylmercury	3 / 3	9.96E+01 - 2.64E+02	1.78E+02	1.71E+02	8.22E+01
<b><i>Largemouth Bass</i></b>					
<b><i>Reconstructed Whole Body</i></b>					
Total Mercury	3 / 3	4.30E+02 - 6.17E+02	5.06E+02	4.70E+02	9.84E+01
Methylmercury	3 / 3	4.73E+02 - 7.31E+02	5.73E+02	5.15E+02	1.39E+02
<b><i>Yellow Perch</i></b>					
<b><i>Whole Body</i></b>					
<b><i>Size Class B</i></b>					
Total Mercury	13 / 13	1.01E+02 - 2.15E+02	1.43E+02	1.41E+02	2.80E+01
<b><i>Size Class C</i></b>					
Total Mercury	13 / 13	7.38E+01 - 2.00E+02	1.56E+02	1.57E+02	3.88E+01
<b><i>Reconstructed Whole Body</i></b>					
<b><i>Size Class D</i></b>					
Total Mercury	4 / 4	3.99E+02 - 4.63E+02	4.23E+02	4.15E+02	2.97E+01
Methylmercury	3 / 3	3.12E+02 - 4.92E+02	4.04E+02	4.08E+02	9.01E+01

<sup>a</sup> Number of sampling locations at which chemical was detected compared with total number of sampling locations; duplicates at a location were averaged and considered one sample.

µg/kg = Micrograms per kilogram

Table 2-20

**Summary of Chemicals Detected in Fish**  
**Operable Unit IV - Nyanza Chemical Dump Superfund Site - Reach 5**  
**Middlesex County, Massachusetts**

Chemical	Frequency of Detection <sup>a</sup>	Range of Detected Concentrations (µg/kg WW)	Arithmetic Mean Concentration (µg/kg WW)	Median (µg/kg WW)	Standard Deviation (µg/kg WW)
<b><i>Sunfish (Bluegill and Pumpkinseed)</i></b>					
<b><i>Whole Body</i></b>					
<b><i>Size Class A</i></b>					
Total Mercury	13 / 13	1.51E+02 - 3.03E+02	2.72E+02	2.88E+02	3.41E+01
<b><i>Size Class B</i></b>					
Total Mercury	11 / 11	8.40E+01 - 1.85E+02	1.22E+02	1.24E+02	2.56E+01
<b><i>Bullhead</i></b>					
<b><i>Whole Body</i></b>					
Total Mercury	3 / 3	1.54E+02 - 2.02E+02	1.89E+02	1.92E+02	9.85E+00
<b><i>Reconstructed Whole Body</i></b>					
Total Mercury	3 / 3	1.38E+02 - 1.70E+02	1.57E+02	1.63E+02	1.67E+01
Methylmercury	3 / 3	1.23E+02 - 1.77E+02	1.58E+02	1.74E+02	3.04E+01
<b><i>Largemouth Bass</i></b>					
<b><i>Reconstructed Whole Body</i></b>					
Total Mercury	4 / 4	2.64E+02 - 5.37E+02	3.93E+02	3.85E+02	1.20E+02
Methylmercury	3 / 3	3.17E+02 - 5.84E+02	4.35E+02	4.03E+02	1.36E+02
<b><i>Yellow Perch</i></b>					
<b><i>Whole Body</i></b>					
<b><i>Size Class C</i></b>					
Total Mercury	3 / 3	1.11E+02 - 1.58E+02	1.38E+02	1.44E+02	2.41E+01
<b><i>Reconstructed Whole Body</i></b>					
<b><i>Size Class D</i></b>					
Total Mercury	3 / 3	1.31E+02 - 4.55E+02	2.72E+02	2.30E+02	1.66E+02
Methylmercury	2 / 2	1.53E+02 - 6.36E+02	3.95E+02	3.95E+02	3.42E+02

<sup>a</sup> Number of sampling locations at which chemical was detected compared with total number of sampling locations;

duplicates at a location were averaged and considered one sample.

µg/kg = Micrograms per kilogram



Table 2-21

**Summary of Chemicals Detected in Fish**  
**Operable Unit IV - Nyanza Chemical Dump Superfund Site - Reach 6**  
**Middlesex County, Massachusetts**

Chemical	Frequency of Detection <sup>a</sup>	Range of Detected Concentrations (µg/kg WW)	Arithmetic Mean Concentration (µg/kg WW)	Median (µg/kg WW)	Standard Deviation (µg/kg WW)
<b><i>Sunfish (Bluegill and Pumpkinseed)</i></b>					
<b><i>Whole Body</i></b>					
<b><i>Size Class A</i></b>					
Total Mercury	12 / 12	7.43E+01 - 1.97E+02	1.30E+02	1.27E+02	3.67E+01
<b><i>Size Class B</i></b>					
Total Mercury	8 / 8	8.06E+01 - 1.32E+02	1.11E+02	1.14E+02	1.70E+01
<b><i>Bullhead</i></b>					
<b><i>Reconstructed Whole Body</i></b>					
Total Mercury	3 / 3	1.03E+02 - 3.21E+02	2.42E+02	3.01E+02	1.21E+02
Methylmercury	3 / 3	9.61E+01 - 2.92E+02	2.22E+02	2.79E+02	1.09E+02
<b><i>Largemouth Bass</i></b>					
<b><i>Reconstructed Whole Body</i></b>					
Total Mercury	3 / 3	4.53E+02 - 7.11E+02	5.45E+02	4.71E+02	1.44E+02
Methylmercury	3 / 3	4.06E+02 - 6.39E+02	5.04E+02	4.68E+02	1.21E+02
<b><i>Yellow Perch</i></b>					
<b><i>Whole Body</i></b>					
<b><i>Size Class A</i></b>					
Total Mercury	1 / 1	9.28E+01 - 9.28E+01	9.28E+01	9.28E+01	NC
<b><i>Size Class B</i></b>					
Total Mercury	2 / 2	6.49E+01 - 1.08E+02	8.65E+01	8.65E+01	3.05E+01
<b><i>Size Class C</i></b>					
Total Mercury	13 / 13	5.78E+01 - 1.36E+02	9.53E+01	1.04E+02	2.54E+01
<b><i>Reconstructed Whole Body</i></b>					
<b><i>Size Class D</i></b>					
Total Mercury	3 / 3	1.51E+02 - 2.61E+02	2.04E+02	2.02E+02	5.50E+01
Methylmercury	3 / 3	1.40E+02 - 2.23E+02	1.87E+02	1.97E+02	4.25E+01

<sup>a</sup> Number of sampling locations at which chemical was detected compared with total number of sampling locations;

duplicates at a location were averaged and considered one sample.

µg/kg = Micrograms per kilogram

NC = Not calculated due to insufficient sample size.

Table 2-22

**Summary of Chemicals Detected in Fish**  
**Operable Unit IV - Nyanza Chemical Dump Superfund Site - Reach 7**  
**Middlesex County, Massachusetts**

Chemical	Frequency of Detection <sup>a</sup>	Range of Detected Concentrations (µg/kg WW)	Arithmetic Mean Concentration (µg/kg WW)	Median (µg/kg WW)	Standard Deviation (µg/kg WW)
<b><i>Sunfish (Bluegill and Pumpkinseed)</i></b>					
<b><i>Whole Body</i></b>					
<b><i>Size Class A</i></b>					
Total Mercury	7 / 7	1.28E+02 - 2.69E+02	1.88E+02	1.86E+02	4.80E+01
<b><i>Bullhead</i></b>					
<b><i>Reconstructed Whole Body</i></b>					
Total Mercury	3 / 3	1.06E+02 - 2.80E+02	1.72E+02	1.29E+02	9.48E+01
Methylmercury	3 / 3	7.59E+01 - 2.69E+02	1.45E+02	8.92E+01	1.08E+02
<b><i>Largemouth Bass</i></b>					
<b><i>Reconstructed Whole Body</i></b>					
Total Mercury	4 / 4	2.01E+02 - 7.35E+02	4.61E+02	4.55E+02	2.31E+02
Methylmercury	3 / 3	1.60E+02 - 7.16E+02	4.36E+02	4.33E+02	2.78E+02
<b><i>Yellow Perch</i></b>					
<b><i>Whole Body</i></b>					
<b><i>Size Class A</i></b>					
Total Mercury	3 / 3	1.62E+02 - 4.04E+02	2.45E+02	1.68E+02	1.38E+02
<b><i>Size Class B</i></b>					
Total Mercury	13 / 13	9.49E+01 - 2.05E+02	1.52E+02	1.53E+02	3.27E+01
<b><i>Size Class C</i></b>					
Total Mercury	13 / 13	8.08E+01 - 1.49E+02	1.16E+02	1.13E+02	2.12E+01
<b><i>Reconstructed Whole Body</i></b>					
<b><i>Size Class D</i></b>					
Total Mercury	4 / 4	1.25E+02 - 2.39E+02	1.74E+02	1.66E+02	5.06E+01
Methylmercury	3 / 3	1.28E+02 - 2.03E+02	1.64E+02	1.62E+02	3.77E+01

<sup>a</sup> Number of sampling locations at which chemical was detected compared with total number of sampling locations;  
duplicates at a location were averaged and considered one sample.

µg/kg = Micrograms per kilogram

NC - Not calculated due to insufficient sample size.

Table 2-23

**Summary of Chemicals Detected in Fish**  
**Operable Unit IV - Nyanza Chemical Dump Superfund Site - Reach 7, Heard Pond - 2004**  
**Middlesex County, Massachusetts**

Chemical	Frequency of Detection <sup>a</sup>	Range of Detected Concentrations (µg/kg WW)	Arithmetic Mean Concentration (µg/kg WW)	Median (µg/kg WW)	Standard Deviation (µg/kg WW)
<b><i>Bullhead</i></b>					
<b><i>Reconstructed Whole Body</i></b>					
Total Mercury	3 / 3	8.06E+01 - 1.00E+02	9.20E+01	9.53E+01	1.02E+01
Methylmercury	3 / 3	1.04E+02 - 1.26E+02	1.18E+02	1.24E+02	1.17E+01
<b><i>Largemouth Bass</i></b>					
<b><i>Reconstructed Whole Body</i></b>					
Total Mercury	3 / 3	1.19E+02 - 1.93E+02	1.58E+02	1.61E+02	3.73E+01
Methylmercury	3 / 3	9.99E+01 - 2.37E+02	1.64E+02	1.56E+02	6.89E+01
<b><i>Yellow Perch</i></b>					
<b><i>Whole Body</i></b>					
<b><i>Size Class A</i></b>					
Total Mercury	13 / 13	9.80E+00 - 2.33E+01	1.50E+01	1.49E+01	3.66E+00
<b><i>Size Class B</i></b>					
Total Mercury	13 / 13	1.57E+01 - 2.92E+01	2.02E+01	1.96E+01	3.51E+00
<b><i>Size Class C</i></b>					
Total Mercury	13 / 13	2.12E+01 - 4.99E+01	3.37E+01	3.24E+01	8.44E+00
<b><i>Reconstructed Whole Body</i></b>					
<b><i>Size Class D</i></b>					
Total Mercury	3 / 3	5.63E+01 - 7.62E+01	6.54E+01	6.37E+01	1.00E+01
Methylmercury	3 / 3	4.52E+01 - 6.81E+01	5.39E+01	4.84E+01	1.24E+01

<sup>a</sup> Number of sampling locations at which chemical was detected compared with total number of sampling locations; duplicates at a location were averaged and considered one sample.  
µg/kg = Micrograms per kilogram

Table 2-24

**Summary of Chemicals Detected in Fish**  
**Operable Unit IV - Nyanza Chemical Dump Superfund Site - Reach 8**  
**Middlesex County, Massachusetts**

Chemical	Frequency of Detection <sup>a</sup>	Range of Detected Concentrations (µg/kg WW)	Arithmetic Mean Concentration (µg/kg WW)	Median (µg/kg WW)	Standard Deviation (µg/kg WW)
<b><i>Sunfish (Bluegill and Pumpkinseed)</i></b>					
<b><i>Whole Body</i></b>					
<b><i>Size Class A</i></b>					
Total Mercury	34 / 34	1.68E+02 - 3.03E+02	2.17E+02	2.14E+02	3.29E+01
<b><i>Size Class B</i></b>					
Total Mercury	6 / 6	1.76E+02 - 2.16E+02	1.97E+02	1.99E+02	1.34E+01
<b><i>Size Class C</i></b>					
Total Mercury	5 / 5	2.08E+02 - 3.49E+02	2.71E+02	2.85E+02	5.85E+01
<b><i>Bullhead</i></b>					
<b><i>Reconstructed Whole Body</i></b>					
Total Mercury	6 / 6	5.91E+01 - 4.65E+02	1.97E+02	1.47E+02	1.46E+02
Methylmercury	3 / 3	4.80E+01 - 1.42E+02	9.78E+01	1.04E+02	4.71E+01
<b><i>Largemouth Bass</i></b>					
<b><i>Reconstructed Whole Body</i></b>					
Total Mercury	6 / 6	3.88E+02 - 1.13E+03	7.51E+02	7.46E+02	2.60E+02
Methylmercury	3 / 3	4.55E+02 - 9.45E+02	6.57E+02	5.72E+02	2.56E+02
<b><i>Yellow Perch</i></b>					
<b><i>Whole Body</i></b>					
<b><i>Size Class A</i></b>					
Total Mercury	3 / 3	1.31E+02 - 2.01E+02	1.75E+02	1.94E+02	3.86E+01
<b><i>Size Class B</i></b>					
Total Mercury	50 / 50	1.25E+02 - 2.39E+02	1.77E+02	1.81E+02	2.78E+01
<b><i>Size Class C</i></b>					
Total Mercury	30 / 30	8.62E+01 - 2.25E+02	1.55E+02	1.52E+02	3.26E+01
<b><i>Reconstructed Whole Body</i></b>					
<b><i>Size Class D</i></b>					
Total Mercury	10 / 10	1.26E+02 - 3.64E+02	2.37E+02	2.35E+02	6.29E+01
Methylmercury	5 / 5	8.42E+01 - 2.87E+02	1.94E+02	1.86E+02	7.73E+01

<sup>a</sup> Number of sampling locations at which chemical was detected compared with total number of sampling locations; duplicates at a location were averaged and considered one sample.

µg/kg = Micrograms per kilogram

NC = Not calculated due to insufficient sample size.

Table 2-25

**Summary of Chemicals Detected in Fish**  
**Operable Unit IV - Nyanza Chemical Dump Superfund Site - Reach 9**  
**Middlesex County, Massachusetts**

Chemical	Frequency of Detection <sup>a</sup>	Range of Detected Concentrations (µg/kg WW)	Arithmetic Mean Concentration (µg/kg WW)	Median (µg/kg WW)	Standard Deviation (µg/kg WW)
<b><i>Sunfish (Bluegill and Pumpkinseed)</i></b>					
<b><i>Whole Body</i></b>					
<b><i>Size Class A</i></b>					
Total Mercury	7 / 7	1.40E+02 - 2.19E+02	1.72E+02	1.68E+02	2.94E+01
<b><i>Size Class B</i></b>					
Total Mercury	7 / 7	2.03E+02 - 2.74E+02	2.35E+02	2.28E+02	2.49E+01
<b><i>Bullhead</i></b>					
<b><i>Reconstructed Whole Body</i></b>					
Total Mercury	3 / 3	1.52E+02 - 1.92E+02	1.76E+02	1.83E+02	2.10E+01
Methylmercury	3 / 3	9.52E+01 - 1.35E+02	1.14E+02	1.11E+02	2.01E+01
<b><i>Largemouth Bass</i></b>					
<b><i>Reconstructed Whole Body</i></b>					
Total Mercury	3 / 3	6.47E+02 - 1.27E+03	9.35E+02	8.85E+02	3.17E+02
Methylmercury	3 / 3	4.98E+02 - 7.99E+02	6.59E+02	6.80E+02	1.52E+02
<b><i>Yellow Perch</i></b>					
<b><i>Whole Body</i></b>					
<b><i>Size Class B</i></b>					
Total Mercury	4 / 4	1.32E+02 - 1.99E+02	1.65E+02	1.65E+02	2.75E+01
<b><i>Size Class C</i></b>					
Total Mercury	13 / 13	1.36E+02 - 2.29E+02	1.70E+02	1.62E+02	2.75E+01
<b><i>Reconstructed Whole Body</i></b>					
<b><i>Size Class D</i></b>					
Total Mercury	3 / 3	2.79E+02 - 4.02E+02	3.34E+02	3.21E+02	6.27E+01
Methylmercury	3 / 3	1.78E+02 - 2.58E+02	2.31E+02	2.57E+02	4.61E+01

<sup>a</sup> Number of sampling locations at which chemical was detected compared with total number of sampling locations;

duplicates at a location were averaged and considered one sample.

µg/kg = Micrograms per kilogram

Table 2-26

**Summary of Chemicals Detected in Fish**  
**Operable Unit IV - Nyanza Chemical Dump Superfund Site - Reach 10**  
**Middlesex County, Massachusetts**

Chemical	Frequency of Detection <sup>a</sup>	Range of Detected Concentrations (µg/kg WW)	Arithmetic Mean Concentration (µg/kg WW)	Median (µg/kg WW)	Standard Deviation (µg/kg WW)
<b><i>Sunfish (Bluegill and Pumpkinseed)</i></b>					
<b><i>Whole Body</i></b>					
<b><i>Size Class A</i></b>					
Total Mercury	12 / 12	1.90E+02 - 2.71E+02	2.32E+02	2.30E+02	2.90E+01
<b><i>Bullhead</i></b>					
<b><i>Reconstructed Whole Body</i></b>					
Total Mercury	3 / 3	1.23E+02 - 2.88E+02	2.29E+02	2.77E+02	9.22E+01
Methylmercury	3 / 3	1.28E+02 - 2.84E+02	2.03E+02	1.98E+02	7.79E+01
<b><i>Largemouth Bass</i></b>					
<b><i>Reconstructed Whole Body</i></b>					
Total Mercury	3 / 3	7.05E+02 - 1.27E+03	1.05E+03	1.17E+03	3.01E+02
Methylmercury	3 / 3	7.11E+02 - 1.31E+03	1.07E+03	1.19E+03	3.18E+02
<b><i>Yellow Perch</i></b>					
<b><i>Whole Body</i></b>					
<b><i>Size Class A</i></b>					
Total Mercury	1 / 1	3.90E+02 - 3.90E+02	3.90E+02	3.90E+02	NC
<b><i>Size Class B</i></b>					
Total Mercury	13 / 13	1.42E+02 - 2.59E+02	1.99E+02	1.90E+02	4.06E+01
<b><i>Size Class C</i></b>					
Total Mercury	13 / 13	1.39E+02 - 2.59E+02	2.04E+02	2.13E+02	3.45E+01
<b><i>Reconstructed Whole Body</i></b>					
<b><i>Size Class D</i></b>					
Total Mercury	3 / 3	1.83E+02 - 4.40E+02	2.77E+02	2.09E+02	1.42E+02
Methylmercury	3 / 3	1.61E+02 - 4.66E+02	2.68E+02	1.77E+02	1.72E+02

<sup>a</sup> Number of sampling locations at which chemical was detected compared with total number of sampling locations;

duplicates at a location were averaged and considered one sample.

µg/kg = Micrograms per kilogram

NC = Not calculated due to insufficient sample size.

Table 2-27

**Summary of Chemicals Detected in Fish**  
**Operable Unit IV - Nyanza Chemical Dump Superfund Site - Charles River**  
**Middlesex County, Massachusetts**

Chemical	Frequency of Detection <sup>a</sup>	Range of Detected Concentrations (µg/kg WW)	Arithmetic Mean Concentration (µg/kg WW)	Median (µg/kg WW)	Standard Deviation (µg/kg WW)
<b><i>Sunfish (Bluegill and Pumpkinseed)</i></b>					
<b><i>Whole Body</i></b>					
<b><i>Size Class A</i></b>					
Total Mercury	12 / 12	1.04E+02 - 1.87E+02	1.45E+02	1.43E+02	2.23E+01
<b><i>Bullhead</i></b>					
<b><i>Reconstructed Whole Body</i></b>					
Total Mercury	3 / 3	7.95E+01 - 1.37E+02	1.13E+02	1.24E+02	3.00E+01
Methylmercury	3 / 3	6.14E+01 - 1.66E+02	1.18E+02	1.27E+02	5.28E+01
<b><i>Largemouth Bass</i></b>					
<b><i>Reconstructed Whole Body</i></b>					
Total Mercury	3 / 3	2.49E+02 - 4.14E+02	3.36E+02	3.46E+02	8.26E+01
Methylmercury	3 / 3	2.64E+02 - 4.41E+02	3.55E+02	3.59E+02	8.86E+01
<b><i>Yellow Perch</i></b>					
<b><i>Whole Body</i></b>					
<b><i>Size Class B</i></b>					
Total Mercury	13 / 13	8.85E+01 - 1.22E+02	1.05E+02	1.06E+02	1.08E+01
<b><i>Size Class C</i></b>					
Total Mercury	13 / 13	9.05E+01 - 1.23E+02	1.04E+02	1.02E+02	9.34E+00
<b><i>Reconstructed Whole Body</i></b>					
<b><i>Size Class D</i></b>					
Total Mercury	3 / 3	1.49E+02 - 1.69E+02	1.60E+02	1.61E+02	1.00E+01
Methylmercury	3 / 3	1.27E+02 - 2.19E+02	1.72E+02	1.71E+02	4.64E+01

<sup>a</sup> Number of sampling locations at which chemical was detected compared with total number of sampling locations; duplicates at a location were averaged and considered one sample.

µg/kg = Micrograms per kilogram

Table 2-28

**Summary of Chemicals Detected in Fish**  
**Operable Unit IV - Nyanza Chemical Dump Superfund Site - Sudbury Reservoir**  
**Middlesex County, Massachusetts**

Chemical	Frequency of Detection <sup>a</sup>	Range of Detected Concentrations (µg/kg WW)	Arithmetic Mean Concentration (µg/kg WW)	Median (µg/kg WW)	Standard Deviation (µg/kg WW)
<b><i>Sunfish (Bluegill and Pumpkinseed)</i></b>					
<b><i>Whole Body</i></b>					
<b><i>Size Class A</i></b>					
Total Mercury	7 / 7	2.23E+01 - 5.81E+01	3.54E+01	2.90E+01	1.46E+01
<b><i>Bullhead</i></b>					
<b><i>Reconstructed Whole Body</i></b>					
Total Mercury	3 / 3	8.81E+01 - 1.85E+02	1.24E+02	9.95E+01	5.28E+01
Methylmercury	3 / 3	8.78E+01 - 1.83E+02	1.32E+02	1.24E+02	4.83E+01
<b><i>Largemouth Bass</i></b>					
<b><i>Reconstructed Whole Body</i></b>					
Total Mercury	2 / 2	1.55E+02 - 2.01E+02	1.78E+02	1.78E+02	3.23E+01
Methylmercury	2 / 2	2.00E+02 - 2.12E+02	2.06E+02	2.06E+02	8.37E+00
<b><i>Yellow Perch</i></b>					
<b><i>Whole Body</i></b>					
<b><i>Size Class A</i></b>					
Total Mercury	6 / 6	2.17E+01 - 3.00E+01	2.63E+01	2.66E+01	2.78E+00
<b><i>Size Class B</i></b>					
Total Mercury	13 / 13	2.25E+01 - 4.54E+01	3.27E+01	3.37E+01	7.28E+00
<b><i>Size Class C</i></b>					
Total Mercury	13 / 13	3.32E+01 - 1.13E+02	6.38E+01	6.20E+01	2.11E+01
<b><i>Reconstructed Whole Body</i></b>					
<b><i>Size Class D</i></b>					
Total Mercury	3 / 3	6.34E+01 - 1.05E+02	8.39E+01	8.35E+01	2.07E+01
Methylmercury	3 / 3	7.61E+01 - 1.18E+02	9.38E+01	8.75E+01	2.14E+01

<sup>a</sup> Number of sampling locations at which chemical was detected compared with total number of sampling locations;

duplicates at a location were averaged and considered one sample.

µg/kg = Micrograms per kilogram



**Table 2-29**

**Large Fish Fillet Methylmercury to Total Mercury Comparison Summary  
Operable Unit IV - Nyanza Chemical Dump Superfund Site  
Middlesex County, Massachusetts**

Species	Total Samples	Range of Concentrations		Mean of Concentrations		Range of MeHg to Total Hg Ratios			Mean MeHg to Total Hg Ratios	Range of RPD		Mean of RPD
		Total Hg	MeHg	Total Hg	MeHg							
Bullhead	35	8.96E+01 - 8.47E+02	7.52E+01 - 6.96E+02	2.70E+02	2.51E+02	0.63	-	1.35	0.94	0	- 46	15
Largemouth Bass	39	1.42E+02 - 1.83E+03	1.23E+02 - 2.07E+03	7.30E+02	7.26E+02	0.63	-	1.35	0.99	1	- 45	17
Yellow Perch	45	5.44E+01 - 8.76E+02	4.53E+01 - 8.33E+02	3.61E+02	3.06E+02	0.12	-	1.32	0.89	1	- 156	22

\* All concentrations are presented in µg/kg, wet. Duplicates averaged.

RPD = Relative percent difference. Calculated as  $\text{abs}(a-b) \div \text{average}(a,b) * 100$ ; where a = tHg concentration and b = associated meHg concentration for that sample.

**Table 2-30**

**Large Fish Offal Methylmercury to Total Mercury Comparison Summary  
Operable Unit IV - Nyanza Chemical Dump Superfund Site  
Middlesex County, Massachusetts**

Species	Total Samples	Range of Concentrations		Mean of Concentrations		Range of MeHg to Total Hg Ratios	Mean MeHg to Total Hg Ratios	Range of RPD	Mean of RPD
		Total Hg	MeHg	Total Hg	MeHg				
Bullhead	35	4.94E+01 - 4.67E+02	3.94E+01 - 3.14E+02	1.55E+02	1.41E+02	0.46 - 1.60	0.94	1 - 74	22
Largemouth Bass	38	1.09E+02 - 1.09E+03	8.73E+01 - 9.82E+02	4.25E+02	3.76E+02	0.50 - 1.78	0.95	0 - 67	22
Yellow Perch	41	5.20E+01 - 5.30E+02	3.99E+01 - 7.50E+02	1.94E+02	1.93E+02	0.56 - 1.76	0.99	0 - 56	23

\* All concentrations are presented in µg/kg, wet. Duplicates averaged.

RPD = Relative percent difference. Calculated as  $\text{abs}(a-b) \div \text{average}(a,b) * 100$ ; where a = tHg concentration and b = associated meHg concentration for that sample.

**Table 2-31**

**Large Fish Whole Body Methylmercury to Total Mercury Comparison Summary  
Operable Unit IV - Nyanza Chemical Dump Superfund Site  
Middlesex County, Massachusetts**

Species	Total Samples	Range of Concentrations		Mean of Concentrations		Range of MeHg to Total Hg Ratios	Mean MeHg to Total Hg Ratios	Range of RPD	Mean of RPD
		Total Hg	MeHg	Total Hg	MeHg				
Bullhead	3	8.88E+01 - 1.63E+02	7.66E+01 - 1.63E+02	1.14E+02	1.11E+02	0.86 - 1.02	0.96	0 - 15	6

\* All concentrations are presented in µg/kg, wet.

RPD = Relative percent difference. Calculated as  $\text{abs}(a-b) \div \text{average}(a,b) * 100$ ; where a = tHg concentration and b = associated meHg concentration for that sample.

Table 2-32

**Summary of Chemicals Detected in Waterfowl**  
**Operable Unit IV - Nyanza Chemical Dump Superfund Site - Reach 1 (Whitehall Reservoir) - 2003**  
**Middlesex County, Massachusetts**

Chemical	Frequency of Detection <sup>a</sup>	Range of Detected Concentrations (µg/kg)	Arithmetic Mean Concentration (µg/kg)	Median (µg/kg)	Standard Deviation (µg/kg)
<b><i>Hooded Merganser</i></b>					
<b><i>Blood</i></b>					
<b><i>Adult<sup>b</sup></i></b>					
Total Mercury	2 / 2	3.54E+02 - 7.61E+02	5.58E+02	5.58E+02	2.88E+02
<b><i>Nestling</i></b>					
Total Mercury	1 / 1	1.13E+03 - 1.13E+03	1.13E+03	1.13E+03	NC
<b><i>Egg</i></b>					
Total Mercury	1 / 1	3.25E+02 - 3.26E+02	3.26E+02	3.26E+02	NC

<sup>a</sup> Number of sampling locations at which chemical was detected compared with total number of sampling locations.

<sup>b</sup> Includes data from one recaptured adult.

µg/kg = Micrograms per kilogram

NC = Not calculated due to insufficient sample size.

Table 2-33

**Summary of Chemicals Detected in Waterfowl**  
**Operable Unit IV - Nyanza Chemical Dump Superfund Site - Reach 8 - 2003**  
**Middlesex County, Massachusetts**

Chemical	Frequency of Detection <sup>a</sup>	Range of Detected Concentrations (µg/kg)	Arithmetic Mean Concentration (µg/kg)	Median (µg/kg)	Standard Deviation (µg/kg)
<i>Wood Duck</i>					
<i>Blood</i>					
<i>Adult</i>					
Total Mercury	4 / 4	2.11E+01 - 4.99E+01	3.61E+01	3.66E+01	1.43E+01
<i>Egg</i>					
Total Mercury	4 / 4	2.50E+01 - 2.21E+02	7.74E+01	3.18E+01	9.59E+01

<sup>a</sup> Number of sampling locations at which chemical was detected compared with total number of sampling locations.

µg/kg = Micrograms per kilogram

Table 2-34

**Summary of Chemicals Detected in Waterfowl**  
**Operable Unit IV - Nyanza Chemical Dump Superfund Site - Delaney - 2003**  
**Middlesex County, Massachusetts**

Chemical	Frequency of Detection <sup>a</sup>	Range of Detected Concentrations (µg/kg)	Arithmetic Mean Concentration (µg/kg)	Median (µg/kg)	Standard Deviation (µg/kg)
<b><i>Hooded Merganser</i></b>					
<b><i>Blood</i></b>					
<b><i>Adult</i></b>					
Total Mercury	2 / 2	7.07E+01 - 4.26E+02	2.48E+02	2.48E+02	2.51E+02
<b><i>Feather</i></b>					
<b><i>Adult</i></b>					
Total Mercury	2 / 2	6.25E+03 - 1.75E+04	1.19E+04	1.19E+04	7.95E+03
<b><i>Egg</i></b>					
Total Mercury	10 / 10	1.47E+02 - 7.26E+02	2.96E+02	2.54E+02	1.80E+02
<b><i>Wood Duck</i></b>					
<b><i>Blood</i></b>					
<b><i>Adult</i></b>					
Total Mercury	5 / 5	1.21E+01 - 8.06E+01	3.54E+01	3.11E+01	2.66E+01
<b><i>Egg</i></b>					
Total Mercury	7 / 7	1.12E+01 - 7.37E+01	4.51E+01	4.97E+01	2.23E+01

<sup>a</sup> Number of sampling locations at which chemical was detected compared with total number of sampling locations.

µg/kg = Micrograms per kilogram

Table 2-35

**Summary of Chemicals Detected in Waterfowl**  
**Operable Unit IV - Nyanza Chemical Dump Superfund Site - Sudbury Reservoir - 2003**  
**Middlesex County, Massachusetts**

Chemical	Frequency of Detection <sup>a</sup>	Range of Detected Concentrations (µg/kg)	Arithmetic Mean Concentration (µg/kg)	Median (µg/kg)	Standard Deviation (µg/kg)
<b><i>Wood Duck</i></b>					
<b><i>Blood</i></b>					
<b><i>Adult</i></b>					
Total Mercury	1 / 1	8.20E+01 - 8.20E+01	8.20E+01	8.20E+01	NC
<b><i>Egg</i></b>					
Total Mercury	1 / 1	5.28E+01 - 5.28E+01	5.28E+01	5.28E+01	NC

<sup>a</sup> Number of sampling locations at which chemical was detected compared with total number of sampling locations.

µg/kg = Micrograms per kilogram

NC = Not calculated due to insufficient sample size.

Table 2-36

**Summary of Chemicals Detected in Waterfowl**  
**Operable Unit IV - Nyanza Chemical Dump Superfund Site - Reach 7 - 2004**  
**Middlesex County, Massachusetts**

Chemical	Frequency of Detection <sup>a</sup>	Range of Detected Concentrations (µg/kg)	Arithmetic Mean Concentration (µg/kg)	Median (µg/kg)	Standard Deviation (µg/kg)
<b><i>Wood Duck</i></b>					
<b><i>Blood</i></b>					
<b><i>Adult</i></b>					
Total Mercury	1 / 1	5.22E+01 - 5.22E+01	5.22E+01	5.22E+01	NC
<b><i>Feather</i></b>					
<b><i>Adult</i></b>					
Total Mercury	1 / 1	5.41E+02 - 5.41E+02	5.41E+02	5.41E+02	NC

<sup>a</sup> Number of sampling locations at which chemical was detected compared with total number of sampling locations.

µg/kg = Micrograms per kilogram

NC = Not calculated due to insufficient sample size.



Table 2-37

**Summary of Chemicals Detected in Waterfowl**  
**Operable Unit IV - Nyanza Chemical Dump Superfund Site - Reach 8 - 2004**  
**Middlesex County, Massachusetts**

Chemical	Frequency of Detection <sup>a</sup>	Range of Detected Concentrations (µg/kg)	Arithmetic Mean Concentration (µg/kg)	Median (µg/kg)	Standard Deviation (µg/kg)
<b><i>Hooded Merganser</i></b>					
<b><i>Blood</i></b>					
<b><i>Adult</i></b>					
Total Mercury	1 / 1	2.12E+01 - 2.12E+01	2.12E+01	2.12E+01	NC
<b><i>Feather</i></b>					
<b><i>Adult</i></b>					
Total Mercury	1 / 1	7.59E+03 - 7.59E+03	7.59E+03	7.59E+03	NC
<b><i>Wood Duck</i></b>					
<b><i>Blood</i></b>					
<b><i>Adult</i></b>					
Total Mercury	1 / 1	4.21E+02 - 4.21E+02	4.21E+02	4.21E+02	NC
<b><i>Feather</i></b>					
<b><i>Adult</i></b>					
Total Mercury	1 / 1	4.42E+02 - 4.42E+02	4.42E+02	4.42E+02	NC

<sup>a</sup> Number of sampling locations at which chemical was detected compared with total number of sampling locations.

µg/kg = Micrograms per kilogram

NC = Not calculated due to insufficient sample size.

Table 2-38

**Summary of Chemicals Detected in Waterfowl**  
**Operable Unit IV - Nyanza Chemical Dump Superfund Site - Sudbury Reservoir - 2004**  
**Middlesex County, Massachusetts**

Chemical	Frequency of Detection <sup>a</sup>	Range of Detected Concentrations (µg/kg)	Arithmetic Mean Concentration (µg/kg)	Median (µg/kg)	Standard Deviation (µg/kg)
<b><i>Wood Duck</i></b>					
<b><i>Blood</i></b>					
<b><i>Adult</i></b>					
Total Mercury	1 / 1	2.53E+01 - 2.53E+01	2.53E+01	2.53E+01	NC
<b><i>Feather</i></b>					
<b><i>Adult</i></b>					
Total Mercury	1 / 1	2.98E+02 - 2.98E+02	2.98E+02	2.98E+02	NC

<sup>a</sup> Number of sampling locations at which chemical was detected compared with total number of sampling locations.

µg/kg = Micrograms per kilogram

NC = Not calculated due to insufficient sample size.

Table 2-39

**Summary of Chemicals Detected in Waterfowl**  
**Operable Unit IV - Nyanza Chemical Dump Superfund Site - Reach 4 - 2005**  
**Middlesex County, Massachusetts**

Chemical	Frequency of Detection <sup>a</sup>	Range of Detected Concentrations (µg/kg)	Arithmetic Mean Concentration (µg/kg)	Median (µg/kg)	Standard Deviation (µg/kg)
<i>Hooded Merganser</i>					
<i>Egg</i>					
Total Mercury	2 / 2	4.98E+02 - 8.16E+02	6.57E+02	6.57E+02	2.25E+02

<sup>a</sup> Number of sampling locations at which chemical was detected compared with total number of sampling locations.

µg/kg = Micrograms per kilogram

Table 2-40

**Summary of Chemicals Detected in Waterfowl**  
**Operable Unit IV - Nyanza Chemical Dump Superfund Site - Reach 8 - 2005**  
**Middlesex County, Massachusetts**

Chemical	Frequency of Detection <sup>a</sup>	Range of Detected Concentrations (µg/kg)	Arithmetic Mean Concentration (µg/kg)	Median (µg/kg)	Standard Deviation (µg/kg)
<b><i>Hooded Merganser</i></b>					
<b><i>Blood</i></b>					
<b><i>Adult<sup>b</sup></i></b>					
Total Mercury	8 / 8	1.67E+02 - 1.88E+03	5.79E+02	4.18E+02	5.50E+02
<b><i>Feather</i></b>					
<b><i>Adult</i></b>					
Total Mercury	5 / 5	8.99E+02 - 7.48E+03	4.87E+03	5.16E+03	2.43E+03
<b><i>Egg</i></b>					
Total Mercury	21 / 21	2.57E+02 - 1.95E+03	7.13E+02	5.78E+02	4.79E+02

<sup>a</sup> Number of sampling locations at which chemical was detected compared with total number of sampling locations.

<sup>b</sup> Includes data from four retrapped birds.

µg/kg = Micrograms per kilogram

Table 2-41

**Summary of Chemicals Detected in Waterfowl  
Operable Unit IV - Nyanza Chemical Dump Superfund Site - Charles River - 2005  
Middlesex County, Massachusetts**

<b>Chemical</b>	<b>Frequency of Detection<sup>a</sup></b>	<b>Range of Detected Concentrations (µg/kg)</b>	<b>Arithmetic Mean Concentration (µg/kg)</b>	<b>Median (µg/kg)</b>	<b>Standard Deviation (µg/kg)</b>
<b><i>Hooded Merganser</i></b>					
<b><i>Blood</i></b>					
<b><i>Adult<sup>b</sup></i></b>					
Total Mercury	2 / 2	6.14E+02 - 4.27E+03	2.44E+03	2.44E+03	2.59E+03
<b><i>Feather</i></b>					
<b><i>Adult</i></b>					
Total Mercury	1 / 1	8.92E+03 - 8.92E+03	8.92E+03	8.92E+03	NC
<b><i>Egg</i></b>					
Total Mercury	2 / 2	7.35E+02 - 2.42E+03	1.58E+03	1.58E+03	1.19E+03

<sup>a</sup> Number of sampling locations at which chemical was detected compared with total number of sampling locations.

<sup>b</sup> Includes data from one retrapped birds.

µg/kg = Micrograms per kilogram

NC = Not calculated due to insufficient sample size.

Table 2-42

**Summary of Chemicals Detected in Waterfowl**  
**Operable Unit IV - Nyanza Chemical Dump Superfund Site - Sudbury Reservoir - 2005**  
**Middlesex County, Massachusetts**

Chemical	Frequency of Detection <sup>a</sup>	Range of Detected Concentrations (µg/kg)	Arithmetic Mean Concentration (µg/kg)	Median (µg/kg)	Standard Deviation (µg/kg)
<b><i>Hooded Merganser</i></b>					
<b><i>Feather</i></b>					
<b><i>Adult</i></b>					
Total Mercury	1 / 1	6.44E+03 - 6.44E+03	6.44E+03	6.44E+03	NC
<b><i>Egg</i></b>					
Total Mercury	2 / 2	2.88E+02 - 5.55E+02	4.22E+02	4.22E+02	1.89E+02

<sup>a</sup> Number of sampling locations at which chemical was detected compared with total number of sampling locations.

µg/kg = Micrograms per kilogram

NC = Not calculated due to insufficient sample size.

Table 2-43

**Summary of Chemicals Detected in Belted Kingfisher**  
**Operable Unit IV - Nyanza Chemical Dump Superfund Site - Reach 1 (Whitehall Reservoir) - 2003**  
**Middlesex County, Massachusetts**

Chemical	Frequency of Detection <sup>a</sup>	Range of Detected Concentrations (µg/kg)	Arithmetic Mean Concentration (µg/kg)	Median (µg/kg)	Standard Deviation (µg/kg)
<i>Belted Kingfisher</i>					
<i>Blood</i>					
<i>Adult</i>					
Total Mercury	2 / 2	1.30E+02 - 3.98E+02	2.64E+02	2.64E+02	1.90E+02

<sup>a</sup> Number of sampling locations at which chemical was detected compared with total number of sampling locations.

µg/kg = Micrograms per kilogram

Table 2-44

**Summary of Chemicals Detected in Belted Kingfisher**  
**Operable Unit IV - Nyanza Chemical Dump Superfund Site - Reach 7 - 2003**  
**Middlesex County, Massachusetts**

Chemical	Frequency of Detection <sup>a</sup>	Range of Detected Concentrations (µg/kg)	Arithmetic Mean Concentration (µg/kg)	Median (µg/kg)	Standard Deviation (µg/kg)
<b><i>Belted Kingfisher</i></b>					
<b><i>Blood</i></b>					
<b><i>Juvenile</i></b>					
Total Mercury	2 / 2	2.62E+02 - 7.66E+02	5.14E+02	5.14E+02	3.56E+02
<b><i>Feather</i></b>					
<b><i>Juvenile</i></b>					
Total Mercury	2 / 2	2.53E+03 - 2.99E+03	2.76E+03	2.76E+03	3.25E+02

<sup>a</sup> Number of sampling locations at which chemical was detected compared with total number of sampling locations.

µg/kg = Micrograms per kilogram



Table 2-45

**Summary of Chemicals Detected in Belted Kingfisher**  
**Operable Unit IV - Nyanza Chemical Dump Superfund Site - Reach 8 - Transfer Station Pit - 2003**  
**Middlesex County, Massachusetts**

Chemical	Frequency of Detection <sup>a</sup>	Range of Detected Concentrations (µg/kg)	Arithmetic Mean Concentration (µg/kg)	Median (µg/kg)	Standard Deviation (µg/kg)
<b><i>Belted Kingfisher</i></b>					
<b><i>Blood</i></b>					
<b><i>Adult<sup>b</sup></i></b>					
Total Mercury	2 / 2	5.71E+02 - 7.78E+02	6.75E+02	6.75E+02	1.46E+02
<b><i>Nestling</i></b>					
Total Mercury	6 / 6	2.30E+01 - 5.76E+02	1.50E+02	6.93E+01	2.11E+02
<b><i>Feather</i></b>					
<b><i>Adult</i></b>					
Total Mercury	1 / 1	1.24E+04 - 1.24E+04	1.24E+04	1.24E+04	NC

<sup>a</sup> Number of sampling locations at which chemical was detected compared with total number of sampling locations.

<sup>b</sup> Includes data from one retrapped bird.

µg/kg = Micrograms per kilogram

NC = Not calculated due to insufficient sample size.

Table 2-46

**Summary of Chemicals Detected in Belted Kingfisher**  
**Operable Unit IV - Nyanza Chemical Dump Superfund Site - Reach 8 - Macone's Pile - 2003**  
**Middlesex County, Massachusetts**

Chemical	Frequency of Detection <sup>a</sup>	Range of Detected Concentrations (µg/kg)	Arithmetic Mean Concentration (µg/kg)	Median (µg/kg)	Standard Deviation (µg/kg)
<b><i>Belted Kingfisher</i></b>					
<b><i>Blood</i></b>					
<b><i>Adult<sup>b</sup></i></b>					
Total Mercury	3 / 3	6.93E+01 - 1.33E+03	4.96E+02	8.89E+01	7.22E+02
<b><i>Feather</i></b>					
<b><i>Adult</i></b>					
Total Mercury	2 / 2	3.82E+03 - 6.98E+03	5.40E+03	5.40E+03	2.23E+03

<sup>a</sup> Number of sampling locations at which chemical was detected compared with total number of sampling locations.

<sup>b</sup> Includes data from one retrapped bird.

µg/kg = Micrograms per kilogram

Table 2-47

**Summary of Chemicals Detected in Belted Kingfisher**  
**Operable Unit IV - Nyanza Chemical Dump Superfund Site - Reach 8 - Route 117 Pit - 2003**  
**Middlesex County, Massachusetts**

Chemical	Frequency of Detection <sup>a</sup>	Range of Detected Concentrations (µg/kg)	Arithmetic Mean Concentration (µg/kg)	Median (µg/kg)	Standard Deviation (µg/kg)
<b><i>Belted Kingfisher</i></b>					
<b><i>Blood</i></b>					
<b><i>Adult<sup>b</sup></i></b>					
Total Mercury	3 / 3	5.90E+02 - 1.01E+03	7.66E+02	7.01E+02	2.15E+02
<b><i>Nestling<sup>b</sup></i></b>					
Total Mercury	7 / 7	5.54E+01 - 2.46E+02	1.04E+02	7.88E+01	6.77E+01
<b><i>Feather</i></b>					
<b><i>Adult</i></b>					
Total Mercury	2 / 2	3.98E+03 - 1.08E+04	7.39E+03	7.39E+03	4.82E+03
<b><i>Egg</i></b>					
Total Mercury	1 / 1	1.50E+02 - 1.52E+02	1.51E+02	1.51E+02	NC

<sup>a</sup> Number of sampling locations at which chemical was detected compared with total number of sampling locations.

<sup>b</sup> Includes data from retrapped birds (one adult and one nestling).

µg/kg = Micrograms per kilogram

NC = Not calculated due to insufficient sample size.

Table 2-48

**Summary of Chemicals Detected in Belted Kingfisher**  
**Operable Unit IV - Nyanza Chemical Dump Superfund Site - Charles River - 2003**  
**Middlesex County, Massachusetts**

Chemical	Frequency of Detection <sup>a</sup>	Range of Detected Concentrations (µg/kg)	Arithmetic Mean Concentration (µg/kg)	Median (µg/kg)	Standard Deviation (µg/kg)
<b><i>Belted Kingfisher</i></b>					
<b><i>Blood</i></b>					
<b><i>Adult</i></b>					
Total Mercury	1 / 1	2.86E+02 - 2.86E+02	2.86E+02	2.86E+02	NC
<b><i>Feather</i></b>					
<b><i>Adult</i></b>					
Total Mercury	1 / 1	7.18E+03 - 7.18E+03	7.18E+03	7.18E+03	NC

<sup>a</sup> Number of sampling locations at which chemical was detected compared with total number of sampling locations.

µg/kg = Micrograms per kilogram

NC = Not calculated due to insufficient sample size.

Table 2-49

**Summary of Chemicals Detected in Tree Swallow**  
**Operable Unit IV - Nyanza Chemical Dump Superfund Site - Reach 3 - 2003**  
**Middlesex County, Massachusetts**

Chemical	Frequency of Detection <sup>a</sup>	Range of Detected Concentrations (µg/kg)	Arithmetic Mean Concentration (µg/kg)	Median (µg/kg)	Standard Deviation (µg/kg)
<b><i>Tree Swallow</i></b>					
<b><i>Blood</i></b>					
<b><i>Adult</i></b>					
Total Mercury	3 / 3	1.06E+02 - 5.12E+02	2.58E+02	1.61E+02	2.17E+02
<b><i>Nestling</i></b>					
Total Mercury	4 / 4	2.46E+01 - 4.81E+01	3.50E+01	3.37E+01	9.73E+00
<b><i>Feather</i></b>					
<b><i>Adult</i></b>					
Total Mercury	3 / 3	9.90E+02 - 2.69E+03	1.57E+03	1.02E+03	9.73E+02
<b><i>Egg</i></b>					
Total Mercury	4 / 4	3.25E+00 - 6.02E+01	3.63E+01	4.09E+01	2.40E+01

<sup>a</sup> Number of sampling locations at which chemical was detected compared with total number of sampling locations.

µg/kg = Micrograms per kilogram

Table 2-50

**Summary of Chemicals Detected in Tree Swallow**  
**Operable Unit IV - Nyanza Chemical Dump Superfund Site - Reach 4 - 2003**  
**Middlesex County, Massachusetts**

Chemical	Frequency of Detection <sup>a</sup>	Range of Detected Concentrations (µg/kg)	Arithmetic Mean Concentration (µg/kg)	Median (µg/kg)	Standard Deviation (µg/kg)
<b><i>Tree Swallow</i></b>					
<b><i>Blood</i></b>					
<b><i>Adult</i></b>					
Total Mercury	1 / 1	1.91E+02 - 1.91E+02	1.91E+02	1.91E+02	NC
<b><i>Nestling</i></b>					
Total Mercury	5 / 5	4.58E+00 - 3.41E+01	2.56E+01	2.79E+01	1.22E+01
<b><i>Feather</i></b>					
<b><i>Adult</i></b>					
Total Mercury	1 / 1	7.94E+02 - 7.94E+02	7.94E+02	7.94E+02	NC
<b><i>Egg</i></b>					
Total Mercury	1 / 1	4.91E+01 - 4.91E+01	4.91E+01	4.91E+01	NC

<sup>a</sup> Number of sampling locations at which chemical was detected compared with total number of sampling locations.

µg/kg = Micrograms per kilogram

NC = Not calculated due to insufficient sample size.

Table 2-51

**Summary of Chemicals Detected in Tree Swallow**  
**Operable Unit IV - Nyanza Chemical Dump Superfund Site - Reaches 7 and 8 - 2003**  
**Middlesex County, Massachusetts**

Chemical	Frequency of Detection <sup>a</sup>	Range of Detected Concentrations (µg/kg)	Arithmetic Mean Concentration (µg/kg)	Median (µg/kg)	Standard Deviation (µg/kg)
<b><i>Tree Swallow</i></b>					
<b><i>Blood</i></b>					
<b><i>Adult</i></b>					
Total Mercury	21 / 21	1.95E+02 - 9.17E+02	4.16E+02	3.38E+02	1.77E+02
<b><i>Feather</i></b>					
<b><i>Adult</i></b>					
Total Mercury	21 / 21	8.40E+02 - 2.52E+03	1.35E+03	1.26E+03	4.16E+02
<b><i>Egg</i></b>					
Total Mercury	30 / 30	7.23E+01 - 2.12E+02	1.28E+02	1.21E+02	3.81E+01

<sup>a</sup> Number of sampling locations at which chemical was detected compared with total number of sampling locations.

µg/kg = Micrograms per kilogram

Table 2-52

**Summary of Chemicals Detected in Tree Swallow**  
**Operable Unit IV - Nyanza Chemical Dump Superfund Site - Charles River - 2003**  
**Middlesex County, Massachusetts**

Chemical	Frequency of Detection <sup>a</sup>	Range of Detected Concentrations (µg/kg)	Arithmetic Mean Concentration (µg/kg)	Median (µg/kg)	Standard Deviation (µg/kg)
<b><i>Tree Swallow</i></b>					
<b><i>Blood</i></b>					
<b><i>Adult</i></b>					
Total Mercury	15 / 15	2.92E+02 - 9.96E+02	5.11E+02	4.63E+02	1.90E+02
<b><i>Feather</i></b>					
<b><i>Adult</i></b>					
Total Mercury	16 / 16	5.91E+02 - 1.56E+03	1.07E+03	1.12E+03	2.69E+02
<b><i>Egg</i></b>					
Total Mercury	15 / 15	6.66E+01 - 2.57E+02	1.37E+02	1.50E+02	5.60E+01

<sup>a</sup> Number of sampling locations at which chemical was detected compared with total number of sampling locations.

µg/kg = Micrograms per kilogram



Table 2-53

**Summary of Chemicals Detected in Tree Swallow**  
**Operable Unit IV - Nyanza Chemical Dump Superfund Site - Sudbury Reservoir - 2003**  
**Middlesex County, Massachusetts**

Chemical	Frequency of Detection <sup>a</sup>	Range of Detected Concentrations (µg/kg)	Arithmetic Mean Concentration (µg/kg)	Median (µg/kg)	Standard Deviation (µg/kg)
<b><i>Tree Swallow</i></b>					
<b><i>Blood</i></b>					
<b><i>Adult</i></b>					
Total Mercury	9 / 9	7.07E+01 - 1.71E+02	1.20E+02	1.19E+02	3.59E+01
<b><i>Nestling</i></b>					
Total Mercury	10 / 10	2.65E+00 - 4.57E+01	1.62E+01	1.33E+01	1.24E+01
<b><i>Feather</i></b>					
<b><i>Adult</i></b>					
Total Mercury	9 / 9	9.55E+02 - 2.27E+03	1.51E+03	1.46E+03	4.66E+02
<b><i>Egg</i></b>					
Total Mercury	14 / 14	2.65E+01 - 1.57E+02	6.08E+01	5.14E+01	3.49E+01

<sup>a</sup> Number of sampling locations at which chemical was detected compared with total number of sampling locations.

µg/kg = Micrograms per kilogram

Table 2-54

**Summary of Chemicals Detected in Tree Swallow**  
**Operable Unit IV - Nyanza Chemical Dump Superfund Site - Reach 3 - 2004**  
**Middlesex County, Massachusetts**

Chemical	Frequency of Detection <sup>a</sup>	Range of Detected Concentrations (µg/kg)	Arithmetic Mean Concentration (µg/kg)	Median (µg/kg)	Standard Deviation (µg/kg)
<b><i>Tree Swallow</i></b>					
<b><i>Blood</i></b>					
<b><i>Adult<sup>b</sup></i></b>					
Total Mercury	15 / 15	6.20E+01 - 6.72E+02	2.24E+02	1.78E+02	1.88E+02
<b><i>Feather</i></b>					
<b><i>Adult<sup>b</sup></i></b>					
Total Mercury	15 / 15	6.65E+02 - 8.56E+03	2.76E+03	1.57E+03	2.53E+03
<b><i>Egg</i></b>					
Total Mercury	21 / 21	4.57E+01 - 3.08E+02	8.64E+01	6.30E+01	6.60E+01

<sup>a</sup> Number of sampling locations at which chemical was detected compared with total number of sampling locations.

<sup>b</sup> Includes data from 4 retrapped birds.

µg/kg = Micrograms per kilogram

NC = Not calculated due to insufficient sample size.

Table 2-55

**Summary of Chemicals Detected in Tree Swallow  
Operable Unit IV - Nyanza Chemical Dump Superfund Site - Reach 4 - 2004  
Middlesex County, Massachusetts**

Chemical	Frequency of Detection <sup>a</sup>	Range of Detected Concentrations (µg/kg)	Arithmetic Mean Concentration (µg/kg)	Median (µg/kg)	Standard Deviation (µg/kg)
<b><i>Tree Swallow</i></b>					
<b><i>Blood</i></b>					
<b><i>Adult<sup>b</sup></i></b>					
Total Mercury	10 / 10	6.25E+01 - 4.70E+02	2.53E+02	2.38E+02	1.21E+02
<b><i>Feather</i></b>					
<b><i>Adult<sup>b</sup></i></b>					
Total Mercury	10 / 10	1.29E+03 - 4.39E+03	2.00E+03	1.70E+03	8.95E+02
<b><i>Egg</i></b>					
Total Mercury	14 / 14	3.19E+01 - 1.72E+02	8.19E+01	7.40E+01	3.82E+01

<sup>a</sup> Number of sampling locations at which chemical was detected compared with total number of sampling locations.

<sup>b</sup> Includes data from one retrapped bird.

µg/kg = Micrograms per kilogram

Table 2-56

**Summary of Chemicals Detected in Tree Swallow**  
**Operable Unit IV - Nyanza Chemical Dump Superfund Site - Reach 7, Heard Pond - 2004**  
**Middlesex County, Massachusetts**

Chemical	Frequency of Detection <sup>a</sup>	Range of Detected Concentrations (µg/kg)	Arithmetic Mean Concentration (µg/kg)	Median (µg/kg)	Standard Deviation (µg/kg)
<b><i>Tree Swallow</i></b>					
<b><i>Blood</i></b>					
<b><i>Adult<sup>b</sup></i></b>					
Total Mercury	19 / 19	3.12E+02 - 1.29E+03	6.30E+02	5.55E+02	2.91E+02
<b><i>Feather</i></b>					
<b><i>Adult<sup>b</sup></i></b>					
Total Mercury	20 / 20	3.78E+02 - 4.54E+03	2.28E+03	2.04E+03	1.10E+03
<b><i>Egg</i></b>					
Total Mercury	22 / 22	8.60E+01 - 4.50E+02	1.68E+02	1.59E+02	7.18E+01

<sup>a</sup> Number of sampling locations at which chemical was detected compared with total number of sampling locations.

<sup>b</sup> Includes data from two retrapped birds.

µg/kg = Micrograms per kilogram

Table 2-57

**Summary of Chemicals Detected in Tree Swallow**  
**Operable Unit IV - Nyanza Chemical Dump Superfund Site - Reach 8 - 2004**  
**Middlesex County, Massachusetts**

Chemical	Frequency of Detection <sup>a</sup>	Range of Detected Concentrations (µg/kg)	Arithmetic Mean Concentration (µg/kg)	Median (µg/kg)	Standard Deviation (µg/kg)
<i><b>Tree Swallow</b></i>					
<i><b>Blood</b></i>					
<i><b>Adult</b></i>					
Total Mercury	14 / 14	3.34E+02 - 1.31E+03	6.91E+02	6.11E+02	2.77E+02
<i><b>Feather</b></i>					
<i><b>Adult</b></i>					
Total Mercury	14 / 14	1.08E+03 - 3.53E+03	2.22E+03	2.18E+03	5.84E+02
<i><b>Egg</b></i>					
Total Mercury	13 / 13	5.00E+01 - 4.64E+02	2.61E+02	2.73E+02	9.22E+01

<sup>a</sup> Number of sampling locations at which chemical was detected compared with total number of sampling locations.

µg/kg = Micrograms per kilogram

Table 2-58

**Summary of Chemicals Detected in Tree Swallow**  
**Operable Unit IV - Nyanza Chemical Dump Superfund Site - Charles River - 2004**  
**Middlesex County, Massachusetts**

Chemical	Frequency of Detection <sup>a</sup>	Range of Detected Concentrations (µg/kg)	Arithmetic Mean Concentration (µg/kg)	Median (µg/kg)	Standard Deviation (µg/kg)
<i><b>Tree Swallow</b></i>					
<i><b>Blood</b></i>					
<i><b>Adult</b></i>					
Total Mercury	6 / 6	3.05E+02 - 5.49E+02	4.05E+02	3.93E+02	8.56E+01
<i><b>Feather</b></i>					
<i><b>Adult</b></i>					
Total Mercury	6 / 6	1.81E+02 - 6.03E+03	2.27E+03	1.66E+03	2.03E+03
<i><b>Egg</b></i>					
Total Mercury	9 / 9	8.20E+01 - 1.51E+02	1.14E+02	1.15E+02	2.17E+01

<sup>a</sup> Number of sampling locations at which chemical was detected compared with total number of sampling locations.

µg/kg = Micrograms per kilogram

NC = Not calculated due to insufficient sample size.

Table 2-59

**Summary of Chemicals Detected in Eastern Kingbird Eggs - 2003**  
**Operable Unit IV - Nyanza Chemical Dump Superfund Site**  
**Middlesex County, Massachusetts**

<b>Chemical</b>	<b>Frequency of Detection<sup>a</sup></b>	<b>Range of Detected Concentrations (µg/kg)</b>	<b>Arithmetic Mean Concentration (µg/kg)</b>	<b>Median (µg/kg)</b>	<b>Standard Deviation (µg/kg)</b>
<b><i>Reach 7</i></b>					
Total Mercury	6 / 6	4.63E+01 - 1.54E+02	1.08E+02	1.14E+02	4.24E+01
<b><i>Reach 8</i></b>					
Total Mercury	8 / 8	6.17E+01 - 2.10E+02	1.38E+02	1.35E+02	4.89E+01
<b><i>Reach 9</i></b>					
Total Mercury	2 / 2	7.99E+01 - 1.48E+02	1.10E+02	1.10E+02	4.32E+01
<b><i>Reach 10</i></b>					
Total Mercury	6 / 6	4.09E+01 - 1.41E+02	9.11E+01	9.71E+01	3.54E+01
<b><i>Charles River</i></b>					
Total Mercury	5 / 5	1.56E+02 - 1.70E+02	1.61E+02	1.58E+02	5.66E+00

<sup>a</sup> Number of sampling locations at which chemical was detected compared with total number of sampling locations.

µg/kg = Micrograms per kilogram

Table 2-60

**Summary of Chemicals Detected in Red-Winged Blackbird  
Operable Unit IV - Nyanza Chemical Dump Superfund Site - Reach 8 - 2005  
Middlesex County, Massachusetts**

Chemical	Frequency of Detection <sup>a</sup>	Range of Detected Concentrations (µg/kg)	Arithmetic Mean Concentration (µg/kg)	Median (µg/kg)	Standard Deviation (µg/kg)
<i>Red-Winged Blackbird</i>					
<i>Blood</i>					
Total Mercury	10 / 10	1.15E+02 - 9.42E+03	4.06E+03	2.65E+03	3.16E+03

<sup>a</sup> Number of sampling locations at which chemical was detected compared with total number of sampling locations.

µg/kg = Micrograms per kilogram



Table 2-61

**Summary of Chemicals Detected in Marsh Birds**  
**Operable Unit IV - Nyanza Chemical Dump Superfund Site - Reach 7 - 2003**  
**Middlesex County, Massachusetts**

Chemical	Frequency of Detection <sup>a</sup>	Range of Detected Concentrations (µg/kg)	Arithmetic Mean Concentration (µg/kg)	Median (µg/kg)	Standard Deviation (µg/kg)
<b><i>Common Yellowthroat</i></b>					
<b><i>Blood</i></b>					
Total Mercury	1 / 1	2.03E+02 - 2.03E+02	2.03E+02	2.03E+02	NC
<b><i>Feather</i></b>					
Total Mercury	1 / 1	1.90E+03 - 1.90E+03	1.90E+03	1.90E+03	NC
<b><i>Northern Waterthrush</i></b>					
<b><i>Feather</i></b>					
Total Mercury	1 / 1	7.95E+02 - 7.95E+02	7.95E+02	7.95E+02	NC
<b><i>Song Sparrow</i></b>					
<b><i>Blood</i></b>					
Total Mercury	9 / 9	1.07E+01 - 1.92E+02	9.91E+01	8.20E+01	5.85E+01
<b><i>Feather</i></b>					
Total Mercury	9 / 9	2.63E+02 - 8.57E+03	2.24E+03	9.20E+02	2.87E+03
<b><i>Swamp Sparrow</i></b>					
<b><i>Blood</i></b>					
Total Mercury	3 / 3	7.08E+01 - 4.31E+02	2.43E+02	2.28E+02	1.81E+02
<b><i>Feather</i></b>					
Total Mercury	2 / 2	5.80E+02 - 4.88E+03	2.73E+03	2.73E+03	3.04E+03
<b><i>Yellow Warbler</i></b>					
<b><i>Blood</i></b>					
Total Mercury	2 / 2	3.83E+01 - 6.79E+01	5.31E+01	5.31E+01	2.09E+01
<b><i>Feather</i></b>					
Total Mercury	1 / 1	1.56E+03 - 1.56E+03	1.56E+03	1.56E+03	NC

<sup>a</sup> Number of sampling locations at which chemical was detected compared with total number of sampling locations.

µg/kg = Micrograms per kilogram

NC = Not calculated due to insufficient sample size.

Table 2-62

**Summary of Chemicals Detected in Marsh Birds**  
**Operable Unit IV - Nyanza Chemical Dump Superfund Site - Reach 8 - 2003**  
**Middlesex County, Massachusetts**

Chemical	Frequency of Detection <sup>a</sup>	Range of Detected Concentrations (µg/kg)	Arithmetic Mean Concentration (µg/kg)	Median (µg/kg)	Standard Deviation (µg/kg)
<b><i>Common Yellowthroat</i></b>					
<b><i>Blood</i></b>					
Total Mercury	4 / 4	4.36E+01 - 4.37E+02	1.82E+02	1.25E+02	1.75E+02
<b><i>Feather</i></b>					
Total Mercury	3 / 3	9.08E+02 - 6.47E+03	4.60E+03	6.42E+03	3.20E+03
<b><i>Song Sparrow</i></b>					
<b><i>Blood</i></b>					
Total Mercury	4 / 4	4.06E+02 - 1.34E+03	6.61E+02	4.48E+02	4.56E+02
<b><i>Feather</i></b>					
Total Mercury	5 / 5	1.27E+03 - 7.79E+03	3.54E+03	1.70E+03	3.01E+03
<b><i>Swamp Sparrow</i></b>					
<b><i>Blood</i></b>					
Total Mercury	5 / 5	7.04E+01 - 1.45E+03	5.41E+02	2.35E+02	5.65E+02
<b><i>Feather</i></b>					
Total Mercury	5 / 5	5.11E+02 - 5.89E+03	3.57E+03	4.56E+03	2.15E+03
<b><i>Yellow Warbler</i></b>					
<b><i>Blood</i></b>					
Total Mercury	2 / 2	4.66E+01 - 6.32E+01	5.49E+01	5.49E+01	1.17E+01
<b><i>Feather</i></b>					
Total Mercury	1 / 1	1.17E+04 - 1.17E+04	1.17E+04	1.17E+04	NC

<sup>a</sup> Number of sampling locations at which chemical was detected compared with total number of sampling locations.

µg/kg = Micrograms per kilogram

NC = Not calculated due to insufficient sample size.

Table 2-63

**Summary of Chemicals Detected in Marsh Birds**  
**Operable Unit IV - Nyanza Chemical Dump Superfund Site - Charles River - 2003**  
**Middlesex County, Massachusetts**

Chemical	Frequency of Detection <sup>a</sup>	Range of Detected Concentrations (µg/kg)	Arithmetic Mean Concentration (µg/kg)	Median (µg/kg)	Standard Deviation (µg/kg)
<b><i>Common Yellowthroat</i></b>					
<b><i>Blood</i></b>					
Total Mercury	2 / 2	5.66E+01 - 3.38E+02	1.97E+02	1.97E+02	1.99E+02
<b><i>Feather</i></b>					
Total Mercury	1 / 1	5.96E+03 - 5.96E+03	5.96E+03	5.96E+03	NC
<b><i>Northern Waterthrush</i></b>					
<b><i>Feather</i></b>					
Total Mercury	1 / 1	4.06E+03 - 4.06E+03	4.06E+03	4.06E+03	NC
<b><i>Song Sparrow</i></b>					
<b><i>Blood</i></b>					
Total Mercury	4 / 4	2.26E+02 - 4.13E+02	3.43E+02	3.67E+02	8.17E+01
<b><i>Feather</i></b>					
Total Mercury	4 / 4	2.02E+03 - 1.36E+04	6.07E+03	4.34E+03	5.20E+03
<b><i>Swamp Sparrow</i></b>					
<b><i>Blood</i></b>					
Total Mercury	6 / 6	1.57E+02 - 4.23E+02	3.06E+02	3.39E+02	1.09E+02
<b><i>Feather</i></b>					
Total Mercury	6 / 6	1.73E+03 - 1.14E+04	4.42E+03	3.48E+03	3.58E+03
<b><i>Yellow Warbler</i></b>					
<b><i>Blood</i></b>					
Total Mercury	4 / 4	4.84E+00 - 4.75E+01	1.88E+01	1.15E+01	1.99E+01
<b><i>Feather</i></b>					
Total Mercury	4 / 4	1.19E+03 - 8.87E+03	3.51E+03	1.99E+03	3.60E+03

<sup>a</sup> Number of sampling locations at which chemical was detected compared with total number of sampling locations.

µg/kg = Micrograms per kilogram

NC = Not calculated due to insufficient sample size.

Table 2-64

**Summary of Chemicals Detected in Marsh Birds**  
**Operable Unit IV - Nyanza Chemical Dump Superfund Site - Reach 7, Heard Pond - 2004**  
**Middlesex County, Massachusetts**

Chemical	Frequency of Detection <sup>a</sup>	Range of Detected Concentrations (µg/kg)	Arithmetic Mean Concentration (µg/kg)	Median (µg/kg)	Standard Deviation (µg/kg)
<i>Song Sparrow</i>					
<i>Blood</i>					
Total Mercury	5 / 5	7.70E+01 - 8.45E+02	2.67E+02	1.59E+02	3.26E+02
<i>Swamp Sparrow</i>					
<i>Blood</i>					
Total Mercury	7 / 7	2.06E+02 - 7.03E+02	3.50E+02	3.29E+02	1.79E+02

<sup>a</sup> Number of sampling locations at which chemical was detected compared with total number of sampling locations.

µg/kg = Micrograms per kilogram

Table 2-65

**Summary of Chemicals Detected in Marsh Birds**  
**Operable Unit IV - Nyanza Chemical Dump Superfund Site - Reach 8 - 2004**  
**Middlesex County, Massachusetts**

Chemical	Frequency of Detection <sup>a</sup>	Range of Detected Concentrations (µg/kg)	Arithmetic Mean Concentration (µg/kg)	Median (µg/kg)	Standard Deviation (µg/kg)
<i>Song Sparrow</i>					
<i>Blood</i>					
Total Mercury	8 / 8	1.28E+02 - 7.17E+02	3.84E+02	4.07E+02	2.15E+02
<i>Swamp Sparrow</i>					
<i>Blood</i>					
Total Mercury	8 / 8	2.20E+02 - 9.57E+02	4.54E+02	3.91E+02	2.58E+02

<sup>a</sup> Number of sampling locations at which chemical was detected compared with total number of sampling locations.

µg/kg = Micrograms per kilogram

Table 2-66

**Summary of Chemicals Detected in Marsh Birds**  
**Operable Unit IV - Nyanza Chemical Dump Superfund Site - Charles River - 2004**  
**Middlesex County, Massachusetts**

Chemical	Frequency of Detection <sup>a</sup>	Range of Detected Concentrations (µg/kg)	Arithmetic Mean Concentration (µg/kg)	Median (µg/kg)	Standard Deviation (µg/kg)
<i>Song Sparrow</i>					
<i>Blood</i>					
Total Mercury	10 / 10	5.90E+01 - 2.09E+02	1.17E+02	8.75E+01	6.02E+01

<sup>a</sup> Number of sampling locations at which chemical was detected compared with total number of sampling locations.

µg/kg = Micrograms per kilogram

Table 2-67

**Mink Data**  
**Operable Unit IV - Nyanza Chemical Dump Superfund Site**  
**Middlesex County, Massachusetts**

Sample ID	Concentration (µg/kg) Total Mercury
<b>Reach 3</b>	
<i>Blood</i>	
S3-0-MBMI001-0-031018	1.77E+02
<i>Fur</i>	
S3-0-MFMI0001-0-031018	5.86E+04
<b>Reach 4</b>	
<i>Blood</i>	
S4-0-MBMI004-0-031025	4.55E+01
<i>Fur</i>	
S4-0-MFMI0004-0-031025	1.23E+03
<b>Reach 5</b>	
<i>Fur</i>	
S5-0-MFMI0002-0-031112	6.22E+03
S5-0-MFMI0003-0-031011	1.83E+04
<i>Liver</i>	
S5-0-MLMI001-0-031112	1.21E+03
S5-0-MLMI002-0-031011	1.13E+03
<i>Brain</i>	
S5-0-MRMI001-0-031112	2.15E+02
S5-0-MRMI002-0-031011	1.18E+02
<b>Reach 7</b>	
<i>Blood</i>	
S7-2-MBMI001-0-031018	9.33E+01
<i>Fur</i>	
S7-2-MFMI0001-0-031018	1.67E+03

µg/kg = Micrograms per kilogram.

**Table 2-68**

**Ecological Assessment and Measurement Endpoints  
Operable Unit IV – Nyanza Chemical Dump Superfund Site  
Middlesex County, Massachusetts**

Assessment Endpoint		Measurement Endpoint
Receptor	Ecological Attribute	
Benthic Invertebrate Community	Community structure, survival, and reproduction	In situ mussel bioaccumulation, growth and toxicity testing using the freshwater mussel.
		Comparison of sediment chemistry with sediment quality values (SQVs) and values from other literature sources.
		Mercury bioaccumulation study using <i>Hexagenia</i> .
		Comparison of mercury concentrations in crayfish tissue with reference area concentrations and with residue effect levels from the literature.
Fish Population	Survival and reproduction	Comparison of surface water chemistry with Federal Ambient Water Quality Criteria (AWQC) and values from other literature sources.
		Comparison of mercury concentrations in fish tissue with reference area concentrations and with residue effect levels from the literature.
Herbivorous Birds (as represented by wood duck)	Survival, reproduction, and neurological effects	Comparison of site-specific egg, blood, and feather concentrations in waterfowl with reference area concentrations and residue effect levels from the literature.
Insectivorous Birds (as represented by tree swallows, eastern kingbirds, and marsh birds)	Reproduction, survival, and neurological effects	Comparison of site-specific egg, blood, and feather concentrations in tree swallows, eastern kingbirds, and marsh birds with reference area concentrations, residue effect levels from literature, and effect levels developed by USFWS as part of their tree swallow egg injection study.
		Quantitative comparison of daily intakes based on dietary intake of mercury by tree swallows from site-specific invertebrates with literature-based values.
Piscivorous Birds (as represented by belted kingfisher, great blue heron, and hooded merganser)	Survival, reproduction, and neurological effects	Quantitative comparison of daily intakes based on dietary intake of mercury using site-specific fish tissue concentrations and site-specific mercury levels in other aquatic-related food items (e.g., crayfish) with literature-based values.
		Comparison of site-specific egg, blood, and feather concentrations in waterfowl with reference area concentrations and residue effect levels from the literature.
Piscivorous Mammals (as represented by the mink)	Survival, reproduction, and neurological effects	Comparison of site-specific blood and fur concentrations in mink and otter with reference area concentrations, and residue effect levels from the literature.
		Quantitative comparison of daily intakes based on dietary intake of mercury in fish and crayfish with literature-based values.



Table 2-69

**Attributes for Judging Measurement Endpoints  
Operable Unit IV – Nyanza Chemical Dump Superfund Site  
Middlesex County, Massachusetts**

<p><b>1. Strength of Association Between Assessment and Measurement Endpoints</b></p> <p><b>Biological linkage between measurement endpoint and assessment endpoint</b>—This attribute refers to the extent to which the measurement endpoint is representative of, correlated with, or applicable to the assessment endpoint. If there is no biological linkage between a measurement endpoint (e.g., a study that may have been performed for some other purpose) and the assessment endpoint of interest, then that study should not be used to evaluate the stated assessment endpoint. Biological linkage pertains to similarity of effect, target organ, mechanism of action, and level of ecological organization.</p> <p><b>Correlation of stressor to response</b>—This attribute relates to the degree to which a correlation is observed between levels of exposure to a stressor and levels of response and the strength of that correlation.</p> <p><b>Utility of measure</b>—This attribute relates to the ability to judge results of the study against well-accepted standards, criteria, or objective measures. As such, the attribute describes the applicability, certainty, and scientific basis of the measure, as well as the sensitivity of a benchmark in detecting environmental harm. Examples of objective standards or measures for judgment might include ambient water quality criteria, sediment quality criteria, biological indices, and toxicity or exposure thresholds recognized by the scientific or regulatory community as measures of environmental harm.</p>
<p><b>2. Data and Overall Study Quality</b></p> <p><b>Quality of data and overall study</b>—This attribute reflects the degree to which data quality objectives and other recognized characteristics of high quality studies are met. The key factor affecting the quality of the data is the appropriateness of data collection and analysis practices. The key factor of the quality of the study is the appropriateness and implementation of the experimental design and the minimization of confounding factors. If data are judged to be of poor or no quality, the study would be rejected for use in the ERA.</p>

Table 2-69, Continued

Attributes for Judging Measurement Endpoints  
Operable Unit IV – Nyanza Chemical Dump Superfund Site  
Middlesex County, Massachusetts

**3. Design and Execution**

**Site-specificity**—This attribute relates to the extent to which media, species, environmental conditions, and habitat types that are used in the study design reflect the site of interest.

**Sensitivity of the measurement endpoint to detecting changes**—This attribute relates to the ability to detect a response in the measurement endpoint, expressed as a percentage of the total possible variability that the endpoint is able to detect. Additionally, this attribute reflects the ability of the measurement endpoint to discriminate between responses to a stressor and those resulting from natural or design variability and uncertainty.

**Spatial representativeness**—This attribute relates to the degree of compatibility or overlap between the study area, locations of measurements or samples, locations of stressors, and locations of ecological receptors and their points of potential exposure.

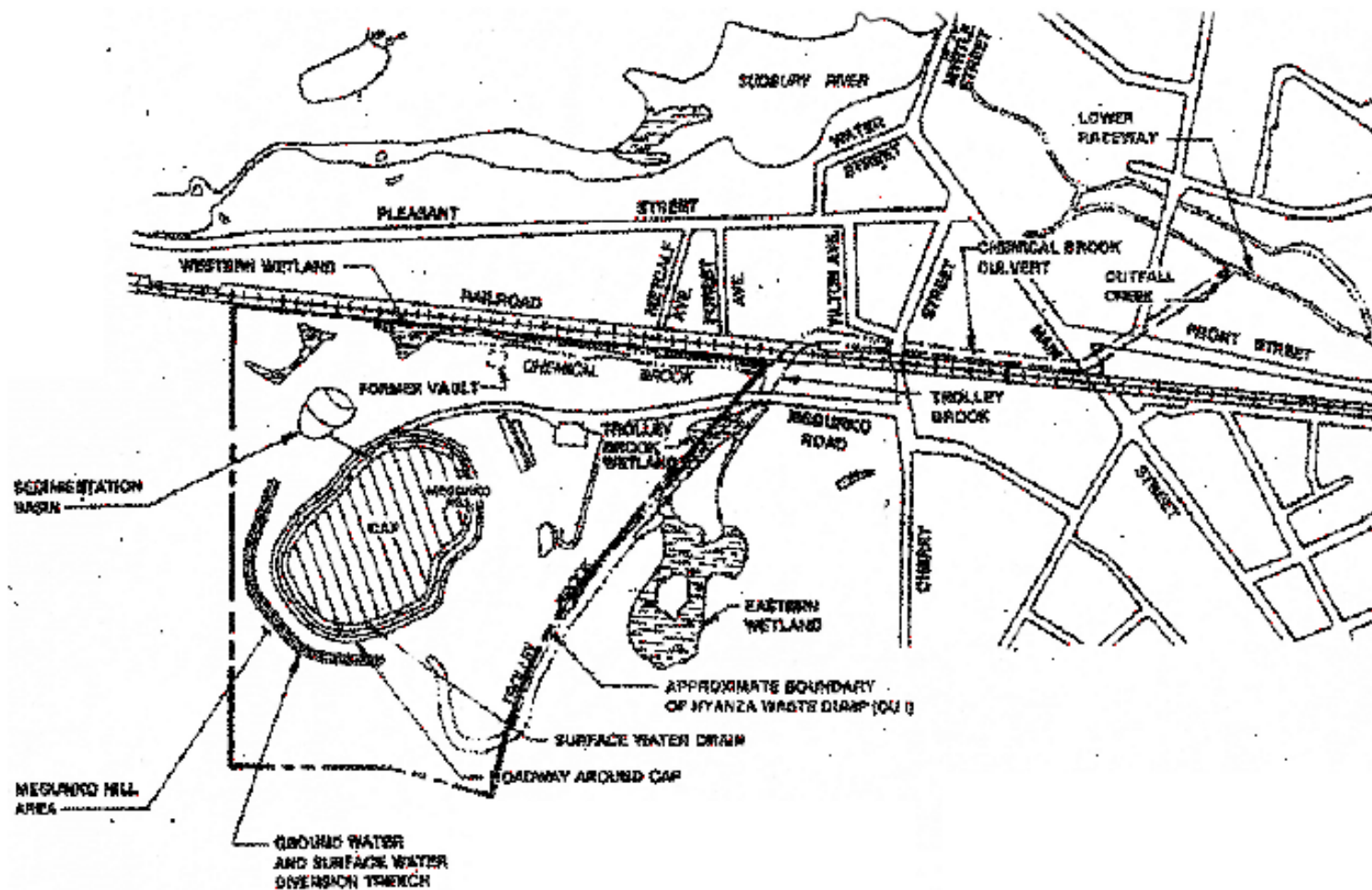
**Temporal representativeness**—This attribute relates to the temporal compatibility or overlap between the measurement endpoint (when data were collected or the period for which data are representative) and the period during which effects of concern would be likely to be detected. Also linked to this attribute is the number of measurement or sampling events over time and the expected variability over time.

**Quantitativeness**—This attribute relates to the degree to which numbers can be used to describe the magnitude of response of the measurement endpoint to the stressor. Some measurement endpoints may yield qualitative or hierarchical results, while others may be more quantitative.

**Use of a standard method**—The extent to which the study follows specific protocols recommended by a recognized scientific authority for conducting the method correctly. Examples of standard methods are study designs or chemical measures published in the Federal Register or the Code of Federal Regulations, developed by ASTM, or repeatedly published in the peer-reviewed scientific literature, including impact assessments, field surveys, toxicity tests, benchmark approaches, toxicity quotients, and tissue residue analyses. This attribute also reflects the suitability and applicability of the method to the endpoint and the site, as well as the need for modification of the method.

Source: Menzie et al., 1996.

## SECTION 2 FIGURES



Legend:



Wetlands



Brooks/Streams

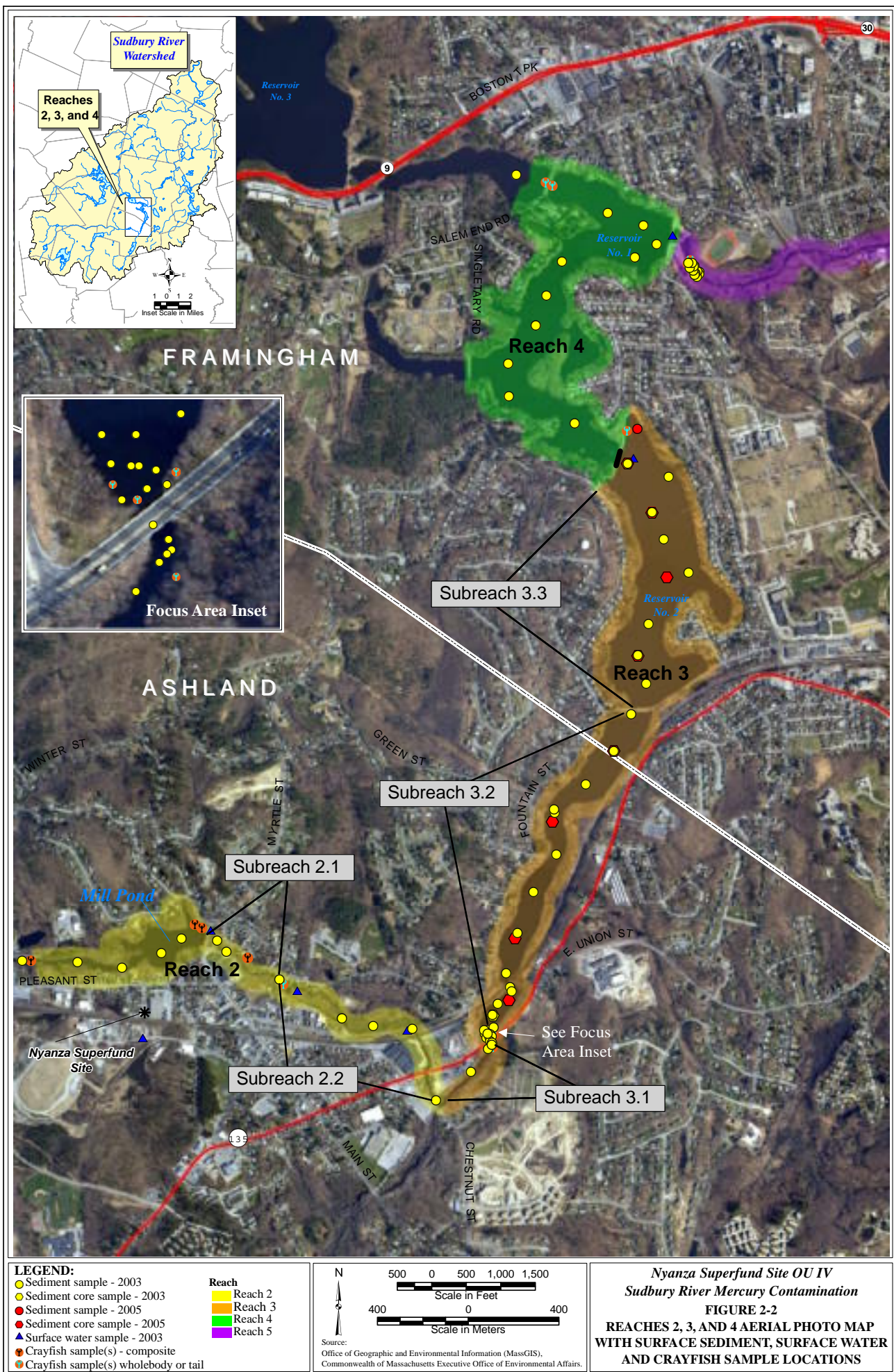


Scale: 1"  $\approx$  700'

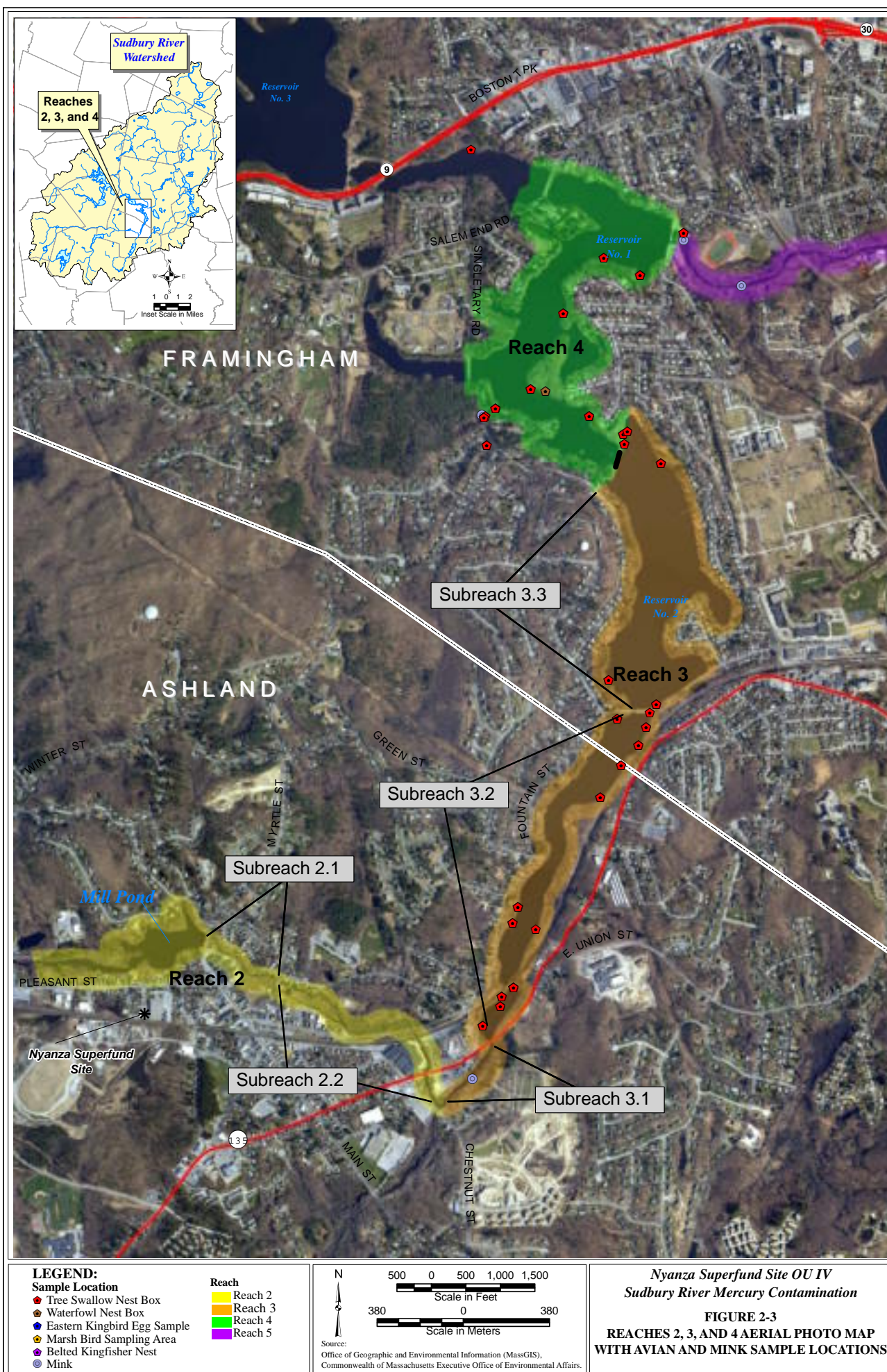
*Nyanza Superfund Site OU IV  
Sudbury River Mercury Contamination*

**Figure 2-1  
Nyanza Facility Map**

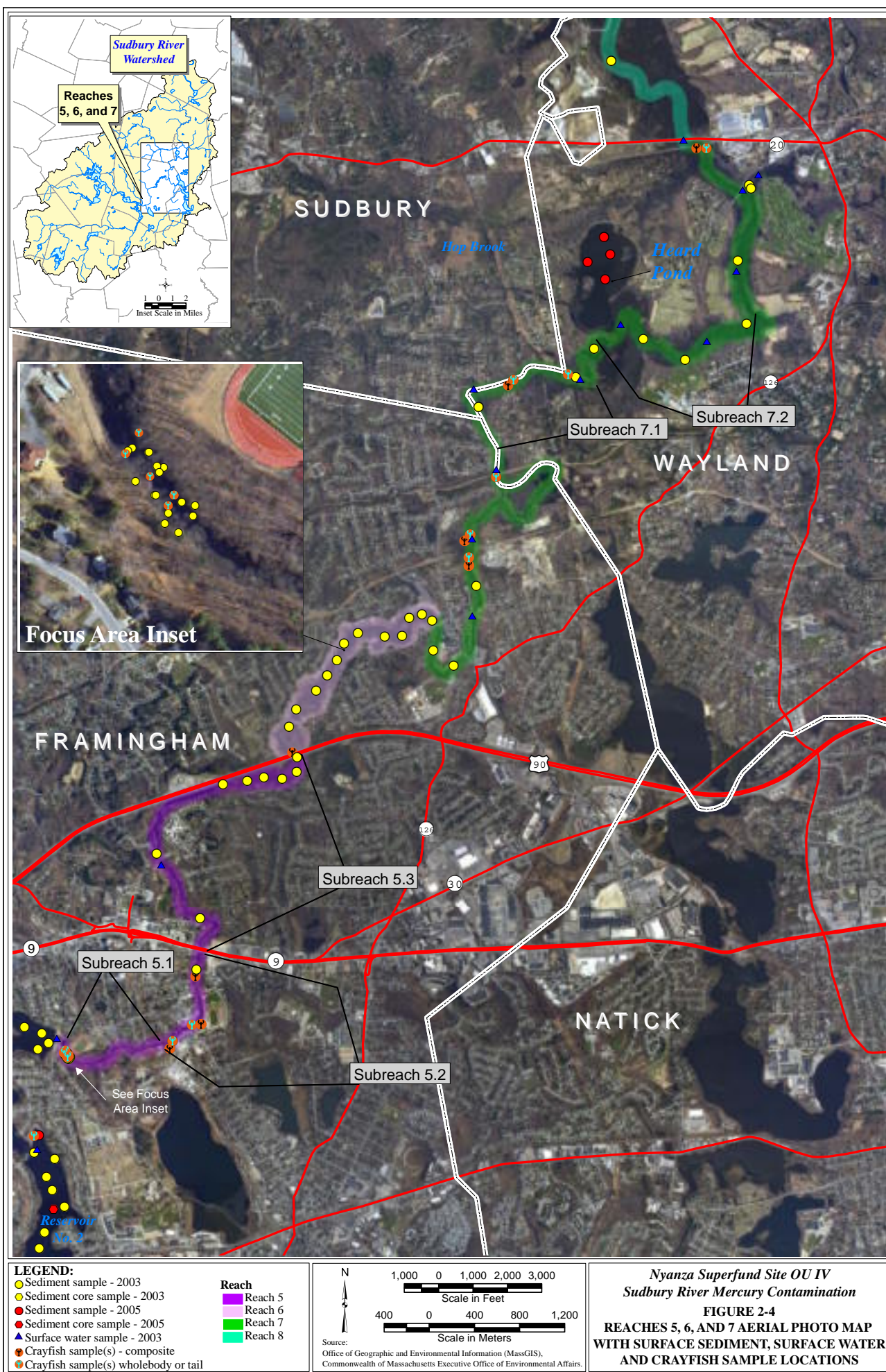




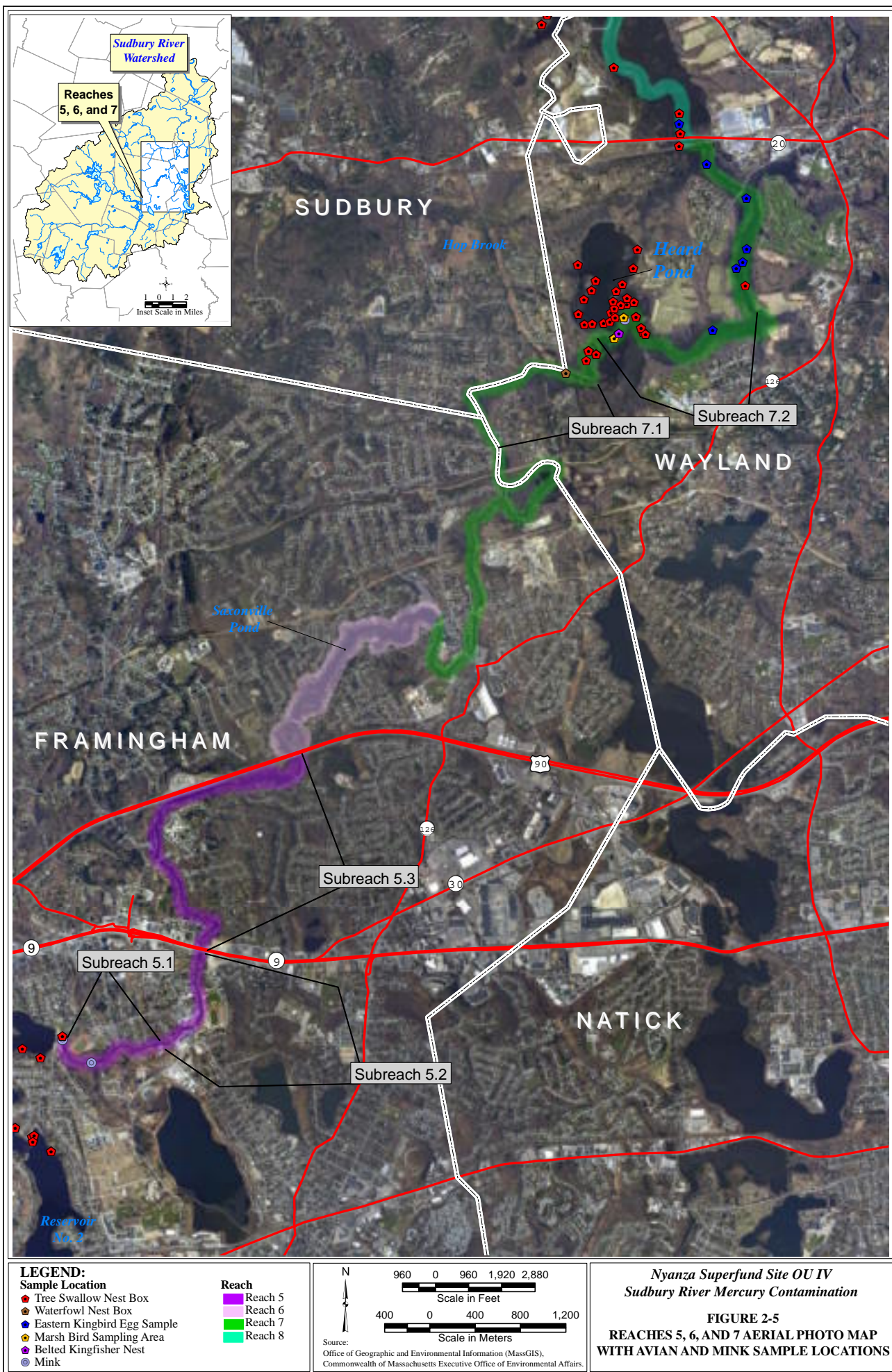




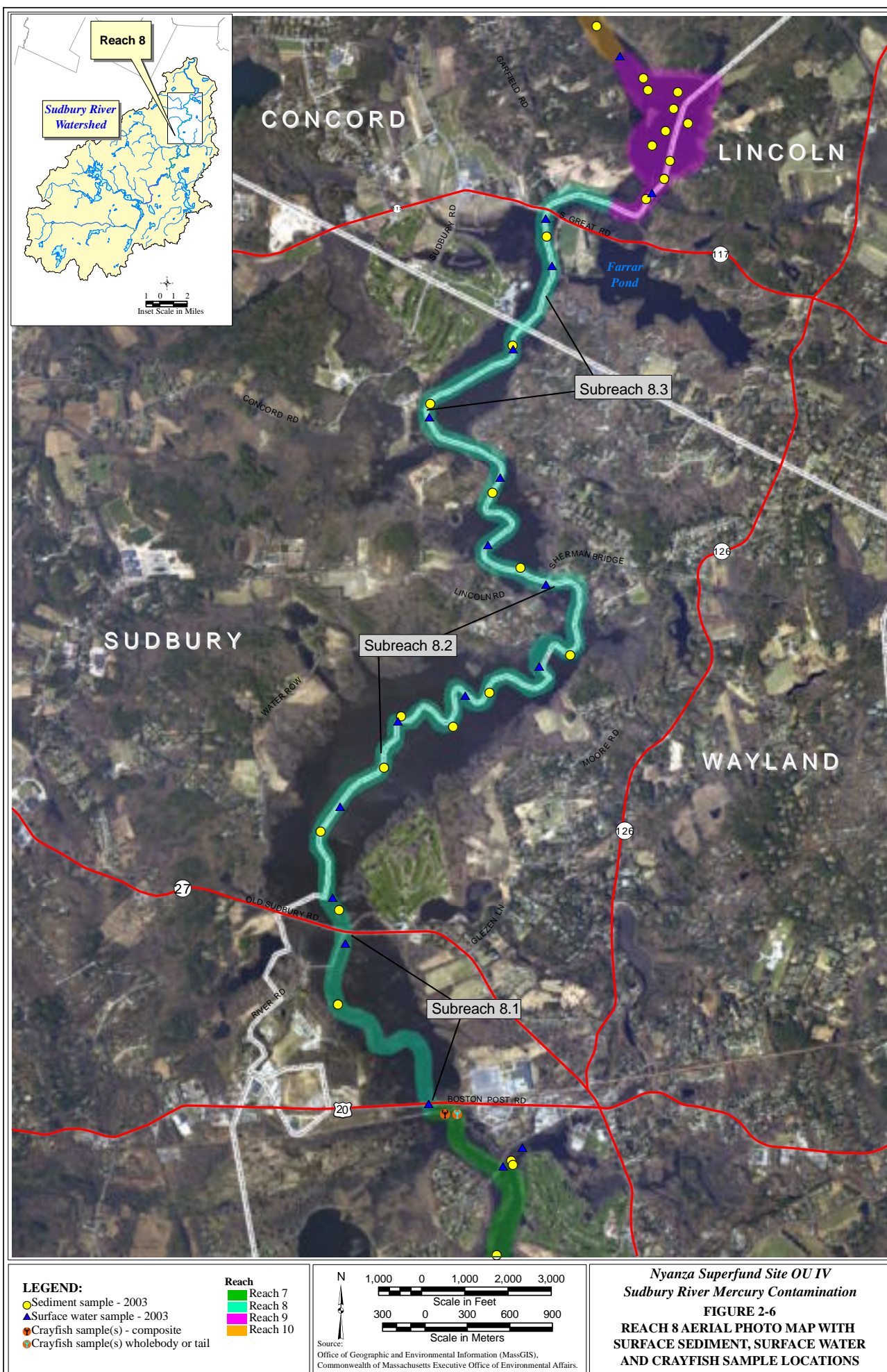




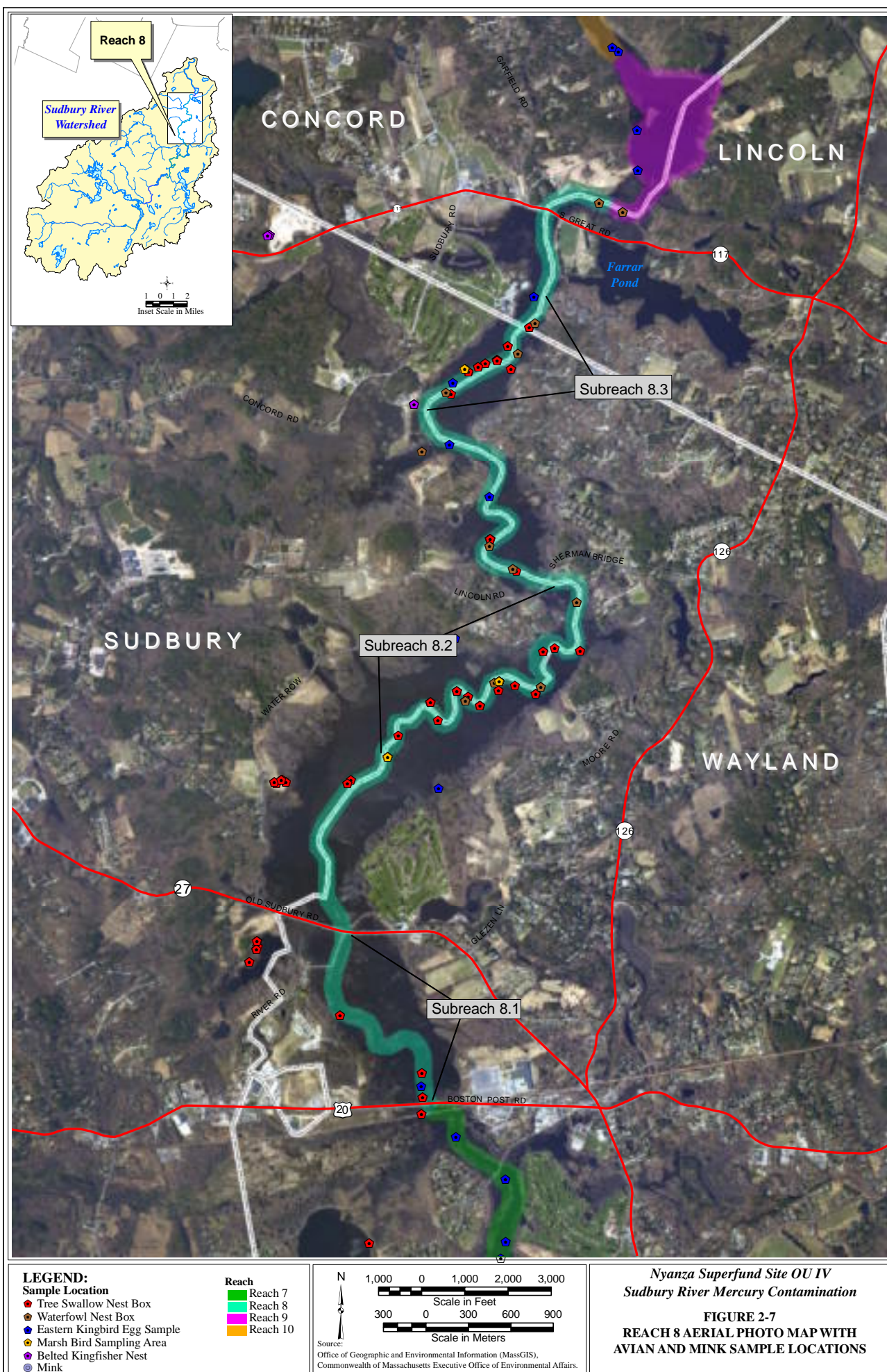




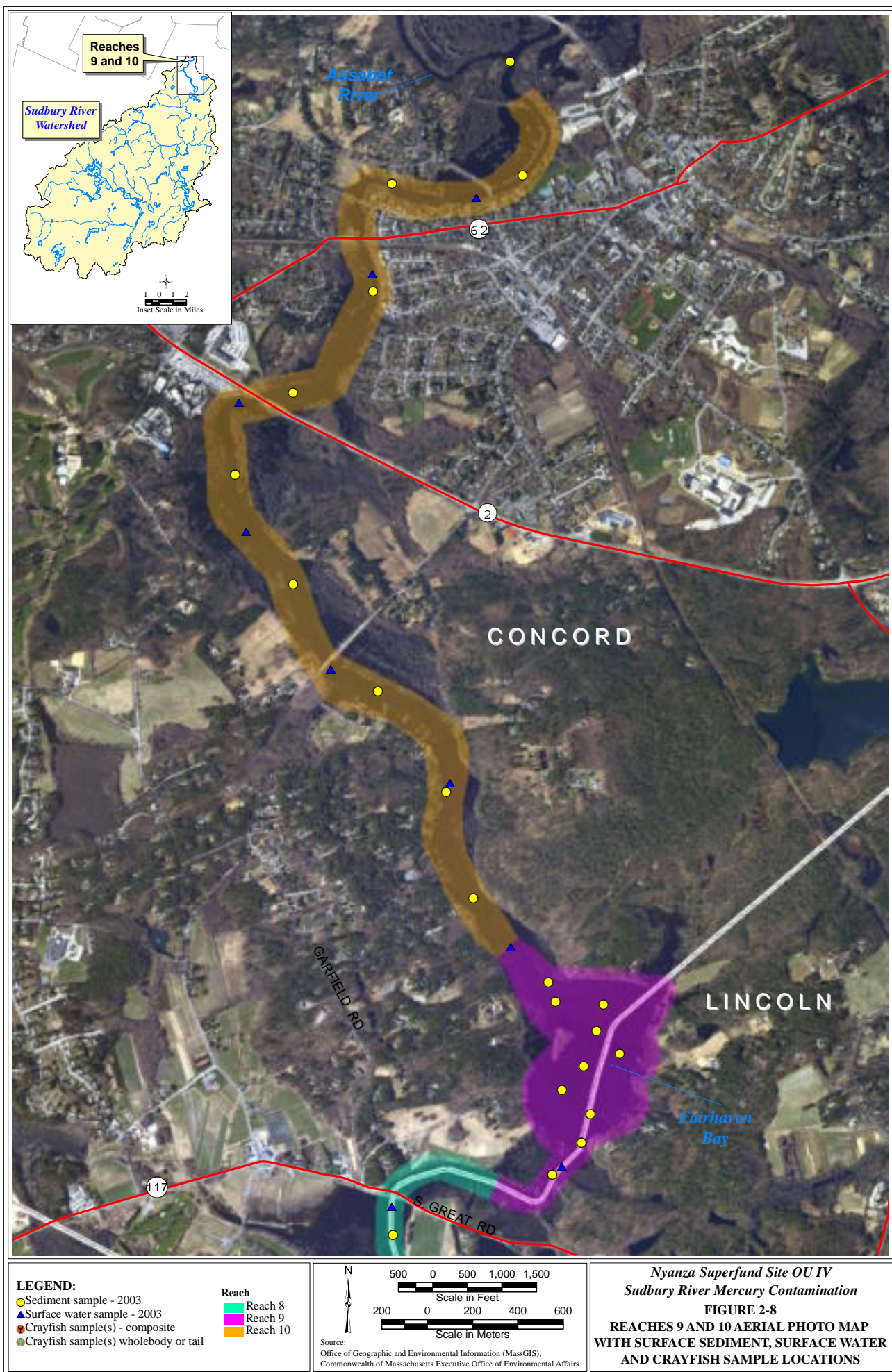




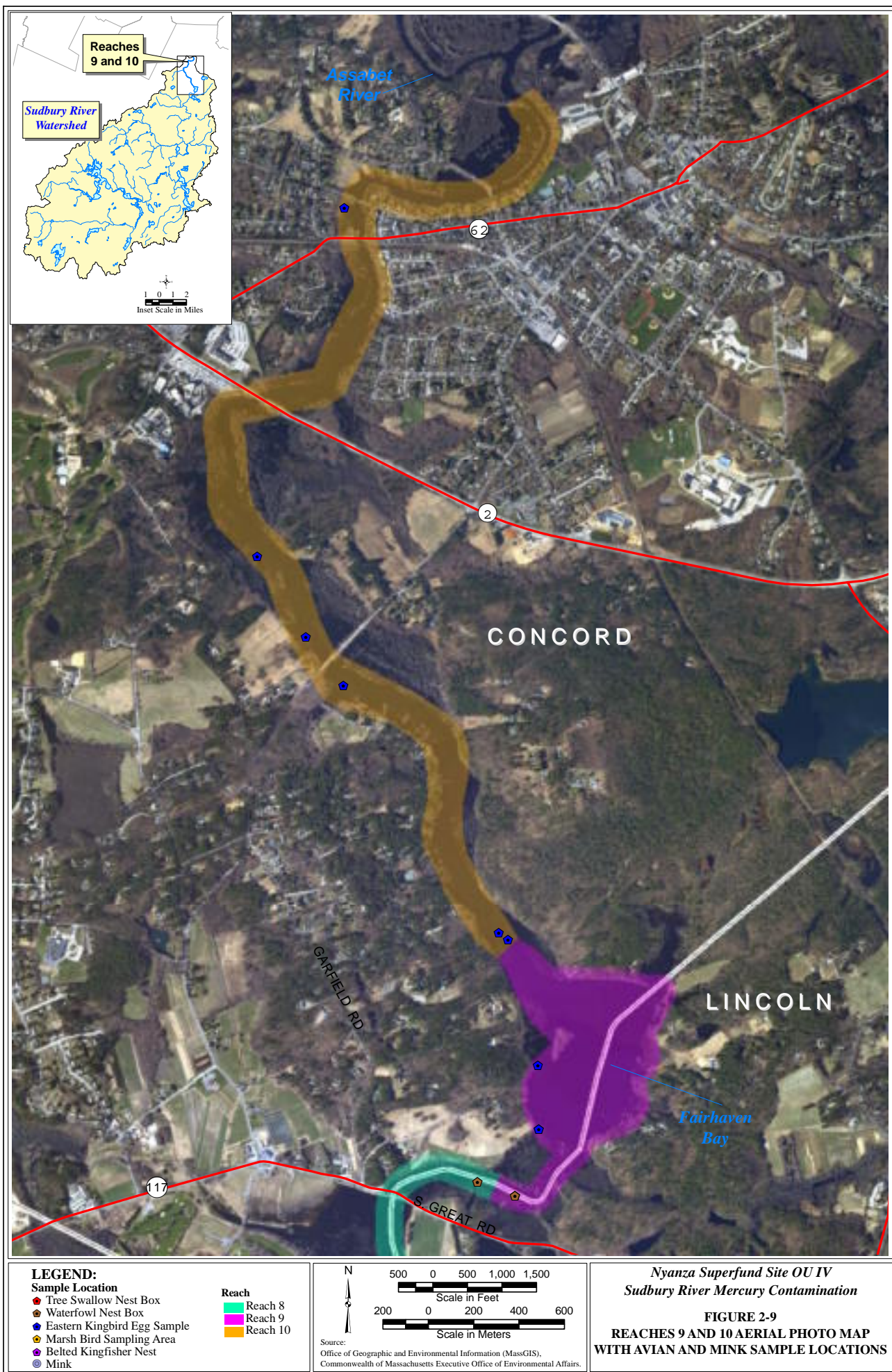




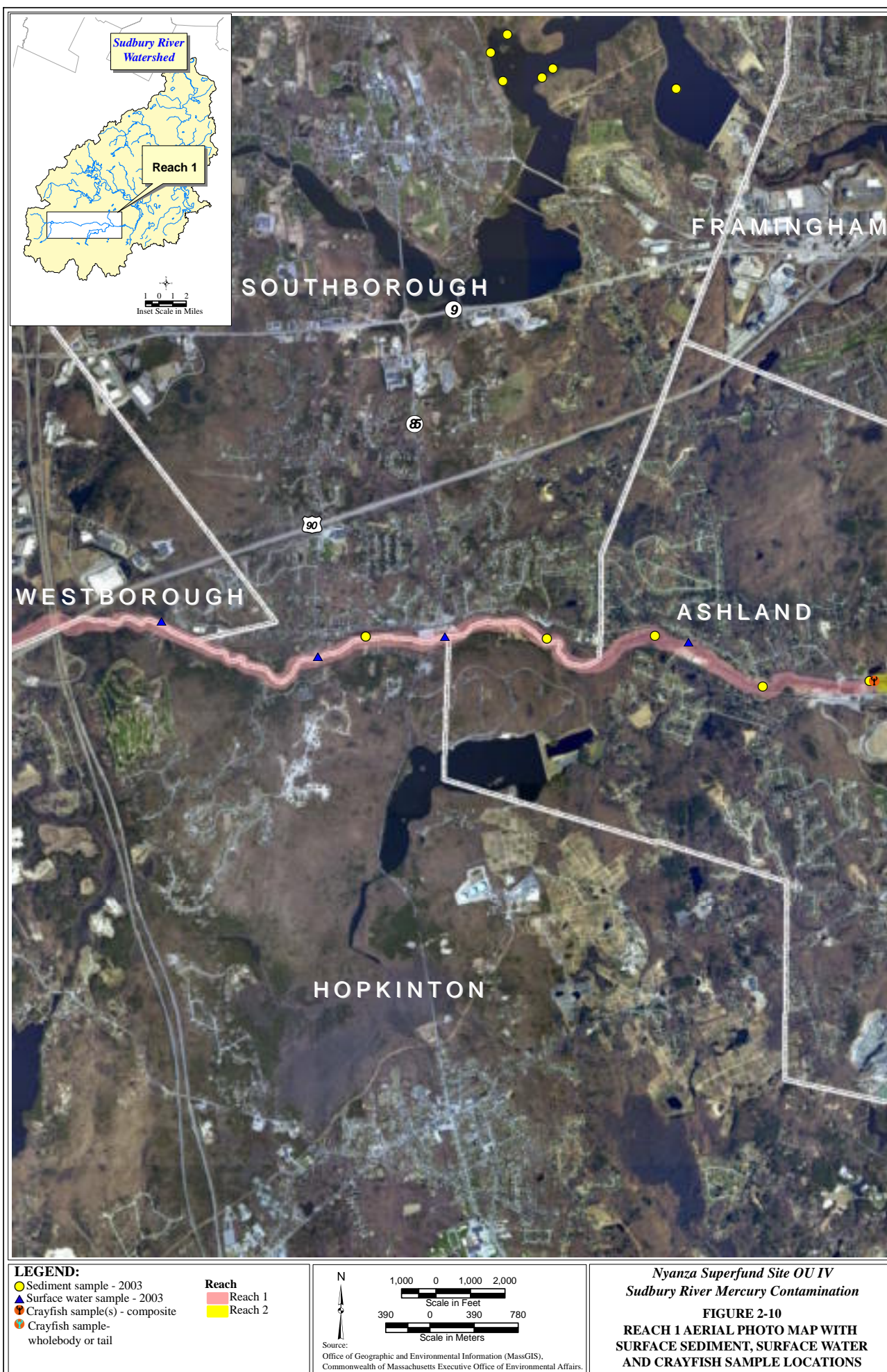




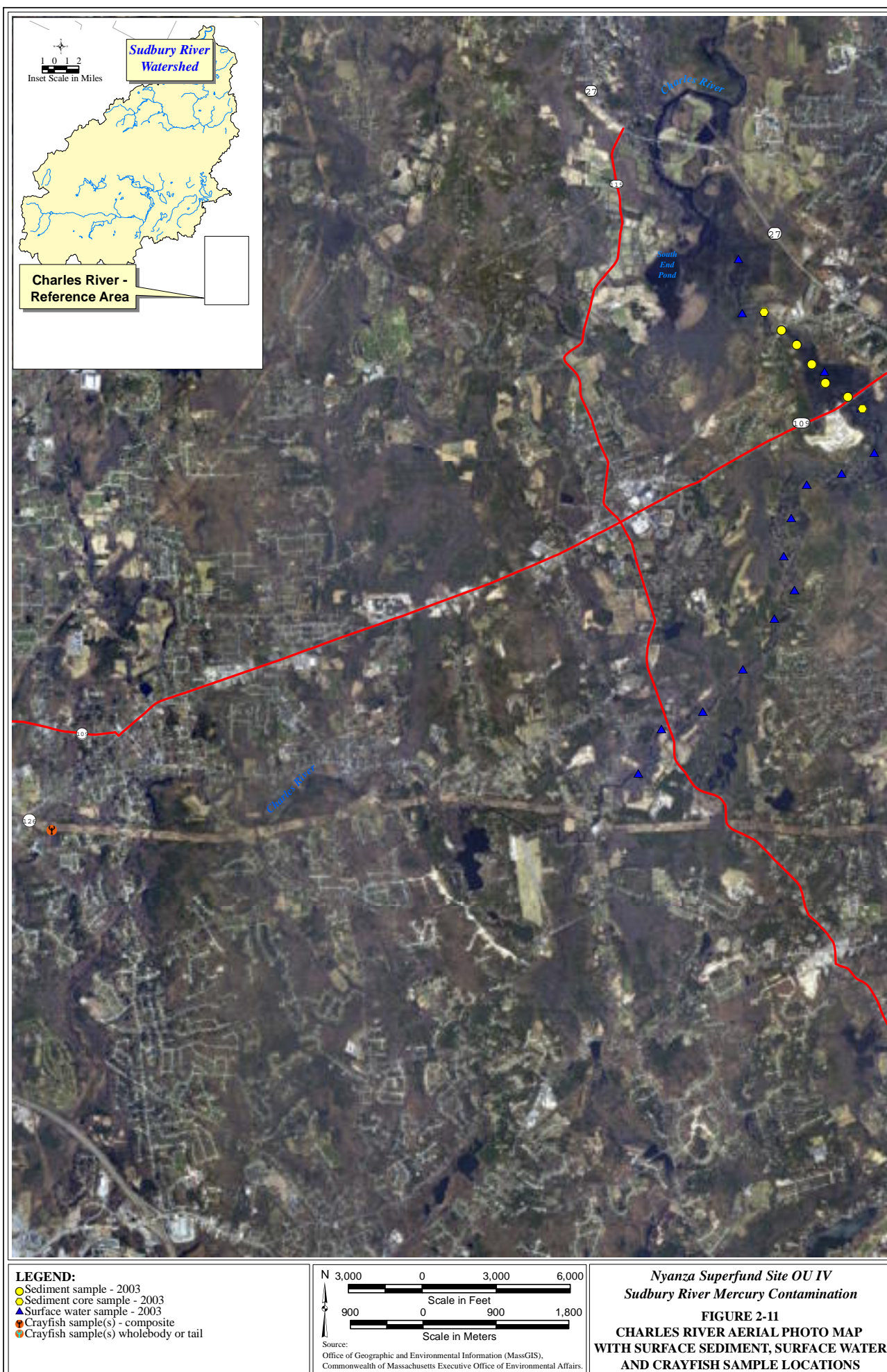




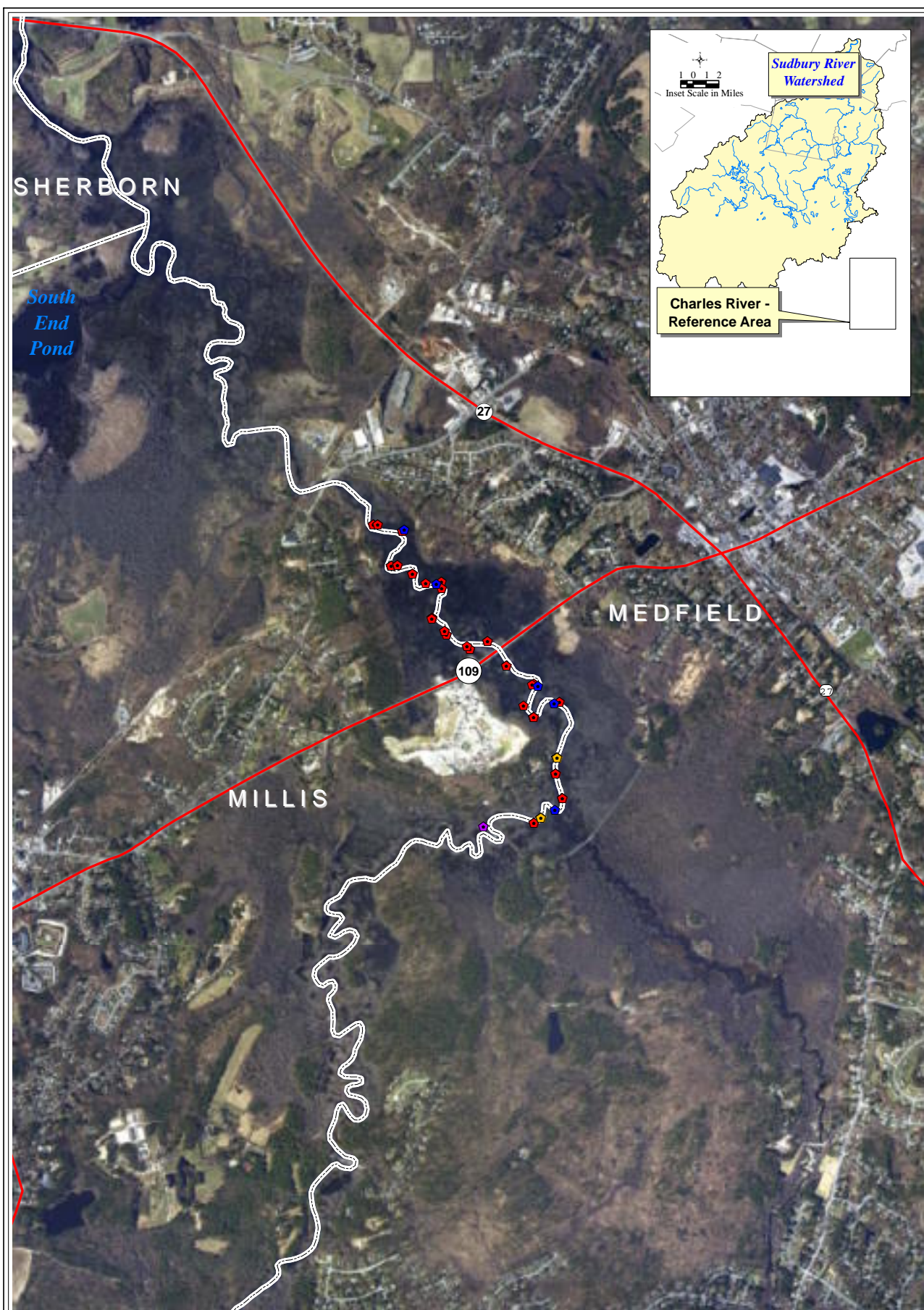








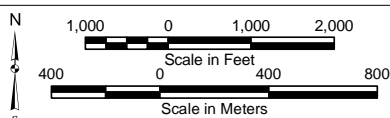




**LEGEND:**

**Sample Location**

- ◆ Tree Swallow Nest Box
- ◆ Waterfowl Nest Box
- ◆ Eastern Kingbird Egg Sample
- Marsh Bird Sampling Area
- ◆ Belted Kingfisher Nest

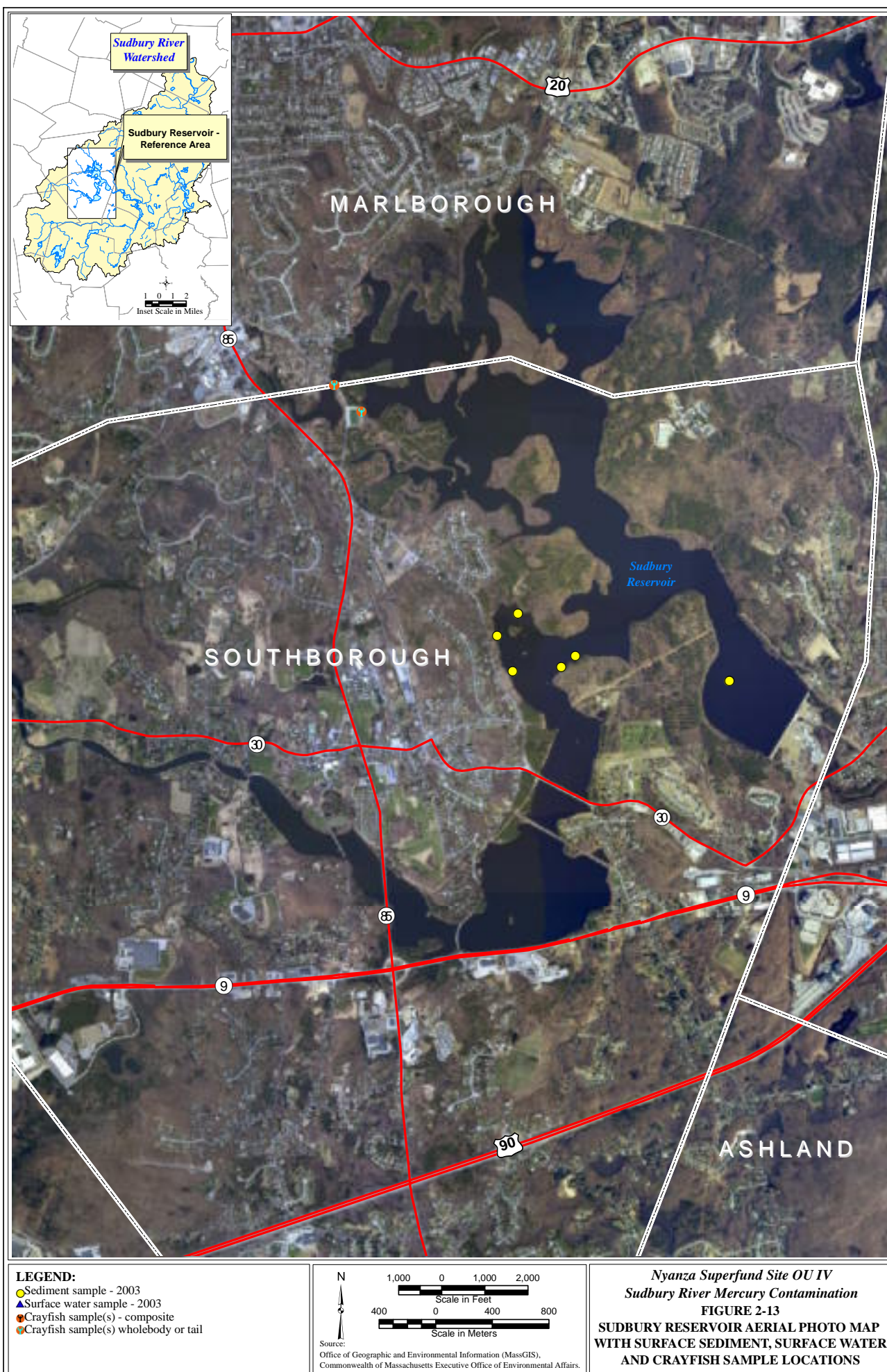


Source:  
Office of Geographic and Environmental Information (MassGIS),  
Commonwealth of Massachusetts Executive Office of Environmental Affairs.

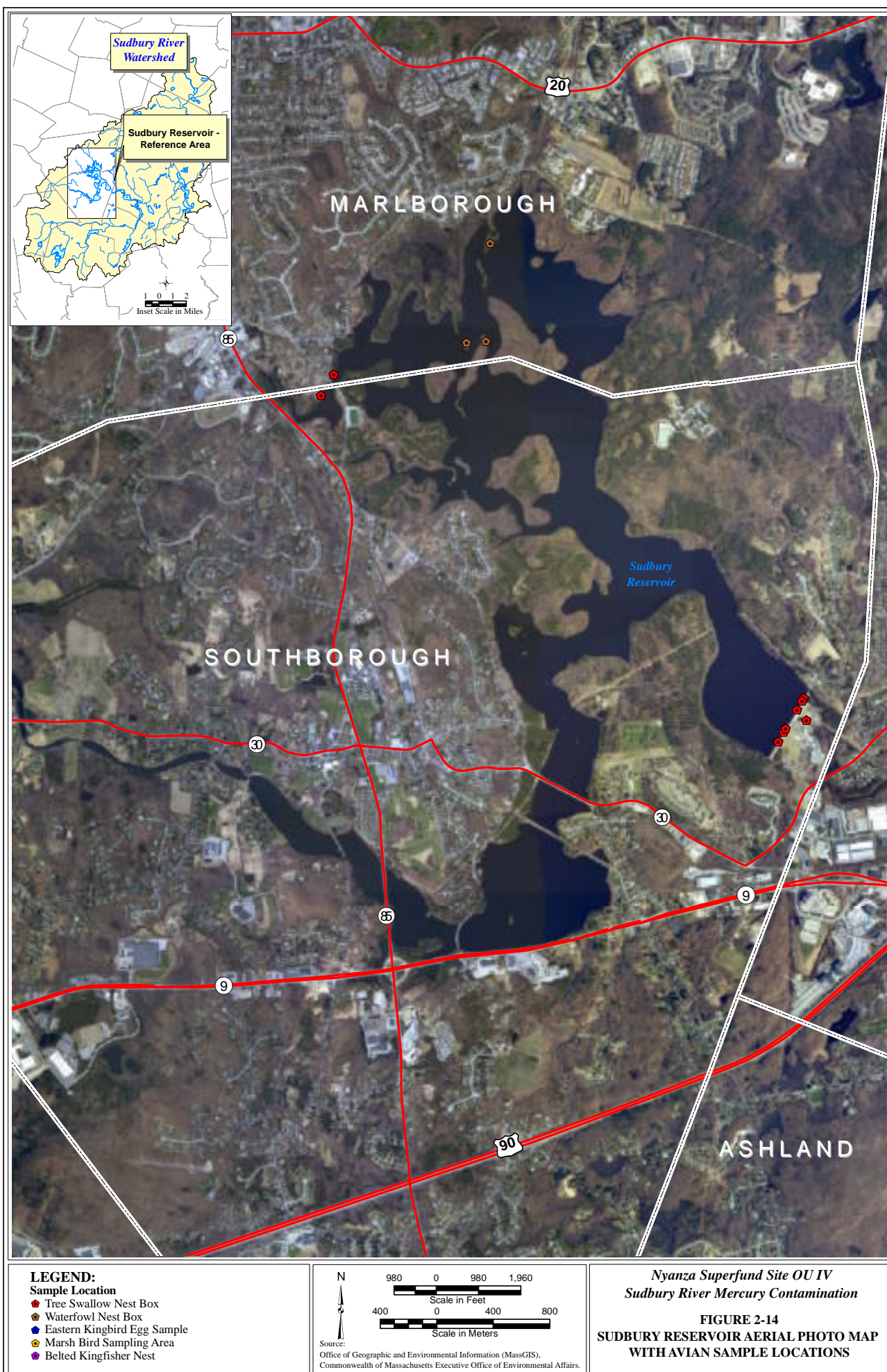
*Nyanza Superfund Site OU IV  
Sudbury River Mercury Contamination*

**FIGURE 2-12  
CHARLES RIVER AERIAL PHOTO MAP  
WITH AVIAN SAMPLE LOCATIONS**





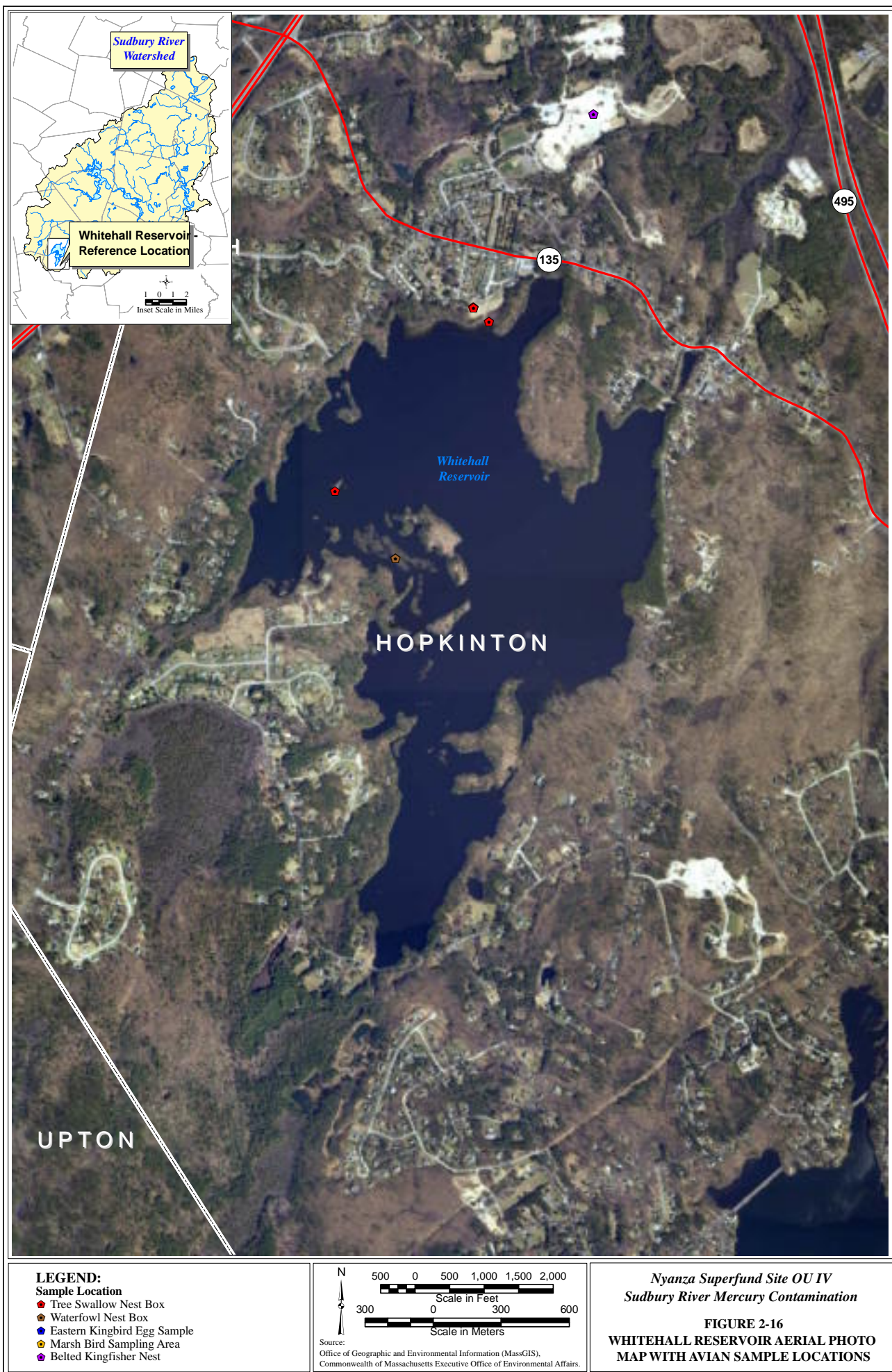


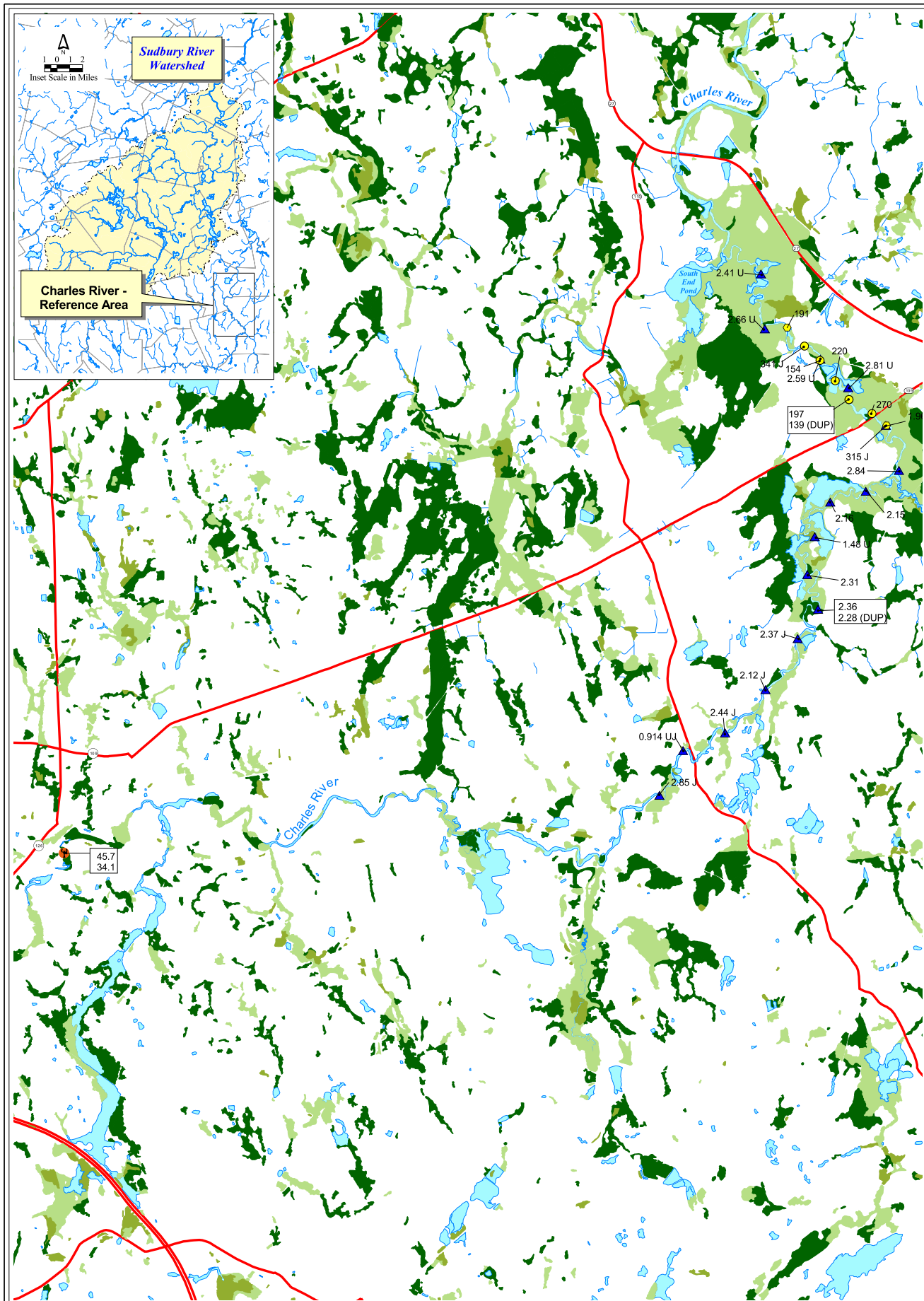












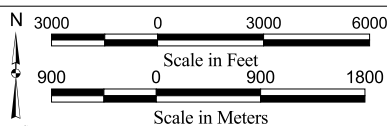
# **LEGEND:**

- Sediment sample - 2003
- Sediment core sample - 2003
- Surface water sample - 2003
- Crayfish sample(s) - composite
- Crayfish sample - wholebody or tail

## **Wetland Habitat**

- Open Water
- Deep Marsh
- Shallow Marsh
- Shrub Swamp
- Deciduous Wood Swamp
- Mixed Wood Swamp

Sediment and crayfish results are in units of ug/kg Hg.  
Surface water results are in units of ng/L Hg.

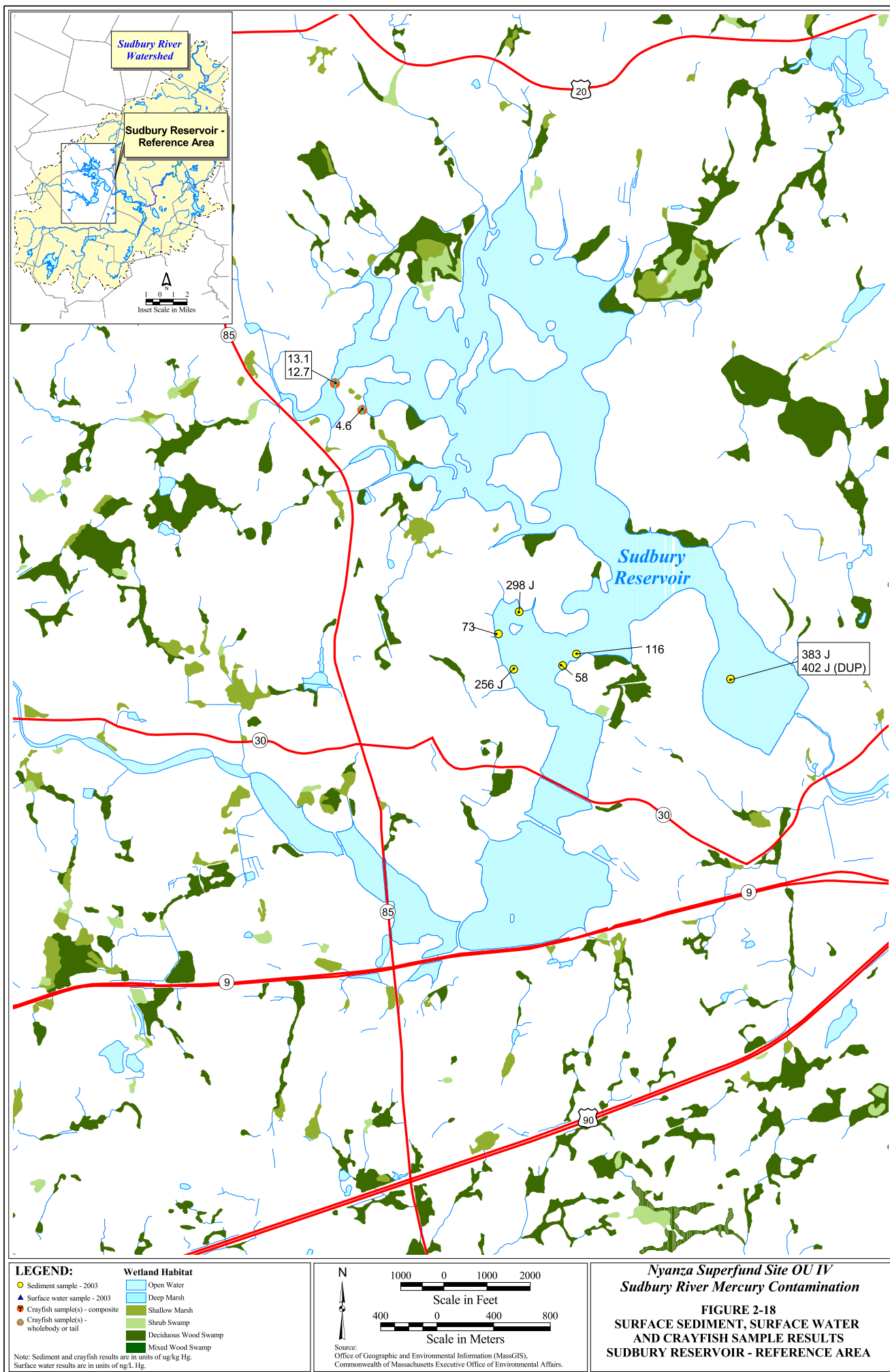


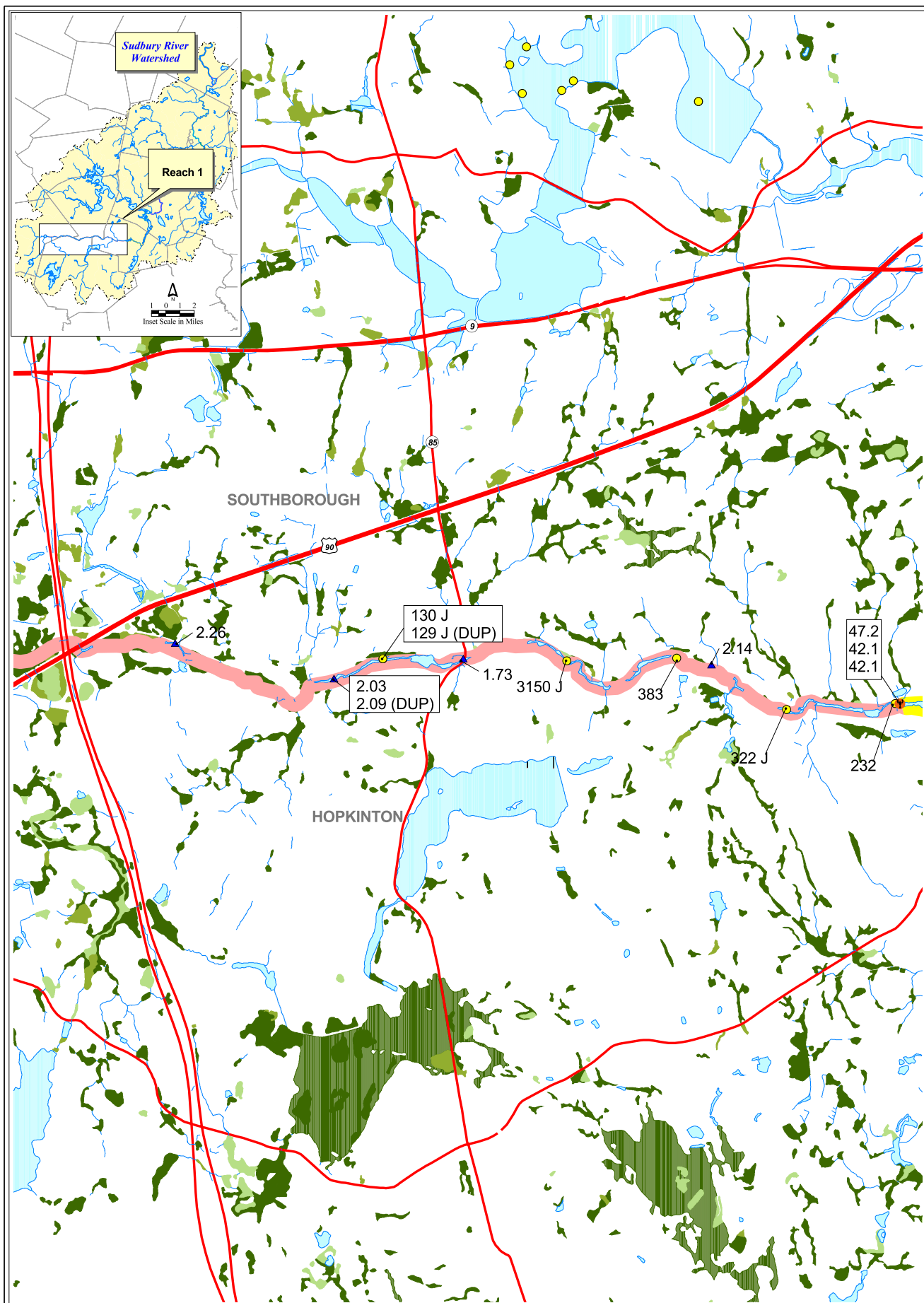
Source:  
Office of Geographic and Environmental Information (MassGIS),  
Commonwealth of Massachusetts Executive Office of Environmental Affairs.

**Nyanza Superfund Site OU IV**  
**Sudbury River Mercury Contamination**

**FIGURE 2-17**  
**SURFACE SEDIMENT, SURFACE WATER**  
**AND CRAYFISH SAMPLE RESULTS**  
**CHARLES RIVER - REFERENCE AREA**







# LEGEND:

- Sediment sample - 2003
- ▲ Surface water sample - 2003
- Crayfish sample(s) - composite
- Crayfish sample - wholebody or tail

## Wetland Habitat

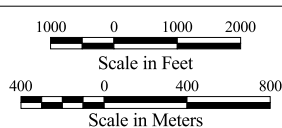
- Open Water
- Deep Marsh
- Shallow Marsh
- Shrub Swamp
- Deciduous Wood Swamp
- Mixed Wood Swamp

## Reach

- Reach 1
- Reach 2

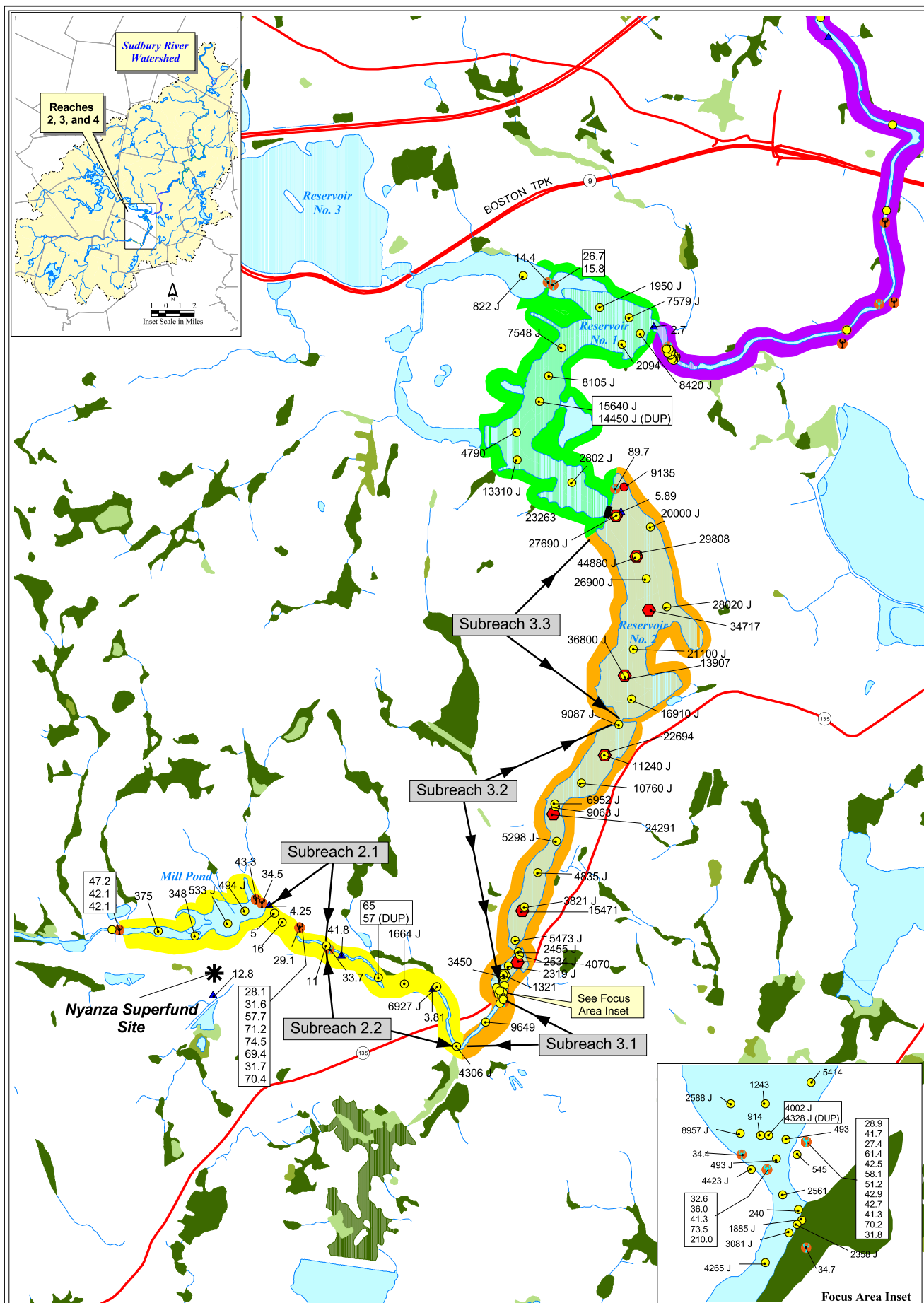
Note: Sediment and crayfish results are in units of ug/kg Hg.  
Surface water results are in units of ng/L Hg.

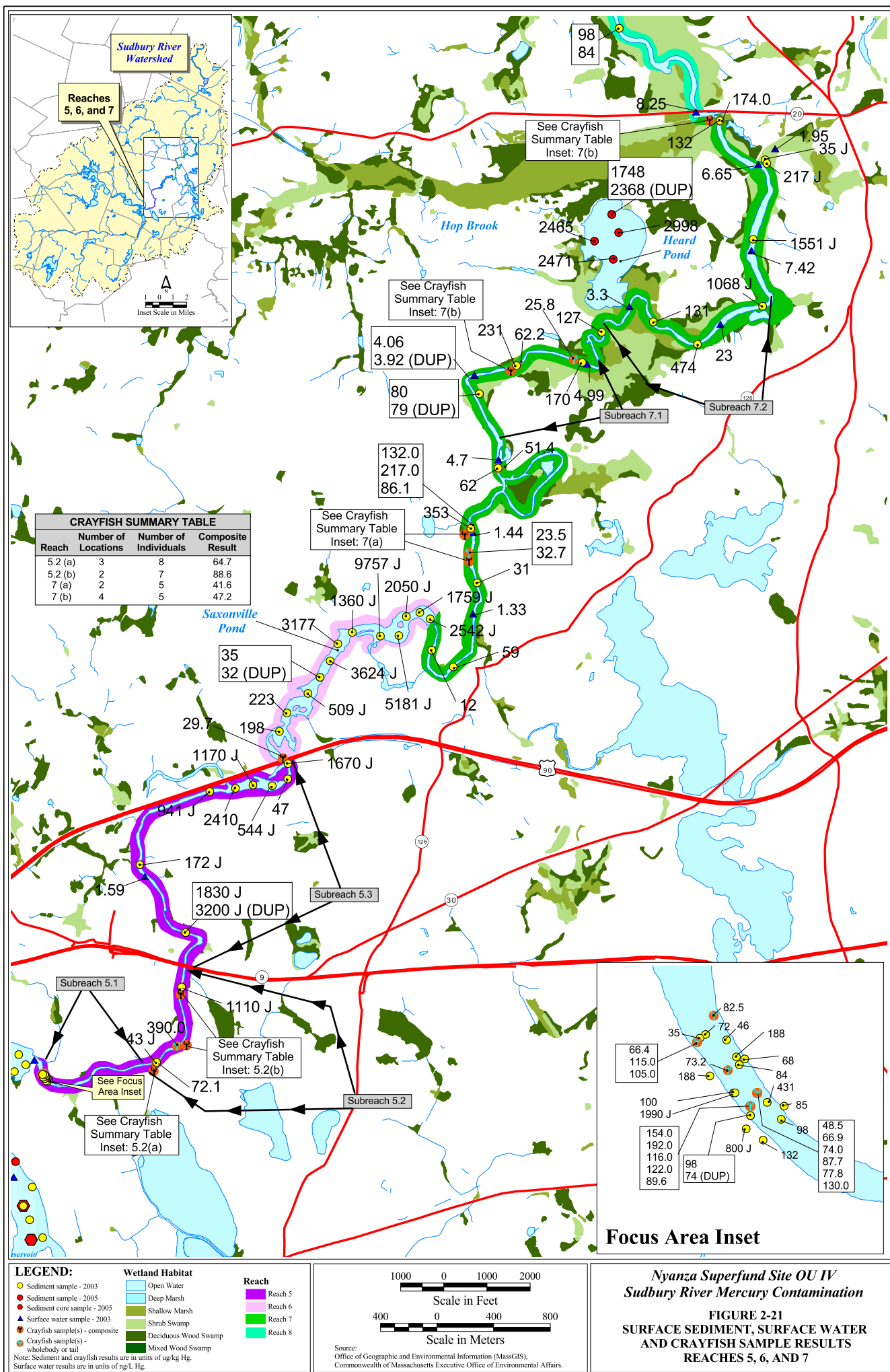
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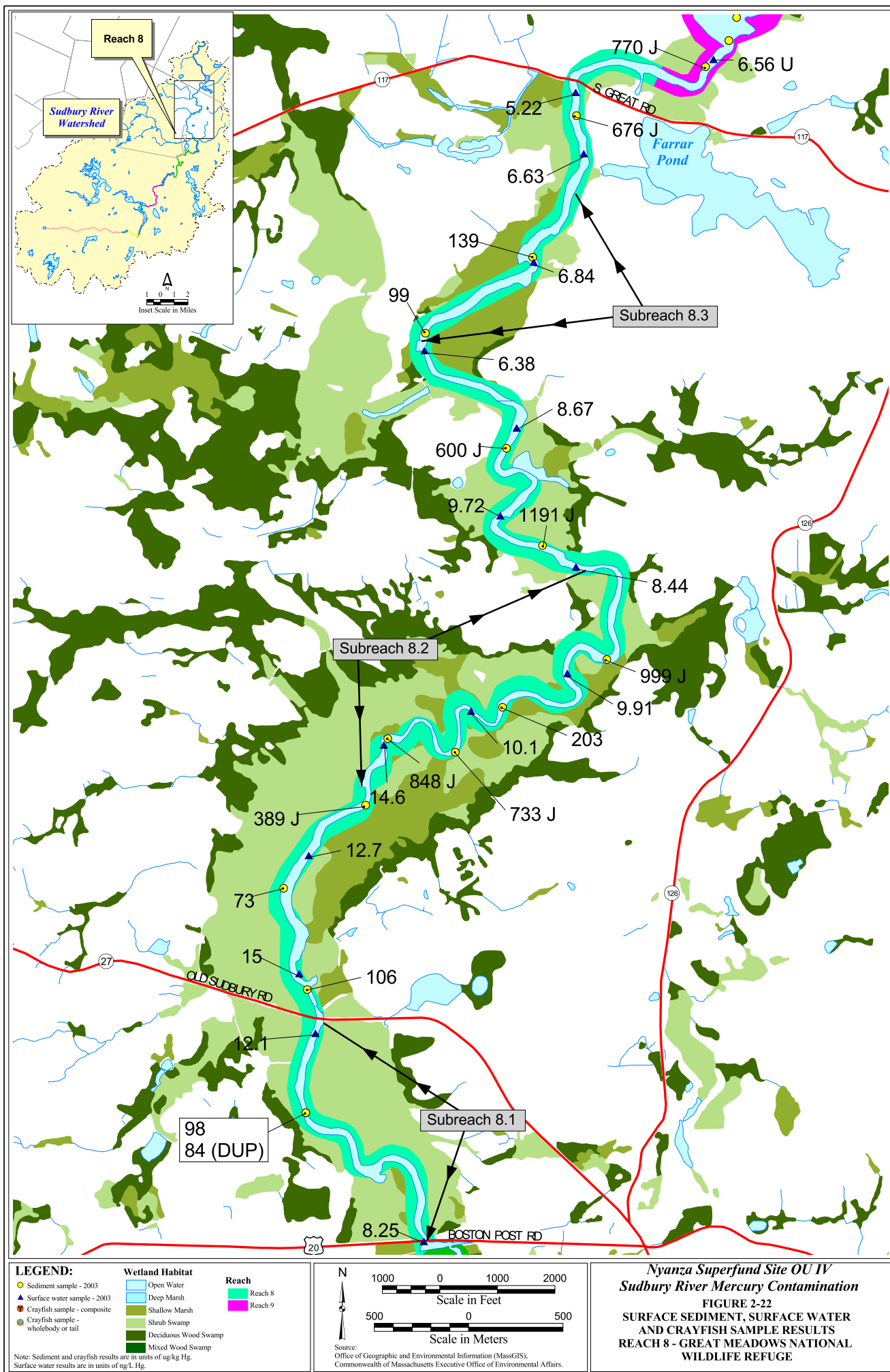
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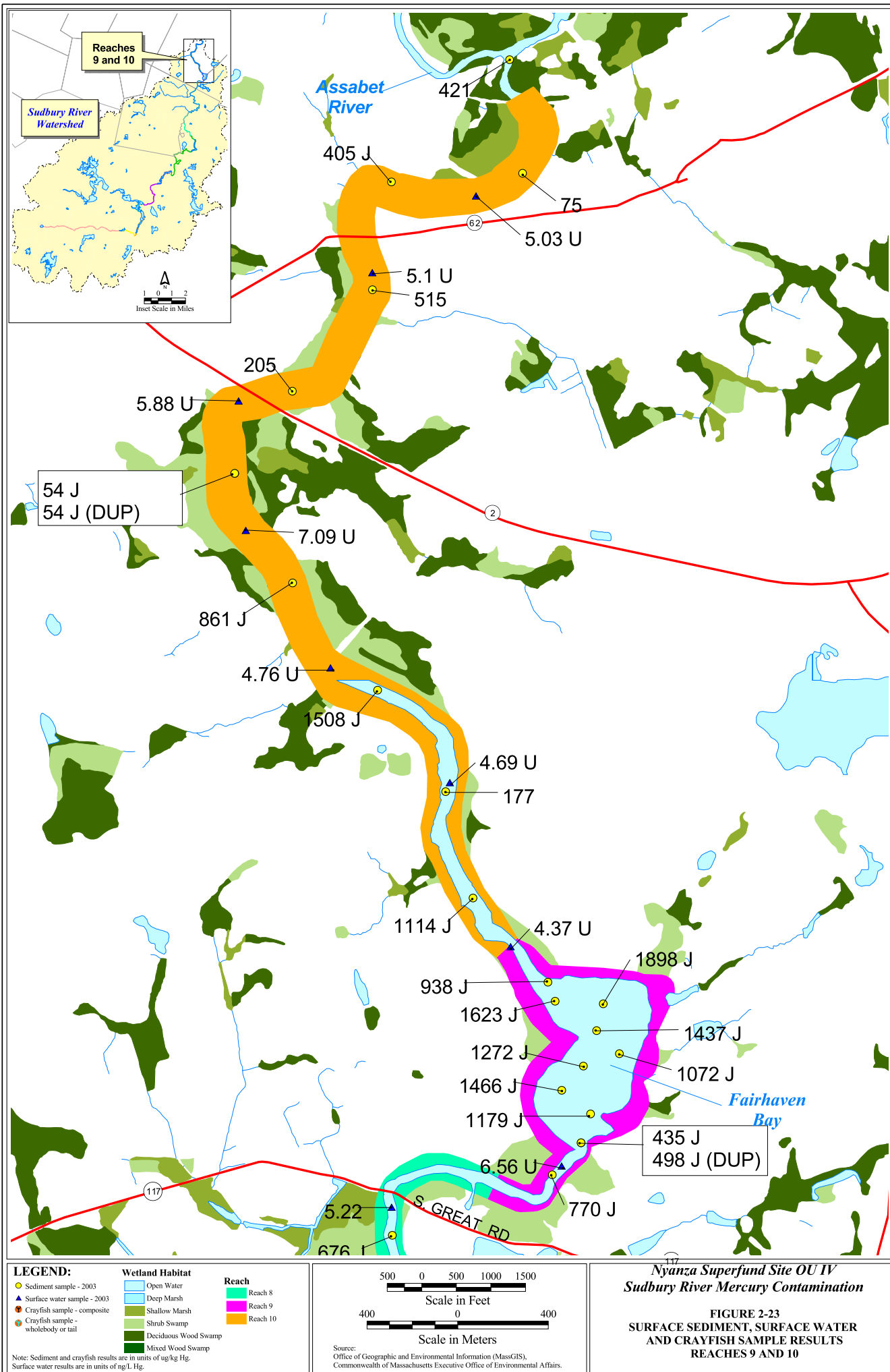
*Nyanza Superfund Site OU IV*  
*Sudbury River Mercury Contamination*  
**FIGURE 2-19**  
**SURFACE SEDIMENT, SURFACE WATER**  
**AND CRAYFISH SAMPLE RESULTS**  
**REACH 1 - REFERENCE AREA**

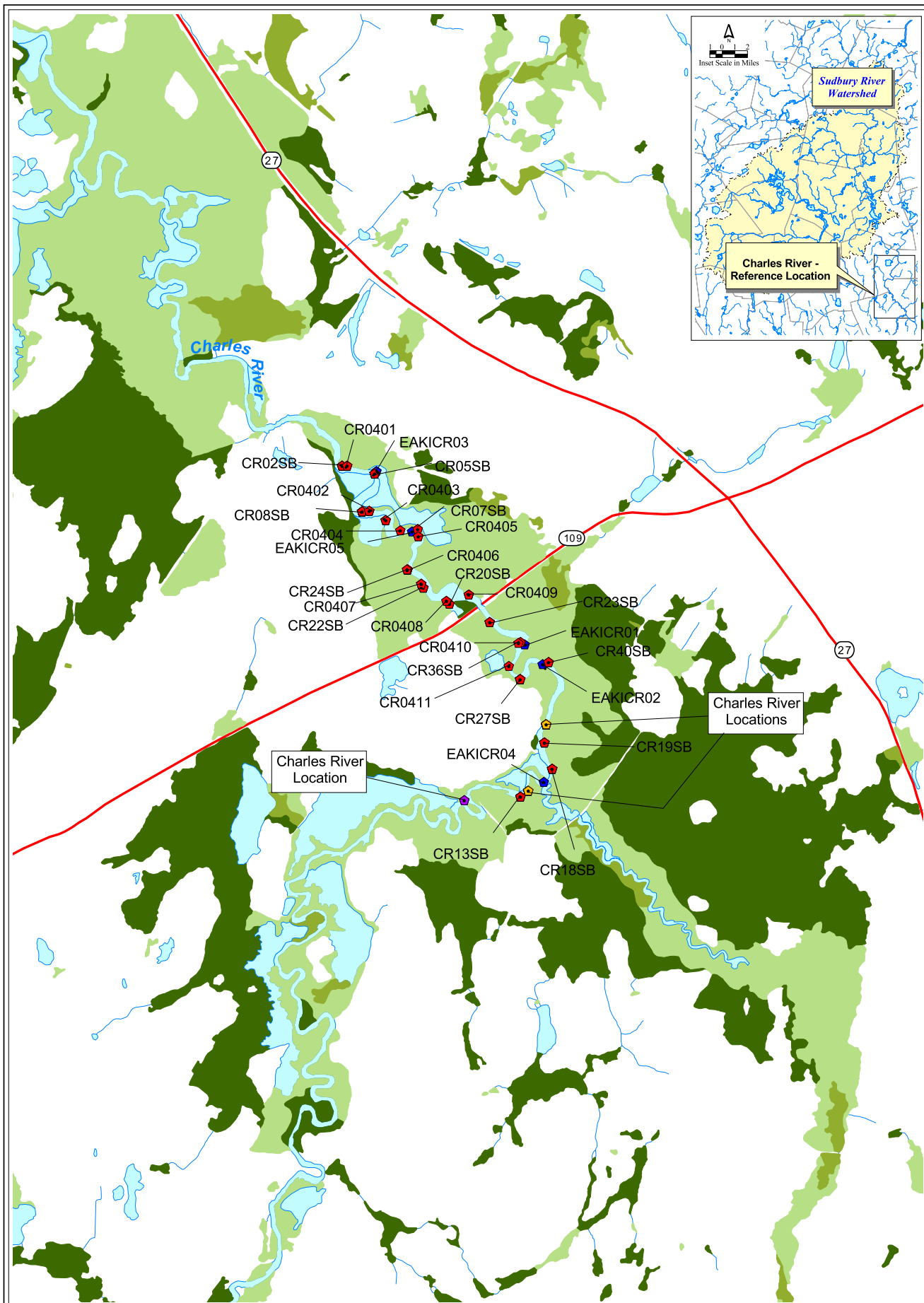












# LEGEND:

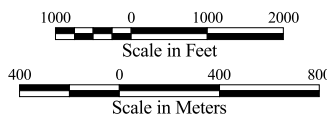
## Sample Location

- ◆ Tree Swallow Nest Box
- ◆ Waterfowl Nest Box
- ◆ Eastern Kingbird Egg Sample
- ◆ Marsh Bird Sampling Area
- ◆ Belted Kingfisher Nest

## Wetland Habitat

- Open Water
- Deep Marsh
- Shallow Marsh
- Shrub Swamp
- Deciduous Wood Swamp
- Mixed Wood Swamp

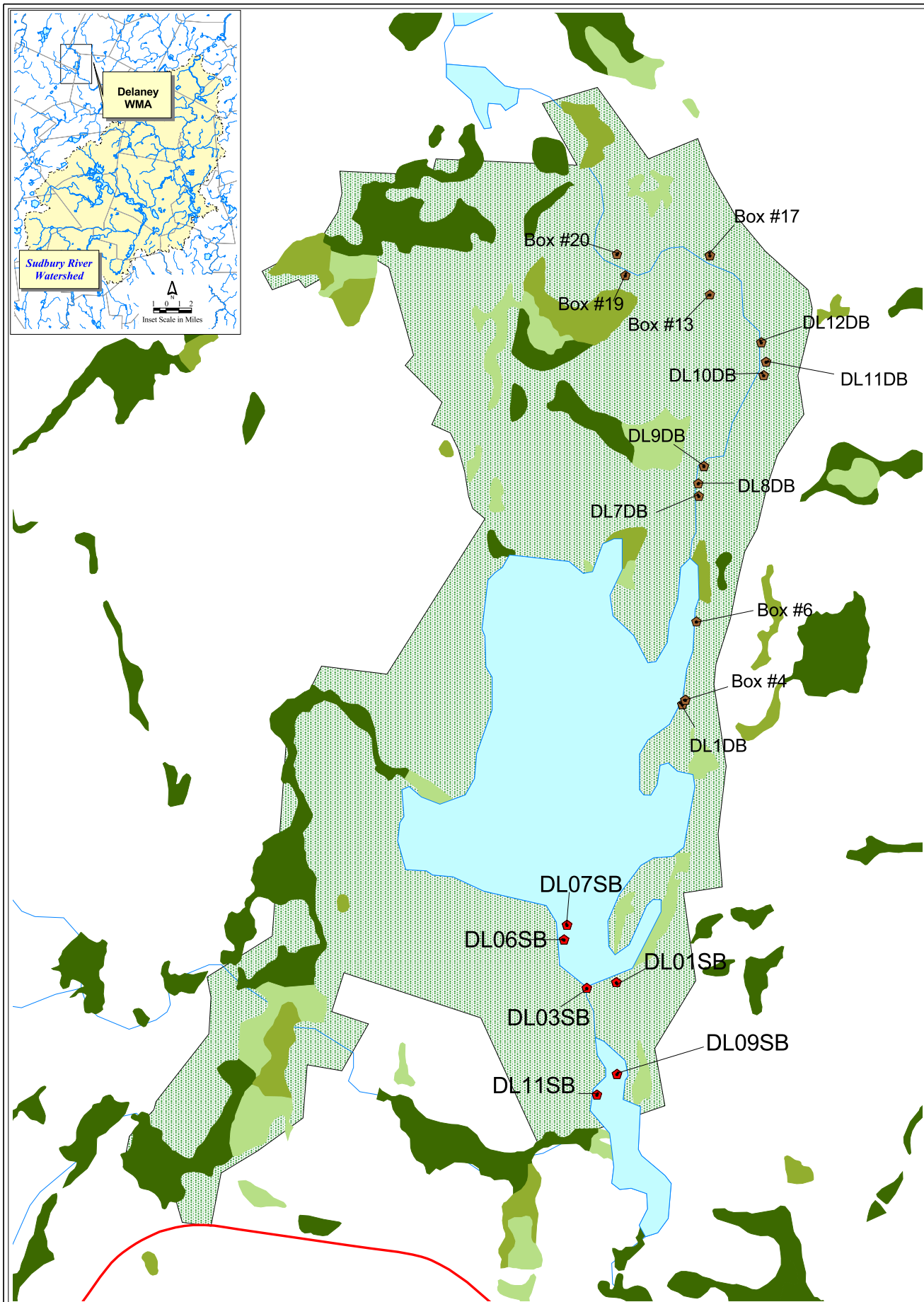
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Source: Office of Geographic and Environmental Information (MassGIS), Commonwealth of Massachusetts Executive Office of Environmental Affairs.

## Nyanza Superfund Site OUIV Sudbury River Mercury Contamination

### FIGURE 2-24 AVIAN SAMPLE LOCATIONS CHARLES RIVER - REFERENCE AREA



# **LEGEND:**

## **Sample Location**

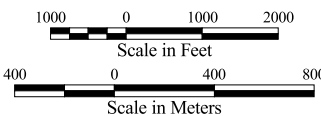
- Tree Swallow Nest Box
- Waterfowl Nest Box
- Eastern Kingbird Egg Sample
- Marsh Bird Sampling Area
- Belted Kingfisher Nest

## **Wetland Habitat**

- Open Water
- Deep Marsh
- Shallow Marsh
- Shrub Swamp
- Deciduous Wood Swamp
- Mixed Wood Swamp

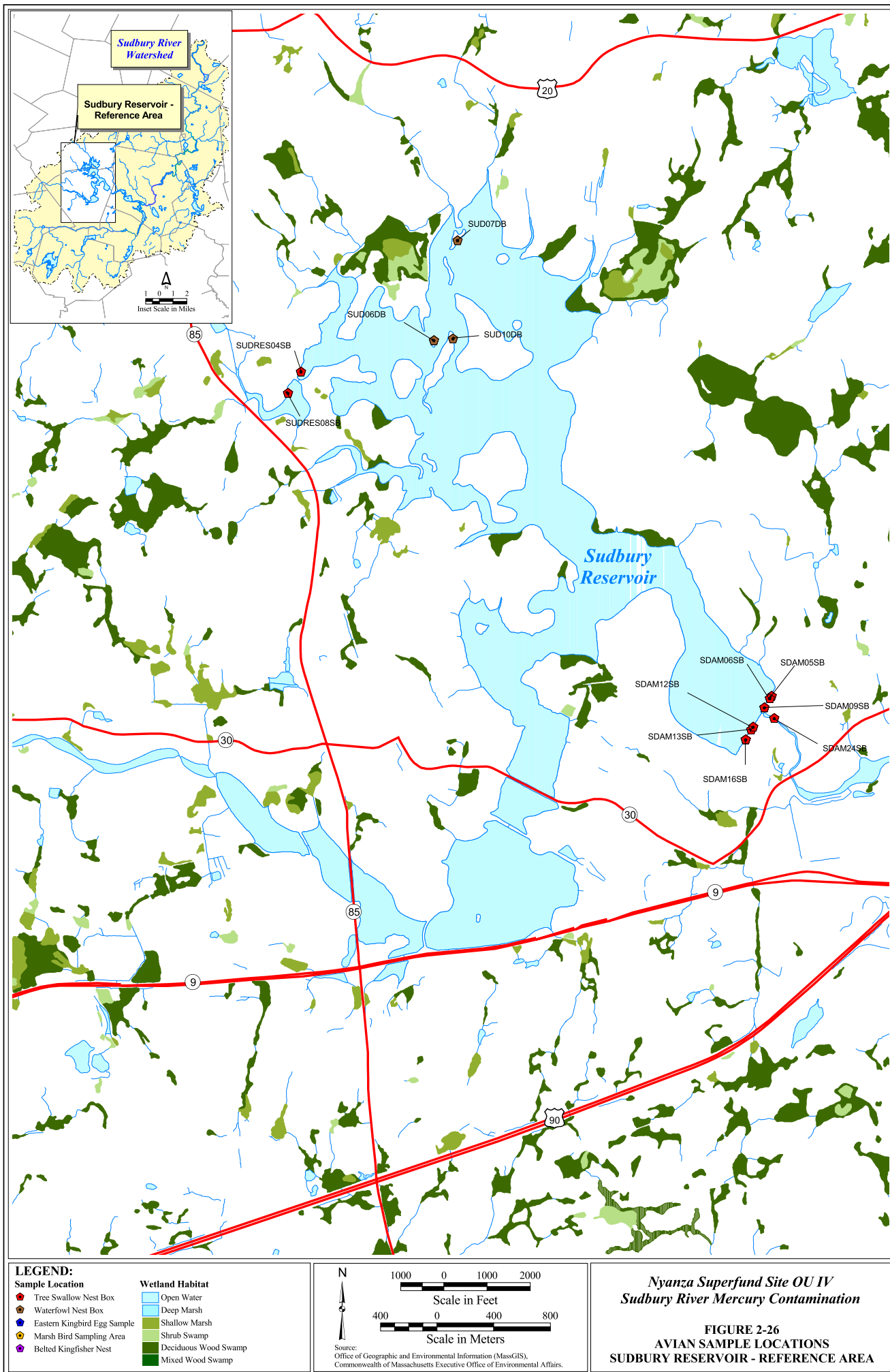
Delaney Wildlife Management Area

N

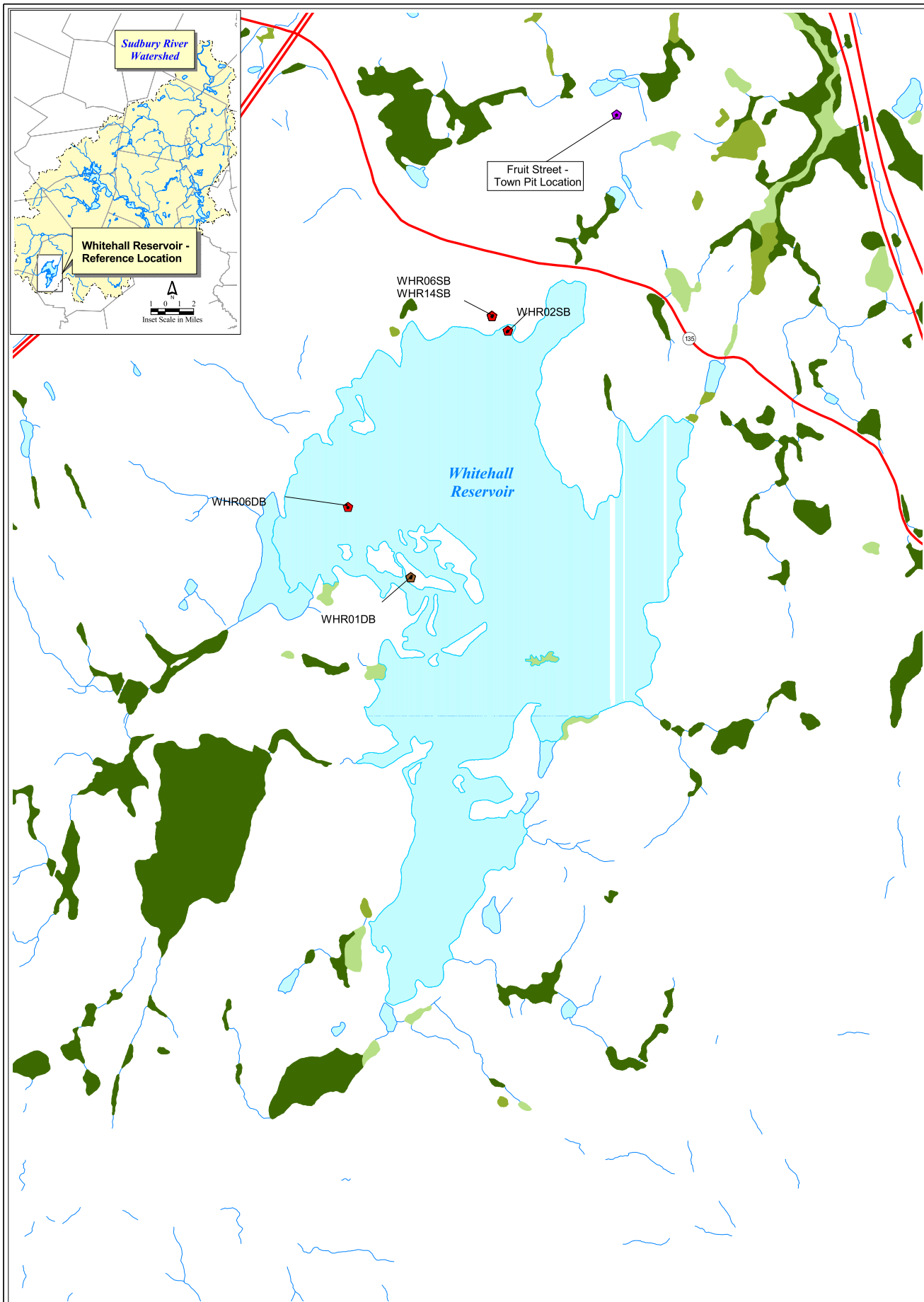


Source: Office of Geographic and Environmental Information (MassGIS), Commonwealth of Massachusetts Executive Office of Environmental Affairs.

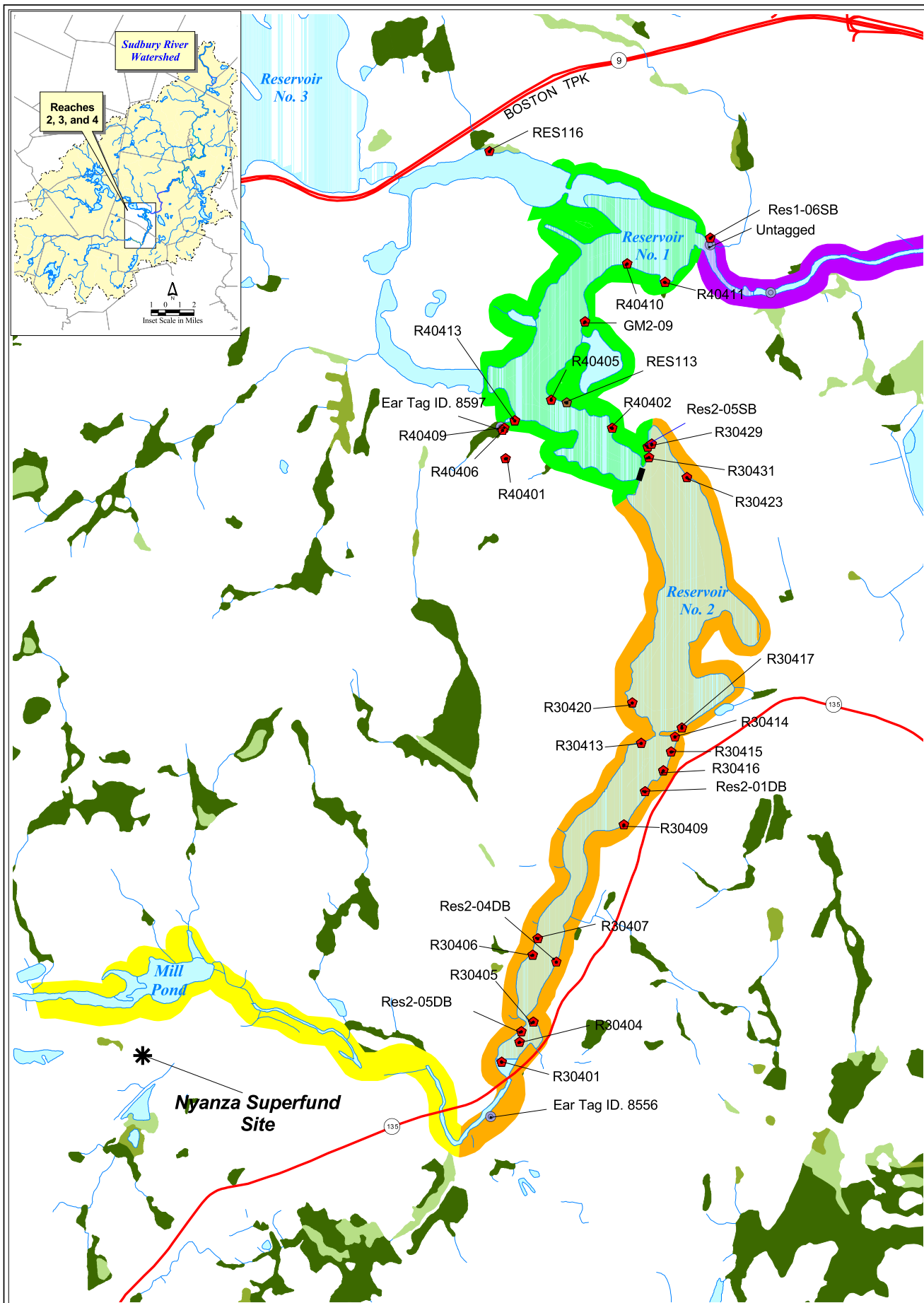
*Nyanza Superfund Site OU IV*  
*Sudbury River Mercury Contamination*  
**FIGURE 2-25**  
**AVIAN SAMPLE LOCATIONS**  
**DELANEY WILDLIFE MANAGEMENT AREA -**  
**REFERENCE AREA**







*Nyanza Superfund Site OU IV*  
*Sudbury River Mercury Contamination*  
**FIGURE 2-27**  
**AVIAN SAMPLE LOCATIONS**  
**WHITEHALL RESERVOIR - REFERENCE AREA**



# **LEGEND:**

## **Sample Location**

- Tree Swallow Nest Box
- Waterfowl Nest Box
- Eastern Kingbird Egg Sample
- Marsh Bird Sampling Area
- Belted Kingfisher Nest
- Mink

## **Wetland Habitat**

- Open Water
- Deep Marsh
- Shallow Marsh
- Shrub Swamp
- Deciduous Wood Swamp
- Mixed Wood Swamp

## **Reach**

- Reach 2
- Reach 3
- Reach 4
- Reach 5

N

500 0 500 1000 1500

Scale in Feet

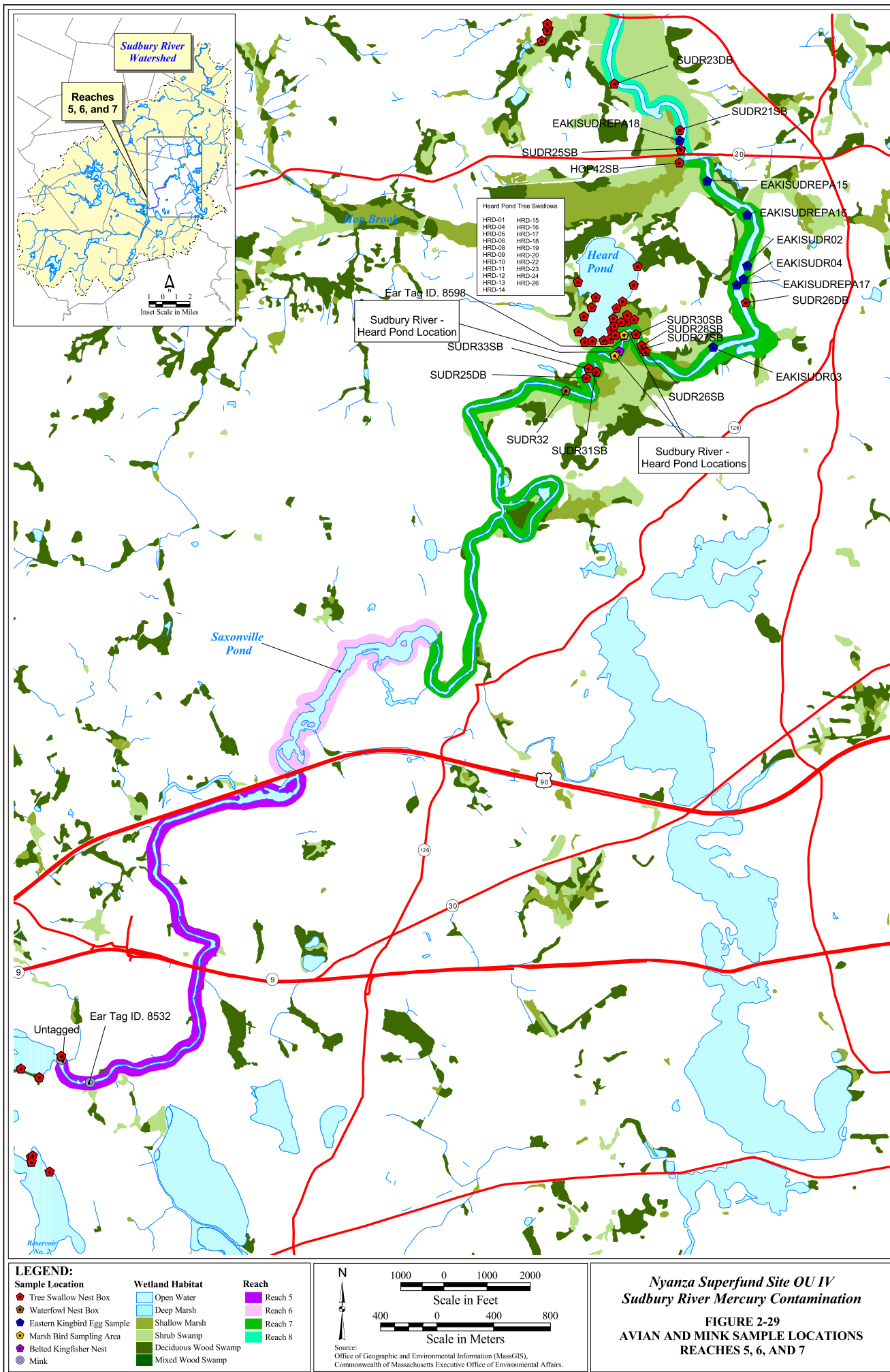
400 0 400

Scale in Meters

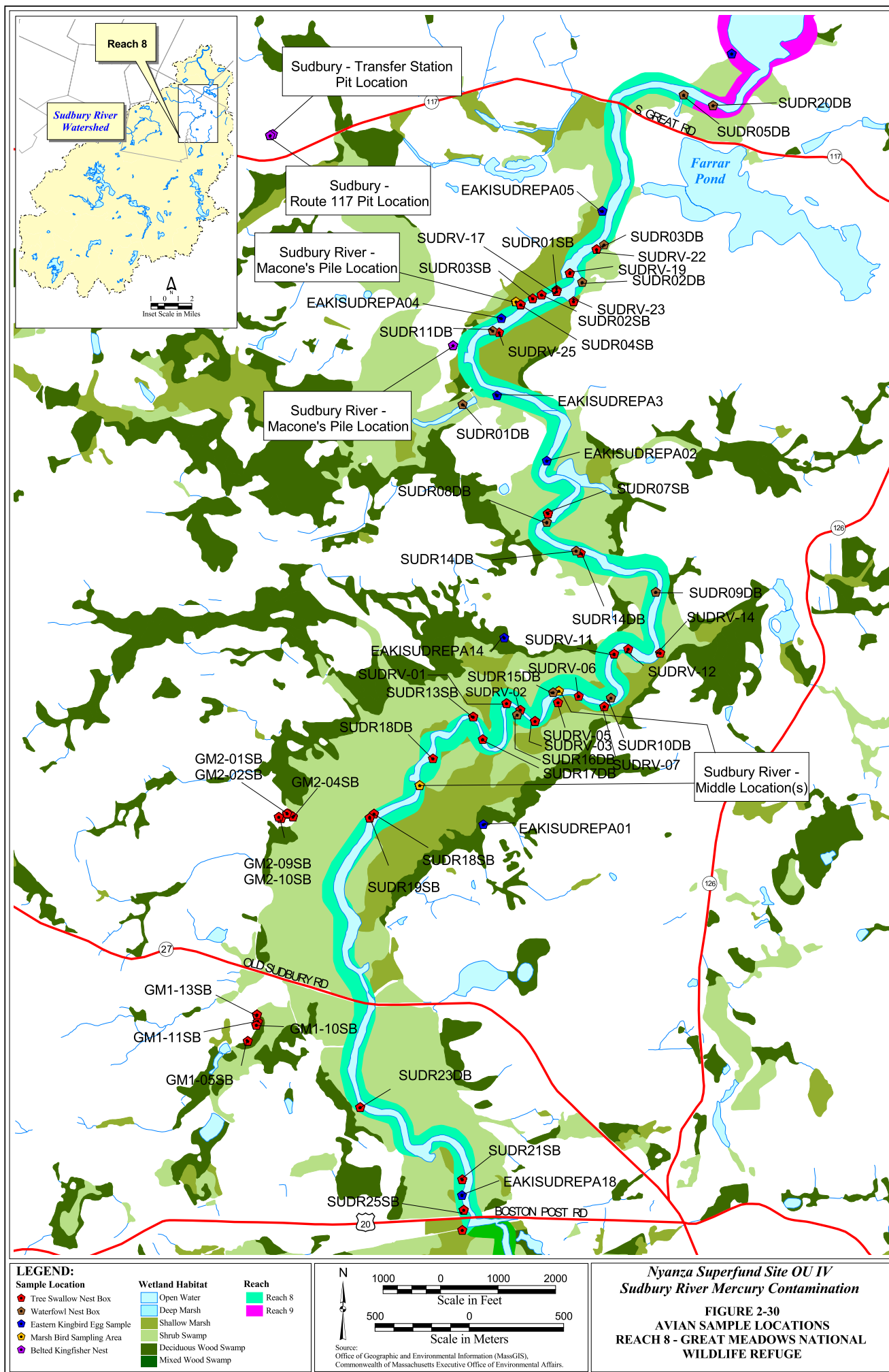
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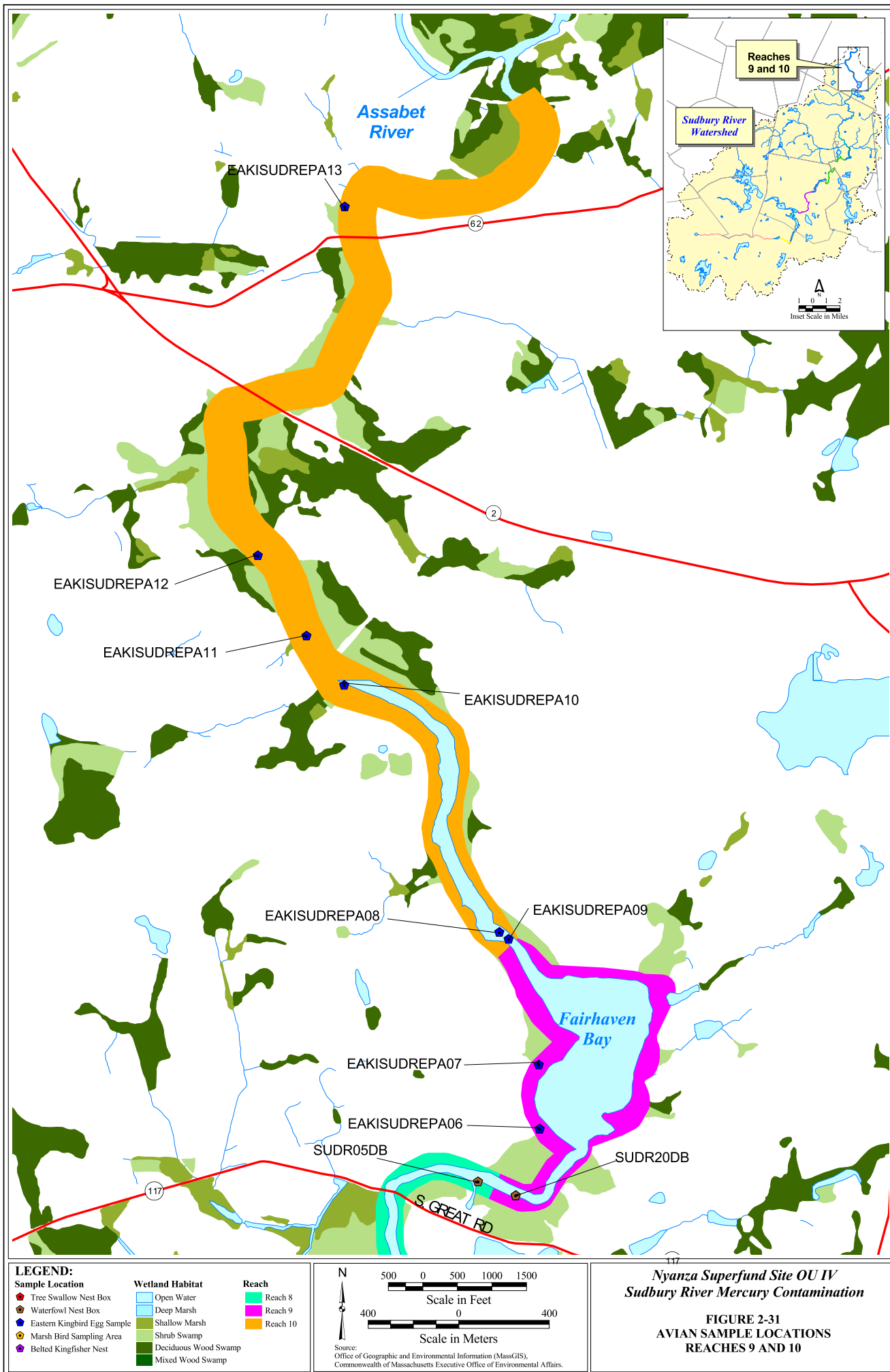
*Nyanza Superfund Site OU IV  
Sudbury River Mercury Contamination*

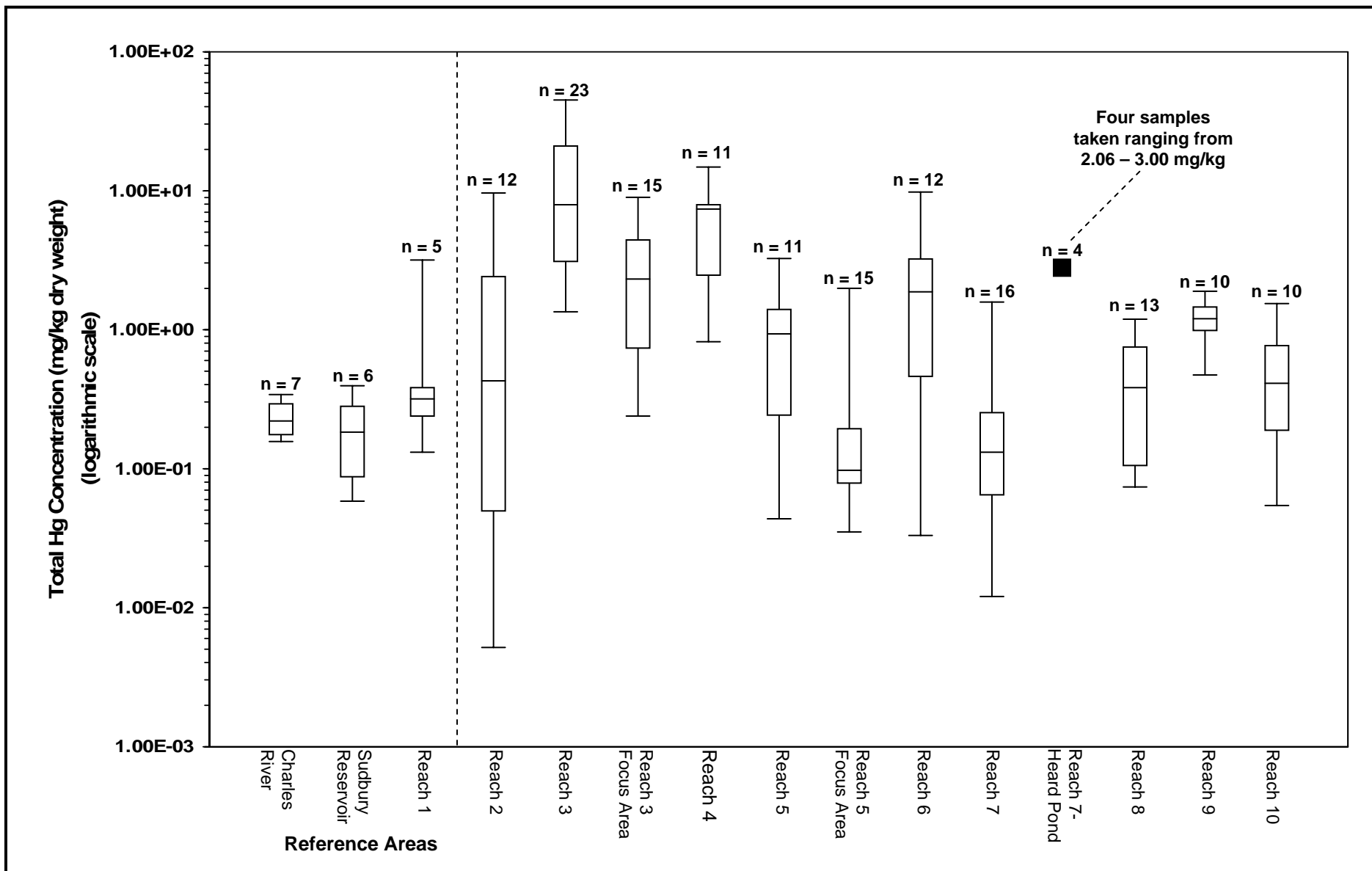
**FIGURE 2-28  
AVIAN AND MINK SAMPLE LOCATIONS  
REACHES 2, 3, AND 4**



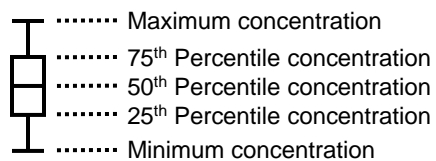






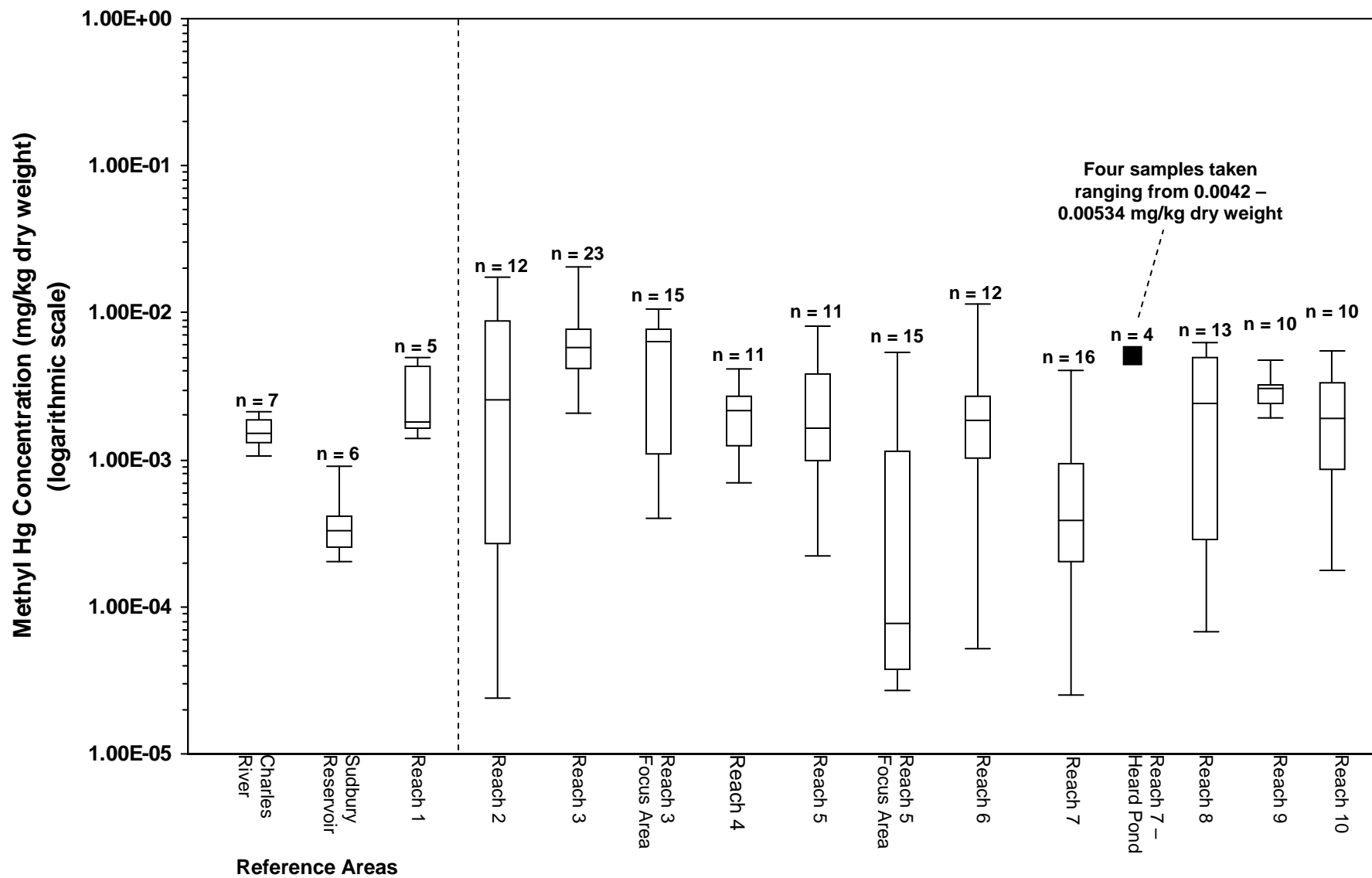


**Legend:**

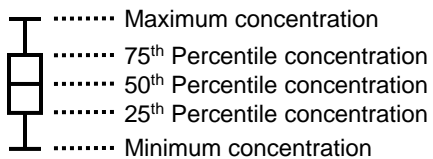


**Nyanza Superfund Site OU IV  
Sudbury River Mercury Contamination**

**Figure 2-32  
Total Mercury Concentrations in  
Sediment Samples – 2003 & 2005**

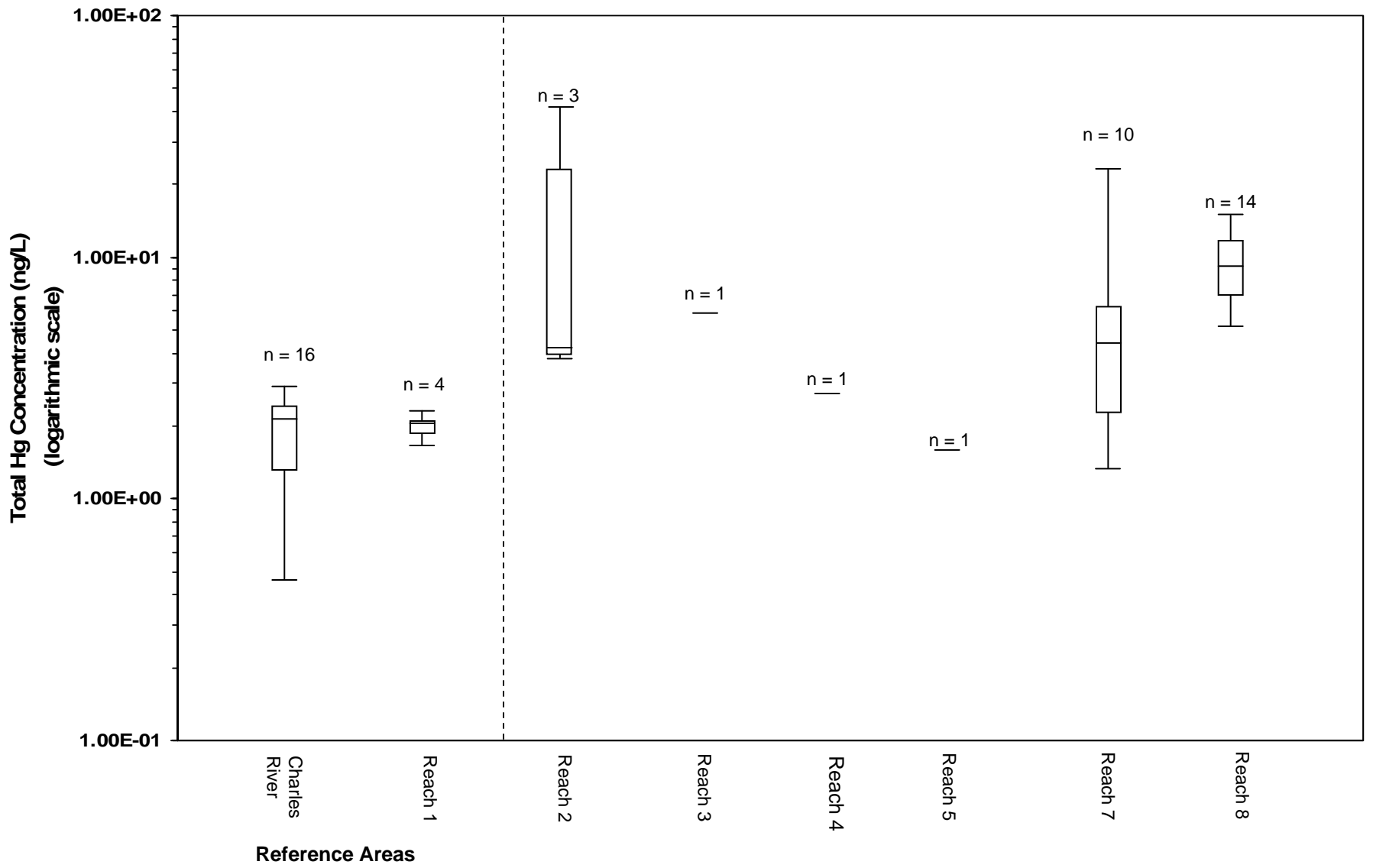


**Legend:**

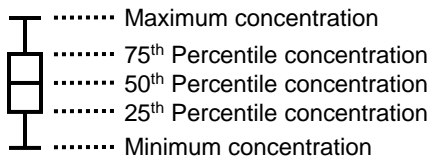


**Nyanza Superfund Site OU IV  
Sudbury River Mercury Contamination**

**Figure 2-33  
Methylmercury Concentrations in  
Sediment Samples - 2003 & 2005**

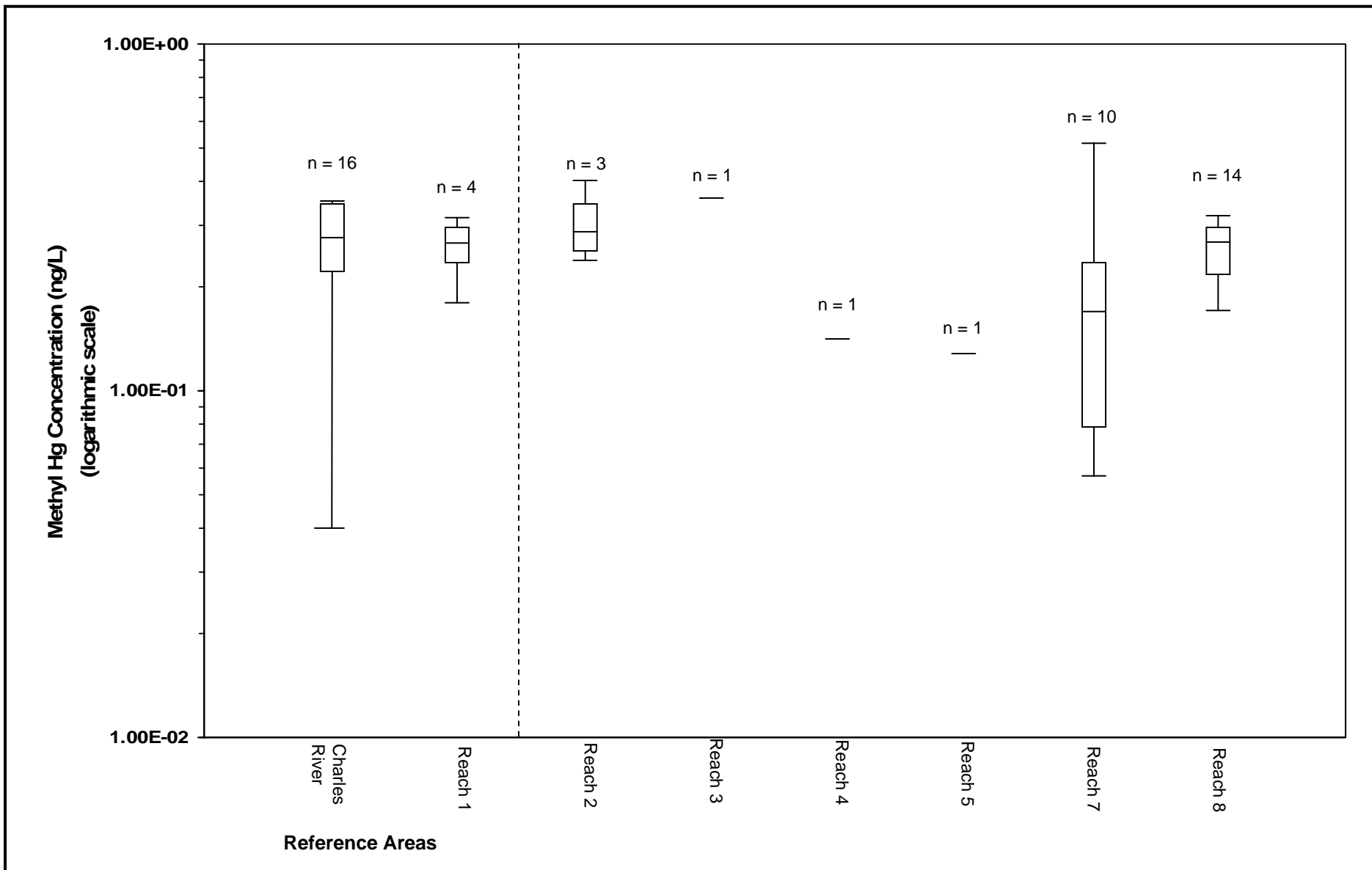


**Legend:**

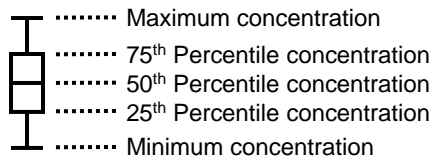


***Nyanza Superfund Site OU IV  
Sudbury River Mercury Contamination***

**Figure 2-34  
Total Mercury Concentrations in  
Surface Water Samples - 2003**

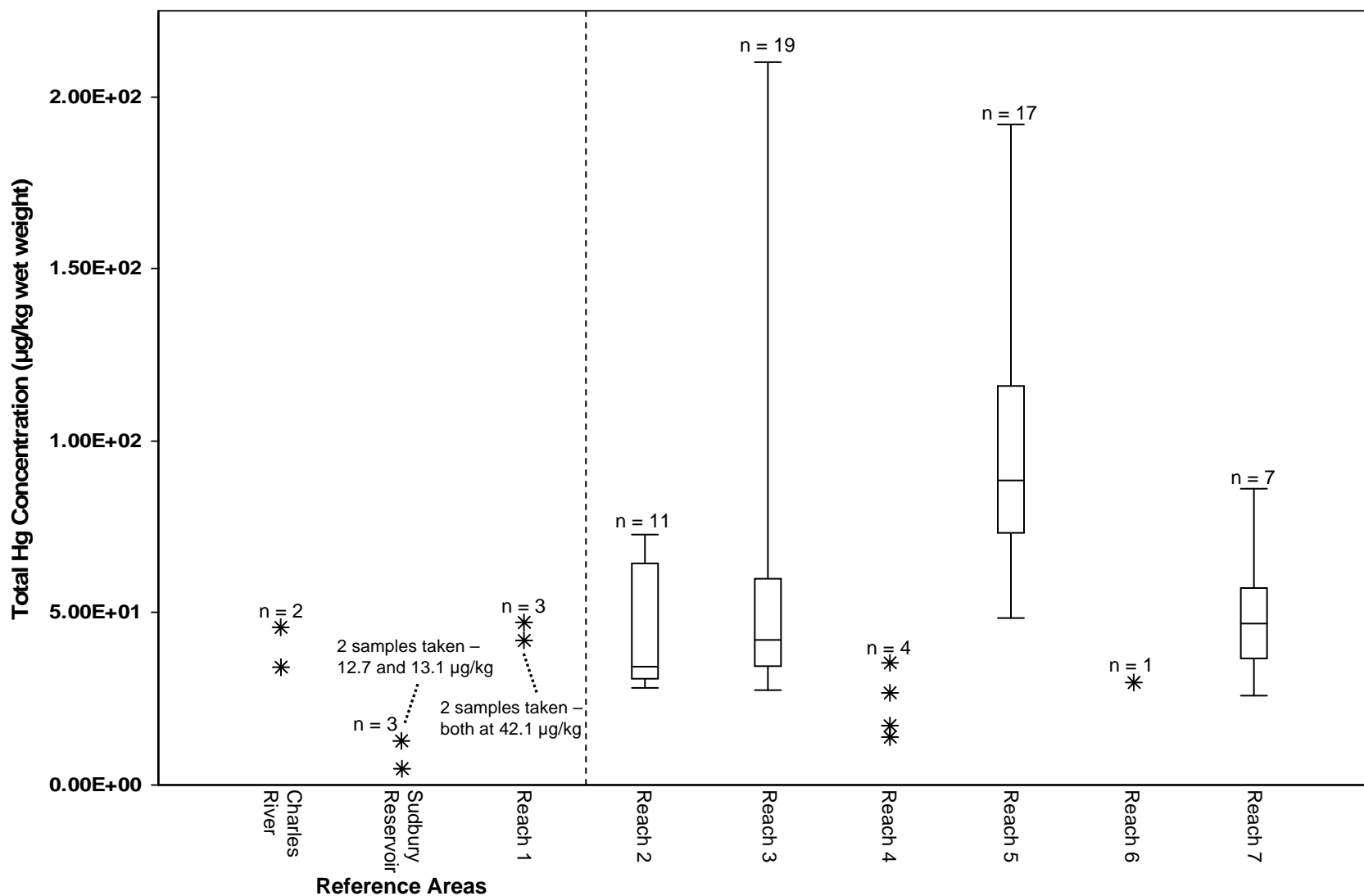


**Legend:**



***Nyanza Superfund Site OU IV  
Sudbury River Mercury Contamination***

**Figure 2-35  
Methylmercury Concentrations in  
Surface Water Samples - 2003**



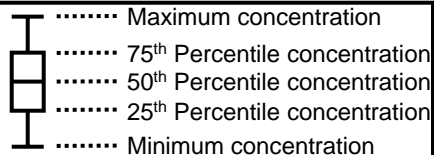
**Legend:**

\* - Whole body crayfish sample

Notes:

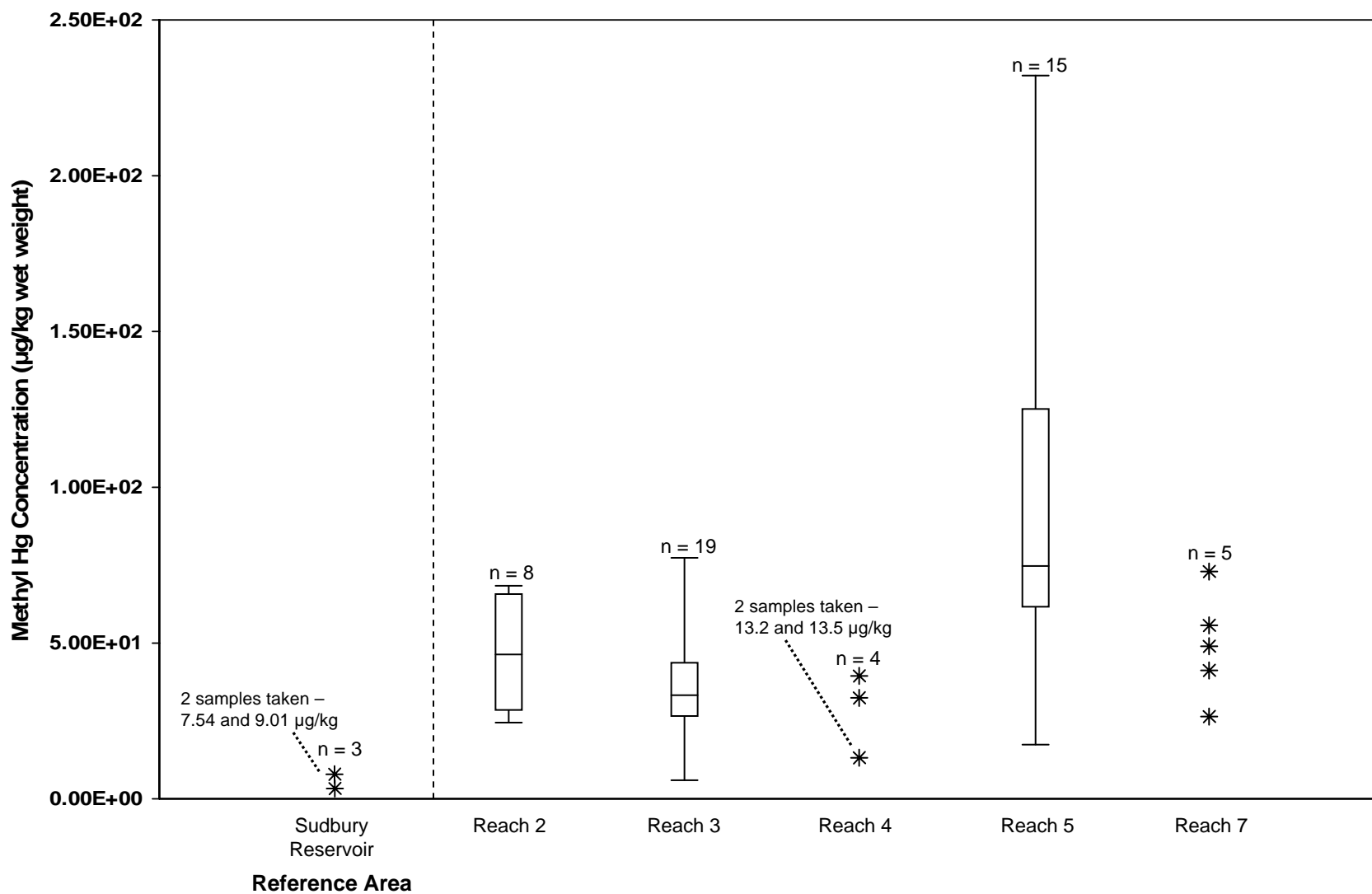
1) Composite samples are included in Charles River (2), Reach 1 (3), Reach 2 (3), Reach 5 (2), Reach 6 (1), and Reach 7 (2). See Table 2-9 for additional details.

2) In addition to the whole body samples, there were also tail samples collected, two from Reach 5 (72.1 and 390 µg/kg) and four from Reach 7 (23.5, 132, 174, and 235 µg/kg).



**Nyanza Superfund Site OU IV  
Sudbury River Mercury Contamination**

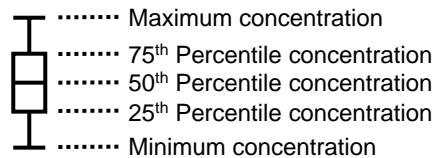
**Figure 2-36  
Total Mercury Concentrations in  
Whole Body Crayfish Samples - 2003**



**Legend:**

\* -Whole body crayfish sample

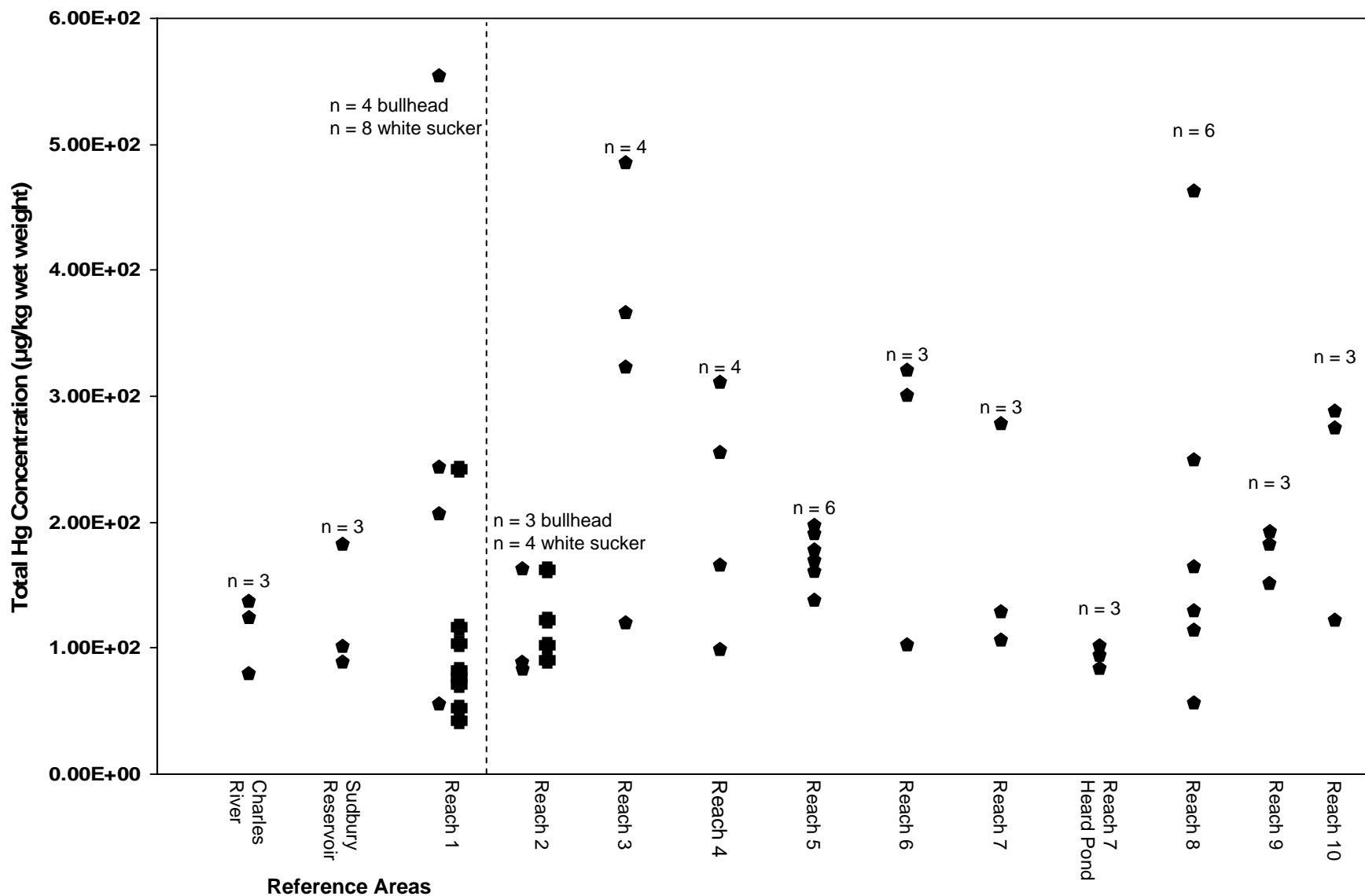
(Note: Samples were individual whole body only.)



**Nyanza Superfund Site OU IV  
 Sudbury River Mercury Contamination**

**Figure 2-37  
 Methylmercury Concentrations in  
 Whole Body Crayfish Samples - 2003**



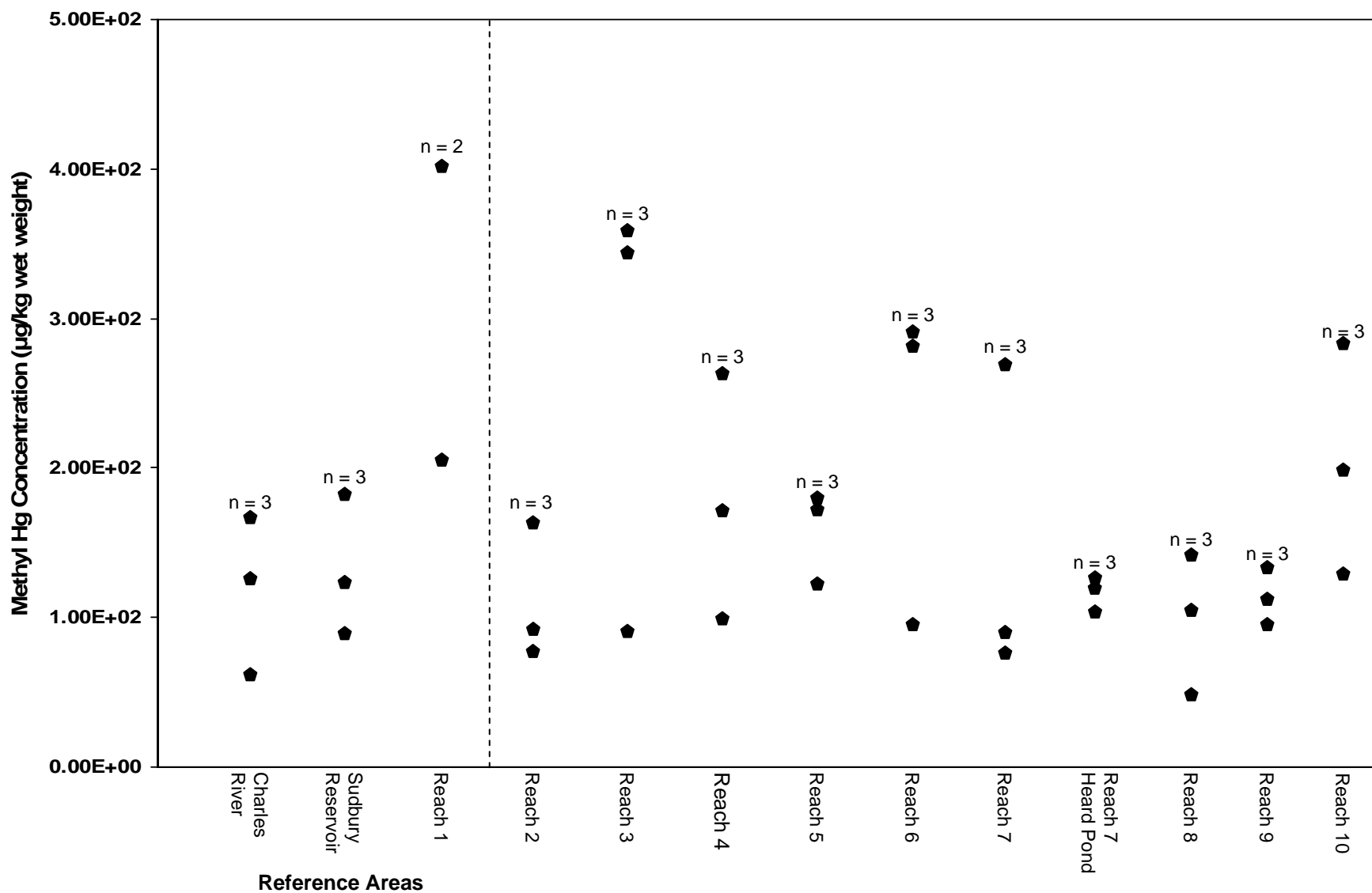


**Legend:**

- ◆ - Bullhead sample
- - White sucker sample

**Nyanza Superfund Site OU IV  
Sudbury River Mercury Contamination**

**Figure 2-38  
Total Mercury Concentrations in  
Bullhead and White Sucker Samples – 2003 & 2004**

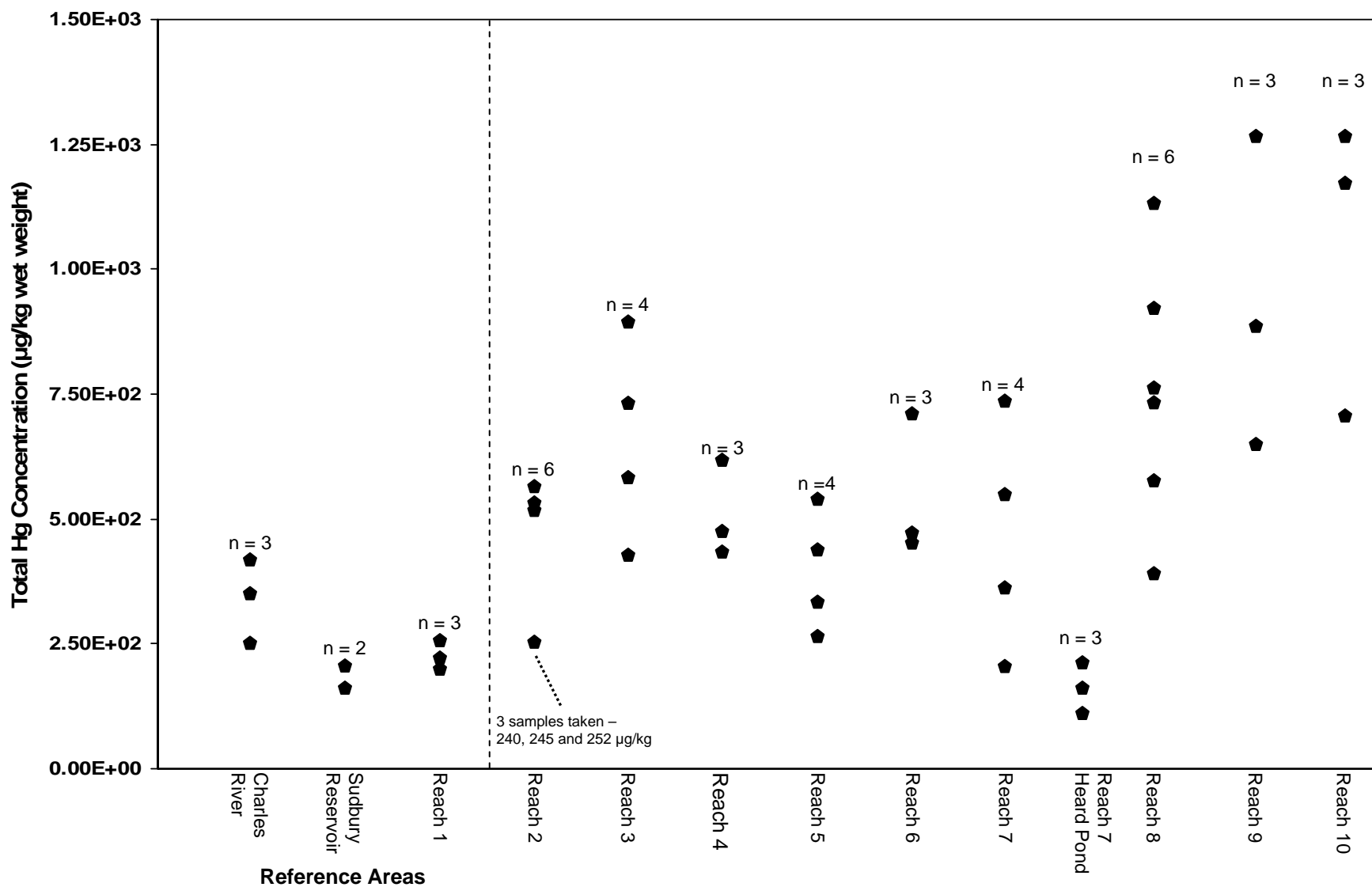


**Legend:**

◆ - Fish sample

***Nyanza Superfund Site OU IV  
Sudbury River Mercury Contamination***

**Figure 2-39  
Methylmercury Concentrations in  
Bullhead Samples – 2003 & 2004**

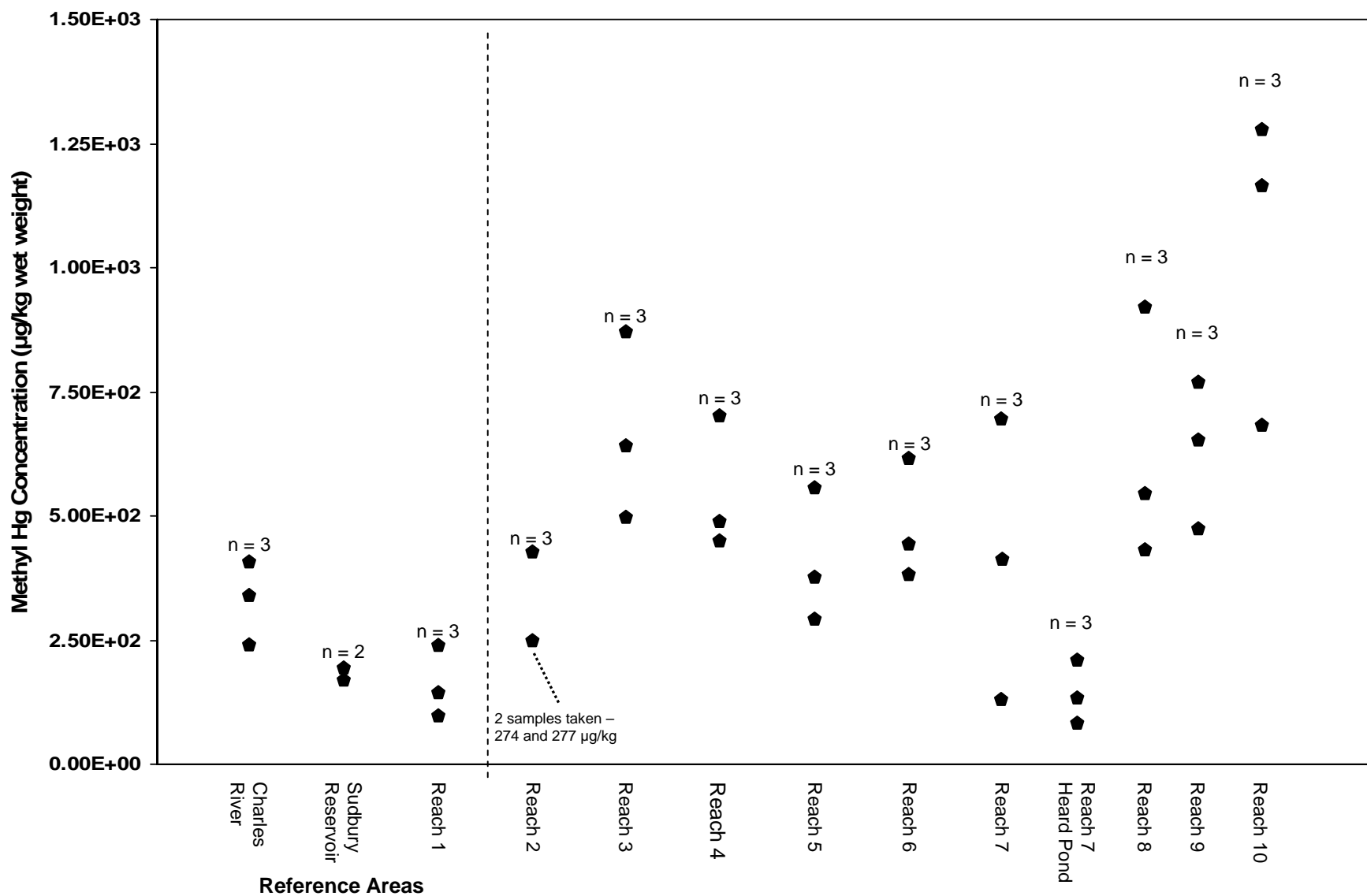


**Legend:**

◆ -Fish, reconstructed whole body

**Nyanza Superfund Site OU IV  
Sudbury River Mercury Contamination**

**Figure 2-40  
Total Mercury Concentrations in  
Largemouth Bass Samples – 2003 & 2004**

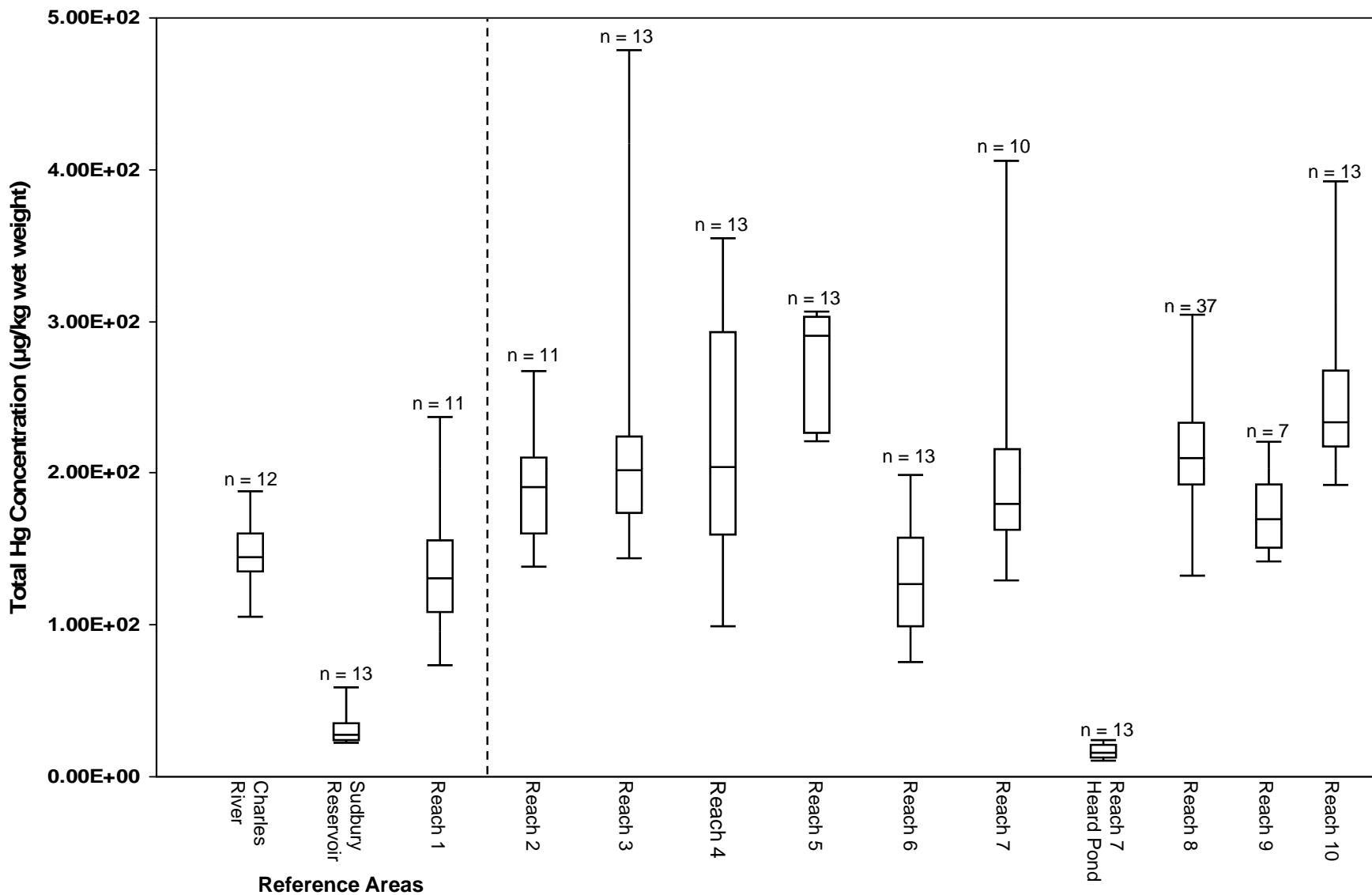


**Legend:**

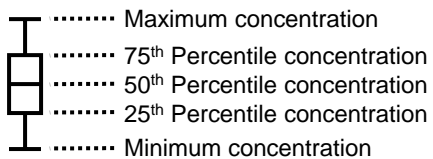
◆ - Fish, reconstructed whole body

**Nyanza Superfund Site OU IV  
Sudbury River Mercury Contamination**

**Figure 2-41  
Methylmercury Concentrations in  
Largemouth Bass Samples – 2003 & 2004**

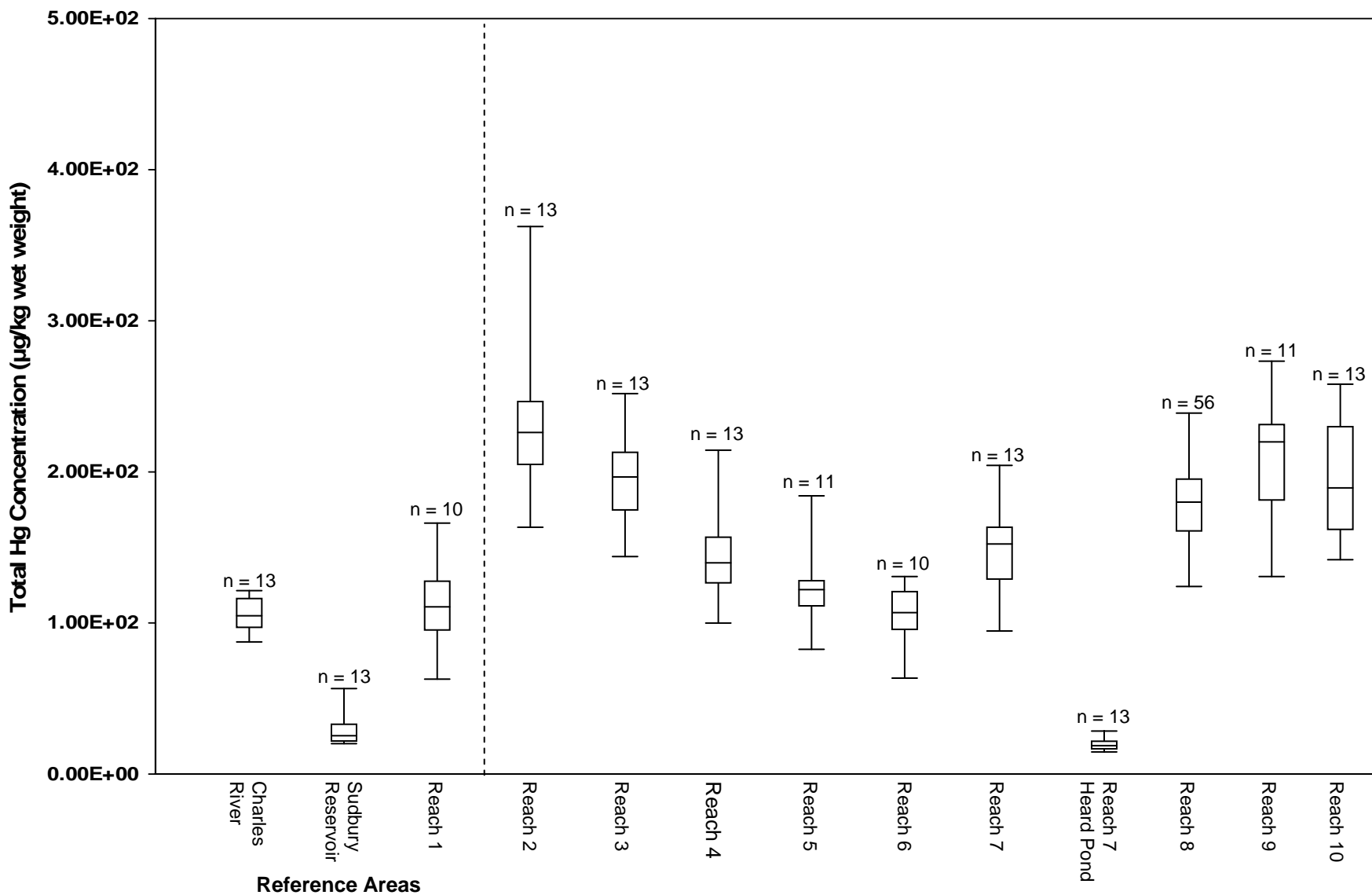


**Legend:**

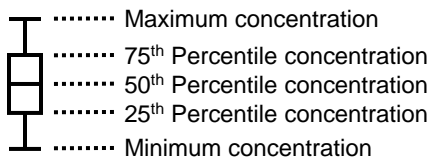


**Nyanza Superfund Site OU IV  
Sudbury River Mercury Contamination**

**Figure 2-42  
Total Mercury Concentrations in Whole Body  
Class A Perch/Sunfish Samples – 2003 & 2004**

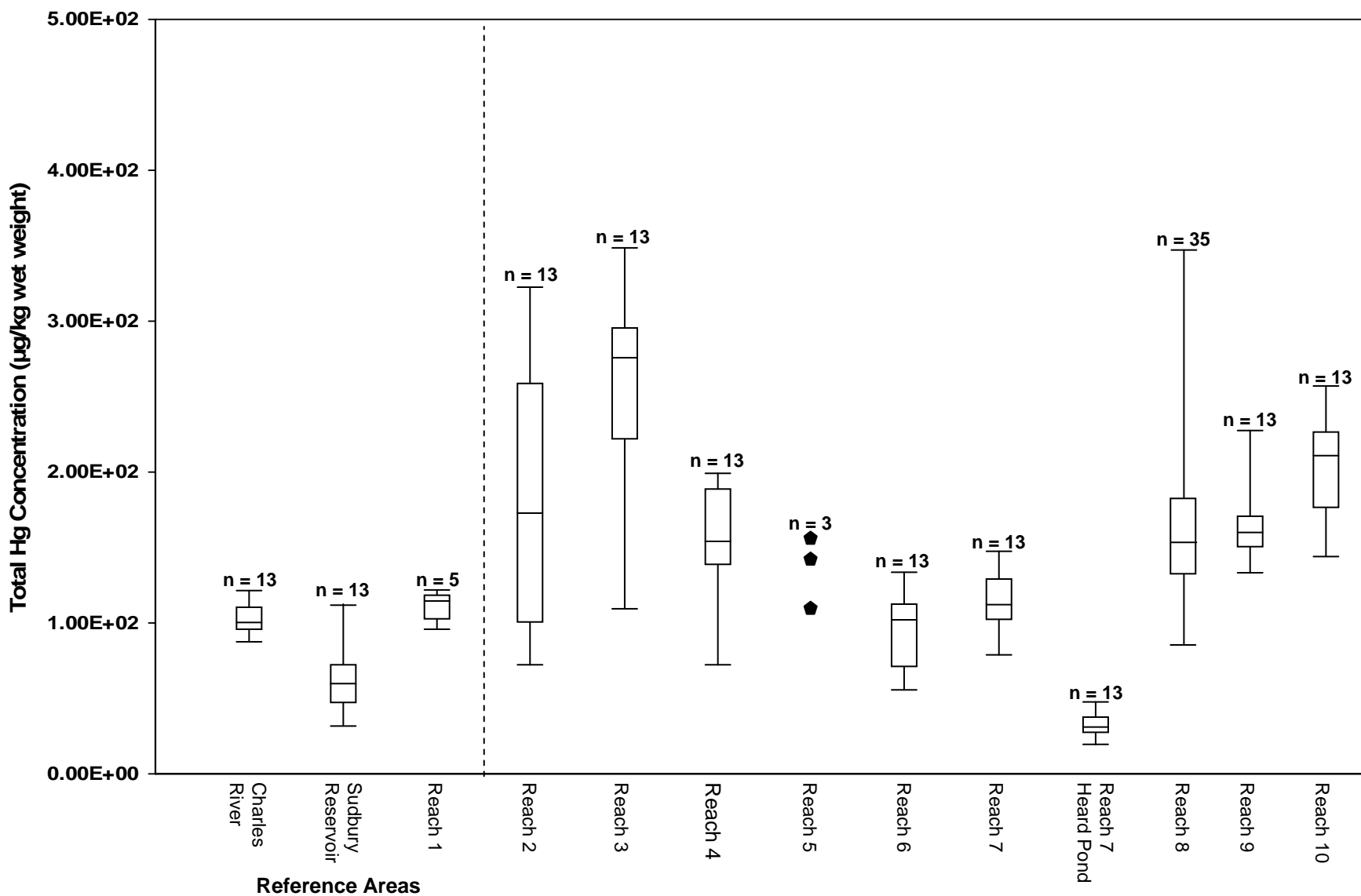


**Legend:**



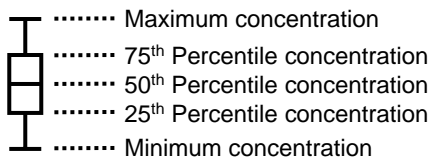
**Nyanza Superfund Site OU IV  
Sudbury River Mercury Contamination**

**Figure 2-43  
Total Mercury Concentrations in Whole Body  
Class B Perch/Sunfish Samples – 2003 & 2004**



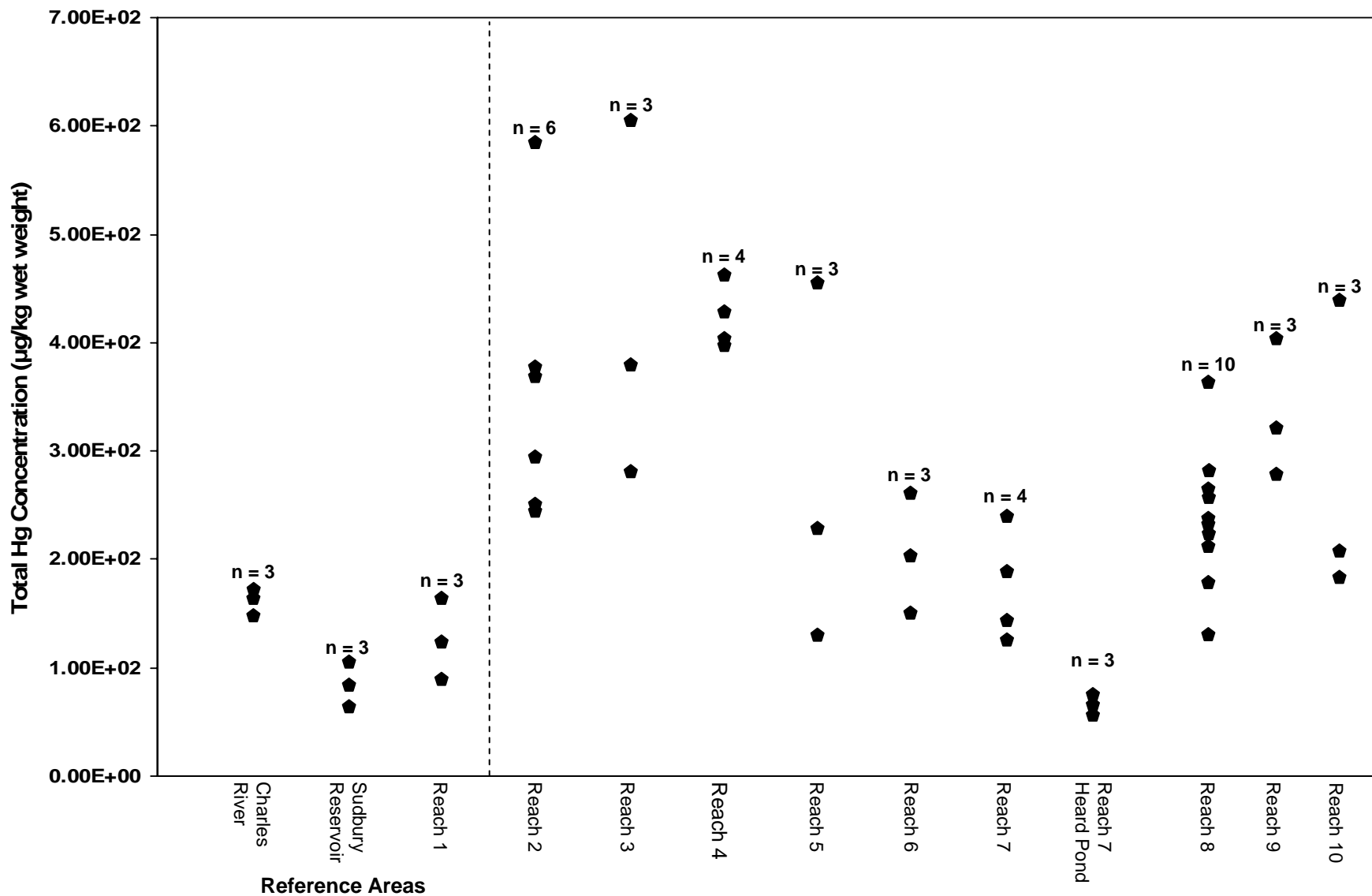
**Legend:**

◆ - Fish sample



**Nyanza Superfund Site OU IV  
Sudbury River Mercury Contamination**

**Figure 2-44  
Total Mercury Concentrations in Whole Body  
Class C Perch/Sunfish Samples – 2003 & 2004**



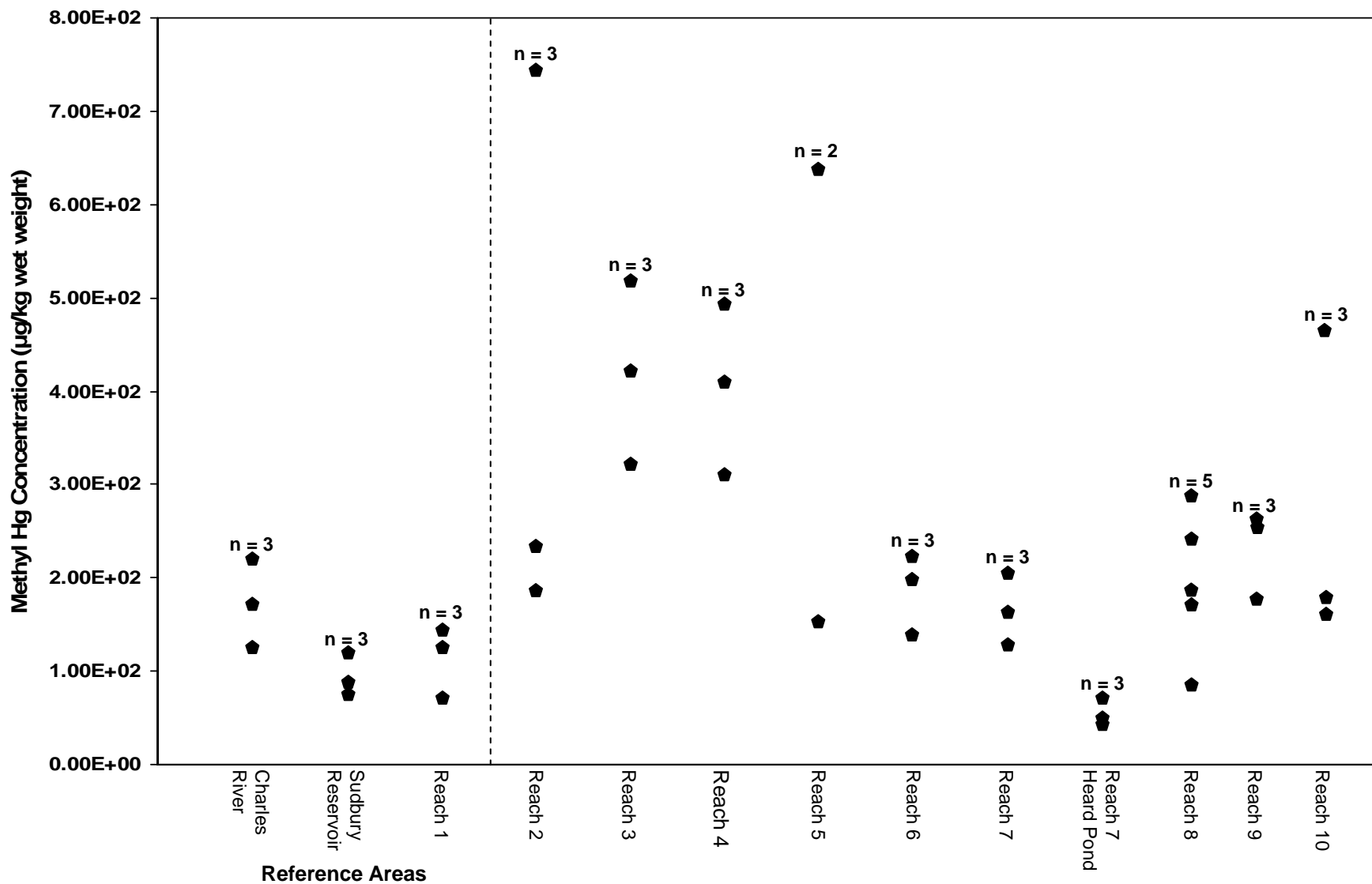
**Legend:**

◆ - Fish, reconstructed whole body

**Nyanza Superfund Site OU IV  
Sudbury River Mercury Contamination**

**Figure 2-45  
Total Mercury Concentrations in Whole Body  
Class D Perch Samples – 2003 & 2004**



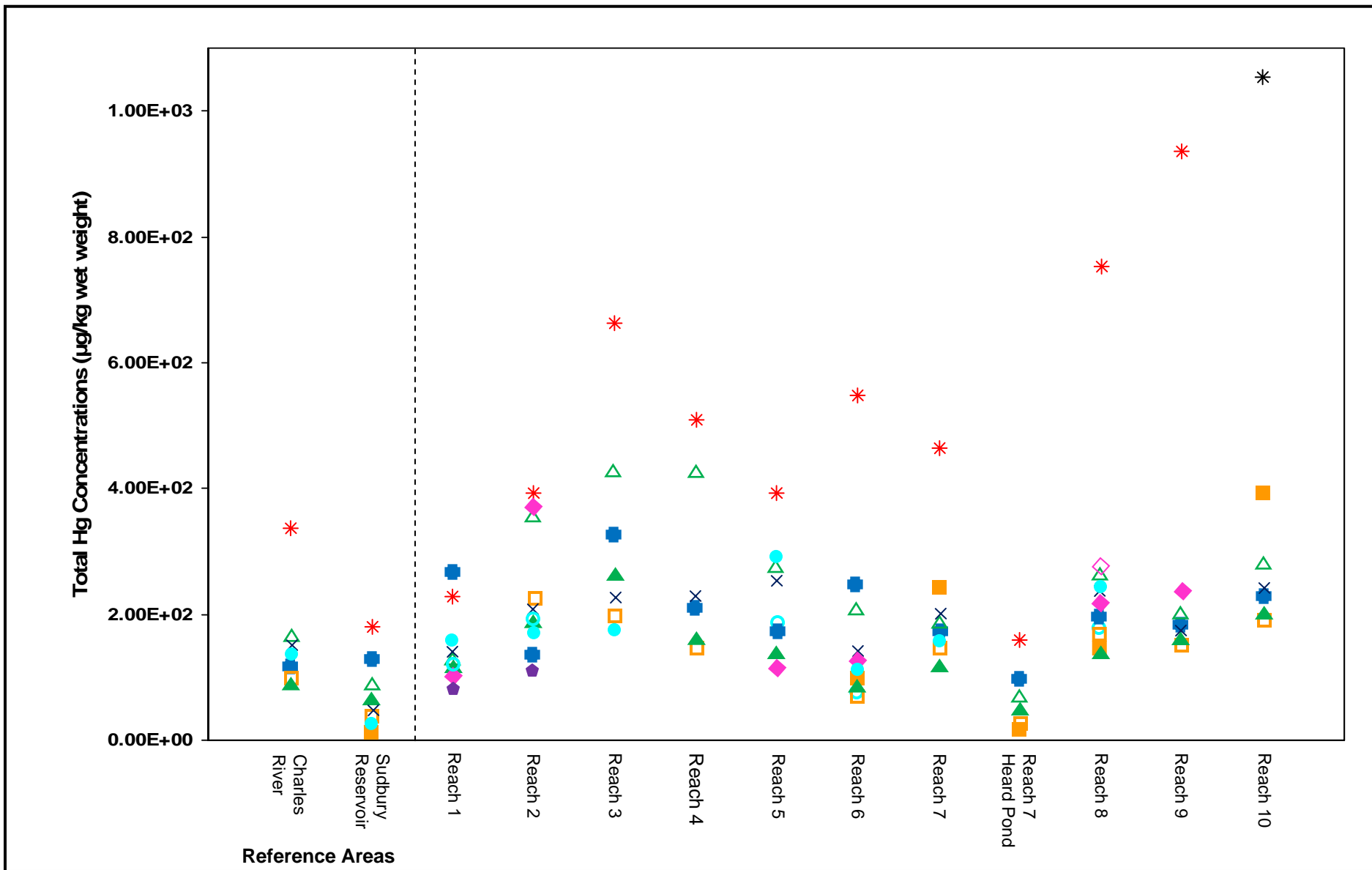


**Legend:**

◆ - Fish, reconstructed whole body

***Nyanza Superfund Site OU IV  
Sudbury River Mercury Contamination***

**Figure 2-46  
Methylmercury Concentrations in Whole Body  
Class D Perch Samples – 2003 & 2004**

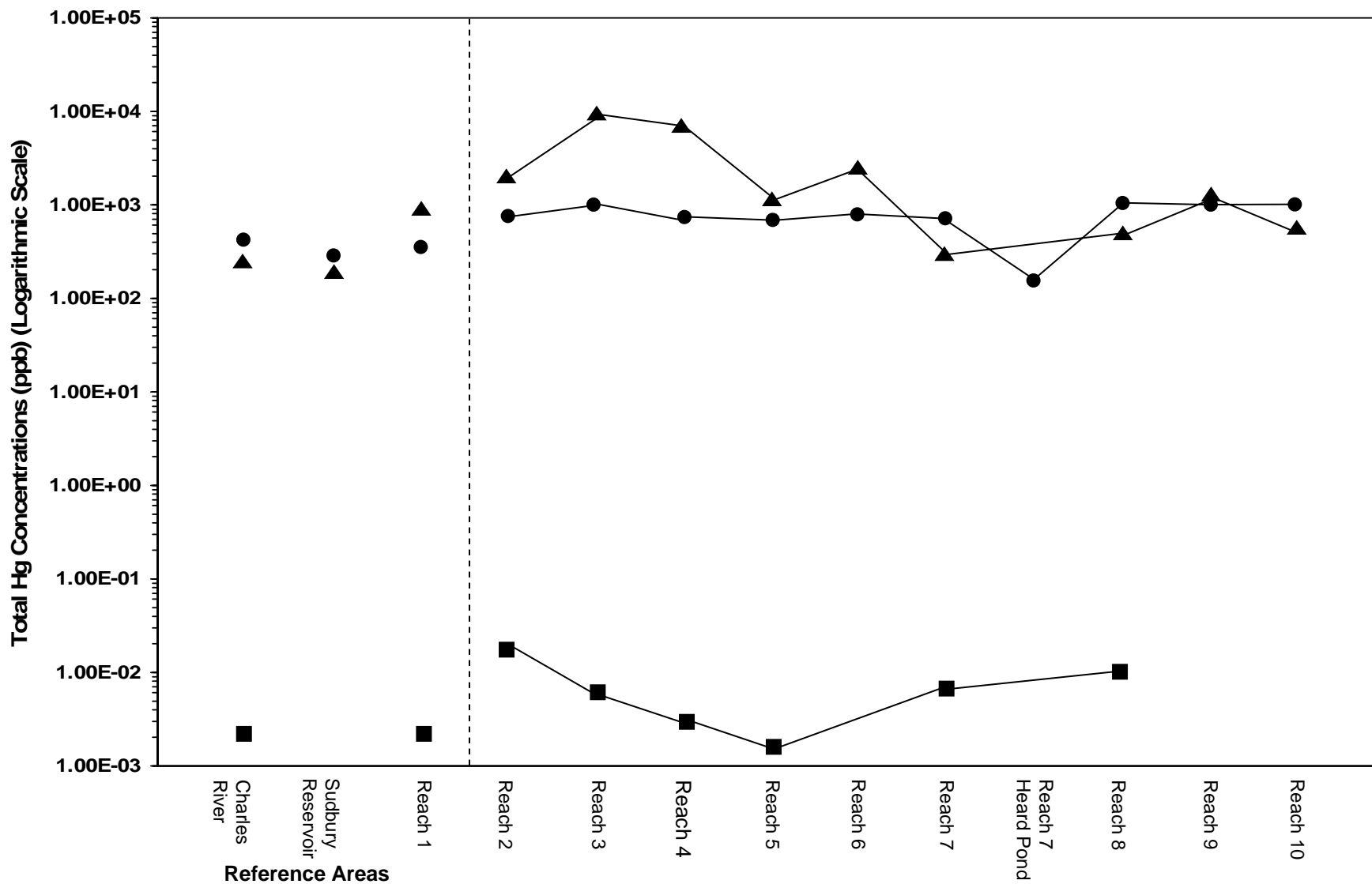


**Legend:**

- \* - Largemouth bass (n=47)
- - Bullhead (n=47)
- - Yellow perch – size class A (n=28)
- - Yellow perch – size class B (n=162)
- ▲ - Yellow perch – size class C (n=168)
- △ - Yellow perch – size class D (n=51)
- × - Bluegill – size class A (n=126)
- ◆ - Bluegill size class B (n=33)
- ◇ - Bluegill – size class C (n=5)
- - White sucker (n=12)
- - Pumpkinseed size class A (n=36)
- - Pumpkinseed – size class B (n=11)

**Nyanza Superfund Site OU IV  
Sudbury River Mercury Contamination**

**Figure 2-47  
Average Total Mercury Concentrations in Whole  
Body and Whole Body Reconstructed Fish Samples - 2003**

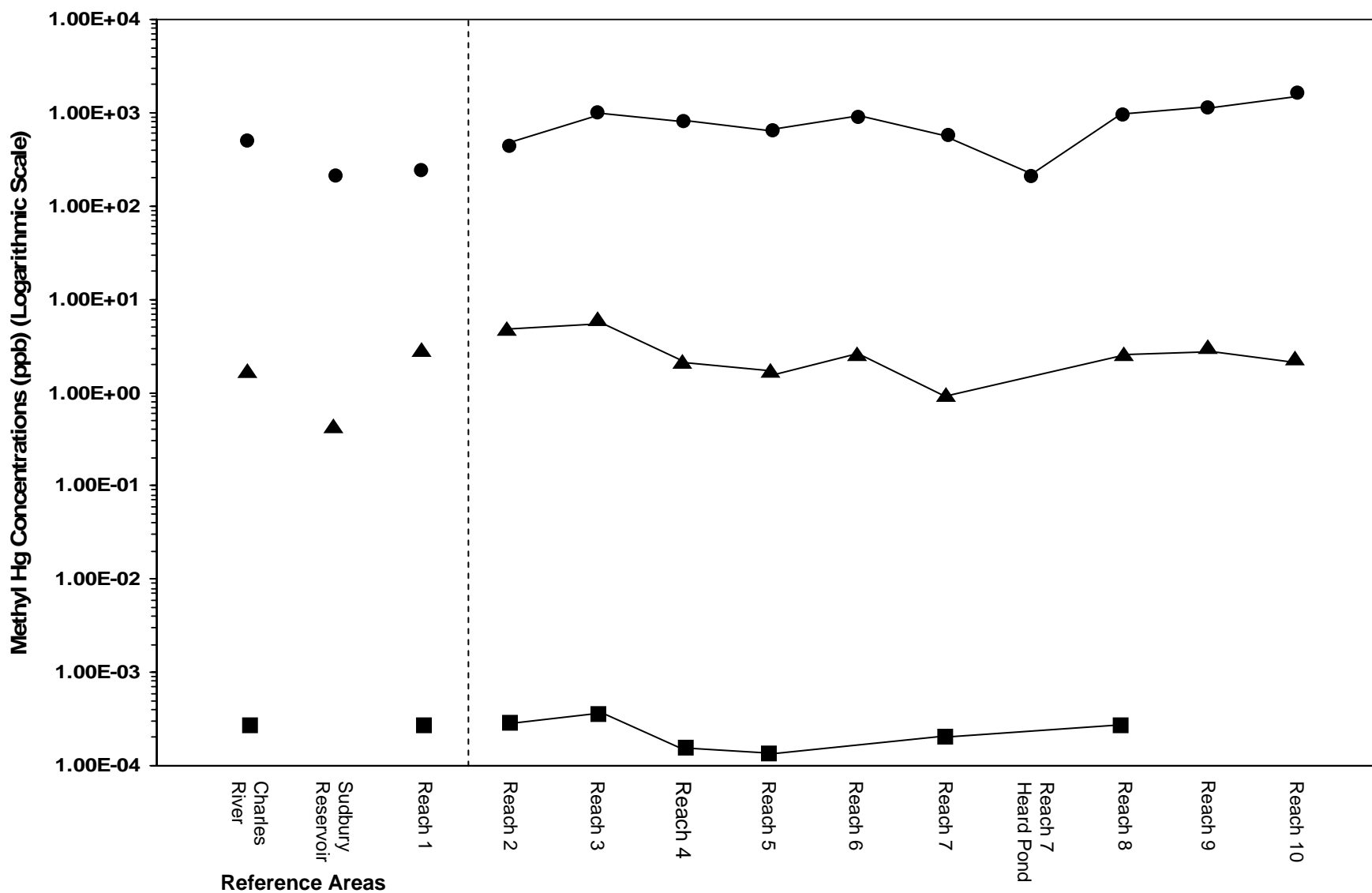


**Legend:**

- - Fish sample, whole body wet weight
- ▲ - Sediment sample, dry weight
- - Surface water sample

**Nyanza Superfund Site OU IV  
Sudbury River Mercury Contamination**

**Figure 2-48**  
**Average Total Mercury Concentrations in**  
**Largemouth Bass (2003 and 2004), Sediment (2003 and 2005),**  
**and Surface Water (2003) Samples**

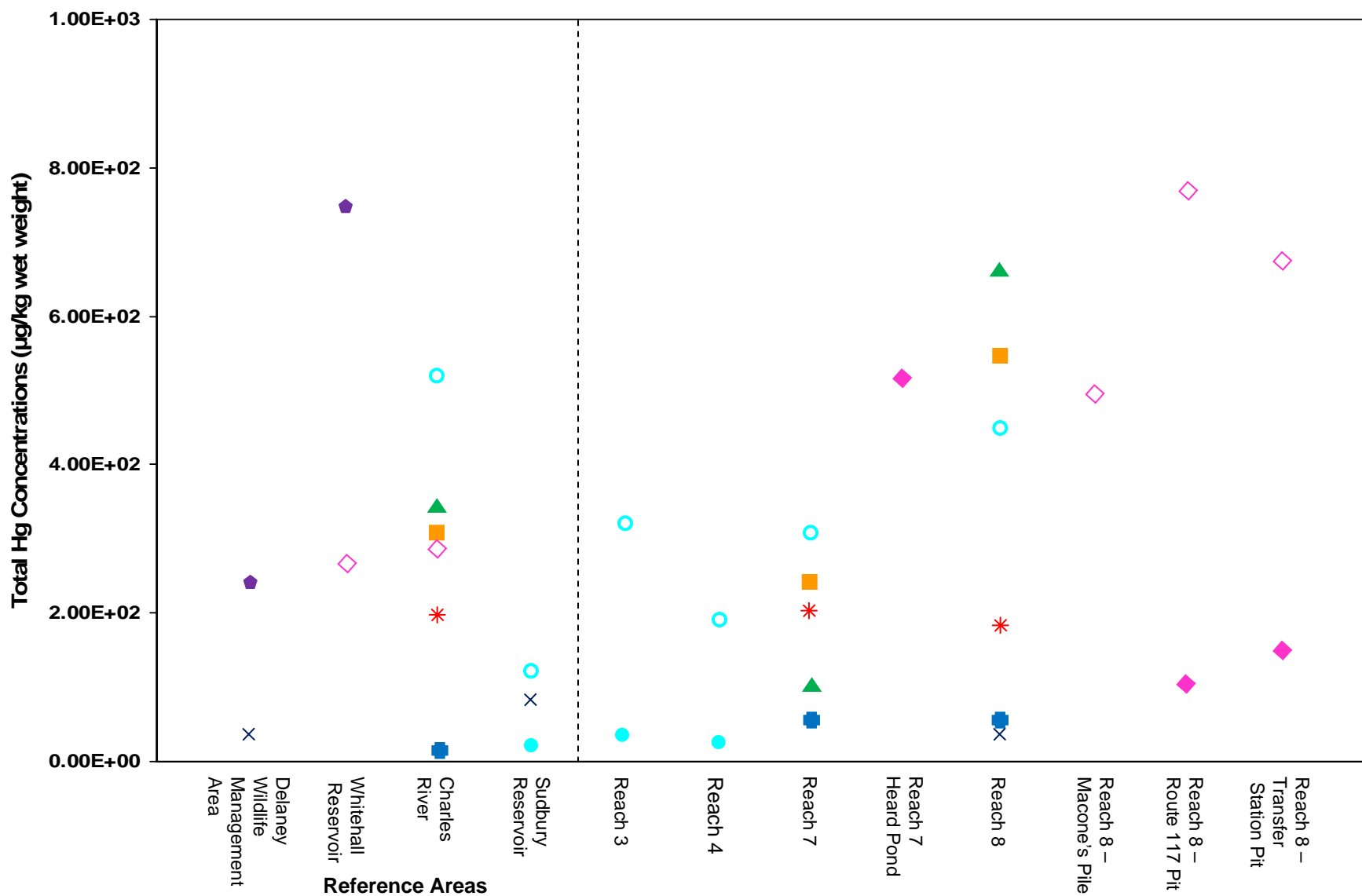


**Legend:**

- - Fish sample, whole body wet weight
- ▲ - Sediment sample, dry weight
- - Surface water sample

**Nyanza Superfund Site OU IV  
Sudbury River Mercury Contamination**

**Figure 2-49**  
**Average Methylmercury Concentrations in**  
**Largemouth Bass (2003 and 2004), Sediment (2003 and 2005),**  
**and Surface Water (2003) Samples**

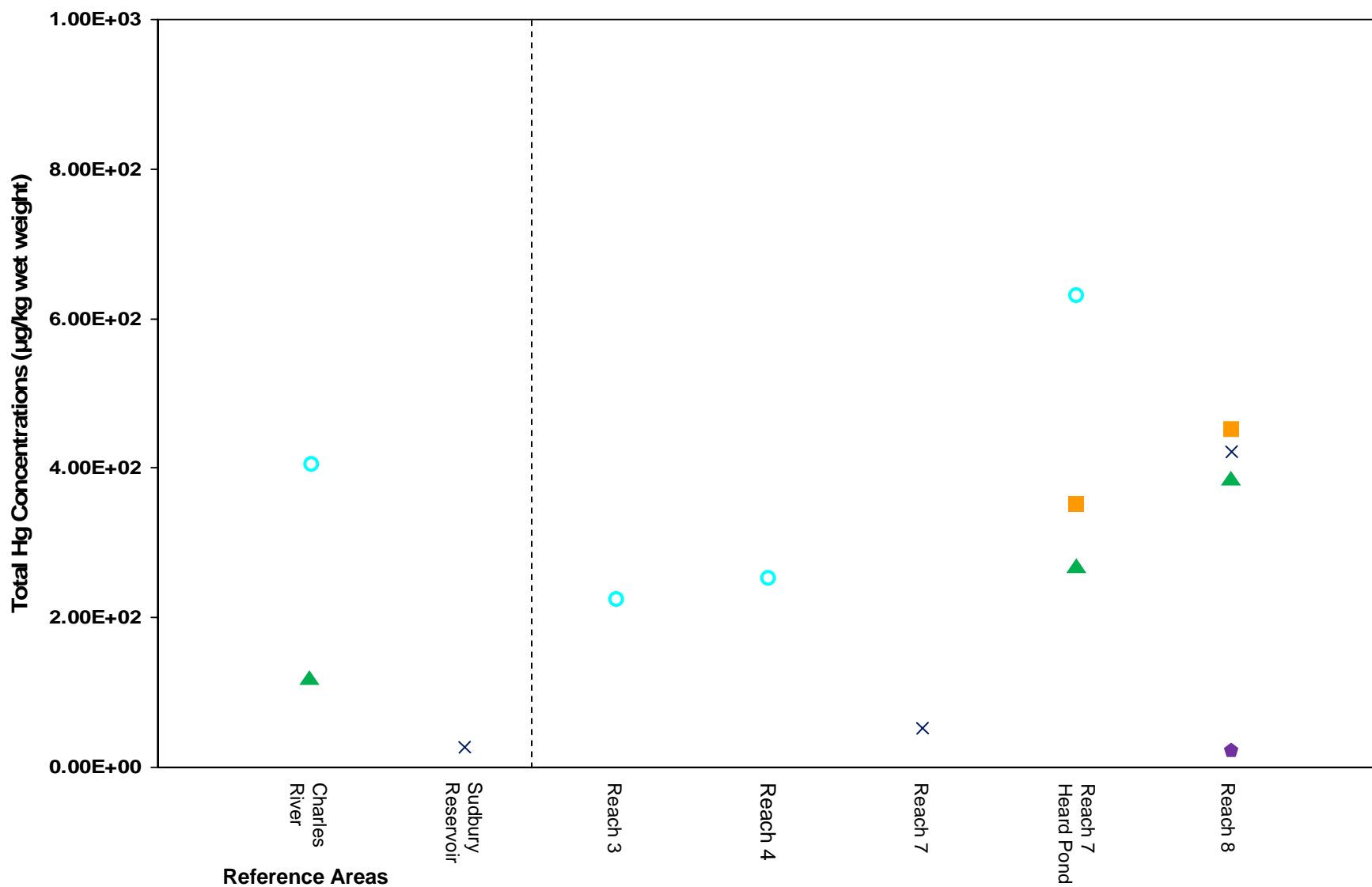


**Legend:**

- \* - Common yellowthroat (n=7)
- ▲ - Song sparrow (n=17)
- - Swamp sparrow (n=14)
- - Yellow warbler (n=8)
- ◆ - Hooded merganser (n=6)
- × - Wood duck (n=10)
- ◆ - Kingfisher, fledgling (n=2)
- ◇ - Kingfisher, adult (n=12)
- - Tree swallow, nestling (n=19)
- - Tree swallow, adult (n=54)

**Nyanza Superfund Site OU IV  
Sudbury River Mercury Contamination**

**Figure 2-50  
Average Total Mercury Concentrations in  
Avian Blood Samples - 2003**

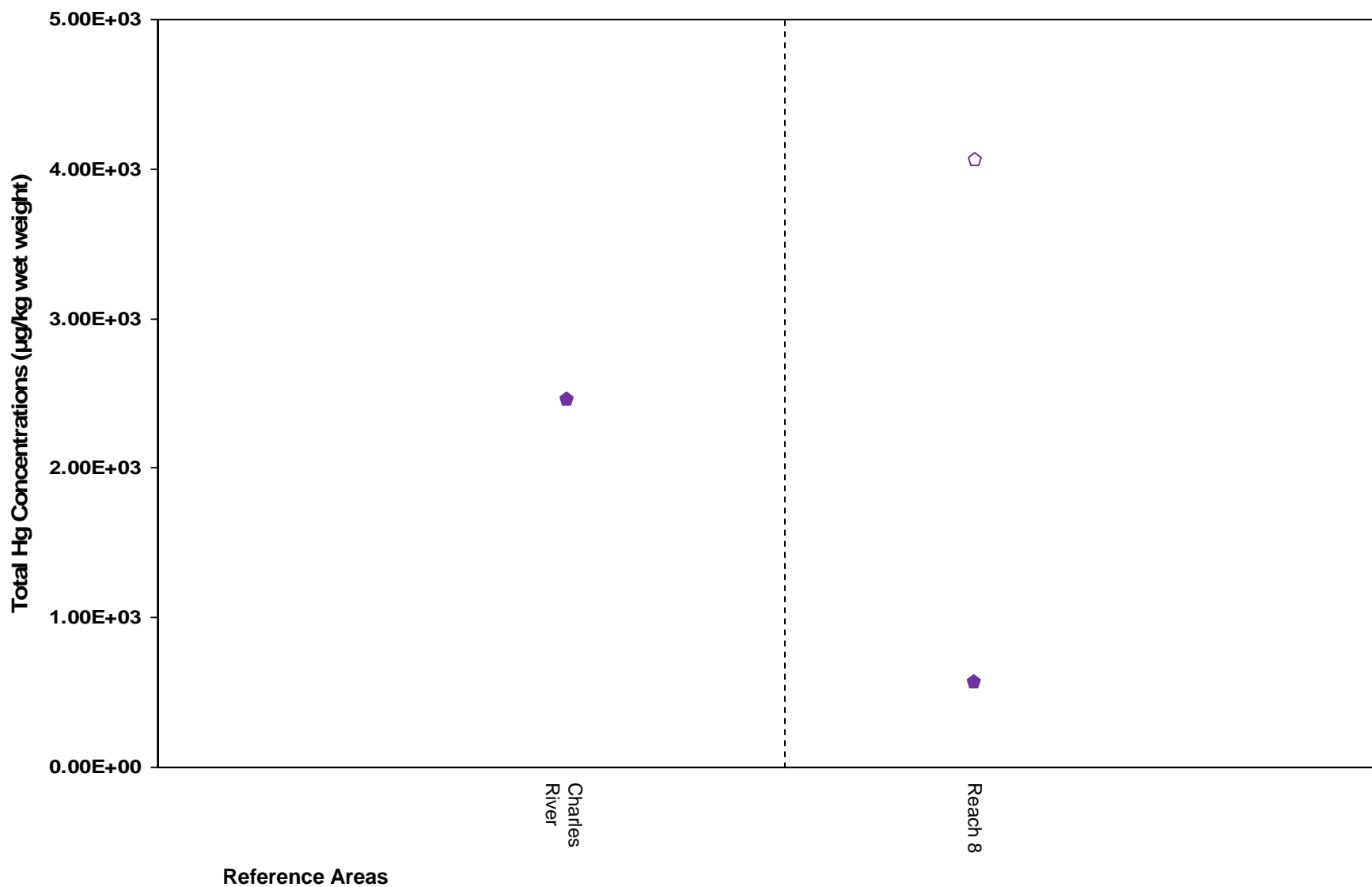


**Legend:**

- ▲ - Song sparrow (n=24)
- - Swamp sparrow (n=15)
- ◆ - Hooded merganser (n=1)
- × - Wood duck (n=3)
- - Tree swallow, adult (n=64)

***Nyanza Superfund Site OU IV  
Sudbury River Mercury Contamination***

**Figure 2-51  
Average Total Mercury Concentrations in  
Avian Blood Samples - 2004**

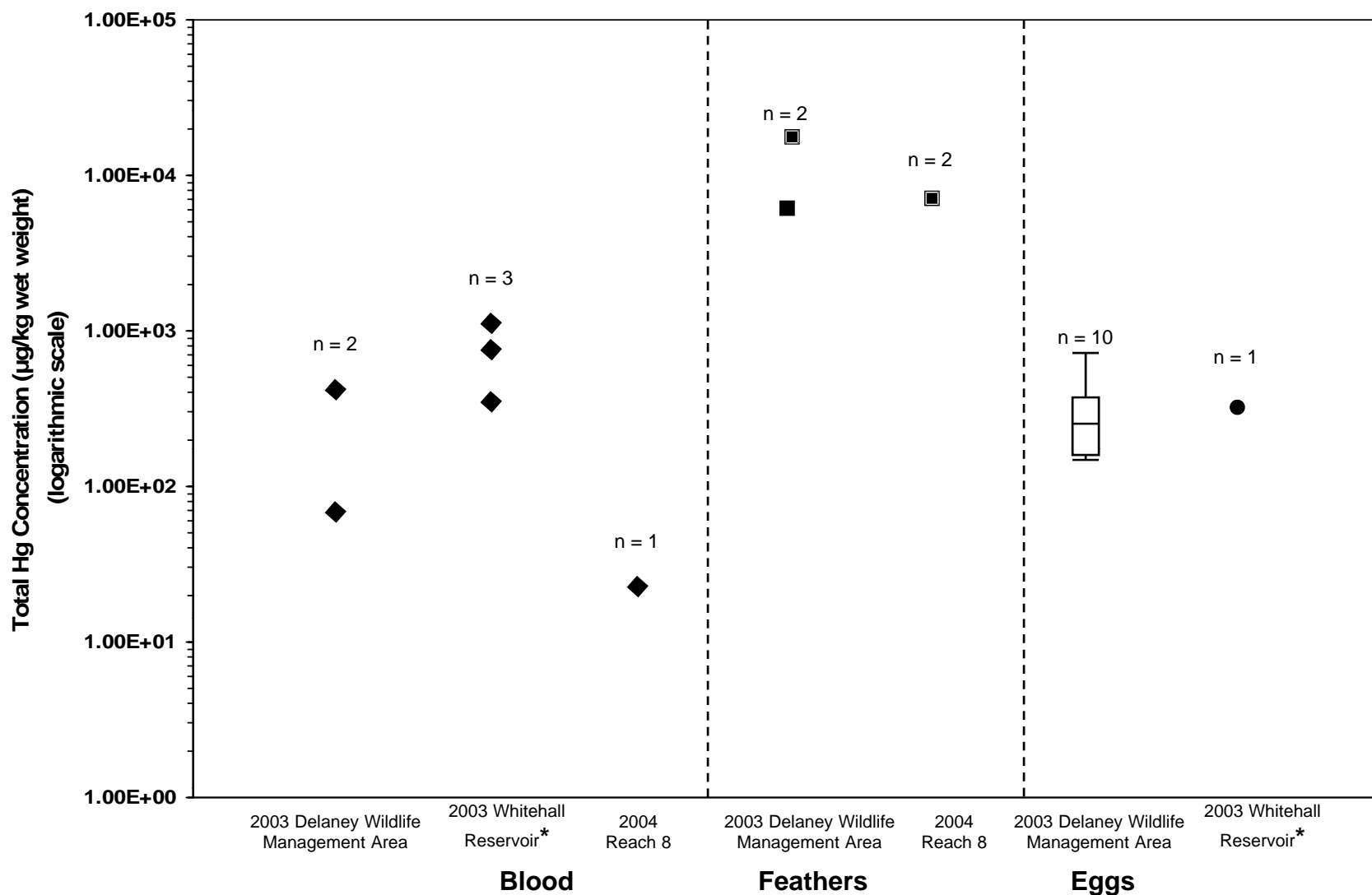


**Legend:**

- - Hooded merganser (n=10)
- - Red-winged blackbird (n=10)

***Nyanza Superfund Site OU IV  
Sudbury River Mercury Contamination***

**Figure 2-52  
Average Total Mercury Concentrations in  
Avian Blood Samples - 2005**



**Legend:**

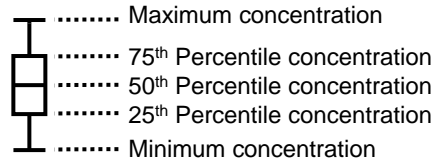
◆ - Blood sample

■ - Feather sample

● - Egg sample

Note: all blood samples from adult birds except for one sample in Whitehall Reservoir.

\*Includes data from a retrapped bird.

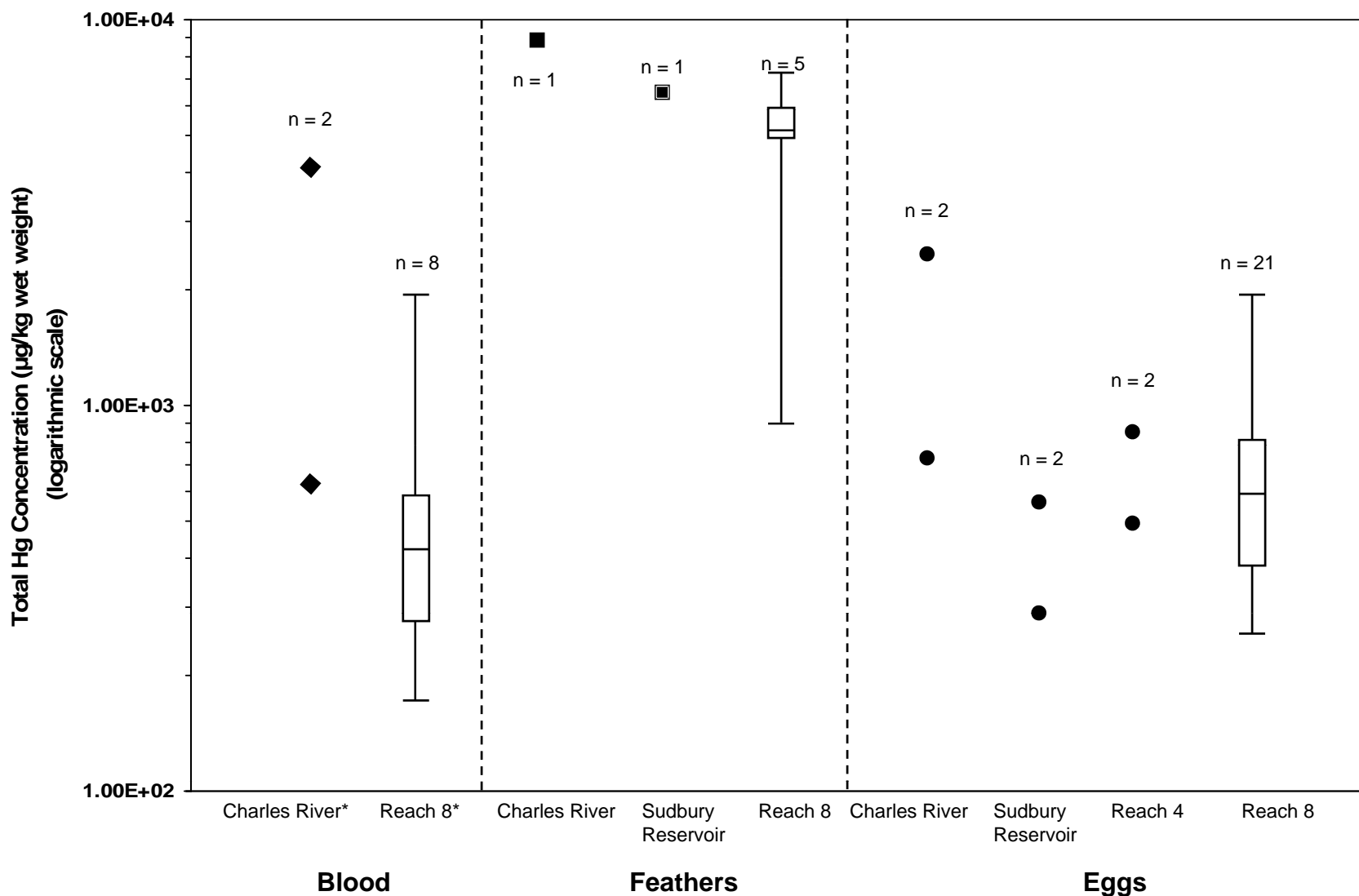


***Nyanza Superfund Site OU IV  
 Sudbury River Mercury Contamination***

**Figure 2-53**

**Total Mercury Concentrations in  
 Hooded Merganser Blood, Feather,  
 and Egg Samples – 2003 & 2004**





**Legend:**

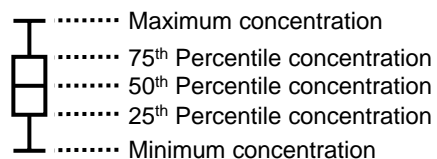
◆ - Blood sample

■ - Feather sample

● - Egg sample

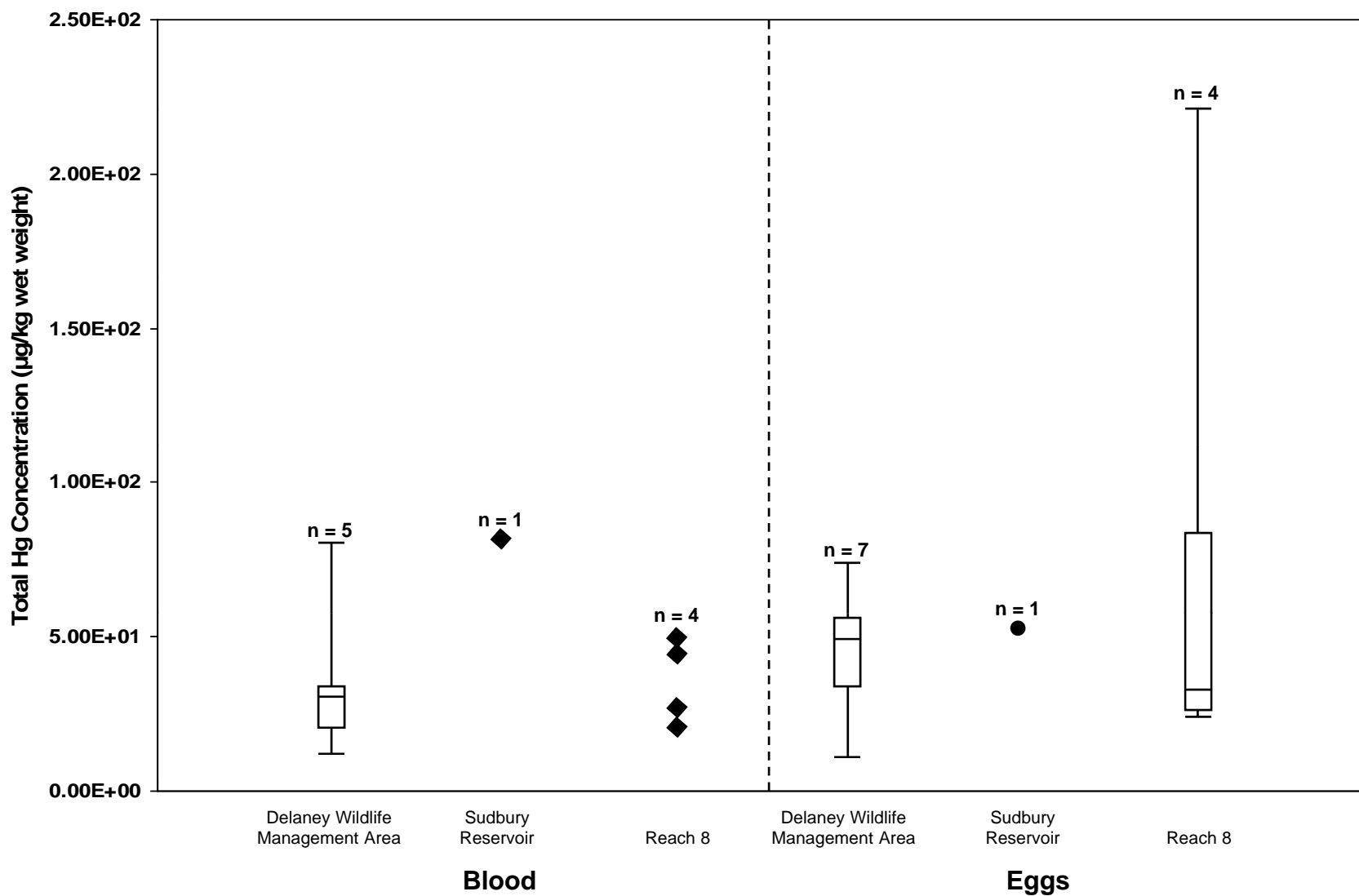
Note: all samples from adult birds.

\*Includes data from retrapped birds (Charles River – 1 sample; Reach 8 – 4 samples).



**Nyanza Superfund Site OU IV  
Sudbury River Mercury Contamination**

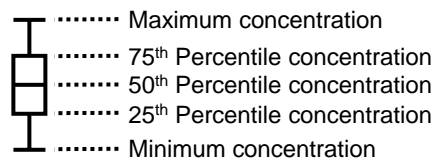
**Figure 2-54  
Total Mercury Concentrations in  
Hooded Merganser Blood, Feather, and Egg Samples - 2005**



**Legend:**

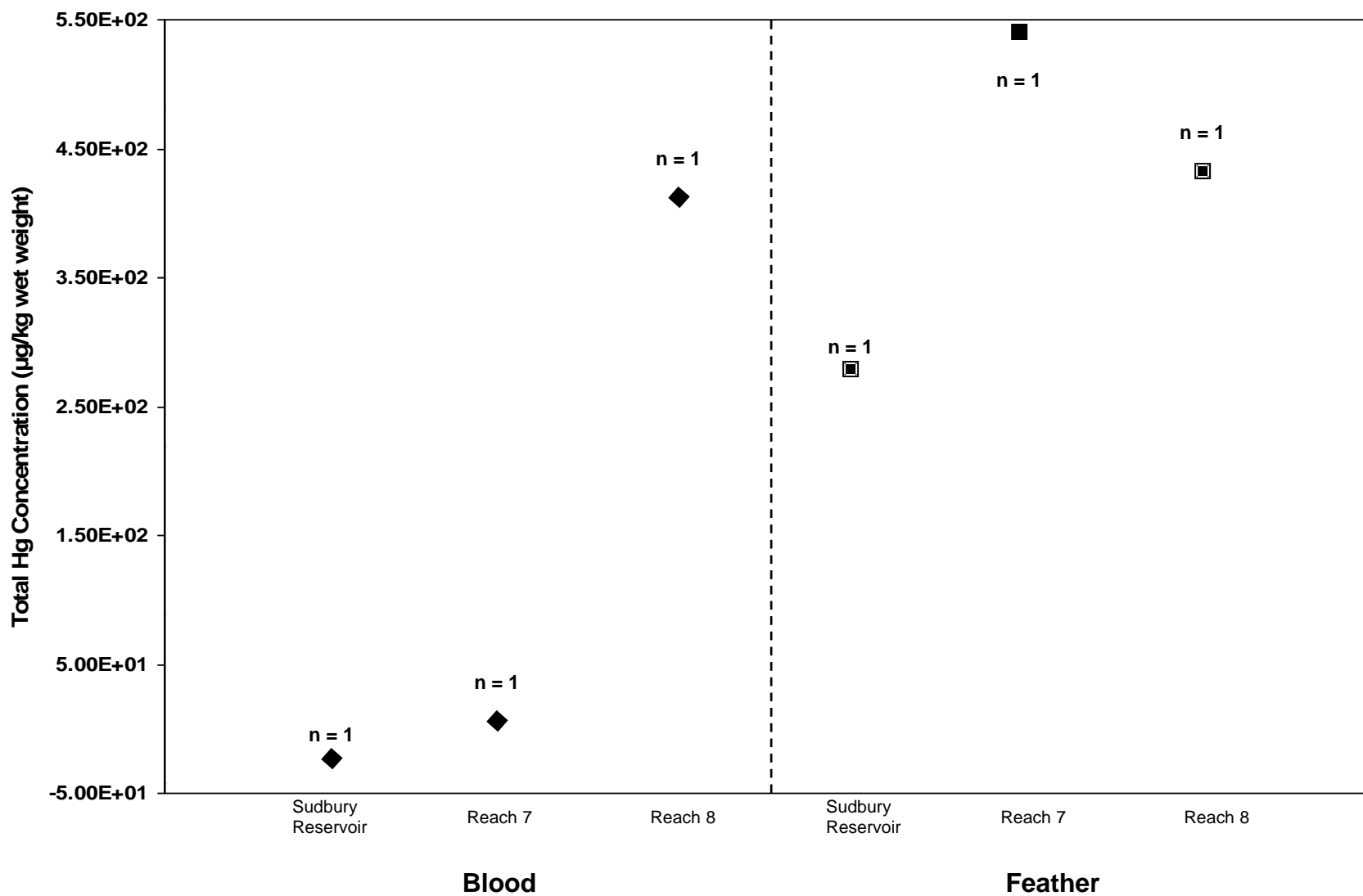
- ◆ - Blood sample
- - Egg sample

Note: all blood samples from adult birds.



***Nyanza Superfund Site OU IV  
Sudbury River Mercury Contamination***

**Figure 2-55  
Total Mercury Concentrations in  
Wood Duck Blood and Egg Samples - 2003**



**Legend:**

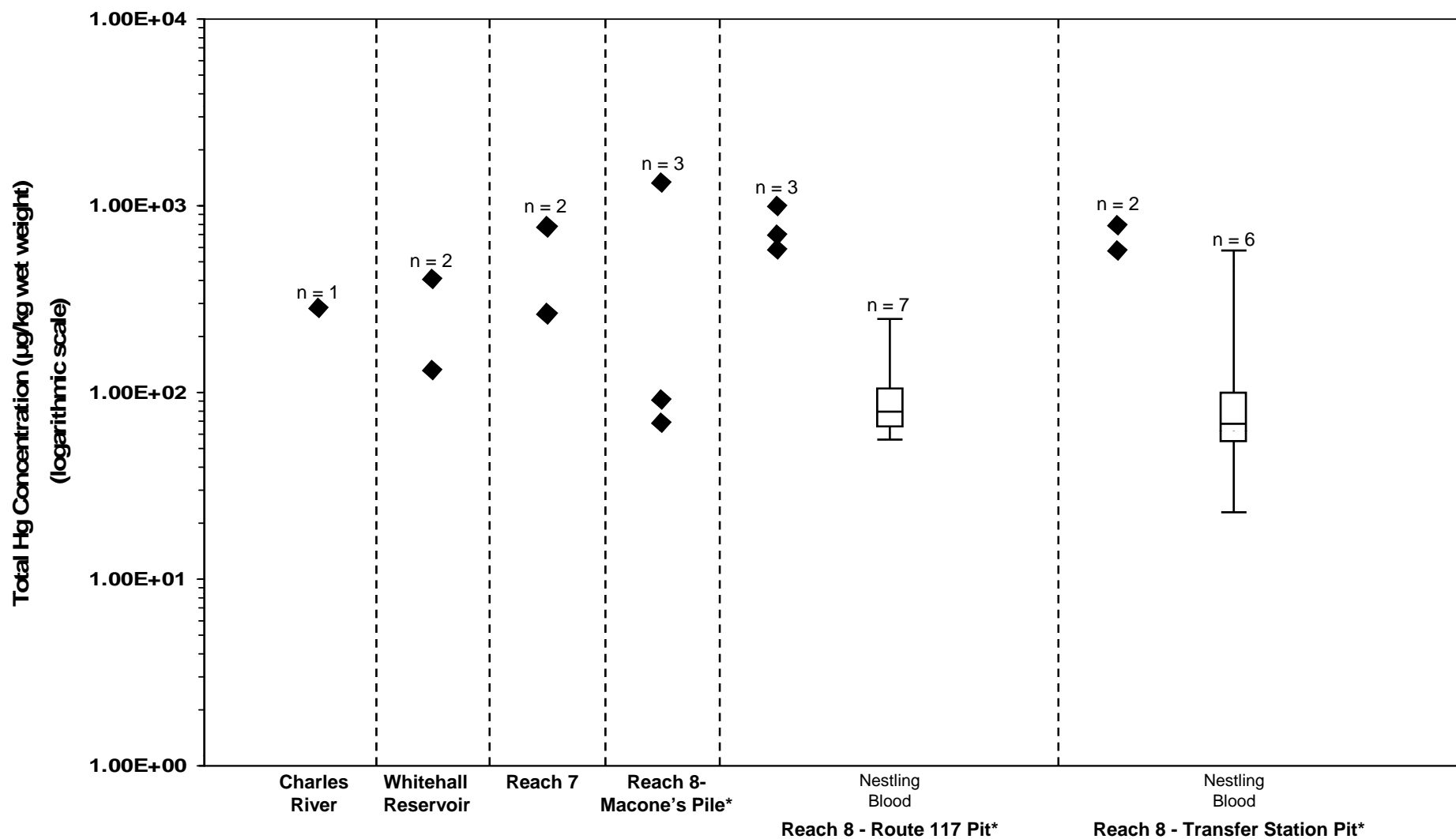
◆ - Blood sample

▣ - Feather sample

Note: all samples from adult birds.

***Nyanza Superfund Site OU IV  
Sudbury River Mercury Contamination***

**Figure 2-56  
Total Mercury Concentrations in  
Wood Duck Blood and Feather Samples - 2004**

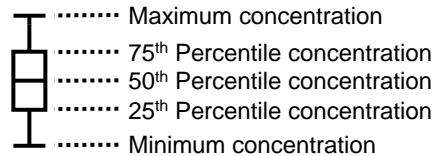


**Legend:**

- ◆ - Adult blood sample
- ◆ - Juvenile blood sample

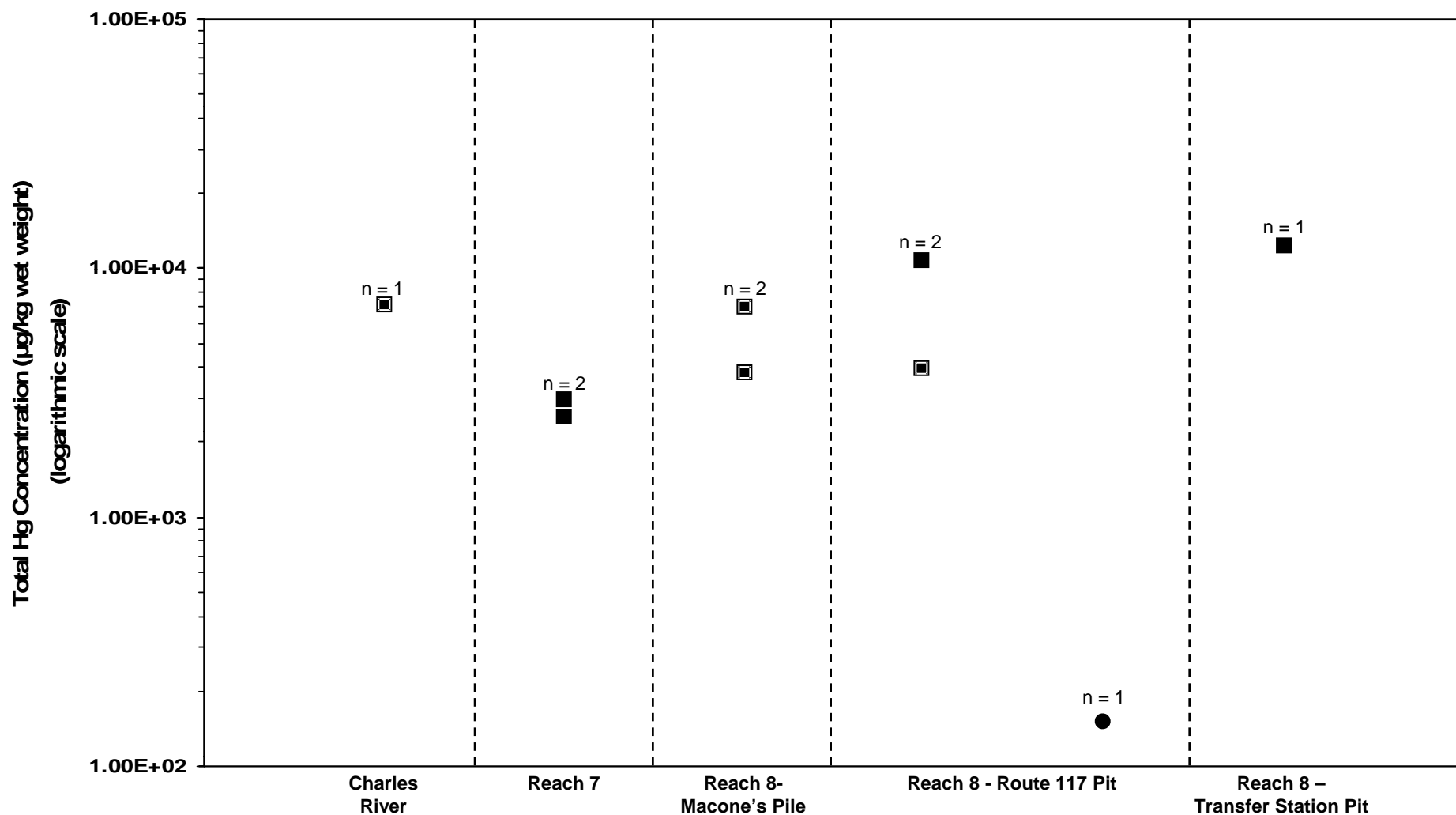
Note – combined represents adults and juveniles.

\*Includes data from retrapped birds (Macone's - 1 adult; Route 117 Pit – 1 nestling and 1 adult; Transfer Station Pit – 1 adult).



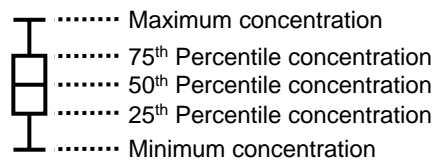
**Nyanza Superfund Site OU IV  
Sudbury River Mercury Contamination**

**Figure 2-57  
Total Mercury Concentrations in  
Belted Kingfisher Blood Samples - 2003**



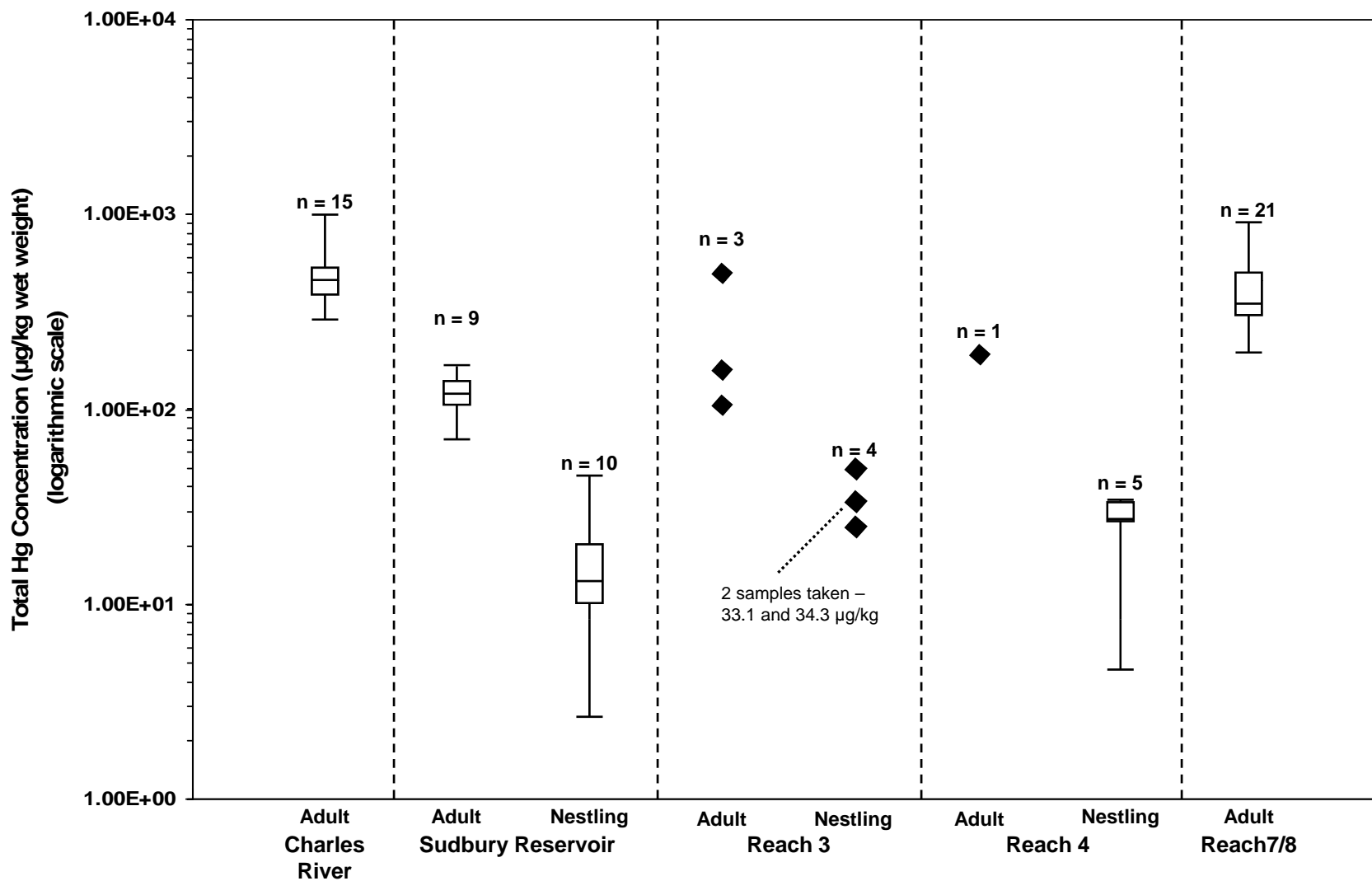
**Legend:**

- - Adult feather sample
- - Juvenile feather sample
- - Egg sample



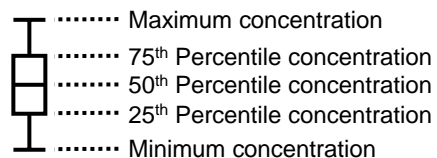
***Nyanza Superfund Site OU IV  
Sudbury River Mercury Contamination***

**Figure 2-58  
Total Mercury Concentrations in  
Belted Kingfisher Feather and Egg Samples - 2003**



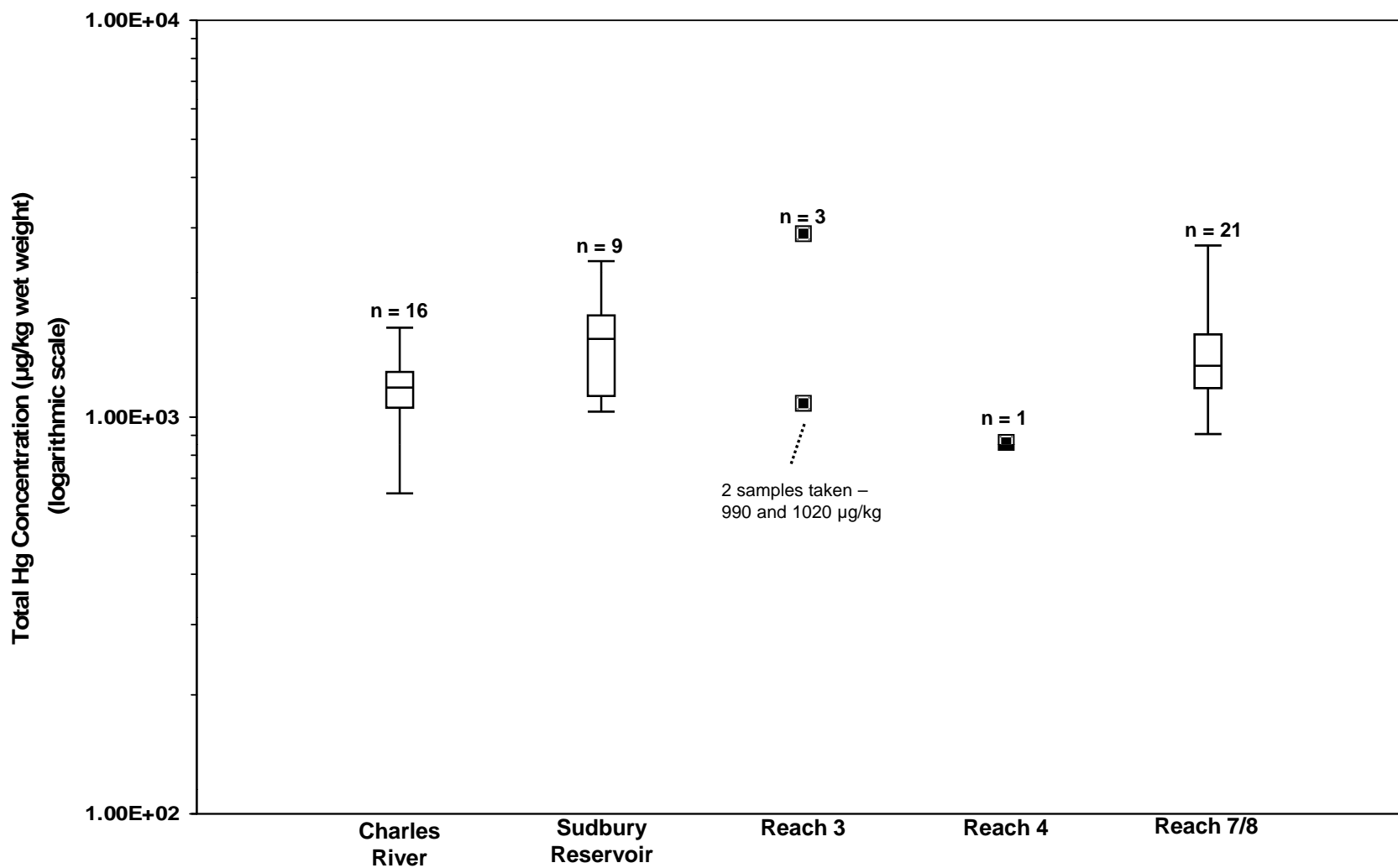
**Legend:**

- ◆ - Blood sample
- ◆ - Nestling blood sample



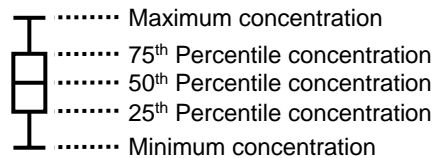
**Nyanza Superfund Site OU IV  
Sudbury River Mercury Contamination**

**Figure 2-59  
Total Mercury Concentrations in  
Tree Swallow Blood Samples - 2003**



**Legend:**

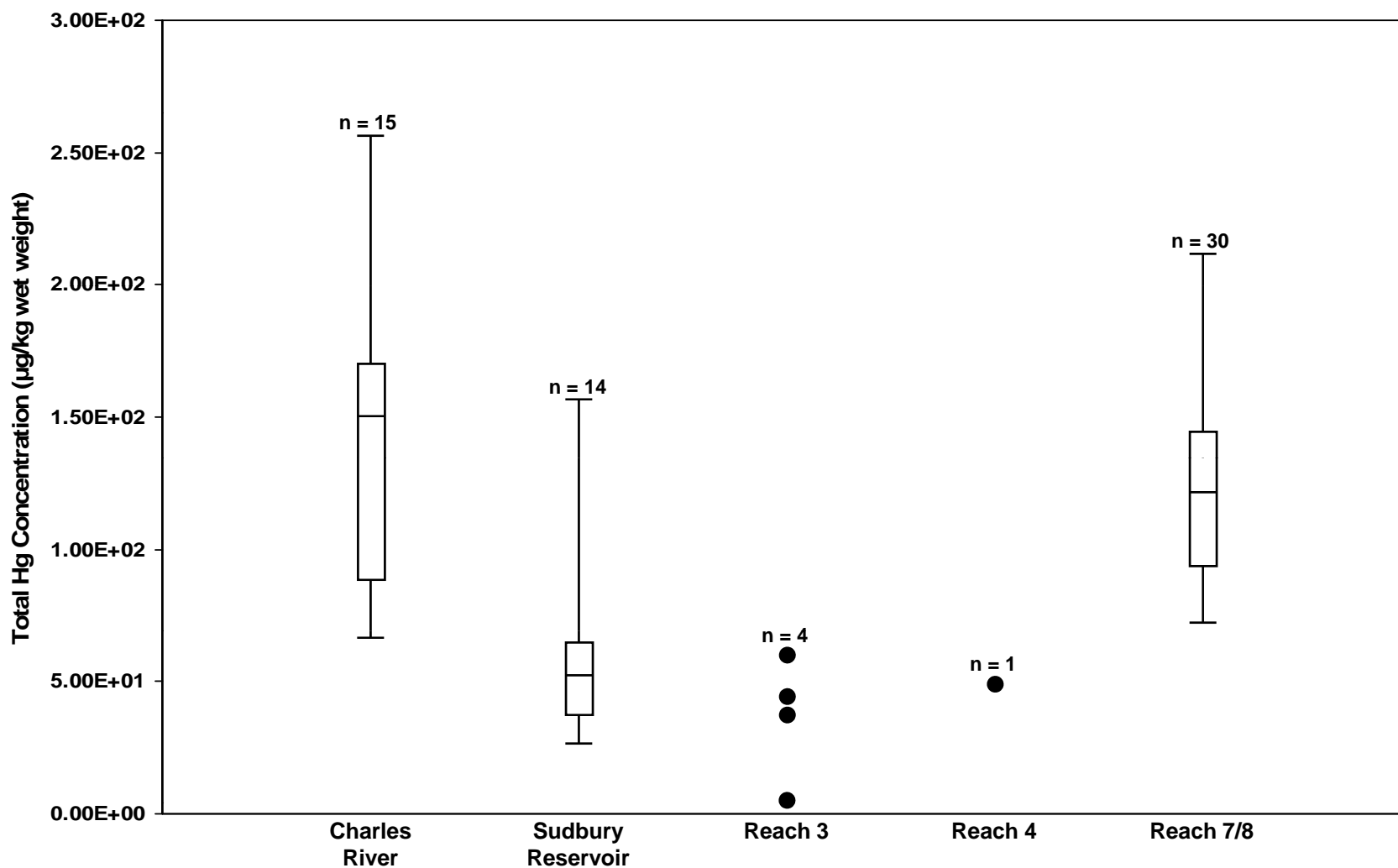
■ - Feather sample



Note: all feather samples from adult birds.

***Nyanza Superfund Site OU IV  
Sudbury River Mercury Contamination***

**Figure 2-60  
Total Mercury Concentrations in  
Tree Swallow Feather Samples - 2003**



**Legend:**

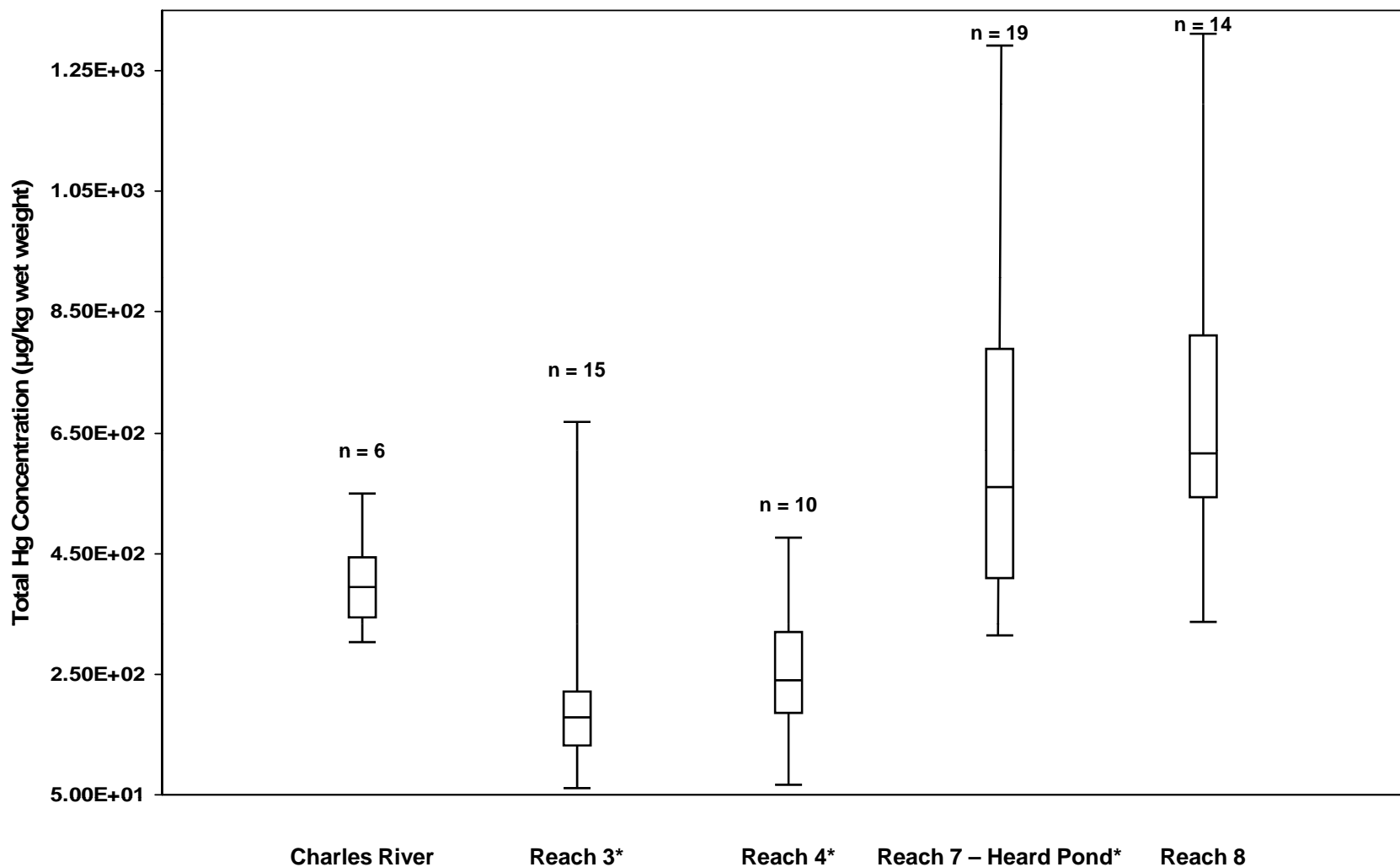
● - Egg sample

..... Maximum concentration  
 ..... 75<sup>th</sup> Percentile concentration  
 ..... 50<sup>th</sup> Percentile concentration  
 ..... 25<sup>th</sup> Percentile concentration  
 ..... Minimum concentration

***Nyanza Superfund Site OU IV  
Sudbury River Mercury Contamination***

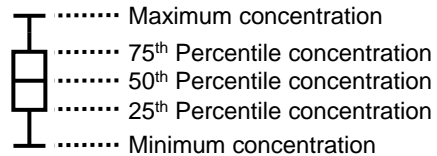
**Figure 2-61  
Total Mercury Concentrations in  
Tree Swallow Egg Samples - 2003**





**Legend:**

◆ - Adult blood sample

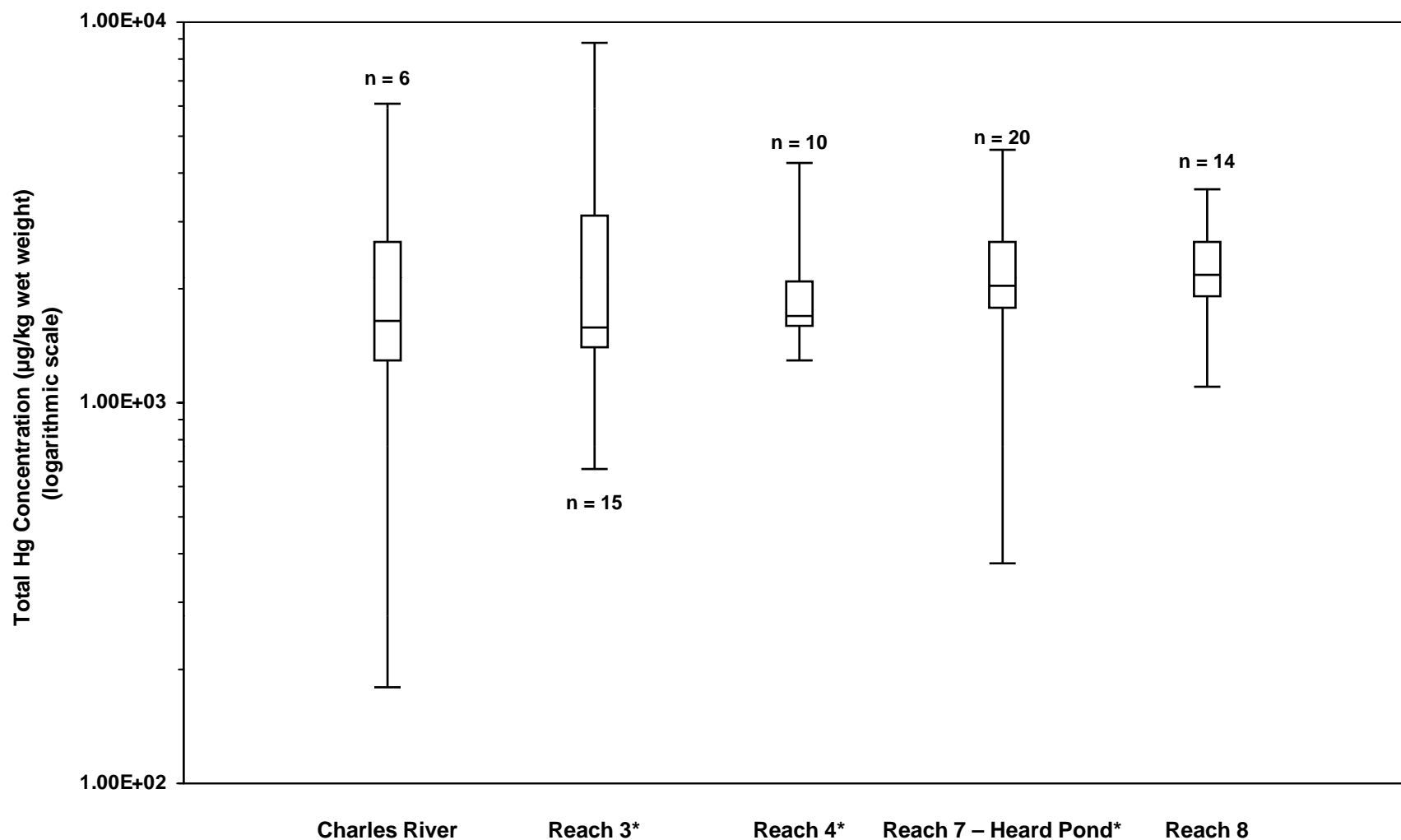


Note – all samples from adult birds.

\*Includes data from retrapped birds (Reach 3 – 4 birds; Reach 4 – 1 bird; and Reach 7 – Heard Pond – 2 birds).

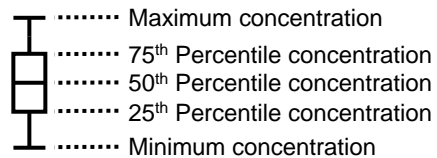
***Nyanza Superfund Site OU IV  
 Sudbury River Mercury Contamination***

**Figure 2-62  
 Total Mercury Concentrations in  
 Tree Swallow Blood Samples - 2004**



**Legend:**

■ - Adult feather sample

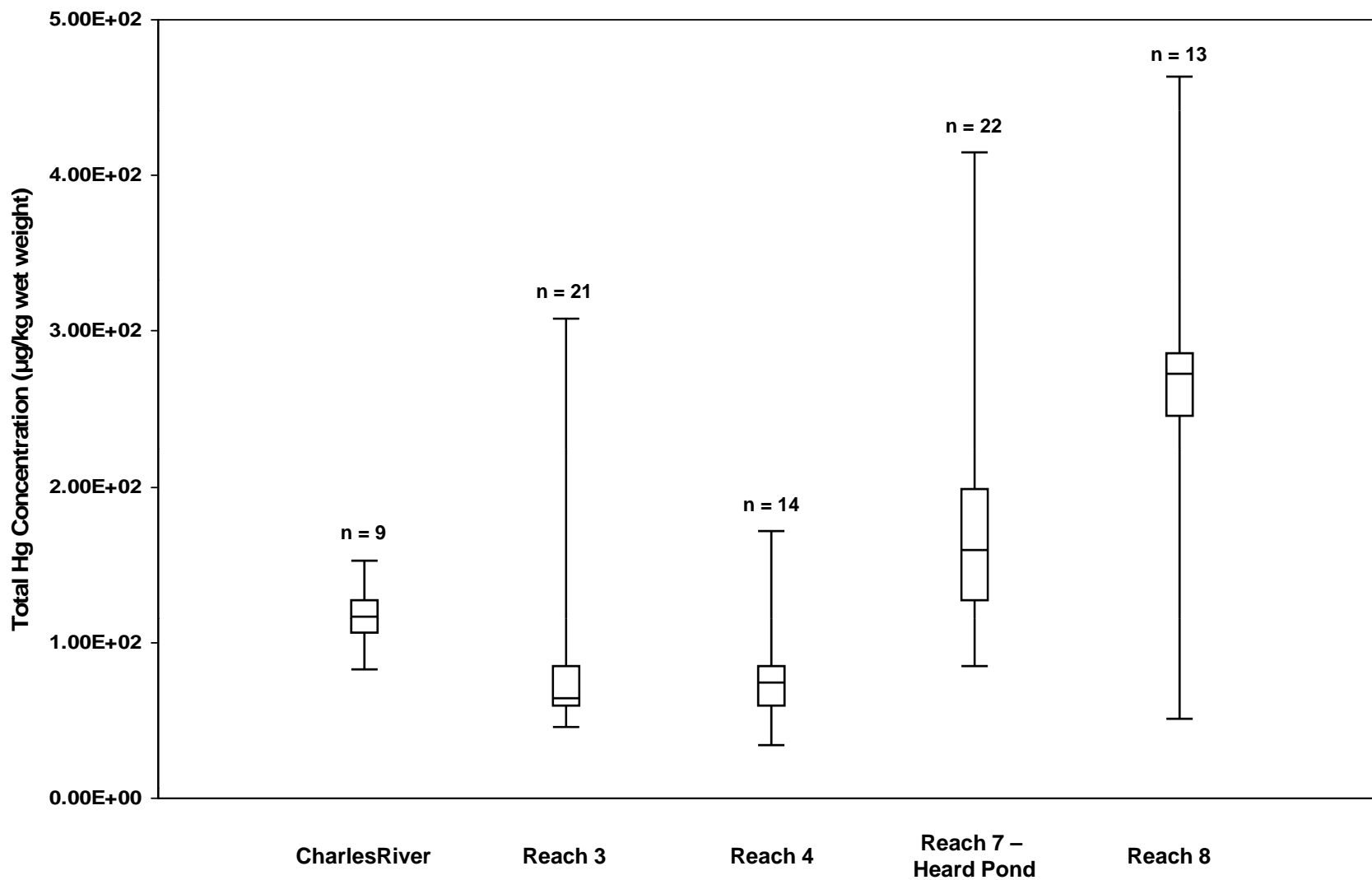


Note: All feather samples from adult birds.

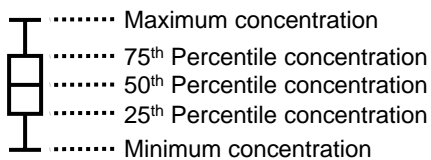
\*Includes data from retrapped birds (Reach 3 – 4 birds; Reach 4 – 1 bird; and Reach 7 – Heard Pond – 1 bird).

***Nyanza Superfund Site OU IV  
Sudbury River Mercury Contamination***

**Figure 2-63  
Total Mercury Concentrations in  
Tree Swallow Feather Samples - 2004**

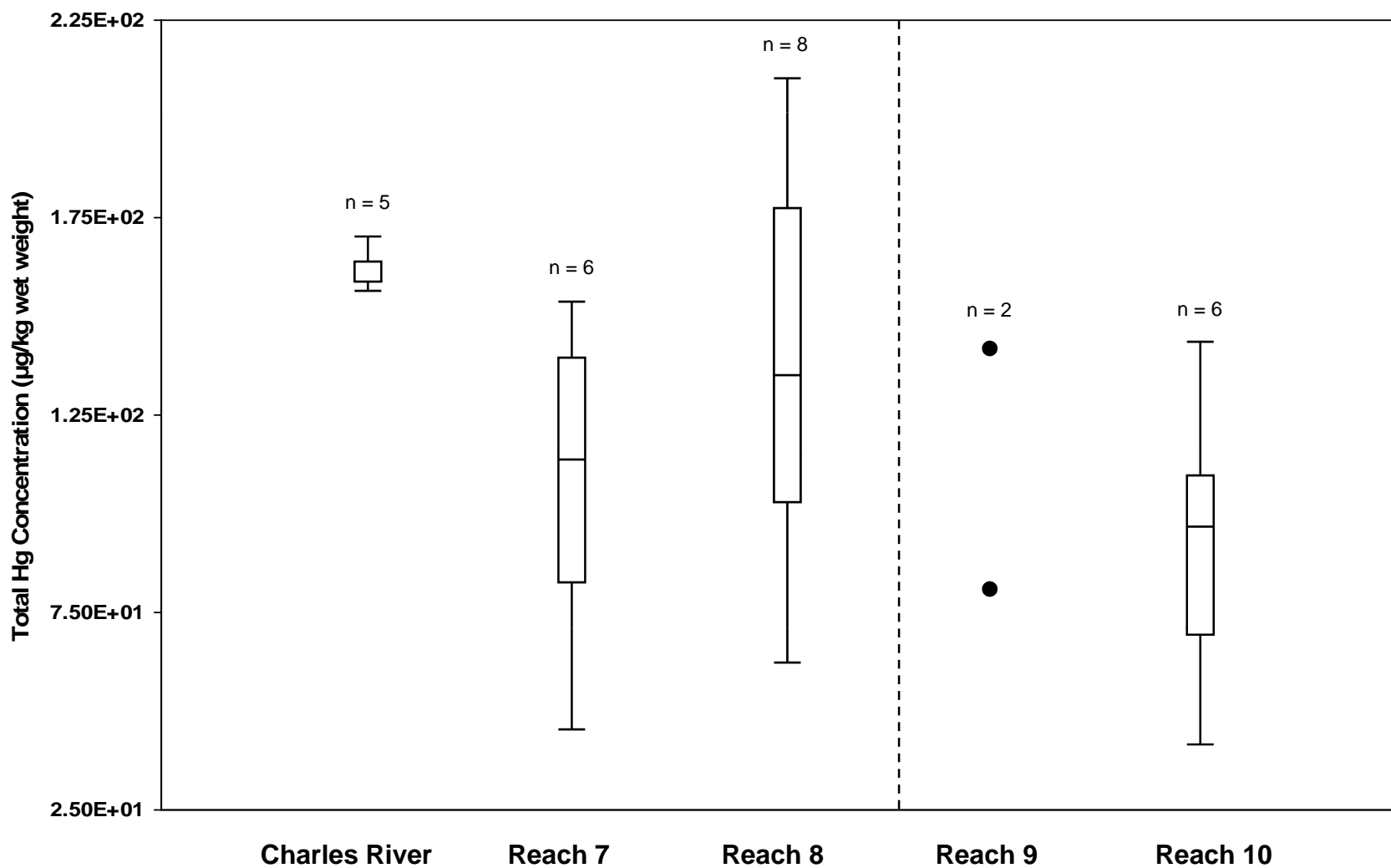


**Legend:**



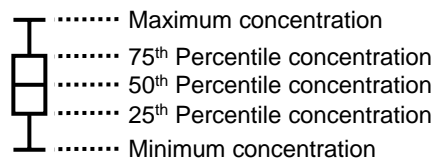
***Nyanza Superfund Site OU IV  
Sudbury River Mercury Contamination***

**Figure 2-64  
Total Mercury Concentrations in  
Tree Swallow Egg Samples - 2004**



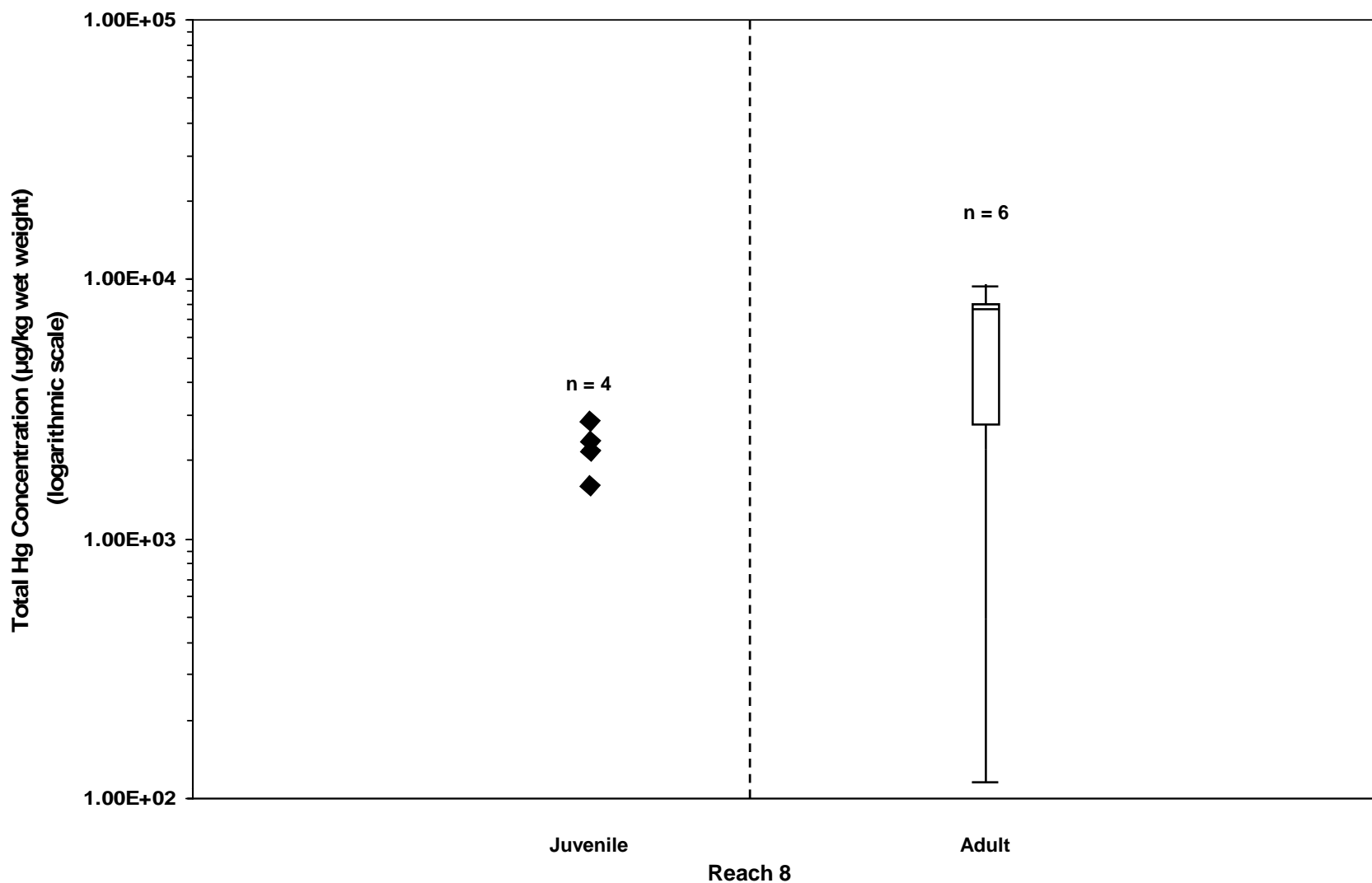
**Legend:**

● - Egg sample



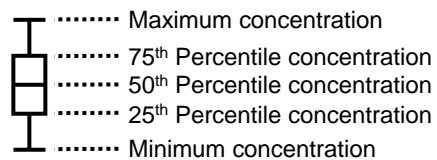
***Nyanza Superfund Site OU IV  
Sudbury River Mercury Contamination***

**Figure 2-65  
Total Mercury Concentrations in  
Eastern Kingbird Egg Samples - 2003**



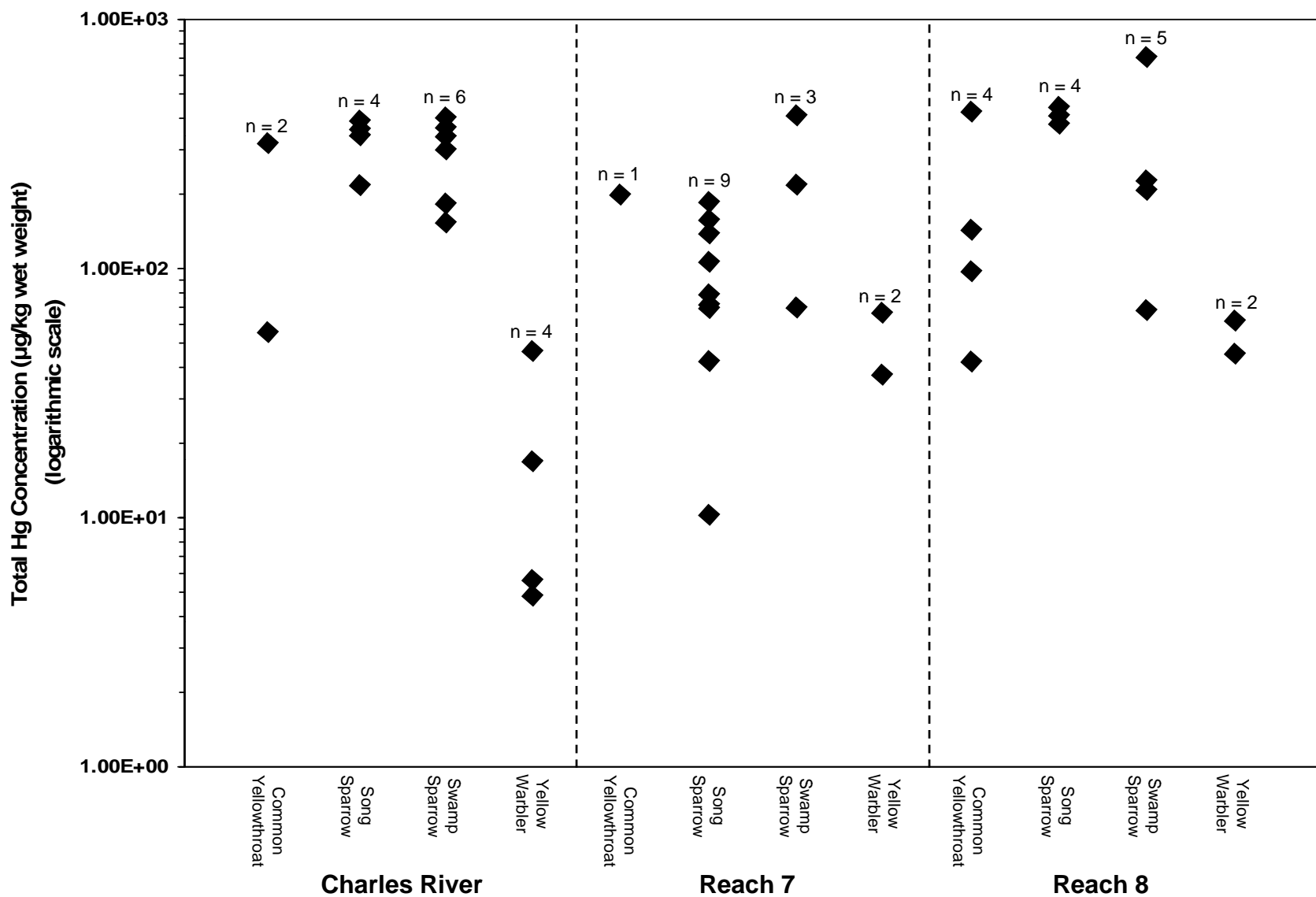
**Legend:**

◆ - Juvenile Blood sample



***Nyanza Superfund Site OU IV  
Sudbury River Mercury Contamination***

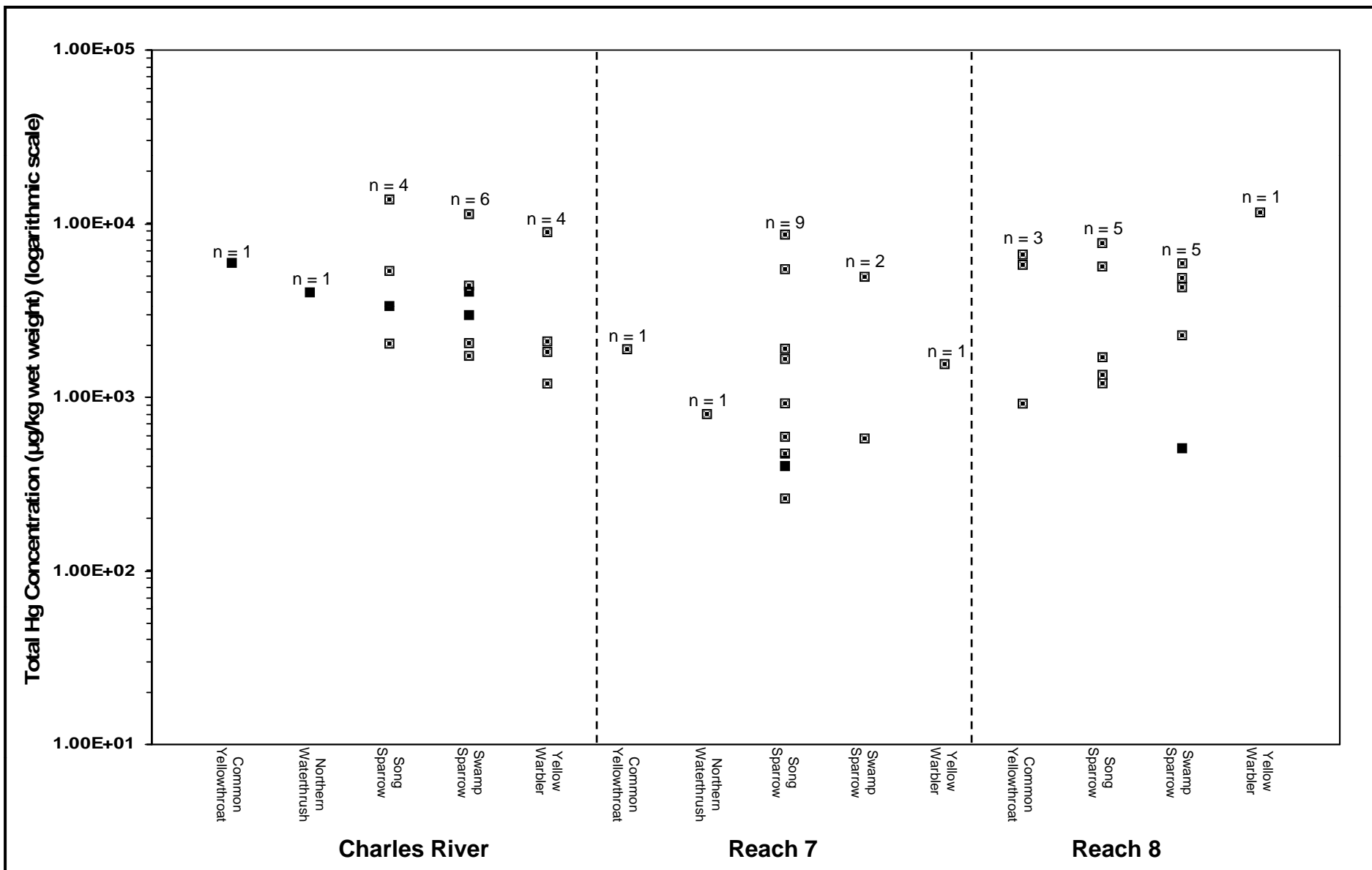
**Figure 2-66  
Total Mercury Concentrations in  
Red-Winged Blackbird Blood Samples - 2005**



**Legend:**  
 ◆ - Blood sample

***Nyanza Superfund Site OU IV  
 Sudbury River Mercury Contamination***

**Figure 2-67  
 Total Mercury Concentrations in  
 Marshbird Blood Samples - 2003**



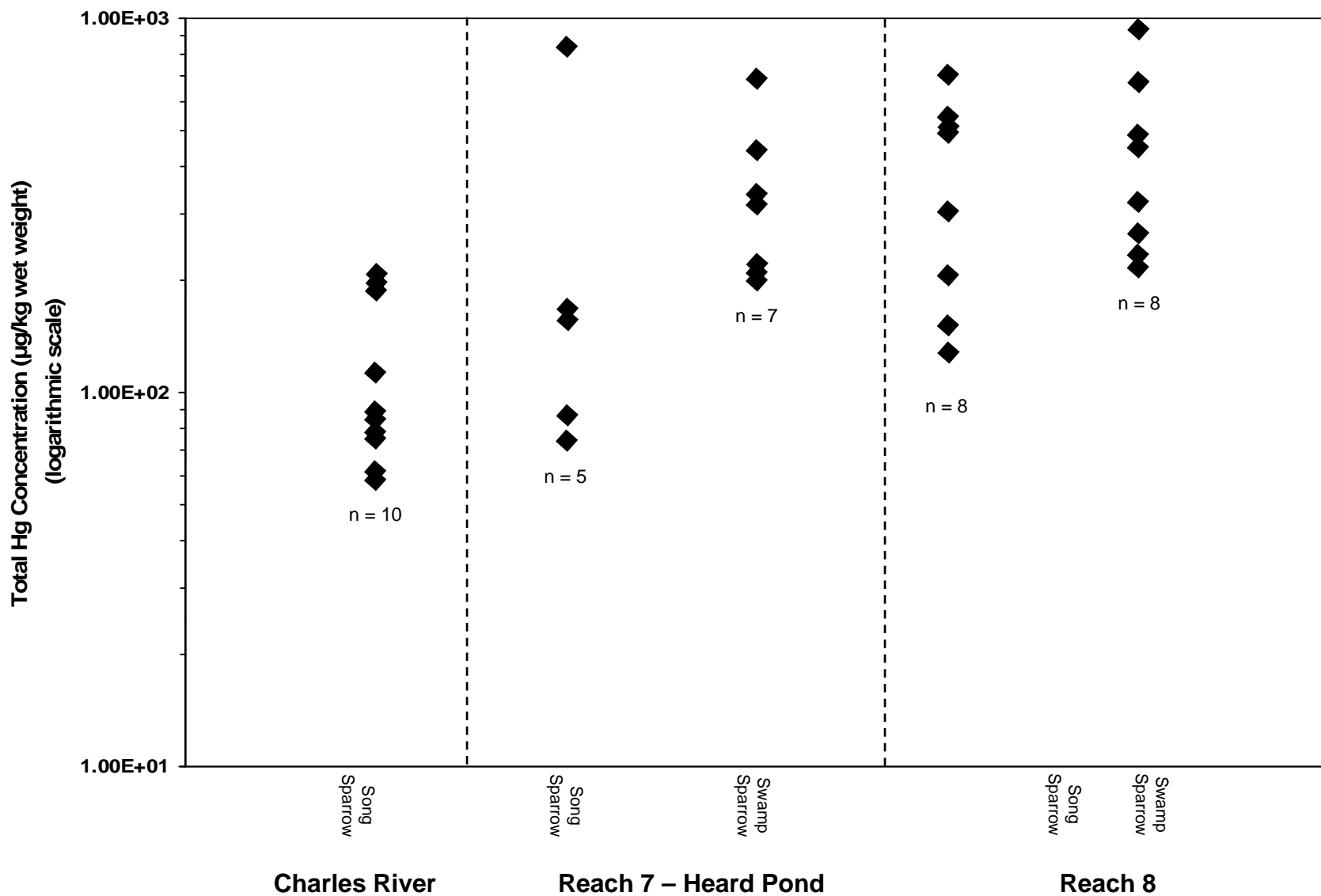
**Legend:**

■ - Feather sample

Note: all feather samples from adult birds.

***Nyanza Superfund Site OU IV  
Sudbury River Mercury Contamination***

**Figure 2-68  
Total Mercury Concentrations in  
Marshbird Feather Samples - 2003**



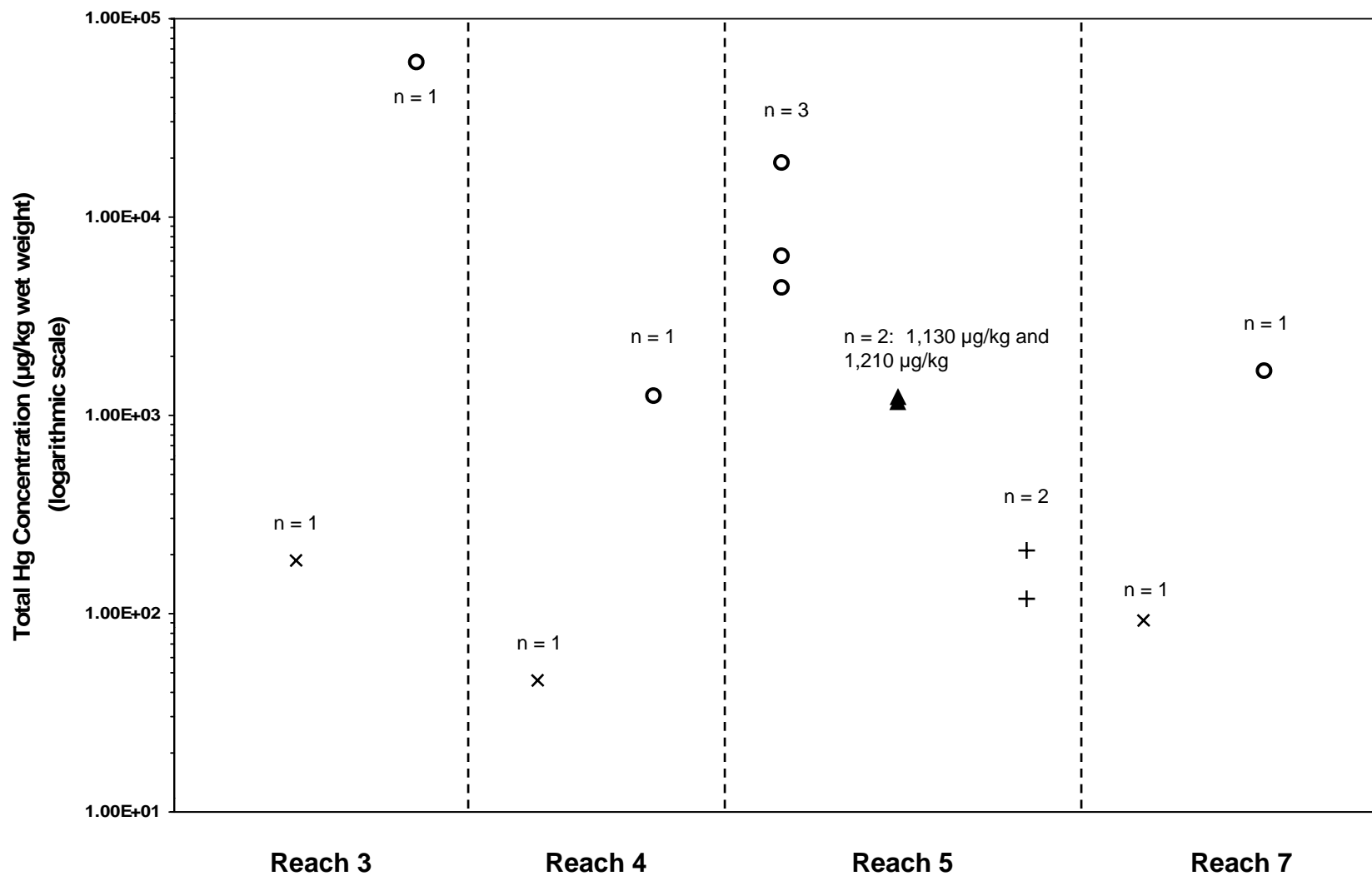
Legend:

◆ - Blood sample

***Nyanza Superfund Site OU IV  
Sudbury River Mercury Contamination***

**Figure 2-69  
Total Mercury Concentrations in  
Marshbird Blood Samples - 2004**



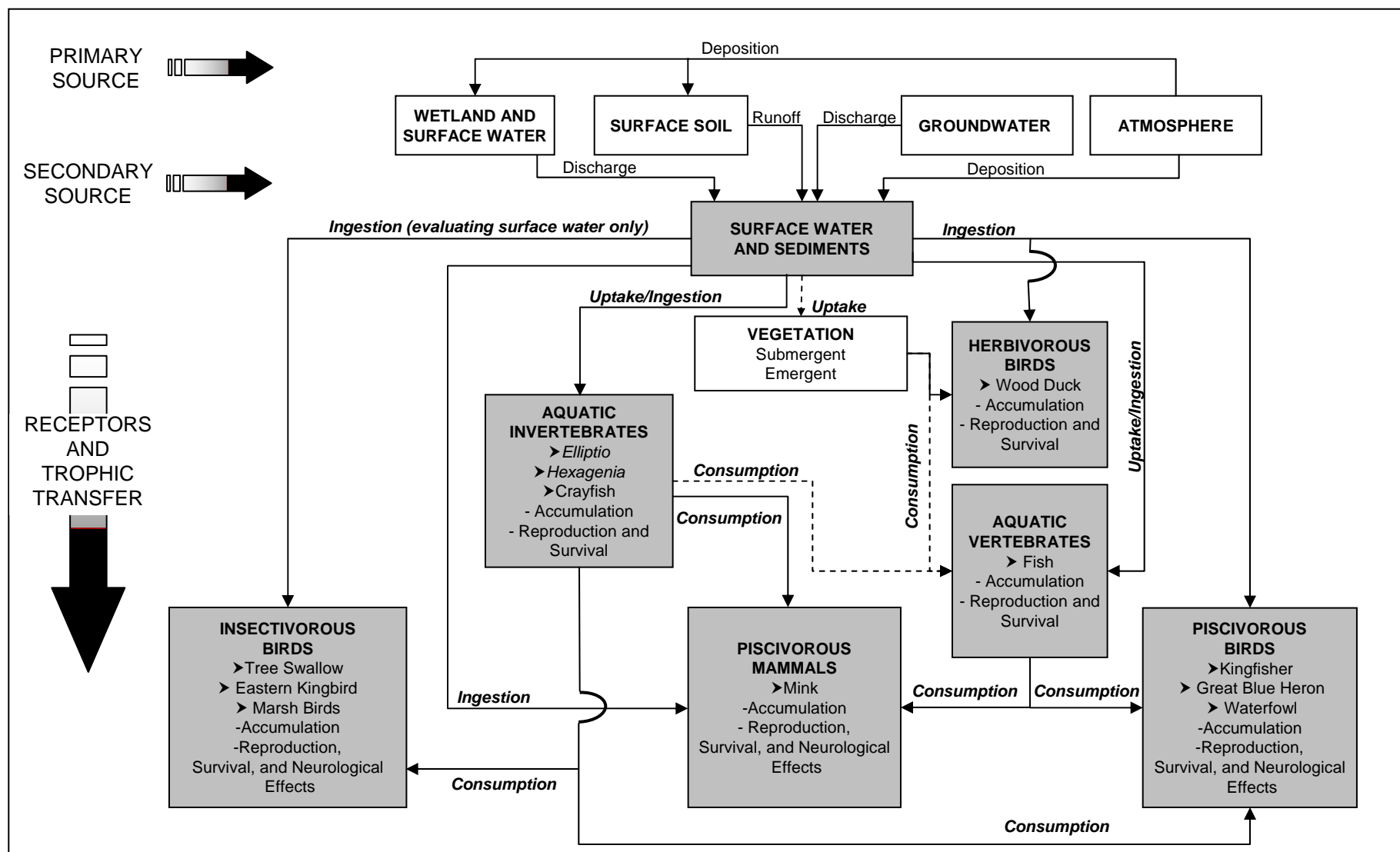


**Legend:**

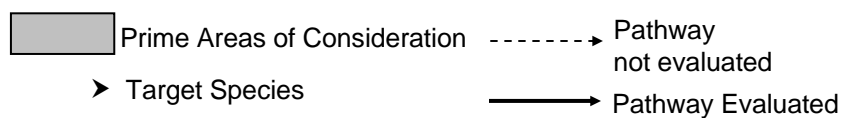
- x - Blood sample
- o - Fur sample
- ▲ - Liver sample
- + - Brain sample

***Nyanza Superfund Site OU IV  
Sudbury River Mercury Contamination***

**Figure 2-70  
Total Mercury Concentrations in  
Mink Blood, Fur, Liver, and Brain Samples - 2003**



#### LEGEND



#### Nyanza Superfund Site OU IV Sudbury River Mercury Contamination

**Figure 2-71**  
**Conceptual Diagram of Potential Transport and Exposure Pathways of Contaminants of Concern from the Site Through the Aquatic Ecosystem**

**Figure 2-72**

**Example Endpoint Weighting Sheet  
Operable Unit IV – Nyanza Chemical Dump Superfund Site  
Middlesex County, Massachusetts**

Score each measurement endpoint from low to high

**Assessment Endpoint:** \_\_\_\_\_

<b>Attribute</b>	<b>Measurement Endpoint A</b>	<b>Measurement Endpoint B</b>	<b>Measurement Endpoint C</b>
<b>I. Relationship between Measurement and Assessment Endpoints</b>			
▪ Degree of Association	Moderate	High	High
▪ Stressor/Response	High	Moderate	High
▪ Utility of Measure	Moderate	High	High
<b>II. Data Quality</b>			
▪ Quality of data	High	High	High
<b>III. Study Design</b>			
▪ Site-specificity	High	High	High
▪ Sensitivity	Moderate	Low	High
▪ Spatial representativeness	Moderate	High	Moderate
▪ Temporal representativeness	Low	Low	Moderate
▪ Quantitativeness	High	High	High
▪ Use of a standard method	Moderate	Moderate	Moderate
<b>Total Endpoint Value</b>	Moderate	Moderate	Moderate-High

## **SECTION 3**

### **ANALYSIS PHASE**

### 3.0 ANALYSIS PHASE

#### 3.1 Introduction

The Analysis Phase of an ERA consists of the technical evaluation of data on the potential exposure to and effects from the stressors identified during the Problem Formulation (Norton et al., 1992; EPA, 1992a), in this case mercury. The Analysis Phase is based on the conceptual model developed during the Problem Formulation and consists of two primary components: 1) Characterization of Exposure and 2) Ecological Effects Characterization. Information typically associated with the Analysis Phase includes exposure source information; measurements of stressor levels (i.e., chemical concentrations); and direct and indirect measurements of exposure (i.e., exposure models) and biological effects. The format of the Analysis Phase follows EPA's *Guidelines for Ecological Risk Assessment* (EPA, 1998).

The Analysis Phase focuses solely on discussions of exposure and potential effects. The Risk Characterization, the final phase of this SBERA, presents the integration and interpretation of exposure and effects information.

A majority of the issues in the Analysis Phase focus on the evaluation and analysis of data. In this SBERA, as in most ERAs, direct measurements of exposure and effects were not available for all aspects of the analysis, and in some situations, the absence of data required that certain assumptions and their associated uncertainties be recognized. Uncertainty and variability present in the Analysis Phase can take three forms - parameter variability, measurement error, and extrapolation uncertainty (EPA, 1992a):

- *Parameter variability* refers to the true heterogeneity of parameters used in the assessment; an example of the variability of a parameter would be the range of chemical concentrations in sediment. Variability can often be quantified by presenting a distribution, or by presenting one or more points of a distribution of the parameter (e.g., mean, range, and 95th percent upper confidence limit [UCL]).
- *Measurement error* is the difference between the true value and the measured value that results from random variation in the characteristic of interest.
- *Extrapolation uncertainty*, one of the principal forms of uncertainty, is present in any ERA in which the measurement and assessment endpoints are not identical. One of the more common forms of extrapolation uncertainty is encountered when laboratory analyses are used to evaluate an attribute of a natural system (e.g., use of laboratory-derived toxicity values). Although this type of uncertainty is unavoidable, it can also be reduced by

careful attention to study design and the use of good professional judgment and common sense (Norton et al., 1992).

Key assumptions and simplifications made during the Analysis Phase are presented and their associated uncertainties are discussed in this section.

The Analysis Phase is organized into two subsections: the Exposure Characterization (Subsection 3.2) and the Ecological Effects Characterization (Subsection 3.3). As stated previously, the information presented in these subsections is integrated with the Risk Characterization to estimate the potential for adverse ecological risks resulting from mercury in the Sudbury River system.

### **3.2 Exposure Characterization**

The objective of the exposure characterization is to combine the spatial and temporal distributions of both the ecological component (i.e., potential species, communities, or habitats) and the chemical stressor (in this case, mercury) to evaluate their co-occurrence (Norton et al., 1992). The most common approach for characterizing ecological exposure is to measure the concentrations of stressors and combine them with assumptions about receptor co-occurrence or uptake (EPA, 1992a). The exposure characterization attempts to evaluate quantifiable routes of exposure (e.g., direct contact with sediment and surface water; and ingestion of surface water and fish) through which species or communities present at the Site may be exposed to mercury.

In general, a chemical exposure characterization has three objectives: (1) characterize releases to the environment; (2) describe the spatial and temporal distributions within the environment; and (3) characterize contact with the ecological component of concern (EPA, 1992a; Suter et al., 1994).

Characterization of historical mercury releases into the target reaches has been presented in the Problem Formulation (Section 2) of this SBERA, and is not addressed further in this section. The Characterization of Exposure is based primarily on measured and in some cases, estimated, mercury exposure concentrations.

The Exposure Characterization is divided into two sections that 1) describe the spatial and temporal distributions of mercury within the Sudbury River, and 2) characterize potential contact between target receptors and mercury in the exposure media.

The following discussion provides a brief description of information that is provided in each subsection. Subsection 3.2.1 presents stressor concentrations in sediments and surface water that were used to directly assess exposure. Subsection 3.2.1 also presents tissue (emergent insect, crayfish, and whole body fish) concentrations that were used to identify potential exposure for avian and mammalian receptor models. Subsection 3.2.2 presents the field studies that were performed to determine the potential for and extent of exposure in various avian and mammalian species on-site. Subsection 3.2.3 presents the quantitative approach that was used to model exposure to avian and mammalian receptors.

### **3.2.1 Media-Specific Chemical Characterization**

This section of the exposure characterization summarizes the distribution of mercury in different media to which receptors identified in the problem formulation may be exposed.

Analytical data are organized into spatially relevant groups for each of the media. The term “spatially relevant group” refers, in large part, to how a representative exposure of a target species to mercury in a specific medium is defined. Typically, an animal's foraging area is used to estimate the areal extent within which an animal is expected to contact an environmental medium, for example soils. The size and the spatial attributes of the foraging area are species-dependent, and the data groupings for each of the target receptors reflect this dependency. For example, since the foraging radius of a mink is much larger than that of a marsh bird, the calculation of an exposure point concentration (EPC) for these species incorporates different data groupings. In many cases, not only is the size of the foraging area species-dependent, but it is also dependent on a number of factors including life stage, dietary requirements, and the proximity of sufficient food to meet those requirements. As discussed in Section 2, this SBERA study area is divided into reaches that reflect distinct flow and habitat conditions. Reach designations also proportion the Sudbury River into logical management units. Exposures for target receptors were assessed on a reach by reach basis to facilitate discussion of potential risks and subsequent remediation decisions. Target receptors and the specific data groupings to which they are exposed are presented in Table 3-1. Note that, for fish intake, fish size class was used to determine exposure groupings. As presented in Section 2.4.1.2.3.4, fish were assigned to size classes based on length as follows:  $5 > \text{total length (TL)} \leq 10$  cm (size class A),  $10 > \text{TL} \leq 15$  cm (size class B),  $15 > \text{TL} \leq 20$  cm (size class C),  $\text{TL} > 20$  cm (size class D). Because of the break-outs of prey size data available for the great blue heron, size classes B

and C had to be combined and a size class  $D \leq 30$  cm data set was developed to calculate the most appropriate exposure point concentrations (see Section 3.2.3.2.3 for more details).

Except for the emergent insects, media-specific summary statistics and raw data for each of the data groupings were previously presented (Section 2.4.1.2 and Appendix D, respectively). For emergent insects, concentrations were obtained as discussed in the Subsection 3.2.1.1.

Finally, the EPCs in selected environmental media (i.e., primarily sediment and biological tissue) within the study area are determined. An EPC is the concentration term used in modeling intake that is an estimate of the arithmetic average concentration for a contaminant based on a set of site sampling results (EPA, 1992c). Calculation of the EPC is presented in Subsection 3.2.1.2.

### 3.2.1.1 Quantifying Concentrations in Emergent Insects

Although data were available for mayfly and dragonfly larvae from the earlier Task Force studies, these concentrations were deemed too old to be used for this SBERA. Instead, emergent insect concentrations were determined using the following regression equation published by Naimo et al. (2000):

$$y = 119.64 + 0.43(x); (r^2 = 0.84)$$

Where:

y = Total mercury concentration in *Hexagenia* larvae (ng/g dry weight - DW).  
x = Total mercury concentration in sediments (ng/g DW).

Concentrations were then converted from ng/g DW to  $\mu\text{g}/\text{kg}$  WW using the following factors:

$$\frac{\mu\text{g}}{\text{kg WW}} = \frac{\text{ng}}{\text{g DW}} \times \frac{\mu\text{g}}{1\text{E}+03 \text{ ng}} \times \frac{1\text{E}+03 \text{ g}}{\text{kg}} \times \text{fraction DW}$$

Where:

Fraction DW =  $(1 - \text{fraction WW } (0.833) = 0.167)$  (value for benthic invertebrates; EPA, 1999)



Emergent insect concentrations were calculated for each sediment sample. Individual concentrations, as well as the summary statistics by reach are presented in Appendix G. The EPCs are calculated herein and presented in Table 3-2.

Because the regression equation used to develop concentrations in emergent insects is valid only for total mercury (total mercury concentrations in sediment were not correlated with methylmercury concentrations in mayflies; Naimo, 2000) total mercury concentrations were calculated, then a fraction of methylmercury was assumed. Naimo et al. (2000) indicate that the methylmercury to total mercury percentages are approximately 1-46%, with the higher percentages being found in the reference areas; Tremblay (1999) found that the percentages for detritivore insect larvae (dipterans, ephemeropterans, and trichopterans) range from 35-45%. Looking at the high end of the site-specific data and low end of the literature values for this assessment, it is assumed that 35% of the total mercury is present in the methylated form. In addition, it is assumed that concentrations found in the larval stage are representative of those found in the adult stage. The significance of these assumptions is discussed in the Uncertainty Analysis (Section 4.2.5).

### **3.2.1.2 EPC Calculation**

EPCs were calculated only for those media that were used in the wildlife modeling efforts (see Table 3-1 and Section 3.2.2). EPCs were calculated by reach for each of the data groupings.

Prior to calculating EPCs, a distribution analysis was performed to determine the best representation of the statistics (e.g., mean) for that parameter. Distributions and subsequent summary statistics were calculated using EPA's ProUCL software (EPA, 2004). ProUCL calculates both parametric (for normal, lognormal, and gamma distributions) and non-parametric UCLs and provides recommendations on which UCL to use depending upon distributional assumptions and the skewness (as represented by the standard deviation of the data). Distributions are tested for using a number of procedures:

- Graphical test based upon a Q-Q plot.
- Lilliefors test ( $\alpha = 0.05$ ; tests for normality or lognormality for data sets with sample sizes greater than or equal to 50).
- Shapiro-Wilk W test ( $\alpha = 0.05$ ; tests for normality or lognormality for data sets with sample sizes less than 50).
- Anderson Darling test ( $\alpha = 0.05$ ; tests for gamma distribution).
- Kolmogorov-Smirnov test ( $\alpha = 0.05$ ; tests for gamma distribution).

The UCL calculation method is then recommended based on the data characteristics presented in Table 3-3.

Typical of most risk assessments, for the reasonable maximum exposure (RME) case, the lower of the maximum detected concentration and the 95% UCL concentration of the mean is used as the EPC. EPCs representing the central tendency exposure (CTE) case that are used in this SBERA are the arithmetic mean concentrations (EPA, 2005).

Maximum detected concentrations, means, data distributions, 95% UCLs, and selected EPCs (for both the RME and CTE cases) are presented in Table 3-2 and 3-4 through 3-12 for each of the exposure medium and area groupings.

### **3.2.2 Individual Field Studies**

To investigate the exposure and potential effects associated with environmental contaminants such as mercury, the chemical concentration in the environmental exposure medium such as water or sediment have been commonly adopted as the dose metric. Traditionally, eco-risk assessors have focused primarily upon indirect quantification of dose of a chemical from exposure estimates based upon chemical concentrations in one or more environmental compartments (e.g., water, sediment, food, soil; see Section 3.2.3) as opposed to direct measurement of chemical residues in target tissues or body fluids of the organism of concern. However, the potential effects of mercury on exposed organisms are the function of the mercury concentration, the form of mercury present, the duration of exposure, and environmental factors affecting bioavailability (such as pH, dissolved organic carbon content, temperature, assimilation efficiency, and metabolism; see Sections 2.4.2 and 2.4.3), which makes exposure modeling a more difficult and uncertain approach for estimating a dose metric. Using body residues rather than relying solely on sediment and surface water concentrations as a dose metric circumvents some exposure modeling problems such as differential bioavailability, varying feeding habitats, and physiological/metabolic variability, thereby providing a clearer connection between exposure and potential effects.

Body residues are surrogates for the contaminant concentration at the Site and should reflect the potential for toxicity to and genetic differences of the organisms being evaluated (Fisher et al., 1999; Hwang et al., 2003). The use of body residues to reduce uncertainties associated with determining exposure and potential effects of contaminants has been advocated by

numerous scientists over the past two decades (McCarty, 1986; van Hoogen and Opperhuizen, 1988; McCarty et al., 1991; Landrum et al., 1992; and Jarvinen and Ankley, 1999). In an effort to encourage the use of body residue levels in the ERA process, the ACOE and the EPA currently support an online Environmental Residue-Effects Database (ERED; <http://el.erdc.usace.army.mil/ered/>) that summarizes chemical-specific residues and effects for numerous organisms.

Actual measured tissue concentrations within organisms (i.e., whole body) or within a specific tissue type (e.g., blood) can be used to support the characterization of exposure during the exposure and effect modeling process as well; helping to reduce the uncertainty associated with using generic bioaccumulation factors to predict tissue levels. These uncertainties are reduced since the direct measurement of residue concentrations explicitly incorporates site- and organism-specific bioavailability, accumulation kinetics, uptake from food in addition to the ambient environment (e.g., surface water in the case of fish), and metabolism (McCarty and Mackay, 1993). Tissue concentrations obtained as part of the individual avian and mammalian field studies were not used for this purpose. However, residues determined for crayfish and fish tissue sampled as part of the 2003-2005 Supplemental Investigation were used in exposure modeling (see Section 3.2.3).

Individual field studies, during which avian (i.e., blood, feathers, and eggs) and mammalian (i.e., blood, fur, brain, and liver) tissue were collected for residue analysis in support of this SBERA, are briefly summarized below. More detailed discussions of the study objectives, species justification, sampling locations, and methods used can be found in the FSP (Avatar, 2003b) and Appendix A. As is frequently the case, slight modifications to the original sampling plans are needed to adapt to conditions encountered in the field (e.g., adjusting target species to reflect presence and sampling success). Any modifications from the original FSP (Avatar, 2003b) have been incorporated in the following discussions.

Note that the majority of tissue samples collected was analyzed at Brooks Rand Laboratory (BRL) in Seattle, WA following quality assurance procedures identified in the QAPP. Tissue samples collected that were included in this SBERA, but were not analyzed at BRL were analyzed at Texas A&M's Trace Element Research Laboratory (TERL) in College Station, TX. Samples analyzed at TERL did not adhere to QA/QC procedures established in the QAPP and are therefore evaluated separately within this report (See Appendix A). All avian and mammal

tissue samples were analyzed for total mercury content. However, since typically >90% of all mercury in avian and mammal tissue is in the methyl form, for exposure purposes, tissue concentrations are considered to be methylmercury.

For avian receptors, blood is the best tissue for evaluating short-term dietary uptake of mercury (Evers et al., 2005). The half-life of methylmercury in the blood of molting chicks is typically less than 10 days (Fournier et al., 2002; Montiero and Furness, 2001). The half-life of mercury in non-molting adult birds has been shown to range from 40-75 days (Montiero and Furness, 2001; Heinz and Hoffman, 2004). Since methylmercury is known to transfer from maternal blood to eggs and is strongly correlated to female blood levels, eggs can serve as good predictors of maternal and juvenile exposure to mercury.

Feather mercury levels frequently reflect blood levels at the time of molt (Bishop et al., 2000); however, methylmercury deposited into muscle tissue may also be available for elimination into feathers. Therefore, for individuals with high mercury exposure, feather mercury levels can be used to evaluate chronic exposures (Evers et al., 2005).

The rationale for the selection of mammal tissues for analysis is presented in Section 3.2.2.5.

In this SBERA, results of the chemical analysis of field collected avian and mammalian tissue are used to assess effects to the organisms themselves and to determine whether there is a difference in contaminant concentrations between the study and reference areas. The results of the tissue analysis (performed by BRL only) were summarized in Section 2.4.1.2., comparisons of tissue concentrations with critical body residues (CBRs) and the comparison of contaminant concentrations between the study and reference areas are presented in Section 4.1.

### **3.2.2.1 Waterfowl Study**

#### **3.2.2.1.1 Study Objectives**

The hooded merganser (*Lophodytes cucullatus*) and wood duck (*Aix sponsa*) were selected as study species because: 1) they are potentially exposed to mercury in their respective diets as a result of trophic transfer, 2) they are cavity nesters and readily occupy artificial nest boxes placed in the study area, 3) they typically lay 7-13 eggs thus removing one for chemical analysis does not negatively affect productivity and does not disrupt nesting behaviors, and 4) they are the only cavity nesting ducks in the study area.

Due to its primary diet of fish and small aquatic invertebrates, the hooded merganser was the focus waterfowl species used to determine the availability of mercury in the Sudbury River within the GMNWR. Due to their abundance in the study area, wood ducks were opportunistically sampled as a secondary study species; however, mercury exposure and accumulation in wood duck are not expected to be as substantial as hooded mergansers because the wood duck's diet consists primarily of seeds, fruit, and aquatic and terrestrial invertebrates (Hepp and Bellrose, 1995).

By comparing mercury levels in breeding waterfowl tissue to CBR levels published in the literature and residue levels available in Biodiversity Research Institute's (BRI's) mercury databases, the potential for adverse ecological effects within the Sudbury River can be assessed in conjunction with other lines of evidence presented throughout this SBERA.

#### **3.2.2.1.2 Target Species Description**

The hooded merganser is widely dispersed throughout northern New England. Mergansers are commonly used as indicator species of aquatic integrity (Haseltine et al., 1981; White and Cromartie, 1977; Zicus et al., 1988; and Derr, 1995). Mergansers are a piscivorous (fish-eating) species, primarily feeding upon small fish but also on aquatic invertebrates (Mallory and Metz, 1999). Dietary studies for hooded mergansers conducted throughout the United States showed that fish were present in 50-100% of the hooded merganser's stomachs analyzed and that crayfish and other aquatic invertebrates (e.g., dragonfly nymphs, caddisfly larvae, and other crustaceans) were the next most common dietary items observed (Dugger et al., 1994). Breeding habitat for hooded mergansers can vary greatly throughout their range, but preference is typically given to emergent marshes, small lakes, ponds, forested creeks and rivers, and swamps (Dugger et al., 1994). There is currently very little information regarding foraging range during the breeding season.

The wood duck is an omnivore with a broad diet (Hepp and Bellrose, 1995). Its diet consists of aquatic and terrestrial insects, invertebrates, nuts, and grains (DeGraff and Yamasaki, 2001). Although foods consumed by wood duck change seasonally, reflecting availability, seeds of woody vegetation and grasses and aquatic vegetation tend to dominate the diets of most wood duck – breeding females being the exception (Hepp and Bellrose, 1995). Immediately before and during egg-laying, female wood duck consume aquatic invertebrates rich in protein and calcium; thereby increasing their likelihood of exposure to mercury present in sediment and

surface water. Like the hooded merganser, the wood duck is a frequent breeder throughout New England. Breeding habitat preferences for wood duck are similar to the hooded merganser, with creeks, rivers, swamps, marshes, and small ponds preferred. Females exhibit a high degree of nest-site fidelity, with many returning to the same cavity to breed (Hepp and Kennamer, 1992). Wood duck home ranges during the nesting season range from 169 ha for breeding pairs to as little as 4 ha for females with broods (Hepp and Bellrose, 1995).

### **3.2.2.1.3 Field Methods**

#### **3.2.2.1.3.1 Nest Box Placement and Monitoring**

Tissue samples (i.e., blood, eggs, and feathers) and nest box data were collected from the Sudbury River drainage, including GMNWR and nearby reference areas in 2003-2005. In early spring of 2003, 39 nest boxes were placed in the GMNWR refuge. An additional 50 boxes were placed on four other waterbodies in central eastern Massachusetts (i.e., Whitehall Reservoir, Charles River, Sudbury Reservoir, and Delaney Wildlife Management Area), located in Worcester and Middlesex counties. Locations of the duck nest boxes evaluated as part of this SBERA can be found in Figures 2-24 through 2-31.

Nest boxes were installed for use as an efficient capture technique in order to collect tissue samples (i.e., whole blood, feathers, abandoned and fresh eggs) from incubating hens for total mercury analysis. The majority of nest boxes sampled were constructed following guidelines presented in Allen et al. (1990). See Appendix A.3 for further details.

Nest boxes were placed along the river channel or in the water close to the shore at various places along the Sudbury River in the GMNWR. Nest boxes were attached to 10' sign posts (poles) or sturdy trees over-hanging or standing within several feet from the water's edge and mounted approximately 5-7 feet off the ground or water. All boxes were single unit with the entrance hole oriented to face open water. Boxes were mounted with 2½-inch bolts (pole mounted) or 3-inch galvanized screws (tree mounted). All boxes were georeferenced using hand-held Global Positioning System (GPS) units.

Nest boxes were checked every 2-3 days from approximately May 1 until the fate of the box was determined. All birds captured were banded with a USFWS issued metal band.

### **3.2.2.1.3.2 Sample Collection and Processing**

Tissue samples consisting of whole blood, secondary flight feathers, and whole eggs were collected from incubating hens.

Blood was drawn from either the brachial vein, located on the underside of the wing or the caudal tibial vein, located over the tarsal joint on the inside of the leg. Different methods are used in blood collection, depending on temperature, size, and age of the birds. Blood was primarily manually drawn using 1 cubic centimeters (cc) syringe with a 25-gauge needle or a 25-gauge butterfly needle drawn by a 3 cc glass Vacutainer® vial. Depending upon the size of the bird, 1-3 cc's of blood was collected.

The second secondary feather was clipped from each wing of an adult female duck. The feathers were clipped with wire cutters, approximately 2 mm above the superior umbilicus. Upon collection the feathers were placed in a zip-lock bag and refrigerated until lab analysis. Methylmercury is contained in the keratin proteins in the feather and is not degradable (Thompson, 1996). All feathers were cleaned at the lab to remove any external contaminants.

Eggs were collected for contaminant analysis. All eggs in a clutch were measured and weighed and the largest egg was collected from each box for total mercury analysis. Incubating hens were captured in the box and a blood and feather sample was collected. Each collected egg was placed in its own zip-lock bag and frozen until lab preparation. Prior to lab analysis, basic measurements (i.e. length, width, egg weight, volume through water displacement) were collected. Eggs were then opened with a sterilized scalpel and the contents placed into a precleaned glass I-Chem® jar. The developmental stage of each egg was recorded and the contents weighed on electronic balance to the nearest 0.001g. The egg length and width were measured with calipers to the nearest 0.01mm. The eggs were then re-frozen until lab analysis.

In addition to tissue samples, the following biological information was recorded: sex based on plumage, bird weight, wing cord length, culmen length, and any physical abnormalities.

### **3.2.2.2 Kingfisher Study**

#### **3.2.2.2.1 Study Objectives**

As with the hooded merganser, the belted kingfisher (*Ceryle alcyon*) was chosen as an indicator species to assess the potential risk of mercury contamination to piscivorous birds.

The EPA in its report to Congress (1997c), states that piscivorous birds, including the belted kingfisher, are at an especially high risk to methylmercury contamination because of their high position in the aquatic food chain. For kingfisher that feed on 70 g of prey daily, the EPA calculated the average daily exposure to mercury to be 25 µg/kg-day. When fish are less available, kingfisher will consume crayfish (Davis, 1980) that can also have elevated mercury concentrations (Parks et al., 1991). Potential risks to belted kingfisher as a result of mercury contamination have been demonstrated in previous studies of mercury contaminated riverine systems (Moore et al., 1999).

Blood (adult and juvenile) and feather (adult) samples from captured kingfisher were collected and analyzed for total mercury in an effort to determine acute and chronic exposures to mercury and to provide residue levels that can be compared to appropriate benchmarks to determine potential mercury related risks. When present, prey items found within the nest were also collected, identified, and analyzed for total mercury content. This information can subsequently be used to verify assumptions used during the exposure and effects modeling portion of this SBERA.

#### **3.2.2.2 Target Species Description**

The belted kingfisher is a relatively common and widely distributed obligate piscivore. It inhabits a diversity of habitats ranging from small streams to large rivers, ponds to large lakes and reservoirs, emergent wetlands, estuaries, and marine environs (Bent, 1940; Hamas, 1994), and feeds on small prey items (predominantly fish) that are generally 4-14 cm long (Bent, 1940; Davis, 1982; Albano, 2000). Kingfishers tend to eat what is locally most available (Davis, 1980; Salyer and Lagler, 1946), especially surface fish, but also crayfish, insects, and small amphibians (Davis, 1982).

Adult male kingfishers may be permanent residents on territories with year-round water access (e.g., coastlines, rivers and estuaries; Pittaway, 1994; Albano, 2000). Kingfishers nesting in Massachusetts inhabit their breeding territory from late March/early April (when nests are excavated) into July/early August (when fledglings disperse). Territory size depends on nest and food availability and juxtaposition of feeding areas (Davis, 1982) as well as presence of other kingfishers in the area. Belted kingfisher's home range is relatively small and generally between 0.4 and 2.2 km (Brooks and Davis, 1987). Davis (1982) determined that linear stream



territories were approximately 1 km during the breeding season. Cornwell (1963) observed the kingfisher territories during breeding season were approximately 1.8 square miles.

Belted kingfishers excavate a 1-3 m burrow in the open, sandy banks of bays, rivers, and lakes. The burrow is usually located within 0.5-2 m from the top of the bank and thus most nests can be accessed for repeated sampling of the young. The availability of suitable nesting sites (i.e., earthen banks) appears critical for the distribution and local abundance of this species (Hamas, 1994). Kingfishers will often nest in active or abandoned gravel pits located in close proximity to water. See Appendix A.4 for further details.

### **3.2.2.2.3 Field Methods**

#### **3.2.2.2.3.1 Capturing Birds**

Kingfisher sampling was conducted in Middlesex County, Massachusetts during April-August 2003. Motorboats or canoes were used to survey the Sudbury and Charles rivers for kingfisher burrows. Active and old gravel pits in the study area were surveyed by car and foot. Burrows that had fresh kingfisher “tracks” (Bent, 1940; Hamas, 1975; Albano, 2000) were concluded to be active and carefully excavated from the rear to determine the status of the nest. While the nest was excavated, a mist net loop trap was placed in front of the burrow to catch the adult if flushed from the nest. A precut plywood “door” was placed to reseal the excavated entrance at the rear of the nest chamber between visits. This rear door was covered with soil and a heavy rock or a dead tree placed over the covered area to prevent predators from digging out and disturbing the burrow (Davis, 1980; Albano, 2000). None of the nests accessed in this manner were subsequently depredated.

At those nests discovered during the nestling period, nestling age was determined by weight and stage of feather development (Hamas, 1975 and 1994; Albano, 2000) and blood samples were collected from the birds that were at least two weeks old. If the chicks were younger than two weeks, investigators returned at a later date to band them and collect blood samples for total mercury analysis.

When the nest location made accessing the burrow prohibitive (e.g., when the nest was located under a tree or too deep in the bank), adults were captured by placing a mist-net in front of the burrow. Birds were caught in the net when entering the burrow.

In cases where a kingfisher was found foraging and the location of its nest was not known, a playback recording of a kingfisher call with a belted kingfisher model placed by a 12 m mist-net on the shore were used as lures. This capture method takes advantage of belted kingfisher's highly territorial nature. When a bird on its feeding territory encounters an "intruder," it attacks the model and gets trapped in the net (Davis, 1982; Albano, 2000).

Locations of all the kingfisher burrows evaluated as part of this SBERA can be found in Figures 2-24, 2-27, 2-29, and 2-30.

#### **3.2.2.2.3.2 Blood and Feather Collection**

For both adults and young, 25 gauge disposable needles were used to puncture the cutaneous ulnar vein in the wing and a green top 0.6 cc microtainer with a blood flow adaptor was used to collect 0.1 to 0.6 cc of blood. Blood samples were stored in the microtainers, placed on ice, and frozen within 2-4 hours of collection. The second secondary feather (from adults) was clipped at calamus (below the base of the vein), placed in clean, labeled plastic bags, and refrigerated.

#### **3.2.2.2.3.3 Sampling of Nestling Food Items**

Fish that were being delivered to the nest were opportunistically collected. When a kingfisher flew into the mist net, it dropped any fish it was carrying in its bill. Fish were placed in clean, labeled, plastic bags and froze them within 2-4 hours. Prior to freezing, the fish were identified to species, and length and weight were recorded.

#### **3.2.2.3 Tree Swallow Study**

##### **3.2.2.3.1 Study Objectives**

The tree swallow (*Tachycineta bicolor*) was selected as a potential indicator of mercury availability in the insect food chain because of its tendency to feed on aquatic insects as they emerge from a waterbody and because it is a cavity nester that will readily use artificial nest boxes. Limited availability of natural cavities and its acceptance of wooden nest boxes permit easy accessibility for sampling at specific locations of interest. Tree swallows also nest relatively densely so that adequate sample sizes can frequently be obtained. Lastly, comparative information about mercury exposure and effects is available from previous studies with tree swallows (Bishop et al., 1995; Gerrard and St. Louis, 2001; Evers et al., 2005).

Blood (adult and juvenile), feathers (adult), and eggs were collected from tree swallows nesting along the Sudbury River and appropriate reference areas. All samples collected were submitted for total mercury analysis. The results of the tissue analysis are used to determine tree swallow exposure to mercury and subsequently compared to critical residue benchmarks to evaluate potential adverse effects that may result from mercury exposure.

#### **3.2.2.3.2 Target Species Description**

Tree swallows prefer to nest in open areas, usually near water (Robertson et al., 1992). Tree swallows are mostly insectivorous, and prefer flying insects (Diptera, Coleoptera, etc.) (Beal, 1918). During the breeding season in Ontario, Canada, tree swallows consumed small insects (<1 cm) – mostly adult flies (Diptera) and small leafhoppers (Homoptera) (Quinney and Ankney, 1985). In New Jersey, swallows fed primarily on adult midges (Chironomidae) (Kraus, 1989). In a study conducted in New York State, McCarty and Winkler (1999) found at least 11 orders of insects in the diet of tree swallow nestlings, with insects in the 3-5 mm range comprising the largest proportion of the diet. Diptera (Nematocera and Brachycera) were the most frequent items followed by Hemiptera and Odonata (McCarty and Winkler, 1999). In Massachusetts, on the Sudbury River and other study sites, tree swallows foraged directly over the water, and adult tree swallows frequently carried damselflies (Odonata) to feed to nestlings.

In general, tree swallows feed within  $\pm 400$  m of their nest box (Quinney and Ankney, 1985) so residue in their tissues (especially blood) reflects sediment contamination near the nest. See Appendix A.1 for further details.

#### **3.2.2.3.3 Field Methods**

Tree swallow nest boxes were placed on the Sudbury River in Reaches 3 (Reservoir 2), 4 (Reservoir 1), 7, 7-Heard Pond, and 8 (GMNWR), the Charles River (control river site), Sudbury Reservoir (control reservoir), and Delaney Wildlife Management Area (control) to attract tree swallows. Nest boxes were placed in areas of suitable habitats along the Sudbury River to assess mercury exposures that result from foraging on emergent aquatic insects. Nest boxes were also placed in comparable reference locations in an effort to establish baseline conditions. Nest boxes were placed using 20-30 m spacing in an effort to increase nest occupancy. Box dimensions were 12" high x 6" wide x 8" deep with a hole diameter of 1.5". The side of the box was hinged to open for easy access and a plastic removable insert acted as a wall. The wood

was not sanded smooth so that the birds could have a rough surface upon which to climb. Locations of the tree swallow boxes were presented in Figures 2-24 through 2-31.

#### **3.2.2.3.3.1 Sample Collection and Processing**

Tree swallow nest box monitoring was initiated in early May 2003, 2004, and 2005. Swallows began laying eggs in late May. Eggs were marked, measured and weighed, and collected one egg per clutch (after at least 3 eggs were present) to avoid nest abandonment. The first egg, one of the first two eggs, or the heaviest egg in each clutch was collected. When a nest was abandoned, the complete clutch was collected. A small blood sample was collected from most females, several males, and most nestlings. Two outer tail feathers were collected from the adult swallows only. All samples were collected for total mercury analysis.

Sex, age and breeding status were determined for each bird. Venipuncture of the cutaneous ulnar vein with a 26 gauge sterile disposable needle allowed collection of 1-2 capillary tubes of blood into heparinized tubes for total mercury analysis. The capillary tubes were sealed with cretoseal and placed in 10 cc plastic vacutainer, labeled with date, site, species, age, and sex information. All birds captured were banded with USFWS issued metal bands and were released unharmed within 15-20 minutes of capture.

#### **3.2.2.4 Marsh Bird Study**

##### **3.2.2.4.1 Study Objectives**

As previously discussed, the insectivorous food-chain has become more prominent as a pathway for evaluating potential risks of bioaccumulative chemicals to higher trophic level organisms (Ankley et al., 1993; Bishop et al., 1995; Evers et al., 2005; Rimmer et al., 2005). Four strictly insectivorous marsh birds (i.e., song sparrow, *Melospiza melodia*; swamp sparrow, *Melospiza Georgiana*; yellow warbler, *Dendroica petechia*; and common yellowthroat, *Geothlypis trichas*) that regularly forage within the Sudbury River floodplain were selected as target indicators of mercury availability. All four species were frequently observed in scrub/shrub habitats that border portions of the Sudbury River, especially in the vicinity of GMNWR.

Blood and feather samples from these species were collected and submitted for total mercury analysis. The results of the tissue analysis are used to evaluate marsh bird exposure to

mercury and are compared to appropriate benchmarks to evaluate potential adverse effects associated with mercury exposure.

In addition, eggs of a fifth species – the eastern kingbird (*Tyrannus tyrannus*) – were opportunistically collected on Sudbury River and the Charles River reference site. Kingbird eggs were analyzed and evaluated in the same way as waterfowl and tree swallow eggs.

Lastly, red-winged blackbirds (*Agelaius phoeniceus*) were targeted for sampling in Reach 8 and the Charles River reference area during 2005 and 2006 because of high mercury levels detected in individuals opportunistically sampled during the 2003 field effort (analyzed by TERL). Note that only the 2005 data are included in this SBERA.

#### **3.2.2.4.2 Target Species Description**

Insectivorous birds breeding in the wetlands and scrub-shrub habitats along Sudbury and Charles Rivers may serve as useful indicators of mercury availability within the Sudbury River ecosystem. During the breeding season, the target species rely heavily on emergent aquatic invertebrates for food. While sampling for the target species, blood samples from several “non-target” insectivorous species, namely the willow flycatcher (*Empidonax traillii*), and northern waterthrush (*Seiurus noveboracensis*) were opportunistically collected because aquatic invertebrates also constitute a large portion of their diet. These samples were analyzed at TERL and a discussion of those results is presented in Appendix A.2.

##### **3.2.2.4.2.1 Song Sparrow**

The song sparrow returns to its breeding area in Massachusetts in March/April and breeds in wide range of forest, shrub, and riparian habitats (Arcese et al., 2002). When available, the characteristic breeding niche consists of scrub/shrub habitats on moist ground next to streams, marshes, lakes, or ponds.

During the breeding season, the song sparrow feeds primarily on insects and other invertebrates and some seeds and fruit (Aldrich, 1984). Invertebrates, rich in protein, like dipterans, leaf-rollers, aphids, and spiders are the dominant food items delivered to nestlings prior to fledging (Arcese et al., 2002). In the Northeast, the song sparrow’s diet consists mostly of plant material during winter (86%) but during summer it consists of >50% animal food. The song sparrow is a generalist and feeds on a wide variety of insects, including from the orders

Coleoptera, Hemiptera, Lepidoptera, Diptera, Odonata, and Ephemeroptera (Judd, 1901). It is assumed that emergent aquatic invertebrates comprise a large portion of its diet in the scrub/shrub wetlands that were sampled for this SBERA.

#### **3.2.2.4.2.2 Swamp Sparrow**

The optimal habitat for this marsh bird is found in marshes with open water, dense low vegetation, and available singing perches (Mowbray, 1997). Shallow (<1.5 m) standing water is one of the principal habitat requirements because of its possible importance as a source of food (Mowbray, 1997).

The swamp sparrow's diet during the breeding season consists mostly of arthropods, damselflies, dragonflies, beetles, ants, and bees (Ellis, 1980). This sparrow is well adapted for foraging on insects and other invertebrates in wet habitats as its longer legs allow effective foraging in shallow water (Wetherbee, 1968; Willson, 1967; Ellis, 1980).

#### **3.2.2.4.2.3 Yellow Warbler**

This marsh bird breeds in wet, deciduous thickets, often dominated by willows, and in disturbed and early successional habitats (Dunn and Garrett, 1997). In a study on the Sudbury River near Concord, adults were observed to forage on shore or in the marsh (Willson, 1967).

This warbler feeds on insects and other arthropods mostly by gleaning (Lowther et al., 1999). Food composition varies by region. In a Manitoba study, 57% of its diet was adult midges (Chironomidae), followed by Lepidoptera larvae, Coleoptera, Hemiptera, Homoptera, and Hymenoptera (Busby and Sealy, 1979).

#### **3.2.2.4.2.4 Common Yellowthroat**

This marsh bird breeds throughout most of United States and Mexico in a variety of habitats, with the highest densities frequently observed in wetland habitat.

The common yellowthroat feeds mainly on insects of various orders, including dipterans, hemipterans, coleopterians, orthopterans, and homopterans; and spiders (Guzy and Ritchison, 1999). One stomach from a bird in Massachusetts contained beetles, flies, and small seeds (Bent, 1953).

#### **3.2.2.4.2.5 Eastern Kingbird**

This marsh bird breeds in a variety of habitats including open or riparian woodlands, and along forest edge (Murphy, 1996).

The kingbird's diet consists of fruit during migration and winter periods and insects during breeding season (Murphy, 1996). Stomach analysis conducted over the species entire range revealed 32% Hymenoptera (bees, ants), 25% Coleoptera (beetles), 12% Orthoptera (grasshoppers), 4% Hemiptera (true bugs), 3% Diptera, and fruits and seeds (Beal, 1912).

#### **3.2.2.4.2.6 Red-winged Blackbird**

This species feeds primarily on plant matter during the non-breeding season (Yasukawa and Searcy, 1995), but switches to an invertebrate diet during the summer. Food composition is determined by the bird's local habitat. The stomach contents of red-winged blackbirds nesting close to agricultural areas consisted of 67% insects and 21% waste grain by volume, while stomach content in nonagricultural habitat consisted of 79% insects and no grain (McNicol et al., 1982). In Manitoba, the diet of red-winged blackbirds in marshes was 100% animal matter (Bird and Smith, 1964). In Minnesota wetlands surrounded by agricultural fields, adults fed nestlings 100% animal diet, consisting on average of 40-58% aquatic invertebrates and 42-61% terrestrial invertebrates. Aquatic invertebrates accounted for 68-89% of the nestling's diet when the adults foraged exclusively in wetlands (Piternan, 1994). Larvae and adult Dipterans (flies) and Odonates (Zygoptera or damselflies) are major insect representatives in the red-winged blackbird nestling diet. The larval stage of most insects in these orders is strictly aquatic.

#### **3.2.2.4.3 Field Methods**

In 2003 and 2004 three study sites (one in Reach 7 and two in Reach 8), located on Sudbury River in GMNWR were sampled. A fourth site served as a control and was located on Charles River. In 2005 and 2006, red-winged blackbirds were targeted in Reach 8 (2005) and Reach 7 and the Charles River reference area (2006). Locations of all red-winged blackbird sampling locations evaluated as part of this SBERA (i.e., 2005 data only) can be found in Figures 2-24, 2-29, and 2-30.

One egg was collected per nest from eastern kingbird nests found along the Sudbury and Charles rivers. Eggs were processed similarly to tree swallow eggs and later analyzed for mercury.

To capture marsh birds, eight to ten, 12 m mist nets were strategically placed within a sampling area. Nets were placed on 6 m aluminum poles along and between shrubs and small trees within 1-20 m from the river edge. The nets were checked every 20-30 minutes. Captured birds were removed and placed in cotton holding bags until processing. All birds were released unharmed 10-30 minutes after capture.

The following information was collected from most individuals: age, sex, weight, wing cord, and body condition indicated by the thickness of fat layer. A small blood sample and two outer tail feathers were collected from adults and selected juveniles; all samples were submitted for total mercury analysis. Each blood sample was placed in a capillary tube, which was then sealed with Creto-seal on both ends and placed in a labeled plastic 10 cc vacutainer. The feathers were placed in a labeled plastic bag. All samples were stored in a field cooler with ice, and samples were later transferred to a locked freezer/refrigerator (blood in the freezer, feathers in the refrigerator).

### **3.2.2.5 Piscivorous Mammal Study**

#### **3.2.2.5.1 Study Objectives**

The mink (*Mustela vison*) is widely distributed in New England and is well-known to be a species sensitive to mercury exposure (Thompson, 1996; EPA, 1997b; Moore et al., 1999). Although mink are known opportunistic feeders in the northeastern United States and southeastern Canada, fish and crayfish are frequently the most identified prey items (Alexander, 1977; Burgess and Bider, 1980). Because the mink is an upper trophic level aquatic predator, it has been frequently used as an indicator of ecological risk for surface water and sediment contaminated with bioaccumulative substances. The mink was selected as a representative mammalian carnivore for this SBERA, since it has been reported within the Sudbury River drainage and is the only piscivorous mammal easily caught with box traps (as mandated by state regulations).

Mercury levels in fur are an indicator of long-term body burden because most organs can demethylate mercury and do not necessarily provide an accurate assessment of toxicity to the individual. Sampling certain matrices, such as muscle or fur (since fur would likely reflect remobilization of methylmercury in the muscle) can provide insights into the lifetime exposure of mercury in the mink or otter. The brain is a particularly relevant tissue in mink as mercury is known to negatively alter neurochemical receptor-binding characteristics. The tendency for



mercury to concentrate in the liver has lead to its inclusion in previous mink accumulation studies.

Total mercury levels in blood and fur (and a limited representation of brain and liver samples) from mink trapped within the Sudbury River drainage were determined and used to assess mercury exposure. Mink blood and fur residue levels are also compared to appropriate benchmarks to evaluate the potential for adverse effects resulting from mercury exposure.

#### **3.2.2.5.2 Target Species Description**

The mink is a carnivorous mammal that feeds on a variety of aquatic and semi-aquatic biota including fish, crayfish, amphibians, snakes, muskrats, small mammals and birds. Most dietary studies for this species have found that fish and crayfish are the dominant food items during the spring, summer, and early fall months (DeGraaf and Rudis, 1986). Mink restrict their foraging to borders of ponds, lakes, streams, and forested wetland habitats with foraging ranges between 1.0 and 6.0 km of shoreline (Gerell, 1970; Linn and Birks, 1981). See Appendix A.5 for further details.

#### **3.2.2.5.3 Field Methods**

A total of 45 traps were placed in multiple locations on the Sudbury River and Sudbury Reservoir where sightings of mink have been recorded or where anecdotal information suggested their presence. Traps were also placed on Reaches 4 and 3 (Reservoirs 1 and 2, respectively) where suitable trapping locations were identified. The total trap effort is variable due to heavy rains washing traps away or submerging them for extended periods of time. One mink was captured in Reach 3 (Reservoir 2); one mink was captured in Reach 4 (Reservoir 1), and three mink were captured along riverine reaches – two from Reach 5 (although one had succumbed prior to trap retrieval) and one from and Reach 7 (see Figures 2-28 and 2-28).

##### **3.2.2.5.3.1 Methods for Live Trapping**

Capturing a live animal permits blood sampling. Analysis of blood samples allows more meaningful comparisons among different sites and regions, because blood mercury levels (1) reflect a recent or short term mercury exposure of a piscivorous mammal and (2) should be independent of age.

Mink were live captured during the fall of 2003 to avoid catching females with their young in the summer. Live box traps were used to trap mink at the study sites. Traps were set along waterways using different types of baits and attractants to help lure the animals. The traps were covered with leaf litter and dirt to camouflage them. Because animals can be live-trapped in areas of low density, potential population impacts are avoided and a comparative template is provided for other studies that cannot afford removing animals.

The traps were checked in the early morning to avoid holding the animal in the trap during the day. Once the animal was caught, it was taken out of the field to administer the tranquilizers to calm the animal during the tissue sample collection.

#### **3.2.2.5.3.2 Sample Collection and Processing**

Once captured, mink were sedated (with a mixture of Ketamine, 2.5 mg/kg and Medetomidine, 0.025 mg/kg), removed from the catch box, and placed upon a padded blanket where the sampling of tissue (blood and fur) and basic measurements (weight and length) were collected. Using a 21-gauge needle and a green top-heparinized vacutainer, approximately 7 cc of whole blood was drawn from the jugular or brachial vein. A small patch of fur was clipped from the area located just above the animal's hind foot using stainless-steel instruments. The fur was cleaned and placed into sealed envelopes. Blood samples were frozen immediately upon collection; fur samples were refrigerated. The animal was placed back into the catch box and administered the antiseden, Atipamezole (0.10 mg/kg).

The animals were anesthetized for no more than thirty minutes before being given the antiseden. Sedation is fully reversed within 5-10 minutes after the injection of Atipamezole. Individuals were kept overnight to monitor health irregularities and released the following morning at the trapping site.

Two animals died as a result of trapping (both from Reach 5). Brain, liver tissue, and the lower jaw were removed from the two dead animals using stainless-steel instruments and placed into sterilized I-CHEM® jars and frozen. A canine tooth was extracted from each and sent to the lab to accurately age the individuals. Fur was taken from the foot of the individual found dead in the trap on the reservoir, and additional fur was taken from the individual that died during the monitoring period.

### **3.2.3 Avian and Mammalian Receptor Exposure Modeling**

The potential for food chain impacts of bioaccumulative chemicals in both aquatic and terrestrial systems is well recognized. Because of the significant biomagnification potential associated with mercury and the potential risk to terminal receptors in the food chain, representative upper trophic level receptors are evaluated as part of this SBERA. Since fish generally represent the terminal receptor in aquatic systems, avian and mammalian species foraging upon these fish may be at substantially higher risk than those receptors at a lower trophic level. Consequently, piscivorous avian and mammalian species that forage from the affected portions of the Sudbury River were evaluated as representative ecological receptors. In addition, numerous studies have identified the utility of evaluating exposure and effects to organisms that forage on insects that emerge from contaminated sediments. Therefore, mercury exposure to insectivorous birds is also evaluated using site-specific exposure and effects models.

#### **3.2.3.1 Modeling Approaches**

Two modeling approaches exist for quantifying risk and they differ dramatically in the level of effort involved and in their abilities to distinguish variability and uncertainty (Thompson and Graham, 1996). The first and most commonly used approach is the “point estimate” or “deterministic” approach, which involves selecting a single number for each of the model inputs from which a point estimate of risk is generated. Choosing single numbers for inputs reduces the level of effort required for the exposure modeling process, but unavoidably ignores uncertainty and variability in the risk estimate. In contrast, the probabilistic approach (e.g., Monte Carlo simulation) can be a viable statistical tool for analyzing uncertainty and variability. These input distributions are then propagated through the model to produce a probability distribution of risk.

Exposure modeling, whether probabilistic or deterministic, represents one of many ways to characterize exposure. As was previously mentioned, a number of receptor-specific exposure models are considered in this SBERA. In an attempt to limit the effort expended as part of the exposure modeling process and still identify potential ecological risks, a “tiered approach” that includes a conservative worst-case (i.e., RME) and more realistic average (i.e., CTE) approach was used (see Section 3.2.1.2).

### 3.2.3.2 Deterministic Exposure Modeling Approach

Exposure models used in this SBERA take the following general form:

$$TDI = FT \times \left[ \left( FIR \times \sum_{i=1}^n C_i \times P_i \right) + SIR \times C_{sed} + WIR \times C_w \right]$$

Where:

- TDI = Total daily intake (mg/kg BW-day)
- FT = Foraging time in the exposure area (unitless)
- FIR = Body weight normalized food intake rate (kg WW/kg BW-day)
- C<sub>i</sub> = Concentration in the <sup>i</sup><sup>th</sup> prey item (mg/kg WW)
- P<sub>i</sub> = Proportion of the <sup>i</sup><sup>th</sup> prey item in the diet (unitless)
- SIR = Sediment ingestion rate (kg DW/kg BW-day)
- C<sub>sed</sub> = Concentration in sediment (mg/kg DW)
- WIR = Water ingestion rate (L/kg BW-day)
- C<sub>w</sub> = Concentration in water (mg/L; converted from ng/L by dividing by 1E+06)

Because of the difficulties in measuring intake of free-ranging wildlife, data on food intake rates (FIRs) are not available for many species. Using FIRs for captive animals potentially underestimates the intake rates because these animals do not expend as much energy as their wild counterparts do, since activities for captive animals do not include behaviors such as foraging and avoiding predators. Therefore, allometric equations using measurements of free metabolic rates (FMRs) are used to determine FIRs.

The FMR represents the daily energy requirement that must be consumed by an animal to maintain among other things, body temperature, organ function, digestion, and reproduction. To maintain these physiological functions as well as to perform daily behavioral activities such as foraging, avoiding predators, defending territories, and mating, the animal must replace the lost energy by metabolizing and assimilating the energy in its food, i.e., its metabolic fuel. The balance between an animal's energy loss and replenishment is reflected in the quality and quantity of food in the animal's diet. Assuming that the animal's habitat supports a variety of food items, selection of diet may reflect a preference toward more energy-rich foods (i.e., higher gross energy), although one must consider the energy expended in pursuit of prey.

Not all food that is consumed by an animal is converted to usable energy. Depending on the digestability of the dietary item and the physiology of a particular animal, a substantial portion of the energy may be lost through clearance. Assimilation Efficiency is a measure of the percentage of food energy (i.e., item-specific gross energy) that is assimilated across the gut wall and is available for metabolism.

The equation used to determine FIRs is as follows:

$$\text{FIR (kg ww/kg BW - day)} = \frac{\text{FMR}}{\sum_{i=1}^n (\text{AE}_i \times \text{GE}_i \times \text{P}_i)}$$

Where:

- FIR = Body weight normalized field ingestion rate (kg WW/kg BW-day equals g WW/g BW-day)
- FMR = Field metabolic rate (kcal/g BW-day; see Table 3-13)
- AE<sub>i</sub> = Assimilation efficiency of the i<sup>th</sup> food item (unitless; see Table 3-14)
- GE<sub>i</sub> = Gross energy of the i<sup>th</sup> food item (kcal/g; see Table 3-14)
- P<sub>i</sub> = Proportion of diet comprised of the i<sup>th</sup> food item (unitless; see Tables 3-15 through 3-18)

Exposure parameters for the calculation of TDI for each the tree swallow, belted kingfisher, great blue heron, and mink are presented in Tables 3-15 through 3-18, respectively.

### 3.2.3.2.1 Tree Swallow

The tree swallow (*Tachycineta bicolor*) was selected as the representative species for insectivorous birds because direct measurements of contaminant tissue concentrations from birds nesting in the Sudbury River drainage were available. Tree swallows nest near water and feed primarily on emerging insects. Consumption of contaminated emergent aquatic insects is the primary route of exposure of swallows to mercury.

The tree swallow is a common, well-studied bird in North America, and its natural history is well-documented (Robertson et al., 1992). Swallows are highly social and nest in loose colonies. They migrate extensively when not nesting and raising young. Outside of the nesting season, migration occurs in large flocks, sometimes numbering up to several thousand birds.

Tree swallows prefer open habitat near water, including fields, marshes, shorelines, and wooded swamps. Swallows nest in holes, and depend on woodpeckers and other excavators to furnish nesting cavities. Nest sites are often scarce and are actively defended. Tree swallows are willing to breed in nest boxes, which can be placed at strategic locations for use in field studies (Nichols et al., 1995).

Adult swallows are aerial feeders, capturing insects in mid-air over open water. During nesting, the birds forage within a limited area (Nichols et al., 1995). Their foraging radius during nesting is only about 400 m, and the average size of meals delivered to nestlings is a 28 mg DW bolus, with 10 to 20 feedings per hour for newly hatched swallows (Quinney and Ankney, 1985). Given the small size of their foraging range, it was assumed that tree swallows would forage solely within each reach.

Tree swallows are small birds with adult weights as low as 16.5 g when food availability is low, and as high as 25.5 g for females during the mating season (Robertson et al., 1992). Newly hatched nestlings weigh approximately 1.5 g and achieve adult weight in approximately 14 days. In Dunning (1984), the mean adult body weight was estimated to be 20.1 g with a standard deviation of 1.58 g ( $n = 82$ ; range = 15.6 to 25.4). Site-specific data indicate that, during the breeding season along the impacted-areas of the Sudbury, the mean adult female body weight is 21.2 g (range of 15-28 g) and the mean adult male body weight is 20.3 g (range of 15-22.6 g). For this SBERA, the site-specific mean adult body weights (male and female) were averaged to yield a mean adult body weight of 20.8 g.

An analysis of the diet delivered to swallow nestlings indicated that it consisted of 45.9% Diptera, 15.6% Ephemeroptera, and 8.7% Homoptera by number, and 41.8% Diptera, 21.3% Ephemeroptera, and 9.2% Lepidoptera by total dry mass (Blancher and McNicol, 1991). A separate study also showed that ephemeropterans and dipterans were common prey for swallows (Robertson et al., 1992).

The FIR employed in the dietary intake model was derived using allometric equations for estimating the metabolic rate of free-living birds using the procedures noted in Section 3.2.3.2. There were sufficient data to generate an allometric equation for passerines, of which tree swallows are members. For swallows, the mean assimilation efficiency was 72% for emergent insects. The mean gross energy from these prey was 1.6 kcal/g WW (EPA, 1993a). Based on

these data, the calculated FMR is 0.94 kcal/g BW-day and the subsequent FIR of the tree swallow is 0.82 kg WW/kg BW-day.

For this assessment, exposure to tree swallows is assumed to occur through ingestion of emergent insects, as well as incidental ingestion of surface water. As noted previously, the concentrations of emergent insects were calculated for both total- and methylmercury.

As noted, the FIR of the tree swallow is 0.82 kg WW/kg BW-day (calculated, see Tables 3-13 and 3-14). It is assumed that the tree swallow's diet is composed of 100% emergent insects. A water ingestion rate of 0.21 L/kg BW-day was used (EPA, 1993a). It is conservatively assumed that the tree swallow obtains 100% of its food and drinking water from each reach ( $P_i=1$  and  $P_w=1$ ). Table 3-15 presents the exposure model and summarizes the exposure factors used to estimate total mercury exposure to the tree swallow.

#### **3.2.3.2.2 Belted Kingfisher**

The belted kingfisher (*Ceryle alcyon*) was selected as the representative species for smaller piscivorous birds because the Sudbury River provides habitat that is suitable for kingfisher and it is within the normal range of the species during the breeding season. Sightings of kingfisher were common along the Sudbury River and they were observed nesting at several locations (see Appendix A.4). Kingfisher feed primarily on fish, and are susceptible to exposure to mercury through food transfer and bioaccumulation of mercury in their prey.

The belted kingfisher is a pigeon-sized member of the Alcedinidae family and is a common bird in North America. Body size for adult birds ranges from 125 to 215 g with little difference between males and females (Hamas, 1994). The breeding range spans the majority of the continent, excluding the far north and the higher elevations of the Rocky Mountains (Hamas, 1994; DeGraaf and Yamasaki, 2001). Nest construction begins in late April (Ellison, 1985), with egg dates ranging from May 14 to June 6 (Veit and Peterson, 1993). In the northern setting of the Sudbury River drainage, kingfishers will generally have only one brood per year (Hamas, 1994), with an average of 6 to 7 eggs per clutch (DeGraaf and Yamasaki, 2001).

Kingfisher feed primarily on fish, although they may also consume large numbers of crayfish (EPA, 1995a). Kingfisher have also been known to consume mollusks, frogs, small snakes, salamanders, insects, crabs, and even mice and young birds (Bull and Farrand, 1977; Landrum et al., 1993; Hamas, 1994). The kingfisher generally feeds by diving to catch fish that swim on

the surface or in shallow water. Clear water less than 2 ft deep is preferred. Prey species include trout, salmon, suckers, perch, minnows, killifish, and sticklebacks (EPA, 1993a). Prey length varies from 2.5 cm (Salyer and Lagler, 1946) to a maximum of 17.8 cm (Salyer and Lagler, 1946) depending upon location and prey availability. However, typical prey length is less than 10 cm (Prose, 1985; Imhof, 1962; Salyer and Lagler, 1946).

Kingfisher nest in burrows that they dig (using their bills and feet) in earthen banks devoid of vegetation (Landrum et al., 1993). Selection and defense of territories by kingfishers depend on season and prey availability. The birds aggressively defend their territories to protect nests during the breeding season (Hamas, 1994). Although the home range of this species varies seasonally, it has been estimated as approximately 0.8 to 2.2 km of shoreline (Salyer and Lagler, 1946; Brooks and Davis, 1987). Given the size of their foraging range, it was assumed that kingfisher would forage solely within each reach.

Body weights of belted kingfisher vary slightly between sexes (Hamas, 1994). Dunning (1993) reported a body weight range of 125 to 215 g with a mean of 148 g. Mean body weights have been reported in this range by Alexander (1977) and Salyer and Lagler (1946). Brooks and Davis (1987) calculated mean body weights of 136 g and 158 g for birds in Pennsylvania and in Ohio, respectively. Hamas (1994) recorded body weights of male and female kingfishers in Minnesota in spring and found females to be slightly heavier than males, 152 and 144 g, respectively. Salyer and Lagler (1946) reported a mean body mass of 170 g for birds in Michigan. In addition to the data obtained from the literature, data on kingfisher collected as part of the Sudbury River investigations were also evaluated. During the summer of 2003, a total of 4 adult kingfisher (2 males, 2 females) were captured for analysis of mercury in blood and feathers. Although these data are less than robust, body weight ranged from 139 g to 165 g; the mean weight of the four birds was 153 g. For this assessment, a body weight of 150 g was assumed based on the means from the available literature-based body weight data.

Alexander (1977) found that the kingfisher diet included fish (46%), amphibians (27%), insects (19%), crustacea (5%), and birds and mammals (1%). In Michigan trout streams, Salyer and Lagler (1946) found trout comprised 30% of the diet, with other fish (29%) and crustacea (41%) completing the diet. Davis (1982) found that kingfishers in Ohio fed mostly on fish (86%) and crayfish (13%). White (1936) found only fish in fecal pellets of kingfisher inhabiting Nova Scotia riparian streams. Combining these data, the kingfisher's diet is composed of an average of 73%



fish (range of 46 to 100%), 15% crustaceans (range of 0 to 41%), and other prey items making up the difference (i.e., insects 5% and amphibians 7%). Because of their small contribution to the overall diet, insects and amphibians were excluded from this modeling effort. Assuming fish and crayfish represent 100% of its diet, the mean proportion of fish and crayfish in the diet of kingfishers was normalized to 83% and 17%, respectively.

The FIR was derived using allometric equations for estimating the metabolic rate of free-living birds using the procedures noted in Section 3.2.3.2. There were insufficient data to generate an allometric equation for Coraciiformes, of which belted kingfishers are members, so the “All birds” equation was used. For kingfisher, mean assimilation efficiencies were 77% for aquatic invertebrates and 79% for fish. The mean gross energies were 1.1 kcal/g WW for aquatic invertebrates and 1.2 kcal/g WW for fish (EPA, 1993a). The calculated FMR is 0.51 kcal/g BW-day) and the subsequent FIR of the kingfisher is 0.54 kg WW/kg BW-day.

For this assessment, exposure to kingfisher is assumed to occur through ingestion of fish and crayfish, as well as incidental ingestion of sediments and surface water. As noted previously, the concentrations of fish and crayfish EPCs are based on total mercury, but assumed to be 100% methylmercury. Because prey items are expected to represent the greatest contribution to mercury exposure, sediment and surface water concentrations of methylmercury were used to calculate exposure and a TDI was calculated for methylmercury only

The FIR of the kingfisher is 0.54 kg WW/kg BW-day (calculated, see Tables 3-13 and 3-14). It is assumed that the kingfisher’s diet is comprised of 17% benthic invertebrates (crayfish), 41.5% each size class A and size class B (total of 83% fish). However, in the lower reaches of the Sudbury (i.e., Reach 7-Heard Pond and Reaches 8 through 10), crayfish were not found during the sampling efforts. Therefore, crayfish were not included in the diet of the kingfisher in those reaches, and the diet was conservatively assumed to be 100% fish. The sediment ingestion rate of the kingfisher is assumed to be 4.5E-03 kg DW/kg BW-day (assuming 75% water content in the diet – EPA, 1993a; and that the soil ingestion rate is 3.3%, similar to that of a mallard – Beyer et al., 1994). A water ingestion rate of 0.11 L/kg BW-day was used (EPA, 1993a). It is conservatively assumed that the kingfisher obtains 100% of its food and drinking water from each reach ( $P_i=1$ ;  $P_s=1$ ;  $P_w=1$ ). Table 3-16 presents the exposure model and summarizes the exposure factors used to estimate methylmercury exposure to the kingfisher.

### 3.2.3.2.3

#### Great Blue Heron

The great blue heron (*Ardea herodias*) was selected as the representative species for larger piscivorous birds because the Sudbury River provides habitat that is suitable for the heron and it is within the normal range of the species during the breeding season. The great blue heron was the most commonly observed wading bird in the Sudbury River during field activities. Heron feed primarily on fish, and may be exposed to mercury through the trophic transfer and bioaccumulation of mercury in its prey.

The great blue heron is the largest member of the Ardeidae family in North America and is distributed throughout both freshwater and saltwater habitats (EPA, 1993a). Based on size and plumage color, as many as seven subspecies have been recognized by taxonomists, with the *Herodias* ssp. being the most common. An adult great blue heron ranges to 160 cm tall and typically weighs between 2.1 to 2.5 kg. Sexes are similar, with males being slightly larger than females on average (Butler, 1992). In its northern range, the great blue heron usually breeds during March through May. Clutch size varies between 3-7 eggs with chicks fledging at approximately two months of age (Naumann, 2002).

The dietary mainstay of the great blue heron is fish ranging from 5 to 30 cm in length (Butler, 1992). Fish comprise the majority of the heron's diet, but great blue heron also eat small rodents, amphibians, snakes, lizards, insects, crustaceans, and occasionally, small birds (Zeiner et al., 1990; Martin et al., 1951). When fishing, heron either stand still and wait for fish to swim within striking distance or slowly wade to catch more sedentary prey. To fish, the heron requires shallow waters (up to 0.5 m) with a firm substrate.

The great blue heron is common along the margins of most freshwater bodies and wetlands. Great blues nest colonially and often use a nest for more than one year. In freshwater marshes, the mean shoreline length defended by a great blue heron is 129 meters (m) and the mean territory area is 0.6 ha (Bayer, 1978). For this SBERA, it was conservatively assumed that herons could forage solely within each reach.

Reported mean body weights for adult herons range from 2,204 grams for females to 2,576 g for males (EPA, 1993a), with an average body weight of 2,390 grams (Sample and Suter, 1994; Dunning, 1984).

Although fish make up the majority of its diet (68% to 98%, as noted below), the heron is an opportunistic feeder so its dietary composition depends upon prey availability. Alexander (1977) found that in a Michigan lake, the heron diet included fish (98%) and crustaceans/amphibians (2%); whereas in a Michigan river, the diet included fish (94%), crustaceans (1%), amphibians (4%), and mammals/birds (1%). Martin et al. (1951) reported that the major items in a heron's diet were fish (68%), crayfish (8%), and insects (8%). Ziener et al. (1990) indicated that the predominant dietary item was fish (75%), with the remainder being comprised of crustaceans, insects, snakes, lizards, and small birds. Averaging the fish and non-fish (represented by crayfish) prey items from each of the studies, the heron's diet is comprised of 84% fish and 16% other prey items. Sample and Suter (1999) determined that within the fish portion of the diet (i.e., assuming fish are 100% of the diet), size class divisions were as follows: 39.2% 0-10 cm (represented by size class A), 47.1% 11-20 cm (represented by size classes B and C combined), and 13.7% 21-30 cm (represented by fish of  $\leq 30$  cm from size class D).

The FIR was derived using allometric equations for estimating the metabolic rate of free-living birds using the procedures noted in Section 3.2.3.2. There were insufficient data to generate an allometric equation for Ciconiiformes, of which herons are members, so the "All birds" equation was used. For herons, mean assimilation efficiencies were 77% for aquatic invertebrates and 79% for fish. The mean gross energies were 1.1 kcal/g WW for aquatic invertebrates and 1.2 kcal/g WW for fish (EPA, 1993a). The calculated FMR is 0.21 kcal/g BW-day and the subsequent FIR of the heron is 0.22 kg WW/kg BW-day.

For this assessment, mercury exposure to great blue herons is assumed to occur through ingestion of mercury in fish and crayfish, as well as incidental ingestion of mercury in sediments and surface water. As noted previously, the mercury concentrations in fish and crayfish EPCs are based on total mercury, but are assumed to be 100% methylmercury. Because prey items are expected to represent the greatest contribution to mercury exposure, only sediment and surface water concentrations of methylmercury were used to calculate exposure and a TDI was calculated for methylmercury only.

The FIR of the heron is 0.22 kg WW/kg BW-day (calculated, see Tables 3-13 and 3-14). It is assumed that the heron's diet is comprised of 16% benthic invertebrates (crayfish), and 32.9% size class A fish, 39.6% size classes B and C fish combined, and 11.5% size class D fish that are  $\leq 30$  cm (84% fish total). However, in the lower reaches of the Sudbury River (i.e., Reach

7-Heard Pond and Reaches 8 through 10), no crayfish were found during the sampling efforts. Therefore, crayfish were not included in the diet of the heron in those reaches, and the diet was conservatively assumed to be 100% fish. The sediment ingestion rate of the heron is assumed to be 1.9E-03 kg DW/kg BW-day (assuming 75% water content in the diet – EPA, 1993a; and that the soil ingestion rate is 3.3%, similar to that of a mallard – Beyer et al., 1994). A water ingestion rate of 0.044 L/kg BW-day was used (EPA, 1993a). It is conservatively assumed that the heron obtains 100% of its food and drinking water from each reach ( $P_i=1$ ;  $P_s=1$ ;  $P_w=1$ ). Table 3-17 presents the exposure model and summarizes the exposure factors used to estimate methylmercury exposure to the heron.

#### **3.2.3.2.4 Mink**

The mink was selected as a representative species for piscivorous mammals because they are known to occur in the Sudbury River watershed (See Appendix A.5), the area contains suitable mink habitat, and their prey are directly and indirectly (through their diet) exposed to mercury. Piscivorous mammals such as mink are at risk to mercury exposure because of their preference for high trophic level aquatic prey. Their diet, consisting of fish, crayfish, amphibians, and waterfowl (Linscombe et al., 1982) makes mink susceptible to exposure to bioaccumulative substances like mercury (Moore and Caux, 1997 and Moore et al., 1999). As a consequence, mink or other piscivorous mammals, inhabiting the Sudbury River have a high potential for significant exposure to mercury.

The mink is a small fur-bearing animal belonging to the mustelid family. Mustelids are characterized by long, slender bodies, short legs, and the presence of a musk gland and, in addition to the mink, include the least (*Mustela nivalis*) and long-tailed (*Mustela frenata*) weasels, striped (*Mephitis mephitis*) and spotted skunks (*Spilogale putorius*) and river otter (*Lutra canadensis*) (EPA, 1993a). Mink are one of the most widespread mammalian carnivores in North America. Its range includes much of the continental USA and Canada.

Mink are found in a variety of wetland, riverine, and lacustrine habitats such as wetlands, small streams, rivers, lakes, tidal flats, cattail marshes, bogs, swamps, and bottomland woods. Habitats associated with small streams are preferred to habitats near large, broad rivers. They prefer irregular shorelines with bushy cover that provides ample prey and den sites. This species will also use upland habitat provided that there is sufficient cover and prey.

Mink are almost exclusively carnivorous. A number of factors influence the composition of the mink's diet. Mink diet varies with season, habitat and availability of prey (Proulx et al., 1987). Shallow water and low flow conditions in streams and rivers contribute to effective aquatic foraging by mink. Commonly important items include fish, crayfish, clams, frogs, snakes, muskrat, voles, and birds. Mink tend to consume more fish in winter and crayfish in spring and summer. In autumn, terrestrial species may increase in importance as prey. Females tend to feed on smaller prey (e.g., fish, crustaceans, and birds), whereas males prefer larger prey (e.g., rabbit and muskrat) (Birks and Dunstone, 1985). Females will take juvenile rabbits in summer (Birks and Dunstone, 1985). Melquist et al. (1981) found that fish taken by mink were mostly cyprinids between 7 and 12 cm long. Similarly, Hamilton (1940) recorded that the average length of fish taken by mink ranged from 7.6 to 10.2 cm. According to Alexander (1977), mink in rivers and streams in lower Michigan and New York consume fish ranging from 15 to 18 cm. Although mink are known to take fish up to 20 cm in length, this is based upon predation of live fish. Because mink will also eat carrion, which does not include the inherent difficulties of procuring larger prey, the concentration data used in this SBERA is not limited to fish of  $\leq 20$  cm but includes all fish lengths.

The size of a water body and water depth can also affect habitat use by this species. For example, large open water areas are not suitable for mink, unless water is shallow. It is hypothesized that mink lack the underwater endurance necessary for locating and pursuing prey (Dunstone and O'Connor, 1979). In large open water areas, mink are capable of efficient hunting only when water is shallow or fish density is high (Dunstone 1983; Allen, 1986). In streams and rivers, pools less than 3 ft deep appear to provide optimal foraging opportunities for mink (Burgess, 1978; Allen, 1986). Mink are common where abundant deadfall and debris create cover for foraging. Logjams in streams create habitat for crayfish and fish prey and also provide shelter for mink.

Since foraging in riverine and lacustrine systems occurs primarily along the shoreline, cover and structural diversity within the riparian vegetative community affect habitat use by mink. Cover can be provided by overhanging or emergent vegetation, rocks or rock crevices, exposed roots, debris, logjams, undercut banks, or boulders (Allen, 1986). The availability of suitable den sites may also affect habitat use by mink. Typically, several dens sites are located close to preferred foraging sites within an individual's home range (Allen, 1986). Dens are established in burrows excavated by other animals (typically muskrats), tree root cavities, rock piles, logjams, and

beaver lodges. Several dens may be established and used at the same time. Dens are found within 200 m of the shoreline (Eagle and Sargeant, 1985; Allen, 1986; Lariviere, 1999).

The actual shape of home territories ranges from linear for riverine habitats to circular for marsh habitats (Birks and Linn, 1982; EPA, 1993a). Home range size depends on food availability, age and sex of mink, season, and social stability. Adult males have larger home ranges (average 85.4% larger) than adult females and adults occupy larger home ranges than juveniles (Gerell, 1970; Lariviere, 1999; Birks and Linn, 1982; Allen, 1986; Whitaker and Hamilton, 1998). Expressed as shoreline length, the average adult home range encompasses 2,600 meters for males and 1,800 meters for females in stream and riverine habitats (Whitaker and Hamilton, 1998). However, linear home ranges may be larger depending of the availability of food and the condition of habitat (Lariviere, 1999). Population density ranges from 3 to 20 mink per square mile. Adult males occupy home ranges that are exclusive of other adult males, but include the home ranges of one or more females (Mitchell, 1961; Birks and Dunstone, 1985; Whitaker and Hamilton, 1998). For this SBERA, it was assumed that mink would forage solely within each reach.

Average body weights (WW of wild animals) of female mink range from 550 g (Mitchell, 1961) to 970 g (Hornshaw et al., 1983) and males range from 630 g to 1,000 g (Whitaker and Hamilton, 1998). For this assessment, a body weight of 946 g was assumed based on the mean weights of males and females during spring (from Mitchell, 1961 as presented in EPA, 1995a).

The primary food items in the mink diet include small mammals, fish, benthic invertebrates (crayfish), birds (waterfowl), and amphibians (Alexander, 1977; Burgess and Bider, 1980; Cowan and Reilly, 1973; Gilbert and Nanckivell, 1982; Hamilton, 1959 and 1940; Melquist et al., 1981; Proulx et al., 1987). Combining the available data, an average of 23% (range of 0 to 64.7%) of the mink diet consists of fish. Mammals comprise 15% of the diet, reptiles and amphibians also constitute an average of 15% (range of 0 to 30%) of the diet, birds (i.e., waterfowl) 11% (range of 0 to 39%) of the diet, and invertebrates constitute 36% of the diet. Because site-specific data were available for only crayfish and fish, and these prey items are likely to accumulate more mercury from the Sudbury River than the terrestrial components of the diet (except potentially for prey associated with Sudbury River wetlands), it was conservatively assumed that the mink's diet consists of only crayfish (i.e., invertebrates) and

fish. Assuming that fish and crayfish represent 100% of the mink diet, the mean proportion of fish and crayfish in the diet of the mink was normalized to 39% and 61%, respectively.

For this SBERA, FIR was estimated using an allometric equation rather than using literature-reported values for captive mink. An allometric model-derived FIR better approximates the increased energy demand of wild mink resulting from higher activity levels incurred while foraging, defending and inspecting territory, and avoiding predators (Lamprey, 1964; Buechner and Golley, 1967; Koplin et al., 1980). The FIR was derived using allometric equations for estimating the metabolic rate of free-living mammals using the procedures noted in Section 3.2.3.2. There were sufficient data to generate an allometric equation for Carnivora, of which mink are members. For mink, mean assimilation efficiencies were 87% for crayfish (based on insects) and 91% for fish. The mean gross energy from these prey was 1.1 kcal/g WW for crayfish (based on a surrogate crustacean, shrimp) and 1.2 kcal/g WW for fish (EPA, 1993a). Based on these data, the calculated FMR is 0.16 kcal/g BW-day and the subsequent FIR of the mink is 0.16 kg WW/kg BW-day.

The exposure of the mink to site-specific COECs is assumed to occur through the ingestion of benthic invertebrates (e.g., crayfish) and fish, as well as the incidental ingestion of sediment, and consumption of surface water (incidental or purposeful). As noted previously, the concentrations of fish and crayfish EPCs are based on total mercury, but assumed to 100% methylmercury. Because prey items are expected to be the greatest contributor to contaminant concentration, only sediment and surface water concentrations of methylmercury were used to calculate exposure and a TDI was calculated for methylmercury only.

The FIR of the mink is 0.16 kg WW/kg BW-day (calculated, see Tables 3-13 and 3-14). It is assumed that the mink's diet is comprised of 61% crayfish and 39% fish (assuming 9.75% each from size classes A, B, C, and D). However, in the lower reaches of the Sudbury River (i.e., Reach 7-Heard Pond and Reaches 8 through 10), no crayfish were found during the sampling efforts. Therefore, crayfish were not included in the diet of the mink in those reaches, and the diet was conservatively assumed to be 100% fish. The sediment ingestion rate of the mink is assumed to be 1.1E-03 kg DW/kg BW-day (assuming 75% water content in the diet – EPA, 1993a; and that the soil ingestion rate is 2.8%, similar to that of a red fox – Beyer et al., 1994). A water ingestion rate of 0.1 L/kg BW-day was used (EPA, 1999). It is conservatively assumed that the mink obtains 100% of its food and drinking water from the Site ( $P_i=1$ ;  $P_s=1$ ;  $P_w=1$ ).

Table 3-18 presents the exposure model and summarizes the exposure factors used to estimate methylmercury exposure to the mink.

#### **3.2.3.2.5 Total Daily Intakes**

TDIs (both RME and CTE) for the four target receptors modeled are presented in Table 3-19.

### **3.3 Ecological Effects Characterization**

The Ecological Effects Characterization is the qualitative and quantitative description of the relationship between the stressor and response (effects) in the exposed individuals, populations, or ecosystems (Suter et al., 1994); and, more specifically (in this assessment), the relationship between observed mercury levels and the assessment and measurement endpoints identified during the Problem Formulation (Norton et al., 1992). This section begins with an evaluation of effects data in the scientific literature relevant to the mercury and methylmercury; followed by specific information used to evaluate the potential for ecological harm. Specifically, for this SBERA, ecological effects associated with the evaluation of the most recent data are primarily characterized by:

- Comparisons with EPA's Freshwater Ambient Water Quality Criteria (AWQC) and other appropriate surface water quality benchmarks and reference area concentrations.
- Comparisons with MacDonald et al. (2000) consensus-based sediment guidelines, reference area concentrations, and regional mercury sediment levels.
- Comparisons of crayfish tissue concentrations with literature-based no-effect and effect levels and reference area concentrations.
- Comparisons of fish tissue concentrations with literature-based no-effect and effect levels, reference area concentrations, and regional mercury fish tissue levels.
- Comparisons of avian tissue (i.e., blood, egg, and feather) concentrations with literature-based no-effect and effect levels and reference area concentrations and regional mercury data available in BRI's mercury database.
- Comparisons of mink tissue (i.e., blood and fur) concentrations with literature-based no-effect and effect levels and reference area concentrations and data available in BRI's mercury database.
- Comparisons of modeled avian and mammalian exposure doses with literature-based toxicity data.



(Note: All discussions of comparisons to reference and regional concentrations are reserved for Section 4.)

In addition to the evaluations proposed above for this assessment, the results of previous studies not reproduced as part of this SBERA are nevertheless, summarized and include:

- Evaluation of sediment mayfly bioaccumulation and toxicity (Naimo et al., 1997).
- Evaluation of freshwater mussel in situ bioaccumulation and toxicity (Salazar et al., 1996).

In general, most risk assessments have found that using a “suite” of stressor-response approaches, such as those selected for this Site provides a more complete Ecological Effects Characterization (EPA, 1998).

Because assessment endpoints frequently cannot be measured directly, one or more measurement endpoints are selected as surrogates to characterize assessment endpoints. Measurement endpoint selection is accomplished by first establishing the relationship between the stressor and assessment endpoint, then identifying relevant surrogates and any additional extrapolations, analyses, and assumptions necessary to predict or infer changes in the assessment endpoint.

As the cause-effect relationship between the measurement endpoint and the assessment endpoint becomes stronger, the uncertainty in extrapolation of the effects data in the risk assessment is reduced. Similarly, the more closely related the test species is to the species of interest, the less uncertainty there is in the risk assessment (Suter, 1993). Extrapolations that frequently occur in an ERA include those from laboratory to field conditions, across taxonomic classifications, and across spatial and temporal scales.

This SBERA concentrates on evaluating direct effects that may be associated with contaminant exposure in various media throughout the affected portion of the Sudbury River. The collection of extensive sediment, surface water, and biological tissue data as part of the 2003-2005 supplemental investigation program and the subsequent analysis of those data are intended to eliminate the uncertainties that are associated with much of the extrapolation that was present in previous assessments (e.g., Weston, 1999a).

Another component integral to the Ecological Effects Characterization involves the selection of stressor-response data that best illustrate a causal relationship. Attributing the causality of

effects, particularly with complex mixtures of chemicals and stressors, continues to be a challenge in ERAs. Individual stressors rarely occur alone; typically there are other chemical, biological, or physical stressors that co-occur and that may alter or compound the effects and risk associated with the subject stressor, thereby increasing the difficulty and uncertainty when trying to identify causality.

As stated previously, the most valuable approach for assessing effects and causality is to provide multiple lines of evidence. The key lines of evidence that can be provided to assist in assigning cause-and-effect relationships, which were formalized by Hill (1965) and adapted to risk assessment by Suter (1993), are summarized as follows:

- Analogy—Cause-and-effect relationship similar to well-established cases.
- Experiment—Changes in effects should follow experimental treatments representing the hypothesized cause.
- Coherence—Implicit relationships should be consistent with available evidence.
- Plausibility—Underlying theory should make it plausible that the effect resulted from the cause.
- Biological gradient—Effect should increase with increasing exposure.
- Temporality—Cause must precede its effect.
- Strength—High magnitude of effect is associated with exposure to stressor.
- Specificity—The more specific the cause, the more convincing the association with an effect.
- Consistency—Consistent association of an effect with a hypothesized cause.

This approach is similar to and consistent with several of the attributes used to assess potential weights associated with each measurement endpoint (see Subsection 2.8).

Whereas information relevant to illustrating the relationship between stressor and its response is provided in the Ecological Effects Characterization, the interpretation of the strength of this relationship is presented in the Risk Characterization.

The remainder of the Ecological Effects Characterization focuses on the Ecological Response Analysis, which examines the relationship between stressor levels and potential adverse ecological effects.

### **3.3.1 Ecological Response Analysis**

The ecological response analysis provides information on three main subject areas:

- Stressor-response analysis—Provides a description of the potential types of stressor-response relationships; a description of the specific effects information used in this

SBERA; and a general discussion of the qualitative WOE associated with each measurement endpoint or endpoint group.

- Causality—Provides a description of the general criteria used to assess the strength of causal relationships between stressors and response.
- Linking measures of effects to assessment endpoints—Provides a discussion of the type of extrapolations typically required to link measurement and assessment endpoints.

These subject areas examine the relationship between stressor levels and effects, present the supporting evidence that the stressor causes the effect, and provide a link between the measurable effect and the assessment endpoint (EPA, 1998). This information is combined and assessed in the Lines of Evidence portion of the Risk Characterization. The following subsections provide a more detailed discussion of the key components essential to developing a comprehensive ecological response analysis.

### **3.3.1.1 Stressor-Response Analysis**

The stressor-response relationship used in an assessment depends on the scope and nature of the ERA defined in the problem formulation. Several different relationships can be established, including:

- single point estimates of effect;
- stressor-response curves;
- no-effect and low-effect levels; and
- cumulative effects distributions.

The majority of quantitative stressor-response techniques have been developed for univariate analysis. These studies, in which one response variable (e.g., incidence of abnormalities, mortality) is measured, reflect the simplest stressor-response relationship. Multivariate techniques, those in which the response of interest is a function of many individual variables (e.g., organism abundance in an aquatic community), also have a long history of use in ecological evaluations (EPA, 1998).

The different stressor-response relationships have inherent uncertainties. Point estimates (e.g., EC<sub>50</sub>) can be useful in simple assessments or to compare risks, but provide little information regarding uncertainty and variability surrounding the point estimate (EPA, 1998).

Stressor-response curves are advantageous in that all of the available experimental data are used, and values other than the data points measured can be interpolated (Suter, 1993). However, sufficient data points necessary to describe the curve may not be available. Stressor-response modeling has been recognized as the most appropriate analysis method for toxicity test data and is considered the best approach for analyzing data at contaminated sites (Suter, 1996a). Often, particular levels of effect (e.g., LD<sub>50</sub>) are determined from curve-fitting analyses. These are point estimates interpolated from the fitted line. Although the level of uncertainty is minimized at the midpoint of the regression curve, the percentage levels selected (e.g., 10%, 50%, 95%) may not be protective for the assessment endpoint (EPA, 1998).

When effects at lower stressor levels are of interest, a no-effect level is frequently established based on comparisons between experimental treatments and control treatments. Statistical hypothesis testing is generally used for this purpose. With this method, the risk assessor does not pick an effect level of concern, and the no-effect level is determined by the experimental conditions (e.g., number of replicates and data variability). Numerous authors (Hoekstra and Van Ewijk, 1992; Laskowski, 1995; Suter, 1996a) have discussed the limitations and drawbacks associated with the use of no observed effect levels (NOEL) in ecotoxicology and ERAs; principal among these concerns are:

- loss of important information regarding significance level
- no accounting for natural variability
- terms suggest effects are low in magnitude and importance, which may not be the case.

Uncertainty also exists with using this relationship when the stressor levels or receptors in the control differ from those used in the experiment. Statistical hypothesis testing is also often used in observational field studies to compare site and reference conditions. General limitations with using hypothesis testing in ERAs have been discussed in detail by Suter (1996a). Suter's overarching concern is that hypothesis testing typically does a poor job at estimating risk. However, confidence in statistical hypothesis testing can be increased through the use of experimental field studies, in conjunction with laboratory studies and observational studies (EPA, 1998).

Multiple-point estimates that can be displayed as cumulative effects distribution functions are generated from combining experimental data. Distributions, frequently referred to as species sensitivity distributions, can be used to identify stressor levels that affect different numbers of

species or portions of populations. This approach has been used by EPA and other regulatory agencies to develop chemical- and medium-specific criteria and benchmarks (Posthuma et al., 2002). The amount of data necessary to derive these distributions is often a limiting factor; to date, sufficient data needed to apply this approach is restricted primarily to toxicity testing of aquatic organisms. Cumulative effects distribution functions can also be derived from probabilistic methods such as the Monte Carlo analysis (EPA, 1998).

The measures of effect evaluated in this SBERA use several of the above approaches. The specific ecological effects to be characterized in this SBERA were listed at the beginning of Subsection 3.3, Ecological Effects Characterization.

The remainder of the Ecological Effects Characterization is divided into four subsections:

- Subsection 3.3.1.1.1 – Abiotic Media Toxicity Values
- Subsection 3.3.1.1.2 – Critical Body Residues and Toxicity Reference Values
- Subsection 3.3.1.1.3 – *Hexagenia* Mayfly Bioavailability Study
- Subsection 3.3.1.1.4 – Eastern *Elliptio* Mussel (*Elliptio complanata*) Bioaccumulation Study

Subsection 3.3.1.1.1 presents EPA established AWQC and consensus-based sediment guidelines that are used to evaluate direct impacts resulting from exposure to mercury levels present in surface water and sediment. Subsection 3.3.1.1.2 presents toxicity reference values (TRVs) and CBRs that are used to assess potential impacts to avian and mammalian receptors. Subsections 3.3.1.1.3 and 3.3.1.1.4 present the objectives and methodologies for the mayfly (*Hexagenia*) and the eastern *Elliptio* mussel (*Elliptio complanata*) bioaccumulation studies, respectively.

To avoid confusion, it should be reiterated that the actual comparison of exposure concentrations to guidelines or benchmarks and the integration and interpretation of exposure and effects data are reserved for the Risk Characterization. The primary function of the Ecological Effects Characterization is to present relevant stressor-response data.

#### **3.3.1.1.1 Abiotic Media Toxicity Values**

##### **3.3.1.1.1.1 Surface Water Criteria**

Under CERCLA, EPA's AWQC are considered applicable or relevant and appropriate requirements (ARARs). EPA's 1985 Guidelines (Stephan et al., 1985) describe an objective,

internally consistent and appropriate way for deriving chemical-specific, numeric water quality criteria for the protection of the presence of, as well as the uses of, fresh water aquatic organisms. AWQC are derived to protect most of the aquatic communities and their uses most of the time (40 CFR 131). When sufficient data is available to support their derivation, EPA provides acute criteria or criterion maximum concentration (CMC) which corresponds to concentrations that would cause less than 50% mortality in 5% of the exposed population in a brief exposure (Suter and Mabrey, 1994). The CMC represents an acute criterion applied as 1-hour average concentrations not to be exceeded more than once in any 3-year period. Acute exposure involves a stimulus severe enough to rapidly induce an adverse response. An acute effect is not always measured in terms of lethality; it can measure a variety of short term adverse effects. Chronic criteria or criteria continuous concentration (CCC) are selected by choosing the most protective value after reviewing and analyzing chronic toxicity information for aquatic organism, aquatic plants, and tissue residue level studies that demonstrate a water/tissue concentration relationship that is unacceptable for consumption by humans or wildlife. The CCC represents a chronic criterion applied as an average four-day concentration not to be exceeded more than once in a three-year period and involving a stimulus that produces an adverse response that lingers or continues for a relatively long period of time, often one-tenth of the life span or more. Chronic exposure should be considered a relative term depending on the lifespan of the organism. A chronic effect can be lethality, growth or reproductive impairment, or any other longer term adverse effect.

EPA has promulgated a CMC of 1,400 ng mercury/L and a CCC of 770 ng/L for dissolved mercury. These criteria were derived from inorganic mercury data, but applied to total mercury (EPA, 2006). Since the site-specific concentration data were analyzed and reported as total recoverable total mercury (i.e., not dissolved total mercury), the criteria were converted from a dissolved to a total value for comparisons with site specific data. This conversion was accomplished using the following equation:

$$\text{Total Recoverable Criterion} = \frac{\text{CMC or CCC}}{0.85 \text{ (EPA, 2004; Appendix A)}}$$

Therefore, the criteria used in this SBERA for the evaluation of total mercury in surface water are a CMC of **1,600 ng/L** and a CCC of **910 ng/L**.

As noted in Subsection 2.4.1.2.3.2, methylmercury generally represents, on average, less than 10 percent of the total mercury detected in surface water per reach (Sudbury River mean = 7.2%). Previously, the CCC was 12 ng/L for total recoverable mercury but was developed based on a final residue value for the fathead minnow (assuming that all of the discharged mercury is methylmercury, and the methylmercury has a bioconcentration factor of 81,700) (EPA, 1986). Given that methylmercury is of primary concern at the Site, the older CCC (i.e., **12 ng/L**) is used to determine the potential for adverse effects from methylmercury. The more recent CCC is used to determine the potential for adverse effects from total mercury. No acute value is available based on methylmercury; therefore, only the evaluation of acute exposure to total mercury is made.

#### **3.3.1.1.1.2 Consensus-based Sediment Guidelines**

Potential direct effects associated with sediment contamination at the Site were evaluated by comparing detected mercury concentrations in sediment to MacDonald et al. (2000) consensus-based values.

MacDonald et al. evaluated the predictive ability of previously derived probable effect concentrations for major classes of compounds including metals, polycyclic aromatic hydrocarbons (PAHs), pesticides and polychlorinated biphenyls (PCBs). A database was developed from 92 published reports that included a total of 1657 samples with high-quality matching sediment toxicity and chemistry data. The database was composed primarily of 10- to 14-day or 28- to 42-day toxicity tests with the amphipod *Hyaella azteca* (designated as the HA10 or HA28 tests) and 10- to 14-day toxicity tests with the midges *Chironomus tentans* or *C. riparius* (designated as the CS10 test). Endpoints reported in these tests were primarily survival or growth. From these data, both threshold effect concentrations (TECs) and probable effect concentrations (PECs) were developed.

TECs identify contaminant concentrations below which harmful effects on sediment-dwelling organisms are not expected. TECs include the following sediment quality guidelines (SQGs): threshold effect levels (TELs), effect range low values (ERLs), lowest effect levels (LELs), minimal effect threshold (METs), and sediment quality advisory levels (SQALs). TECs were calculated by determining the geometric mean of the SQGs. Consensus-based TECs were calculated only if three or more published SQGs were available for a chemical. The mercury TEC is **0.18 mg/kg DW**.

The evaluation of the predictive ability of PECs was conducted to determine the incidence of effects above and below various mean PEC quotients (mean quotients of 0.1, 0.5, 1.0, and 5.0). The PECs are SQGs that were established as concentrations of individual chemicals above which adverse effects in sediments are expected to frequently occur. A PEC quotient was calculated for each chemical in each sample in the database by dividing the concentration of a chemical by the PEC for that chemical. A mean quotient was calculated for each sample by summing the individual quotient for each chemical and then dividing this sum by the number of PECs evaluated, thereby deriving a mean PEC for those chemicals evaluated. The individual PEC for each substance was considered to be reliable if >75% of the sediment samples were correctly predicted to be toxic using the PEC. The mercury PEC is **1.06 mg/kg DW**.

For this assessment TECs and PECs were used to compare with site-specific sediment mercury concentrations in an attempt to bracket potential risk to benthic organisms from mercury contamination in the Sudbury River.

### **3.3.1.1.2 Critical Body Residues and Toxicity Reference Values**

#### **3.3.1.1.2.1 Introduction**

EPA Region 1 conducted an extensive literature review (see Appendices H through J), the goal of which was to create a database that attempts to quantify the relationship between measured mercury concentrations in selected tissues (crayfish, whole body fish or fish muscle, bird eggs, bird blood, feathers, mammal blood and fur) and toxicological responses in crayfish, fish, birds and mammals; and to identify potential effects to birds and mammals resulting from mercury exposure. Studies were selected according to their quality and relevance to the selected assessment endpoints. Preference was given to studies that directly addressed the effects of mercury exposure on reproduction, survival, behavior, and growth. Some of the key elements of this literature review and database development were as follows:

- group the CBRs (reported as µg Hg/kg target tissue) and TRVs (reported as mg Hg/kg BW-day) by species, age group, tissue type and effects,
- report “no-effect” laboratory results as well as field-collected residue data which are not explicitly linked to measured effects,
- calculate no-effect and effect TRVs for birds and mammals based on reported mercury concentrations (mg Hg/kg food) added to food used in toxicity tests,
- report all CBRs and TRVs in terms of WW,
- indicate when results were estimated through extrapolation from figures or data tables,
- identify entries which may be questionable based on uncertainties noted by the authors or problems identified during the review process,



- note whether organic or inorganic mercury was measured,
- clearly separate the no-effects from the effect data,
- depending on data availability, use statistical distributions to suggest conservative receptor- and tissue-specific CBRs and TRVs, and
- identify any remaining critical data gaps that might require further attention.

Sources searched during the literature review process included:

- The ERED Database (<http://www.wes.army.mil/el/ered>)
- TOXNET (<http://toxnet.nlm.nih.gov>)
- Environment Abstracts
- Sciencedirect (<http://www.sciencedirect.com>)
- Jarvinen and Ankley, 1999 (hardcopy database)

A detailed discussion of the literature review process, data treatment, and CBR and TRV database structure is provided in Appendices H through J. Summaries of the data available in the CBR and TRV databases are presented in Tables 3-20 and 3-21, respectively.

The following discussion presents the results of this extensive literature review and presents toxicity data in the order presented below:

- Crayfish CBRs
- Fish CBRs
- Bird CBRs
- Mammal CBRs
- Bird TRVs
- Mammal TRVs

Presentation of the CBRs and TRVs is followed by a “Summary and Conclusions” section.

### **3.3.1.1.2.2                      CBR Development: Linking Mercury Tissue Residue Levels to Ecological Effects in Wildlife Receptors**

#### **3.3.1.1.2.2.1                      Introduction**

A large body of literature has been published linking concentrations of mercury in animals to effects measured at the level of cells, tissues, organs, organisms or populations. The goal of these extensive literature searches (Appendix H - TDF No. 870B and Appendix I - TDF No. 1851A) conducted to identify CBRs was to focus on those few receptors, tissues and endpoints with direct relevance to this SBERA. CBR values identified in these searches are presented in the following subsections. Subsequent evaluations of the literature resulted in revisions or

additions of CBRs (Appendix K – TDF No. 1162B). These new CBRs were incorporated in this SBERA and are discussed where appropriate.

#### **3.3.1.1.2.2.2 Endpoints**

The focus of this SBERA is an evaluation of local population-level endpoints (see Table 2-68). It was therefore decided not to focus on toxicological endpoints if they occurred at a level of organization below that of the whole organism. Examples of such endpoints included various blood parameters (e.g., hematocrit, ratio of red to white blood cells, leucocyte counts), concentrations of hormones, genetic damage, tissue-level damage, or organ-level damage. The reason for this approach is that it there tends to be a high degree of uncertainty present when trying to link effects observed at the sub-organism level to population-type responses of interest to this SBERA.

For crayfish, fish and wildlife receptors, the categories of endpoints of interest included behavioral changes (since mercury is a potent neurotoxin), mortality within and across generations, whole organism growth, or reproduction. Depending on the study and the receptor species, the last category included a wide array of responses, such as fertility, clutch size, embryo implantation success, number of offspring per exposed female, or sex ratios.

#### **3.3.1.1.2.2.3 Development of Critical Body Residue Thresholds**

Deriving CBRs for mercury is a relatively straightforward process. For a given study, the measured mercury residues in crayfish, fish, bird eggs, blood, feathers or fur were matched with one or more no-effects or conservative effects endpoints reported for the same test organisms. The endpoints of interest included mortality, growth, reproduction, or behavior.

Sufficient data were obtained for fish to derive a defensible “effect-to-no-effect” ratio. Using this ratio, it became possible to estimate conservative no-effect residue concentrations when only effect data were reported in a paper. The approach used in deriving this ratio for fish is outlined in the subsection discussing the development of the fish CBRs.

Because of limitations in the dataset, the effect-to-no-effect ratio approach was not used for crayfish, birds (with the exception of eggs and blood), or mammals to derive a no-effect CBR when only an effect CBR was provided.

### 3.3.1.1.2.3.1

### Crayfish CBRs

Crayfish are found in various reaches of the Sudbury River. These organisms, along with other benthic invertebrates, form the forage base for smaller fish and are also preyed upon by larger fish, birds, and mammals. Their intimate relationship with sediments and scavenging feeding behavior make crayfish exposure to mercury contaminated sediment highly likely. Because of the limited data available regarding effects data of mercury in freshwater crayfish tissues, the literature search included all species belonging to the Order Decapoda. This group also includes crabs, lobsters, shrimps, and prawns (some of which were saltwater species).

Crayfish were collected from various sections of the Sudbury River and processed for tissue residue analysis for use in this SBERA. The literature review focused on obtaining data linking whole body mercury levels in decapods to organism or population-level effects. Since whole body residue – effects data for decapods were limited, it was decided to also include tail or abdominal muscle residue – effects data, since muscle serves as a long-term repository for mercury. The following types of studies were excluded in the database development:

- Studies which linked effects to mercury residues measured in an organ or tissue (e.g., liver, gonads, gills, hepatopancreas, or carapace) but not in tail/abdominal muscle or whole body.
- Studies which reported measured mercury levels in whole body or muscle, but did not link those concentrations to effects; this step eliminated a large body of literature pertaining to laboratory experiments (e.g., studies on the uptake and depuration dynamics of mercury in decapods) and field survey studies.

The crayfish residue database (see Appendix I) provides all of the available crayfish mercury CBRs collected for this project. Table 3-22 summarizes the most conservative species-specific no-effect and effect mercury residue data available for decapods; this table was developed based on information presented in Appendix I (see Attachment 2). The data in Table 3-22 were then plotted (Figure 3-1) to help visualize the range of species-specific no-effect and effect thresholds.

As shown in Table 3-22, data are available for a small range of decapod species and responses. From an ecological perspective, however, reproduction generally represents the endpoint of greatest concern for the long-term maintenance of healthy populations in the wild. However, none of the studies included in the database investigated the link between mercury

residues in decapods and effect on their reproductive potential. Therefore, studies that investigated individual survival or endpoints that could affect survival (e.g., reduced ability to find shelter) were used as the basis for developing crayfish CBRs.

Note that none of the studies included in the database had bounded toxicity values. That is, for a study, the highest concentration reported was associated with no effects or the lowest concentration reported was associated with effects. Therefore, identified no-effect mercury thresholds likely overestimate risk; whereas, the effect mercury thresholds probably underestimate risk.

Nine species-specific no-effect tissue residue concentrations for mercury were available for decapods. Because of the uncertainties in the decapod tissue residue database, the highest-available no-effect mercury concentration was not selected as the no-effect CBR. Instead, the median of the nine values (i.e., 1,500 µg/kg WW) was selected as a reasonably-conservative no-effect crayfish CBR. This CBR indicates that a whole body total mercury concentration of up to **1,500 µg/kg WW** would not be expected to result in long-term harm to crayfish inhabiting the Sudbury River.

Only three species-specific effect tissue residue concentrations for mercury were available for decapods. Two of the three studies used crayfish as the test species. The first crayfish study, although highly-relevant, did not present whether residue concentrations were in wet or dry weight, and therefore was not used for CBR development. The study by Brant et al. (2002) was a longer term laboratory study (142 days) to determine growth behavioral changes (i.e., the ability to seek shelter). Growth in three-year old males, and the ability to seek shelter in crayfish of all ages and both sexes was significantly impaired when total mercury in abdominal muscle reached 6,500 µg/kg. Since the Brant et al. (2002) study was not designed to establish a lowest observed effect level (LOEL), and the minimum threshold at which a subtle but ecologically-relevant effect could be expected to occur was likely overestimated, an uncertainty factor of 2.0 was applied to 6,500 µg/kg WW tissue value. The CBR indicates that a whole body total mercury concentration at or above **3,250 µg/kg WW** would be expected to result in long-term harm to crayfish inhabiting the Sudbury River.

The Sudbury River supports a variety of fish species and the potential exposure of these fish to mercury reflects a variety of chemical and biological factors. One of the more important factors is the feeding behavior and trophic position of the fish. Top carnivores, like the largemouth bass, may be highly exposed as a result of biomagnification of mercury up the food chain. Smaller fish (e.g., young-of year perch, centrarchids and cyprinids), while residing in one of the lower trophic levels, may nevertheless, experience significant exposure due to their localized foraging and dietary preference (e.g., benthic invertebrates). Moreover, the smaller fish not only serve as a forage base for larger predatory fish but also serve as prey for piscivorous birds and mammals. Because the Sudbury River is a freshwater system and for the reasons cited above, the literature review focused mainly on freshwater fish species of a variety of taxonomic groups. The aim was to provide a range of mercury tissue residue effects data to assess the risk to fish in this SBERA. In some instances, species not particularly relevant to the Sudbury River were included when the data was of an extremely high quality and the information provided new insight into potential mercury-related effects. For example, a saltwater species (mummichog, *Fundulus heteroclitus*) was included because high quality data were available for a multi-generational reproductive study. In addition, data on the larval stage of an amphibian (*Xenopus laevis*) was included with tissue residue concentrations linked to effects on embryonic development in vertebrates.

Fish were collected from various sections of the Sudbury River and processed for tissue residue analysis for use in this SBERA. The literature review focused on obtaining data which linked effects in fish to whole body mercury levels. The alternatives were to collect data linking effects in fish to mercury levels measured in muscle (i.e., fillets) or eviscerated whole body, since muscle represents a large fraction of total body weight. The following types of studies were not included in the fish tissue database developed for this SBERA database:

- Studies which linked effects to mercury residue levels in one or more internal organs (e.g., liver, gonads, gills) but not to muscle or whole (eviscerated) body residue levels.
- Studies which reported measured mercury levels in whole (eviscerated) body or muscle but did not link those concentrations to effects in fish; this step eliminated a large body of literature pertaining to local or regional fish mercury surveys.

- Studies which reported effects to fish and the exposure concentrations in the water, but not fish tissue residue levels; this step eliminated a large body of toxicity testing literature.

#### **3.3.1.1.2.2.3.2.1 Calculating an “Effect-to-No-Effect” Ratio for Fish**

For a number of fish papers, data were available only to link measured mercury tissue residue levels to an effects endpoint. It was desirable to augment the fish CBR database by using the existing data to estimate a reasonable no-effects mercury tissue residue in fish when none had been reported.

Sufficient paired no-effects and effects residue data were available in the database to develop a defensible “effects to no-effects ratio.” This analysis is summarized in Table 3-23. Table 3-23 indicates that the “effects to no-effects ratio” for seven fish species ranged from 1.1 to 9.5, with a mean of 3.5 (n = 11). Based on this information, a conservative value of 10 was selected to convert a measured effect residue level to a no-effect residue level when the latter was not presented in the study or could not be derived directly from the available information.

Note that this conversion was not used to estimate an effect residue level when a study provided only a no-effect level. In that case, only the no-effect tissue residue level was reported and used in the analysis. In addition, note that although effect-to-no-effect ratios were calculated for many fish studies, the studies ultimately used to derive the fish CBRs did not employ this methodology.

#### **3.3.1.1.2.2.3.2.2 Fish CBR Database**

The fish residue database (see Appendix J) provides most of the available fish mercury CBRs collected for this project. Two papers were published subsequent to the literature search performed to support Appendix J that are appropriate for the development of fish CBRs (i.e., Sandheinrich and Miller, 2006 and Drevnick and Sandheinrich, 2003). Table 3-24 was developed based on information presented in Appendix J (see Attachment 5.1) and the two more recent fish toxicity studies. Table 3-24 summarizes the most conservative species-specific no-effect and effect mercury residue data available for each fish (and one amphibian) species. The data in Table 3-24 were then plotted (Figures 3-2 and 3-3) to help visualize the range of species-specific no-effect and effect thresholds.

The information provided in the fish residue database (see Appendix J) is organized by age group (i.e., eggs/embryos and all older life stages). This division recognizes that fish embryos can be significantly more sensitive to mercury exposure compared with post-embryonic life stages. It would also have been incorrect to include embryonic data to calculate a CBR for comparison against whole body or muscle mercury residue data from older fish collected from the Sudbury River. Hence, the embryonic data were kept separate in the database and only used for reference.

As shown in Table 3-24, data are available for a wide range of fish species and responses. From an ecological perspective, however, reproduction represents the endpoint of greatest concern for the long-term maintenance of healthy fish populations in the wild. Based on this reasoning, the CBRs were derived from only those studies that quantified reproductive impairment based on tissue mercury levels in parent fish.

Six long-term reproductive studies summarized in Table 3-24 fell into this category, namely:

- 1) Sandheinrich and Miller, 2006 (fathead minnows exposed to organic mercury in diet);
- 2) Drevnick and Sandheinrich, 2003 (fathead minnows exposed to organic mercury in diet);
- 3) Hammerschmidt et al., 2002 (fathead minnows exposed to organic mercury in diet);
- 4) Snarski and Olson, 1982 (fathead minnows exposed to inorganic mercury in water);
- 5) Matta et al., 2001 (mummichogs exposed to organic mercury in diet); and
- 6) McKim et al., 1976 (multi-generational test using brook trout exposed to organic mercury in water).

Of the three species evaluated in the studies, reproduction in brook trout appeared to be up to one order of magnitude less sensitive to mercury than the other two species. Because of the uncertainties inherent in a residue benchmark evaluation approach, it was decided to err on the conservative side and omit the brook trout data and focus on the two remaining species.

To derive a conservative no-effect CBR for reproduction in fish, a geometric mean of **380 µg/kg WW** was calculated for the reproductive no-effect whole body mercury concentrations reported by Snarski and Olson (1982) and Matta et al. (2001). The no-effect concentration reported by Hammerschmidt et al. (2002) that was excluded from this calculation because this value represents the whole body mercury concentration for their control fish. This value is similar to the whole body threshold-effect level (t-TEL) of 200 µg/kg WW developed by Beckvar et al. (2005). The t-TEL was calculated as the geometric mean of the 15<sup>th</sup> percentile concentration for effects data and the 50<sup>th</sup> percentile of their no-effects dataset.

A geometric mean was calculated for the lowest effect whole body mercury concentrations reported for the fathead minnow studies by Snarski and Olson (1982), Hammerschmidt et al. (2002), Drevnick and Sandheinrich (2003), and Sandheinrich and Miller (2006). This value equaled 870 µg/kg WW. A conservative effect CBR for reproduction in fish was then calculated as the geometric mean of the fathead minnow and mummichog effects values. The final result equaled **980 µg Hg/kg whole body-WW**.

In summary, conservative no-effect and effect CBRs associated with reproductive impairment as a result of mercury exposure expressed as tissue concentrations are equal to **380 and 980 µg Hg/kg whole body WW**, respectively. Based on these thresholds, long-term population-level risk to fish can be assumed to be negligible if measured mercury residues in whole body fish remain below the no-effect CBR. A potential for risk can be assumed to be present if measured mercury levels in whole body fish/axial muscle exceed the effect CBR.

#### **3.3.1.1.2.2.3.3 Wildlife CBRs**

Because of the difficulty associated with directly evaluating terrestrial community level effects, the wildlife receptors evaluated in this SBERA were selected to serve as surrogates for those feeding guilds that were expected to have the highest potential for mercury exposure. These species included the belted kingfisher (*Ceryle alcyon*), hooded merganser (*Lophodytes cucullatus*), tree swallow (*Tachycineta bicolor*), and mink (*Mustela vison*).

Mink (fur) and tree swallows (eggs only) were the only target species (tissue types) for which data were available to directly link effects to mercury tissue residue levels. To evaluate the other wildlife receptors and tissue types, literature-derived data for a variety of species of mammals and birds were evaluated to develop the wildlife tissue-residue database. For birds, the focus was on species known to feed and/or nest along freshwater aquatic habitats. However, studies of birds which feed or nest in estuarine or marine environments were included if they provided useful information. The aim was to develop a comprehensive database for use in the effects assessment of this SBERA.

This SBERA (see the Field Sampling Plan; Avatar, 2003b) used several non-lethal (with the exception of avian egg samples) approaches to collect tissue samples from wildlife receptors along the Sudbury River. As a result, the literature review focused on articles providing a link between effects and mercury residue levels for the following tissues:



- birds: blood, feathers, and eggs
- mammals: blood and fur

Published mercury residue data were excluded if they pertained to body parts which could only be obtained by sacrificing a wildlife receptor. This requirement eliminated a large amount of literature related to mercury concentrations in brains, muscles, livers, kidneys or other internal organs collected from birds or mammals.

Studies were included in the database if they reported on background levels of mercury in eggs, blood, feathers or fur. The reason for the inclusion is that those background data were assumed not to be associated with effects and thus could potentially be used to represent concentrations indicative of conservative no observed effect levels.

Initially, “generic” CBRs were developed and applied to all bird species (i.e., piscivores, omnivores, and insectivores) or all mammals. Subsequently, CBRs developed specifically for tree swallows were used for all insectivorous birds (including marsh birds).

#### **3.3.1.1.2.2.3.3.1 Avian CBRs**

A list of the bird tissue residue studies reviewed for this assessment are presented in Appendix J (Attachment 6.1) Table 3-25 presents a summary of the egg, blood and feather no-effect and effect mercury residue data available for each individual bird species.

Avian residue data were combined across age groups (pre-fledged and post-fledged) for blood and feather residue levels to increase the size of the data set with which to derive blood and feather CBRs. When data were available for both pre-fledged and post-fledged birds of the same species, the more conservative of the two sets of values were selected. This approach ensures that residue data for the most sensitive life stage were always used to derive species-specific values. In addition to the tabular presentation, these data were graphed to provide a visual presentation of species-specific egg, blood, and feather no-effect and effect thresholds. These plots are shown in Figure 3-4 (eggs), Figure 3-5 (blood), and Figure 3-6 (feathers).

**Eggs** — Table 3-25 shows that 20 no-effect and 17 effect data points for mercury residues in eggs were available for 24 bird species. The most sensitive species and life stage appears to be the chicken embryo as reported by Heinz (2003).

Heinz (2003) conducted an injection study during which eggs are injected on the 3<sup>rd</sup> day of development with a methylmercury solution, and embryo survival was measured through 90% of the incubation period. Heinz (2003) noted that the most sensitive species tested was the chicken, with significantly higher mortality in embryos exposed to 50 µg MeHg/kg WW during development than the control. At least 11 other species were tested in this study, with lowest observed adverse effect levels (LOAELs) ranging from 100 to 1,600 µg MeHg/kg WW. Literature review of field studies indicated that the lowest mean total mercury concentration in field-collected eggs associated with impaired reproductive success measured 1,390 µg/kg WW for the common loon (*Gavia immer*; Barr, 1986).

Given the robustness of the effects database for bird eggs, a species sensitivity approach was used to develop CBRs. This approach is similar to methods used by EPA when developing AWQC (Stephan et al., 1985). In this approach, studies with like endpoints (in this case, reproductive) are ranked and a percentile value is selected as the endpoint value. Because of the size of the toxicological data set available for bird eggs, it was assumed that the 10<sup>th</sup> percentile value, **160 µg MeHg/kg WW**, would be a conservative estimate of the effect CBR. Note that field studies used to derive this value reported mercury in terms of total, not methylmercury. However, since the majority of the values used to derive the CBR were laboratory studies in which methylmercury was applied and that the majority of mercury found in eggs is in the methylated form, it was assumed that the CBR best represents a methylmercury value. The effect CBR of **160 µg MeHg/kg WW** value falls between the effect values generated by Heinz (2003) for the common grackle (*Quiscalus quiscula*; 100 µg MeHg/kg WW) and the ring-necked pheasant (*Phasianus colchicus*) and snowy egret (*Egretta thula*; 200 µg MeHg/kg WW).

A no-effect mercury CBR for bird eggs of **90 µg MeHg/kg WW** was also calculated using the 10<sup>th</sup> percentile approach. To see if this value was realistic, no-effect-to-effect ratios were calculated for studies with bounded toxicological data (i.e., no-effect and effect levels). The average ratio was approximately 2.0 (Table 3-26). Applying the ratio to the 10<sup>th</sup> percentile effect value of 160 µg MeHg/kg WW, the estimated no-effect CBR would be 80 µg MeHg/kg WW egg, which is very close to the 10<sup>th</sup> percentile no-effect value. Because responses in field studies tend to be higher than in injection studies (from which the no-effect to effect ratio was derived), the **90 µg MeHg/kg WW** egg value was selected as the avian egg no-effect CBR. Note that this value falls between the no-effect values generated by Heinz

(2003) for the common grackle (100 µg MeHg/kg WW) and by Elliott et al. (1989) representing the highest geometric mean (98 µg tHg/kg WW) of great blue heron eggs collected from 4 colonies that showed no adverse reproductive effects.

It should be noted that the species-sensitivity based avian egg CBRs are likely conservative due to the number of egg injection studies incorporated into their derivation (11/20 no-effect studies and 12/17 effect-level studies), as it is believed that the toxicity of injected methylmercury is approximately twice that of the same concentration of methylmercury being naturally deposited in eggs. This is possibly caused by the fact that injected methylmercury is dissolved in a carrier that floats around in the egg and can contact the embryo, whereas naturally deposited (via maternal transfer) methylmercury is bound to proteins (mostly egg albumen) and not as available to cause embryotoxicity (Heinz, 2006).

Subsequent analysis of the available mercury residue data (See Appendices L and M) identified other CBRs that may be appropriate, including developing CBRs specific to tree swallows. For generic egg values, the no-effect and effect values of **500 and 1,000 µg tHg/kg WW** suggested for free-living birds in a review paper by Thompson (1996) were selected to assess potential risk to waterfowl and kingfisher. These values are less conservative than those suggested by the Heinz injection study data, but likely more reflective of field conditions.

Tree swallow-specific CBRs were developed from the one study (i.e., Heinz, 2003). The residue levels associated with no-effects and effects on embryo mortality were 400 µg MeHg/kg WW and 800 µg MeHg/kg WW, respectively. The egg injection to maternal transfer toxicity correction factor of 2 (see above) was applied to the no-effect and effect values from the study to arrive at no-effect and effect CBRs of **800 and 1,600 µg MeHg/kg WW**, respectively. The values developed for tree swallows can be applied to all insectivorous birds (e.g., marsh birds).

The BRI Exposure Profile Reports (Appendix A) employ other CBR values. Note that the BRI reports present only effect level-based CBRs. The effect CBRs for eggs used in the BRI reports for piscivores (i.e., mergansers and kingfisher) was 1,300 µg/kg WW based on a field study showing smaller egg volume in loons. For omnivores (i.e., wood ducks) an effect CBR of 800 µg MeHg/kg WW was selected; this value was based on egg injection studies showing decreased embryo survival in mallards. For insectivores (i.e., marsh birds and tree

swallows), an effect-based CBR of 400 µg MeHg/kg WW was recommended based on egg injection studies showing decreased embryo survival in common grackles at 100 µg MeHg/kg WW with an uncertainty factor of four applied. The uncertainty factor was applied because experimentally injected mercury is more toxic than mercury deposited via maternal transfer. The factor of four was derived by comparing the experimental methylmercury dosing effect CBRs for significant decreases in embryo survival (Heinz, 2003) in grackle eggs of 100 µg MeHg/kg WW and in mallard eggs 3,200 µg MeHg/kg WW; or four times the effect CBR. The comparisons of tissue concentrations with CBRs as presented in the exposure profile reports are summarized in the Risk Characterization.

**Blood** – Figure 3-5 illustrates the results of five no-effect and four effect blood mercury concentrations available for seven bird species. The most sensitive species and life stage appears to be the common loon chick as reported by Nocera and Taylor (1998). None of the studies in the blood database assessed reproductive impairment directly.

The Nocera and Taylor (1998) study results are based on field observations of loon chick behavior associated with an intensive blood sampling program. The authors found a strong correlation between increased blood mercury (form not noted, assuming total mercury) concentration in chicks and changes in two behavioral responses (i.e., decrease in the amount of time riding parents' backs and increase in time spent preening). The authors indicated that these behavioral changes resulted in increased energy expenditures which were not compensated for with a higher feeding rate or more begging to parents for food. These results suggested a reduction in the overall fitness of the affected chicks. Using their data set, Nocera and Taylor (1998) indicated that blood total mercury concentrations between 1,250 and 1,500 µg/kg WW were at, or near, a critical behavioral and/or lethal effect level for loon chicks.

Based on these observations, **1,250 µg tHg/kg WW** was selected as a conservative effect-based blood CBR for all avian species. This proposed value is about one order of magnitude lower than the next two effects CBRs (i.e., great egret = 11,000-12,000 µg/kg and pigeon = 12,000 µg/kg). It also appears overly conservative when compared to no-effect blood residue levels available from the database. However, because of the limited amount of effect data for mercury in blood and the subtle neurological impairments, it

seemed prudent to err on the cautious side unless additional blood data become available in the near future to justify a higher value.

Available no effect blood levels were approximately equal to or greater than the selected effect-based CBR value. Therefore, the effect-based CBR value of 1,250 µg/kg WW was divided by 2 to obtain a no effect-based CBR value of approximately **600 µg tHg/kg WW**.

The BRI Exposure Profile Reports (Appendix A) employ other CBR values. Note that the BRI reports present only effect level-based CBRs. The effect CBRs for blood used in the BRI reports for piscivores (i.e., mergansers and kingfisher) was 3,000 µg/kg WW based on a field study showing reproductive, behavioral, and physiological effects in loons (mercury form not noted); and for omnivores (i.e., wood ducks) was 2,500 µg mercury/kg WW based on an effects-level from an egg injection studies showing decreased embryo survival in mallards from exposure to methylmercury and applying a tree swallow blood-egg total mercury concentration relationship analysis. For insectivores (i.e., marsh birds and tree swallows) an effects-level CBR of 1,270 µg mercury/kg WW based was derived from egg injection studies showing decreased embryo survival in common grackles from exposure to methylmercury (see above section regarding egg CBRs for derivation) and applying a tree swallow blood-egg total mercury concentration relationship analysis. The comparisons of tissue concentrations with CBRs as presented in the exposure profile reports are summarized in the Risk Characterization.

**Feathers** — Figure 3-6 shows that 13 no-effect and three effect feather mercury concentrations were available for 15 bird species. The most sensitive species appears to be the mallard duck as reported by Heinz (1979).

Heinz (1979) measured the reproductive success of mallards fed a constant methylmercury contaminated diet over three consecutive generations. He reported that his dietary exposure resulted in various reproductive impairments, including significantly more eggs laid outside of nest boxes, a reduction in the number of sound eggs, and a reduction in the number of one-week old ducklings produced. He also analyzed the total mercury concentration in hen feathers over three generations and reported that residue levels in feathers exceeding an average of **9,100 µg tHg/kg WW** were associated with the reproductive impacts discussed above.

The suggested effect CBR for feathers is low when compared to the two other effect data points presented in Table 3-25. However, the strength of the Heinz (1979) study (i.e., exposure over three consecutive generations, reproductive endpoints) clearly indicates that this effect CBR is relevant. Also, because of the limited amount of effect data for mercury in feathers, it would be prudent to err on the cautious side unless additional data become available in the near future to justify a higher value.

A total mercury effect CBR of **9,100 µg tHg/kg WW** was used in this SBERA for all avian species (Heinz, 1979). Subsequent analysis of the available mercury residue data (See Appendices L and M) identified a no-effect CBR specific to tree swallows based on the Gerrard and St. Louis (2001) study that reported no detrimental effects on clutch size, incubation time, hatchability, nestling growth, or fledging success in pre-fledging tree swallow chicks with feathers containing an average residue level of **1,210 µg tHg/kg WW**. This value was used as the no-effect CBR for feathers for all avian species in this SBERA.

The BRI Exposure Profile Reports (Appendix A) employ other CBR values. Note that the BRI reports present only effect level-based CBRs. The effect CBRs for feathers used in the BRI reports for piscivores (i.e., mergansers and kingfisher) was 19,800 µg /kg FW based on mean mercury levels in egret feathers during years characterized by declines in population levels; and for omnivores (i.e., wood ducks) was 9,000 µg/kg FW based on adverse behavioral effects in mallards dosed with mercury (form not noted). Feather CBRs were not developed by BRI for insectivores (i.e., marsh birds and tree swallows). The comparisons of tissue concentrations with CBRs as presented in the exposure profile reports are summarized in the Risk Characterization.

#### **3.3.1.1.2.2.3.3.2 Mammal CBRs**

A list of all the mammal tissue residue studies reviewed for this assessment is presented in Appendix J (Attachment 7.1). Table 3-27 presents a summary of the most conservative blood and fur no-effect and effect mercury residue data available for each mammal species. The data in Table 3-27 were graphed to provide a visual presentation of species-specific no-effect and effect thresholds for mercury in mammal blood (Figure 3-7) and mammal fur (Figure 3-8).

**Blood** — Figure 3-7 shows that the scientific literature reviewed identified six no-effect and four effect blood mercury concentrations for seven mammal species. The two most

sensitive species appear to be the macaque monkey (Burbacher et al., 1988) and the cat (Charbonneau et al., 1976). Of those two, the monkey study is the most relevant because it reports on reproductive endpoints and also provides the most conservative residue levels.

Burbacher et al. (1988) fed macaque monkeys a diet containing methylmercury for approximately one year. Blood concentrations of adult females of  $>1,500 \mu\text{g tHg/kg WW}$  were associated with significant reductions in the percent of viable deliveries. No effects on percent viable deliveries were noted at blood concentrations  $<1,000 \mu\text{g tHg/kg}$ . Maternal toxicity was noted at blood concentrations of  $2,000 \mu\text{g tHg/kg}$ .

Based on the data presented by Charbonneau et al. (1976) and summarized in Table 3-27, it is reasonable to assume that if adult cats had been allowed to breed during their two-year exposure period, then the no-effect and effect blood residue levels for reproduction would have been lower than the threshold for neurotoxicity ( $<3,500 \mu\text{g tHg/kg WW}$  no-effect and  $>5,000 \mu\text{g tHg/kg WW}$  effect) in adult cats, and might have been similar to those reported for the monkey study.

Based on this information, the generic no-effect and effect blood residue levels for mercury in mammal blood were estimated from the Burbacher et al. (1988) monkey study as  $1,000 \mu\text{g tHg/kg}$  or lower and  $1,500 \mu\text{g tHg/kg}$  or higher, respectively.

However, subsequent analysis of the available mercury residue data (See Appendices L and M) identified other CBRs that may be appropriate, including developing a no-effect blood CBR specific to mink. Blood mercury levels up to  **$630 \mu\text{g tHg/kg WW}$**  in mink were correlated with brain mercury levels below those known to cause toxicity (Wolfe and Norman, 1998). This value was selected as the no-effect level CBR. This receptor-specific value is used in conjunction with the generic mammal effect level CBR of  **$1,500 \mu\text{g tHg/kg WW}$**  in this SBERA.

The BRI Exposure Profile Report (Appendix A.5) employs other CBR values. Note that the BRI reports present only effect level-based CBRs. The effect CBR for blood used in the BRI report was  $680 \mu\text{g/kg}$  based on negative alterations to the brain's cholinergic system from a mink dosing study. The comparisons of tissue concentrations with the CBR as presented in the report are summarized in the Risk Characterization.

**Fur** — Figure 3-8 shows that a review of the scientific literature identified four no-effect and three effect fur mercury concentrations for four mammal species. The most sensitive species appeared to be the deer mouse (Burton et al., 1977), followed by the mink (Halbrook et al., 1997). Of those two, the mink study was the most relevant because it reported on reproductive endpoints generated under controlled laboratory conditions and the mink is a target receptor in this SBERA.

The deer mouse study (Burton et al., 1977) used animals collected in the field from a reference location and an area containing mouse food high in mercury content. The mice were brought into the laboratory and tested for swimming ability and stress tolerance (i.e., behavioral endpoints). While it may not be immediately obvious how impacts to these endpoints might affect the long-term health of a population, it was assumed that they reflected reduced fitness. Significant differences were observed in these endpoints between the two populations which were reflected in the different mercury contents of their fur. Based on this information, the generic no-effect and effect residue level in mammal fur were estimated at 1,300 µg tHg/kg WW and 7,800 µg tHg/kg WW, respectively.

However, since mink data were available, and the reproductive endpoint is likely more ecologically significant for mink than significant changes in the swimming ability and stress tolerance in lab tests for deer mouse (a non-aquatic mammal) the no-effects and effects threshold established by Halbrook et al. (1997) for reproductive impairment in mink were used for the mink fur CBRs. Halbrook et al. (1997) reported that **7,710 µg/kg** was the highest mean fur mercury (form not noted, assuming total mercury) concentration corresponding to no-effect on litter size and that **19,030 µg/kg** was lowest mean fur mercury (assuming total mercury) concentration corresponding to an effect on litter size.

The BRI Exposure Profile Report (Appendix A.5) employs other CBR values. Note that the BRI reports present only effect level-based CBRs. The effect CBR for blood used in the BRI report was 20,000 µg/kg based on an Ontario study considering otter populations to have reduced survivorship in high-mercury areas. The comparisons of tissue concentrations with the CBR as presented in the exposure profile report are summarized in the Risk Characterization.

**Liver and Brain** — ESAT did not develop CBRs for mammal liver or brain. The BRI Exposure Profile Report (Appendix A.5) did develop an effect CBR for each of these tissues.



A brain tissue effect CBR of 4,100 µg/kg (WW versus DW and mercury form not noted) was used, based on negative alterations to the brain's cholinergic system from a mink dosing study. As for a liver tissue effect CBR, 20,000 µg tHg/kg was used, based on sublethal and lethal effects in mink. The comparisons of tissue concentrations with these CBRs as presented in the exposure profile report are summarized in the Risk Characterization.

#### **3.3.1.1.2.3 Wildlife TRVs**

##### **3.3.1.1.2.3.1 Avian TRVs**

Over 30 potential bird TRVs were calculated in support of this SBERA. The following discussion presents a detailed summary of the procedures followed for developing bird TRVs.

Ideally, the information required to derive study-specific TRVs included measured or nominal mercury concentrations in the food (mg Hg/kg food) and a daily FIR (kg food/kg BW-day) which resulted in an ecologically significant no-effect or an effect, respectively. With this information, TRVs were calculated as follows:

$$TRV_{\text{no-effect}} \text{ (mg Hg/kg BW-day)} = \text{food Hg conc}_{\text{no-effect}} \times FIR_{\text{no-effect}} \quad (\text{Equation 1})$$

$$TRV_{\text{effect}} \text{ (mg Hg/kg BW-day)} = \text{food Hg conc}_{\text{effect}} \times FIR_{\text{effect}} \quad (\text{Equation 2})$$

Unfortunately, most bird feeding studies provided only the concentration of mercury in the feed together with descriptions of no-effects and/or effects resulting from the exposures to that mercury concentration. Therefore, it frequently became necessary to estimate FIRs in order to calculate the TRVs. Two general approaches were used to achieve this goal:

- If available and appropriate, measured FIRs reported in a different study were used for the same or a closely-related species and age group, or
- FIRs were estimated using a generic allometric equation.

The generic allometric equation for estimating the FIR in non-passerine birds (i.e., birds other than perching song birds belonging to Order Passeriformes) was reported by EPA (1993a) as follows:

$$FIR \text{ (g dry food/bird/day)} = 0.301 BW^{0.751} \text{ (BW in g, WW)} \quad (\text{Equation 3})$$

Equation 3 required a bird's body weight to estimate a FIR in terms of g dry food consumed per animal per day. However, the units of the FIR had to be converted to kg wet food/kg BW-day for use in the TRV database. The output of Equation 3 was therefore modified as follows:

- Step 1: divide the FIR obtained using Equation 3 by an appropriate age-specific body weight (in kg) to generate the FIR in terms of g dry food/kg BW-day,
- Step 2: divide the age-specific FIR by 1000 to convert the units from g dry food to kg dry food.
- Step 3: change the age-specific “dry” food FIR to an age-specific “wet” food FIR.

This last step was straightforward for the few studies which had dosed their experimental birds using “wet” food (e.g., egrets fed mercury-contaminated fish or hawks fed mercury-contaminated chickens). In those instances, the assumption was made that the water content of fresh succulent food equaled 0.80. Therefore, the “dry food” FIR was simply multiplied by a factor of five in order to estimate a corresponding “wet food” FIR.

Spalding et al. (2000) provided the opportunity to directly compare measured FIRs to estimated FIRs in young egrets fed “wet” food. Appendix J (see Appendix 1) provides the calculations using two different allometric equations. The first allometric equation was Equation 3 discussed previously, whereas the second allometric equation was specific for colonial wading birds as reported in EPA (1993a). The difference between the measured and estimated FIRs equaled 22% and 4%, respectively. These calculations suggested that a reasonable match could be developed between measured and estimated FIRs using allometric equations in birds which were fed “wet” food.

Step 3 was not straightforward for studies which used birds that were fed mercury-contaminated pelletized food *ad libitum* (e.g., pheasants, chickens, quails, ducks). Appendix J shows that when the available measured FIRs were compared to the FIRs derived using the non-passerine allometric equation (Equation 3), the measured FIRs consistently fell between the estimated “dry” and “wet” food FIRs. A mean correction factor of 2.0 was calculated using the data summarized in Appendix J (see Appendix 2). When appropriate, this mean correction factor was used to transform an estimated “dry” food FIR to an FIR more representative of birds fed pelletized food.

Finally, most studies summarized in the TRV database used young birds which gained significant weight during the course of a feeding experiment. This weight gain represented a challenge because measured FIRs were typically unavailable and therefore estimated FIRs had

to be calculated based on body weight. The FIR would change throughout a particular exposure period since body weight increased continuously during the rapid growth phase of the young exposed birds.

This problem was solved by estimating body weight at regular time intervals during a particular exposure period. A FIR would then be calculated for each time interval using that interval's measured or estimated body weight. The final FIR used for estimating a daily dose for the whole exposure period was calculated by summing the individual FIRs and dividing the total by the number of time intervals. While this approach did not represent a perfect time integration, the results presented in Appendix J, are consistent with similar results provided in the scientific literature.

A list of all the bird toxicity studies reviewed for this assessment is presented in Appendix J (Attachment 6.4). Table 3-28 presents a summary of the most conservative no-effects and effects TRVs for each bird species. It shows that eight no-effect and ten effect TRVs were available for 12 bird species, including the fish-eating great egret. The data in Table 3-28 were graphed (see Figure 3-9) to provide a visual presentation of species-specific no-effect and effects thresholds. The information provided in Figure 3-9 can be summarized as follows:

- The most sensitive effect TRV for birds equaled 0.093 mg MeHg/kg BW-day based on measured reductions in appetite and growth in juvenile great egrets reported by Spalding et al. (2000). Since this value represented the lowest mercury dose used in the study, a no-effect TRV could not directly be derived for this species. The next lowest effect TRV, which reflected significant increases in the mortality of exposed chickens (Soares et al., 1973), equaled 0.21 mg MeHg/kg BW-day.
- A study by Heinz (1974), which reported on the impact of long-term mercury exposure on reproduction in mallard ducks, provided supporting information to establish an upper limit for a no-effect TRV. Heinz (1974) reported no significant impact on egg hatchability or duckling survival in hens receiving a dose of 0.071 mg MeHg/kg BW-day (note that the author reported a significant drop in egg hatchability and duckling survival at a dose of 0.43 mg MeHg/kg BW-day). In addition, Lewis and Furness (1991) exposed black-headed gull chicks for ten consecutive days to 0.07 mg MeHg/kg BW-day, which represents a dose chosen to be within the range of exposures naturally experienced by wild gull chicks. The authors reported no negative effects on their experimental birds.

Based on the information summarized above, a no-effect dose of 0.071 mg MeHg/kg BW-day and effect daily dose of **0.093 mg MeHg/kg BW-day** were selected as the generic bird TRVs.

It was suspected, however, that the no-effect TRV for birds was not sufficiently conservative because the ratio of the no-effect TRV to effect TRV equaled only 1.3 (i.e.,  $0.093 \div 0.071$ ). This relatively small difference was due to the fact that the TRVs were derived from two different studies and species. A review of the ratios for species-specific no-effect and effect TRVs in Table 3-28 indicated that they ranged from 2 to >10. Based on these observations, it was decided to adjust the no-effect TRV by dividing the effect TRV for egrets (i.e., 0.093 mg MeHg/kg BW-day) by a factor of 2.0. Therefore, the revised generic no-effect TRV for birds equals **0.047 mg MeHg/kg BW-day**.

#### **3.3.1.1.2.3.2 Mammalian TRVs**

TRVs for mammal feeding studies identified for the database used mainly adult animals which were assumed to retain a constant body weight throughout an exposure period (unless otherwise indicated). Hence, there was no need to estimate body weights at different time intervals during a long-term exposure in order to calculate an average FIR. Unlike many of the avian toxicity papers, about half of the mammal toxicity papers reviewed provided their own calculated daily doses, which simplified the process.

A list of all the mammal toxicity studies reviewed for this assessment is presented in Appendix J (Attachment 7.4). Table 3-29 presents a summary of the most conservative no-effect and effect TRVs available for each individual mammal species. The data in Table 3-29 were graphed to provide a visual presentation of species-specific no-effect and effect thresholds (see Figure 3-10).

Conservative TRVs were available for eight mammal species, including mink and river otter, both piscivores. The information provided in Figure 3-10 can be summarized as follows:

- Based on the available data, it appears that mammals are, on average, more sensitive to methylmercury than birds. Five (i.e., mink, cat, monkey, otter, and dog) of the seven effect TRVs were equal to or lower than 0.1 mg MeHg/kg BW-day. The difference between the lowest effect TRV (mink = 0.035 mg MeHg/kg BW-day; Halbrook et al., 1997) and highest effect TRV (dog = 0.1 mg MeHg/kg BW-day; Earl et al., 1973) in this group was less than a factor of 3.
- Three (i.e., mink, cat, and monkey) no-effect TRVs were available for the group of five species mentioned in the previous paragraph. The difference between the lowest no-effect TRV (mink = 0.014 mg MeHg/kg BW-day; Halbrook et al., 1997) and highest no-

effect TRV (monkey = 0.050 mg MeHg/kg BW-day; Burbacher et al., 1988) in this group was also less than a factor of 3.

Overall, mink was the most sensitive species to methylmercury, closely followed by the cat. The Halbrook et al. (1997) study exposed mink to methylmercury in the diet for 7 months. Effects were noted on litter size (i.e., number of kits per female) at 0.035 mg MeHg/kg BW-day. The NOEL was 0.014 mg MeHg/kg BW-day. Therefore, the generic no-effect and effect TRV for methylmercury in mammals was set at **0.014 mg MeHg/kg BW-day** and **0.035 mg MeHg/kg BW-day**, respectively, to reflect the high sensitivity of mink to methylmercury exposure. They were not considered too conservative on the basis that the measured no-effects and effect TRVs for several other mammal species fell within a factor of three of the proposed values.

#### **3.3.1.1.2.4 Summary and Conclusions**

A comprehensive literature search on the effects of mercury to fish, birds and mammals was completed and summarized in this section. The ultimate goal of this effort was to develop defensible no-effect and effect CBRs and TRVs for use in this SBERA.

Table 3-30 summarizes the proposed CBRs for whole body fish/muscle, bird and mammal blood, bird eggs, feathers, and fur; however, it should be noted that more than one CBR is included in the risk characterization to illustrate the range and potential severity of effects. It is worth noting that the effects CBRs for bird and mammal blood, and feathers and fur are quite similar.

Table 3-31 summarizes the proposed TRVs for birds and mammals; however it should be noted that more than one TRV (i.e., a no-effect and an effect-based TRV) is included in the risk characterization to illustrate the range and potential severity of effects. These values suggest that sensitive species of mammals can be expected to be affected by mercury at doses which are about three times lower than those affecting sensitive species of birds.

As a reality check, the proposed TRVs in Table 3-31 were compared against values presented in EPA (1997c). EPA (1997c) calculated reference doses (RfDs) for methylmercury, which they defined as chronic no observed adverse effect levels (NOAELs). Those RfDs, which were calculated from laboratory toxicity studies divided by appropriate uncertainty factors, ideally would be equivalent to the generic no-effect TRVs provided in Table 3-31. Unfortunately, EPA (1997c) did not provide chronic LOAELs for comparison against the generic effect TRVs.

EPA (1997c) calculated an RfD for avian wildlife equal to 0.021 mg Hg/kg BW-day and a RfD for mammalian wildlife equal to 0.018 mg Hg/kg BW-day. These two values compare favorably to the no-effect TRVs in Table 3-21, considering that the latter were developed based on completely different lines of evidence than the EPA (1997c) RfDs.

The values summarized in Tables 3-30 and 3-31 can be considered conservative but for the most part realistic. The degree of conservatism built into the CBRs and TRVs likely protects a range of potential wildlife receptors against the subtle neurologic effects of mercury which may not have been captured by the non-behavioral endpoints assessed in this review. An example of this phenomenon is the behavioral studies with loon chicks (Nocera and Taylor, 1998) which provided the CBR for bird blood.

The CBRs and TRVs presented should be considered robust due to the reductive approach used to generate most of these values. The selection process first identified the most stringent within-species values and then selected the most stringent inter-species values for use as the generic CBRs and TRVs (except for the bird egg CBR which was based on the 10<sup>th</sup> percentile of the available effects data, and the two fish CBRs which were derived from several reproduction studies).

#### **3.3.1.1.3                      *Hexagenia* Mayfly Bioavailability Study**

Information regarding the bioavailability of mercury in contaminated sediments is necessary to assess the potential entry of methylmercury into the aquatic food chain. The USGS (Naimo et al., 1997) performed a *Hexagenia* mayfly bioaccumulation study to:

- 1) determine if mayfly nymphs exposed to mercury-contaminated sediments would accumulate methylmercury;
- 2) determine if accumulation of methylmercury in mayflies is a function of total mercury concentrations in the sediment; and
- 3) assess which contaminated areas of the Sudbury River have the greatest potential for food chain transfer of mercury.
- 4) measure growth and survival to determine if changes in these measures could be correlated to sediment mercury concentrations.

The *Hexagenia* (burrowing) mayfly bioaccumulation study specifically was performed for the Sudbury River for the reasons listed below.

- *Hexagenia* are common North American river benthic detritivores present in the Sudbury River.

- *Hexagenia* are important in the diets of fish and some waterfowl.
- The substrates in which they are found are generally high in organic and silt content – characteristics that increase exposure to sediment–associated contaminants.
- *Hexagenia* readily bioaccumulate methylmercury associated with ingested sediment and detritus; therefore providing an indirect measure of the methylmercury production in the mercury-contaminated surface sediments and of the potential flux of methylmercury into the benthic food chain.
- *Hexagenia* nymph mercury and methylmercury bioaccumulation tests have been validated; therefore providing meaningful results by which to assess exposure and potential subsequent risks.

Four 21-day bioaccumulation tests with sediments collected from contaminated areas of the Sudbury River and reference areas were performed. Sediment samples for the bioaccumulation study were collected in 1994 and 1995 during May, July, and September, the months when microbial methylation activity in sediments is greatest. Fine-grained sediments were collected from the uppermost 4 to 6 cm in reservoirs, flowing reaches, riparian wetlands and a riverine lake. Each bioaccumulation test employed a randomized block experimental design and included either six replicates of six sediment treatments (tests 1 and 2) or nine replicates of four sediment treatments (tests 3 and 4). Each sediment source represents a treatment.

Tests 1 and 2 were performed during 1994 on sediments collected from four depositional areas (Reach 4 [Reservoir 1], Reach 3 [Reservoir 2], Reach 9 [Fairhaven Bay], and Whitehall Reservoir [reference area]) and two free-flowing areas in the Sudbury River (Reaches 1 and 8). The contaminated free-flowing section sampled was in Reach 8 (GMNWR) and Reach 1 (the reference area upstream of the Nyanza chemical dumpsite).

Tests 3 and 4 were performed during 1995 on sediments collected from two contaminated wetlands, one reference wetland (Hop Brook), and one contaminated depositional area (Fairhaven Bay). Fairhaven Bay was included in all tests to facilitate the comparison of results between years.

*Hexagenia* nymphs (mostly *H. bilineata*) were collected from Pool 8 of the Upper Mississippi River within 1 day of the start of each test. Concentrations of mercury are very low in mayflies and sediments from this reach of the Mississippi (Dukerschein et al., 1992 and Beauvais et al., 1995).

The experimental procedure is presented in detail in *Bioavailability of Sediment-associated Mercury to Hexagenia Mayflies in a Contaminated Floodplain River* (Naimo et al., 1997) (See Appendix N). Survival and growth were measured for each of the four tests. After 21 days, total and methylmercury concentrations in sediment, water, and mayflies were analyzed. These data were checked for normality and homogeneity of variance. Variation in mean concentrations among treatments were compared by ANOVA. If the ANOVA was significant, a Tukey's *hsd* multiple range test was performed.

Results of the bioaccumulation study are presented in Section 4 – Risk Characterization.

#### **3.3.1.1.4 Eastern Mussel (*Elliptio complanata*) Bioaccumulation Study**

As stated previously, information regarding the bioavailability of mercury in contaminated sediments is necessary to assess the potential entry of methylmercury into the aquatic food chain. NOAA conducted a bioaccumulation study using the freshwater mussel, *Elliptio complanata*, with the following objectives:

- 1) Measure total mercury and methylmercury bioaccumulation within the Sudbury River downstream from the Nyanza Site.
- 2) Identify source areas for mercury transport downstream.
- 3) Estimate chronic effects of mercury on resident bioindicator species.

A transplant study method (receptor population taken from a non-contaminated area and “transplanted” to the experimental area) was selected because an *in-situ* study combines the experimental control of laboratory studies with the realism of field studies. In addition, caged animals facilitate measurements of bioaccumulation and toxic effects.

Bivalve molluscs (e.g., mussels) have been used as biomonitors for approximately 30 years. Mussels are particularly good to use for environmental studies since they are ubiquitous, sedentary, and easy to collect, handle, cage, and measure. Mussels may be exposed to contaminants in sediment and water during filtration activities (feeding and respiration). Mussels can integrate and accumulate bioavailable contaminants (including mercury) at concentrations much greater than those found in environmental media. Mussels can also tolerate elevated contaminant concentrations; however, their response to environmental perturbations is evidenced in altered physiology and metabolism. These changes are manifested by altered growth, since growth is an integration of many biological processes.



*E. complanata*, the mussel used in the NOAA study, is commonly found in northeastern North America and is endemic to the Sudbury River. Transplanted mussels were originally harvested from Lake Massesecum in Bradford, New Hampshire.

Eight study stations were set up: six in the Sudbury river downstream of the Nyanza Site, one in the river upstream of the Site (river reference), and one in Whitehall Reservoir (reservoir reference). Stations 1, 4, 5, and 7 were located in impoundments (Whitehall Reservoir and Reaches 3, 6, and 9, respectively), whereas Stations 2, 3, 6, and 8 were located in free-flowing segments of the Sudbury River (Reaches 1, 2, 8, and 10, respectively). Stations 6 and 8 were located in wetland areas of the river. Three racks of 35 mussels, a total of 105 mussels, were deployed at each station. The experimental procedure is presented in detail in *An In-Situ Assessment of Mercury Contamination in the Sudbury River, Massachusetts, Using Bioaccumulation and Growth in Transplanted Mussels* (Salazar et al., 1996) (see Appendix O).

The biological parameters measured were survival; shell length, width, height; and whole animal WW. These parameters were measured before deployment, after 42 days (mid-test), and after 84 days (retrieval). After retrieval, chemical analyses were performed on mussel tissue, and chemical analysis and conventionals (TOC, grain size) were performed on 24 sediment samples (three replicates for each of eight stations).

Chemical data were analyzed for homogeneity in variances prior to conducting ANOVAs and Duncan's multiple range test to determine differences among stations. If the data did not meet requirements for parametric analyses, non-parametric equivalents (i.e., Kruskal-Wallis non-parametric ANOVA and Dunn's Multiple Comparison Test) were used. Correlation analyses were also conducted. All statistics were performed at a 95% confidence level.

Results of the *E. complanata* bioaccumulation study are presented in Section 4 – Risk Characterization.

#### **3.3.1.2 Causality**

In a chemical risk assessment context, causality is defined as the relationship between one or more stressors and the response to the stressor(s). Uncertainty in the conclusions of an ERA would be high without the proper support linking a cause (stressor) to an effect (response).

General criteria for affirming causality for observational data are: (1) strength of association; (2) predictive performance; (3) demonstration of a stressor-response relationship; and (4) consistency of association. All these criteria need not be satisfied to infer causality; rather, each criterion incrementally reinforces causality. The same is true when evaluating the following criteria for rejecting causality. Criteria for rejecting causality in observational data are (1) inconsistency in association; (2) temporal incompatibility; and (3) factual implausibility. Other factors relevant to assessing causality are the specificity of association and theoretical and biological plausibility (EPA, 1998). The use of multiple criteria to assess causality is in fact a WOE approach. A similar WOE approach is applied in Section 4.3 to assess the confidence associated with any prediction of adverse ecological impacts.

Most of the studies used to evaluate potential ecological risk for this SBERA (i.e., benchmark and CBR comparisons, and exposure and effect modeling) are predictive in nature and do not readily lend themselves to a direct assessment of causality. The two exceptions being the freshwater mussel and mayfly bioaccumulation studies that directly measured mercury exposure and associated effects. Where possible, causality is evaluated qualitatively.

### **3.3.1.3 Linking Measurement Endpoints to Assessment Endpoints**

When assessment endpoints are different from their measurement endpoints, the two must be linked to evaluate the environmental values of concern. At times, extrapolations need to be used to link the endpoints. Extrapolations from the measurement to the assessment endpoints may include comparisons:

- Between taxa (e.g., common loon to merganser).
- Between responses (e.g., mortality to growth).
- From laboratory to field.
- Between geographic areas.
- Between spatial scales.
- Between exposure durations (e.g., acute to chronic).
- Between individual effects and population, community, or ecosystem effects.

Extrapolations have a level of uncertainty associated with the adequacy of the data on which they are based. Linkages can be based on professional judgment or empirical (e.g., allometric extrapolation equations) or process models (e.g., trophic transfer models). A common tool employed in risk assessments to deal with the uncertainty encountered when trying to link measurement and assessment endpoints is the use of uncertainty or safety factors (Chapman et al., 1998; Duke and Taggart, 2000; Suter et al., 2000). Basically, uncertainty factors are

conservative empirical factors used to reduce the probability of underestimating risk. Examples of uncertainty factors frequently used in ERAs include: acute-to-chronic ratios, interspecies adjustment factors, and no-effect-to-effect ratios. Many of uncertainty factors used in this SBERA have been presented in prior sections of the report. A more detailed evaluation of the implication of using uncertainty factors is presented in Section 4.2.5, the Uncertainty Analysis.

## SECTION 3 TABLES

Table 3-1

**Target Receptor Exposure Media per Reach**  
**Operable Unit IV - Nyanza Chemical Dump Superfund Site**  
**Middlesex County, Massachusetts**

Organizational or Feeding Guild	Target Receptor Species	Exposure Medium		Dietary Item							
				Emergent Insects <sup>b</sup>	Benthic Invertebrates <sup>c</sup>	Fish <sup>d</sup>					
		Sediment <sup>a</sup>	Surface Water			Size Class A	Size Class B	Size Class B&C Combined	Size Class C	Size Class D	Size Class D ≤30 cm
Aquatic Organisms	Class-specific, no specific species	-	tHg and MeHg	-	-	-	-	-	-	-	-
Benthic Organisms	Class-specific, no specific species	tHg	-	-	-	-	-	-	-	-	-
Insectivorous Bird	Tree Swallow	-	tHg and MeHg	√	-	-	-	-	-	-	-
Piscivorous Bird	Belted Kingfisher	MeHg	MeHg	-	√	√	√	-	-	-	-
Piscivorous Bird	Great Blue Heron	MeHg	MeHg	-	√	√	-	√	√	-	√
Piscivorous Mammal	Mink	MeHg	MeHg	-	√	√	√	-	√	√	-

<sup>a</sup>Sediment grouping includes data from 0-5 cm bgs only.

<sup>b</sup>tHg concentrations assumed to be 35% MeHg.

<sup>c</sup>Includes wholebody and composite data. tHg concentrations assumed to be comprised of 100% MeHg.

<sup>d</sup>tHg concentrations assumed to be 100% MeHg.

Table 3-2

**Summary of Exposure Point Concentrations in Emergent Insects  
Operable Unit IV - Nyanza Chemical Dump Superfund Site  
Middlesex County, Massachusetts**

<b>Chemical</b>	<b>Maximum Detected Concentration (mg/kg)</b>	<b>Arithmetic Mean Concentration (mg/kg)</b>	<b>Data Distribution<sup>a</sup></b>	<b>Calculation Method<sup>a</sup></b>	<b>95 % UCL of the Mean<sup>a</sup> (mg/kg)</b>	<b>RME Exposure Point Concentration (mg/kg)</b>	<b>CTE Exposure Point Concentration (mg/kg)</b>
<b>Reach 1</b>							
Total Mercury	2.46E-01	8.05E-02	Non-Parametric	95% Chebyshev (Mean, Sd) UCL	2.62E-01	2.46E-01	8.05E-02
Methylmercury	NA	NA	NA	NA	NA	8.62E-02	2.82E-02
<b>Reach 2</b>							
Total Mercury	7.13E-01	1.66E-01	Lognormal	95% Chebyshev (MVUE) UCL	4.18E-01	4.18E-01	1.66E-01
Methylmercury	NA	NA	NA	NA	NA	1.46E-01	5.81E-02
<b>Reach 3</b>							
Total Mercury	3.24E+00	1.10E+00	Gamma	Approximate Gamma UCL	1.39E+00	1.39E+00	1.10E+00
Methylmercury	NA	NA	NA	NA	NA	4.85E-01	3.84E-01
<b>Reach 4</b>							
Total Mercury	1.14E+00	4.93E-01	Normal	Student's-t UCL	6.76E-01	6.76E-01	4.93E-01
Methylmercury	NA	NA	NA	NA	NA	2.37E-01	1.73E-01
<b>Reach 5</b>							
Total Mercury	2.50E-01	9.12E-02	Normal	Student's-t UCL	1.26E-01	1.26E-01	9.12E-02
Methylmercury	NA	NA	NA	NA	NA	4.42E-02	3.19E-02
<b>Reach 6</b>							
Total Mercury	7.21E-01	2.02E-01	Gamma	Approximate Gamma UCL	3.53E-01	3.53E-01	2.02E-01
Methylmercury	NA	NA	NA	NA	NA	1.24E-01	7.07E-02
<b>Reach 7</b>							
Total Mercury	1.31E-01	4.12E-02	Non-Parametric	95% Chebyshev (Mean, Sd) UCL	7.44E-02	7.44E-02	4.12E-02
Methylmercury	NA	NA	NA	NA	NA	2.60E-02	1.44E-02
<b>Reach 7 - Heard Pond</b>							
Total Mercury	2.35E-01	1.99E-01	Normal	Student's-t UCL	2.32E-01	2.32E-01	1.99E-01
Methylmercury	NA	NA	NA	NA	NA	8.12E-02	6.98E-02
<b>Reach 8</b>							
Total Mercury	1.06E-01	5.39E-02	Normal	Student's-t UCL	6.78E-02	6.78E-02	5.39E-02
Methylmercury	NA	NA	NA	NA	NA	2.37E-02	1.89E-02
<b>Reach 9</b>							
Total Mercury	1.56E-01	1.07E-01	Normal	Student's-t UCL	1.25E-01	1.25E-01	1.07E-01
Methylmercury	NA	NA	NA	NA	NA	4.36E-02	3.75E-02
<b>Reach 10</b>							
Total Mercury	1.28E-01	5.83E-02	Normal	Student's-t UCL	7.84E-02	7.84E-02	5.83E-02
Methylmercury	NA	NA	NA	NA	NA	2.74E-02	2.04E-02
<b>Charles River</b>							
Total Mercury	4.45E-02	3.70E-02	Normal	Student's-t UCL	4.09E-02	4.09E-02	3.70E-02
Methylmercury	NA	NA	NA	NA	NA	1.43E-02	1.30E-02
<b>Sudbury Reservoir</b>							
Total Mercury	4.88E-02	3.43E-02	Normal	Student's-t UCL	4.23E-02	4.23E-02	3.43E-02
Methylmercury	NA	NA	NA	NA	NA	1.48E-02	1.20E-02

<sup>a</sup> Based on ProUCL recommendation.

mg/kg = Milligrams per kilogram.

NA = Not applicable; methylmercury EPCs are based on 35% of total mercury EPCs.

**Table 3-3**

**Summary of the UCL Calculation Methods  
Operable Unit IV, Nyanza Chemical Dump Superfund Site  
Middlesex County, Massachusetts**

<b>Data Distribution</b>	<b>UCL Method Used</b>
Normal	Student's t statistic
Lognormal <sup>a</sup>	H-statistic 95 percent Chebyshev Minimum Variance Unbiased Estimate (MVUE) 97.5 percent Chebyshev MVUE 99 percent Chebyshev MVUE 95 percent Chebyshev (Mean, Std) 99 percent Chebyshev (Mean, Std)
Gamma <sup>b</sup>	Approximate gamma Adjusted gamma 95 percent based on Bootstrap-t Hall's bootstrap
Either Lognormal and Gamma	Assumed gamma distribution. See UCL calculation methods for gamma distribution.
Either Normal, Lognormal, or Gamma <sup>c</sup>	See UCL methods for normal, lognormal, and gamma distributions.
Non-parametric <sup>d</sup>	95 percent Chebyshev (Mean, Std) 97.5 percent Chebyshev (Mean, Std) 99 percent Chebyshev (Mean, Std) 95 percent Student's t or Modified t-statistic Hall's bootstrap

<sup>a</sup>ProUCL recommends one of six methods based on the skewness and sample size of the data set.

<sup>b</sup> ProUCL recommends one of four methods based on the skewness and sample size of the data set.

<sup>c</sup>When ProUCL indicates that the distribution of a dataset may be either normal, lognormal, or gamma, the distribution and UCL calculation method recommended by ProUCL was used.

<sup>d</sup>ProUCL recommends one of six methods based on the skewness and sample size of the data set.

Table 3-4

**Summary of Exposure Point Concentrations in Sediment  
Operable Unit IV - Nyanza Chemical Dump Superfund Site  
Middlesex County, Massachusetts**

<b>Chemical</b>	<b>Maximum Detected Concentration (mg/kg)</b>	<b>Arithmetic Mean Concentration (mg/kg)</b>	<b>Data Distribution<sup>a</sup></b>	<b>Calculation Method<sup>a</sup></b>	<b>95 % UCL of the Mean<sup>a</sup> (mg/kg)</b>	<b>RME Exposure Point Concentration (mg/kg)</b>	<b>CTE Exposure Point Concentration (mg/kg)</b>
<b>Reach 1</b>							
Methylmercury	5.98E-03	2.77E-03	Normal	Student's-t UCL	4.33E-03	4.33E-03	2.77E-03
<b>Reach 2</b>							
Methylmercury	1.75E-02	4.68E-03	Gamma	Adjusted Gamma UCL	1.46E-02	1.46E-02	4.68E-03
<b>Reach 3</b>							
Methylmercury	2.07E-02	6.66E-03	Gamma	Approximate Gamma UCL	7.64E-03	7.64E-03	6.66E-03
<b>Reach 3 - Focus Area</b>							
Methylmercury	1.05E-02	4.89E-03	Non-parametric	99% Chebyshev (Mean, Sd) UCL	1.42E-02	1.05E-02	4.89E-03
<b>Reach 4</b>							
Methylmercury	4.05E-03	2.09E-03	Normal	Student's-t UCL	2.66E-03	2.66E-03	2.09E-03
<b>Reach 5</b>							
Methylmercury	8.12E-03	2.66E-03	Normal	Student's-t UCL	4.05E-03	4.05E-03	2.66E-03
<b>Reach 5 - Focus Area</b>							
Methylmercury	5.29E-03	1.10E-03	Non-parametric	99% Chebyshev (Mean, Sd) UCL	5.97E-03	5.29E-03	1.10E-03
<b>Reach 6</b>							
Methylmercury	1.13E-02	2.51E-03	Gamma	Approximate Gamma UCL	4.65E-03	4.65E-03	2.51E-03
<b>Reach 7</b>							
Methylmercury	3.95E-03	9.27E-04	Gamma	Approximate Gamma UCL	1.76E-03	1.76E-03	9.27E-04
<b>Reach 7 - Heard Pond</b>							
Methylmercury	5.39E-03	5.05E-03	Normal	Student's-t UCL	5.45E-03	5.39E-03	5.05E-03
<b>Reach 8</b>							
Methylmercury	6.20E-03	2.59E-03	Gamma	Approximate Gamma UCL	5.10E-03	5.10E-03	2.59E-03
<b>Reach 9</b>							
Methylmercury	4.65E-03	2.93E-03	Normal	Student's-t UCL	3.38E-03	3.38E-03	2.93E-03
<b>Reach 10</b>							
Methylmercury	5.43E-03	2.25E-03	Normal	Student's-t UCL	3.28E-03	3.28E-03	2.25E-03
<b>Charles River</b>							
Methylmercury	2.10E-03	1.57E-03	Normal	Student's-t UCL	1.85E-03	1.85E-03	1.57E-03
<b>Sudbury Reservoir</b>							
Methylmercury	9.09E-04	3.98E-04	Gamma	Approximate Gamma UCL	6.96E-04	6.96E-04	3.98E-04

<sup>a</sup>Based on ProUCL recommendation.

mg/kg = Milligrams per kilogram.



Table 3-5

**Summary of Exposure Point Concentrations in Surface Water  
Operable Unit IV - Nyanza Chemical Dump Superfund Site  
Middlesex County, Massachusetts**

<b>Chemical</b>	<b>Maximum Detected Concentration (ng/L)</b>	<b>Arithmetic Mean Concentration (ng/L)</b>	<b>Data Distribution<sup>a</sup></b>	<b>Calculation Method<sup>a</sup></b>	<b>95 % UCL of the Mean<sup>a</sup> (ng/L)</b>	<b>RME Exposure Point Concentration (ng/L)</b>	<b>CTE Exposure Point Concentration (ng/L)</b>
<b>Reach 1</b>							
Total Mercury	2.26E+00	2.05E+00	Normal	Student's-t UCL	2.31E+00	2.26E+00	2.05E+00
Methylmercury	3.10E-01	2.60E-01	Normal	Student's-t UCL	3.26E-01	3.10E-01	2.60E-01
<b>Reach 2</b>							
Total Mercury	4.18E+01	1.66E+01	ND	ND	NC	4.18E+01	1.66E+01
Methylmercury	3.92E-01	3.06E-01	ND	ND	NC	3.92E-01	3.06E-01
<b>Reach 3</b>							
Total Mercury	5.89E+00	5.89E+00	ND	ND	NC	5.89E+00	5.89E+00
Methylmercury	3.61E-01	3.61E-01	ND	ND	NC	3.61E-01	3.61E-01
<b>Reach 4</b>							
Total Mercury	2.70E+00	2.70E+00	ND	ND	NC	2.70E+00	2.70E+00
Methylmercury	1.42E-01	1.42E-01	ND	ND	NC	1.42E-01	1.42E-01
<b>Reach 5</b>							
Total Mercury	1.59E+00	1.59E+00	ND	ND	NC	1.59E+00	1.59E+00
Methylmercury	1.25E-01	1.25E-01	ND	ND	NC	1.25E-01	1.25E-01
<b>Reach 7</b>							
Total Mercury	2.30E+01	5.88E+00	Gamma	Approximate Gamma UCL	1.04E+01	1.04E+01	5.88E+00
Methylmercury	5.18E-01	2.05E-01	Gamma	Approximate Gamma UCL	2.87E-01	2.87E-01	2.05E-01
<b>Reach 8</b>							
Total Mercury	1.50E+01	9.61E+00	Normal	Student's-t UCL	1.11E+01	1.11E+01	9.61E+00
Methylmercury	3.23E-01	2.58E-01	Normal	Student's-t UCL	2.82E-01	2.82E-01	2.58E-01
<b>Charles River</b>							
Total Mercury	2.85E+00	1.87E+00	Normal	Student's-t UCL	2.19E+00	2.19E+00	1.87E+00
Methylmercury	3.62E-01	2.49E-01	Non-Parametric	95% Chebyshev (Mean, Sd) UCL	3.68E-01	3.62E-01	2.49E-01

<sup>a</sup> Based on ProUCL recommendation.

ng/L = Nanograms per liter.

NC = Not calculated due to insufficient sample size.

ND = Not determined due to insufficient sample size.

Table 3-6

**Summary of Exposure Point Concentrations in Crayfish (Whole Body)  
Operable Unit IV - Nyanza Chemical Dump Superfund Site  
Middlesex County, Massachusetts**

<b>Chemical</b>	<b>Maximum Detected Concentration (mg/kg WW)</b>	<b>Arithmetic Mean Concentration (mg/kg WW)</b>	<b>Data Distribution<sup>a</sup></b>	<b>Calculation Method<sup>a</sup></b>	<b>95 % UCL of the Mean<sup>a</sup> (mg/kg WW)</b>	<b>RME Exposure Point Concentration (mg/kg WW)</b>	<b>CTE Exposure Point Concentration (mg/kg WW)</b>
<b>Reach 1</b>							
Total Mercury	4.72E-02	4.38E-02	ND	ND	NC	4.72E-02	4.38E-02
<b>Reach 2</b>							
Total Mercury	7.45E-02	4.57E-02	Non-Parametric	Mod-t UCL (Adjusted for skewness)	5.58E-02	5.58E-02	4.57E-02
<b>Reach 3</b>							
Total Mercury	2.10E-01	5.52E-02	Non-Parametric	Mod-t UCL (Adjusted for skewness)	7.28E-02	7.28E-02	5.52E-02
<b>Reach 4</b>							
Total Mercury	3.62E-02	2.31E-02	Normal	Student's-t UCL	3.48E-02	3.48E-02	2.31E-02
<b>Reach 5</b>							
Total Mercury	1.92E-01	9.83E-02	Normal	Student's-t UCL	1.14E-01	1.14E-01	9.83E-02
<b>Reach 6</b>							
Total Mercury	2.97E-02	2.97E-02	ND	ND	NC	2.97E-02	2.97E-02
<b>Reach 7</b>							
Total Mercury	8.61E-02	4.96E-02	Normal	Student's-t UCL	6.43E-02	6.43E-02	4.96E-02
<b>Charles River</b>							
Total Mercury	4.57E-02	3.99E-02	ND	ND	NC	4.57E-02	3.99E-02
<b>Sudbury Reservoir</b>							
Total Mercury	1.31E-02	1.01E-02	ND	ND	NC	1.31E-02	1.01E-02

<sup>a</sup> Based on ProUCL recommendation.

mg/kg = Milligrams per kilogram.

NC = Not calculated due to insufficient sample size.

ND = Not determined due to insufficient sample size.

Table 3-7

**Summary of Exposure Point Concentrations in Fish (Whole Body - Size Class A)  
Operable Unit IV - Nyanza Chemical Dump Superfund Site  
Middlesex County, Massachusetts**

<b>Chemical</b>	<b>Maximum Detected Concentration (mg/kg WW)</b>	<b>Arithmetic Mean Concentration (mg/kg WW)</b>	<b>Data Distribution<sup>a</sup></b>	<b>Calculation Method<sup>a</sup></b>	<b>95 % UCL of the Mean<sup>a</sup> (mg/kg WW)</b>	<b>RME Exposure Point Concentration (mg/kg WW)</b>	<b>CTE Exposure Point Concentration (mg/kg WW)</b>
<b>Reach 1</b>							
Total Mercury	2.52E-01	1.37E-01	Normal	Student's-t UCL	1.62E-01	1.62E-01	1.37E-01
<b>Reach 2</b>							
Total Mercury	2.65E-01	1.87E-01	Normal	Student's-t UCL	2.09E-01	2.09E-01	1.87E-01
<b>Reach 3</b>							
Total Mercury	4.77E-01	2.19E-01	Non-Parametric	Mod-t UCL (Adjusted for skewness)	2.64E-01	2.64E-01	2.19E-01
<b>Reach 4</b>							
Total Mercury	3.53E-01	2.20E-01	Normal	Student's-t UCL	2.57E-01	2.57E-01	2.20E-01
<b>Reach 5</b>							
Total Mercury	3.03E-01	2.72E-01	Non-Parametric	Mod-t UCL (Adjusted for skewness)	2.89E-01	2.89E-01	2.72E-01
<b>Reach 6</b>							
Total Mercury	1.97E-01	1.27E-01	Normal	Student's-t UCL	1.46E-01	1.46E-01	1.27E-01
<b>Reach 7</b>							
Total Mercury	4.04E-01	2.05E-01	Gamma	Approximate Gamma UCL	2.55E-01	2.55E-01	2.05E-01
<b>Reach 7 - Heard Pond</b>							
Total Mercury	2.33E-02	1.50E-02	Normal	Student's-t UCL	1.68E-02	1.68E-02	1.50E-02
<b>Reach 8</b>							
Total Mercury	3.03E-01	2.14E-01	Normal	Student's-t UCL	2.23E-01	2.23E-01	2.14E-01
<b>Reach 9</b>							
Total Mercury	2.19E-01	1.72E-01	Normal	Student's-t UCL	1.94E-01	1.94E-01	1.72E-01
<b>Reach 10</b>							
Total Mercury	3.90E-01	2.44E-01	Gamma	Approximate Gamma UCL	2.70E-01	2.70E-01	2.44E-01
<b>Charles River</b>							
Total Mercury	1.87E-01	1.45E-01	Normal	Student's-t UCL	1.56E-01	1.56E-01	1.45E-01
<b>Sudbury Reservoir</b>							
Total Mercury	5.81E-02	3.12E-02	Non-Parametric	Mod-t UCL (Adjusted for skewness)	3.71E-02	3.71E-02	3.12E-02

<sup>a</sup> Based on ProUCL recommendation.

mg/kg = Milligrams per kilogram.

Table 3-8

**Summary of Exposure Point Concentrations in Fish (Whole Body - Size Class B)  
Operable Unit IV - Nyanza Chemical Dump Superfund Site  
Middlesex County, Massachusetts**

<b>Chemical</b>	<b>Maximum Detected Concentration (mg/kg WW)</b>	<b>Arithmetic Mean Concentration (mg/kg WW)</b>	<b>Data Distribution<sup>a</sup></b>	<b>Calculation Method<sup>a</sup></b>	<b>95 % UCL of the Mean<sup>a</sup> (mg/kg WW)</b>	<b>RME Exposure Point Concentration (mg/kg WW)</b>	<b>CTE Exposure Point Concentration (mg/kg WW)</b>
<b>Reach 1</b>							
Total Mercury	1.67E-01	1.12E-01	Normal	Student's-t UCL	1.29E-01	1.29E-01	1.12E-01
<b>Reach 2</b>							
Total Mercury	3.63E-01	2.21E-01	Normal	Student's-t UCL	2.50E-01	2.50E-01	2.21E-01
<b>Reach 3</b>							
Total Mercury	2.53E-01	1.95E-01	Normal	Student's-t UCL	2.09E-01	2.09E-01	1.95E-01
<b>Reach 4</b>							
Total Mercury	2.15E-01	1.43E-01	Normal	Student's-t UCL	1.57E-01	1.57E-01	1.43E-01
<b>Reach 5</b>							
Total Mercury	1.85E-01	1.22E-01	Lognormal	95% H-UCL	1.38E-01	1.38E-01	1.22E-01
<b>Reach 6</b>							
Total Mercury	1.32E-01	1.06E-01	Normal	Student's-t UCL	1.18E-01	1.18E-01	1.06E-01
<b>Reach 7</b>							
Total Mercury	2.05E-01	1.52E-01	Normal	Student's-t UCL	1.68E-01	1.68E-01	1.52E-01
<b>Reach 7 - Heard Pond</b>							
Total Mercury	2.92E-02	2.02E-02	Normal	Student's-t UCL	2.19E-02	2.19E-02	2.02E-02
<b>Reach 8</b>							
Total Mercury	2.39E-01	1.79E-01	Normal	Student's-t UCL	1.85E-01	1.85E-01	1.79E-01
<b>Reach 9</b>							
Total Mercury	2.74E-01	2.10E-01	Normal	Student's-t UCL	2.33E-01	2.33E-01	2.10E-01
<b>Reach 10</b>							
Total Mercury	2.59E-01	1.99E-01	Normal	Student's-t UCL	2.19E-01	2.19E-01	1.99E-01
<b>Charles River</b>							
Total Mercury	1.22E-01	1.05E-01	Normal	Student's-t UCL	1.11E-01	1.11E-01	1.05E-01
<b>Sudbury Reservoir</b>							
Total Mercury	4.54E-02	3.27E-02	Normal	Student's-t UCL	3.63E-02	3.63E-02	3.27E-02

<sup>a</sup> Based on ProUCL recommendation.  
mg/kg = Milligrams per kilogram.

Table 3-9

**Summary of Exposure Point Concentrations in Fish (Whole Body - Size Classes B & C)  
Operable Unit IV - Nyanza Chemical Dump Superfund Site  
Middlesex County, Massachusetts**

<b>Chemical</b>	<b>Maximum Detected Concentration (mg/kg WW)</b>	<b>Arithmetic Mean Concentration (mg/kg WW)</b>	<b>Data Distribution<sup>a</sup></b>	<b>Calculation Method<sup>a</sup></b>	<b>95 % UCL of the Mean<sup>a</sup> (mg/kg WW)</b>	<b>RME Exposure Point Concentration (mg/kg WW)</b>	<b>CTE Exposure Point Concentration (mg/kg WW)</b>
<b>Reach 1</b>							
Total Mercury	2.07E-01	1.14E-01	Normal	Student's-t UCL	1.30E-01	1.30E-01	1.14E-01
<b>Reach 2</b>							
Total Mercury	3.63E-01	2.00E-01	Normal	Student's-t UCL	2.24E-01	2.24E-01	2.00E-01
<b>Reach 3</b>							
Total Mercury	3.50E-01	2.28E-01	Normal	Student's-t UCL	2.48E-01	2.48E-01	2.28E-01
<b>Reach 4</b>							
Total Mercury	2.15E-01	1.50E-01	Normal	Student's-t UCL	1.61E-01	1.61E-01	1.50E-01
<b>Reach 5</b>							
Total Mercury	2.02E-01	1.37E-01	Normal	Student's-t UCL	1.51E-01	1.51E-01	1.37E-01
<b>Reach 6</b>							
Total Mercury	1.36E-01	9.99E-02	Normal	Student's-t UCL	1.08E-01	1.08E-01	9.99E-02
<b>Reach 7</b>							
Total Mercury	2.05E-01	1.34E-01	Normal	Student's-t UCL	1.45E-01	1.45E-01	1.34E-01
<b>Reach 7 - Heard Pond</b>							
Total Mercury	4.99E-02	2.69E-02	Gamma	Approximate Gamma UCL	3.02E-02	3.02E-02	2.69E-02
<b>Reach 8</b>							
Total Mercury	3.49E-01	1.76E-01	Gamma	Approximate Gamma UCL	1.83E-01	1.83E-01	1.76E-01
<b>Reach 9</b>							
Total Mercury	2.74E-01	1.88E-01	Normal	Student's-t UCL	2.02E-01	2.02E-01	1.88E-01
<b>Reach 10</b>							
Total Mercury	2.59E-01	2.02E-01	Normal	Student's-t UCL	2.14E-01	2.14E-01	2.02E-01
<b>Charles River</b>							
Total Mercury	1.23E-01	1.05E-01	Normal	Student's-t UCL	1.08E-01	1.08E-01	1.05E-01
<b>Sudbury Reservoir</b>							
Total Mercury	1.13E-01	4.83E-02	Gamma	Approximate Gamma UCL	5.61E-02	5.61E-02	4.83E-02

<sup>a</sup> Based on ProUCL recommendation.

mg/kg = Milligrams per kilogram.

Table 3-10

**Summary of Exposure Point Concentrations in Fish (Whole Body - Size Class C)  
Operable Unit IV - Nyanza Chemical Dump Superfund Site  
Middlesex County, Massachusetts**

<b>Chemical</b>	<b>Maximum Detected Concentration (mg/kg WW)</b>	<b>Arithmetic Mean Concentration (mg/kg WW)</b>	<b>Data Distribution<sup>a</sup></b>	<b>Calculation Method<sup>a</sup></b>	<b>95 % UCL of the Mean<sup>a</sup> (mg/kg WW)</b>	<b>RME Exposure Point Concentration (mg/kg WW)</b>	<b>CTE Exposure Point Concentration (mg/kg WW)</b>
<b>Reach 1</b>							
Total Mercury	2.07E-01	1.18E-01	Normal	Student's-t UCL	1.51E-01	1.51E-01	1.18E-01
<b>Reach 2</b>							
Total Mercury	3.24E-01	1.80E-01	Normal	Student's-t UCL	2.19E-01	2.19E-01	1.80E-01
<b>Reach 3</b>							
Total Mercury	3.50E-01	2.60E-01	Normal	Student's-t UCL	2.94E-01	2.94E-01	2.60E-01
<b>Reach 4</b>							
Total Mercury	2.00E-01	1.56E-01	Normal	Student's-t UCL	1.75E-01	1.75E-01	1.56E-01
<b>Reach 5</b>							
Total Mercury	2.02E-01	1.63E-01	Normal	Student's-t UCL	1.90E-01	1.90E-01	1.63E-01
<b>Reach 6</b>							
Total Mercury	1.36E-01	9.53E-02	Normal	Student's-t UCL	1.08E-01	1.08E-01	9.53E-02
<b>Reach 7</b>							
Total Mercury	1.49E-01	1.16E-01	Normal	Student's-t UCL	1.26E-01	1.26E-01	1.16E-01
<b>Reach 7 - Heard Pond</b>							
Total Mercury	4.99E-02	3.37E-02	Normal	Student's-t UCL	3.78E-02	3.78E-02	3.37E-02
<b>Reach 8</b>							
Total Mercury	3.49E-01	1.70E-01	Gamma	Approximate Gamma UCL	1.86E-01	1.86E-01	1.70E-01
<b>Reach 9</b>							
Total Mercury	2.29E-01	1.70E-01	Normal	Student's-t UCL	1.84E-01	1.84E-01	1.70E-01
<b>Reach 10</b>							
Total Mercury	2.59E-01	2.04E-01	Normal	Student's-t UCL	2.21E-01	2.21E-01	2.04E-01
<b>Charles River</b>							
Total Mercury	1.23E-01	1.04E-01	Normal	Student's-t UCL	1.09E-01	1.09E-01	1.04E-01
<b>Sudbury Reservoir</b>							
Total Mercury	1.13E-01	6.38E-02	Normal	Student's-t UCL	7.43E-02	7.43E-02	6.38E-02

<sup>a</sup> Based on ProUCL recommendation.

mg/kg = Milligrams per kilogram.

Table 3-11

**Summary of Exposure Point Concentrations in Fish (Whole Body - Size Class D)  
Operable Unit IV - Nyanza Chemical Dump Superfund Site  
Middlesex County, Massachusetts**

<b>Chemical</b>	<b>Maximum Detected Concentration (mg/kg WW)</b>	<b>Arithmetic Mean Concentration (mg/kg WW)</b>	<b>Data Distribution<sup>a</sup></b>	<b>Calculation Method<sup>a</sup></b>	<b>95 % UCL of the Mean<sup>a</sup> (mg/kg WW)</b>	<b>RME Exposure Point Concentration (mg/kg WW)</b>	<b>CTE Exposure Point Concentration (mg/kg WW)</b>
<b>Reach 1</b>							
Total Mercury	5.55E-01	1.64E-01	Gamma	Approximate Gamma UCL	2.27E-01	2.27E-01	1.64E-01
<b>Reach 2</b>							
Total Mercury	5.84E-01	3.09E-01	Normal	Student's-t UCL	3.81E-01	3.81E-01	3.09E-01
<b>Reach 3</b>							
Total Mercury	8.95E-01	4.73E-01	Normal	Student's-t UCL	5.92E-01	5.92E-01	4.73E-01
<b>Reach 4</b>							
Total Mercury	6.17E-01	3.67E-01	Normal	Student's-t UCL	4.48E-01	4.48E-01	3.67E-01
<b>Reach 5</b>							
Total Mercury	5.37E-01	2.86E-01	Normal	Student's-t UCL	3.71E-01	3.71E-01	2.86E-01
<b>Reach 6</b>							
Total Mercury	7.11E-01	3.30E-01	Normal	Student's-t UCL	4.47E-01	4.47E-01	3.30E-01
<b>Reach 7</b>							
Total Mercury	7.35E-01	2.78E-01	Gamma	Approximate Gamma UCL	4.08E-01	4.08E-01	2.78E-01
<b>Reach 7 - Heard Pond</b>							
Total Mercury	1.93E-01	1.05E-01	Normal	Student's-t UCL	1.33E-01	1.33E-01	1.05E-01
<b>Reach 8</b>							
Total Mercury	1.13E+00	3.59E-01	Gamma	Approximate Gamma UCL	4.71E-01	4.71E-01	3.59E-01
<b>Reach 9</b>							
Total Mercury	1.27E+00	4.82E-01	Normal	Student's-t UCL	7.19E-01	7.19E-01	4.82E-01
<b>Reach 10</b>							
Total Mercury	1.27E+00	5.18E-01	Gamma	Approximate Gamma UCL	9.14E-01	9.14E-01	5.18E-01
<b>Charles River</b>							
Total Mercury	4.14E-01	2.03E-01	Normal	Student's-t UCL	2.72E-01	2.72E-01	2.03E-01
<b>Sudbury Reservoir</b>							
Total Mercury	2.01E-01	1.22E-01	Normal	Student's-t UCL	1.56E-01	1.56E-01	1.22E-01

<sup>a</sup> Based on ProUCL recommendation.

mg/kg = Milligrams per kilogram.

Table 3-12

**Summary of Exposure Point Concentrations in Fish (Whole Body - Size Class D≤ 30 cm)**  
**Operable Unit IV - Nyanza Chemical Dump Superfund Site**  
**Middlesex County, Massachusetts**

<b>Chemical</b>	<b>Maximum Detected Concentration (mg/kg WW)</b>	<b>Arithmetic Mean Concentration (mg/kg WW)</b>	<b>Data Distribution<sup>a</sup></b>	<b>Calculation Method<sup>a</sup></b>	<b>95 % UCL of the Mean<sup>a</sup> (mg/kg WW)</b>	<b>RME Exposure Point Concentration (mg/kg WW)</b>	<b>CTE Exposure Point Concentration (mg/kg WW)</b>
<b>Reach 1</b>							
Total Mercury	5.55E-01	1.58E-01	Gamma	Approximate Gamma UCL	2.54E-01	2.54E-01	1.58E-01
<b>Reach 2</b>							
Total Mercury	5.84E-01	3.25E-01	Gamma	Approximate Gamma UCL	4.13E-01	4.13E-01	3.25E-01
<b>Reach 3</b>							
Total Mercury	6.06E-01	4.25E-01	Normal	Student's-t UCL	5.44E-01	5.44E-01	4.25E-01
<b>Reach 4</b>							
Total Mercury	4.63E-01	3.46E-01	Normal	Student's-t UCL	4.25E-01	4.25E-01	3.46E-01
<b>Reach 5</b>							
Total Mercury	2.30E-01	1.66E-01	Normal	Student's-t UCL	2.18E-01	2.18E-01	1.66E-01
<b>Reach 6</b>							
Total Mercury	3.21E-01	2.07E-01	Normal	Student's-t UCL	2.90E-01	2.90E-01	2.07E-01
<b>Reach 7</b>							
Total Mercury	2.80E-01	1.83E-01	Normal	Student's-t UCL	2.29E-01	2.29E-01	1.83E-01
<b>Reach 7 - Heard Pond</b>							
Total Mercury	7.62E-02	6.54E-02	ND	ND	NC	7.62E-02	6.54E-02
<b>Reach 8</b>							
Total Mercury	4.65E-01	2.39E-01	Normal	Student's-t UCL	2.79E-01	2.79E-01	2.39E-01
<b>Reach 9</b>							
Total Mercury	4.02E-01	2.55E-01	Normal	Student's-t UCL	3.34E-01	3.34E-01	2.55E-01
<b>Reach 10</b>							
Total Mercury	4.40E-01	2.79E-01	Normal	Student's-t UCL	3.75E-01	3.75E-01	2.79E-01
<b>Charles River</b>							
Total Mercury	1.69E-01	1.48E-01	Normal	Student's-t UCL	1.65E-01	1.65E-01	1.48E-01
<b>Sudbury Reservoir</b>							
Total Mercury	1.05E-01	8.78E-02	Normal	Student's-t UCL	1.03E-01	1.03E-01	8.78E-02

<sup>a</sup> Based on ProUCL recommendation.

mg/kg = Milligrams per kilogram.

NC = Not calculated due to insufficient sample size.

ND = Not determined due to insufficient sample size.



**Table 3-13**

**Calculation of Field Metabolic Rates\***  
**Operable Unit IV, Nyanza Chemical Dump Superfund Site**  
**Middlesex County, Massachusetts**

$\text{FMR (kcal/g BW - day)} = a \times \text{BW}^b \times \frac{1 \text{ kcal}}{4.1876 \text{ kJ}} \div \text{BW}$					
Target Receptor	Allometric Equation Basis	a	b	Body Weight in Grams	FMR (kcal/g BW-day)
Tree Swallow	Birds – Passerines	10.4	0.68	20.8 (mean adult body weight; site-specific data)	0.94
Kingfisher	Birds – All Birds	10.5	0.681	150 (mean body weight based on means from Dunning, 1993; Alexander, 1977; Salyer and Lagler, 1946; Brooks and Davis, 1987; and Hamas, 1994)	0.51
Great Blue Heron	Birds – All Birds	10.5	0.681	2390 (mean body weight from Dunning, 1984)	0.21
Mink	Mammals – Carnivora	1.67	0.869	946 (mean adult body weight based on male and female means in spring; Mitchell, 1961 as in EPA, 1995a)	0.16

\*From Nagy et al., 1999 unless otherwise indicated.

**Table 3-14**

**Assimilation Efficiency (AE) and Gross Energy (GE) of Anticipated Prey Items  
Operable Unit IV, Nyanza Chemical Dump Superfund Site  
Middlesex County, Massachusetts**

<b>Predator/Prey Item</b>	<b>Assimilation Efficiency (unitless)</b>	<b>Basis of Value</b>	<b>Gross Energy (kcal/g ww)</b>	<b>Basis of Value</b>
<b>Birds</b>				
Emergent Insects	0.72	Birds – terrestrial insects	1.6	Mean of grasshoppers/crickets and beetles
Crayfish	0.77	Waterfowl – aquatic invertebrates	1.1	Shrimp
Fish	0.79	Eagles/seabirds – fish	1.2	Bony fishes
<b>Mammals</b>				
Crayfish	0.87	Small mammals – insects	1.1	Shrimp
Fish	0.91	Mammals – fish	1.2	Bony fishes

Source: EPA, 1993a.

**Table 3-15**

**Dietary Exposure Parameters for the Tree Swallow  
Operable Unit IV, Nyanza Chemical Dump Superfund Site  
Middlesex County, Massachusetts**

Parameter	Definition	Value	Reference
FT	Foraging time in the exposure area (unitless).	1	Professional judgment
FIR <sub>IB</sub>	Food ingestion rate of insectivorous birds (kg WW/kg BW-day).	0.82	Calculated
C <sub>EI</sub>	Concentration of COEC in emergent insects (mg COEC/kg WW; converted from µg/kg by dividing by 1E+03).	Reach-specific	Table 3-2
P <sub>EI</sub>	Proportion of diet comprised of emergent insects (unitless).	1	Blancher and McNicol, 1991; Robertson et al., 1992
WIR	Water ingestion rate for insectivorous bird (L/kg BW-day).	0.21	Estimated based on $0.059 \times BW^{0.67}$ (kg) and a mean body weight of 0.0201 kg (Dunning, 1984)
C <sub>W</sub>	Concentration of COEC in water column (mg COEC/L water; converted from ng/L by dividing by 1E+06).	Reach-specific	Table 3-5

**Table 3-16**

**Dietary Exposure Parameters for the Belted Kingfisher  
Operable Unit IV, Nyanza Chemical Dump Superfund Site  
Middlesex County, Massachusetts**

Parameter	Definition	Value	Reference
FT	Foraging time in the exposure area (unitless).	1	Professional judgment
FIR <sub>PB</sub>	Food ingestion rate of piscivorous birds (kg WW/kg BW-day).	0.54	Calculated
C <sub>BI</sub>	Concentration of COEC in benthic invertebrates (i.e., crayfish; mg COEC/kg WW; converted from µg/kg by dividing by 1E+03).	Reach-specific	Table 3-6
P <sub>BI</sub>	Proportion of diet comprised of benthic invertebrates (unitless).	0.17 (Reaches 1 through 7, Charles River, and Sudbury Reservoir)	Mean of Alexander, 1977; Salyer and Lagler, 1948; Davis, 1982; and White, 1936 and assuming only crayfish and fish comprise the kingfisher's diet.
		0 (Heard Pond and Reaches 8 through 10)	Crayfish not caught in these reaches.
C <sub>F-Class A</sub>	Concentration of COEC in fish ≥ 5 to <10 cm long (mg COEC/kg WW; converted from µg/kg by dividing by 1E+03).	Reach-specific	Table 3-7
P <sub>F-Class A</sub>	Proportion of diet comprised of fish from size class A (unitless).	0.415 (Reaches 1 through 7, Charles River, and Sudbury Reservoir)	Mean of Alexander, 1977; Salyer and Lagler, 1948; Davis, 1982; and White, 1936 and assuming only crayfish and fish comprise the kingfisher's diet and that fish from size class A comprise 50% of the fish intake.
		0.5 (Heard Pond and Reaches 8 through 10)	Crayfish not caught in these reaches; therefore it is conservatively assumed that fish comprise 100% of the kingfisher's diet. Also assumed that fish from size class A comprise 50% of the fish intake.

**Table 3-16, Continued**

**Dietary Exposure Parameters for the Belted Kingfisher  
Operable Unit IV, Nyanza Chemical Dump Superfund Site  
Middlesex County, Massachusetts**

Parameter	Definition	Value	Reference
C <sub>F-Class B</sub>	Concentration of COEC in fish $\geq 10$ to $<15$ cm long (mg COEC/kg WW; converted from $\mu\text{g/kg}$ by dividing by $1\text{E}+03$ ).	Reach-specific	Table 3-8
P <sub>F-Class B</sub>	Proportion of diet comprised of fish from size class B (unitless).	0.415 (Reaches 1 through 7, Charles River, and Sudbury Reservoir )	Mean of Alexander, 1977; Salyer and Lagler, 1948; Davis, 1982; and White, 1936 and assuming only crayfish and fish comprise the kingfisher's diet and that fish from size class B comprise 50% of the fish intake.
		0.5 (Heard Pond and Reaches 8 through 10)	Crayfish not caught in these reaches; therefore it is conservatively assumed that fish comprise 100% of the kingfisher's diet. Also assumed that fish from size class B comprise 50% of the fish intake.
SIR	Sediment ingestion rate for piscivorous birds (kg DW/kg BW-day).	4.5E-03	Based on a WW ingestion rate of 0.28 kg/kg-day (EPA, 1993a), assuming 75% water content in the diet (based on bony fish), and conservatively assuming a kingfisher ingests 3.3% of the dry food intake based on the mallard, an aquatic avian species known to feed on aquatic plants and invertebrates (Beyer et al., 1994)
C <sub>Sed</sub>	Concentration of COEC in bed sediment (mg COEC/kg DW soil).	Reach-specific	Table 3-4
WIR	Water ingestion rate for piscivorous bird (L/kg BW-day).	0.11	Estimated based on $0.059 \times \text{BW}^{0.67}$ (kg) and a mean body weight of 0.150 kg (Dunning, 1993; Alexander, 1977; Salyer and Lagler, 1946; Brooks and Davis, 1987; and Hamas, 1994)
C <sub>W</sub>	Concentration of COEC in water column (mg COEC/L water; converted from ng/L by dividing by $1\text{E}+06$ ).	Reach-specific	Table 3-5

**Table 3-17**

**Dietary Exposure Parameters for the Great Blue Heron  
Operable Unit IV, Nyanza Chemical Dump Superfund Site  
Middlesex County, Massachusetts**

Parameter	Definition	Value	Reference
FT	Foraging time in the exposure area (unitless).	1	Professional judgment
FIR <sub>PB</sub>	Food ingestion rate of piscivorous birds (kg WW/kg BW-day).	0.22	Calculated
C <sub>BI</sub>	Concentration of COEC in benthic invertebrates (i.e., crayfish; mg COEC/kg WW; converted from µg/kg by dividing by 1E+03).	Reach-specific	Table 3-6
P <sub>BI</sub>	Proportion of diet comprised of benthic invertebrates (unitless).	0.16 (Reaches 1 through 7, Charles River, and Sudbury Reservoir)	Mean of Alexander, 1977; Martin et al., 1951; and Zeiner et al., 1990 and assuming only crayfish and fish comprise the heron's diet.
		0 (Heard Pond and Reaches 8 through 10)	Crayfish not caught in these reaches.
C <sub>F-Class A</sub>	Concentration of COEC in fish ≥ 5 to <10 cm long (mg COEC/kg WW; converted from µg/kg by dividing by 1E+03).	Reach-specific	Table 3-7
P <sub>F-Class A</sub>	Proportion of diet comprised of fish from size class A (unitless).	0.329 (Reaches 1 through 7, Charles River, and Sudbury Reservoir)	Mean of Alexander, 1977; Martin et al., 1951; and Zeiner et al., 1990 and assuming only crayfish and fish comprise the heron's diet and that fish from size class A comprise 39.2% of the fish intake.
		0.392 (Heard Pond and Reaches 8 through 10)	Crayfish not caught in these reaches; therefore it is conservatively assumed that fish comprise 100% of the heron's diet. Also assumed that fish from size class A comprise 39.2% of the fish intake.
C <sub>F-Class B and C</sub>	Concentration of COEC in fish ≥ 10 to <20 cm long (mg COEC/kg WW; converted from µg/kg by dividing by 1E+03).	Reach-specific	Table 3-9

**Table 3-17, Continued**

**Dietary Exposure Parameters for the Great Blue Heron  
Operable Unit IV, Nyanza Chemical Dump Superfund Site  
Middlesex County, Massachusetts**

Parameter	Definition	Value	Reference
P <sub>F</sub> -Class B and C	Proportion of diet comprised of fish from size classes B and C (unitless).	0.396 (Reaches 1 through 7, Charles River, and Sudbury Reservoir)	Mean of Alexander, 1977; Martin et al., 1951; and Zeiner et al., 1990 and assuming only crayfish and fish comprise the heron's diet and that fish from size classes B and C comprise 47.1% of the fish intake.
		0.471 (Heard Pond and Reaches 8 through 10)	Crayfish not caught in these reaches; therefore it is conservatively assumed that fish comprise 100% of the heron's diet. Also assumed that fish from size classes B and C comprise 47.1% of the fish intake.
C <sub>F</sub> -Class D ≤ 30 cm	Concentration of COEC in fish ≥ 20 to ≤ 30 cm long (mg COEC/kg WW; converted from µg/kg by dividing by 1E+03).	Reach-specific	Table 3-12
P <sub>F</sub> - Class D ≤ 30 cm	Proportion of diet comprised of fish from size class D that are ≤ 30 cm long (unitless).	0.115 (Reaches 1 through 7, Charles River, and Sudbury Reservoir)	Mean of Alexander, 1977; Martin et al., 1951; and Zeiner et al., 1990 and assuming only crayfish and fish comprise the heron's diet and that fish from size class D ≤ 30 cm long comprise 13.7% of the fish intake.
		0.137 (Heard Pond and Reaches 8 through 10)	Crayfish not caught in these reaches; therefore it is conservatively assumed that fish comprise 100% of the heron's diet. Also assumed that fish from size class D ≤ 30 cm long comprise 13.7% of the fish intake.

**Table 3-17, Continued**

**Dietary Exposure Parameters for the Great Blue Heron  
Operable Unit IV, Nyanza Chemical Dump Superfund Site  
Middlesex County, Massachusetts**

<b>Parameter</b>	<b>Definition</b>	<b>Value</b>	<b>Reference</b>
SIR	Sediment ingestion rate for piscivorous birds (kg DW/kg BW-day).	1.9E-03	Based on a WW ingestion rate of 0.11 kg/kg-day, assuming 75% water content in the diet (based on bony fish), and conservatively assuming a heron ingests 3.3% of the dry food intake based on the mallard, an aquatic avian species known to feed on aquatic plants and invertebrates (Beyer et al., 1994)
C <sub>Sed</sub>	Concentration of COEC in bed sediment (mg COEC/kg DW soil).	Reach-specific	Table 3-4
WIR	Water ingestion rate for piscivorous bird (L/kg BW-day).	0.044	Estimated based on $0.059 \times BW^{0.67}$ (kg) and a mean body weight of 2.39 kg (Dunning, 1984)
C <sub>w</sub>	Concentration of COEC in water column (mg COEC/L water; converted from ng/L by dividing by 1E+06).	Reach-specific	Table 3-5



**Table 3-18**

**Dietary Exposure Parameters for the Mink  
Operable Unit IV, Nyanza Chemical Dump Superfund Site  
Middlesex County, Massachusetts**

Parameter	Definition	Value	Reference
FT	Foraging time in the exposure area (unitless).	1	Professional judgment
FIR <sub>PM</sub>	Food ingestion rate of piscivorous mammal (kg WW/kg BW-day).	0.16	Calculated
C <sub>BI</sub>	Concentration of COEC in benthic invertebrates (i.e., crayfish; mg COEC/kg WW; converted from µg/kg by dividing by 1E+03).	Reach-specific	Table 3-6
P <sub>BI</sub>	Proportion of diet comprised of benthic invertebrates (unitless).	0.61 (Reaches 1 through 7, Charles River, and Sudbury Reservoir)	Mean of Alexander, 1977; Burgess and Bider, 1980; Cowan and Reilly, 1973; Gilbert and Nanckivell, 1982; Hamilton, 1959 and 1940; Melquist et al., 1981; Proulx et al., 1987 and assuming only crayfish and fish comprise the mink's diet.
		0 (Heard Pond and Reaches 8 through 10)	Crayfish not caught in these reaches.
C <sub>F-Class A</sub>	Concentration of COEC in fish ≥ 5 to <10 cm long (mg COEC/kg WW; converted from µg/kg by dividing by 1E+03).	Reach-specific	Table 3-7
P <sub>F-Class A</sub>	Proportion of diet comprised of fish from size class A (unitless).	0.0975 (Reaches 1 through 7, Charles River, and Sudbury Reservoir)	Mean of Alexander, 1977; Burgess and Bider, 1980; Cowan and Reilly, 1973; Gilbert and Nanckivell, 1982; Hamilton, 1959 and 1940; Melquist et al., 1981; Proulx et al., 1987 and assuming only crayfish and fish comprise the mink's diet and that fish from size class A comprise 25% of the fish intake.
		0.25 (Heard Pond and Reaches 8 through 10)	Crayfish not caught in these reaches; therefore it is conservatively assumed that fish comprise 100% of the mink's diet. Also assumed that fish from size class A comprise 25% of the fish intake.

**Table 3-18, Continued**

**Dietary Exposure Parameters for the Mink  
Operable Unit IV, Nyanza Chemical Dump Superfund Site  
Middlesex County, Massachusetts**

Parameter	Definition	Value	Reference
C <sub>F-Class B</sub>	Concentration of COEC in fish $\geq$ 10 to <15 cm long (mg COEC/kg WW; converted from $\mu\text{g/kg}$ by dividing by $1\text{E}+03$ ).	Reach-specific	Table 3-8
P <sub>F-Class B</sub>	Proportion of diet comprised of fish from size class B (unitless).	0.0975 (Reaches 1 through 7, Charles River, and Sudbury Reservoir)	Mean of Alexander, 1977; Burgess and Bider, 1980; Cowan and Reilly, 1973; Gilbert and Nanckivell, 1982; Hamilton, 1959 and 1940; Melquist et al., 1981; Proulx et al., 1987 and assuming only crayfish and fish comprise the mink's diet and that fish from size class B comprise 25% of the fish intake.
		0.25 (Heard Pond and Reaches 8 through 10)	Crayfish not caught in these reaches; therefore it is conservatively assumed that fish comprise 100% of the mink's diet. Also assumed that fish from size class B comprise 25% of the fish intake.
C <sub>F-Class C</sub>	Concentration of COEC in fish $\geq$ 15 to <20 cm long (mg COEC/kg WW; converted from $\mu\text{g/kg}$ by dividing by $1\text{E}+03$ ).	Reach-specific	Table 3-10
P <sub>F-Class C</sub>	Proportion of diet comprised of fish from size class C (unitless).	0.0975 (Reaches 1 through 7, Charles River, and Sudbury Reservoir)	Mean of Alexander, 1977; Burgess and Bider, 1980; Cowan and Reilly, 1973; Gilbert and Nanckivell, 1982; Hamilton, 1959 and 1940; Melquist et al., 1981; Proulx et al., 1987 and assuming only crayfish and fish comprise the mink's diet and that fish from size class C comprise 25% of the fish intake.
		0.25 (Heard Pond and Reaches 8 through 10)	Crayfish not caught in these reaches; therefore it is conservatively assumed that fish comprise 100% of the mink's diet. Also assumed that fish from size class C comprise 25% of the fish intake.
C <sub>F-Class D</sub>	Concentration of COEC in fish $\geq$ 20 cm long (mg COEC/kg WW; converted from $\mu\text{g/kg}$ by dividing by $1\text{E}+03$ ).	Reach-specific	Table 3-11

**Table 3-18, Continued**

**Dietary Exposure Parameters for the Mink  
Operable Unit IV, Nyanza Chemical Dump Superfund Site  
Middlesex County, Massachusetts**

Parameter	Definition	Value	Reference
P <sub>F-Class D</sub>	Proportion of diet comprised of fish from size class D (unitless).	0.0975 (Reaches 1 through 7, Charles River, and Sudbury Reservoir)	Mean of Alexander, 1977; Burgess and Bider, 1980; Cowan and Reilly, 1973; Gilbert and Nanckivell, 1982; Hamilton, 1959 and 1940; Melquist et al., 1981; Proulx et al., 1987 and assuming only crayfish and fish comprise the mink's diet and that fish from size class D comprise 25% of the fish intake.
		0.25 (Heard Pond and Reaches 8 through 10)	Crayfish not caught in these reaches; therefore it is conservatively assumed that fish comprise 100% of the mink's diet. Also assumed that fish from size class D comprise 25% of the fish intake.
SIR	Sediment ingestion rate for piscivorous mammals (kg DW/kg BW-day).	1.1E-03	Based on a WW ingestion rate of 0.16 kg/kg-day, assuming 75% water content in the diet (based on bony fish), and conservatively assuming a mink ingests 2.8% of the dry food intake based on the red fox, an omnivorous terrestrial receptor (Beyer et al., 1994)
C <sub>Sed</sub>	Concentration of COEC in sediment (mg COEC/kg DW soil).	Reach-specific	Table 3-4
IR <sub>W</sub>	Water ingestion rate for piscivorous mammals (L/kg BW-day).	0.1	Estimated based on $0.099 \times BW^{0.9}$ (kg) and a mean body weight of 0.946 kg (EPA, 1995a)
C <sub>W</sub>	Concentration of COEC in water column (mg COEC/L water; converted from ng/L by dividing by 1E+06).	Reach-specific	Table 3-5

Table 3-19

**Total Daily Intake Summary**  
**Operable Unit IV - Nyanza Chemical Dump Superfund Site**  
**Middlesex County, Massachusetts**

Chemical	Dose/Receptor (mg/kg BW-day)							
	RME				CTE			
	Tree Swallow	Belted Kingfisher	Great Blue Heron	Mink	Tree Swallow	Belted Kingfisher	Great Blue Heron	Mink
<i>Reach 1</i>								
Total Mercury	2.02E-01	NA	NA	NA	6.60E-02	NA	NA	NA
Methylmercury	7.07E-02	6.97E-02	3.11E-02	1.51E-02	2.31E-02	5.98E-02	2.54E-02	1.26E-02
<i>Reach 2</i>								
Total Mercury	3.42E-01	NA	NA	NA	1.36E-01	NA	NA	NA
Methylmercury	1.20E-01	1.08E-01	4.71E-02	2.20E-02	4.76E-02	9.57E-02	4.08E-02	1.85E-02
<i>Reach 3</i>								
Total Mercury	1.14E+00	NA	NA	NA	9.01E-01	NA	NA	NA
Methylmercury	3.98E-01	1.13E-01	5.70E-02	2.83E-02	3.15E-01	9.80E-02	4.84E-02	2.33E-02
<i>Reach 4</i>								
Total Mercury	5.54E-01	NA	NA	NA	4.04E-01	NA	NA	NA
Methylmercury	1.94E-01	9.61E-02	4.46E-02	1.96E-02	1.42E-01	8.37E-02	3.86E-02	1.61E-02
<i>Reach 5</i>								
Total Mercury	1.04E-01	NA	NA	NA	7.48E-02	NA	NA	NA
Methylmercury	3.63E-02	1.06E-01	4.36E-02	2.65E-02	2.62E-02	9.73E-02	3.92E-02	2.27E-02
<i>Reach 6</i>								
Total Mercury	2.90E-01	NA	NA	NA	1.66E-01	NA	NA	NA
Methylmercury	1.01E-01	6.18E-02	2.84E-02	1.57E-02	5.80E-02	5.50E-02	2.42E-02	1.32E-02
<i>Reach 7</i>								
Total Mercury	6.10E-02	NA	NA	NA	3.38E-02	NA	NA	NA
Methylmercury	2.13E-02	1.01E-01	3.91E-02	2.12E-02	1.18E-02	8.45E-02	3.29E-02	1.65E-02
<i>Reach 7 - Heard Pond</i>								
Total Mercury	1.90E-01	NA	NA	NA	1.63E-01	NA	NA	NA
Methylmercury	6.66E-02	1.04E-02	6.87E-03	8.40E-03	5.72E-02	9.49E-03	6.05E-03	6.96E-03
<i>Reach 8</i>								
Total Mercury	5.56E-02	NA	NA	NA	4.42E-02	NA	NA	NA
Methylmercury	1.95E-02	1.10E-01	4.66E-02	4.26E-02	1.55E-02	1.06E-01	4.38E-02	3.69E-02
<i>Reach 9</i>								
Total Mercury	1.02E-01	NA	NA	NA	8.78E-02	NA	NA	NA
Methylmercury	3.58E-02	1.15E-01	4.78E-02	5.32E-02	3.07E-02	1.03E-01	4.21E-02	4.14E-02
<i>Reach 10</i>								
Total Mercury	6.43E-02	NA	NA	NA	4.78E-02	NA	NA	NA
Methylmercury	2.25E-02	1.32E-01	5.68E-02	6.50E-02	1.67E-02	1.20E-01	5.04E-02	4.66E-02
<i>Charles River</i>								
Total Mercury	3.35E-02	NA	NA	NA	3.03E-02	NA	NA	NA
Methylmercury	1.17E-02	6.40E-02	2.65E-02	1.46E-02	1.06E-02	5.97E-02	2.47E-02	1.26E-02
<i>Sudbury Reservoir</i>								
Total Mercury	3.47E-02	NA	NA	NA	2.81E-02	NA	NA	NA
Methylmercury	1.21E-02	1.77E-02	1.06E-02	6.02E-03	9.83E-03	1.53E-02	9.05E-03	4.89E-03

NA = Not available.

**Table 3-20**

**Summary Statistics for the Mercury Critical Body Residue (CBR) Database  
Operable Unit IV, Nyanza Chemical Dump Superfund Site  
Middlesex County, Massachusetts**

Receptor Group	Age Group	Tissue Type Analyzed	# of Species	Number of Measured CBR Data Points	
				No Effect CBR	Effect CBR
Crayfish	Not available	whole body or muscle	11	9	3
Fish	eggs	egg/embryo	6	3	7
	fry to adults	whole body or muscle	19	34	20
Birds	embryos	egg content	30	27	27
	pre-fledglings	blood	4	4	2
		feathers	14	14	2
	post-fledglings	blood	4	3	3
		feathers	6	4	2
Mammals	juveniles to adults	blood	8	11	11
		fur	5	5	6

Note: The number of species within each receptor group adds up to more than the total number species in the database because a species may have been analyzed for more than one tissue type and/or age group.

**Table 3-22**

**Summary of the Most Conservative Species-Specific No Effect and Effect Whole Body or Muscle Mercury Residue Data for  
Crayfish  
Operable Unit IV, Nyanza Chemical Dump Superfund Site  
Middlesex County, Massachusetts**

Decapod species	Exposure route (duration)	Hg used in exposure	Measured no effect tissue conc. (wet weight)			Measured effect tissue concentration (wet weight)			Reference
			Residue level	Response	Comment	Residue level	Response	Comment	
crayfish ( <i>Astacus leptodactylus</i> )	inorganic Hg dissolved in water (15 days)	HgCl <sub>2</sub>	220 µg/kg (TotHg)	no effect on survival in adult males	average measured residue in whole organisms (n = 2)	-	-	an effect Hg conc. was not found for this species	Laporte et al., 1996
crayfish ( <i>Astacus astacus</i> )	ingestion of Hg-contaminated clams (30 days)	MeHg	420 µg/kg (TotHg)	no effect on survival in adult males	average measured residue in whole organisms	-	-	an effect Hg conc. was not found for this species	Simon and Boudou, 2001
lobster ( <i>Homarus gammarus</i> )	Hg dissolved in seawater (14 days)	HgCl <sub>2</sub>	700 µg/kg (TotHg?)	no effect on survival in intermolt adults	average measured residue in tail muscle (datum is for single lobster)	-	-	an effect Hg conc. was not found for this species	Brown et al., 1988
shore crab ( <i>Carcinus maenas</i> )	ingestion of Hg-contaminated cockles (30 days)	HgCl <sub>2</sub> & MeHg	820 µg/kg (TotHg)	no effect on survival in adult females	average measured residue in muscle (type unknown)	-	-	an effect Hg conc. was not found for this species	Bjerregaard and Christensen, 1993
grass shrimp ( <i>Palaemonetes pugio</i> )	Hg dissolved in sea water (30 days)	HgCl <sub>2</sub>	1,500 µg/kg	no effect on survival in egg-carrying females	average measured residue in whole organisms	-	-	an effect Hg conc. was not found for this species	Barthalmus, 1977
nordic shrimp ( <i>Pandalus borealis</i> )	ingestion of MeHg-contaminated mussels (22 days)	MeHg	1,600 µg/kg (TotHg)	no effect on survival or apparent effect on behavior	average measured residue in abdominal muscle	-	-	an effect Hg conc. was not found for this species	Rouleau et al., 1992
Norway lobster ( <i>Nephrops norvegicus</i> )	Hg dissolved in sea water (30 days)	MeHg	1,860 µg/kg (TotHg)	no effect on survival in young adults	average measured residue in tail muscle	-	-	an effect Hg conc. was not found for this species	Canli and Furness, 1993

Table 3-22, Continued

**Summary of the Most Conservative Species-Specific No Effect and Effect Whole Body or Muscle Mercury Residue Data for  
Crayfish  
Operable Unit IV, Nyanza Chemical Dump Superfund Site  
Middlesex County, Massachusetts**

Decapod species	Exposure route (duration)	Hg used in exposure	Measured no effect tissue conc. (wet weight)			Measured effect tissue concentration (wet weight)			Reference
			Residue level	Response	Residue level	Response	Residue level	Response	
pink shrimp ( <i>Penaeus duorarum</i> )	ingestion of Hg-contaminated fish (28 days)	MeHg	2,320 µg/kg (TotHg)	no effect on molt frequency, growth, or survival in juveniles	average measured residue in whole organisms	-	-	an effect Hg conc. was not found for this species	Evans et al., 2000
blue crab ( <i>Callinectes sapidus</i> )	ingestion of Hg-contaminated fish (28 days)	MeHg	3,330 µg/kg (TotHg)	no effect on molt frequency, growth, or survival in juveniles	average measured residue in whole organism	-	-	an effect Hg conc. was not found for this species	Evans et al., 2000
crayfish ( <i>unknown species</i> )	ingestion of Hg-contaminated fish (68 days)	MeHg	-	-	a no effect Hg conc. was not found for this species	5,460 µg/kg (TotHg)	reduced weight gain	average measured residue in abdominal muscle	Parks et al., 1988
crayfish ( <i>Procambarus clarkii</i> )	ingestion of Hg-contaminated fish (140 days)	MeHg	-	-	a no effect Hg conc. was not found for this species	6,500 µg/kg (TotHg)	reduced growth and increased time to seek shelter	average measured residue in abdominal muscle	Brant et al., 2002 (SETAC poster)
fiddler crab ( <i>Uca pugnax</i> )	Hg dissolved in sea water (22 days)	MeHg	-	-	a no effect Hg conc. was not found for this species	12,900 µg/kg (TotHg)	reduced limb length after molting and limb regeneration in older lifestages	average measured residue in whole organisms	Callahan and Weiss, 1983

**Table 3-23**

**Deriving an Effect to No Effect Ratio Based on Measured Tissue Residue Data in Fish  
Operable Unit IV, Nyanza Chemical Dump Superfund Site  
Middlesex County, Massachusetts**

<b>Fish species</b>	<b>Life Stage Analyzed for Hg</b>	<b>Endpoint</b>	<b>No Effect Hg Tissue Residue (µg/kg)</b>	<b>Effect Hg Tissue Residue (µg/kg)</b>	<b>Ratio of Effect to No Effect</b>	<b>Reference</b>
fathead minnow	adult	reproduction & spawning success	96	680	8.9	Hammerschmidt et al., 2002
grayling	eggs	adult feeding efficiency	90	270	3.0	Fjeld et al., 1998
mummichog	adult males	survival	200	470	2.4	Matta et al., 2001
mummichog	parents	sex ratio in offspring	440	1,100	2.5	Matta et al., 2001
walleye	juvenile	growth	250	2,370	9.5	Friedman et al., 1996
fathead minnow	adult	reproduction	320	1,360	4.3	Snarski & Olson, 1982
rainbow trout	fingerling	survival	680	1,600	2.4	Macleod & Pessah, 1973
brook trout	adult	reproduction	3,500	5,000	1.4	McKim et al., 1976
rainbow trout	fingerling	growth	7,500	8,500	1.1	Rodgers & Beamish, 1982
rainbow trout	fingerling	growth	12,500	15,000	1.2	Wobeser 1975
Japanese medaka	embryo	survival	16,000	29,000	1.8	Heisinger & Green, 1975

Note: the tissue residue data are for eggs, whole body, or muscle tissue.



**Table 3-24**

**Summary of the Most Conservative Species-Specific No Effect and Effect Whole Body or Muscle Mercury Residue Data for  
Fish and Amphibians  
Operable Unit IV, Nyanza Chemical Dump Superfund Site  
Middlesex County, Massachusetts**

Fish Species	Exposure Route & Duration	Hg used in Exposure	Measured or Estimated No Effect Tissue Conc. (Wet Weight)			Measured Effect Tissue Concentration (Wet Weight)			Reference
			Residue Level	Response	Comment	Residue Level	Response	Comment	
EGGS, EMBRYOS AND LARVAE									
channel catfish	water; 10 d	inorganic Hg	1.4 µg/kg	no effect on hatching success	estimated residue = 14 µg/kg ÷ 10	14 µg/kg	measurable reduction in survival at hatching & 4 d post hatch	measured residue	Birge et al., 1979
rainbow trout	water; 8 d	inorganic Hg	10 µg/kg	no effect on embryo mortality	estimated residue = 100 µg/kg ÷ 10	100 µg/kg	100% embryo mortality	measured residue	Birge et al., 1979
frog (Xenopus Laevis)	water; 4 d	inorganic Hg	81 µg/kg	no effect on embryo growth and malformation	estimated residue = 810 µg/kg ÷ 10	810 µg/kg	increased embryo malformations; decreased growth	measured residue	Prati et al., 2002
grayling	water; 10 d	organic Hg	90 µg/kg	lowest TM conc. in newly-hatched embryos resulting in no effect on feeding efficiency in adults tested 3 yrs later	measured residue	270 µg/kg	lowest TM conc. in newly-hatched embryos resulting in reduced feeding efficiency in adults tested 3 yrs later	measured residue	Fjeld et al., 1998
walleye	maternal transfer	not applicable	<297 µg/kg	no effect on reproductive success, larval survival or larval growth	measured residue	-	-	Not available	Latif et al., 2001
Japanese medaka	water; 16 d	inorganic Hg	16,000 µg/kg	no effect on hatching success	measured residue	29,000 µg/kg	hatching success reduced by 80%	measured residue	Heisinger & Green, 1975
ALEVINS, FINGERLINGS, JUVENILES, SUBADULTS AND ADULTS									
minnow (Phoxinus phoxinus)	water; 7 d	inorganic Hg	17 µg/kg	no effect on survival	measured residue	-	-	Not available	Cuvin-Aralar & Furness, 1990
fathead minnow	lab diet; 250 d	organic Hg	68	no effect on reproduction	equals control value; exclude from CBR calculation	714	suppression of spawning behavior reflected in the reduced reproductive success	measured residue	Sandheinrich and Miller, 2006
fathead minnow	lab diet; 250 d	organic Hg	71	no effect on reproduction	equals control value; exclude from CBR calculation	864	inhibited gonadal development of females; reduction of spawning and reproductive success	measured residue	Drevnick and Sandheinrich, 2003

**Table 3-24, Continued**

**Summary of the Most Conservative Species-Specific No Effect and Effect Whole Body or Muscle Mercury Residue Data for  
Fish and Amphibians  
Operable Unit IV, Nyanza Chemical Dump Superfund Site  
Middlesex County, Massachusetts**

Fish Species	Exposure Route & Duration	Hg used in Exposure	Measured or Estimated No Effect Tissue Conc. (Wet Weight)			Measured Effect Tissue Concentration (Wet Weight)			Reference
			Residue Level	Response	Comment	Residue Level	Response	Comment	
fathead minnow	lab diet; 286 d	organic Hg	96 µg/kg	no effect on reproduction or spawning success	measured residue in control adult females	680 µg/kg	decreased reproductive and spawning success; no effect on adult growth or mortality	measured residue in exposed adult females	Hammerschmidt et al., 2002
guppy	sediments ; 20 d	inorganic Hg	200 µg/kg	no effect on survival in adult males	measured residue	-	-	Not available	Kudo & Mortimer, 1979
mummi-chog	lab diet; 102 d	organic Hg	200 µg/kg	no effect on survival in adult males & females	measured residue	470 µg/kg	significant mortality in adult males, but not females; no effect on growth, fecundity or fertilization	measured residue	Matta et al., 2001
finescale dace	natural diet; 90 d	not applicable	250 µg/kg	no effect on growth in adults	measured residue	-	-	Not available	Bodaly & Fudge, 1999
walleye	lab diet	organic Hg	250 µg/kg	no effect on growth in juvenile males & females	measured residue	2,370 µg/kg	signif. decrease in growth in juvenile males, but not females; no effect on survival	measured residue	Friedman et al., 1996
carp	water; 34 d	inorganic Hg	280 µg/kg	no effect on survival or growth in juveniles (12 g)	measured residue	-	-	Not available	Yediler & Jacobs, 1995
catfish (Anabas scadens)	water; 45 d	inorganic Hg	280 µg/kg	estimated no effect on growth or blindness	estimated residue = 2.8 µg/kg ±10	2,800 µg/kg	signif. reduction in growth and increased blindness	measured residue	Panigrahi & Misra, 1978
fathead minnow	water; 287 d	inorganic Hg	320 µg/kg	no effect on reproduction	measured residue in parents	1,360 µg/kg	significant reproductive inhibition	measured residue in parents	Snarski & Olson, 1982
mosquito-fish	water; not avail.	inorganic Hg	400 µg/kg	no impact on predator avoidance by mosquitofish previously exposed to Hg	measured residue	1,900 µg/kg	impaired predator avoidance behavior by mosquitofish previously exposed to Hg	value is geom. mean of min-max for measured effect residues	Kania & O'Hara, 1974 as reported in Wiener & Spry, 1996

**Table 3-24, Continued**

**Summary of the Most Conservative Species-Specific No Effect and Effect Whole Body or Muscle Mercury Residue Data for  
Fish and Amphibians  
Operable Unit IV, Nyanza Chemical Dump Superfund Site  
Middlesex County, Massachusetts**

Fish Species	Exposure Route & Duration	Hg used in Exposure	Measured or Estimated No Effect Tissue Conc. (Wet Weight)			Measured Effect Tissue Concentration (Wet Weight)			Reference
			Residue Level	Response	Comment	Residue Level	Response	Comment	
mummi-chog	lab diet; 102 d	organic Hg	440 µg/kg	no effect on 2nd generation sex ratio	measured residue in parents	1,100 µg/kg	significant increase in female:male ratio in 2nd generation	measured residue in parents	Matta et al., 2001
rainbow trout	lab diet	organic Hg	470 µg/kg	no effect on growth or survival in 14 cm trout after 30 d of exposure	measured residue (Boudou & Ribeyre, 1985)	8,500 µg/kg	significant reduction in growth in trout fingerlings after 84 d of exposure	measured residue (Rodgers & Beamish, 1982)	-
grubby (marine fish)	lab diet; 20 d	organic Hg	505 µg/kg	no effect on survival or stress response in adult males & females	measured residue	-	-	Not available	Pelletier & Audet, 1995
northern pike	3-4 oral doses	organic Hg	1,250 µg/kg	estimated no effect on survival	estimated residue = 12.5 µg/kg ÷ 10	12,500 µg/kg	reduced survival in adults	measured residue	Miettinen et al., 1970 as reported in Jarvinen & Ankley, 1999
rock bass	natural diet	not applicable	1,400 µg/kg	no adverse effect on general well-being	measured residue	-	-	Not available	Bidwell & Heath, 1993 as reported in Wiener & Spry, 1996
brook trout (2nd gener.)	maternal transfer + water; 1 yr	organic Hg	<3,500 µg/kg	no effect on survival in adults or reproductive success	measured residue (no effect range = 2.0 to 3.5 µg/kg)	5,000 µg/kg	signif. mortality in adults; reduced hatchability; decreased juvenile weight	measured residue (effect range = 5,000 to 8,000 µg/kg)	McKim et al., 1976
large-mouth bass	natural diet	not applicable	<5,420 µg/kg	no effect on condition factor or gonadosomatic index in adult males	measured residue	-	-	Not available	Friedman et al., 2002
goldfish	water; 4 d	inorganic Hg	9,000 µg/kg	no effect on survival; no signs of toxicity	measured residue	-	-	Not available	McKone et al., 1971
eel	water; 32 d	inorganic Hg	15,300 µg/kg	no effect on mortality	measured residue	-	-	Not available	Noel-Lambot & Bouquegneau, 1977

<sup>a</sup>The most conservative no effect and effect tissue residue concentrations are presented when data on more than one study were available for a particular target species.

**Table 3-25**

**Summary of the Most Conservative Species-Specific No Effect and Effect Egg, Blood and Feather Mercury Residue Data for Birds  
Operable Unit IV, Nyanza Chemical Dump Superfund Site  
Middlesex County, Massachusetts**

Bird Species	Expos. Route	Hg used in Exposure	Measured No Effect Mercury Concntration (µg/kg WW)			Measured Effect Mercury Concentration (µg/kg WW)			Reference
			Residue Level	Response	Comment	Residue Level	Response	Comment	
MERCURY IN BIRD EGGS									
barn swallow	natural diet	not applicable	<25 µg/kg	no effect on reproductive success	value is geometric mean Hg conc. for eggs collected from a Se-contaminated site	-	-	an effect CBR for eggs was not available for this species	King et al., 1994
chicken	egg injection	organic Hg	-	not available	NOAEL was control; eggs injected 3 days after fertilization	50 µg/kg	LOAEL for embryo survival	eggs injected 3 days after fertilization	Heinz, 2003
common grackle	egg injection	organic Hg	50 µg/kg	NOAEL for embryo survival	eggs injected 3 days after fertilization	100 µg/kg	LOAEL for embryo survival	eggs injected 3 days after fertilization	Heinz, 2003
great blue heron	natural diet	not applicable	98 µg/kg	no apparent effect on reproductive success	value is highest geom. mean Hg conc. for eggs collected from 4 colonies	-	-	an effect CBR for eggs was not available for this species	Elliott et al., 1989
ring-necked pheasant	egg injection	organic Hg	100 µg/kg	NOAEL for embryo survival	eggs injected 3 days after fertilization	200 µg/kg	LOAEL for embryo survival	eggs injected 3 days after fertilization	Heinz, 2003
snowy egret	egg injection	organic Hg	100 µg/kg	NOAEL for embryo survival	eggs injected 3 days after fertilization	200 µg/kg	LOAEL for embryo survival	eggs injected 3 days after fertilization	Heinz, 2003
white ibis	egg injection	organic Hg	200 µg/kg	NOAEL for embryo survival	eggs injected 3 days after fertilization	400 µg/kg	LOAEL for embryo survival	eggs injected 3 days after fertilization	Heinz, 2003
tricolored heron	egg injection	organic Hg	200 µg/kg	NOAEL for embryo survival	eggs injected 3 days after fertilization	400 µg/kg	LOAEL for embryo survival	eggs injected 3 days after fertilization	Heinz, 2003
osprey	natural diet	not applicable	<340 µg/kg	no apparent effect on mean reproductive output	value is the highest reported mean Hg conc. from the study sites	-	-	Not available	Hughes et al., 1997

**Table 3-25, Continued**

**Summary of the Most Conservative Species-Specific No Effect and Effect Egg, Blood and Feather Mercury Residue Data for Birds  
Operable Unit IV, Nyanza Chemical Dump Superfund Site  
Middlesex County, Massachusetts**

Bird Species	Expos. Route	Hg used in Exposure	Measured No Effect Mercury Concentration (µg/kg WW)			Measured Effect Mercury Concentration (µg/kg WW)			Reference
			Residue Level	Response	Comment	Residue Level	Response	Comment	
herring gull	natural diet	not applicable	up to 390 µg/kg	no apparent effect on reproductive success	value is highest median Hg conc. for eggs from 3 colonies on Great Lakes	-	-	Not available	Gilman et al., 1977
Foster's tern	natural diet	not applicable	400 µg/kg	no apparent effect on hatching success	value represents the mean Hg conc. in eggs	-	-	Not available	King et al., 1991
mallard	lab diet to parents	organic Hg	-	-	Not available	740 µg/kg	failure to hatch	lowest Hg conc. in an egg resulting in failure to hatch	Heinz & Hoffman, 2003
brown pelican	egg injection	organic Hg	400 µg/kg	NOAEL for embryo survival	eggs injected 3 days after fertilization	800 µg/kg	LOAEL for embryo survival	eggs injected 3 days after fertilization	Heinz, 2003
tree swallow	egg injection	organic Hg	400 µg/kg	NOAEL for embryo survival	eggs injected 3 days after fertilization	800 µg/kg	LOAEL for embryo survival	eggs injected 3 days after fertilization	Heinz, 2003
clapper rail	egg injection	organic Hg	400 µg/kg	NOAEL for embryo survival	eggs injected 3 days after fertilization	800 µg/kg	LOAEL for embryo survival	eggs injected 3 days after fertilization	Heinz, 2003
greater sandhill crane	egg injection	organic Hg	400 µg/kg	NOAEL for embryo survival	eggs injected 3 days after fertilization	800 µg/kg	LOAEL for embryo survival	eggs injected 3 days after fertilization	Heinz, 2003
black skimmer	natural diet	not applicable	460 µg/kg	no apparent effect on hatching success	value represents the mean Hg conc. measured in eggs	-	-	Not available	King et al., 1991
great egret	natural diet	not applicable	up to 490 µg/kg	no effect on breeding performance in terms of clutch size, fledging success & brood size	Not available	-	-	Not available	Rumbold et al., 2001
common loon	natural diet	not applicable	up to 590 µg/kg	no apparent effect on reproductive success	value is mean Hg conc. for eggs from control lakes	1,390 µg/kg	impaired reproductive success	value is mean conc. in eggs from Hg-impacted lakes	Barr, 1986
Canada goose	egg injection	organic Hg	800 µg/kg	NOAEL for embryo survival	eggs injected 3 days after fertilization	1,600 µg/kg	LOAEL for embryo survival	eggs injected 3 days after fertilization	Heinz, 2003

**Table 3-21**

**Summary Statistics for the Mercury Toxicity Reference Value (TRV) Database  
Operable Unit IV, Nyanza Chemical Dump Superfund Site  
Middlesex County, Massachusetts**

Receptor Group <sup>a</sup>	Age Group	# of species	Number of TRV Data points	
			No Effect TRV	Effect TRV
Birds	juveniles	7	13	17
	adults	8	8	11
Mammals	juveniles	0	-	-
	adults	8	22	28

<sup>a</sup> TRVs could not be calculated for fish because food ingestion rates and/or mercury concentrations in food were not available.

**Table 3-25, Continued**

**Summary of the Most Conservative Species-Specific No Effect and Effect Egg, Blood and Feather Mercury Residue Data for Birds  
Operable Unit IV, Nyanza Chemical Dump Superfund Site  
Middlesex County, Massachusetts**

Bird Species	Expos. Route	Hg used in Exposure	Measured No Effect Mercury Concentration (µg/kg WW)			Measured Effect Mercury Concentration (µg/kg WW)			Reference
			Residue Level	Response	Comment	Residue Level	Response	Comment	
double-crested cormorant	egg injection	organic Hg	800 µg/kg	NOAEL for embryo survival	eggs injected 3 days after fertilization	1,600 µg/kg	LOAEL for embryo survival	eggs injected 3 days after fertilization	Heinz, unpublished data
common tern	maternal diet	not applicable	-	-	Not available	3,650 µg/kg	hatching success = 27%; fledging success = 10-12%	eggs came from colony impacted by a chlorine plant in Ontario, Canada	Fimreite, 1974 as reported in Connors et al., 1975
Japanese quail	lab diet to parents	organic Hg	1,800 µg/kg	no apparent effect on chick survival or behavior	value is mean Hg conc. for eggs from hens fed the 2 ppm Hg diet	3,700 µg/kg	about 50% mortality in chicks	value is mean hg conc. for eggs from hens fed the 4 ppm Hg diet	Eskeland et al., 1979
black duck	lab diet to parents	-	-	-	Not available	4,200 µg/kg	mean Hg concentration in eggs containing dead embryos	value is mean Hg conc. in yolk	Finley & Stendell, 1978
<b>MERCURY IN BIRD BLOOD</b>									
great egret (pre-fledged)	-	-	1,200 µg/kg	no impact on nestling survival or fledging success	value is mean for chicks collected in FL; residue is from natural diet (Sepulveda et al., 1999)	11,000 to 12,000 µg/kg	signif. lower weight index (= BW, bill length) in nestlings after 11 weeks exposure to 0.5 ppm Hg	value is blood Hg conc. after 11 & 14 weeks of exposure (Spalding et al., 2000)	-
common loon (pre-fledged)	natural diet	not applicable	-	-	Not available	>1,250 µg/kg	signif. drop in the amount of time riding parents= back; signif. increase in time spent preening	value is based on blood sampling in chicks & behavioral observations in the field	Nocera & Taylor, 1998
great blue heron (pre-fledged)	natural diet	not applicable	1,300 µg/kg	no impact on growth rates; brain & liver Hg conc. too low to result in Hg toxicity	value is highest mean for blood collected over 2 years at 3 locations	-	-	Not available	Wolfe & Norman, 1998

**Table 3-25, Continued**

**Summary of the Most Conservative Species-Specific No Effect and Effect Egg, Blood and Feather Mercury Residue Data for Birds  
Operable Unit IV, Nyanza Chemical Dump Superfund Site  
Middlesex County, Massachusetts**

Bird Species	Expos. Route	Hg used in Exposure	Measured No Effect Mercury Concentration (µg/kg WW)			Measured Effect Mercury Concentration (µg/kg WW)			Reference
			Residue Level	Response	Comment	Residue Level	Response	Comment	
Cory's shear-water(pre-fledged)	lab diet	organic Hg	up to 4,300 µg/kg	no effect on body condition or growth	value is max Hg conc. in high-dosed birds; caution: single oral dose study	-	-	Not available	Monteiro & Furness, 2001
great skuas(post-fledged)	capsules	organic Hg	<7,800 µg/kg	no mortality or loss of body weight; no signs of neurotoxicity	residue value is conc. measured in the bird receiving the highest dose; caution: value is for a single bird	-	-	Not available	Bearhop et al., 2000
pigeon(post-fledged)	oral doses; > 3 months	organic Hg	-	-	Not available	12,000 µg/kg	overt signs of neurotoxicity in 2 of 3 pigeons tested	value is apparent average provided by the authors; only one exposure conc. tested	Evans et al., 1982
mallard(post-fledged)	lab diet	organic Hg	9,300 µg/kg	no signs of neurotoxicity	value is mean blood conc. in adults after 12 weeks of dosing	45,300 µg/kg	high mortality and severe neurotoxicity	value is mean blood conc. in adults after 12 weeks of dosing	Bhatnagar et al., 1982
<b>MERCURY IN FEATHERS</b>									
Brewer's blackbird(pre-fledged)	natural diet	not applicable	140 µg/kg	no apparent effects; brain & liver Hg conc. too low to result in Hg toxicity	value is the mean for pooled feathers	-	-	Not available	Wolfe & Norman, 1998
cliff swallow(pre-fledged)	natural diet	not applicable	320 µg/kg	no apparent effects; brain & liver Hg conc. too low to result in Hg toxicity	value is the mean for pooled feathers	-	-	Not available	Wolfe & Norman, 1998
red-winged blackbird(pre-fledged)	natural diet	not applicable	360 µg/kg	no apparent effects; brain & liver Hg conc. too low to result in Hg toxicity	value is the mean for pooled feathers	-	-	Not available	Wolfe & Norman, 1998



**Table 3-25, Continued**

**Summary of the Most Conservative Species-Specific No Effect and Effect Egg, Blood and Feather Mercury Residue Data for Birds**  
**Operable Unit IV, Nyanza Chemical Dump Superfund Site**  
**Middlesex County, Massachusetts**

Bird Species	Expos. Route	Hg used in Exposure	Measured No Effect Mercury Concentration (µg/kg WW)			Measured Effect Mercury Concentration (µg/kg WW)			Reference
			Residue Level	Response	Comment	Residue Level	Response	Comment	
tree swallow(pre-fledged)	natural diet	not applicable	1,200 µg/kg	no effect on eggs per clutch, incubation time, hatchability, nestling growth or fledging success	value is a 6-year mean Hg conc. from nestlings collected around a flooded reservoir	-	-	Not available	Gerrard & St. louis, 2001
great egret(post-fledged)	lab diet; 14 wks	organic Hg	up to 2,000 µg/kg	no effect on growth in controls	value is estimated max. in controls between wk 1 & 14	70,000-110,000 µg/kg	reduced growth compared to controls	value is estimated Hg conc. in growing feathers between wk 11 & 14	Spalding et al., 2000
great blue heron(pre-fledged)	natural diet	not applicable	up to 3,160 µg/kg	no impact on growth rates; brain & liver Hg conc. too low to result in Hg toxicity	value is highest mean for feathers collected over 2 years at 3 locations	-	-	Not available	Wolfe & Norman, 1998
double-crested cormorant(pre-fledged)	natural diet	not applicable	up to 4,050 µg/kg	no apparent effects; brain & liver Hg conc. too low to result in Hg toxicity	value is highest mean for feathers collected over 2 years	-	-	Not available	Wolfe & Norman, 1998
great skua(post-fledged)	natural diet	not applicable	7,000 µg/kg	no effect on laying date, clutch volume, # of added eggs, hatching success or chick survival	value is mean Hg conc. for adult body feathers	-	-	Not available	Thompson et al., 1991
mallard(post-fledged)	lab diet to parents & young	organic Hg	-	-	Not available	>9,100 µg/kg	more eggs laid outside nestboxes; drop in # of sound eggs/hen/d; drop in # of 1 wk old ducklings produced	value is lowest annual mean Hg conc. in adult feathers over 3 generations	Heinz, 1979
black-headed gull(pre-fledged)	oral doses	organic Hg	10,000 µg/kg	non-lethal and/or having no long-term deleterious effects	value is mean for highest dose group	-	-	Not available	Lewis & Furness, 1991

**Table 3-25, Continued**

**Summary of the Most Conservative Species-Specific No Effect and Effect Egg, Blood and Feather Mercury Residue Data for Birds  
Operable Unit IV, Nyanza Chemical Dump Superfund Site  
Middlesex County, Massachusetts**

Bird Species	Expos. Route	Hg used in Exposure	Measured No Effect Mercury Concentration (µg/kg WW)			Measured Effect Mercury Concentration (µg/kg WW)			Reference
			Residue Level	Response	Comment	Residue Level	Response	Comment	
osprey(pre-fledged)	maternal transfer + natural diet	not applicable	up to 11,000 µg/kg	no apparent effect on reproductive output	value is mean Hg conc. for nestling feathers collected from nest in Great Lakes region and Delaware Bay	-	-	Not available	Hughes et al., 1997
Cory's shear-water(pre-fledged)	lab diet	organic Hg	up to 12,300 µg/kg	no effect on body condition or growth	caution: single oral dose study; value is mean for highest dose tested	-	-	Not available	Monteiro & Furness, 2001
common loon(post-fledged)	natural diet	not applicable	16,500 µg/kg	no effect on reproduction or annual adult return rates	value is geometric mean for the highest feather Hg conc. quartile	-	-	Not available	Meyer et al., 1998
bald eagle(pre-fledged)	maternal transfer + natural diet	not applicable	up to 20,000 µg/kg	no effect on productivity (# young/nest) or nesting success (fledging at least 1 young)	value is max. geom. mean from among 6 areas in Great Lakes region	-	-	Not available	Bowerman et al., 1994
black duck(pre-fledged)	maternal transfer + lab diet	organic Hg	-	-	Not available	40,900 µg/kg	100% mortality in ducklings	value is lowest of two mean Hg conc. for feathers from dead ducklings	Finley & Stendell, 1978

**Table 3-26**

**Deriving an Effect to No Effect Ratio Based on Measured Tissue Residue Data in Bird Eggs**  
**Operable Unit IV, Nyanza Chemical Dump Superfund Site**  
**Middlesex County, Massachusetts**

<b>Bird species</b>	<b>Endpoint</b>	<b>No Effect Hg Tissue Residue (µg/kg)</b>	<b>Effect Hg Tissue Residue (µg/kg)</b>	<b>Ratio of Effect to No Effect</b>	<b>Reference</b>
Common grackle	Embryo survival	50	100	2	Heinz, 2003
Ring-necked pheasant	Embryo survival	100	200	2	Heinz, 2003
Snowy egret	Embryo survival	100	200	2	Heinz, 2003
White ibis	Embryo survival	200	400	2	Heinz, 2003
Tricolored heron	Embryo survival	200	400	2	Heinz, 2003
Brown pelican	Embryo survival	400	800	2	Heinz, 2003
Tree swallow	Embryo survival	400	800	2	Heinz, 2003
Clapper rail	Embryo survival	400	800	2	Heinz, 2003
Greater sandhill crane	Embryo survival	470	800	2	Heinz, 2003
Common loon	Reproductive success	590	1,390	2.4	Barr, 1986
Canada goose	Embryo survival	800	1,600	2	Heinz, 2003
Double-crested cormorant	Embryo survival	800	1,600	2	Heinz, 2003
Japanese quail	Chick survival	1,800	3,700	2.1	Eskeland et al., 1979

Note: the tissue residue data are for eggs, whole body, or muscle tissue.

**Table 3-27**

**Summary of the Most Conservative Species-Specific No Effect and Effect Blood and Fur Mercury Residue Data for Mammals**  
**Operable Unit IV, Nyanza Chemical Dump Superfund Site**  
**Middlesex County, Massachusetts**

Mammal Species	Expos. Route & Durat.	Hg used in Exposure	Measured No Effect Concentration (µg/kg, WW)			Measured Effect Concentration (µg/kg, WW)			Reference
			Residue Level	Response	Comment	Residue Level	Response	Comment	
Hg IN BLOOD									
raccoon	natural diet	not applicable	400 µg/kg	no histopathological changes observed in the brain	brain Hg conc. was well below published NOAEL and LOAEL values	-	-	Not available	Wolfe & Norman, 1998
mink	natural diet	not applicable	<630 µg/kg	see comment	brain Hg levels associated with this blood level was too low to cause toxicity	-	-	Not available	Wolfe & Norman, 1998
macaque monkey	lab diet; > 1 year	organic Hg	<1,000 µg/kg	no effect on % viable deliveries	blood [Hg] measured in adult females	>1,500 µg/kg	signif. reduction in the % viable deliveries	blood [Hg] is for adult females; signs of Hg tox @ 2,000 µg/kg	Burbacher et al., 1988
cat	oral; 24 months	organic Hg	<3,500 µg/kg	no signs of neurological impairment	upper range of blood TM concentration	>5,000 µg/kg	mild neurological impairment starting after 60 wks of treatment	lower range of blood TM concentration	Charbonneau et al., 1976
lab mouse	intubation; 42 days	organic Hg	<4,700 µg/kg	no effect on growth; no signs of neurotoxicity	-	-	-	Not available	Evans et al., 1982
harp seal	gel caps in fish	organic Hg	-	-	Not available	9,930 µg/kg	decline in appetite and loss of body weight	residue value represents total blood Hg	Ronald et al., 1977 as reported in Wolfe et al., 1998
rat	lab diet; up to 26 months	organic Hg	30,00 µg/kg	no effect on growth or mortality; no overt signs of neurotoxicity	value is mean blood concentration at end of treatment in the no effect group	116,200 µg/kg	reduced growth & increased mortality; signs of neurotoxicity	value is mean blood concentration from moribund, dying & surviving animals	Munro et al., 1980

**Table 3-27, Continued**

**Summary of the Most Conservative Species-Specific No Effect and Effect Blood and Fur Mercury Residue Data for Mammals  
Operable Unit IV, Nyanza Chemical Dump Superfund Site  
Middlesex County, Massachusetts**

Mammal Species	Expos. Route & Durat.	Hg used in Exposure	Measured No Effect Concentration (µg/kg, WW)			Measured Effect Concentration (µg/kg, WW)			Reference
			Residue Level	Response	Comment	Residue Level	Response	Comment	
Hg IN FUR									
deer mouse	natural diet	not applicable	1,300 µg/kg	no effect on swimming ability or stress tolerance in lab tests	Hg conc. in mice collected from reference site	7,800 µg/kg	signif. changes in swimming ability and stress tolerance in lab tests	Hg conc. in mice collected from a site w/ high Hg conc. food	Burton et al., 1977
cat	capsules ; 90 days	organic Hg	7,600 µg/kg	no neurologic or histopathologic abnormalities	value is mean for fur collected at end of treatment	170,000 µg/kg	all exposed cats showed signs of neurotoxicity	value is mean for fur collected at end of treatment or when convulsions severe	Eaton et al., 1980
mink	lab diet; 6 months	organic Hg	7,710 µg/kg	highest mean fur [Hg] w/ no effect on litter size	value is mean (range) in fur from adult females	19,030 µg/kg	lowest mean fur [Hg] w/ effect on for litter size	value is mean (range) in fur from adult females	Halbrook et al., 1997
river otter	natural diet	not applicable	8,800 µg/kg	no effect on 18 month survivorship	fur samples came from field-collected animals	-	-	Not available	Ben-David et al., 2001
raccoon	natural diet	not applicable	11,000 µg/kg	no histopathological changes observed in the brain	brain Hg conc. was well below published NOAEL and LOAEL values	-	-	Not available	Wolfe & Norman, 1998

**Table 3-28**

**Summary of the Most Conservative Species-Specific No Effect and Effect Toxicity Reference Values (TRV) for Organic Mercury in Birds**  
**Operable Unit IV, Nyanza Chemical Dump Superfund Site**  
**Middlesex County, Massachusetts**

Bird Species	Exposure Route & Duration	Hg used in Exposure	No Effect TRV			Effect TRV			Reference
			Daily Dose	Response	Comment	Daily Dose	Response	Comment	
black-headed gull	daily gelatin capsule; 10 days	organic Hg	0.07 mg/kg/d	no significant effects reported	-	-	-	Not available	Lewis & Furness, 1991
great egret	daily gelatin capsule; 13 weeks	organic Hg	-	-	Not available	0.093 mg/kg/d	significant effects on appetite and growth	study used juveniles; the lowest daily dose tested resulted in a significant effect	Spalding et al, 2000
chicken	diet; 7 weeks	organic Hg	0.101 mg/kg/d	no effect on mortality	study used hatchling cockerels	0.212 mg/kg/d	significant increase in mortality	study used hatchling cockerels	Soares et al., 1973
ring-necked pheasant	diet; 12 weeks	organic Hg	-	-	Not available	0.26 mg/kg/d	drop in egg hatchability, increased embryonic mortality & increased # of infertile eggs	-	Fimreite, 1971
mallard duck	diet; 1 year	organic Hg	0.071 mg/kg/d	no effects on egg hatchability or duckling survival	study used adults	0.43 mg/kg/d	significant reduction in egg hatchability and duckling survival	study used adults	Heinz, 1974
black duck	diet; 28 weeks	organic Hg	-	-	Not available	0.43 mg/kg/d	significant decrease in # of incubating hens, egg hatchability & duckling survival	study used adults; only a single dose was tested	Finley & Stendell, 1978
pigeon	intubation; > 3 months	organic Hg	-	-	Not available	0.71 mg/kg/d	overt signs of neurotoxicity in two of the three exposed pigeons	latency period = 64.5 days; data are for lowest tested dose	Evans et al., 1982
Japanese quail	diet; 42 days	organic Hg	0.39 mg/kg/d	no effect on hatchling survival	adult quail dosed over 6 weeks	0.78 mg/kg/d	significant hatchling mortality	adult quail dosed over 6 weeks	Eskeland et al., 1979
Duck (Rouen)	diet; 5 weeks	organic Hg	0.41 mg/kg/d	no effects	study used ducklings	4.3 mg/kg/d	significant weight loss and higher mortality	study used ducklings	Gardiner, 1972

**Table 3-28, Continued**

**Summary of the Most Conservative Species-Specific No Effect and Effect Toxicity Reference Values (TRV) For Organic Mercury in Birds  
Operable Unit IV, Nyanza Chemical Dump Superfund Site  
Middlesex County, Massachusetts**

Bird Species	Exposure Route & Duration	Hg used in Exposure	No Effect TRV			Effect TRV			Reference
			Daily Dose	Response	Comment	Daily Dose	Response	Comment	
red-tailed hawk	diet; 12 weeks	organic Hg	0.45 mg/kg/d	no effect on weight gain; no overt signs of neurotoxicity	this exposure group consisted of only three birds	1.0 mg Hg/kg/d	loss of BW; neurotoxicity in one of the three birds before it died	this exposure group consisted of only three birds	Fimreite & Karstad, 1971
zebra finch	diet; 76 days	organic Hg	0.88 mg/kg/d	no effects on mortality; no neurotoxicity	study used adults	1.75 mg/kg/d	behavioral signs typical of neurotoxicity	study used adults	Scheuhammer, 1988
great skuas	weekly gelatin capsule; 20 wks	organic Hg	1.3 mg/kg/d	no effects on weight gain; no signs of neurotoxicity	the value is for the highest-dosed bird; study used juveniles	-	-	Not available	Bearhop et al., 2000

**Table 3-29**

**Summary of the Most Conservative Species-Specific No Effect and Effect Toxicity Reference Values (TRV) For Organic Mercury in Mammals  
Operable Unit IV, Nyanza Chemical Dump Superfund Site  
Middlesex County, Massachusetts**

Mammal Species	Exposure Route & Duration	Hg used in Exposure	No Effect TRV			Effect TRV			Reference
			Daily Dose	Response	Comment	Daily Dose	Response	Comment	
mink	diet; 7 months	organic Hg	0.014 mg/kg/d	no effect on litter size	litter size = kits/female	0.035 mg/kg/d	significant reduction in litter size	most conservative mink TRV available from database	Halbrook et al., 1997
cat	diet; 2 years	organic Hg	0.020 mg/kg/d	no treatment-related effects as compared to controls	-	0.046 mg/kg/d	mild impairment of the hopping reaction due to neurotoxicity after 60 weeks of exposure	most conservative TRV available from the database	Charboneau et al., 1976
monkey	> 1 year	organic Hg	0.050 mg/kg/d	no effect on # of viable offspring	-	0.070 mg/kg/d	significant decrease in the # of viable offspring	this effect TRV was the only one available from the database	Burbacher et al., 1988
river otter	diet; > 6 months	organic Hg	-	-	Not available	0.090 mg/kg/d	anorexia and ataxia in 2 of 3 exposed otters	symptoms developed between day 168 & 199 of exposure	O'Connor & Nielsen, 1980
dog	oral dosing during pregnancy	organic Hg	-	-	Not available	0.1 mg/kg/d	high incidence of stillbirths	this TRV was the only one available from the database	Earl et al., 1973
rat	diet; up to 26 months	organic Hg	0.050 mg/kg/d	no significant effect on growth or mortality; no signs of neurotoxicity	-	0.25 mg/kg/d	reduced growth, increased mortality & signs of neurotoxicity	most conservative rat TRV available from database	Munro et al., 1980
mouse	diet; 2 years	organic Hg	0.174 mg/kg/d	no effect on mortality or growth; no signs of neurotoxicity	-	0.859 mg/kg/d	higher mortality; lower weight gain; symptoms of neurotoxicity	most conservative mouse TRV available from database	Mitsumori et al., 1990
ferret	diet; >2 months	organic Hg	-	-	Not available	0.8 mg/kg/d	neurotoxicity in both exposed females w/in 3 wks; time to death = 58 d	this TRV was the only one available from the database	Hanko et al., 1970



**Table 3-30**

**Summary of Tissue-Specific No Effect and Effect CBRs for Fish, Birds and Mammals  
Operable Unit IV, Nyanza Chemical Dump Superfund Site  
Middlesex County, Massachusetts**

Receptor Group	Tissue Type	Hg Critical Body Residues (CBR; µg Hg/kg tissue)	
		No Effect	Effect
Crayfish	whole body/muscle	1,500	3,250
Fish	whole body/muscle	380	980
Birds – piscivorous (i.e., hooded merganser and kingfisher) and wood duck	Eggs	500	1,000
	Blood	600	1,250
	Feathers	1,200	9,100
Birds – insectivorous (i.e., tree swallows and marsh birds)	Eggs	800	1,600
	Blood	600	1,250
	Feathers	1,200	9,100
Mammal	Blood	630	1,500
	Fur	7,700	19,000

Notes:

- 1) All units are wet weight, except for feather values, which are in fresh weight.
- 2) BRI values, as used in Appendix A reports were effects-based only as follows:
  - a. Avian eggs
    - i. Piscivores (i.e., merganser and kingfisher): 1,300 µg/kg WW
    - ii. Omnivores (i.e., wood duck): 800 µg MeHg/kg WW
    - iii. Insectivores (i.e., marsh birds and tree swallows): 400 µg MeHg/kg
  - b. Avian blood
    - i. Piscivores: 3,000 µg/kg
    - ii. Omnivores: 2,500 µg Hg/kg
    - iii. Insectivores: 1,270 µg Hg/kg
  - c. Feathers
    - i. Piscivores: 19,800 µg/kg FW
    - ii. Omnivores: 9,000 µg/kg FW
    - iii. Insectivores – none
  - d. Mink blood: 680 µg/kg
  - e. Mink fur: 20,000 µg/kg
  - f. Liver: 20,000 µg tHg/kg
  - g. Brain: 4,100 µg/kg

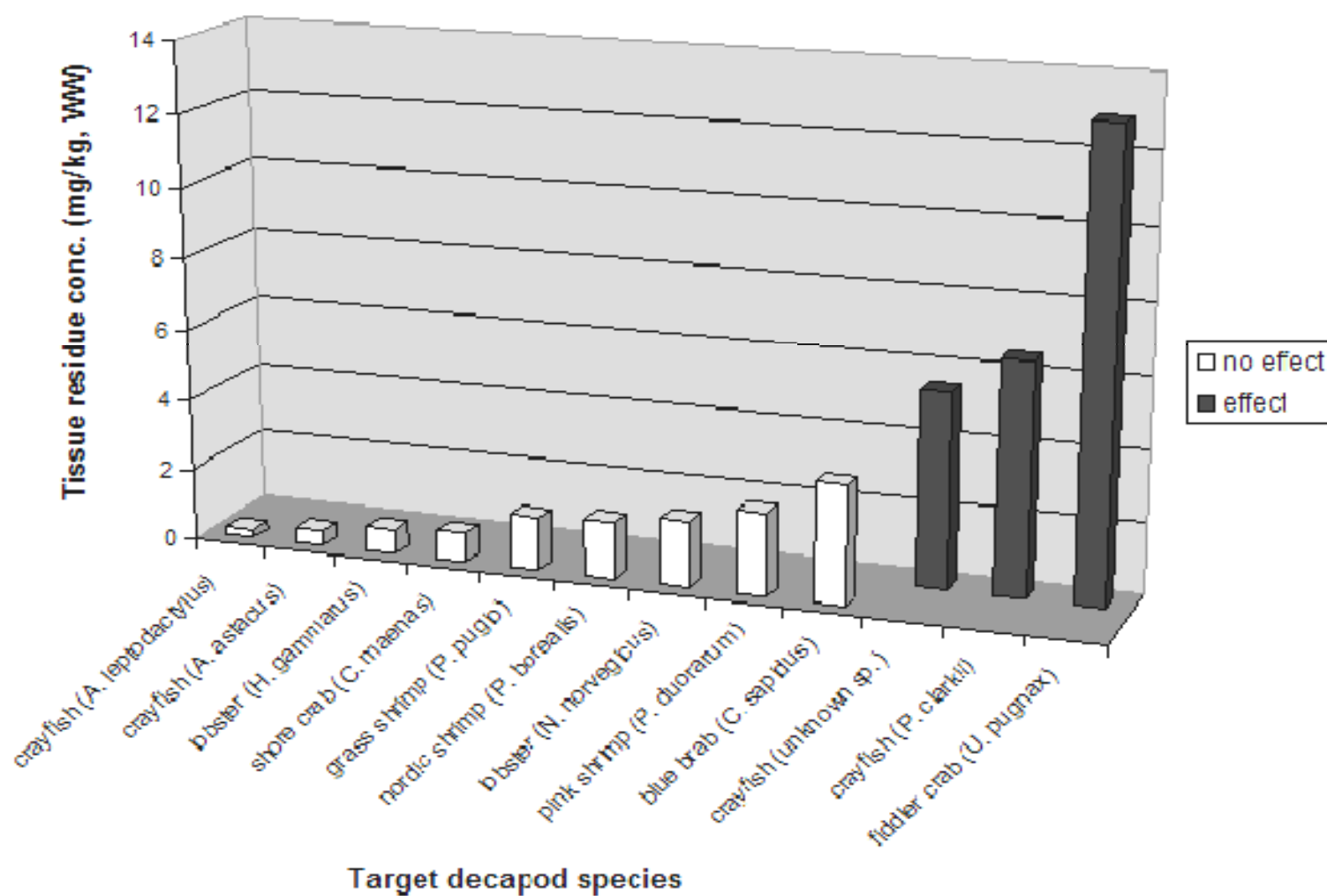
**Table 3-31**

**Summary of Generic No Effect and Effect TRVs for Birds and Mammals  
Operable Unit IV, Nyanza Chemical Dump Superfund Site  
Middlesex County, Massachusetts**

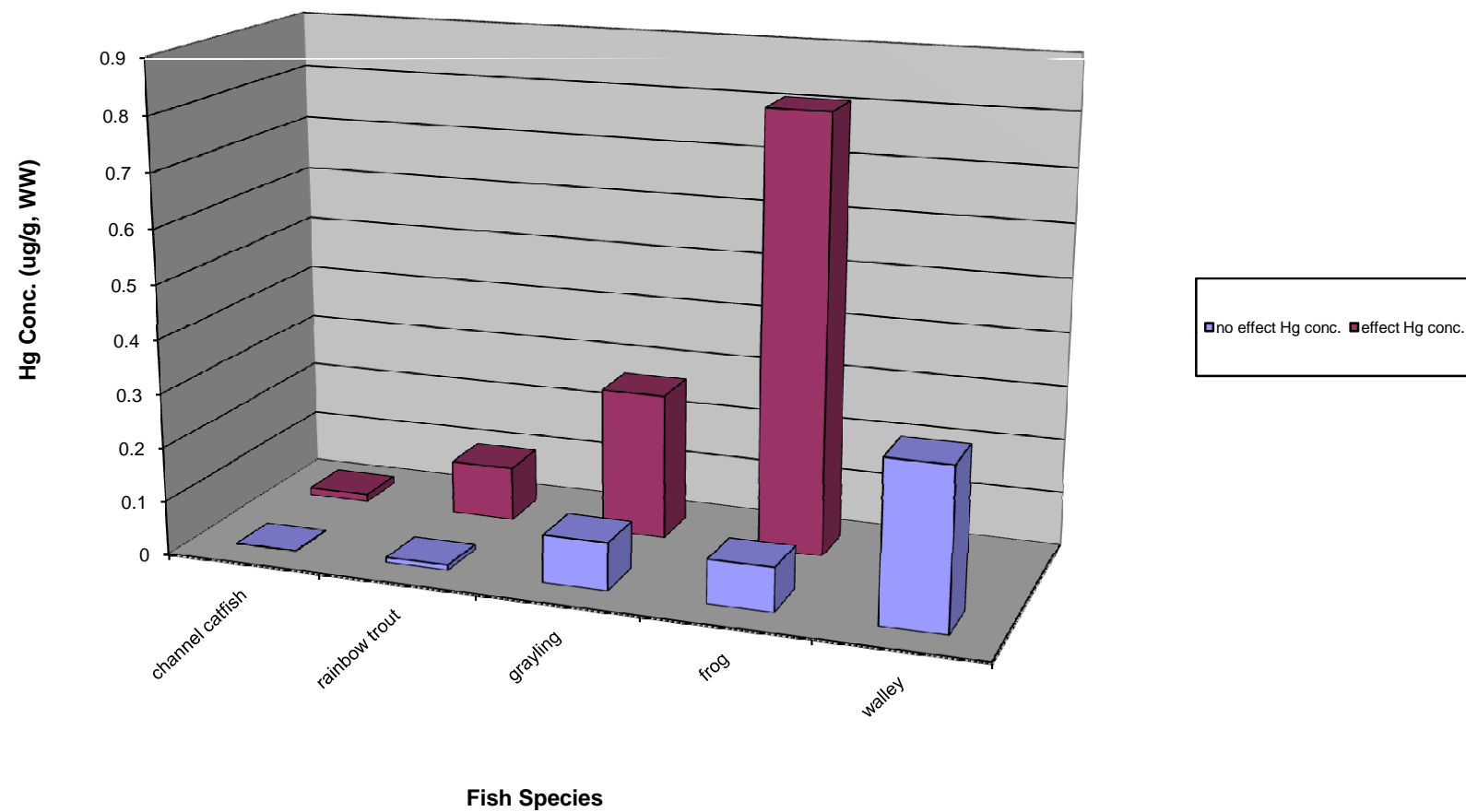
Receptor Group	MeHg Toxicity Reference Values (TRVs; mg MeHg/kg BW-day)	
	No Effect	Effect
Birds	0.047	0.093
Mammals	0.014	0.035

## SECTION 3 FIGURES

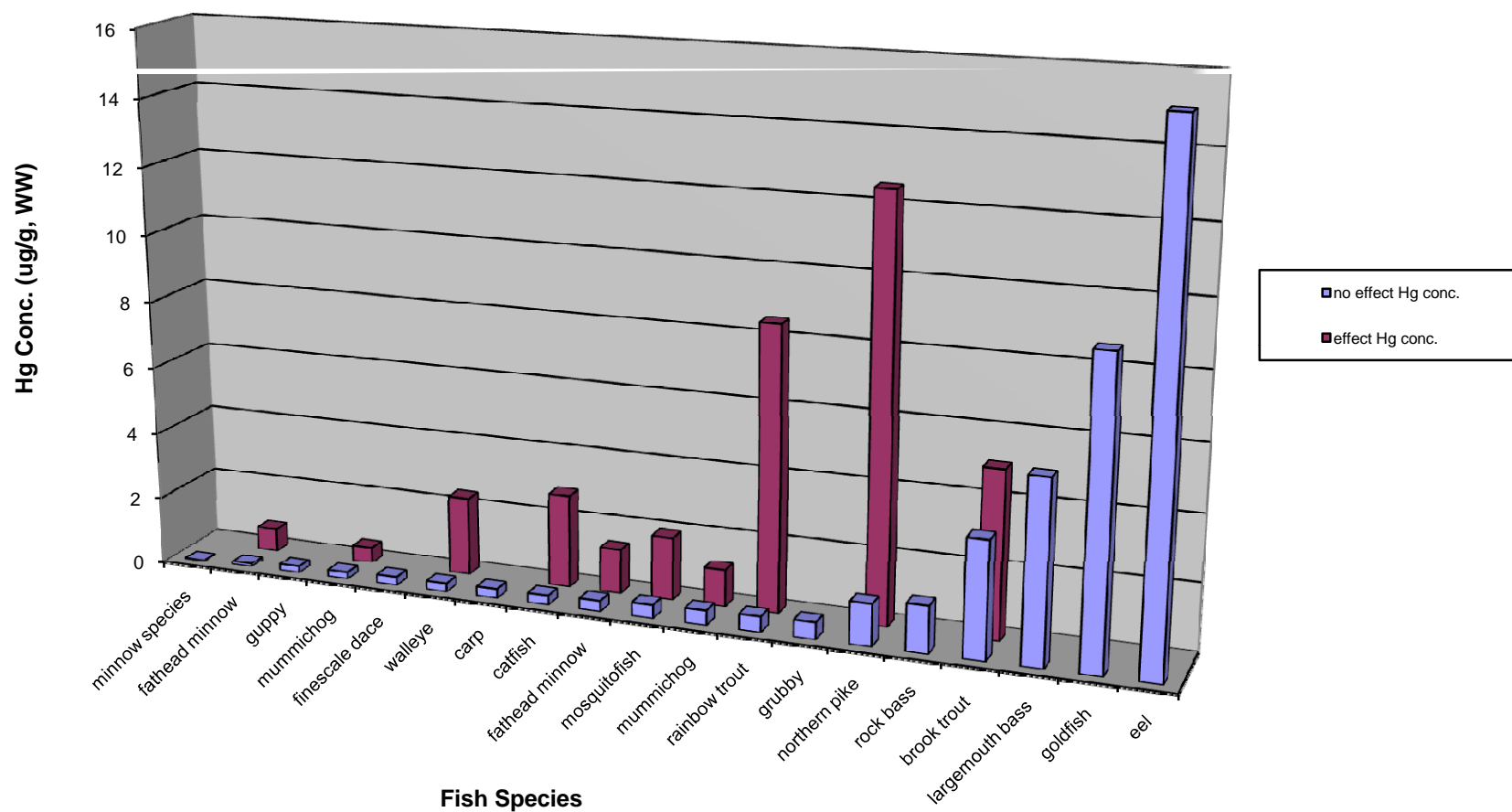
**Figure 3-1: Species-specific no effect and effect Hg concentrations in muscle or whole body for freshwater and marine decapods**



**Figure 3-2: Most conservative species-specific no effect and effect Hg concentrations in fish eggs**



**Figure 3-3: Most conservative species-specific no effect and effect Hg concentrations in post-larval fish**



**Figure 3-4: Most conservative species-specific no effect and effect mercury concentrations in bird eggs**

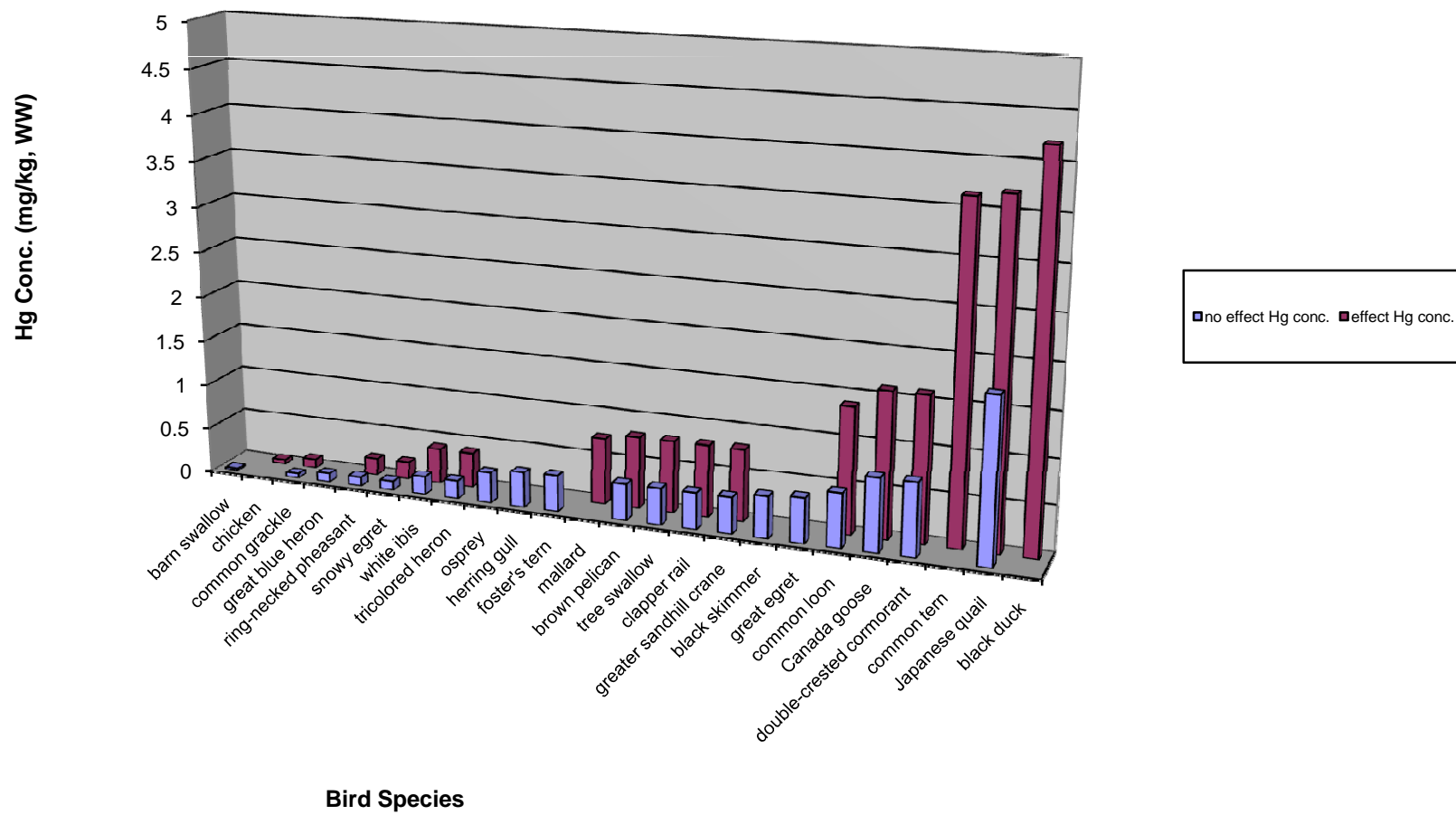
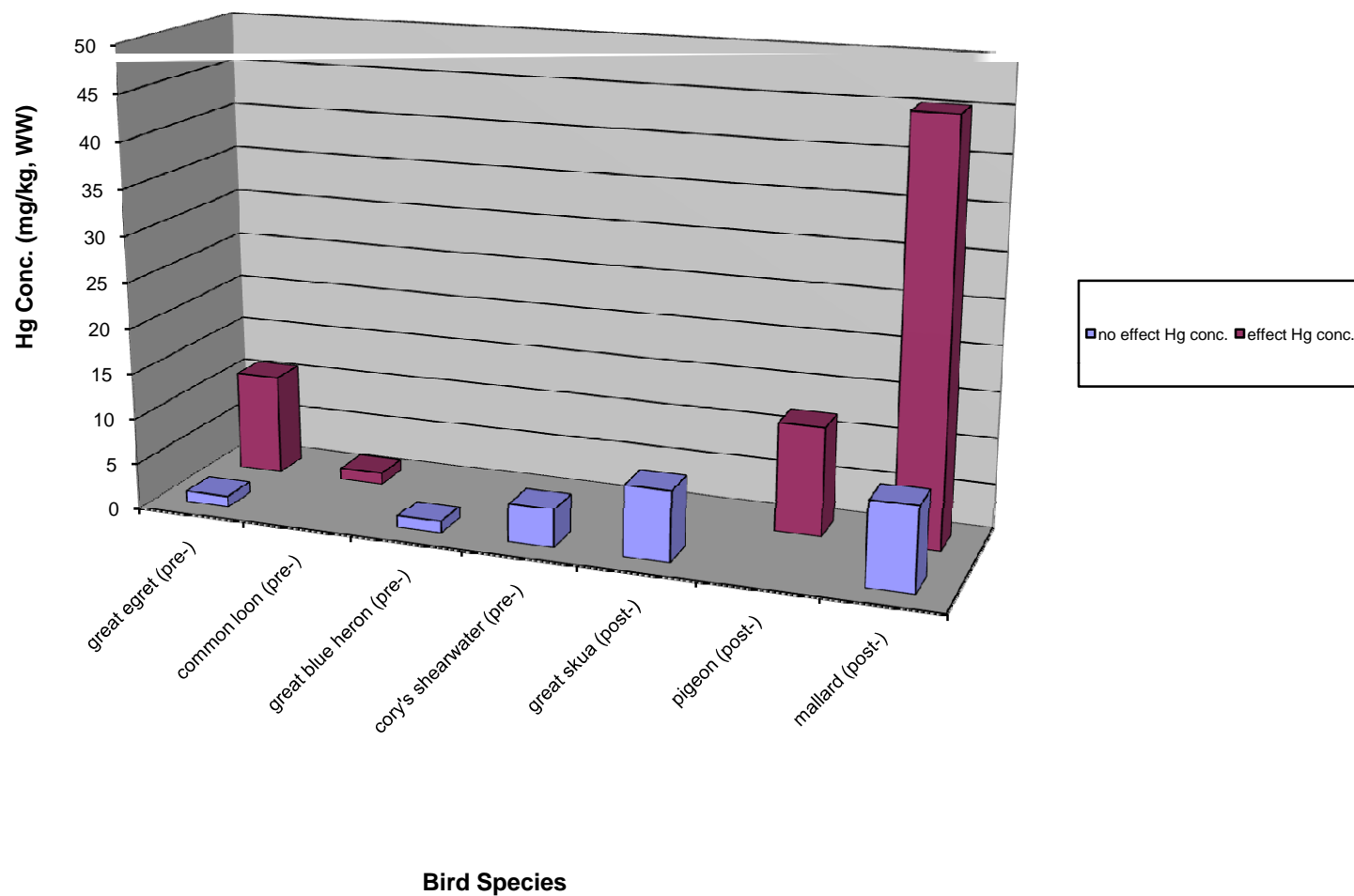
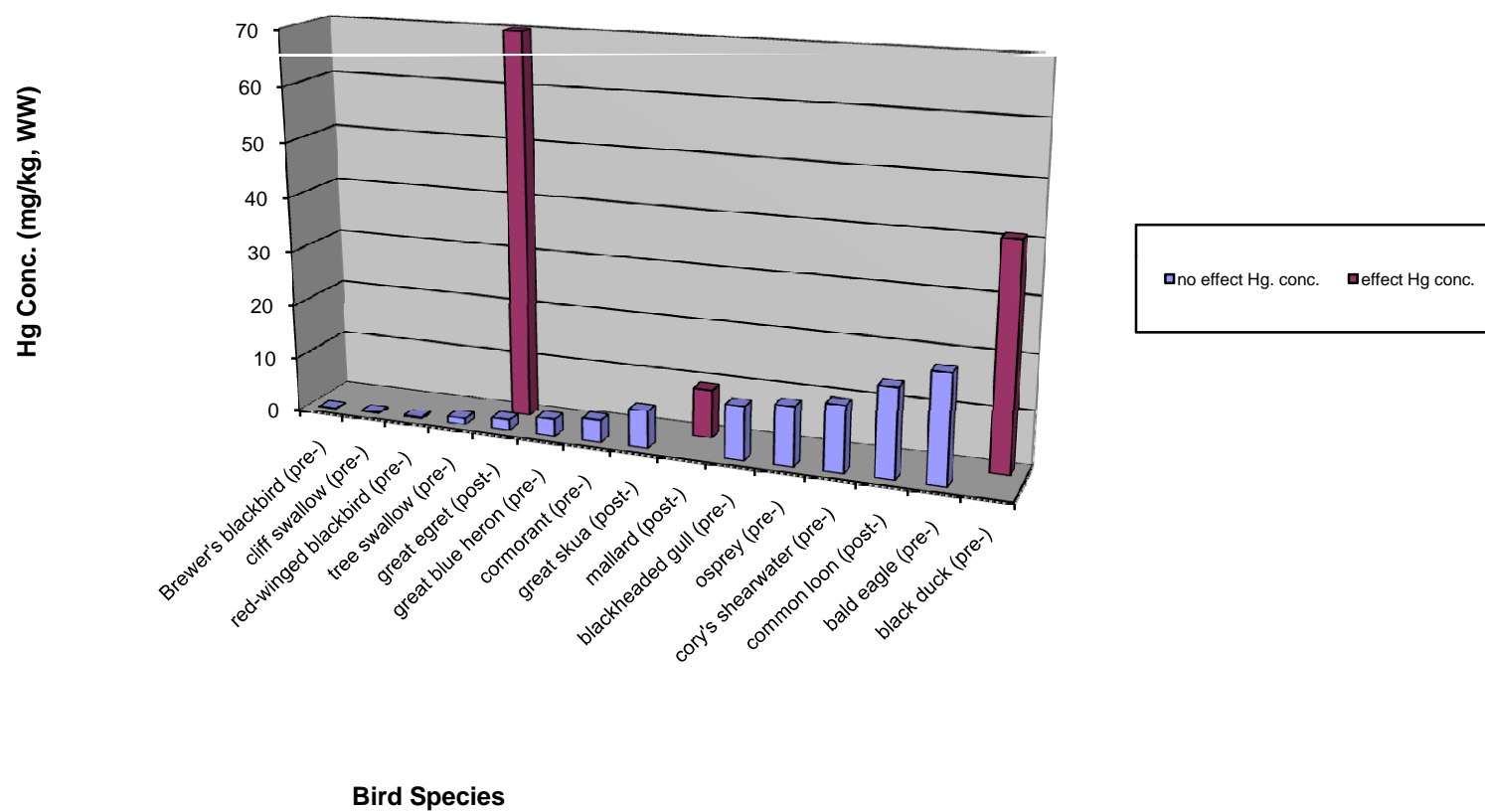


Figure 3-5: Most conservative species-specific no effect and effect mercury concentrations in bird blood

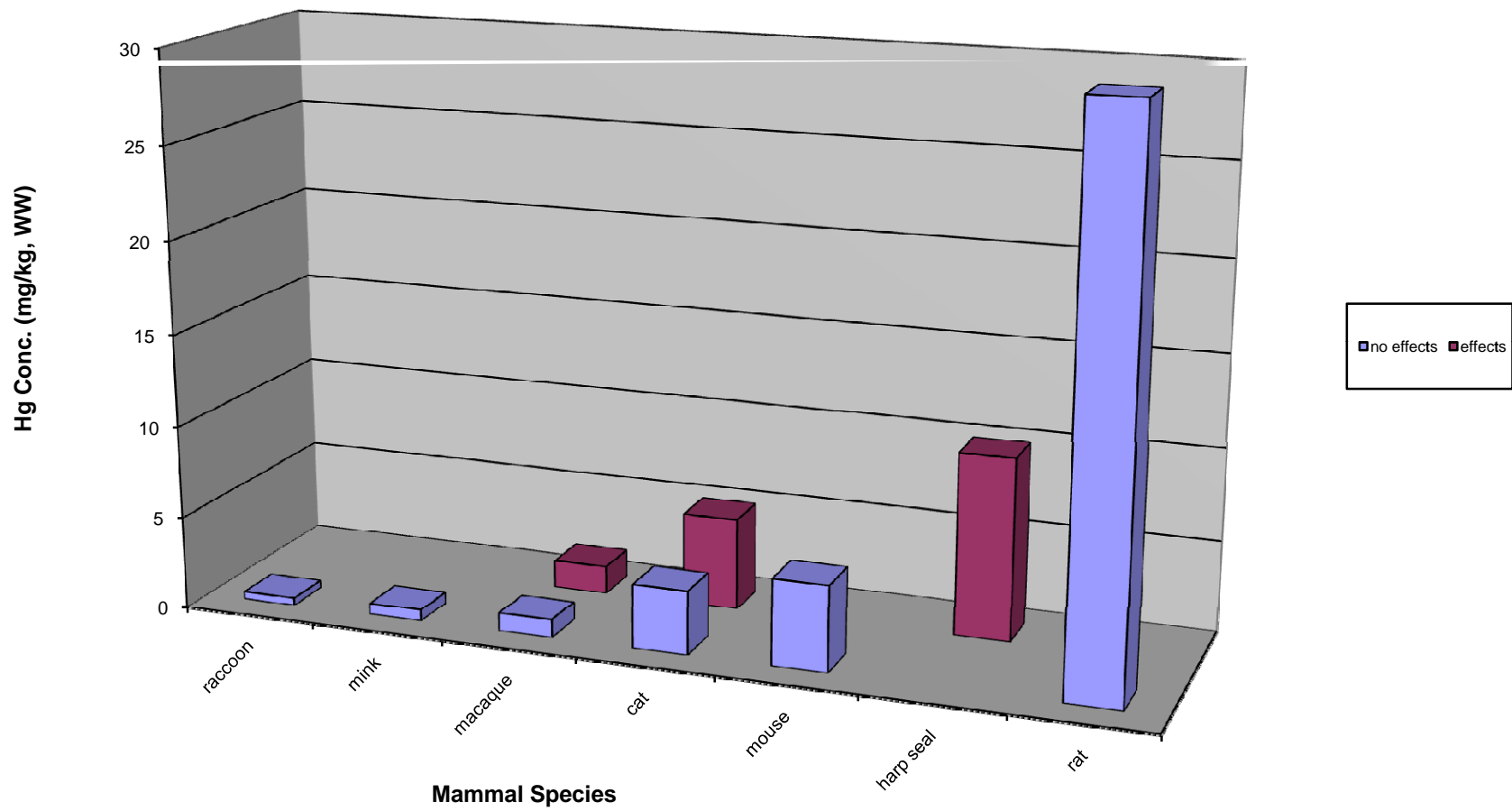




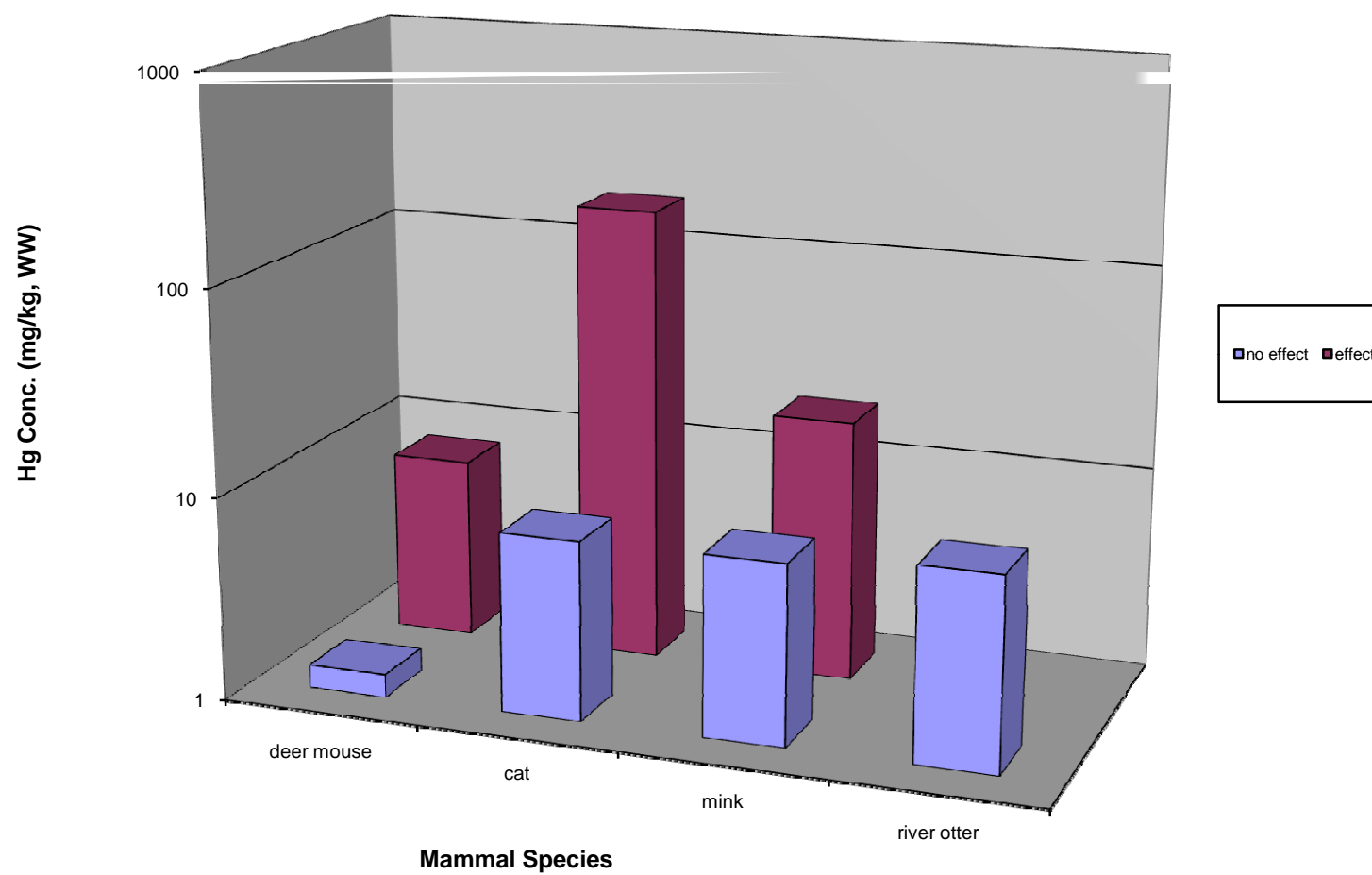
**Figure 3-6: Most conservative species-specific no effect and effect mercury concentrations in bird feathers**



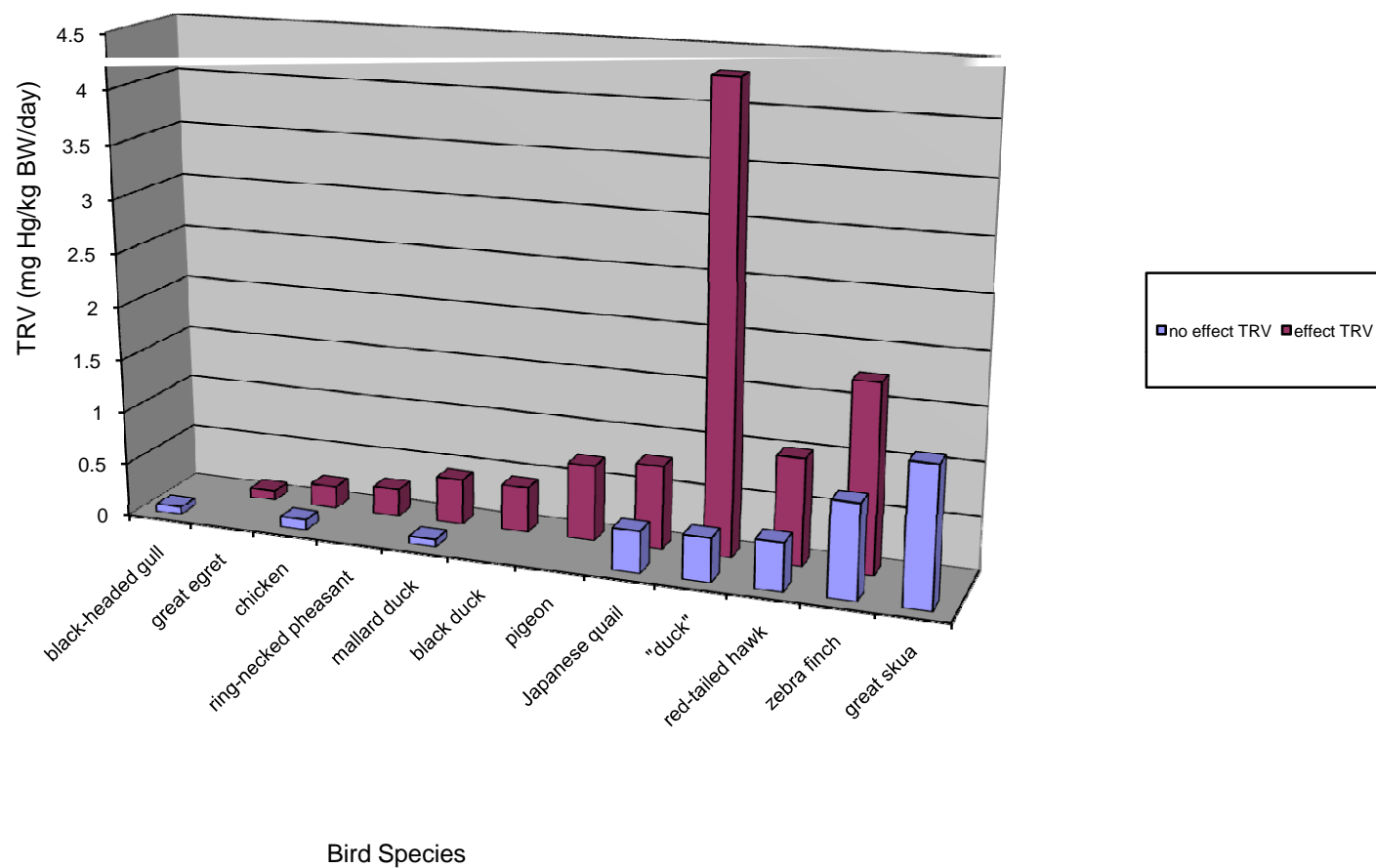
**Figure 3-7: Most conservative species-specific no effect and effect blood Hg concentrations in mammals**



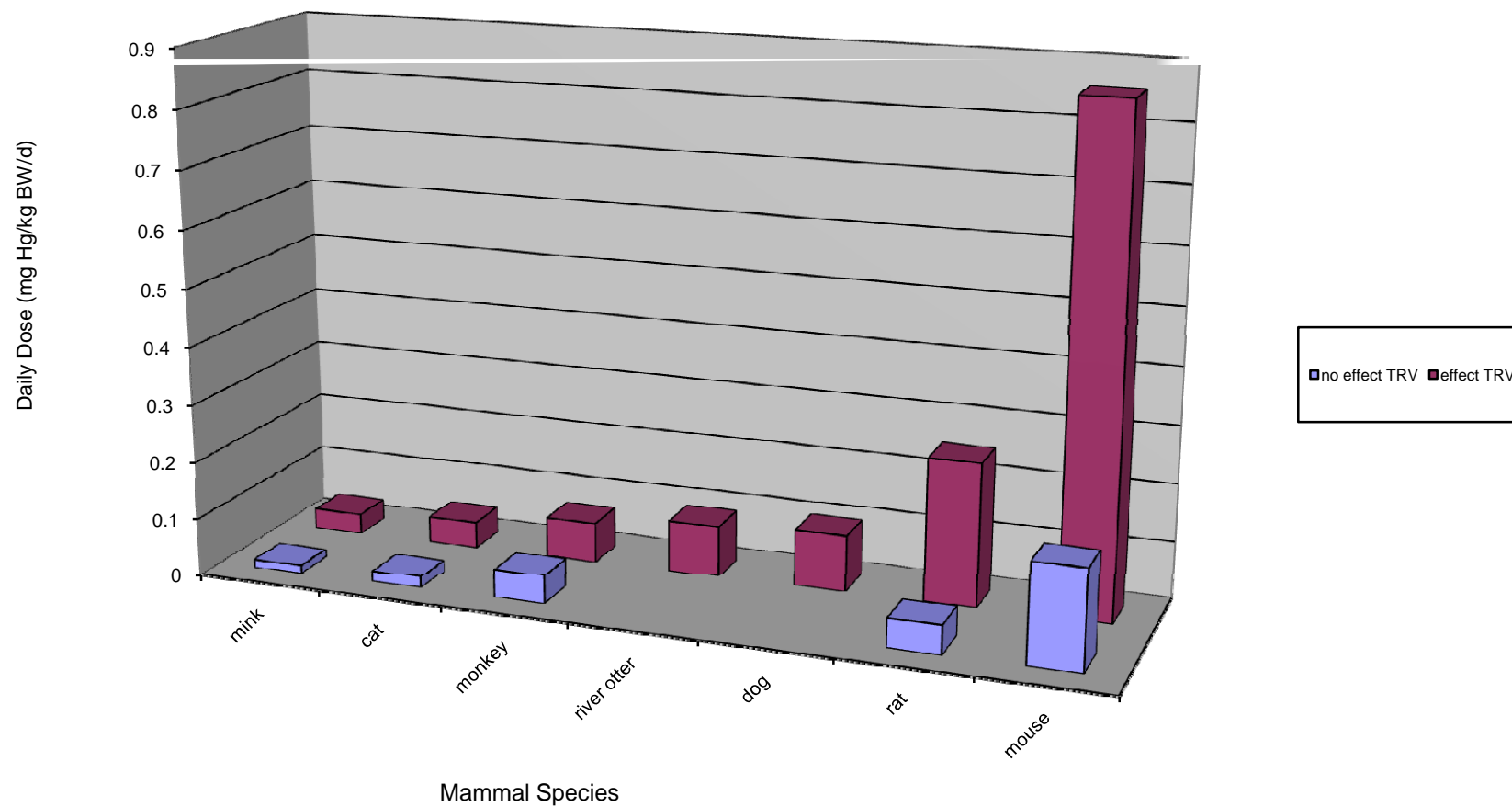
**Figure 3-8: Most conservative no effect and effect Hg concentrations for mammal fur**



**Figure 3-9: Most conservative species-specific no effect and effect Hg toxicity reference values (TRVs) for birds**



**Figure 3-10: Most conservative species-specific no effect and effect Hg toxicity reference values (TRVs) for mammals**



## **SECTION 4**

### **RISK CHARACTERIZATION**

## **4.0 RISK CHARACTERIZATION**

### **4.1 Introduction**

The Risk Characterization is the final phase of the ERA, the purpose of which is to evaluate the likelihood that adverse effects have occurred or may occur as a result of exposure to the COPECs (EPA, 1998 and 1992a). As previously discussed, the COECs for this SBERA are total and methylmercury. The goal of the Risk Characterization is to provide estimates of risk to the assessment endpoints identified in the Problem Formulation (Section 2) by integrating information presented in the Analysis Phase (Section 3) and by interpreting individual and population level effects.

The following Risk Characterization is divided into two stages: risk estimation and risk description. The Risk Estimation (Subsection 4.2) integrates exposure and effects information from the Analysis Phase and estimates the likelihood of adverse effects on the assessment endpoint of concern. A summary of the qualitative and quantitative elements of uncertainty also is included as part of the risk estimation. The Risk Description (Subsection 4.3) provides a complete and informative synthesis of the overall conclusions regarding risk estimates; addresses the uncertainty, assumptions, and limitations; and is useful for risk management decision making.

The ultimate goal of the Risk Characterization is to fully describe the strengths and weaknesses of the risk assessment so that risk managers fully understand the conclusions reached in the ERA.

### **4.2 Risk Estimation**

#### **4.2.1 Introduction**

The risk estimation describes the likelihood of adverse effects to assessment endpoints by integrating exposure and effects data (EPA, 1992a). The risk estimation process uses exposure and ecological effects information described in the Analysis Phase. However, it is important to recognize that the interpretation and synthesis of the results presented in the Risk Estimation are reserved for the Risk Description (Subsection 4.3).

Risk estimations can range from highly quantitative to highly qualitative presentations. For example, it is likely that a qualitative approach might consist of the direct comparison of site-specific tissue concentrations to literature or database derived effect levels, while a quantitative approach is typical for the evaluation of detailed exposure and effects models like those used to

evaluate effects to tree swallow, kingfisher, heron, or mink (see Section 4.3). This SBERA evaluates, for each measurement endpoint, the relevant data accumulated during previous site investigations. Background risks to target receptors are also evaluated using appropriate site-specific background and regional information.

The type, quality, and quantity of data collected followed the approach outlined in the conceptual model and specified as part of the DQOs. The uncertainties specific to each estimate are fully outlined. Regardless of the quantitative or qualitative nature of the assessment, professional judgment was needed for the interpretation (i.e., risk description) of any observed or predicted adverse effects.

Risks can be estimated by using one or a combination of the following approaches: (1) estimates expressed as qualitative categories; (2) estimates comparing single-point estimates of exposure and effects, i.e., the hazard quotient approach (HQ); (3) estimates incorporating the entire stressor-response relationship; (4) estimates incorporating variability in exposure and effects estimates (e.g., Monte Carlo analysis); (5) estimates based on process models that rely on theoretical approximations of exposure and effects (e.g., sediment equilibrium partitioning); and (6) estimates based on empirical approaches, including field data (e.g., sediment toxicity testing). This SBERA combines several of these approaches to estimate the potential risks to ecological receptors.

The risk estimation is formatted such that the risks for each reach are presented by measurement endpoint within the ecological entity (or receptor) for an assessment endpoint as follows:

- Risk to Aquatic Biota (Section 4.2.2)
  - Benthic Invertebrate Community (Section 4.2.2.1)
  - Fish Population (Section 4.2.2.2)
- Risk to Avian Life (Section 4.2.3)
  - Insectivorous Birds (Section 4.2.3.1)
  - Piscivorous Birds (Section 4.2.3.2)
- Risk to Mammalian Life (Section 4.2.4)
  - Piscivorous Mammals (Section 4.2.4.1)

The general approaches for evaluating risks from the field studies, HQs, and reference area/regional mercury level comparisons are presented in subsections below.



#### **4.2.1.1 Field Studies**

Field studies were essentially used to determine exposure to selected receptors known to forage in the Sudbury River. Tissue samples were collected for residue analysis. Residue concentrations were used to compare with CBRs to determine if body burdens are indicative of those associated with adverse effects. Comparisons of tissue concentrations with CBRs are discussed in more detail in the subsection that follows.

#### **4.2.1.2 Hazard Quotient Analyses**

HQs were developed to determine potential effects to target receptors from exposure to mercury contaminated surface water, sediment, and prey items. The HQ approach used for this evaluation simplifies the comparison process and allows for a more standardized interpretation of the results (i.e., the HQ reflects the magnitude by which the sample concentration exceeds or is less than the guideline, benchmark, or TRV). In general, if an HQ exceeds 1, some potential for risk is expected (EPA, 1993c). While the quotient method does not measure risk in terms of likelihood of effects at the individual or population level, it does provide a valid benchmark for judging potential risk (EPA, 1994a).

HQs were calculated specific to measurement receptor and exposure scenario location (e.g., reach) evaluated in this SBERA as follows:

$$HQ = EEL/TV$$

Where:

- HQ = hazard quotient (unitless)
- EEL = estimated exposure level (Communities: medium concentration in units of µg or mg Hg/kg or ng Hg/L medium; wildlife target receptors: dose in units of mg Hg/kg BW-day)
- TV = toxicity value (benchmark in µg or mg Hg/kg or ng Hg/L medium; CBRs in µg Hg/kg WW or FW tissue; or TRV in mg Hg/kg BW-day)

For community measurement receptors, the mercury concentrations in each of the potential exposure medium within each reach are compared with medium- and chemical-specific ecological benchmarks. For individual target species, the mercury concentrations in each of the tissues are compared with CBRs. Lastly, for each target receptor, the predicted daily doses were compared with TRVs. Specifically, HQs were calculated comparing the following data and toxicity values:

- Surface water concentrations with freshwater surface water Federal AWQC for the Protection of Aquatic Life (EPA, 2006 and EPA, 1986).
- Sediment concentrations with freshwater sediment TECs and PECs from MacDonald et al. (2000) consensus-based values.
- Crayfish concentrations with crayfish CBRs.
- Fish concentrations with fish CBRs
- Avian and mammalian tissue concentrations with avian and mammalian CBRs, respectively.
- Modeled avian and mammalian exposure doses with TRVs.

#### **4.2.1.3 Site-Specific Reference Area and Regional Mercury Level Comparisons**

##### **4.2.1.3.1 Site-Specific Reference Area Comparisons**

Statistical comparisons were conducted for mercury concentrations in sediment, whole body fish tissue (based on size class), and surface water samples collected from potentially affected reaches of the Sudbury River and the appropriate site-specific reference areas. Recall that the individual reaches of the Sudbury River were assigned reach-specific reference areas based on similarity of habitat conditions within the stream (Subsection 2.3.1) and statistical comparisons of samples collected from these areas were made accordingly:

<b>Reference Area</b>	<b>River Reach</b>
Reach 1	2, 5, 7, and 10
Charles River	8 and 9
Sudbury Reservoir	3, 4, 6, and 7-Heard Pond
Hop Brook Wetland	<i>Hexagenia</i> Study Wetland Areas Only

Comparisons made follow statistical guidelines presented in EPA's *Guidance for Comparing Background and Chemical Concentrations in Soil for CERCLA Sites* (EPA, 2002).

Where sufficient data allow, statistical tests of significant differences between means were performed using either parametric or nonparametric tests. Distributions and subsequent summary statistics were calculated using EPA's ProUCL software (EPA, 2004). ProUCL determines parametric (for normal, lognormal, and gamma distributions) and non-parametric distributions depending on the skewness of the data (often represented by the standard deviation of the data). Data distributions were tested using a number of procedures including:

- Graphical test based upon a Q-Q plot.
- Shapiro-Wilk W test (tests for normality or lognormality for data sets with samples sizes less than 50).
- Anderson Darling test (tests for gamma distribution).
- Kolmogorov-Smirnov test (tests for gamma distribution).

The statistical test chosen to run the statistical comparison was based on both the data distribution and the equality of variance and the following selection criteria:

- Based on the data distribution, the two-sample parametric Student's t-test (Equal Variance t-test) was used for comparisons of samples with normal data distribution and equal variance.
- For data sets with normal distributions but unequal variances, a variation of the Equal Variance t-test was run, viz., the Aspin-Welch Unequal Variance Test.
- For data sets that did not demonstrate a normal distribution, the non-parametric Kolmogorov-Smirnov Test was used.

For the t-tests and non-parametric analogs to the t-test, a p-level of  $\geq 0.05$  was used to indicate that no significant difference exists between the means of the mercury levels in samples collected from the site impacted reaches and those collected from their respective reference areas.

The results of these comparisons are presented by medium as appropriate in the subsections below.

#### **4.2.1.3.2 Regional Mercury Level Comparisons**

For most ecosystems, atmospheric deposition is the primary source of mercury contamination (Krabbenhoft and Weiner, 1999). Numerous studies (EPA, 1997b; NESCAUM, 2003; VanArsdale et al., 2005) have identified the northeastern United States as a major depositional area in North America. Mercury deposition to lakes, reservoirs, and watersheds is directly influenced by the proximity and strength of mercury emission sources and the type of mercury emissions; and indirectly by local and regional weather patterns (VanArsdale et al., 2005). Because mercury contamination sources outside of the Nyanza facility may be contributing levels observed within the Sudbury River watershed, in addition to site-specific reference area comparisons, regional studies that measured mercury concentrations in sediments and fish tissue were identified.

A summary of each regional study used for comparative purposes is provided in Sections 4.2.2.1.5.2 (sediments) and 4.2.2.2.2.2 (fish). In general, comparisons between data collected for this SBERA and regional levels are qualitative to semi-quantitative because raw data for the regional studies were not available.

## **4.2.2 Risk to Aquatic Biota**

### **4.2.2.1 Benthic Invertebrate Community**

#### **4.2.2.1.1 *Hexagenia* Study**

##### **4.2.2.1.1.1 Mercury in Sediment and Mayflies**

Mean concentrations of total mercury in test sediments varied more than 100-fold among the six treatments in 1994 (tests 1 and 2). Lowest sediment concentrations were detected in reference areas (0.09 to 0.272) mg/kg while the highest total mercury concentrations in sediments were observed in Reaches 4 and 3 (Reservoirs 1 and 2, respectively) – 7.548 to 22.059 mg/kg, respectively. Mean concentrations of total mercury in sediments varied about 10-fold among the four treatments during 1995 (tests 3 and 4). Lowest sediment concentrations were detected in the Hop Brook Wetland reference area, 0.186 to 0.261 mg/kg, while the highest total mercury concentrations were observed in the contaminated wetlands (adjacent to Reach 8) and Reach 9 (Fairhaven Bay), 1.2 to 2.562 mg/kg, respectively.

The methylmercury concentrations in mayflies exposed to sediment collected from contaminated areas in 1994 were only two to three times those in mayflies exposed to sediment from the two reference areas. The fraction of total mercury present as methylmercury ranged from 1.2 to 28.5%, with the highest percentages in mayflies exposed to reference area sediment. Mayflies exposed to sediments from contaminated sites accumulated more methylmercury than did mayflies exposed to reference sediments. However, the net accumulation of methylmercury in mayflies was not correlated with total mercury in sediments (Spearman correlation  $r_s = 0.60$ ;  $p=0.08$ ).

The methylmercury concentrations in mayflies exposed to sediments collected from contaminated areas in 1995 ranged from 122 to 184  $\mu\text{g/kg}$ , whereas concentrations in mayflies exposed to reference wetland sediments averaged approximately 36  $\mu\text{g/kg}$ . The fraction of total mercury present as methylmercury ranged from 11 to 41%, with the highest percentage in mayflies exposed to reference area sediments. Mayflies exposed to sediments from contaminated wetland sites accumulated significantly greater amounts of methylmercury than mayflies exposed to reference wetland sediment, however, the net accumulation of methylmercury in mayflies was not correlated with total mercury in sediments (Spearman correlation;  $r_s = 0.73$ ,  $p = 0.06$ ).

When data from both years of the study were combined, there was a significant, positive correlation between the concentration of total mercury in mayflies and test sediment. However, total mercury concentrations in test sediments were not a good predictor of methylmercury concentrations in mayflies.

#### **4.2.2.1.1.2 Mayfly Growth and Survival**

The growth of mayflies evaluated in 1994 varied significantly among sediment treatments, but was unrelated to the total mercury concentrations in test sediment. Average mayfly growth in the Whitehall Reservoir reference area, 2.2 mm (test 1) and 2.3 mm (test 2) was significantly less than a majority of the other treatments, 5.1 mm (test 1) and 6.1 mm (test 2). Slower growth in mayflies exposed to sediments from Whitehall Reservoir may have resulted from physical characteristics of the test sediment such as high organic content.

The growth of mayflies evaluated in 1995 varied among treatments, but was also unrelated to the total mercury concentrations in test sediment. Average mayfly growth in the Northern Contaminated Wetland (adjacent to Reach 8) was significantly lower than that in the Hop Brook reference-wetland during both tests 3 and 4. The overall mean growth of mayflies was greater in test 3 (5.8 mm) than in test 4 (3.5 mm), which may be related to water levels in the study area when sediments were sampled.

Variation in mayfly growth seems unrelated to mercury exposure. The growth of mayflies (all data combined) did not decrease with (1) increasing concentrations of methylmercury in water, (2) total mercury in sediment, (3) total mercury in mayflies, and (4) methylmercury in mayflies.

Survival of mayflies in all tests was unrelated to the concentrations of total mercury in test sediment. Overall mayfly survival ranged from 90% in test 3 to 96% in test 2. Mean mayfly survival did not vary among treatment in any test.

#### **4.2.2.1.1.3 Comparison of Sediment Concentrations Identified During the *Hexagenia* Study and the 2003 Sediment Data**

Mean total mercury concentrations detected in sediments collected from the Sudbury River and used in the *Hexagenia* study and the concentrations found in those reaches in the most recent comprehensive sediment sampling (2003) are as follows.

Reach	Mean Sediment Concentration (mg/kg-DW)	
	<i>Hexagenia</i> Study*	2003 Sampling (n)
1994		
Reach 1	0.09 – 0.2	0.843 (5)
Reach 3	14.8 – 22.1	15 (40)
Reach 4	7.55 – 11.2	6.59 (11)
Reach 8	0.88 – 1.92	0.473 (13)
Reach 9	1.72 – 1.78	1.21 (10)
1995		
Reach 9	1.43 – 1.79	1.21 (10)

Note: Table contains only areas where data were available from both studies.

\*Represents range of means between the two tests for that year. 1994 analyses included 6 samples from each station per test. 1995 analyses included 9 samples from each station per test.

The 2003 Supplemental Investigation mean data for Reach 1 was higher than the mean mercury sediment data used in the *Hexagenia* study. Conversely, concentrations in Reaches 4, 8, and 9 (1994 and 1995) were higher in the historic data. Concentrations in Reach 3 were approximately the same.

#### 4.2.2.1.2 *Elliptio* Study

As previously noted, *An In-Situ Assessment of Mercury Contamination in the Sudbury River, Massachusetts, using Bioaccumulation and Growth in Transplanted Freshwater Mussels*, was conducted to measure the bioaccumulation of total- and methylmercury in a resident bioindicator species, the freshwater mussel, *Elliptio complanata*, and to evaluate the chronic effects of mercury exposure to that species. The objectives of the study and the design of the study to meet those objectives have been discussed previously in Subsection 3.3.1.1.4 of the Analysis Phase of this report. For a comprehensive discussion, the complete text of the study is provided in Appendix N of this SBERA.

The bioavailability of mercury was evaluated at eight (8) locations along the Sudbury River including three stations plus one reference in the impounded reaches of the river (Stations 1 [Whitehall Reservoir], 4 [ Reach 3], 5 [Reach 6], and 7 [Reach 9]) and three stations plus one reference in the free-flowing reaches of the river (Stations 2 [Reach 1], 3 [Reach 2], 6 [Reach 8], and 8 [Reach 10]). Note that two of these stations (Stations 6 and 8) were located within wetland areas of the river to assess the potential increase in methylmercury in these areas and the consequent increase in bioavailability.

#### **4.2.2.1.2.1 Survival of Deployed Mussels**

Table 4-1 provides a summary of mussel survival at the mid-study (day 42) and end of study (day 84) periods. At mid-study, the mean survival rate for all 8 stations was 82.5 percent with a range of 100 percent to 43 percent. This low survival rate was observed in Reach 8 (Sherman Street Bridge station; Station 6) in the GMNWR. Low survival, as well as low growth rates in Reach 8 (Station 6) was attributed in part to sulfides, as well as dense plant material in the sediment. Because of these conditions, these mussels were relocated at mid-test. At the end of the study, survival ranged from 83 percent to 36 percent, again with the lowest survival recorded in Reach 8 (Station 6).

Of particular significance was a higher than anticipated mortality of mussels at the two reference locations, Whitehall Reservoir (Station 1 - 17 percent) and the Reach 1 (Woods Street location; Station 2 - 9 percent). In addition, mussels deployed at these two locations had negative changes in whole-animal WW suggesting no growth. Consequently, the suitability of these locations as reference sites was questioned and a statistical comparison of survival between “unaffected” and “potentially affected” sites could not be performed. In addition, due to the high mortality in Reach 8 (Station 6), the researchers chose to eliminate the results of this location from the comparative analyses.

#### **4.2.2.1.2.2 Bioaccumulation of Mercury in Mussels**

Table 4-2 presents a summary of the mean “concentrations” and mean “content” of mercury in mussels deployed at each station at the start (day 0), midpoint (day 42), and end (day 84) of the study. First, Table 4-2 presents the concentration of total mercury, methylmercury, and inorganic mercury on the basis of both wet and dry tissue weight, e.g.,  $\mu\text{g Hg/kg DW}$ . Second, the mercury “content” adjusted for animal growth is also provided ( $\text{ng Hg-dry}$ ). This measure eliminates the diluting effect of the growth of the animal during the course of the study and provides a measure of the “absolute” increase or decrease of mercury in its various forms. In addition, the percent of the total mercury content that was measured as methylmercury is also provided.

#### **4.2.2.1.2.3 Mercury Concentration Summary**

The mean tissue concentration data (as  $\mu\text{g Hg/kg DW}$ ) indicate a statistically significant increase in the total mercury in the mussel tissues at the two reference stations over the course of the study (Figure 4-1). This may be due, in part, to the loss in body weight of the mussels at

these two stations which without a proportional loss of mercury would increase the tissue concentration of mercury. In addition, the total mercury concentration in mussels placed in Reach 3 (at the Inlet to Reservoir 2; Station 3) also showed a significant increase in the total mercury over the study period. Note that mussel growth was minimal at this location. The total mercury concentrations in mussels at the two farthest downriver locations (Reach 9 - Station 7 [Fairhaven Bay], and Reach 10 - Station 8 [Thoreau Street Bridge]) were either similar to or lower than the initial concentration of total mercury.

The mean tissue concentration data for methylmercury (as  $\mu\text{g MeHg/kg DW}$ ) roughly parallels the observations for total mercury concentrations. Results indicate statistically significant increases in methylmercury for all locations except for Reaches 9 and 10 (Stations 7 and 8, respectively).

#### **4.2.2.1.2.4 Mercury Content Summary**

The mean tissue content data (as ng Hg-dry) indicate that there were no statistically significant ( $p=0.05$ ) changes in the total mercury content over the course of the study (Figure 4-2). Except for mussels located in Reach 2 (Station 3) and in Reach 3 (Station 4), the total mercury content in all mussel tissues was slightly lower at the end of the study.

Methylmercury content in mussels (as ng dry) increased at all stations over the study duration. This increase was statistically significant ( $p= 0.05$ ) for mussels at all locations except Reach 1 (Wood Street reference station; Station 2) and Reach 8 (Sherman Street Bridge station; Station 6) in the GMNWR. The average increase in methylmercury content ranged from 40 to 110 ng per mussel representing an increase of 36 to 100 percent in methylmercury in the mussels during the period of the study. The greatest increase was observed in mussels deployed in Reach 3 (Station 4).

Correlation analyses for total mercury concentrations in sediment and tissue indicated that there were no significant relationships at the 95-percent confidence level. Moreover, an expected increase in the rate of methylmercury uptake in the mussels located in the vicinity of the riverine wetlands relative to the non-wetland locations was not demonstrated. It was hypothesized that the methylmercury concentrations in mussel tissue could be associated with high methylmercury concentrations in water, although this correlation was not tested in this study due to lack of synoptic surface water data.



#### **4.2.2.1.2.5 Growth of Mussels**

Figure 4-3 presents a summary of the mean growth rates, changes in tissue weight, shell length, and shell weight by location. In general, mussel growth increased downriver from Reach 3 (Station 4) to Reach 10 (Station 8) (with the exception of Reach 8 - Station 6). Considering all growth metrics evaluated, mussels located in the reference locations, Whitehall Reservoir (Station 1) and Reach 1 (Wood Street; Station 2), and in Reach 2 (Reservoir 2 Inlet; Station 3) demonstrated little to no growth. Mussels located in Reach 9 (Fairhaven Bay; Station 7) and Reach 10 (Thoreau Street Bridge; Station 8) exhibited the highest growth rates.

#### **4.2.2.1.2.6 Bioavailability of Mercury and Effects of Mercury on Mussel Growth**

The primary objectives of the mussel transplant study were to determine how far downstream from the Nyanza Site that mercury was bioavailable, and whether adverse effects were associated with exposure to the bioavailable mercury.

The use of concentration data alone suggests the preferential accumulation of total mercury by mussels closest to the Nyanza Site and depuration by those mussels in the wetlands in the lower reach of the Sudbury River study area. However, the use of content data, which normalizes the mercury data for growth, indicates that the total mercury content data showed no statistical difference in uptake among locations.

Similarly, the concentration data also indicates that methylmercury was not significantly bioaccumulated by mussels placed at the two farthest downriver locations (Reach 9 - Fairhaven Bay and Reach 10 - Thoreau Street Bridge). However, when data are normalized for growth, the methylmercury content data strongly suggests that mussels at all locations, including these two stations, increased their body burden of methylmercury.

A somewhat unexpected result was that there was no significant increase (above the other stations) in methylmercury content in mussels that were placed in locations adjacent to wetlands. It had been hypothesized that the mussels in these areas would demonstrate higher content due to the increased bioavailability of mercury resulting from methylation processes in the wetlands.

Correlation analyses were conducted on a number of mussel growth metrics and mercury concentrations in tissue. Correlations that were statistically significant are presented in Table 4-3. The results of the correlation indicate a fairly strong relationship between elevated mercury

levels in tissues and decreased growth, as defined herein. In comparing the correlations with the various forms of mercury, it is interesting to note that the relationship between the concentration of methylmercury and mussel growth is not as strong as that for either total or inorganic mercury. Again, recall that methylmercury was the only form of mercury that showed a significant increase in mussel tissue over the course of the study.

There were no significant correlations between mercury content and any of the mussel growth metrics. From an ecotoxicological perspective this is significant because it is the concentration of the contaminants in mussel tissue that appears to elicit the response and not the per-animal content (Depledge and Rainbow, 1990). While the total mercury content is informative for understanding the accumulation and depuration processes, the observed effects thresholds are determined using concentration data.

Mussel growth rates exhibited a downriver trend with growth rates lowest near the Nyanza Site and highest farther away from the Site. The effects on mussel growth are correlated to, and are likely associated with exposure to methylmercury. However, without supporting sediment and surface water chemistry data, it cannot be definitely concluded that the measured effects are due only to mercury exposure. The presence of other unmeasured chemicals or environmental factors, such as food availability, may have influenced mussel growth.

#### **4.2.2.1.2.7 Comparison of Sediment Concentrations Identified During the *Elliptio* Study and the 2003 Sediment Data**

Mean total mercury concentrations detected in sediments where mussels were deployed and the concentrations found in those reaches in the most recent comprehensive sediment sampling (2003) are as follows.

Reach	Mean Concentration (mg/kg DW)	
	<i>Elliptio</i> Study (n = 3)	2003 Sampling (n)
Reach 1	0.11	0.843 (5)
Reach 2	17.9	2.03 (12)
Reach 3	0.17	15 (40)
Reach 6	5.4	2.53 (12)
Reach 8	0.5	0.473 (13)
Reach 9	0.07	1.21 (10)
Reach 10	0.36	0.534 (10)

Note: Table contains only areas where data were available from both studies.

The 2003 Supplemental Investigation mean data for Reaches 1, 3, 9, and 10 were higher than the mean mercury data detected where mussels were deployed. Conversely, concentrations in Reaches 2 and 6 were higher in the historic data. Concentrations in Reach 8 were approximately the same. Note that the data from 2003 represent the mean concentrations of samples taken throughout the reach, whereas the data from the mussel study reflect only where the mussels were deployed.

#### **4.2.2.1.3 Crayfish CBRs**

Potential effects associated with mercury contamination in the Sudbury River were evaluated by comparing total mercury concentrations in crayfish tissue to derived CBRs.

Crayfish data were available for Reaches 2 through 7 and reference areas (Reach 1, Charles River, and Sudbury Reservoir). The crayfish data set had no concentrations exceeding either the no-effect or the effect-based CBRs (i.e., all HQs < 1; Table 4-4 and Figure 4-4). Based on the maximum detected concentrations per reach, site impacted HQs ranged from 0.009 (effects CBR, Reach 6 concentration) to 0.14 (no-effects CBR, Reach 3 concentration). Reference HQs ranged from 0.004 (effects CBR, Sudbury Reservoir) to 0.03 (no-effects CBR, Reach 1). Crayfish whole body and tail concentration data collected for this assessment were comparable to data collected by Haines et al. (1997) in Reach 3 from 1994 and 1995 and reported by Pennuto et al. (2005) for crayfish collected from 2000-2003 in Maine, New Hampshire, and Vermont.

#### **4.2.2.1.4 Sediment Benchmark Comparisons**

Sediment effects were estimated by comparing sediment chemical concentrations, by sample, with sediment quality guidelines developed by MacDonald et al. (2000).

Table 4-5 summarizes the HQs calculated based on the MacDonald et al. (2000) TEC and PECs, presenting the frequency with which benchmark values were exceeded (HQ >1). Individual sample HQs are provided in Appendix O.

##### **4.2.2.1.4.1 Site Impacted Areas (Reaches 2 through 10)**

###### **4.2.2.1.4.1.1 Reach 2**

In Reach 2, the magnitude of the TEC- and PEC-based HQs for total mercury range from 0.029 to 54 and 0.0049 to 9.1, respectively. Of the 12 sediment samples, 8 have total mercury concentrations that exceed the TEC, and 4 have concentrations that exceed the PEC (i.e.,

HQ>1). Of the samples with total mercury concentrations that exceed the TEC, 5 have HQs less than 10, and 3 have HQs greater than 10 and less than 100. For the samples with total mercury concentrations exceeding the PEC, the HQs were <10. The average concentration of 2.03 mg/kg (see Table 2-6) exceeds both the TEC and the PEC (HQs = 11 and 1.9, respectively).

#### **4.2.2.1.4.1.2                      Reach 3**

In Reach 3, the magnitude of the TEC- and PEC-based HQs for total mercury range from 7.3 to 249 and 1.2 to 42, respectively. Of the 39 sediment samples, all of the samples have total mercury concentrations that exceed the TEC and the PEC (i.e., HQ>1). Of the samples with total mercury concentrations that exceed the TEC, 1 has an HQ less than 10, 22 have HQs greater than 10 and less than 100, and 16 have HQs greater than 100 and less than 1,000. For the samples with total mercury concentrations exceeding the PEC, 17 have HQs less than 10 and 22 have HQs greater than 10 and less than 100. The average concentration of 15 mg/kg (see Table 2-6) exceeds both the TEC and the PEC (HQs = 83 and 14, respectively).

#### **4.2.2.1.4.1.3                      Reach 3 – Focus Area**

In the Focus Area of Reach 3 (see Figure 2-4), the magnitude of the TEC- and PEC-based HQs for total mercury range from 1.3 to 50 and 0.23 to 8.5, respectively. Of the 15 sediment samples, all of the samples have total mercury concentrations that exceed the TEC and 10 have concentrations that exceed the PEC (i.e., HQ>1). Of the samples with total mercury concentrations that exceed the TEC, 6 have HQs less than 10 and 9 have HQs greater than 10 and less than 100. For the samples with total mercury concentrations exceeding the PEC, all of the HQs are less than 10. The average concentration of 2.74 mg/kg (see Table 2-6) exceeds both the TEC and the PEC (HQs = 15 and 2.6, respectively).

#### **4.2.2.1.4.1.4                      Reach 4**

In Reach 4, the magnitude of the TEC- and PEC-based HQs for total mercury range from 4.6 to 84 and 0.78 to 14, respectively. Of the 11 sediment samples, all of the samples have total mercury concentrations that exceed the TEC and 10 have concentrations that exceed the PEC (i.e., HQ>1). Of the samples with total mercury concentrations that exceed the TEC, 1 has an HQ less than 10 and 10 have HQs greater than 10 and less than 100. For the samples with total mercury concentrations exceeding the PEC, 8 have HQs less than 10 and 2 have HQs

greater than 10 and less than 100. The average concentration of 6.59 mg/kg (see Table 2-6) exceeds both the TEC and the PEC (HQs = 37 and 6.2, respectively).

#### **4.2.2.1.4.1.5                      Reach 5**

In Reach 5, the magnitude of the TEC- and PEC-based HQs for total mercury range from 0.24 to 18 and 0.041 to 3, respectively. Of the 10 sediment samples, 7 of the samples have total mercury concentrations that exceed the TEC and 5 have concentrations that exceed the PEC (i.e., HQ>1). Of the samples with total mercury concentrations that exceed the TEC, 5 have HQs less than 10 and 2 have HQs greater than 10 and less than 100. For the samples with total mercury concentrations exceeding the PEC, all of the HQs are less than 10. The average concentration of 1.05 mg/kg (see Table 2-6) exceeds the TEC (HQ = 5.8) and is approximately equal to the PEC (HQ = 1.0).

#### **4.2.2.1.4.1.6                      Reach 5 – Focus Area**

In the Focus Area of Reach 5 (see Figure 2-6), the magnitude of the TEC- and PEC-based HQs for total mercury range from 0.19 to 11 and 0.033 to 1.9, respectively. Of the 15 sediment samples, 5 of the samples have total mercury concentrations that exceed the TEC and 1 has a concentration that exceeds the PEC (i.e., HQ>1). Of the samples with total mercury concentrations that exceed the TEC, 4 have HQs less than 10 and 1 has an HQ greater than 10 and less than 100. For the sample with a total mercury concentration exceeding the PEC, the HQ is less than 10. The average concentration of 0.29 mg/kg (see Table 2-6) exceeds the TEC (HQ = 1.6) and is less than the PEC (HQ = 0.3).

#### **4.2.2.1.4.1.7                      Reach 6**

In Reach 6, the magnitude of the TEC- and PEC-based HQs for total mercury range from 0.19 to 54 and 0.031 to 9.2, respectively. Of the 12 sediment samples, 11 of the samples have total mercury concentrations that exceed the TEC and 8 have concentrations that exceed the PEC (i.e., HQ>1). Of the samples with total mercury concentrations that exceed the TEC, 5 have HQs less than 10 and 6 have HQs greater than 10 and less than 100. For the samples with total mercury concentrations exceeding the PEC, all of the HQs are less than 10. The average concentration of 2.53 mg/kg (see Table 2-6) exceeds both the TEC and the PEC (HQs = 14 and 2.4, respectively).

**4.2.2.1.4.1.8****Reach 7**

In Reach 7, the magnitude of the TEC- and PEC-based HQs for total mercury range from 0.066 to 8.6 and 0.011 to 1.5, respectively. Of the 16 sediment samples, 6 of the samples have total mercury concentrations that exceed the TEC and 2 have concentrations that exceed the PEC (i.e.,  $HQ > 1$ ). Of the samples with total mercury concentrations that exceed the benchmarks, all have HQs less than 10. The average concentration of 0.296 mg/kg (see Table 2-6) exceeds the TEC ( $HQ = 1.6$ ) and is less than the PEC ( $HQ = 0.28$ ).

**4.2.2.1.4.1.9****Reach 7-Heard Pond**

In Reach 7-Heard Pond, the magnitude of the TEC- and PEC-based HQs for total mercury range from 11 to 17 and 1.9 to 2.8, respectively. Of the 4 sediment samples, all of the samples have total mercury concentrations that exceed the TEC and PEC (i.e.,  $HQ > 1$ ). For the samples with total mercury concentrations exceeding the TEC, all of the samples have HQs greater than 10 and less than 100. For the samples with total mercury concentrations exceeding the PEC, all of the samples have HQs less than 10. The average concentration of 2.5 mg/kg (see Table 2-6) exceeds both the TEC and the PEC ( $HQs = 14$  and  $2.4$ , respectively).

**4.2.2.1.4.1.10****Reach 8**

In Reach 8, the magnitude of the TEC- and PEC-based HQs for total mercury range from 0.41 to 6.6 and 0.069 to 1.1, respectively. Of the 13 sediment samples, 8 of the samples have total mercury concentrations that exceed the TEC and 1 has a concentration that exceeds the PEC (i.e.,  $HQ > 1$ ). Of the samples with total mercury concentrations that exceed the benchmarks, all have HQs less than 10. The average concentration of 0.473 mg/kg (see Table 2-6) exceeds the TEC ( $HQ = 2.6$ ) and is less than the PEC ( $HQ = 0.45$ ).

**4.2.2.1.4.1.11****Reach 9**

In Reach 9, the magnitude of the TEC- and PEC-based HQs for total mercury range from 2.6 to 11 and 0.44 to 1.8, respectively. Of the 10 sediment samples, all of the samples have total mercury concentrations that exceed the TEC and 7 have concentrations that exceed the PEC (i.e.,  $HQ > 1$ ). Of the samples with total mercury concentrations that exceed the TEC, 9 have HQs less than 10 and 1 has an HQ greater than 10 and less than 100. For the samples with total mercury concentrations exceeding the PEC, all of the HQs are less than 10. The average concentration of 1.21 mg/kg (see Table 2-6) exceeds both the TEC and the PEC ( $HQs = 6.7$  and  $1.1$ , respectively).

#### **4.2.2.1.4.1.12**

#### **Reach 10**

In Reach 10, the magnitude of the TEC- and PEC-based HQs for total mercury range from 0.30 to 8.4 and 0.051 to 1.4, respectively. Of the 10 sediment samples, 7 of the samples have total mercury concentrations that exceed the TEC and 2 have concentrations that exceed the PEC (i.e.,  $HQ > 1$ ). Of the samples with total mercury concentrations that exceed the benchmarks, all have HQs less than 10. The average concentration of 0.534 mg/kg (see Table 2-6) exceeds the TEC ( $HQ = 3.0$ ) and is less than the PEC ( $HQ = 0.50$ ).

#### **4.2.2.1.4.1.13**

#### **Sediment Cores**

The sediment core concentrations from Reach 3 (Reservoir 2; depths 0-12 cm from 2003 and 0-20 cm from 2005 sampling) are also compared with TECs and PECs. The magnitude of the TEC- and PEC-based HQs for total mercury for the 36 samples range from 0.47 to 267 and 0.081 to 45, respectively.

#### **4.2.2.1.4.2**

#### **Reference Areas**

##### **4.2.2.1.4.2.1**

##### **Reach 1**

In Reach 1, the magnitude of the TEC- and PEC-based HQs for total mercury range from 0.72 to 18 and 0.12 to 3.0, respectively. Of the 5 sediment samples, 4 have total mercury concentrations that exceed the TEC, and 1 has a concentration that exceeds the PEC (i.e.,  $HQ > 1$ ). Of the samples with total mercury concentrations that exceed the TEC, 3 have HQs less than 10, and 1 has an HQ greater than 10 and less than 100. For the sample with a total mercury concentration exceeding the PEC, the HQ was  $< 10$ . The average concentration of 0.843 mg/kg (see Table 2-6) exceeds the TEC ( $HQ = 4.7$ ) and is less than the PEC ( $HQ = 0.80$ ).

##### **4.2.2.1.4.2.2**

##### **Charles River**

In the Charles River, the magnitude of the TEC- and PEC-based HQs for total mercury range from 0.86 to 1.9 and 0.15 to 0.32, respectively. Of the 7 sediment samples, 5 of the samples have total mercury concentrations that exceed the TEC and none has a concentration that exceeds the PEC (i.e.,  $HQ > 1$ ). Of the samples with total mercury concentrations that exceed the benchmark, all have HQs less than 10. The average concentration of 0.237 mg/kg (see Table 2-6) exceeds the TEC ( $HQ = 1.3$ ) and is less than the PEC ( $HQ = 0.22$ ).

The sediment core concentrations from Charles River (0-12 cm) are also compared with TECs and PECs. The magnitude of the TEC- and PEC-based HQs for total mercury for the eight samples range from 0.28 to 2.9 and 0.048 to 0.5, respectively.

#### **4.2.2.1.4.2.3 Sudbury Reservoir**

In the Sudbury Reservoir, the magnitude of the TEC- and PEC-based HQs for total mercury range from 0.32 to 2.2 and 0.054 to 0.37, respectively. Of the 6 sediment samples, 3 of the samples have total mercury concentrations that exceed the TEC and none has a concentration that exceeds the PEC (i.e.,  $HQ > 1$ ). Of the samples with total mercury concentrations that exceed the benchmark, all have HQs less than 10. . The average concentration of 0.199 mg/kg (see Table 2-6) exceeds the TEC ( $HQ = 1.1$ ) and is less than the PEC ( $HQ = 0.19$ ).

#### **4.2.2.1.5 Comparison of Sediment Concentrations with Site-Specific Reference and Regional Levels**

##### **4.2.2.1.5.1 Site-Specific Reference**

Statistical comparisons of total mercury concentrations in sediment samples collected from potentially affected reaches of the Sudbury River and from appropriate reference areas were made. (See Section 4.2.1.3.1 for approach.) The results of the statistical comparisons are presented in Table 4-6.

##### **4.2.2.1.5.1.1 Comparisons with Reach 1**

Sediment total mercury concentrations in Reach 1 were not statistically different from those found in the samples collected from site impacted fast flowing reaches (i.e., Reaches 2, 5, 7, and 10).

##### **4.2.2.1.5.1.2 Comparisons with Charles River**

Sediment total mercury concentrations in the Charles River were not statistically different from those found in Reach 8, but were statistically different from (lower than) those found in Reach 9.

##### **4.2.2.1.5.1.3 Comparisons with Sudbury Reservoir**

Sediment total mercury concentrations in the Sudbury Reservoir were statistically different from (lower than) those found in the samples collected from Reaches 3, 4, 6, and 7-Heard Pond.



#### **4.2.2.1.5.2**

#### **Regional Sediment Mercury Concentrations**

Atmospheric deposition plays a significant role in mercury loading in freshwater systems throughout North America and particularly in the northeast (EPA, 1997c; Krabbenhoft et al., 1999; Kamman and Engstrom, 2002; VanArsdale et al., 2005). Mercury contamination of aquatic ecosystems in the northeast has been well documented in lake sediment (NESCOUM, 1998); with historical deposition studies for mercury showing peak loading occurring during the 1960s and 1970s (Lorey and Driscoll, 1999; Kamman and Engstrom, 2005). In general, mercury loading in lake sediment has decreased over the last two decades (Kamman et al., 2002). Given that mercury contamination in freshwater sediments is a ubiquitous occurrence throughout the northeast, it is valuable in the ERA process to compare sediment mercury concentrations identified within the Sudbury River watershed with regional levels. We purposefully avoid the use of the term “background” when discussing comparisons to regional levels because the controls typically associated with the establishment of background concentrations (EPA, 2002) are not applicable in this qualitative comparison. Some of the uncertainties associated with comparisons are presented in the following discussion.

Three reports (MassDEP, 1997; USGS, 2002; Kamman et al., 2005) that contained regional sediment mercury information were selected to provide a regional perspective on mercury sediment concentrations. Sediment concentration information presented in these reports includes chemistry data collected in streams/rivers, reservoirs, and lakes. Whenever possible, the type of waterbody associated with data presented will be distinguished. Comparisons of regional sediment mercury concentrations to site impacted Sudbury River reaches will focus on comparing data collected under “similar” flow conditions [i.e., regional riverine data will be compared to Sudbury River flowing reach data (Reaches 2, 5, 7, 8, 9, and 10) and regional reservoir and lake (lacustrine) data will be compared to Sudbury River impoundment reaches (Reaches 3, 4, and 6)]. The following discussion provides a brief overview of the data provided in each of the regional studies evaluated and a qualitative comparison of regional sediment mercury concentrations to concentrations observed in Sudbury River impacted reaches.

As part of a study evaluating the distribution of mercury concentrations in fish collected from Massachusetts lakes, MassDEP (1997) collected fish, water, and sediment samples in 24 Massachusetts lakes that were located in three ecological subregions (Green Mountain/Berkshire Highlands, Worcester/Monadnock Plateau, and Narragansett/Bristol Lowlands). These lakes are not associated with any active point sources of contamination. Two surficial sediment samples were collected in each lake, one in the deepest hole and the

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other halfway to shore; these samples were composited and subsequently submitted for trace metal, pesticide, and PCB analysis. Analysis of conventional sediment parameters like TOC and grain size, were not included and ultra-clean sampling protocols were not followed. The primary focus of this report was to determine the patterns of variation in edible tissue (e.g., fish) mercury concentrations and the relationships of these patterns to characteristics of the surface water, sediment, and waterbody.

As part of the National Water Quality Assessment Program, the USGS (2002) collected trace element and organic compound data in streambed sediment and fish tissue from 14 coastal New England streams in 1998 and 1999. Surficial sediment (top 2 cm) samples were collected during low-flow conditions at sites that spanned a wide population density and urban land use range. Five to 10 representative subsamples were composited from depositional areas in each river. The rivers selected were all located in the New England Coastal Basins (NECB) study area which covers 23,000 mi<sup>2</sup> in western Maine, eastern New Hampshire, and Massachusetts, and nearly all of Rhode Island. The rivers selected are not representative of the entire NECB study area, but focused more on urbanized areas. It should be noted that there appeared to be no effort to exclude sites that might be influenced by point source discharges; therefore, it would be inappropriate to assume all the sediment concentration data collected in this evaluation is representative of anthropogenic background conditions.

Kamman et al. (2005) compiled a summary of freshwater sediment mercury concentrations for northeastern North America, from datasets developed by federal, state/provincial, and academic monitoring or research projects. Sediment samples (478 total mercury and 204 methylmercury) were collected from lakes (n=276), rivers (n=81), and reservoirs (n=121). Data associated with known point-source contaminated sites were not included in this compilation. Sampling depths varied between 2 and 10 cm, with 91% being collected in the top 5 cm. Raw data for all the samples included in this summary were not provided; mean and standard error total mercury values for sediments in different waterbody types were estimated from Figure 5 in Kamman et al. (2005).

Figures 4-5 through 4-9 provide comparisons and summary statistics from the sediment mercury data presented in the three previously discussed regional studies. Results of this type of comparison provide additional information that can be considered during the remedial decision process. Comparisons of Sudbury River reach (flowing water reaches) to regional riverine values are presented in Figures 4-5 and 4-6. When Sudbury River sediment

concentrations were compared (Figure 4-5) to values provided by USGS (2002), it is readily apparent that levels observed in the Sudbury River tend to be lower than regional mercury sediment concentrations. This is not surprising given the USGS report made no attempt to identify rivers that were not impacted by potential point source input for mercury. When Sudbury River flowing reach sediment levels were compared (Figure 4-6) to riverine data summarized by Kamman et al. (2005), all site-related reaches and reference area means exceeded regional mercury levels. The fact that Kamman et al. (2005) specifically selected riverine data not impacted by known contaminant point sources probably accounts for the differences observed; although the fact that the site-specific reference area data was substantially higher than regional levels is surprising.

Figure 4-7 provides comparisons of Sudbury River impoundment data to regional reservoir data compiled by Kamman et al. (2005). Sudbury River impacted reaches (3, 4, and 6) have higher concentrations than regional reservoirs; it is also worth noting that our site-specific reference area for the impounded reaches (i.e., Sudbury Reservoir) had sediment mercury concentrations that were similar to the more extensive reservoir data set provided by Kamman et al. (2005).

Figures 4-8 and 4-9 provide comparisons of Sudbury River impoundment data to regional lake data presented in reports by Kamman et al. (2005) and MassDEP (1997). The results of these comparisons mirror the findings previously presented for reservoirs with site impacted reaches showing higher concentrations than regional lake levels and our site-specific reference area concentrations (i.e., Sudbury Reservoir) very similar to regional levels.

There are numerous sources of uncertainty that should be considered when interpreting the comparisons to regional sediment mercury levels presented; the following is a brief list of some of the major sources:

- Sample-specific conventional parameters like TOC and grain size were not available to assure that comparable sediment “types” were being compared.
- Sampling protocols and objectives were not presented for each data source utilized in the compilation by Kamman et al. (2005).
- MassDEP (1997) lake data were based on composites of only two sediment samples per lake.
- USGS (2002) riverine data were based on composites of 10 samples for each river; no description of sample location selection priority is provided.

- As was previously discussed, sites used in the USGS (2002) study are not representative of the entire NECB area, but focus on the more urbanized areas and are therefore more likely to include point-source impacts.
- Comparisons to lakes and reservoirs that are not part of a complex riverine system like the Sudbury River may be overly conservative because their dominant source of mercury input is often limited to atmospheric deposition and to a lesser extent localized surface water runoff.

#### **4.2.2.2 Fish Population**

##### **4.2.2.2.1 Fish CBR Comparisons**

Empirical cumulative distribution functions (CDFs) were used to illustrate the number of whole body fish samples exceeding CBRs for fish. The no-effect levels (NELs) and low-effect levels (LELs) as identified in the Effects Characterization (Section 3.3.1.1.2.2.3.2) are presented on the CDFs, as well as a number of other no effect- and effect-levels for other endpoints and/or receptors. The comparisons between the whole body fish data and the CBRs are discussed by reach below.

##### **4.2.2.2.1.1 Site Impacted Areas (Reaches 2 through 10)**

###### **4.2.2.2.1.1.1 Reach 2**

In Reach 2, approximately 90% of the samples have concentrations below the NEL and 100% of the samples have concentrations below the LEL (Figure 4-10). All four of the samples with total mercury concentrations exceeding the NEL were size class D with a species break-out of three largemouth bass and one yellow perch. The mean concentration when considering all data was below the NEL.

###### **4.2.2.2.1.1.2 Reach 3**

In Reach 3, approximately 85% of the samples have concentrations below the NEL and 100% of the samples have concentrations below the LEL (Figure 4-11). All seven of the samples with total mercury concentrations exceeding the NEL were size class D with a species break-out of four largemouth bass, two yellow perch, and one yellow bullhead. The mean concentration when considering all data was below the NEL.

###### **4.2.2.2.1.1.3 Reach 4**

In Reach 4, approximately 85% of the samples have concentrations below the NEL and 100% of the samples have concentrations below the LEL (Figure 4-12). All seven of the samples with

total mercury concentrations exceeding the NEL were size class D with a species break-out of three largemouth bass and four yellow perch. The mean concentration when considering all data was below the NEL.

#### **4.2.2.2.1.1.4                      Reach 5**

In Reach 5, approximately 90% of the samples have concentrations below the NEL and 100% of the samples have concentrations below the LEL (Figure 4-13). All three of the samples with total mercury concentrations exceeding the NEL were size class D with a species break-out of two largemouth bass and one yellow perch. The mean concentration when considering all data was below the NEL.

#### **4.2.2.2.1.1.5                      Reach 6**

In Reach 6, approximately 95% of the samples have concentrations below the NEL and 100% of the samples have concentrations below the LEL (Figure 4-14). All three of the samples with total mercury concentrations exceeding the NEL were size class D largemouth bass. The mean concentration when considering all data was below the NEL.

#### **4.2.2.2.1.1.6                      Reach 7**

In Reach 7, approximately 95% of the samples have concentrations below the NEL and 100% of the samples have concentrations below the LEL (Figure 4-15). Both of the samples with total mercury concentrations exceeding the NEL were size class D largemouth bass. In Reach 7-Heard Pond, 100% of the samples have concentrations below the NEL and, accordingly below the LEL (Figure 4-16). The mean concentration when considering all data was below the NEL.

#### **4.2.2.2.1.1.7                      Reach 8**

In Reach 8, approximately 95% of the samples have concentrations below the NEL (Figure 4-17). All seven of the samples with total mercury concentrations exceeding the NEL were size class D with a species break-out of six largemouth bass and one yellow bullhead. Only one whole body fish sample had a concentration greater than the LEL – a size class D largemouth bass. The mean concentration when considering all data was below the NEL.

#### **4.2.2.2.1.1.8                      Reach 9**

In Reach 9, approximately 90% of the samples have concentrations below the NEL (Figure 4-18). All four of the samples with total mercury concentrations exceeding the NEL were size class D with a species break-out of three largemouth bass and one yellow perch. Only one

whole body fish sample had a concentration greater than the LEL – a size class D largemouth bass. The mean concentration when considering all data was below the NEL.

#### **4.2.2.2.1.1.9                      Reach 10**

In Reach 10, approximately 90% of the samples have concentrations below the NEL (Figure 4-19). All four of the samples with total mercury concentrations exceeding the NEL were size class D with a species break-out of three largemouth bass and one yellow perch. Two fish samples had concentrations greater than the LEL; both were size class D largemouth bass. The mean concentration when considering all data was below the NEL.

#### **4.2.2.2.1.2                      Reference Areas**

##### **4.2.2.2.1.2.1                      Reach 1**

In Reach 1, almost 100% of the samples have concentrations below the NEL and 100% of the samples have concentrations below the LEL (Figures 4-10, 4-13, 4-15, and 4-19). The one sample with a total mercury concentration exceeding the NEL was a size class D yellow bullhead. The mean concentration when considering all data was 138 µg/kg WW and falls below the NEL.

##### **4.2.2.2.1.2.2                      Charles River**

In the Charles River, almost 100% of the samples have concentrations below the NEL and 100% of the samples have concentrations below the LEL (Figures 4-17 and 4-18). The one sample with a total mercury concentration exceeding the NEL was a size class D largemouth bass. The mean concentration when considering all data was 134 µg/kg WW and falls below the NEL.

##### **4.2.2.2.1.2.3                      Sudbury Reservoir**

In the Sudbury Reservoir, 100% of the samples have concentrations below the NEL and LEL (Figures 4-11, 4-12, 4-14, and 4-16).

#### **4.2.2.2.2                      Comparison of Fish Tissue Concentrations with Site-Specific Reference and Regional Levels**

##### **4.2.2.2.2.1                      Site-Specific Reference Comparison**

Statistical comparisons of total mercury concentrations in fish tissue samples collected from potentially affected reaches of the Sudbury River and from appropriate reference areas are

made on a species-specific basis. For the comparisons with the yellow perch, size-class comparisons are also made. The objective of these comparisons is to determine if there are significant differences in mercury concentrations in fish between the potentially affected reaches of the Sudbury River and associated reference areas. Procedures for the statistical comparisons were presented in Section 4.2.1.3.1. The results of the statistical comparisons are presented in Table 4-7.

#### **4.2.2.2.1.1 Yellow Perch**

Data are available for four size classes of yellow perch:

- Size Class A =  $5 < \text{Total Fish Length (TL)} \leq 10$  cm
- Size Class B =  $10 < \text{TL} \leq 15$  cm
- Size Class C =  $15 < \text{TL} \leq 20$  cm
- Size Class D =  $\text{TL} > 20$  cm

Based on available tissue data, whole body data comparisons were made of the  $5 < \text{TL} \leq 10$  cm and  $10 < \text{TL} \leq 15$  cm length fish; and axial muscle (fillet) data comparisons were made of the  $15 < \text{TL} \leq 20$  cm and  $\text{TL} > 20$  cm fish. Note that the two smaller size classes have a minimum of 13 fish per reach with which to make the statistical comparison. In the case of the larger fish, only 3 whole body samples per reach are available which is inadequate to test statistical significance of the comparisons. As such, fillet data for which there are 13 samples per reach were used for the statistical analysis.

**Swift-Flowing Reaches (2, 5, and 7)** – Results of the statistical comparison for yellow perch collected from each of the flowing reaches show that the mercury levels in whole body perch from each of four size classes from Reach 2 (Mill Pond and downstream of the dam) are significantly higher ( $p < 0.05$ ) than mercury concentrations found in the same size fish from the associated reference area (Reach 1). In Reach 5 (the Sudbury River below Winter Street dam), only the smallest of the size classes (i.e.,  $5 < \text{TL} \leq 10$  cm) had mercury levels that are significantly higher than those found in the reference area. Mercury concentrations in whole body perch tissue from Reach 7 (the Sudbury River below the Saxonville Dam) are also significantly higher than that in the reference area for  $5 < \text{TL} \leq 10$  cm and  $10 < \text{TL} \leq 15$  cm size classes. None of the yellow perch in the  $15 < \text{TL} \leq 20$  cm and  $\text{TL} > 20$  cm length range in Reaches 5 and 7, have mercury concentrations in fillet tissue at levels significantly different from those found in fish from the reference area.

**Slow-Flowing Reaches (8, 9, and 10)** – Comparison of yellow perch from the slow-flowing reaches of the Sudbury River indicate that the mercury concentrations in whole body tissue of perch of all four size classes from each of the reaches are significantly higher than those found in the fish collected from the reference area for this flow regime (i.e., Charles River).

**Lacustrine Reaches (3, 4, 6, and 7-Heard Pond)** – As with the comparison for the slow-flowing reaches, mercury levels in yellow perch from all size classes collected from each of the lacustrine waters on the Sudbury River are significantly higher than those found in similar size fish collected from the Sudbury Reservoir. Note that mercury levels in fish collected from Reach 7-Heard Pond were significantly lower than those found in fish from the Sudbury Reservoir.

#### **4.2.2.2.2.1.2 Largemouth Bass**

Results of the statistical comparison (Table 4-7) indicate that the mercury levels in the whole body tissue of all largemouth bass collected from the Sudbury River, regardless of flow regime, are significantly ( $p < 0.05$ ) higher than the mercury concentrations measured in largemouth bass from their respective reference areas. As with the yellow perch, the mercury concentrations in largemouth bass from Reach 7-Heard Pond were significantly lower than those found in bass from the Sudbury Reservoir.

#### **4.2.2.2.2.1.3 Comparisons of Normalized Fish Data**

EPA's Atlantic Ecology Division (Narragansett) performed several statistical analyses with which to determine the significance of several variables potentially associated with mercury uptake in fish from the Sudbury River. Among these variables are tissue type, species, location on river, and sampling times. A comprehensive discussion of these analyses can be found in the *Technical Memorandum – Results of Statistical Analyses of Fish and Bird Total Mercury Residues in Support on Nyanza Operable Unit OU IV (Sudbury River) Baseline Ecological Risk Assessment* (see Appendix F).

Bivariate plots of individual fish mercury concentrations versus age, length, and weight for each species were examined for relationships between mercury levels and these variables. Based on results demonstrating the strongest positive correlations with fish length for yellow perch, bullhead, sunfish and largemouth bass, total mercury concentrations in fish tissue were normalized to a species-specific standard length (see Appendix E). Note that this analysis evaluates the mercury levels aggregated for all fish regardless of size by species. In the previous site-specific reference comparison, variability in mercury concentrations in fish due to



size factors was controlled by limiting the comparisons to fish within the same size (length) bracket.

Fish tissue for each species was normalized to derive a predicted mercury concentration for a “standard-sized fish,” defined as the arithmetic mean fish length over all fish evaluated. The predicted mercury concentration of a standard-sized fish for a species was used as a basis for comparison of mercury levels in fish, e.g., yellow perch among reaches of the Sudbury River and reference areas. Mean mercury concentrations in fish from each area were obtained by regressing individual fish mercury concentrations on body lengths for fish for each area and solving the regression equation for the predicted tissue mercury associated with the length of the standard-sized fish. Note that greater confidence holds for the comparisons with yellow perch and largemouth bass where a much more robust data set strengthens the regression. Although the comparison of the sunfish and bullhead data is informative, fewer data for these species limit the evaluation. A more comprehensive discussion of the standardization approach is provided in *Technical Memorandum*, (see Appendix E).

Figures 4-20 through 4-23 depict the results of a one-way ANOVA of the mercury concentrations among the 9 affected reaches of the Sudbury River (i.e., Reach 2 through Reach 10), and the three reference locations. Note that each figure provides the mean mercury concentration ( $\pm 1$  s.d.) for an individual species across the 12 areas evaluated. Areas identified with the same letter (a through g) were not statistically different from each other at  $p \geq 0.05$ .

A summary of the results by species is presented below.

#### **4.2.2.2.2.1.3.1 Yellow Perch**

The order of highest to lowest concentration of mercury in a standard-size yellow perch in the Sudbury River and reference areas are:

Reach 3 > Reaches 2, 4, 9, 10 > Reach 8 > Reaches 1, 5, 6, 7 & Charles River  
> Sudbury Reservoir > Reach 7- Heard Pond

Areas grouped together indicate that there was not a statistically significant difference ( $p \geq 0.05$ ) in mercury levels in standard-size yellow perch among those areas (Figure 4-20).

In addition:

- Mean mercury concentrations in standardized yellow perch in Reaches 2, 3, 4, 8, 9, and 10 are significantly higher than those levels found in any of the reference areas (i.e., Reach 1, Charles River, and Sudbury Reservoir).
- Mean mercury concentrations in standardized yellow perch in Reaches 5, 6, and 7 are similar and are not significantly different from those levels found in the reference areas, Reach 1 and Charles River.
- The mean mercury concentration in standardized yellow perch in Reach 3 (Reservoir 2) is significantly higher than mercury levels in the reference areas and any other reach evaluated.
- The mean mercury concentration in standardized yellow perch in Reach 7-Heard Pond is significantly lower than mercury levels in the reference areas and any other reach evaluated.

#### **4.2.2.2.1.3.2 Largemouth Bass**

The order of highest to lowest concentration of mercury in a standard-size largemouth bass in the Sudbury River and reference areas are (Figure 4-21):

Reaches 3, 8, 9 > Reaches 4, 10 > Reaches 2, 5, 6, 7 > Reach 1, Charles River  
> Sudbury Reservoir > Reach 7- Heard Pond

In addition:

- With the exception of the reference reach of the Sudbury River (Reach 1), the mean concentration of mercury in whole body largemouth bass throughout the Sudbury River Proper (i.e., not Reach 7-Heard Pond) are significantly higher ( $p < 0.05$ ) than the level of mercury observed in bass from the reference areas.
- The lowest concentrations of mercury in largemouth bass were observed in Reach 7-Heard Pond.

#### **4.2.2.2.1.3.3 Bullhead**

Statistical comparison of standard-size bullhead among reaches of the Sudbury River and reference areas show that with the exception of bullhead from Reach 3, mercury levels in fish from the other reaches and reference areas are similar. This is demonstrated by the significant overlap of statistically similar reaches shown in Figure 4-22. Bullhead from Reach 7-Heard Pond were the lowest, but not statistically different from those from Reach 2 (which were not statistically different from all other reaches except 3 and 6).

#### **4.2.2.2.1.3.4**

#### **Sunfish**

Statistical comparison of standard-size sunfish among reaches of the Sudbury River show that with the exception of sunfish from Reach 6 (Saxonville Pond), mercury levels in standard-size sunfish from all other reaches were significantly higher than those observed in fish from the reference areas (Figure 4-23). (Note that sunfish were not standardized to a particular length because only fish between 5 and 10 cm were included in the analysis.) Sunfish were not collected from Reach 7-Heard Pond.

In summary,

- Mercury concentrations in standard size yellow perch, largemouth bass and sunfish are, for the most part (with the notable exception of Reach 7-Heard Pond), significantly higher in the affected reaches than those observed for the reference areas. This holds especially true for the lacustrine and low-flowing reaches (e.g., reservoirs).
- Among all species evaluated, mercury levels in standard size fish are consistently highest in Reaches 3 (Reservoir 2) and 9 (Fairhaven Bay).
- With the exception of largemouth bass, mercury in Reach 8 (GMNWR) fish, where it was speculated that enhanced methylation would increase bioavailability, is similar throughout all reaches. However, for the largemouth bass, normalized mercury levels in Reach 8 were among the highest observed and similar to those levels found in Reach 3 (Reservoir 2) and Reach 9 (Fairhaven Bay).

#### **4.2.2.2.2**

#### **Regional Comparison of Mercury in Fish Collected from the Sudbury River**

The following narrative presents the studies that were used to compare mercury levels in fish collected from the Sudbury River with similar data collected in other water bodies throughout Massachusetts. A summary of each of the sources of data is provided in Table 4-8. For each study, this table summarizes the title and authors of the study, the water body investigated, the period of the study, and the species of fish and number collected and analyzed. Note that for those studies that were part of a state-wide monitoring program and subsequent reports represented updates of the monitoring program, the most current report and its data are used for comparisons with the Nyanza data.

As a preface to the comparisons, it is important to note that the absence of the raw data or the lack of adequate description in the methodology in these studies precludes a more precise discrimination of data. Where data allowed, comparisons were made using those data that

were obtained using sampling protocols and analytical metrics similar to those used in the fish collection program for Nyanza OU 4 Site Investigations.

#### **4.2.2.2.2.1**

#### **Massachusetts Fish Tissue Mercury Studies: Long-Term Monitoring Results, 1999-2004 (MADEP, 2006)**

Prior to 1999, the MADEP conducted several studies to understand the degree to which the Commonwealth's freshwater fish populations were contaminated with mercury. In 1999, a long-term monitoring network of lakes was established to provide temporal tracking of changes in the mercury levels in fish in the Commonwealth. In part, this effort has been used to determine the effect associated with state- and regionally-mandated reductions in mercury use and emissions from municipal solid waste combustion and medical waste incineration. Results from the monitoring of these surface waters also provide a perspective on the scale of natural variability in tissue mercury concentrations for comparison with other sources of variation. This report, *Massachusetts Fish Tissue Mercury Studies: Long-Term Monitoring Results, 1999-2004*, presents the results from the first 5 years of this effort.

Figure 4-24 presents a comparison of the mean mercury concentrations in the axial muscle (fillet) of yellow perch (> 20 cm TL) collected between 1999 and 2004 from 20 lakes in Massachusetts with mercury levels in same size class yellow perch collected from the Sudbury River. (Note: sufficient data were not provided for regional data to normalize concentrations to a standard length. Therefore, neither the regional nor the site-specific concentrations were normalized to a standard length for this exercise.) Mean mercury concentrations presented for the regional lakes are the results of the most recent monitoring year; which in most cases is 2004. Visual comparison indicates that the mean mercury concentrations in yellow perch from Reaches 4 and 3 (Reservoirs 1 and 2, respectively), Reach 9 (Fairhaven Bay) and Reach 2 (Mill Pond) are substantially higher than the mean mercury levels observed in 80 percent of the regional lakes. With the exception of Reach 7-Heard Pond, the mean mercury levels in the remaining reaches appear to be comparable to those observed in fish from the regional areas. It is important to note, however, that one of the objectives of this study was to highlight the changes in fish tissue mercury concentrations that have taken place in the high mercury deposition areas during a period when emissions from major point sources of mercury to the atmosphere have declined substantially in Massachusetts and across the region. As such, mercury levels of some of the regional areas may reflect a bias toward industrialized locales. In such instances, the estimates of the mean concentrations of mercury in fish associated with these regional areas are likely to be overstated. Assuming this to be true, the percentage of

actual regional lakes for which the mean mercury levels in yellow perch from the Sudbury River would exceed mercury levels in the regional lakes would likely be higher.

#### **4.2.2.2.2.2 Fish Mercury Distribution in Massachusetts, USA Lakes (Rose et al., 1999)**

Yellow perch, largemouth bass, and brown bullhead were collected from 24 of Massachusetts least impacted water bodies to determine the distribution, patterns of variability, and potential controlling physicochemical factors associated with mercury uptake in the edible tissue (fillet) of these species. Unlike the previous study in which a number of the regional lakes were in industrial areas, mercury concentrations in this study were collected from 8 lakes not likely to have been affected by point sources in each of 3 ecological subregions of Massachusetts. These subregions include the Green Mountain/Berkshire in the northwestern, Worcester/Monadnock in the north central, and the Narragansett/Bristol in the southeastern areas of the state.

Figure 4-25 presents a comparison of the mean mercury concentrations in the axial muscle (fillet) of the yellow perch from each of the 22 regional lakes and the mercury levels in the fillet tissue from the Sudbury River. Note that in Rose et al., only yellow perch between 20 and 25 cm TL were collected. As such, only mercury data for yellow perch greater than 20 cm TL collected from each of the Sudbury reaches are compared with the regional data. (Note: sufficient data were not provided for regional data to normalize concentrations to a standard length. Therefore, neither the regional nor the site-specific concentrations were normalized to a standard length for this exercise.)

A visual comparison indicates that the mean mercury concentration in the muscle tissue of yellow perch from Reaches 4 and 3 (Reservoirs 1 and 2, respectively) are substantially higher than the mercury levels in yellow perch in more than 85% of the regional lakes. Mercury levels in fish from Reaches 4 and 3 (Reservoirs 1 and 2, respectively) are comparable with those observed in 2 regional lakes with the highest mercury levels i.e., Upper Nauleag Lake and Gales Pond. It is of interest to note that the mean mercury level in perch collected from the Sudbury Reservoir, the lacustrine control area, is as low as the lowest levels detected in the regional lakes which indicates its suitability as a near-field regional water body.

Figure 4-26 presents a comparison of the mean mercury concentrations in the axial muscle (fillet) of the largemouth bass from each of the 18 regional lakes and the mercury levels in the fillet tissue from the Sudbury River. (Note: sufficient data were not provided for regional data to

normalize concentrations to a standard length. Therefore, neither the regional nor the site-specific concentrations were normalized to a standard length for this exercise.) Visual comparison indicates that with the exception of Reach 7-Heard Pond, the mean mercury levels in the fillet tissue of largemouth bass in the Sudbury River are generally higher than those observed in the same species collected from the regional areas. Further, mercury concentrations in largemouth bass from Reach 3 (Reservoir 2), Reach 8 (GMNWR), Reach 9 (Fairhaven Bay), and Reach 10 (Fairhaven Bay to the confluence with Assabet River) appear to be substantially higher than those observed in the regional areas.

#### **4.2.2.2.2.3**

#### **Mercury in Freshwater Fish of Northeast North America – a Geographic Perspective Based on Fish Tissue Monitoring Databases (Kamman et al., 2005)**

This paper represents a synthesis of several databases that have compiled records of mercury levels in several species of fish as well as physicochemical properties of the water bodies from which the fish were collected. The synthesis was limited to data available from 24 studies of water bodies located in northeast North America and include the northeastern United States as well as eastern Canada and the Canadian Maritime Provinces. Of the studies examined, 21 evaluated the levels of mercury in yellow perch collected almost exclusively from lakes in the region. To account for the confounding issues associated with fish size, Kamman et al. normalized the fillet data for yellow perch to a standard fish length of 20 cm TL.

Based on a record of 2,888 fish, mercury concentrations detected in the axial muscle of standardized yellow perch collected throughout northeast North America ranged from < 50 to 5,030 µg/kg WW with a mean mercury concentration of  $351 \pm 198$  µg/kg WW. By comparison, fillet data for yellow perch (TL > 20 cm) collected from the Sudbury River ranges from 60 (Reach 7-Heard Pond) to 910 µg/kg WW (Reach 3). Mean mercury levels in yellow perch from Reach 3 ( $560 \pm 890$  µg/kg WW), Reach 4 ( $520 \pm 188$  µg/kg WW), Reach 2 ( $430 \pm 149$  µg/kg WW), and Reach 9 ( $440 \pm 19$  µg/kg WW) were somewhat higher than those found in yellow perch collected throughout northeast North America. Neither the range nor the mean mercury concentrations in yellow perch from the Sudbury River were strikingly different from those found in yellow perch collected throughout northeast North America.

In addition to the evaluation of fillet data for yellow perch, Kamman et al. also summarized mercury levels in the whole bodies of 841 smaller perch (standardized 12.9 cm TL fish) collected in the region. Mercury concentrations in these fish ranged from < 50 to 3,170 µg/kg WW with a mean concentration of  $290 \pm 73$  µg/kg WW. Again by comparison, whole body

concentrations of mercury in yellow perch in the same size class collected from the Sudbury River ranged from 20 (Reach 7-Heard Pond) to 260 µg/kg/WW (Reaches 2 and 10). All of the reach means in the Sudbury River were similar to or less than those of the regional mean for this size class of yellow perch, with the highest mean for this size class observed in Reach 2 ( $222 \pm 31$  µg/kg WW). Again, mercury levels in whole body yellow perch of size  $10 < TL \leq 15$  cm in the Sudbury River are similar to the regional levels.

#### **4.2.2.2.3 Surface Water Comparison with AWQCs**

Potential direct effects associated with surface water contamination in the Sudbury River were evaluated by comparing mercury and methylmercury concentrations in surface water to federal AWQCs.

The surface water data set had no concentrations exceeding either the acute or chronic AWQC (i.e., all HQs < 1). Individual sample hazard quotients are provided in Appendix P.

#### **4.2.2.2.4 Comparison of Surface Water Concentrations with Site-Specific Reference Concentrations**

When sufficient data were available, statistical comparisons of total mercury and methylmercury concentrations in surface water samples collected from potentially affected reaches of the Sudbury River and from appropriate reference areas were made. The surface water data used in the BERA was collected by USGS as part of a synoptic comparison with results from a 1995 surface water survey. The goal of this collection effort was to evaluate any surface water changes in Hg and MeHg concentrations that may have resulted from natural attenuation and remediation of wetland soils at the Nyanza site. Additional surface water data collected recently by EPA (but not available for inclusion in this report) are consistent with the surface water data presented herein. The results of the statistical comparisons are presented in Table 4-9.

##### **4.2.2.2.4.1.1 Comparisons with Reach 1**

Comparisons could only be made with Reach 7 (n=10), because there were insufficient samples to perform a statistical comparison with reference for Reaches 2 (n=3) and 5 (n=1), and surface water samples were not analyzed from Reach 10. Comparing total and methylmercury concentrations in Reach 7 with the Reach 1 reference location, surface water concentrations were not statistically different from those found in the reference area.

#### **4.2.2.2.4.1.2 Comparisons with the Charles River**

Comparisons could only be made with Reach 8 (n=14), because surface water samples were not analyzed from Reach 9. Comparing total and methylmercury concentrations in Reach 8 with the Charles River reference location (n=16), methylmercury concentrations were not statistically different from those found in the reference area, but total mercury concentrations were.

#### **4.2.2.2.4.1.3 Comparisons with the Sudbury Reservoir**

Comparisons could not be made for Sudbury River impoundments (Reaches 3, 4, and 6) because only one sample was collected in Reaches 3 and 4; no surface water data was collected in Reach 6 or the Sudbury Reservoir (reference location).

### **4.2.3 Risk to Avian Life**

#### **4.2.3.1 Insectivorous Birds**

##### **4.2.3.1.1 Tree Swallows**

##### **4.2.3.1.1.1 Tree Swallow Tissue Mercury Accumulation and Effects**

As noted in Section 2.4.1.2.3.5.3, blood, feather, and egg samples were submitted for tree swallows from 6 locations in 2003 – Reach 3 (Reservoir 2), Reach 4 (Reservoir 1), Reach 7, Reach 8 (GMNWR), Charles River, and Sudbury Reservoir; and 5 locations in 2004 – Reach 3, Reach 4, Reach 7-Heard Pond, Reach 8, and Charles River. Samples were analyzed only for total mercury. Chemical concentration results were presented in Tables 2-49 through 2-58 and in Figures 2-39 through 2-44. Note that some of the data compared to CBRs include blood concentrations from the same bird (i.e., samples were obtained from birds that were recaptured later in the season). These data were not segregated from data collected from birds captured only once, as this risk estimation considers the range of concentrations in tree swallows during the breeding season and insufficient data were available to determine temporal trends in mercury concentrations.

Data regarding the tree swallow tissue mercury accumulation and effects are presented below and organized as follows: discussion of tissue mercury content, comparison of site-specific tissue concentrations with appropriate CBRs (site impacted followed by reference area results), and comparisons of site impacted concentrations with site-specific reference and regional mercury levels.



#### **4.2.3.1.1.1**

#### **Tree Swallow Tissue Mercury Content**

This section summarizes the tissue mercury concentration data, putting the concentrations in spatial context and briefly discussing potential relationships observed within and between tissue types. Blood concentrations in adult tree swallows from the Sudbury River study area ranged from 106 to 917 µg/kg (Reaches 3 and 8, respectively) in 2003 and 62 to 1,310 µg/kg (Reaches 4 and 8, respectively) in 2004. Nestling blood concentrations (collected in 2003 only) ranged from 4.58 to 48.1 µg/kg (Reaches 4 and 3, respectively). Feather concentrations (taken from adult birds) ranged from 794 to 2,690 µg/kg (Reaches 4 and 3, respectively) in 2003 and 378 to 8,560 µg/kg (Reaches 7-Heard Pond and 8, respectively) in 2004. Egg concentrations ranged from 37.5 to 212 µg/kg (Reaches 3 and 8, respectively) in 2003 and 31.9 to 464 µg/kg (Reaches 4 and 8, respectively) in 2004. Overall, tissue concentrations were highest in Reaches 7 and 8 during both sampling years.

Blood concentrations in adult tree swallows from the reference areas ranged from 70.7 to 996 µg/kg (Sudbury Reservoir and Charles River, respectively) in 2003 and 305 to 549 µg/kg (Charles River only sampled) in 2004. Nestling blood concentrations (collected in 2003 only) ranged from 2.65 to 45.7 µg/kg (Sudbury Reservoir only sampled). Feather concentrations (taken from adult birds) ranged from 591 to 2,270 µg/kg (Charles River and Sudbury Reservoir, respectively) in 2003 and 181 to 6,025 µg/kg (Charles River only sampled) in 2004. Egg concentrations ranged from 26.5 to 257 µg/kg (Sudbury Reservoir and Charles River, respectively) in 2003 and 82 to 151 µg/kg (Charles River only sampled) in 2004. When comparing the tissue concentrations from the two reference areas sampled in 2003, Charles River had higher concentrations in blood and eggs, but the Sudbury Reservoir had higher concentrations in feathers.

As presented in the BRI Tree Swallow Exposure Profile Report (Appendix A.1), no significant relationship was found between blood and feather mercury levels in swallows sampled for this study ( $r^2=9E-05$ ). A linear regression model was developed to predict egg mercury levels from adult maternal blood mercury levels ( $r^2=0.4449$ ). This relationship was based on 99 paired blood and egg levels, the greater parts of which were collected at the Nyanza Site.

#### **4.2.3.1.1.2**

#### **Tree Swallow CBR Comparisons: Site Impacted Areas**

Between the two sampling years, data from site impacted areas are available for Reaches 3, 4, 7, 7-Heard Pond, and 8 (Figures 4-27 through 4-41). For blood, both a no-effect level and effect level were available. CBR comparisons with samples collected in 2003 and 2004 show that

blood concentrations exceed the no-effect level for 2 and 7 samples collected from Reach 8 in 2003 and 2004, respectively and 2 samples collected from Reach 3 in 2004. All concentrations are below effect levels, with the exception of one sample each from 2004 from Reaches 7-Heard Pond and 8, which minimally exceed the CBR value. The mean concentrations were below the no-effect level, except for the mean concentration in 2004 Reach 7-Heard Pond and Reach 8 blood samples.

For feathers, both a no-effect level and effect level were available. The concentrations in two of three feather samples collected from Reach 3 in 2003 were below the no-effect level; whereas the concentration in the other sample was between the no-effect and effect levels. The mean concentration was above the no-effect level. Approximately 20% of the feathers in Reach 3 (2004 collections) were below the no-effect level; the rest were between the no-effect and effect levels. The mean concentration was above the no-effect level. All of the feather concentrations for Reach 4 samples collected in 2003 were below the no-effect level; whereas all of the concentrations in samples collected in 2004 were between the no-effect and effect levels. The mean concentration from samples collected in 2004 was above the no-effect level. Reach 7 (2003 collection) had 20% of the feather concentrations falling below the no-effect level, with the rest falling between the no-effect and effect levels. The mean concentration was above the no-effect level. Reach 7-Heard Pond (2004 collection) had 10% of the feather concentrations falling below the no-effect level, with the rest between the no-effect and effect levels. The mean concentration was above the no-effect level. Feathers were collected from Reach 8 during both 2003 and 2004. In 2003, approximately one-half of the Reach 8 feather concentrations were at or below the no-effect level; with the other half falling between the no-effect and effect levels. In 2004, approximately 10% of the Reach 8 feather concentrations fell below the no-effect level, with the other 90% falling between the no-effect and the effect levels. The mean feather concentrations in Reach 8 collected in both 2003 and 2004 were above the no-effect level.

For eggs, both a no-effect level and effect level were available. All of the concentrations in egg samples fall below the no-effect level.

In general, results presented in the BRI Tree Swallow Exposure Profile (Appendix A.1) agree with the blood CBR comparisons presented above. Feather data were not considered in the BRI analysis. The results of their egg concentration evaluation versus the CBR were similar to those described above.

#### **4.2.3.1.1.1.3**

#### **Tree Swallow CBR Comparisons: Reference Areas**

Reference data for tree swallow tissues are available for the Charles River (2003 and 2004) and the Sudbury Reservoir (2003 only) (Figures 4-27 through 4-41). For blood, both a no-effect level and effect level were available. Comparisons with blood (collected 2003) show that four samples have concentrations above the no-effect level. The mean concentration was less than the no-effect level. All tree swallow blood collected from the Charles River reference area in 2004 shows that concentrations are below both the no-effect and effect levels.

For feathers, both a no-effect level and effect level were available. For the samples collected from the Charles River in 2003, 75% were at or below the no-effect level; with the rest between the no-effect and effect levels. The mean concentration was below the no-effect level. In 2004, approximately 16% of the samples had concentrations below the no-effect level, with the rest between the no-effect and effect levels. The mean concentration was between the no-effect level and effect level. For the feathers collected from the Sudbury Reservoir (collected 2003), approximately 35% of the samples were below the no-effect level, with the rest between the no-effect and effect levels. The mean concentration was between the no-effect level and effect level.

For eggs, both a no-effect level and effect level were available. All of the egg concentrations fall below the no-effect level.

#### **4.2.3.1.1.1.4**

#### **Comparison of Tree Swallow Tissue Concentrations among River Reaches, Site-Specific Reference, and Regional Levels**

The BRI Tree Swallow Exposure Profile compared Sudbury River mercury concentrations with site-specific reference and regional mercury values (see Appendix A.1). Note that all of the comparisons of tree swallow tissue mercury concentrations from samples obtained during the supplemental investigation were based on pooled BRL and TERL data (when available).

Statistical testing on log-transformed data pooled across sampling years indicated that mean blood mercury levels in tree swallows were not significantly different among Reach 3, the Sudbury Reservoir and Delaney Wildlife Management Area. However, mean blood mercury levels of tree swallows from Reach 4 and Delaney Wildlife Management Area (reference area) were significantly higher than in tree swallows from Sudbury Reservoir (one-way ANOVA;  $F=6.3$ ;  $p<0.002$ ). Blood concentrations in adult (male and female pooled) tree swallows were not significantly different between Reach 7 (Subreach 2) and Reach 7-Heard Pond combined,

and Reach 8 and the Charles River (one-way ANOVA;  $F=1.3$ ;  $p<0.28$ ). Nestling blood samples showed similar patterns.

The blood mercury levels in Reaches 3 and 4 were similar to those measured on contaminated estuaries in the Scarborough Marsh State Game Area and in the Rachael Carson National Wildlife Refuge in Maine, and the reservoirs in the Rangeley Lakes area in Maine. Tree swallow blood mercury levels from Reach 7 (Subreach 2) and Reach 7-Heard Pond combined, and Reach 8 were approximately twice those found in the Parker River (Massachusetts).

Tree swallow feather mercury concentrations were not statistically significantly different among any sites in 2003 ( $p<0.7$ ) or 2004 ( $P<0.8$ ). However, concentrations from Reach 8 ( $t= -5.$ );  $p<0.001$ ) and from the Charles River ( $t= -2.4$ ;  $p<0.03$ ) were significantly higher in 2004 than in 2003. One possible explanation could be that the swallows that nested the first year the boxes were available were younger than the following year nesting birds.

Mean mercury levels in eggs collected from Reaches 3 and 4 (pooled across years) were not statistically different from those collected from Delaney Wildlife Management Area or the Sudbury Reservoir (one-way ANOVA;  $F=2.6$ ;  $p<0.06$ ). A one-way ANOVA detected no significant differences in 2003 mean mercury levels in eggs collected from Reach 8 and the Charles River ( $F=0.085$ ;  $p<0.77$ ). However, the eggs collected in 2004 from Reach 8 had significantly higher mercury levels than eggs from Reach 7-Heard Pond and from the Charles River ( $F=17$ ;  $p<0.0001$ ).

The egg mercury levels in Reaches 3 and 4 were equivalent to those measured from Scarborough Marsh State Game Area, the Rachael Carson National Wildlife Refuge, and the reservoirs in the Rangeley Lakes area (all in Maine). Tree swallow egg mercury levels from Reach 7 (Subreach 2) and Reach 7-Heard Pond combined, and Reach 8 were approximately twice those found in the Parker River (Massachusetts).

#### **4.2.3.1.1.2 Tree Swallow Exposure and Effects Modeling Results**

The modeled risks to insectivorous birds potentially exposed to mercury in emergent insects, as well as surface water in the Sudbury River were evaluated for the tree swallow. Total exposure doses were compared to both effect- and no-effect toxicity values. The results are presented in Tables 4-10 and 4-11, respectively, and are discussed by reach/reference area below.

#### **4.2.3.1.1.2.1**

#### **Tree Swallow Modeling Results: Site Impacted Areas**

As a reminder (see Section 3.2.1.1), total mercury concentrations in aquatic insects (the primary food source for tree swallows) were estimated using a sediment to mayfly regression equation developed by Naimo et al. (2000). Methylmercury concentrations were estimated from the total mercury concentrations by assuming that 35% of the total mercury is methylmercury. Both total and methylmercury exposure doses were compared to the tree swallow TRV, which was based on a methylmercury toxicity study (see Section 3.3.1.1.2.3.1). Therefore, HQs for total mercury are likely to overestimate risk. In addition, numerous tree swallow blood samples were collected throughout the study area during the breeding season and only 2 of 92 blood samples exceeded the lowest effect CBR. As was previously discussed, mercury blood levels are good indicators of recent mercury exposure and bioavailability. Given the higher confidence associated with this line of evidence relative to the food chain modeling approach, confirms overly conservative nature of the tree swallow modeling effort.

#### **4.2.3.1.1.2.1.1**

#### **Reach 2**

The total mercury HQs for tree swallows foraging in Reach 2 range from 1.46 (CTE – Effect TRV) to 7.29 (RME – No-Effect TRV). All of the tree swallow total mercury HQs calculated for this reach exceed unity (i.e.,  $HQ \geq 1.0$ ). The methylmercury HQs for tree swallows foraging in Reach 2 range from 0.521 (CTE – Effect TRV) to 2.55 (RME – No-Effect TRV). Only the tree swallow methylmercury HQs based on the RME case and both the No-Effect and Effect TRV (2.55 and 1.29, respectively) are greater than unity.

#### **4.2.3.1.1.2.1.2**

#### **Reach 3**

The total mercury HQs for tree swallows foraging in Reach 3 range from 9.69 (CTE – Effect TRV) to 24.2 (RME – No-Effect TRV). All of the total mercury tree swallow HQs calculated for this reach exceed unity. The methylmercury HQs for tree swallows foraging in Reach 3 range from 3.39 (CTE – Effect TRV) to 8.46 (RME – No-Effect TRV). All of the tree swallow methylmercury HQs calculated for this reach also exceed unity.

#### **4.2.3.1.1.2.1.3**

#### **Reach 4**

The total mercury HQs for tree swallows foraging in Reach 4 range from 4.35 (CTE – Effect TRV) to 11.8 (RME – No-Effect TRV). All of the tree swallow total mercury HQs calculated for this reach exceed unity. The methylmercury HQs for tree swallows foraging in Reach 4 range

#### 4.2.3.1.1.2.1.4 Reach 5

#### 4.2.3.1.1.2.1.5 Reach 6

**4.2.3.1.1.2.1.6** **Reach 7**

#### 4.2.3.1.1.2.1.7 Reach 7-Heard Pond

Nobis Engineering, Inc.

**4.2.3.1.1.2.1.8****Reach 8**

The total mercury HQs for tree swallows foraging in Reach 8 range from 0.476 (CTE – Effect TRV) to 1.18 (RME – No-Effect TRV). Only the tree swallow total mercury HQ based on the RME case and No-Effect TRV is greater than unity. The methylmercury HQs for tree swallows foraging in Reach 8 range from 0.166 (CTE – Effect TRV) to 0.414 (RME – No-Effect TRV). All of the tree swallow methylmercury HQs calculated for this reach are below unity.

**4.2.3.1.1.2.1.9****Reach 9**

The total mercury HQs for tree swallows foraging in Reach 9 range from 0.944 (CTE – Effect TRV) to 2.17 (RME – No-Effect TRV). The tree swallow total mercury HQs based on the RME cases (No-Effect TRV= 2.17; Effect TRV = 1.10) and CTE case, No-Effect TRV (1.87) are greater than unity. The methylmercury HQs for tree swallows foraging in Reach 9 range from 0.330 (CTE – Effect TRV) to 0.761 (RME – No-Effect TRV). All of the tree swallow HQs calculated for this reach are below unity.

**4.2.3.1.1.2.1.10****Reach 10**

The total mercury HQs for tree swallows foraging in Reach 10 range from 0.514 (CTE – Effect TRV) to 1.37 (RME – No-Effect TRV). Only the tree swallow total mercury HQ based on the RME case and No-Effect TRV (1.37) is greater than unity. The methylmercury HQs for tree swallows foraging in Reach 10 range from 0.180 (CTE – Effect TRV) to 0.479 (RME – No-Effect TRV). All of the tree swallow methylmercury HQs calculated for this reach are below unity.

**4.2.3.1.1.2.2****Tree Swallow Modeling Results: Reference Areas****4.2.3.1.1.2.2.1****Reach 1**

The total mercury HQs for tree swallows foraging in Reach 1 range from 0.710 (CTE – Effect TRV) to 4.30 (RME – No-Effect TRV). The tree swallow total mercury HQs based on the RME cases (No-Effect TRV= 4.30; Effect TRV = 2.17) and CTE case, No-Effect TRV (1.41) are greater than unity. The methylmercury HQs for tree swallows foraging in Reach 1 range from 0.249 (CTE – Effect TRV) to 1.5 (RME – No-Effect TRV). Only the tree swallow methylmercury HQ based on the RME case and No-Effect TRV is greater than unity.

**4.2.3.1.1.2.2.2****Charles River**

The total mercury HQs for tree swallows foraging in the Charles River range from 0.326 (CTE – Effect TRV) to 0.713 (RME – No-Effect TRV). All of the tree swallow total mercury HQs

calculated for this reference area are below unity. The methylmercury HQs for tree swallows foraging in the Charles River range from 0.114 (CTE – Effect TRV) to 0.249 (RME – No-Effect TRV). All of the tree swallow methylmercury HQs calculated for this reference area are also below unity.

#### **4.2.3.1.1.2.2.3 Sudbury Reservoir**

The total mercury HQs for tree swallows foraging in the Sudbury Reservoir range from 0.302 (CTE – Effect TRV) to 0.738 (RME – No-Effect TRV). All of the tree swallow total mercury HQs calculated for this reference area are below unity. The methylmercury HQs for tree swallows foraging in the Sudbury Reservoir range from 0.106 (CTE – Effect TRV) to 0.258 (RME – No-Effect TRV). All of the tree swallow methylmercury HQs calculated for this reference area are also below unity.

#### **4.2.3.1.2 Eastern Kingbird**

##### **4.2.3.1.2.1 Eastern Kingbird Tissue Mercury Accumulation and Effects**

As noted in Section 2.4.1.2.3.5.4, egg samples were submitted for kingbirds from 5 locations in 2003 – Reach 7 (river adjacent to Heard Pond), Reach 8 (GMNWR), Reach 9 (Fairhaven Bay), Reach 10 (Fairhaven Bay outlet to the confluence with the Assabet River), and the Charles River. Samples were only analyzed for total mercury. Chemical concentrations were presented in Table 2-56 and Figure 2-65.

Data regarding the eastern kingbird tissue mercury accumulation and effects are presented below and organized as follows: discussion of tissue mercury content and comparison of site-specific tissue concentrations with appropriate CBRs (site impacted followed by reference area results).

##### **4.2.3.1.2.1.1 Kingbird Tissue Mercury Content**

This section summarizes the tissue mercury concentration data, putting the concentrations in spatial context and briefly discussing potential relationships observed within and between tissue types. For the site-related data, the egg concentrations ranged from 40.9 to 210 µg/kg (Reaches 10 and 8, respectively). For the kingbird reference data (i.e., Charles River), the egg concentrations range from 156 to 170 µg/kg. Reference area concentrations were, in general, higher than concentrations from the site impacted areas.



#### **4.2.3.1.2.1.2 Eastern Kingbird CBR Comparisons: Site Impacted Areas**

The same set of no-effect level and effect level CBRs used for tree swallows (see Section 4.2.3.1.1.2.1), were used for kingbird eggs. All of the egg concentrations fall below the no-effect level.

#### **4.2.3.1.2.1.3 Eastern Kingbird CBR Comparisons: Reference Areas**

The Charles River reference area had all concentrations of mercury in eastern kingbird eggs fall below the no-effect level (Figure 4-42).

#### **4.2.3.1.3 Red-winged Blackbird**

##### **4.2.3.1.3.1 Red-winged Blackbird Tissue Mercury Accumulation and Effects**

As noted in Section 2.4.1.2.3.5.5, egg samples were submitted for red-winged blackbird from 1 location in 2005 – Reach 8 (GMNWR). Samples were only analyzed for total mercury. Chemical concentrations were presented in Table 2-60 and Figure 2-46.

Data regarding the red-winged blackbird tissue mercury accumulation and effects are presented below and organized as follows: discussion of tissue mercury content, comparison of site-specific tissue concentrations with appropriate CBRs (site impacted followed by reference area results), comparisons of site impacted concentrations with site-specific reference mercury levels.

##### **4.2.3.1.3.1.1 Red-winged Blackbird Tissue Mercury Content**

This section summarizes the tissue mercury concentration data, putting the concentrations in spatial context and briefly discussing potential relationships observed within and between tissue types. Red-winged blackbird blood concentrations ranged from 115 to 9,420 µg/kg. The sampling occurred in early August 2005 when the Sudbury River water level was low, resulting in a wide area of exposed mud. These exposed conditions, along with high temperatures, likely created optimal conditions for accelerated mercury methylation. Organisms that spend most of their life cycle in the contaminated floodplain sediments are likely exposed to elevated levels of methylmercury. It appears, based on the high mercury blood levels reported in some samples, that red-winged blackbirds, who feed on the sediment-dwelling prey, are exposed to high levels of mercury in mid- to late-summer (post-fledging and pre-migration period).

#### **4.2.3.1.3.1.2**

#### **Red-winged Blackbird CBR Comparisons: Site Impacted Areas**

All but one red-winged blackbird blood sample had concentrations greater than the effect level (Figure 4-43). The mean concentrations (juvenile and adult) are greater than the no-effect level.

The BRI Marsh Bird Exposure Profile Report (Appendix A.2) contains data from 2006 red-winged blackbird blood samples collected from Reach 7 that were not included in this SBERA. BRI noted that 1 of 13 blood samples from Reach 7 exceeded the no-effect-based CBR. The mean concentration was below the no-effect level.

#### **4.2.3.1.3.1.3**

#### **Red-winged Blackbird CBR Comparisons: Reference Areas**

Red-winged blackbirds were not caught in any reference area during the 2005 sampling effort. However, the BRI Marsh Bird Exposure Profile Report (Appendix A.2) contains data from 2006 red-winged blackbird blood samples collected from the Charles River reference area that were not included in this SBERA. Five of the eight blood samples from the Charles River exceeded the no-effect-based CBR. One of eight blood samples exceeded the effect-based CBR. The mean concentration was between the no-effect and effect level.

#### **4.2.3.1.3.1.4**

#### **Comparisons with Site-Specific Reference**

In the BRI Marsh Bird Exposure Profile Report (Appendix A.2), blood concentrations in red-winged blackbirds sampled in 2006 were higher in birds captured on the Charles River than those captured in Reach 7.

#### **4.2.3.1.4**

#### **Marsh Birds**

##### **4.2.3.1.4.1**

##### **Marsh Bird Tissue Mercury Accumulation and Effects**

As noted in Section 2.4.1.2.3.5.6, both blood and feather samples were submitted for marsh birds from 3 locations in 2003 – Reach 7 (river adjacent to Heard Pond), Reach 8 (Middle Reach), and the Charles River; and 3 locations in 2004 – Reach 7-Heard Pond, Reach 8 (Middle Reach), and the Charles River. Note that Reach 7 samples were collected at different locations in 2003 and 2004. Samples were only analyzed for total mercury. Chemical concentrations were presented in Tables 2-67 through 2-69 and Figures 2-67 through 2-69.

Data regarding the marsh bird tissue mercury accumulation and effects are presented below and organized as follows: discussion of tissue mercury content, comparison of site-specific

tissue concentrations with appropriate CBRs (site impacted followed by reference area results), comparisons of site impacted concentrations with site-specific reference mercury levels.

#### **4.2.3.1.4.1.1 Marsh Bird Tissue Mercury Content**

This section summarizes the tissue mercury concentration data, putting the concentrations in spatial context and briefly discussing potential relationships observed within and between tissue types. Blood concentrations in marsh birds from the Sudbury River study area ranged from 38.3 to 1,450 µg/kg (Reaches 7 – yellow warbler and 8 – swamp sparrow, respectively) in 2003 and 77 to 957 µg/kg (Reaches 7-Heard Pond – song sparrow and 8 – swamp sparrow, respectively) in 2004. Feather concentrations ranged from 263 to 11,700 µg/kg (Reaches 7 – song sparrow and 8 – yellow warbler, respectively) in 2003. Feathers were not analyzed from the 2004 sampling year.

Blood concentrations in marsh birds from the Charles River reference areas ranged from 4.84 to 423 µg/kg (yellow warbler and swamp sparrow, respectively) in 2003 and 59 to 209 µg/kg (song sparrow) in 2004. Feather concentrations ranged from 1,190 to 13,600 µg/kg (yellow warbler and song sparrow, respectively) in 2003. Feathers were not analyzed from the 2004 sampling year.

BRI's Marsh Bird Exposure Profile (Appendix A.2) noted that mercury levels in blood and feathers in hatch-year juvenile song sparrows and swamp sparrows showed a positive correlation ( $r^2=0.52$ ), even though no significant relationship was found between mercury levels in blood and feathers of the adults ( $r^2=0.009$ ). This pattern would seem to indicate that the growth of adult feathers did not occur within the breeding territories or potentially there were differences in mercury bioavailability within and between years.

#### **4.2.3.1.4.1.2 Marsh Bird CBR Comparisons: Site Impacted Areas**

Between the two sampling year collection efforts, data from site impacted areas are available for Reaches 7, 7-Heard Pond, and 8 (Figures 4-44 through 4-48). Marsh bird blood levels for Reach 7 (collected in 2003) show that concentrations were below the no-effect levels. Approximately 15% of the Reach 7-Heard Pond blood samples were above the no-effect level (one song sparrow and one swamp sparrow sample), but none exceeded the effect level. Approximately 20% of the 2003 Reach 8 blood samples were above the no-effect level (one song sparrow and two swamp sparrows), with approximately 10% above the effect level (one song sparrow and one swamp sparrow sample). Approximately 20% of the 2004 Reach 8

blood samples were above the no-effect level (one song sparrow and two swamp sparrows), but none exceeded the effect level. Mean concentrations from both years were below the no-effect levels.

CBR comparisons with feathers collected in Reach 7 show that 50% of the concentrations were below the no-effect level, with the rest between the no-effect and effect levels. The mean concentration was between the no-effect and effect level. In Reach 8, approximately 15% of the concentrations were below the no-effect level, with approximately 80% between the no-effect and effect levels. There was one feather sample collected from Reach 8 in 2003 (from a yellow warbler) that was above the effect level. The mean concentration was between the no-effect and effect level. Feathers were not analyzed in 2004.

Results presented in the BRI Marsh Bird Exposure Profile (Appendix A.2) agree with these results based on blood data. Feather data were not considered in the BRI analysis.

#### **4.2.3.1.4.1.3 Marsh Bird CBR Comparisons: Reference Areas**

Marsh birds were collected from the Charles River reference area in both 2003 and 2004. CBR comparisons with blood collected in both years indicate that concentrations are well below the no-effect level CBR (Figures 4-44 through 4-48). One feather concentration (approximately 6% of the samples) was below the no-effect level CBR and approximately 10% of the feather samples (collected in 2003 only) were above the effect level (one song sparrow and one swamp sparrow sample). The mean concentration was between the no-effect and effect level.

Results presented in the BRI Marsh Bird Exposure Profile (Appendix A.2) agree with these results based on blood data. Feather data were not considered in the BRI analysis.

#### **4.2.3.1.4.1.4 Comparisons with Site-Specific Reference**

In the BRI Marsh Bird Exposure Profile Report (Appendix A.2), blood concentrations within target species were not significantly different across sampling locations ( $p > 0.1$ ). However, when TERL data were included in the analyses, blood mercury concentrations in both song- and swamp sparrows were higher in Reach 8 compared with Reach 7 and the Charles River. Note that these analyses combined data across sampling years.

#### **4.2.3.2 Piscivorous Birds**

##### **4.2.3.2.1 Waterfowl**

###### **4.2.3.2.1.1 Waterfowl Tissue Mercury Accumulation and Effects**

As noted in Section 2.4.1.2.3.5.1, blood, feather, and egg samples were submitted for hooded mergansers and wood ducks from 4 locations in 2003 – Reach 1 (Whitehall Reservoir), Reach 8, Delaney Wildlife Management Area, and Sudbury Reservoir; 3 locations in 2004 – Reach 7, Reach 8, and Sudbury Reservoir; and 4 locations in 2005 – Reach 4, Reach 8, Charles River, and Sudbury Reservoir. Samples were analyzed only for total mercury. Chemical concentration results were presented in Tables 2-32 through 2-42 and Figures 2-33 through 2-36. Note that some of the data compared to CBRs include blood concentrations from the same bird (i.e., samples were obtained from birds that were recaptured later in the season). These data were not segregated from data collected from birds captured only once, as this risk estimation considers the range of concentrations in hooded mergansers during the breeding season and insufficient data were available to determine temporal trends in mercury concentrations.

Data regarding the waterfowl tissue mercury accumulation and effects are presented below and organized as follows: discussion of tissue mercury content, comparison of site-specific tissue concentrations with appropriate CBRs (site impacted followed by reference area results), comparisons of site impacted concentrations with site-specific reference and regional mercury levels.

###### **4.2.3.2.1.1.1 Waterfowl Tissue Mercury Content**

This section summarizes the tissue mercury concentration data, putting the concentrations in spatial context and briefly discussing potential relationships observed within and between tissue types. Blood concentrations in hooded mergansers from the Sudbury River study area were 21.2 µg/kg (only one sample, Reach 8, 2004) and 167 to 1,880 µg/kg (Reach 8, 2005). Hooded merganser feather concentrations ranged from 7,590 µg/kg (only one sample, Reach 8, 2004) and 899 to 7,480 µg/kg (Reach 8, 2005). Eggs were collected in 2005 only. The hooded merganser egg concentrations ranged from 257 to 1,950 µg/kg (Reach 8).

Blood concentrations in wood duck from the Sudbury River study ranged from 21.1 to 49.9 µg/kg (Reach 8, 2003) and 52.2 to 421 µg/kg (Reaches 7 and 8, respectively; 2004). Wood duck feather concentrations ranged from 442 to 541 µg/kg (Reaches 8 and 7, respectively;

2004). Eggs were collected in 2003 only. The wood duck egg concentrations ranged from 25 to 221 µg/kg (Reach 8).

Blood concentrations in hooded mergansers from the reference areas ranged from 7.07 to 761 µg/kg (Delaney Wildlife Management Area and Reach 1 – Whitehall Reservoir, respectively in 2003) and 614 to 4,270 µg/kg (Charles River, 2005). Hooded merganser feather concentrations ranged from 6,250 to 17,500 µg/kg (Delaney Wildlife Management Area, 2003) and 6,440 to 8,920 µg/kg (Sudbury Reservoir and Charles River, respectively, 2005). Eggs were collected in 2003 and 2005 only. The concentrations ranged from 147 to 726 µg/kg (Delaney Wildlife Management Area, 2003) and 288 to 2,420 µg/kg (Sudbury Reservoir and Charles River, respectively in 2005). One nestling blood sample was submitted in 2003. This sample, from Reach 1 – Whitehall Reservoir had a concentration of 326 µg/kg.

Blood concentrations in wood duck from the reference areas were 12.1 to 82 µg/kg (Delaney Wildlife Management Area and Sudbury Reservoir, respectively in 2003) and 25.3 µg/kg (Sudbury Reservoir, 2004). Wood duck feather concentrations were available only for 2004 from the Sudbury Reservoir. The concentration was 298 µg/kg. Eggs were collected in 2003 only. The concentrations ranged from 11.2 to 73.7 µg/kg (Delaney Wildlife Management Area).

#### **4.2.3.2.1.1.2 Waterfowl CBR Comparisons: Site Impacted Areas**

##### **4.2.3.2.1.1.2.1 Hooded Merganser**

From the three sampling years, data from site impacted areas are available for hooded mergansers from Reaches 4 and 8 (Figures 4-49 and 4-51). Comparisons of blood concentrations from hooded merganser samples collected in 2004 and 2005 (samples collected from Reach 8 only) showed two concentrations from samples collected in 2005 were above the no-effect level but all were below the effect level except for one sample collected in 2005. The average blood concentrations from Reach 8 in both 2004 and 2005 were below the no-effect levels. Feather concentrations from 2004 and 2005 (samples collected from Reach 8 only) were, in general, between the no-effect and effect level CBRs. One feather sample collected in Reach 8 in 2005 was below the no-effect level. The average feather concentrations from Reach 8 in both 2004 and 2005 were between the no-effect and effect levels. Eggs from site impacted areas were only collected in 2005 from Reaches 4 and 8. One of the two samples from Reach 4 was below the no-effect CBR and the other was between the no-effect and effect CBR. For Reach 8, the majority of samples had concentrations falling between the no-effect and effect

CBR, with one concentration exceeding the effect CBR. The average egg concentrations from all site-impacted areas were between the no-effect and effect levels.

Results for hooded mergansers presented in the BRI Waterfowl Exposure Profile (Appendix A.3) generally agree with these results.

#### **4.2.3.2.1.1.2.2 Wood Duck**

From the three sampling year waterfowl collection efforts, wood duck samples were only collected and analyzed in 2003 and 2004. Data from site impacted areas are available only from Reaches 7 and 8 (Figures 4-52 and 4-54). Comparisons of blood concentrations from wood duck samples collected in 2003 and 2004 were well below the no-effect level. Feather concentrations were only available from 2004 and were below the no-effect level. Eggs from site impacted areas were only collected in 2003 from Reach 8. All concentrations were lower than the no-effect level.

Results for wood ducks presented in the BRI Waterfowl Exposure Profile (Appendix A.3) generally agree with these results.

#### **4.2.3.2.1.1.3 Waterfowl CBR Comparisons: Reference Areas**

##### **4.2.3.2.1.1.3.1 Hooded Merganser**

Between the three sampling year collection efforts, data from the Delaney Wildlife Management Area, Whitehall Reservoir, and Sudbury Reservoir are available for hooded mergansers (Figures 4-49 and 4-51). Comparisons of blood concentrations from hooded merganser samples collected in 2003 and 2005 (samples were not collected from Sudbury Reservoir) showed concentrations were above the no-effect level in two birds at each area (Whitehall Reservoir – 2003; Charles River – 2005). Concentrations were all below the effect level except for one sample collected from the Charles River in 2005. Average blood concentrations were below the no-effect level in samples from Delaney Wildlife Management Area (2003); between the no-effect and effect concentrations in samples from Whitehall Reservoir (2003); and above the effect level in samples from Charles River (2005). Feather concentrations fall between the no-effect and effect levels for both the Charles River and Sudbury Reservoir (one sample from each); one sample collected in 2003 from the Delaney Wildlife Management Area was above the effect level, with the average of the two available samples being above the effect level. When egg concentrations were compared with the CBRs, 2003 samples from Delaney Wildlife Management Area and Whitehall Reservoir had concentrations lower than the no-effect level,

except for one from Delaney which falls between the no-effect and effect levels. The average concentrations from Delaney were below the no-effect level. For the 2005 samples from the Charles River, one sample falls between the no-effect and effect levels, while the other falls above the effect level. The average concentration was above the effect level. From the Sudbury Reservoir, of the two 2005 samples, one was below the no-effect level and one was between the no-effect and effect levels. The average concentration was below the no-effect level.

#### **4.2.3.2.1.1.3.2 Wood Duck**

Of the three sampling year collection efforts, wood duck were only collected and analyzed for the 2003 and 2004 seasons. Data from the reference areas were available from Delaney Wildlife Management Area and Sudbury Reservoir (Figures 4-52 and 4-54). Comparisons of blood concentrations from wood duck samples showed concentrations were below the no-effect level. Only one feather concentration was available from 2004 (Sudbury Reservoir location), and it was between the no-effect and effect level. Eggs from reference areas were only collected in 2003. All egg concentrations were below the no-effect level CBR as well.

#### **4.2.3.2.1.1.4 Comparison of Waterfowl Tissue Concentrations with Site-Specific Reference and Regional Levels**

The BRI Waterfowl Exposure Profile compared Sudbury River mercury concentrations with site-specific reference and regional mercury values (see Appendix A.3). Geometric mean blood and egg mercury levels from hooded mergansers and wood ducks from the Sudbury River tended to be higher than at the site-specific reference locations, with the exception of the Charles River. Mean feather mercury levels were lower on the Sudbury River than at the local reference locations.

Mean mercury concentrations from Sudbury River wood duck blood samples were similar to samples collected in Maine; whereas the mean mercury concentrations from Sudbury River hooded merganser blood samples were approximately half that of those collected in Maine.

The mean mercury level for hooded merganser eggs collected in Maine was similar to the mean value for those collected in the Sudbury River.



#### **4.2.3.2.2 Kingfisher**

##### **4.2.3.2.2.1 Kingfisher Tissue Mercury Accumulation and Effects**

As noted in Section 2.4.1.2.3.5.2, blood, feather, and egg samples were submitted for belted kingfishers from 6 locations – Reach 1 (Whitehall Reservoir), Reach 7, Reach 8 (Transfer Station Pit, Macone's Pile, and Route 117 Pit), and Charles River; all kingfisher samples were collected in 2003. Samples were analyzed only for total mercury. Chemical concentration results were presented in Tables 2-43 through 2-48 and Figures 2-57 and 2-58.

Data regarding the kingfisher tissue mercury accumulation and effects are presented below and organized as follows: discussion of tissue mercury content, comparison of site-specific tissue concentrations with appropriate CBRs (site impacted followed by reference area results), comparisons of site impacted concentrations with site-specific reference and regional mercury levels.

##### **4.2.3.2.2.1.1 Kingfisher Tissue Mercury Content**

This section summarizes the tissue mercury concentration data, putting the concentrations in spatial context and briefly discussing potential relationships observed within and between tissue types. The minimum and maximum adult blood concentrations (70 and 1,330 µg/kg) were observed in Reach 8 at Macone's Pile in the same bird, sampled two months apart. Based on field notes, the higher concentration was associated with times that this bird was foraging along the Sudbury River; the low concentration was associated with times when he was foraging waters other than the Sudbury. Foraging in waterbodies outside of the study area confounds interpretation of the results. Adult feather concentrations ranged from 3,820 µg/kg (Reach 8 – Macone's Pile) to 12,400 µg/kg (Reach 8 – Transfer Station Pit). Juvenile feather concentrations were lower (2,530 to 2,990 µg/kg, sampled only in Reach 7). Kingfisher feather concentrations did not correlate with paired blood mercury levels.

One cracked egg (from the burrow in Reach 8 at the Route 117 pit) was collected for analysis. The concentration was 151 µg/kg. It could not be determined if this was the largest or the first egg laid in the clutch.

##### **4.2.3.2.2.1.2 Kingfisher CBR Comparisons: Site Impacted Areas**

Eight adult and two juvenile (considered as adults for this analysis) blood samples were collected and analyzed (Figure 4-55). Comparisons of blood concentrations showed five samples (one each from Reach 7, Reach 8-Macone's Pile, and Reach 8-Transfer Station Pit

and two from Reach 8-Route 117 Pit) had concentrations above the no-effect level. All but one sample (from Macone's Pile) had concentrations that were below the effect level. The average adult/juvenile blood concentrations were below the no-effect level in samples from Reach 7 and Macone's Pile and between the no-effect and effect levels in samples from the Route 117 Pit and Transfer Station Pit. All nestling blood concentrations were below the blood no-effect level.

Seven feather samples (5 adult and 2 juveniles) were collected and analyzed (Figure 4-56). Five of seven concentrations were between the no-effect and the effect level. One sample each from Reach 8 (Route 117 Pit) and Reach 8 (Transfer Station Pit) had concentrations greater than the effect level. Average concentrations for reaches with more than one sample were between the no-effect and effect levels.

One egg concentration was available from the Reach 8 Route 117 Pit. The one egg concentration was below the no-effect level CBR.

Results presented in the BRI Kingfisher Exposure Profile (Appendix A.4) agree with these results based on blood and egg data. Feather data were not considered in the BRI analysis.

#### **4.2.3.2.2.1.3 Kingfisher CBR Comparisons: Reference Areas**

Adult kingfisher blood samples were collected at both the Charles River (n=1) and Whitehall Reservoir (n=2) reference sites (Figures 4-55). All three reference area samples had detected total mercury concentrations below the no-effect level. One adult feather sample was collected in the Charles River reference area; the mercury concentration in that sample falls between the no-effect and effect level (Figure 4-56).

#### **4.2.3.2.2.1.4 Comparison of Kingfisher Tissue Concentrations with Site-Specific Reference and Regional Levels**

The BRI Kingfisher Exposure Profile compared Sudbury River mercury concentrations with site-specific reference and regional mercury values (see Appendix A.4, Figure 5). Mean blood and feather mercury levels from kingfisher collected near Reaches 7 and 8 were slightly higher than those measured in the three birds from the two reference locations. Mean mercury kingfisher blood levels from the Sudbury River were similar to mercury levels in kingfishers collected in Michigan, New Hampshire, and Vermont, but tended to be lower than mercury levels found in kingfishers in Maine.

#### **4.2.3.2.2.2 Kingfisher Exposure and Effects Modeling Results**

The modeled risks to piscivorous birds potentially exposed to mercury in crayfish and fish, as well as surface water and sediments in the Sudbury River were evaluated for the kingfisher. Total exposure doses were compared to both effect- and no-effect toxicity values. The results are presented in Tables 4-10 and 4-11, respectively, and are discussed by reach/reference area below.

#### **4.2.3.2.2.2.1 Kingfisher Modeling Results: Site Impacted Areas**

##### **4.2.3.2.2.2.1.1 Reach 2**

The methylmercury HQs for kingfisher foraging in Reach 2 range from 1.03 (CTE – Effect TRV) to 2.3 (RME – No-Effect TRV). The kingfisher methylmercury HQs based on the RME cases (No-Effect TRV= 2.3; Effect TRV = 1.16) and CTE case, No-Effect TRV (2.04) are greater than unity (i.e., HQ  $\geq$  1.0).

##### **4.2.3.2.2.2.1.2 Reach 3**

The methylmercury HQs for kingfisher foraging in Reach 3 range from 1.05 (CTE – Effect TRV) to 2.4 (RME – No-Effect TRV). All of the kingfisher methylmercury HQs calculated for this reach exceed unity.

##### **4.2.3.2.2.2.1.3 Reach 4**

The methylmercury HQs for kingfisher foraging in Reach 4 range from 0.899 (CTE – Effect TRV) to 2.04 (RME – No-Effect TRV). Only the kingfisher methylmercury HQs based on the No-Effect TRV for both the RME and CTE cases (2.04 and 1.78, respectively) are greater than unity.

##### **4.2.3.2.2.2.1.4 Reach 5**

The methylmercury HQs for kingfisher foraging in Reach 5 range from 1.05 (CTE – Effect TRV) to 2.25 (RME – No-Effect TRV). All of the kingfisher methylmercury HQs calculated for this reach exceed unity.

##### **4.2.3.2.2.2.1.5 Reach 6**

The methylmercury HQs for kingfisher foraging in Reach 6 range from 0.591 (CTE – Effect TRV) to 1.31 (RME – No-Effect TRV). Only the kingfisher methylmercury HQs based on the

No-Effect TRV for both the RME and CTE cases (1.31 and 1.17, respectively) are greater than unity.

## Reach 7

The methylmercury HQs for kingfisher foraging in Reach 7 range from 0.909 (CTE – Effect TRV) to 2.14 (RME – No-Effect TRV). The kingfisher methylmercury HQs based on the RME cases (No-Effect TRV= 2.14; Effect TRV = 1.08) and CTE case, No-Effect TRV (1.8) are greater than unity.

## Reach 7-Heard Pond

The methylmercury HQs for kingfisher foraging in Reach 7-Heard Pond range from 0.102 (CTE – Effect TRV) to 0.222 (RME – No-Effect TRV). None of the kingfisher methylmercury HQs exceed unity.

## Reach 8

The methylmercury HQs for kingfisher foraging in Reach 8 range from 1.14 (CTE – Effect TRV) to 2.35 (RME – No-Effect TRV). All of the kingfisher methylmercury HQs calculated for this reach exceed unity.

## Reach 9

The methylmercury HQs for kingfisher foraging in Reach 9 range from 1.11 (CTE – Effect TRV) to 2.45 (RME – No-Effect TRV). All of the kingfisher methylmercury HQs calculated for this reach exceed unity.

## Reach 10

The methylmercury HQs for kingfisher foraging in Reach 10 range from 1.29 (CTE – Effect TRV) to 2.81 (RME – No-Effect TRV). All of the kingfisher methylmercury HQs calculated for this reach exceed unity.

## Kingfisher Modeling Results: Reference Areas

## Reach 1

The methylmercury HQs for kingfisher foraging in Reach 1 range from 0.643 (CTE – Effect TRV) to 1.48 (RME – No-Effect TRV). Only the kingfisher methylmercury HQs based on the

No-Effect TRV for both the RME and CTE cases (1.48 and 1.27, respectively) are greater than unity.

#### **4.2.3.2.2.2.2 Charles River**

The methylmercury HQs for kingfisher foraging in the Charles River range from 0.642 (CTE – Effect TRV) to 1.36 (RME – No-Effect TRV). Only the kingfisher methylmercury HQs based on the No-Effect TRV for both the RME and CTE cases (1.36 and 1.27, respectively) are greater than unity.

#### **4.2.3.2.2.2.3 Sudbury Reservoir**

The methylmercury HQs for kingfisher foraging in the Sudbury Reservoir range from 0.164 (CTE – Effect TRV) to 0.376 (RME – No-Effect TRV). All of the kingfisher methylmercury HQs calculated for this reference area are below unity.

#### **4.2.3.2.3 Great Blue Heron**

##### **4.2.3.2.3.1 Great Blue Heron Exposure and Effects Modeling Results**

The risks to piscivorous birds potentially exposed to mercury in crayfish and fish, as well as surface water and sediments in the Sudbury River were evaluated for the heron. Total exposure doses were compared to both effect- and no-effect toxicity values. The results are presented in Tables 4-10 and 4-11, respectively, and are discussed by reach/reference area below.

##### **4.2.3.2.3.1.1 Great Blue Heron Modeling Results: Site Impacted Areas**

###### **4.2.3.2.3.1.1.1 Reach 2**

The methylmercury HQs for great blue heron foraging in Reach 2 range from 0.439 (CTE – Effect TRV) to 1.00 (RME – No-Effect TRV). All of the heron methylmercury HQs calculated for this reach are at or below unity (i.e.,  $HQ < 1.0$ ).

###### **4.2.3.2.3.1.1.2 Reach 3**

The methylmercury HQs for great blue heron foraging in Reach 3 range from 0.521 (CTE – Effect TRV) to 1.21 (RME – No-Effect TRV). Only the heron methylmercury HQs based on the No-Effect TRV for both the RME and CTE cases (1.21 and 1.03, respectively) are greater than unity.

**4.2.3.2.3.1.1.3****Reach 4**

The methylmercury HQs for great blue heron foraging in Reach 4 range from 0.415 (CTE – Effect TRV) to 0.949 (RME – No-Effect TRV). All of the heron methylmercury HQs calculated for this reach are below unity.

**4.2.3.2.3.1.1.4****Reach 5**

The methylmercury HQs for great blue heron foraging in Reach 5 range from 0.422 (CTE – Effect TRV) to 0.927 (RME – No-Effect TRV). All of the heron methylmercury HQs calculated for this reach are below unity.

**4.2.3.2.3.1.1.5****Reach 6**

The methylmercury HQs for great blue heron foraging in Reach 6 range from 0.260 (CTE – Effect TRV) to 0.603 (RME – No-Effect TRV). All of the heron methylmercury HQs calculated for this reach are below unity.

**4.2.3.2.3.1.1.6****Reach 7**

The methylmercury HQs for great blue heron foraging in Reach 7 range from 0.353 (CTE – Effect TRV) to 0.832 (RME – No-Effect TRV). All of the heron methylmercury HQs calculated for this reach are below unity.

**4.2.3.2.3.1.1.7****Reach 7-Heard Pond**

The methylmercury HQs for great blue heron foraging in Reach 7-Heard Pond range from 0.0651 (CTE – Effect TRV) to 0.146 (RME – No-Effect TRV). All of the heron methylmercury HQs calculated for this reach are below unity.

**4.2.3.2.3.1.1.8****Reach 8**

The methylmercury HQs for great blue heron foraging in Reach 8 range from 0.471 (CTE – Effect TRV) to 0.991 (RME – No-Effect TRV). All of the heron methylmercury HQs calculated for this reach are below unity.

**4.2.3.2.3.1.1.9****Reach 9**

The methylmercury HQs for great blue heron foraging in Reach 9 range from 0.452 (CTE – Effect TRV) to 1.02 (RME – No-Effect TRV). All of the heron methylmercury HQs calculated for this reach are below unity.

#### **4.2.3.2.3.1.1.10**

#### **Reach 10**

The methylmercury HQs for great blue heron foraging in Reach 10 range from 0.542 (CTE – Effect TRV) to 1.21 (RME – No-Effect TRV). Only the heron methylmercury HQs based on the No-Effect TRV for both the RME and CTE cases (1.21 and 1.07, respectively) are greater than unity.

#### **4.2.3.2.3.1.2**

#### **Great Blue Heron Modeling Results: Reference Areas**

##### **4.2.3.2.3.1.2.1**

##### **Reach 1**

The methylmercury HQs for great blue heron foraging in Reach 1 range from 0.273 (CTE – Effect TRV) to 0.663 (RME – No-Effect TRV). All of the heron methylmercury HQs calculated for this reach are below unity.

##### **4.2.3.2.3.1.2.2**

##### **Charles River**

The methylmercury HQs for great blue heron foraging in the Charles River range from 0.266 (CTE – Effect TRV) to 0.564 (RME – No-Effect TRV). All of the heron methylmercury HQs calculated for this reference area are below unity.

##### **4.2.3.2.3.1.2.3**

##### **Sudbury Reservoir**

The methylmercury HQs for great blue heron foraging in the Sudbury Reservoir range from 0.0973 (CTE – Effect TRV) to 0.227 (RME – No-Effect TRV). All of the heron methylmercury HQs calculated for this reference area are below unity.

#### **4.2.4 Risk to Mammalian Life**

##### **4.2.4.1 Piscivorous Mammals**

As noted in Section 2.4.1.2.3.6, blood, fur, brain, and liver samples were submitted for mink from 5 individuals from 4 locations – Reach 3 (Reservoir 2), Reach 4 (Reservoir 1), Reach 5, and Reach 7. No site-specific reference area samples were collected. Samples were analyzed only for total mercury. Chemical concentration results were presented in Table 2-67.

##### **4.2.4.1.1 Mink Tissue Mercury Accumulation and Effects**

Data regarding the mink tissue mercury accumulation and effects are presented below and organized as follows: discussion of tissue mercury content, comparison of site-specific tissue concentrations with appropriate CBRs, comparisons of site impacted concentrations with regional mercury levels.

#### **4.2.4.1.1.1 Mink Tissue Mercury Content**

This section summarizes the tissue mercury concentration data, putting the concentrations in spatial context and briefly discussing potential relationships observed within and between tissue types. The concentrations of total mercury in mink blood ranged from 46 µg/kg WW (Reach 4) to 177 µg/kg WW (Reach 3). Mink fur concentrations ranged from 1,200 µg/kg FW from an individual captured in Reach 4 to 58,600 µg/kg FW in an individual captured in Reach 3. Concentrations in the brain and liver were measured from individuals captured in Reach 5 only and ranged from 118 to 215 µg/kg WW in brain and from 1,130 to 1,210 µg/kg WW in liver.

#### **4.2.4.1.1.2 Mink CBR Comparisons: Site Impacted Areas**

Comparisons of blood and fur concentrations to CBRs are presented in Figure 4-57. Comparisons of blood concentrations showed that all samples had concentrations that were below the no-effect levels. Concentrations of total mercury in mink fur compared with CBRs showed that samples collected from individuals captured in Reaches 4 and 7 were below the no-effect level. For fur samples collected from Reach 5, two samples were below the no-effect level and one was between the no-effect and effect levels. The average concentration from Reach 5 was between the no-effect and effect level. The one fur sample collected from Reach 3 had a concentration greater than the effect level.

Data were not available to develop CBRs with which to compare brain and liver concentrations.

The BRI Mink Exposure Profile (Appendix A.5) indicates that, using the CBR values they developed, only one mink from Reach 3 had fur values exceeding the CBR. In addition, blood, brain, and liver mercury levels were greater than the BRI-derived CBRs.

#### **4.2.4.1.1.3 Comparison of Mink Concentrations with Regional Levels**

The BRI Mink Exposure Profile compared Sudbury River mercury concentrations with regional mercury values (see Appendix A.5). As noted previously, site-specific reference concentrations were not available for mink. Sudbury River mink had lower mercury levels (geometric mean) for fur, liver, and brain tissues than mink caught in Maine and Ontario (See Appendix A.5, Table 4 and Figure 3). Mink sampled from the Sudbury River had mean fur concentrations that were higher than those measured in New Hampshire or Nova Scotia.



#### **4.2.4.1.2 Mink Exposure and Effect Modeling Results**

The risks to piscivorous mammals potentially exposed to mercury in crayfish and fish, as well as surface water and sediments in the Sudbury River were evaluated for the mink. Total exposure doses were compared to both effect- and no-effect toxicity values. The results are presented in Tables 4-10 and 4-11, respectively, and are discussed by reach/reference area below.

##### **4.2.4.1.2.1 Mink Exposure Modeling Results: Site Impacted Areas**

###### **4.2.4.1.2.1.1 Reach 2**

The methylmercury HQs for mink (i.e., piscivorous mammals) foraging in the Reach 2 range from 0.527 (CTE – Effect TRV) to 1.57 (RME – No-Effect TRV). Only the mink methylmercury HQs based on the No-Effect TRV for both the RME and CTE cases (1.57 and 1.32, respectively) are greater than unity (i.e.,  $HQ \geq 1.0$ ).

###### **4.2.4.1.2.1.2 Reach 3**

The methylmercury HQs for mink (i.e., piscivorous mammals) foraging in the Reach 3 range from 0.666 (CTE – Effect TRV) to 2.02 (RME – No-Effect TRV). Only the mink methylmercury HQs based on the No-Effect TRV for both the RME and CTE cases (2.02 and 1.66, respectively) are greater than unity.

###### **4.2.4.1.2.1.3 Reach 4**

The methylmercury HQs for mink (i.e., piscivorous mammals) foraging in the Reach 4 range from 0.460 (CTE – Effect TRV) to 1.4 (RME – No-Effect TRV). Only the mink methylmercury HQs based on the No-Effect TRV for both the RME and CTE cases (1.4 and 1.15, respectively) are greater than unity.

###### **4.2.4.1.2.1.4 Reach 5**

The methylmercury HQs for mink (i.e., piscivorous mammals) foraging in the Reach 5 range from 0.650 (CTE – Effect TRV) to 1.89 (RME – No-Effect TRV). Only the mink methylmercury HQs based on the No-Effect TRV for both the RME and CTE cases (1.89 and 1.62, respectively) are greater than unity.

**4.2.4.1.2.1.5****Reach 6**

The methylmercury HQs for mink (i.e., piscivorous mammals) foraging in Reach 6 range from 0.377 (CTE – Effect TRV) to 1.12 (RME – No-Effect TRV). Only the mink methylmercury HQ based on the No-Effect TRV for the RME case (1.12) is greater than unity.

**4.2.4.1.2.1.6****Reach 7**

The methylmercury HQs for mink (i.e., piscivorous mammals) foraging in the Reach 7 range from 0.473 (CTE – Effect TRV) to 1.51 (RME – No-Effect TRV). Only the mink methylmercury HQs based on the No-Effect TRV for both the RME and CTE cases (1.51 and 1.18, respectively) are greater than unity.

**4.2.4.1.2.1.7****Reach 7-Heard Pond**

The methylmercury HQs for mink (i.e., piscivorous mammals) foraging in Reach 7-Heard Pond range from 0.199 (CTE – Effect TRV) to 0.60 (RME – No-Effect TRV). None of the mink methylmercury HQs exceed unity.

**4.2.4.1.2.1.8****Reach 8**

The methylmercury HQs for mink (i.e., piscivorous mammals) foraging in Reach 8 range from 1.05 (CTE – Effect TRV) to 3.04 (RME – No-Effect TRV). All of the mink methylmercury HQs calculated for this reach exceed unity.

**4.2.4.1.2.1.9****Reach 9**

The methylmercury HQs for mink (i.e., piscivorous mammals) foraging in Reach 9 range from 1.18 (CTE – Effect TRV) to 3.80 (RME – No-Effect TRV). All of the mink methylmercury HQs calculated for this reach exceed unity.

**4.2.4.1.2.1.10****Reach 10**

The methylmercury HQs for mink (i.e., piscivorous mammals) foraging in Reach 10 range from 1.33 (CTE – Effect TRV) to 4.64 (RME – No-Effect TRV). All of the mink methylmercury HQs calculated for this reach exceed unity.

#### **4.2.4.1.2.2 Mink Exposure Modeling Results: Reference Areas**

##### **4.2.4.1.2.2.1 Reach 1**

The methylmercury HQs for mink (i.e., piscivorous mammals) foraging in Reach 1 range from 0.359 (CTE – Effect TRV) to 1.08 (RME – No-Effect TRV). Only the mink methylmercury HQ based on the No-Effect TRV for the RME case (1.08) is greater than unity.

##### **4.2.4.1.2.2.2 Charles River**

The methylmercury HQs for mink (i.e., piscivorous mammals) foraging in the Charles River range from 0.360 (CTE – Effect TRV) to 1.04 (RME – No-Effect TRV). All of the mink methylmercury HQs calculated for this reference area are at or below unity.

##### **4.2.4.1.2.2.3 Sudbury Reservoir**

The methylmercury HQs for mink (i.e., piscivorous mammals) foraging in the Sudbury Reservoir range from 0.140 (CTE – Effect TRV) to 0.430 (RME – No-Effect TRV). All of the mink methylmercury HQs calculated for this reference area are below unity.

#### **4.2.5 Uncertainty Analysis**

##### **4.2.5.1 Introduction**

As mentioned previously, one of the major components of the Risk Characterization is the discussion of the uncertainties associated with estimating risk. Many of the uncertainties associated with the measurement endpoints selected as part of this SBERA were discussed throughout the Problem Formulation and Analysis Phase. The primary objective of the uncertainty analysis is to combine and summarize the uncertainty present throughout the ERA process so that this information can be combined with other risk estimation information to more completely describe actual or potential risk and to assess the ecological significance of observed or predicted impacts. As stated previously, the actual integration and interpretation of the information presented in the Risk Estimation section are provided in the Risk Description (Section 4.3).

The Uncertainty Analysis identifies and, to the extent possible, quantifies the uncertainties present in the Problem Formulation, Analysis Phase, and Risk Characterization. As previously discussed, virtually every step in an ERA involves numerous assumptions that contribute to the total uncertainty in the final evaluation of risk (e.g., are loon tissue effect levels appropriate for comparisons with merganser tissue concentrations). The uncertainties that are incorporated in

this SBERA may result in an increase or decrease in the estimated potential for adverse ecological effects. When methodologies and input factors for this SBERA were selected, conservative, yet realistic approaches and values were used when site-specific information is unavailable (e.g., dietary intake values for avian and mammalian exposure models). This approach to handling uncertainty may tend to overestimate risks; however, it should be noted that only conservative assumptions compatible with sound scientific evidence or processes were used.

Uncertainties in ERAs may be identified as belonging to one or more of the four following categories: conceptual model formulation uncertainty, data and information uncertainty, natural variability (stochasticity), and error (EPA, 1992a). These are not discrete categories, and overlap does exist among them. EPA's Ecological Framework document provides a more detailed discussion of these generic uncertainty categories (EPA, 1992a).

After discussing general uncertainties (Subsection 4.2.5.2) associated with the ERA process used for this SBERA, the Uncertainty Analysis follows the order of presentation of endpoints used in the previous subsection on Risk Estimation (i.e., field studies followed by HQ analyses) and discusses uncertainties specific to each endpoint. Where possible, the effect of a given uncertainty, i.e., under- or overestimate of risk, is noted. In instances where the direction of the uncertainty is unknown, i.e., may under-or overestimate risk, the effect generally is not stated.

#### **4.2.5.2 General Uncertainties**

There are numerous uncertainties that may be associated with this SBERA in general, or to one or more measurement endpoints specifically that were used in this SBERA. In an effort to limit the repetitious listing of common uncertainties, the general uncertainty categories previously presented (i.e., conceptual model formulation, information and data, natural variability, and error) are used to highlight common uncertainties present throughout the assessment. The general uncertainties associated with these categories are described below.

##### **4.2.5.2.1 Conceptual Model Formulation**

- Food web and trophic dynamics within an aquatic system directly impacts bioavailability and biomagnification of mercury.
- Detected concentrations in surface water and sediment may not be indicative of bioavailable concentrations. This is addressed throughout the remainder of the uncertainty analysis.

- Target receptors identified in the Problem Formulation were selected to represent a variety of organisms with similar feeding and behavioral strategies and to assist in the evaluation of measurement endpoints. However, species-specific exposure and susceptibility to toxic effects within similar feeding groups may vary and result in differing risk potential. Target receptors were selected with the intent of optimizing exposure and assuming that a significant portion of their life cycles was restricted to the area of contamination. The assumption that avian and mammalian target receptors spend a significant portion of their life cycles at the Site may be conservative (i.e., overestimate risk).

#### **4.2.5.2.2 Information and Data**

- Factors unrelated to mercury contamination may influence the number and composition of species that reproduce or forage on-site and the frequency of their exposure to site-related contamination. Examples of these types of factors include habitat modification in the vicinity of the Site, natural population fluctuations, off-site contaminant release, and migration.
- There is uncertainty surrounding the extrapolation of laboratory data to field conditions.
- Surface water grab samples represent snapshots of surface water conditions in the Sudbury River; they may not reflect chronic water conditions and unless taken frequently over time as was done by USGS (Waldron et al., 1997) may not capture acute mercury pulses.
- Media sampling typically was not random, most sampling strategies used were designed to identify “worst case” situations (e.g., sediment sampling in depositional areas), which would tend to overestimate risk.
- In general, media chemical sampling was limited to direct measurement of mercury and methylmercury concentrations; the presence of other chemicals that may act synergistically or antagonistically (e.g., selenium) with mercury was not determined.
- Numerous authors (Cairns, 1988; Chapman, 1995; Forbes et al., 2001) have expressed concern regarding the extrapolation of individual species effects evaluations to population level impacts.

#### **4.2.5.2.3 Natural Variability (Stochasticity)**

- Fluctuations in seasonal or annual temperature, precipitation, and flow conditions may temporarily affect habitat suitability and subsequent receptor exposure. These fluctuations can also directly influence mercury bioavailability within an aquatic system.
- Within a target species, there exists variability in species sensitivity to mercury-related toxicity.

- Water body characteristics, such as DOC, sediment TOC, sunlight, water clarity, anoxia, and sulfate concentrations, appear to affect methylation and demethylation reactions. Variations in these properties can cause significant variations in fish concentrations among lakes (EPA, 1997d), and likely riverine and wetland habitats. Fish mercury levels are sensitive to factors that promote methylmercury mobility from the sediments to the water column; these factors include sediment DOC, pH, temperature, and sediment-pore water partition coefficients.
- There is considerable uncertainty and apparent variability in the movement of mercury from the abiotic (e.g., sediment and surface water) elements of the aquatic system through the aquatic food chain (EPA, 1997d).
- Spatial and temporal variations in sediment conditions (both physical and chemical) are often observed at very small scales. Given the heterogeneity of the sediment environment, sample size and location greatly affect the certainty associated with determination of effects.

#### **4.2.5.2.4 Error**

- Analytical variability in the analysis of total and methylmercury in prey tissue, sediment, and surface water causes some uncertainty in sample-specific concentrations and the calculation of EPCs. Quality control samples, such as duplicates, provide some information on the analytical variability. The relative percent difference (RPD; absolute value of the difference divided by the average expressed as a percentage) between the two measurements describes the magnitude of the variability. For each medium and analyte, the range and average RPDs are presented in Table 4-12. Overall, for total mercury and methylmercury on a data category basis, 50% of the duplicate pairs were within 7% and 12% of each other, respectively. In addition, 96% and 87% of the pairs for total- and methylmercury, respectively had an RPD of <50%.
- Use of the SQL or one-half the reported SQL of data from samples in which a contaminant was not detected introduces further uncertainty to the estimation of exposure concentrations. Because the true distribution of concentrations below the SQL is unknown, assuming concentrations of one-half the SQL may over- or underestimate actual levels.
- The use of summary statistics and estimates of variability are reflective of the sampling strategy and sample sizes. Non-random sampling may introduce bias and small sample sizes may fail to capture actual magnitude and variability.
- The hazard quotient approach used throughout the assessment fails to account for uncertainty in the point estimates used and typically compounds conservatism by using “worst case” assumptions when selecting parameter estimates.
- Quantification of NOECs and LOECs (this also includes NOAELs and LOAELs) depends critically on experiment size and variability, and as such has been criticized by numerous

authors (Hockstra and Van Ewijk, 1992; Laskowski, 1995; Chapman et al., 1998) as having limited value in assessing risk.

#### **4.2.5.3 Individual Field Study Uncertainties**

##### **4.2.5.3.1 *Hexagenia* Bioaccumulation and Effects Study**

While advances in the standardization and methodologies associated with laboratory-based sediment bioaccumulation and toxicity tests continue, numerous uncertainties still exist when trying to extrapolate the results of these tests from a few species to an enormously complex ecosystem (Cairns and Mount, 1990, Chapman, 1995). A reduction of these uncertainties can be achieved only by understanding the basic processes that affect chemical accumulation and toxicity, such as speciation, partitioning, solubility, thermodynamics, and microbial metabolism (Burgess and Scott, 1992). These multiple factors are often interrelated, complex, and largely unknown for most environmental samples; consequently, uncertainty is best addressed and minimized by using standardized procedures that provide better quality assurance and quality control.

No single sediment test can be expected to be adequate for the detection of bioaccumulation and potential adverse effects of complex mixtures of contaminants because of the differences in relative sensitivities in both indigenous species and test organisms (Chapman, 1987, Geisy et al., 1990). The uncertainty analysis that follows discusses some of the general uncertainties associated with sediment bioaccumulation and toxicity testing. The influence (positive or negative) of these uncertainties on the resulting estimation is difficult to determine without subsequent validation studies.

- Physical, chemical, and microbial alterations occur in sediments during sampling, shipping, and testing; thereby altering bioaccumulation potential and toxicity that may or may not be present in situ.
- The problem of "positive" results (i.e., reduced survival or growth) resulting not from anthropogenic contaminants, but from other innate physicochemical characteristics of the test sediments, is always possible because monitoring and evaluating many of the possible factors are not practical (Ankley et al., 1994).
- Standard test methods may not address such concerns as delayed toxicity (Buikema et al., 1982).
- Indigenous organisms may pass through the sediment screening process and may impact testing endpoints such as growth and survival (Burton, 1991).

- Several factors can affect sediment testing precision, including test control organism age, condition, sensitivity, handling, feeding, overlying water quality, and training of laboratory personnel (Burton, 1992).
- Test organisms collected from the Upper Mississippi Drainage may have different bioaccumulation and toxicity potential than mayflies native to the Sudbury River.

#### 4.2.5.3.2 *Elliptio* Study

Several uncertainties were ascribed to this study and are discussed below.

- *Elliptio complanata* harvested from the relatively pristine Lake Massesecum in Bradford, New Hampshire and used in this study were shown to contain unexpectedly high levels of mercury. Tissues of mussels collected from the lake had mean total and methylmercury concentrations of 640 and 140 µg/kg DW, respectively. The effects of this finding are unknown and the possibility of adaptive tolerance has been hypothesized. Enhanced mercury tolerance by induction of metallothioneins has been demonstrated in the marine mussel, *Mytilus*, exposed to mercury (Roesijadi et al., 1982). The extent to which these elevated body burdens may have affected the mussels and the subsequent results of the study are unknown.
- Significant mortality and poor growth of mussels at the reference locations precluded the use of the results from these stations as reference or background conditions for all metrics used in this study. Consequently, statistical comparisons of “affected” populations and “potentially unaffected” populations of mussels, as well as other meaningful interpretations relative to background were not possible. Statistical comparisons were only available with which to assess changes between stations.
- The absence of co-located surface water data for mercury in the Sudbury River limited the correlation of the uptake of mercury in the mussels and the source or mechanism of that uptake. Although it is likely that both sediment and surface water contribute to the uptake, the proportional contributions, as well as the form of the mercury in the water column, i.e., dissolved or particulate, could not be ascertained.
- The basis for the growth studies included such measurements as shell height, width, length, and weight of each *Elliptio*. Due to relatively limited time period for growth, the potential for the chipping of shell margins, as well as difficulty in obtaining consistent measurements inherent in measuring and weighing mussels, there is some potential for an over- or underestimation of the animal growth. These uncertainties, when incorporated in the results, may affect the interpretation of the effect of mercury on the mussels.
- Flow conditions and habitat characteristics at the study stations were variable, being roughly divided into impounded areas and free-flowing areas. These varying hydrological conditions could directly or indirectly affect various factors such as water temperature,



food availability and other factors that would in turn affect the growth of the mussels. In the absence of a controlled environment, these factors confound the interpretation of growth results.

- This study attempts to correlate potential effects on mussel growth with exposure to methylmercury. However, the potential exists for other chemicals in the surface water and sediments of the Sudbury River to similarly affect mussel growth. Without supporting sediment and surface water chemistry data for other chemical analytes, it cannot be concluded definitely that the measured effects are due only to mercury exposure.
- It should also be noted that the source of methylmercury that was accumulated by mussels throughout the study area is uncertain. It is likely that the Nyanza Site is the primary source, particularly in the areas represented by Reaches 2, 3, and 6 (Stations 3, 4 and 5, respectively). It is uncertain whether the source of methylmercury in the wetland area is due to the downstream transport of sediment-bound mercury or other more localized sources.

#### **4.2.5.3.3 Individual Wildlife Studies**

##### **4.2.5.3.3.1 General Field Study Uncertainties**

- Several authors (Wren and Stokes, 1988; Thompson, 1996; Hoffman and Heinz, 1998; Heinz and Hoffman, 1998; Wolfe et al., 1998) have reported that, in birds, selenium can act as an antagonist to the toxic effects of mercury. Because selenium concentrations were not measured as part of the supplemental biological sampling program, there is no way to assess if mercury toxicity may be impacted by co-located selenium levels.
- It is virtually impossible to tell if samples collected include “non-healthy” individuals because their foraging and nesting skills may be compromised by effects tied to mercury exposure.
- Field studies that collect samples from contaminated media and biota that are taken from an exposed environment and used as replicates in hypothesis testing are, in fact, pseudoreplicates (Hurlbert, 1984; Suter, 1996a) and the results of hypothesis testing need to be interpreted with caution.
- It is possible that only individuals with low mercury exposure as immatures survive to reach the adult age class. None of the field studies evaluated long term survival of exposed juveniles.

##### **4.2.5.3.3.1.1 Avian Field Study Uncertainties**

- Small sample sizes for several avian tissue groups (e.g., merganser blood and egg) limit the power associated with statistical tests and value of associated summary statistics.

- Avian tissues were primarily collected in spring and early summer when methylmercury concentrations in surface water tend to be lower than during low-flow and warmer conditions (i.e., summer and early autumn). Therefore, it may be reasonable to assume that avian blood levels may be higher in late summer and early fall.
- Avian field studies did not attempt to directly measure reproductive effects (i.e., hatching or fledging success); therefore, tissue residue levels could only be compared to literature-based effect levels to determine potential effects.
- Egg laying order has a significant impact on the concentration of mercury in eggs (Kennamer et al., 2005; Evers et al., 2005); therefore, the results of egg comparisons (both within study and to literature-based values) may reflect effects associated more with laying order than locational effects.
- Mercury concentrations in feathers will vary with time of molt, feather type, individual age, and species (Monteiro et al., 1995; Evers et al., 1998; Rimmer et al., 2005). In general, mercury concentrations in feathers is reflective of blood levels at the time of molt (Bearhop et al., 2000), but can also be reflective of concentrations in muscle tissue for individuals that have been exposed to high levels of mercury in the environment (Burger, 1993). Therefore, mercury feather concentrations observed for this study are likely indicative of long-term mercury exposure and may be more representative of exposure concentrations present at locations other than those found within the study area or reference locations.

#### **4.2.5.3.3.2 Target Receptor-Specific Field Study Uncertainties**

##### **4.2.5.3.3.2.1 Marsh Bird**

- Eastern kingbird egg mercury concentrations may not reflect the mercury levels in the areas in which they are laid. The kingbird's diet includes a variety of foods, including berries and terrestrial insects; therefore, this species may not be the best indicator species for the evaluation of an aquatic ecosystem.
- Red-winged blackbird blood samples were collected in August, post-fledge and pre-migration. The toxicity values were based on reproductive effects. Although the effect level in blood was exceeded in all but one sample, it is not known what effects these levels have on bird physiology and survival. In addition, it is not known what ability the blackbirds may have to depurate mercury prior to the egg-laying period.
- The diets of the four target marsh birds (i.e., song sparrow, swamp sparrow, yellow warbler, and common yellowthroat) include non-aquatic invertebrates (e.g., beetles, bees, spiders) that may not be exposed to mercury contamination associated with the Sudbury River.

#### **4.2.5.3.3.2.2**

#### **Waterfowl Study**

- Wood duck mercury egg levels are not expected to be comparable to mercury egg levels for piscivorous waterfowl; and therefore, interpretation of results using wood duck data need to account for this lack of conservatism.

#### **4.2.5.3.3.2.3**

#### **Kingfisher**

- Kingfisher nests were not located directly on the Sudbury River. While it was assumed the belted kingfisher sampled forage primarily along the Sudbury River, during the breeding season, adult kingfisher foraging ranges can exceed 2 km (Sample and Suter, 1994); therefore, it may be possible that a portion of their dietary exposure comes from locations outside the Sudbury River floodplain.

#### **4.2.5.3.3.2.4**

#### **Mink**

- Small sample sizes hindered the determination of natural variability in mercury concentrations in mink tissues and prevented the evaluation of statistical differences between areas.
- The home range of a mink in stream length can vary from 1,800 to 5,000 m (Linscombe et al., 1982); therefore, mercury concentrations in mink tissue are likely associated with exposure to multiple Sudbury River reaches and may even be the result of exposures outside the Sudbury floodplain.

#### **4.2.5.4**

#### **Hazard Quotient Uncertainties**

When sufficient data are available to quantify exposure and effects estimates, the simplest approach for comparing estimates is the ratio approach (EPA, 1998). As presented in Section 4.2.1.2, the HQ is being used throughout this SBERA to evaluate risk to target receptors and communities. The advantages to using this approach are: 1) it is quick and simple to use; 2) risk managers are familiar with its application; and 3) it provides an efficient means to identify high- or low- risk situations. There are however, a number of limitations associated with this approach that have been discussed by several authors (Smith and Cairns, 1993; Suter, 1993; Suter et al., 2000). They include: 1) inability to provide incremental quantification of risk (e.g., an HQ of 10, does not necessarily mean 10X more risk than an HQ of 1); 2) not appropriate for evaluating secondary effects; and 3) the quotient approach does not explicitly consider uncertainty.

#### **4.2.5.4.1 Benchmark Comparisons**

##### **4.2.5.4.1.1 Sediment Benchmarks**

In general, sediment benchmarks do not address possible synergistic, antagonistic, or additive effects of contaminant mixtures; do not consider unmeasured chemicals; and are not useful for chemicals for which little or no toxicological information is available (Giesy and Hoke, 1990). Specific uncertainties with the values used in this SBERA are noted below.

- The TEC value, below which concentrations are not expected to cause adverse effects, may underestimate the potential for toxic effects caused by mercury. Out of 79 samples evaluated, the number of samples predicted to be not toxic (based on the TEC value) was 35. The actual number of samples observed to be not toxic was 12, giving a percentage of samples correctly predicted to be not toxic of 34.3%.
- The PEC value, above which concentrations are expected to cause adverse effects, is a reliable indicator of effects from mercury. Out of 79 samples evaluated, the number of samples predicted to be toxic (based on the PEC value) was 4. The actual number of samples observed to be toxic was 4, giving a percentage of samples correctly predicted to be toxic as 100%.

The sediment benchmarks used in this evaluation were developed using the co-occurrence-based approach which involves compiling sets of sediment data that contain some information on sediment biological characteristics, such as laboratory measured toxicity or benthic organism assemblages and the total concentration of potential contaminants in the sediment. Several authors have provided detailed discussions of the limitations associated with the approach to assessing potential ecological effects associated with sediment contamination (O'Connor et al., 1998; O'Connor, 1999; Lee and Jones-Lee, 2002). The following list highlights the primary uncertainties identified with the sediment co-occurrence approach.

- Approach assumes there is always a causal relationship between the concentration of each contaminant in sediment and the ecological impact of that sediment.
- Presumes that the effect reported for each sediment evaluated was caused independently by each of the measured contaminants in the sediment.
- Assumes no other chemical or condition not included in the database has any influence on the effect(s) observed.
- Presumes that all effects information used to develop the benchmark is directly related to ecologically significant impacts to the benthic community.
- Does not consider bioaccumulation and food chain effects.

#### 4.2.5.4.1.2

#### Surface Water Criteria

The use of EPA's AWQC for evaluating the potential impacts of reported contaminant concentrations in surface water has the following general associated uncertainties:

- The use of the AWQC as a screening tool does not consider site-specific interactions with other chemicals present and cannot be interpreted as a direct measurement of site-specific bioavailability.
- The total mercury AWQCs account for direct exposure only, and do not account for the possibility that uptake from food may add to the contaminant intake from water alone. This may underestimate risk.
- There may be differences between the species with toxicological data used to develop the AWQC and those present in the Sudbury River.
- EPA's AWQC are based on a threshold for statistical significance rather than biological significance.
- There is uncertainty surrounding the extrapolation of laboratory data (used to develop criteria) to field conditions.
- Acute and subchronic laboratory toxicity tests frequently do not measure the most sensitive ecological endpoints; in particular, fecundity is often not measured (Suter, 1996b).
- Chronic AWQCs are based on the most statistically sensitive of the measured response parameters in each chronic or subchronic test. Therefore, cumulative effects over the life cycle of fish and invertebrates are not considered (Suter, 1996a). This would tend to underestimate risk.
- Depending upon site-specific bioavailability of mercury in the water column, back-calculating a total recoverable total mercury AWQC using the 0.85 conversion factor may under- or overestimate risk.
- The criteria for total mercury is based on data for inorganic mercury. Comparing inorganic mercury-based criteria with total mercury concentrations will bias the HQ low if organic mercury comprises a substantial amount of the total mercury. Some surface water samples included as much as 40% methylmercury.
- The potential for chronic effects from exposure to methylmercury in surface water were estimated using an "old" total recoverable AWQC which was based on a final residue value (FRV) for the fathead minnow and a bioconcentration factor for methylmercury of 81,700 (EPA, 1986). Because the FRV was intended to protect wildlife that consumed aquatic life, EPA now believes it may not be as protective as criteria derived from the

Final Chronic Value. In addition, bioaccumulation factors (BAFs) instead of bioconcentration factors (BCFs) are favored for use as predictors of fish tissue concentrations as it includes consideration of the uptake of contaminants from all routes of exposure. Therefore, it is likely that HQs generated to determine the potential for methylmercury to cause effects in aquatic organisms are underestimates.

- No methylmercury-based acute AWQC exists. Comparing the total mercury acute criteria to methylmercury concentrations may underestimate the risk to aquatic life from acute exposures to methylmercury.

#### **4.2.5.4.2 Critical Body Residue Comparisons**

Although the concentrations in tissues associated with adverse effects have been measured in some studies, the significance of the link between the concentration within tissues and exhibition of toxic effects is not known. Comparisons between tissue concentrations and literature values may under- or overestimate the potential for adverse effects in target receptors, because toxicity may be dependent upon the concentration within a particular organ not well represented by whole body or component (e.g., fillet tissue and feather) concentrations. In addition, many CBRs are based on laboratory studies that do not have the ability to consider potential adaptive behavior by organisms within a contaminated area.

The following list of uncertainties highlights some of the major limitations associated with using CBRs to assess ecological risks.

- The influence of the kinetics of uptake and depuration on biological response for mercury must be understood when interpreting the relation of tissue residues to effects (e.g., short-term exposure to highly toxic concentrations may result in lower residue levels than long-term exposure to lower concentrations).
- For the body residue approach to be most effective, there needs to be a clear understanding of the mechanisms or modes of actions for the COEC. If this information is not available, inappropriate tissues might be sampled.
- The tissue residue approach may not be effective for chemicals that are metabolized to more active forms; in which case the parent chemical residue level may not correlate with effects.

In addition, the interpretation and application of toxicological data in the ecological effects characterization are potentially the greatest sources of uncertainty in the CBR comparisons. Appropriate toxicity data specific to target receptors were not always available; therefore, application of literature-derived toxicity data to the species of concern was sometimes necessary. When selecting toxicological data to compare with site-specific conditions, every

effort was made to use data for the most closely related species to the target receptors. However, species sensitivity may vary even among closely related species. Variations in species sensitivity may be due to differences in some of the following factors: toxicity, tolerance thresholds, toxic symptoms exhibited, time period until toxic effects are observed, and metabolism of the ingested chemical. Because study designs and presentation of results can be quite different, steps were taken to make sure the concentrations and/or doses were comparable. As such, the primary uncertainties potentially associated with the derivation of CBRs noted below.

- To facilitate direct comparison between CBRs and site-specific tissue concentrations, all data that were reported in DW were converted to WW. Assumptions made were as follows: crayfish and fish–80% moisture; bird blood–80% moisture; bird eggs–76% moisture; feathers and fur–FW equals WW. The available measured moisture contents in site-specific data, ranged, in general, from 59 to 82% for crayfish, 57 to 87% for fish, and 57 to 89% in bird eggs (moisture content not available for other tissues). Considering the range and distribution of moisture content in crayfish, fish, and bird eggs, site-specific values may be higher or lower than the assumed, but for the most part, the values modified from DW to WW are lower than what would be calculated using sample-specific information (i.e., conservative).
- Some blood concentrations identified in the literature were reported on a per volume (mL) instead of a per weight (e.g., g) basis. It was assumed that blood density was not different from one, and therefore, values in µg/mL were equal to those in µg/g. This may under- or overestimate CBR values.

Specific target receptor CBR uncertainties are noted below.

#### **4.2.5.4.2.1 Crayfish**

- Except for the studies by Parks et al. (1988) and Brant et al. (2002), who exposed crayfish for 68 days and 140 days, respectively, all the other studies in the CBR database used much shorter exposure durations (two-four weeks). Such a pattern was not surprising because most studies deemed suitable for CBR development were of a physiological nature. With some exceptions, the authors were mostly interested in measuring the uptake and/or depuration dynamics of mercury but not in quantifying its long-term toxicology. Hence, they selected sub-lethal mercury concentrations and relatively-short exposure periods. The available information also indicated that tissue residue levels did not reach steady state for at least four weeks, indicating that some of the no-effect tissue residue levels did not reflect equilibrium conditions. Lastly, it is not known if the higher subchronic no-effect tissue residues, from which the median was calculated and used as the no-effect CBR, might have become effect tissue residues given a longer exposure period. Therefore, the no-effect CBR for crayfish may underestimate risk.

- In the development of crayfish CBRs, only Evans et al. (2000) investigated the potential link between mercury tissue residues and toxic responses in the early life stages of the decapods. Adults generally show lower sensitivity than early life stages, therefore, the CBRs for crayfish may underestimate risk.
- None of the studies included in the crayfish database investigated the link between mercury residues in decapods and effect on their reproductive potential, which is generally considered a more sensitive endpoint than survival, growth, weight gain, on which the no-effect CBR was based. Therefore, the no-effect CBR for crayfish may underestimate risk. It is not known if increased time to seek shelter (endpoint in effect CBR basis) is more or less sensitive than reproduction.
- None of the studies included in the crayfish database were performed to determine true NOELs and/or LOELs (i.e., dose-responses were not established). Hence, the no-effect mercury thresholds in the database were most likely lower (i.e., more conservative) than the true NOEL for the target species, whereas the available effect mercury thresholds were probably higher (i.e., less conservative) than the true LOELs for the target species.
- It was assumed that mercury residues measured in crayfish muscle and whole body were equivalent. A limited data review (three papers) indicated that the ratio between muscle and whole body mercury concentration in crayfish, and in decapods by extrapolation, varied between around 0.5 and 2.0 depending on the form of the mercury used, the uptake route, and the exposure duration. It also suggested that the muscle and whole body tissue residue data may be roughly interchangeable within a margin of error equivalent to a factor of 2.
- The no-effect level CBR was the median no-effect level from nine studies. Species evaluated in the studies were all decapods and included crayfish (*Astacus astacus* and *A. leptodactylus*), shrimp, crab, and lobster. Crayfish for which site-specific data were available are *Oronectes virilis* and *O. rusticus*. Given the differences in taxonomy, some differences in toxicokinetics are expected. It is not known if these differences would lead to an overall under- or overestimate of risk.
- The effect level CBR was based on one study that used *Procambarus clarkii*. Crayfish for which site-specific data were available are *Oronectes virilis* and *O. rusticus*. *P. clarkia* are native to northeastern Mexico to the south central United States. Given the differences in taxonomy and territory, some differences in toxicokinetics are expected. It is not known if these differences would lead to an overall under- or overestimate of risk.

#### 4.2.5.4.2.2 Fish

- The no-effect and effect level CBRs were based on studies that used fathead minnow (*Pimephales promelas*) and mummichog (*Fundulus heteroclitus*). Fish for which site-specific data were available are brown bullhead, yellow bullhead, bluegill, pumpkinseed, yellow perch, and largemouth bass. Given the differences in taxonomy, some



differences in toxicokinetics are expected. It is not known if these differences would lead to an overall under- or overestimate of risk.

- There was a paucity of fish residue studies on which to base the no-effect (n=3) and effect CBR (n=5); therefore, it is difficult to assess whether the fish CBRs were conservative or not.
- As noted in Section 2.4.1.2.3.4.1, regression equations were developed to estimate wholebody fish total mercury concentrations from fillet concentrations. Estimated data were not included in the estimation of risk in this SBERA (e.g., cumulative distribution frequency graphs; i.e., Figures 4-10 through 4-19). Maximum and average concentrations in specific species/size classes and all fish for the dataset used in this SBERA and a dataset including regressed (i.e., estimated) fish concentrations are presented in Table 4-13. The following differences in results are noted when considering the dataset including the regressed data against the NEL.
  - average concentrations of size class D yellow perch in Reach 3 and 4 would be below the NEL;
  - average concentrations of size class D brown bullhead in Reach 3 would be above the NEL; and
  - maximum concentrations of size class D brown bullhead in Reaches 3 and 10, largemouth bass in Sudbury Reservoir, yellow bullhead in Reach 7, and yellow perch in Reaches 6 and 8 would be above the NEL.

The following differences in results are noted when considering the dataset including the regressed data against the LEL.

- average concentrations of size class D largemouth bass in Reach 10 would be below the LEL; and
- maximum concentrations of largemouth bass in Reaches 2 and 3, size class D brown bullhead in Reach 3, and the all fish dataset in Reaches 2 and 3 would be above the LEL.

#### **4.2.5.4.2.3 Avian**

This SBERA was conducted using avian CBR information compiled by ESAT in 2004 (see Appendices F through H). Further review of the data in 2006 resulted in subdividing avian data into two categories: generic and tree swallow. CBRs were subsequently developed for these two categories when possible (Appendices I and J).

In general, generic values were used to estimate risks to waterfowl and kingfisher; whereas the tree swallow values were used to estimate risks to tree swallows and marsh birds.

Uncertainties associated with the derivation of the avian CBRs are noted in the subsection below.

- Avian residue data were combined across age groups (i.e., pre-fledged and post-fledged) for blood and feathers to increase the size of the data set from which CBRs could be derived. In addition, if data were available for both pre-fledge and post-fledge birds of the same species, the more conservative of the two sets of values was selected. This is a conservative approach that may overestimate risks.
- The generic egg CBRs are values suggested in a review study. It is likely that the values of 500 and 1,000 µg tHg/kg WW (no-effect and effect CBRs, respectively) would need to be adjusted downward to protect sensitive bird species; and the use of these values therefore, is more likely to underestimate than overestimate risk.
- The tree swallow egg CBRs are based on one egg injection study by Heinz (2003) with reproduction as the endpoint. Reproductive endpoints are generally more sensitive than others and the use of these values likely provides good to conservative estimates of risk.
- Only a generic bird blood CBR was developed. It is an effect-based CBR developed using the most sensitive endpoint found (i.e., behavioral changes resulting in a drop in the overall fitness of chicks). This value, 1,250 µg tHg/kg WW, is lower than any of the no-effect levels identified, and may be overly conservative. This effect-based CBR was divided by two to obtain a no-effect CBR. It is not known if this extrapolated CBR is conservative or not.
- A generic effect CBR for bird feathers was developed from the most sensitive endpoint found (i.e., reproductive impacts). This value, 9,100 µg tHg/kg WW, is lower than many of the no-effect levels identified, and may be overly conservative. (See following bullets for further discussion.)
- A tree swallow-specific feather no-effect CBR was developed from one study (Gerrard and St. Louis, 2001) that reported no detrimental effects on clutch size, incubation time, hatchability, nestling growth, or fledging success in pre-fledging tree swallow chicks with feathers containing an average of 1,210 µg tHg/kg WW. Because this no-effect level is unbounded, the true NOAEL is likely higher and use of this value may be overly conservative.
- Because no generic feather no-effect CBR was developed, the tree swallow-specific feather no-effect CBR was used as a surrogate. While this value is likely conservative for use in assessing tree swallows, it is not known in which direction the uncertainty lies when applying this CBR to other species.

#### **4.2.5.4.2.4 Mammalian**

- A blood no-effect CBR was developed for mink based on a value in blood that did not result in brain levels known to cause toxicity. This value provides a conservative no-effect level for mink blood.
- The fur CBRs were based on a mink study assessing reproduction. Reproductive endpoints are generally more sensitive than others and the use of these values likely provides good to conservative estimates of risk.

#### **4.2.5.4.3 TRV Comparisons with Exposure Modeling Results**

Uncertainties associated with the wildlife modeling and subsequent comparisons with TRVs can be divided into two categories: those associated with the exposure estimate (i.e., estimating daily intake) and those associated with the TRVs. General uncertainties associated with each are discussed below, followed by target-receptor specific uncertainties.

##### **4.2.5.4.3.1 General Exposure Characterization Uncertainties Associated with Wildlife Dose Modeling**

In the exposure assessment, numerous assumptions were made to estimate daily intakes for selected target species (i.e., tree swallow, kingfisher, great blue heron, and mink). Because site-specific receptor information was not available, assumptions were made regarding ingestion rates, frequency of exposure, and EPCs. This SBERA used a deterministic approach for calculating exposures (both RME and CTE); exposure parameters used were point estimates and did not incorporate information regarding parameter-specific variability. In general, an effort was made to use modeling assumptions that were conservative, yet realistic. The primary assumptions used in the exposure characterization follow.

- Prey tissue data collected in summer (fish) and fall (fish and crayfish) were combined to determine EPCs in each reach. Due to the seasonal variations of tissue concentrations, the combining of data in this manner may under- or overestimate the exposure of wildlife to mercury during any given season.
- Tissue residue concentrations detected in crayfish and fish were assumed to be representative of other prey items of the same trophic level that may be ingested by the target receptors. This assumption may under- or overestimate risk, depending upon the actual prey items ingested.
- Risks were calculated for total mercury or methylmercury each alone. Calculating risk in this manner does not account for additivity, synergism, or antagonism of other contaminants to which receptors may be exposed. Calculating risks on a chemical-by-chemical basis may result in an over- or underestimation of total potential risk.

- The ingestion route is the only exposure route evaluated in this analysis because there is limited information to assess other potential exposure routes such as dermal absorption and inhalation. Exposure via dermal absorption and inhalation may be of particular concern for species that clean themselves by rolling in any dry surface (i.e., river otters) (EPA, 1993a). By not estimating exposure by these pathways, risks are likely underestimated.
- Crayfish data were not available in Reaches 7-Heard Pond and 8 through 10. For the receptors that consume crayfish (i.e., kingfisher, heron, and mink), it was assumed that fish comprised 100% of their diet in these reaches. This assumption is believed to be conservative because the fish prey taken by the target receptors are generally of a higher trophic level than crayfish (i.e., trophic level 3.0 or greater for fish as opposed to 2.5-2.7 for crayfish; EPA, 1995a); which translates to higher mercury concentrations. Therefore, risks to kingfisher, heron, and mink in Reaches 8 through 10 may be overestimated.
- Average body weights were used to estimate exposure intakes for all target receptors. This approach may under- or overestimate daily intake for individuals depending upon their sex, age, breeding status, and time of year.
- Risks were calculated on a reach by reach basis and it was assumed that the tree swallow, kingfisher, heron, and mink obtained 100% of their diet within a reach. Given the feeding ranges of these receptors, dietary changes during breeding, and that prey populations are, at times, low or inaccessible (e.g., due to ice), this may be a conservative assumption.
- Calculating risks on a reach by reach basis does not account for the ability of a receptor to forage in more than one reach. Risks may be underestimated for an individual that, in general, forages in a less contaminated reach but occasionally forays into a more contaminated area. The reverse is also true.
- Although sediment ingestion rates are presented as a percentage of the diet, it was conservatively assumed that any sediment ingestion intake was in addition to 100% of the dietary (food) intake, and not part of the total diet. This may overestimate the intake of contaminants.
- The sediment ingestion rates were calculated by applying a percentage of sediment assumed to be in the diet to a DW food ingestion rate. DW food ingestion rates, were calculated from WW food ingestion rates for the kingfisher, great blue heron, and mink assuming that all prey contained 75% moisture (bony fishes; EPA, 1993a). However, because different fish species and crayfish contain various amounts of water, the use of a single moisture content value for each tissue type may result in an over- or underestimate of daily sediment intake rate

- Drinking water intake rates were estimated from average body weights using allometric equations developed by Calder and Braun (1983). Additional sources of water are not accounted for in this equation (i.e., metabolic water and water contained in food). This equation may over- or underestimate potential intake via water consumption.
- As noted previously, regression equations were developed to estimate wholebody fish total mercury concentrations from fillet concentrations (see Section 2.4.1.2.3.4.1 for details of regressions). Estimated data were not included in the estimation of risk in this SBERA (e.g., fish EPCs for modeling efforts). NOAEL- and LOAEL-based hazards were calculated including regressed (i.e., estimated) fish concentrations in the EPC calculation and are presented in Tables 4-14 and 4-15. The following differences in results are observed when considering the dataset including the regressed data. Note that, because of the fish sizes assumed for their diets, only the great blue heron and mink are affected by this exercise.
  - No effect-based RME case for the great blue heron in Reaches 2 and 9 would decrease below an HQ of one.
  - No effect-based RME case for the mink in Charles River would decrease to below an HQ of one.
- Comparisons between fish concentrations in site impacted areas and reference areas were presented in Section 4.2.2.2.2.2. However, the species/size-class combinations presented therein are not the same as what were used in the wildlife exposure modeling. Kingfisher were assumed to be exposed to all fish (not just perch) size classes A and B; great blue heron were assumed to be exposed to all fish in size classes A, B and C combined, and  $D \leq 30$  cm; and mink were assumed to be exposed to all fish in size classes A, B, C, and D. As such, additional statistical comparisons with reference areas were performed (as per the approach presented in Section 4.2.5.4.2.2) using the species/size class combinations evaluated in the wildlife exposure modeling. These results are presented in Table 4-16 and discussed below.
- **Comparisons with Reach 1:** For Reach 2, the mercury concentrations in all size classes of fish (i.e., A, B, C, B and C combined, D, and  $D < 30$  cm) were statistically different from the concentrations in fish collected from Reach 1.

For Reach 5, the mercury concentrations in size classes A and D were statistically different from the concentrations in these size class collected from Reach 1. Concentrations in size classes B, C, B and C combined, and  $D < 30$  cm were not statistically different from the reference area.

For Reach 7, the mercury concentrations in size classes A and B were statistically different from the concentrations in these size class collected from Reach 1. Concentrations in size classes C, B and C combined, D, and  $D < 30$  cm were not statistically different from the reference area.

For Reach 10, the mercury concentrations in all size classes of fish (i.e., A, B, C, B and C combined, D, and D <30 cm) were statistically different from the concentrations in fish collected from Reach 1.

- **Comparisons with the Charles River** – For Reach 8, the mercury concentrations in all size classes of fish (i.e., A, B, C, B and C combined, and D <30 cm) except for size class D were statistically different from the concentrations in these size class collected from the Charles River.

For Reach 9, the mercury concentrations in all size classes of fish (i.e., A, B, C, B and C combined, and D <30 cm) except for size class D were statistically different from the concentrations in these size class collected from the Charles River.

- **Comparisons with the Sudbury Reservoir** – For Reaches 3, 4, and 6, the mercury concentrations in all size classes of fish (i.e., A, B, C, B and C combined, D, and D <30 cm) were statistically different from the concentrations in fish collected from the Sudbury Reservoir.

For Reach 7-Heard Pond, the mercury concentrations in size classes A, B, C, and B and C combined were statistically different (lower) from the concentrations in fish collected from Sudbury Reservoir. The concentrations in size class D were not statistically different from those in Sudbury Reservoir. Comparisons were not made with size class D <30 cm due to insufficient sample size.

#### **4.2.5.4.3.2 General Effects Characterization Uncertainties Associated with TRV Development**

As with the development of CBRs, the interpretation and application of toxicological data in the ecological effects characterization are potentially the greatest sources of uncertainty in the estimate of risk from avian and mammalian food chain modeling. Appropriate toxicity data specific to target receptors were not always available; therefore, application of literature-derived toxicity data to the species of concern was sometimes necessary. When selecting toxicological data to compare with site-specific conditions, avian TRVs were selected from the lowest-available bird NOAELs and LOAELs. However, species sensitivity may vary even among closely related species. Variations in species sensitivity may be due to differences in some of the following factors: toxicity, tolerance thresholds, toxic symptoms exhibited, time period until toxic effects are observed, and metabolism of the ingested chemical. Mink TRVs were derived from studies on mink. Because study designs and presentation of results can be quite different, steps were taken to make sure the concentrations and/or doses were comparable. As such, the primary uncertainties potentially associated with the derivation of TRVs are noted below.

- Literature reviews showed that dosing birds and mammals with inorganic mercury resulted in less severe effects than dosing with equivalent concentrations of organic mercury. For conservatism, avian and mammalian TRVs were calculated using only studies in which the

receptors were exposed to organic mercury. Although much, if not all of the mercury to which these higher organisms are exposed is in the organic form, any deviations from 100% organic exposure would cause the potential risks determined herein to be overestimated.

- The bioavailability and toxicity of metal ions to wildlife are dependent on the form in which they exist in the environment (i.e., speciation). Factors that determine the naturally occurring forms of metals include sediment texture, sediment and surface water chemistry, pH, redox potential, and solute and ligand concentrations. Because analytical procedures used to evaluate metal concentrations do not provide species-specific concentrations, the associated bioavailability and toxicity are difficult to assess. In this SBERA, the medium-specific concentration either as measured or as estimated, was conservatively considered to be completely bioavailable. This assumption will lead to an overestimate of risk.
- The medium in which a chemical is administered in toxicity tests can have a substantial effect on its gastrointestinal absorption. However, sufficient information was not available with which to make adjustments in bioavailability to account for these differences when calculating exposure doses for the target receptors. For example, if a TRV value was culled from a study that used dietary exposure adjustments, the target receptor exposure dose would have to be calculated based on the relative bioavailability of the chemical in the study diet as it compares with the bioavailability of the chemical in invertebrates or fish. An inability to account for differences in bioavailability may over- or underestimate potential hazards to site receptors.
- In calculating TRVs, adjustments (uncertainty factors) were not applied to toxicity data to account for differences in species. The possibility exists that the indicator species may be more sensitive to a certain chemical exposure than the test species. It may also be possible that the animal used in the laboratory or field study from which the TRV is derived may be more sensitive than the receptor species. Therefore, the TRVs may be overly conservative, or may not be adequately protective.
- Because the no-effect to effect-level ratios for the originally selected avian TRVs resulted in a ratio of only 1.3, an avian no-effect TRV was derived by applying a safety factor of 2 to the selected LOAEL. A review of inter-study specific no-effect to effect ratios ranged from 2 to 10; therefore, the resultant TRV may not be protective of all species.
- The selected avian effect TRV was based on a study in which great egrets were fed a mercury contaminated diet. Average daily doses were not provided in the paper, but were provided for weeks 3 and 13 of the 13-week study. The FIR per week (from 2 to 13 weeks) was determined from a figure in the original study. Using the FIR data, and the doses given for the two weeks, dose/FIR ratios were determined. The average of these ratios was used to determine doses for the other weeks. The average daily dose was then calculated. This calculation method employs a few assumptions, leading to uncertainty. One is that the FIR was determined accurately from the figure provided.

Another is that the dose/FIR values are the same over the duration of the study. It is not known whether these assumptions are likely to lead to an over- or underestimate of risk.

#### 4.2.5.4.3.3 Target Receptor-Specific Uncertainties

##### 4.2.5.4.3.3.1 Tree Swallow

- Because tree swallows feed upon flying insects and recent site-specific data for such were not available, concentrations in emergent insects were calculated using a site-specific regression model for *Hexagenia* (mayflies). This model developed the relationship between total mercury in sediments and total mercury in *Hexagenia* larvae ( $r^2=0.84$ ). However, the data on which the regression was based was on sediment concentrations of 0.09 to 22.1 mg/kg. Data collected during the supplemental investigation ranged from 0.005 to 44.88 mg/kg. It is not known if the emergent insect concentrations estimated from sediment concentrations outside the regression range are under- or overestimated. This issue affects each reach, except for Reach 1, Reach 3 Focus Area, Reach 4, and Reach 9 as follows:

Reach	Sediment Samples		
	n	n < 0.09 mg/kg	n > 22.1 mg/kg
S2	12	4	0
S3	23	0	5
S5	11	2	0
S5 - FA	15	7	0
S6	12	1	0
S7	16	6	0
S8	13	1	0
S0	10	2	0
CR	13	2	0
SR	6	2	0

- It was assumed (based on site-specific and literature-based data) that 35% of the total mercury was in methyl form. If insectivorous birds foraging along the Sudbury River are consuming prey from a higher trophic level (e.g., Odonates), the amount of methylmercury in the diet is likely underestimated.
- It was assumed that concentrations in *Hexagenia* larvae are representative of those in the adult. In addition, it was assumed that mayflies are representative of all potential aquatic insects ingested, including Diptera, which are often the primary prey item of tree swallows. It is not known which direction this affects the risk estimates.



- Because tree swallows are almost exclusively insectivorous, the uncertainty regarding the assumption that their diet is 100% emergent insects is small.
- FIRs were calculated based on the FMR of the tree swallow because FIRs for tree swallows were not available. The “passerine” regression model from Nagy et al. (1999) was selected as being the most appropriate for the tree swallow. Examples of species used to develop this model include the grey-breasted silvereye, crescent honey eater, great tit, and bullfinch. Insectivores like the tree swallow comprised approximately 65% of the species with data that were input to form the regression. Because tree swallows were one of the species for which data were available, and the empirical FMR was equal to 209 kJoules/day whereas the calculated FMR was 81 kJoules/day, the regression equation used to develop the FMR may underestimate the FIR by 60%.
- The body weights of adult tree swallows are well documented and have little variation among mature adults. Representative adult body weights from the literature ranged from 15.6 to 25.5 g with a mean cited in Dunning (1984) of 20.1 g. Site-specific body weights during breeding season ranging from 15 to 28 g with the average of mean adult female and male body weights being 20.8 g. The site-specific values are quite similar to the literature values. There is likely very little uncertainty associated with tree swallow body weight used in this SBERA.
- The fraction of prey that is contaminated was assumed to be 100% from each reach. Given the small foraging range of the tree swallow and abundance of prey along the Sudbury River, the uncertainty regarding this assumption is small.
- The avian TRV used to estimate the potential for risk was based on a study of great egrets. Tree swallows and egrets are not of the same order; therefore, it is possible that there are taxonomic differences between the two in the mercury toxicokinetics. It is not known what effect this may have on risks.

#### **4.2.5.4.3.3.2**

#### **Kingfisher**

- Because it was assumed that dietary exposure represented the most important pathway for exposure of kingfisher to mercury and it was assumed that the total mercury concentrations in prey were comprised mostly of the methylmercury form, it was assumed that the only contaminant in sediments and surface water was methylmercury. Because there are toxic effects associated with inorganic mercury, risk to the kingfisher is underestimated. However, given the small contribution of sediment and surface water ingestion to the TDI, the underestimation is likely insignificant.
- Site-specific dietary component data were not available. Although kingfishers are known to feed predominantly on fish, they also may consume crayfish, mollusks, and some amphibian and reptile species (EPA, 1993a). Only crayfish and fish were included in this analysis because the other potential dietary items have a small contribution to total diet and site-specific tissue concentrations are not available for them. As noted previously,

the surrogates for the prey items not included are assumed to be conservative; and therefore, potentially overestimate risk.

- For the portion of diet that consists of fish, it was assumed that 50% of the fish were from size class A ( $>5$  but  $\leq 10$  cm) and 50% of the fish were from size class B ( $<10$  but  $\leq 15$  cm). Given that typical prey length is less than 10 cm (Prose, 1985; Imhof, 1962; Salyer and Lagler, 1946) and larger fish tend to have higher mercury concentrations, this assumption likely overestimates the TDI.
- FIRs were calculated based on the FMR of the kingfisher because FIRs for kingfishers were not available. The “all birds” regression model from Nagy et al. (1999) was selected as being the most appropriate for the kingfisher. Information on piscivores, such as the pied kingfisher (*Ceryle rudis*), were included in the data to which the regression was fitted. However, the body weight of the pied kingfisher is approximately half that of the belted kingfisher; and therefore it is inappropriate to make comparisons of actual and calculated FMRs for the purposes of determining direction of uncertainty.
- Literature values for the average body weight of the kingfisher were used to determine total daily intakes. A small sample set of site-specific data were available ( $n=5$ ), with a range of 139 to 165 grams and a mean of 153 g. Given that the literature value used in this SBERA was a mean of 150 g, the uncertainty associated with the body weight used is small.
- The fraction of prey that is contaminated was assumed to be 100% from each reach. Given the small foraging range of the kingfisher and abundance of prey along the Sudbury River, this assumption would be valid. However, very few kingfisher burrows were located along the Sudbury River. Most were located in dirt or gravel piles in upland areas. Because the burrows were not located in the banks of the river, the birds must travel to a water source to forage. Because of the numerous streams in the Sudbury River drainage, it is possible that kingfisher nesting outside of the river are also foraging in other waters. Therefore, assuming that 100% of the kingfisher's diet is obtained from each reach likely overestimates risk.
- The assumption that sediment comprises 3.3% of the kingfisher's diet (on a dry-weight basis), based on data for a mallard (EPA, 1993a) may over- or underestimate the daily intake of mercury from incidental sediment ingestion.
- The avian TRV used to estimate the potential for risk was based on a study of great egrets. Kingfisher and egrets are not of the same order; therefore, it is possible that there are taxonomic differences between the two in the mercury toxicokinetics. It is not known what effect this may have on risks.

#### 4.2.5.4.3.3

#### Great Blue Heron

- Because it was assumed that dietary exposure represented the most important pathway for exposure of herons to mercury and it was assumed that the total mercury

concentrations in prey were comprised mostly of the methylmercury form, it was assumed that the only contaminants in sediments and surface water was methylmercury.

- Site-specific dietary component data were not available. Although herons are known to ingest fish, amphibians, reptiles, crustaceans, insects, birds, and mammals (EPA, 1993a), only crayfish and fish were included in this analysis because the other potential dietary items have a small contribution to total diet and site-specific tissue concentrations are not available for them. As noted previously, the surrogates for the prey items not included are assumed to be conservative; and therefore, potentially overestimate risk.
- FIRs were calculated based on the FMR of the heron because FIRs for herons were not available. The “all birds” regression model from Nagy et al. (1999) was selected as being the most appropriate for the great blue heron because sufficient information on Ciconiiformes were not available to fit a regression. Non-heron Ciconiiformes (e.g., petrels and shearwaters) included in the regression model data, have among other things, different diets, foraging habits, and markedly different body weights from the great blue heron. Because piscivorous birds similar to the heron were not represented, it is difficult to determine the direction and magnitude of the uncertainty introduced by the use of this model.
- The great blue heron is a highly mobile species that may forage for food at distances in excess of 30 km from its nesting or roosting area (Butler, 1992). Given the proximity of other surface waters for foraging, the assumption that 100% of foraging occurs within each of the reaches likely overestimates the potential risk posed to the heron.
- The assumption that sediment comprises 3.3% of the heron's diet (on a dry-weight basis), based on data for a mallard (Beyer et al., 1994) may over- or underestimate the daily intake of mercury from incidental sediment ingestion.
- The avian TRV used to estimate the potential for risk was based on a study of great egrets. Great blue herons and great egrets are of the same genus; therefore, it is likely that the mercury toxicokinetics between the two species is similar. This likely similarity reduces uncertainty in the risk estimate.

#### **4.2.5.4.3.3.4**

#### **Mink**

- Because it was assumed that dietary exposure represented the most important pathway for exposure of mink to mercury and it was assumed that the total mercury concentrations in prey were comprised mostly of the methylmercury form, it was also assumed that the only contaminant in sediments and surface water was methylmercury.
- There should be little uncertainty associated with the selected mammalian TRVs, as the values were based on a study using the target species (i.e., mink) and assessed reproductive effects. However, the daily doses selected as the TRVs were derived by

multiplying the concentration in food by an estimated FIR from EPA, 1993a. This FIR is for adult female farm-raised mink during the winter season. As noted previously, the food requirements of farm-raised or captive animals are generally less than that of their wild counterparts. Assuming a lower FIR would produce a lower dose, therefore adding a layer of conservatism to the selected values.

## **4.3 Risk Description**

### **4.3.1 Introduction**

The risk description is the part of the ERA in which the risk assessors integrate and interpret the available information into conclusions about risks to the assessment endpoints.

The risk description incorporates two primary elements. The first is the lines of evidence evaluation, which provides a process and framework for determining confidence in the risk estimate. The second is the determination of ecological adversity, which represents whether the valued structural or functional attributes of the ecological entities under consideration are altered, the degree of adversity to the entities, and if recovery is possible (EPA, 1998). The following risk description is divided into two subsections: Weight-of-Evidence Analysis (Subsection 4.3.2) and the Risk Summary (Subsection 4.3.3).

### **4.3.2 Weight-of-Evidence Analysis**

As discussed in the Problem Formulation, the actual evaluation of how well a measurement endpoint and its one or more lines of evidence represent an assessment endpoint is determined in the Weight-of-Evidence (WOE) analysis. The goal of the WOE analysis is to integrate all relevant findings of the ERA in an effort to determine the occurrence or potential for adverse ecological impacts. This is accomplished by: 1) assigning weights to each measurement endpoint; 2) evaluating the magnitude of response with respect to each measurement endpoint; and 3) determining the concurrence among the measurement endpoint(s) used to answer the question(s) posed by the assessment endpoint.

Weights were assigned to measurement endpoints based on 10 attributes (see Table 2-69) in relation to: 1) strength of association between assessment and measurement endpoints; 2) data and study quality; and 3) study design and execution. In determining the magnitude of response in a measurement endpoint an "Interpretive Ecological Risk Matrix" was developed for each endpoint. A general matrix is as follows.

Risk Scenario	RME Case	CTE Case	Population Risk?	Confidence Level
1	$N \leq 1$ & $L \leq 1$	$N \leq 1$ & $L \leq 1$	unlikely	high
2	$N > 1$ & $L \leq 1$	$N \leq 1$ & $L < 1$	unlikely	high
3	$N > 1$ & $L > 1$	$N \leq 1$ & $L \leq 1$	possible	low
4	$N > 1$ & $L \leq 1$	$N > 1$ & $L \leq 1$	possible	low/moderate
5	$N > 1$ & $L > 1$	$N > 1$ & $L \leq 1$	possible	moderate
6	$N > 1$ & $L > 1$	$N > 1$ & $L > 1$	possible	high

Where N = an HQ based on dividing an RME or CTE by the no-effect-based toxicity value and L = an HQ based on dividing an RME or CTE by the effect-based toxicity value. Note that this is a general matrix for assessing hazard quotients; the matrices for field studies (i.e., *Hexagenia* and mussel studies) are study-specific as presented on their respective tables. In addition, it is important to note that “unlikely” indicates that *population-level* effects are unlikely to the receptors represented by the measurement endpoint and that “possible” indicates that there is a potential for adverse *population-level* effects to the receptors represented by the measurement endpoint.

Endpoint-specific risk matrices were developed and presented along with the results in Tables 4-17 through 4-45.

When evaluating concurrence among measurement endpoints, there is an examination of the agreement or lack thereof among measurement endpoints as they relate to a specific assessment endpoint. Logical connection, interdependence, and correlations among measurement endpoints need to be considered.

A color-coded method as employed in the interpretative risk matrix along with information on the measurement endpoints’ weight and response provides an easy visual examination of agreements on divergences among the measurement endpoints. Evaluating available lines of evidence also provides a structure under which a conclusion regarding confidence in the risk estimate can be made. The following three categories of factors were considered when evaluating the individual lines of evidence (EPA, 1998):

- Adequacy and quality of data—Influences confidence in the results of a study and the conclusions that may be drawn from it. For example: 1) Were the DQOs clearly presented and met by the experimental design? 2) Were the natural variabilities in the ecological parameters under evaluation understood well enough to result in a study yielding data sufficiently sensitive and robust to identify mercury-related perturbations?

- Degree and type of uncertainty associated with the evidence—Essential to understanding the limitations and assumptions of the approaches used in the ERA before a complete description of risks and their ecological significance is developed.
- Relationship of the evidence to the risk assessment questions—Determines the relative importance of the evidence to the assessment endpoint evaluated. Lines of evidence that establish a cause-and-effect relationship based on a definitive mechanism instead of associations only, and those that are directly related to the risk hypotheses are most likely of greatest importance.

Agreement between different lines of evidence increases confidence in the conclusions derived in the risk estimation. When lines of evidence disagree, it is important to distinguish between true inconsistencies and those related to uncertainty and variability associated with each measurement endpoint. The evaluation process involves more than just listing the evidence that supports or refutes the risk estimate. This SBERA presents in detail the considerations and interpretations involved in evaluating all lines of evidence. As with assigning qualitative significance ratings to the measurement endpoints, professional judgment is required when evaluating the various results and conflicting lines of evidence.

#### **4.3.2.1 Measurement Endpoint Weights**

##### **4.3.2.1.1 Attribute Scaling**

As noted during the Problem Formulation stage (specifically, Section 2.8 – Weight of Evidence Approach), it was assumed that all attributes were of equal importance so there was no “attribute scaling” conducted.

##### **4.3.2.1.2 Attribute Weighting**

As noted in the Problem Formulation phase, the second element of the measurement endpoint weighting process, “attribute weighting,” was performed for measurement endpoints using a qualitative scale ranging from low to high and following “attribute weighting” guidelines provided in Menzie et al. (1996; Table 2). This process, even when following the guidelines, is somewhat subjective and was accomplished using the combined professional judgment of the ecological risk assessors.

After assigning a weight for each of the 10 attributes, a total measurement endpoint value was determined by averaging the 10 attribute weights. Consistency in the weighting process was ensured by assigning each attribute weight a numerical score of 1 (low) through 5 (high). The final qualitative measurement endpoint value was determined by applying the following

classification scale to the arithmetic average of the attribute weights: 1-1.49 (Low), 1.50-2.49 (Low/Moderate), 2.50-3.49 (Moderate), 3.50-4.49 (Moderate/High), and  $\geq 4.5$  (High).

The attribute and total measurement endpoint weights and the rationale for their selection are provided in Tables 4-46 through 4-60. The weighting process is presented by assessment endpoint and associated measurement endpoint.

#### **4.3.2.2 Magnitude of Response and Endpoint Concurrence**

Completed matrices illustrating the results of the WOE assessment specific to each reach are presented in Tables 4-61 through 4-70.

##### **4.3.2.2.1 Reach 2**

Table 4-61 depicts the WOE for Reach 2 for each of the assessment endpoints; the text below describes the potential risks.

**Benthic Invertebrate Community Structure, Survival, and Reproduction** – Three measurement endpoints were evaluated for this assessment endpoint for Reach 2 (Table 4-61). The field study measurement endpoint (i.e., the *Elliptio* study) was weighted “moderate-high” and risk was “possible/moderate.” The sediment and tissue chemistry endpoints (i.e., comparison of sediment concentrations with consensus-based values and comparison of crayfish tissue concentrations with CBRs) were weighted “low/moderate” and “moderate”, respectively. Risks were indicated to be “possible/high” based on sediment chemistry (note: 8/12 samples exceeded the TEC and 4/12 samples exceeded the PEC), but risk was indicated to be “unlikely/high” based on crayfish tissue chemistry. Combined, these lines of evidence suggest mercury contamination might be having an adverse effect on the benthic community in Reach 2. It is possible that the toxicity expected based on sediment chemistry and field studies is not being expressed based on the tissue chemistry due to various issues with bioavailability.

**Fish Population Survival and Reproduction** – Two measurement endpoints were evaluated for this assessment endpoint for Reach 2 (Table 4-61). The tissue chemistry measurement endpoint (i.e., comparison of fish tissue concentrations with CBRs) was weighted “moderate/high” and indicated that risk was “unlikely/high” for all species/size class combinations, except for the largemouth bass, which was noted as “possible/low-moderate.” Note that 90% of the fish tissue concentrations were below the NEL, and 10% of fish samples with concentrations greater than the NEL (but lower than the LEL) were TL > 20 cm. The water

chemistry endpoint was weighted “low/moderate” and did not indicate risk (i.e., “unlikely/high”). Combined, these lines of evidence suggest that it is not likely that mercury contamination is having an adverse effect on the overall fish community in Reach 2.

**Insectivorous Bird Survival, Reproduction, and Neurological Effects** – Only one measurement endpoint was evaluated for this assessment endpoint for Reach 2 (Table 4-61); therefore, there is no true discussion of concurrence for this endpoint. The tree swallow exposure modeling measurement endpoint was weighted “moderate” and risk was indicated to be “possible/moderate.” Note however, that this designation was determined from total mercury HQs for the RME case based on the no-effects based TRV of 7.3 and based on the effect-based TRV of 3.7.

**Piscivorous Bird Survival, Reproduction, and Neurological Effects** – Two measurement endpoints were evaluated for this assessment endpoint for Reach 2 (Table 4-61). Both of these measurement endpoints were based on wildlife receptor modeling (i.e., belted kingfisher and great blue heron) and were weighted “moderate.” “Possible/moderate” risk was indicated for the belted kingfisher, but risk was “unlikely/high” for the great blue heron. This “possible/moderate” designation for the kingfisher was determined from HQs for the RME case based on the no-effects based TRV of 2.3 and based on the effect-based TRV of 1.2. Combined, these lines of evidence suggest that mercury contamination may possibly be causing minimal adverse effects in smaller piscivorous birds, but not larger piscivorous birds foraging in Reach 2. However, the kingfisher exposure estimate is likely very conservative because kingfisher burrows were not found along the banks of the Sudbury River; foraging was observed in water bodies other than the Sudbury; and half of the fish portion of the dietary intake was comprised of larger fish (assumed to be more contaminated) than are most often taken as prey.

**Piscivorous Mammal Survival, Reproduction, and Neurological Effects** – Only one measurement endpoint, mink exposure modeling, was evaluated for this assessment endpoint for Reach 2 (Table 4-61). The modeling measurement endpoint was weighted “moderate-high” and adverse effects from mink foraging in Reach 2 were “possible/low-moderate.”

#### **4.3.2.2.1.1 Summary – Reach 2**

Overall, ecologically adverse effects from mercury contamination in Reach 2 are mixed for aquatic organisms (i.e., possible for benthic and unlikely for aquatic communities), but may be occurring in insectivorous birds. Based on the available data, it is likely that if negative effects



on the fish population are occurring, it is isolated to the larger (i.e., TL > 20 cm) fish. Given the uncertainties associated with the risk estimates, the potential risks associated with smaller piscivorous birds and piscivorous mammals are likely not ecologically significant. Adverse effects do not appear to be occurring in larger piscivorous birds (e.g., great blue heron). Note that the evidence for these conclusions is not as robust as for some other reaches as only one measurement endpoint was evaluated for insectivorous birds and piscivorous mammals, and that the results for all birds and mammals were based solely on exposure modeling. Although similar mercury concentrations in sediment do not necessarily correlate with similar bioavailability and subsequent toxicity; it is also important to note that while risk was possible for the benthic community in Reach 2, the sediment concentrations were not significantly different from those in the reference area (i.e., Reach 1; see Table 4-6).

#### **4.3.2.2.2                      Reach 3**

Table 4-62 depicts the WOE for Reach 3 for each of the assessment endpoints; the text below describes the potential risks.

**Benthic Invertebrate Community Structure, Survival, and Reproduction** – Four measurement endpoints were evaluated for this assessment endpoint for Reach 3 (Table 4-62). The field study measurement endpoints (i.e., the *Hexagenia* and *Elliptio* studies) were weighted “moderate-high” and noted risks were “unlikely/moderate” for the *Hexagenia* and “possible/moderate” for the *Elliptio*. The sediment and crayfish tissue chemistry endpoints (i.e., comparison of sediment concentrations with consensus-based values and comparison of crayfish tissue concentrations with CBRs) were weighted “low/moderate” and “moderate”, respectively. Risks were indicated to be “possible/high” based on sediment chemistry (note: 39/39 samples exceeded both the TEC and the PEC), but risk was indicated to be “unlikely/high” based on crayfish tissue chemistry. Combined, these lines of evidence suggest that mercury contamination might be having an adverse effect on the benthic community in Reach 3. It is possible that the toxicity expected based on sediment chemistry is not being expressed based on the tissue chemistry and some fields studies due to various issues with bioavailability.

**Fish Population Survival and Reproduction** – Two measurement endpoints were evaluated for this assessment endpoint for Reach 3 (Table 4-62). The tissue chemistry measurement endpoint (i.e., comparison of fish tissue concentrations with CBRs) was weighted “moderate/high” and risk was “unlikely/high” for all species/size class combinations, except for

the yellow perch size class D and largemouth bass, which were noted as “possible/low-moderate.” Note that 85% of the fish tissue concentrations were below the NEL, and 15% of fish samples with concentrations greater than the NEL (but lower than the LEL) were TL > 20 cm. The water chemistry endpoint was weighted “low/moderate” and did not indicate risk (i.e., “unlikely/undetermined”) using the one available sample point. Combined, these lines of evidence suggest that it is not likely that mercury contamination is having an adverse effect on the overall fish community in Reach 3.

**Insectivorous Bird Survival, Reproduction, and Neurological Effects** – Four measurement endpoints were evaluated for this assessment endpoint for Reach 3 (Table 4-62). Three of these measurement endpoints were based on tissue chemistry (i.e., comparison of tissue concentrations with CBRs) for various tree swallow tissue types and were weighted “moderate-high.” The tree swallow blood and egg chemistry indicated “unlikely/high” risk; whereas the tree swallow feather chemistry indicated that risk was “possible/low-moderate.”

The tree swallow modeling endpoint was weighted “moderate” and indicated that risk was of “possible/high” magnitude. This designation was determined from total mercury HQs for the RME case based on the no-effects based TRV of 24.2 and based on the effect-based TRV of 12.2.

Combined, these lines of evidence suggest that mercury contamination may be causing limited adverse effects in tree swallows, and by extension, to other insectivorous birds foraging in Reach 3.

**Piscivorous Bird Survival, Reproduction, and Neurological Effects** – Two measurement endpoints were evaluated for this assessment endpoint for Reach 3 (Table 4-62). Both measurement endpoints were based on wildlife exposure modeling (belted kingfisher and great blue heron) and weighted “moderate.” The belted kingfisher modeling indicated “possible/moderate” risk; whereas risk to the great blue heron was “possible/low-moderate.” The designation for the belted kingfisher was determined from HQs for the RME case based on the no-effects based TRV of 2.4 and based on the effect-based TRV of 1.2. Combined, these lines of evidence suggest that mercury contamination may possibly be causing minimal adverse effects in piscivorous birds foraging in Reach 3. However, the kingfisher exposure estimate is likely very conservative because kingfisher burrows were not found along the banks of the Sudbury River; foraging was observed in water bodies other than the Sudbury; and half of the

fish portion of the dietary intake was comprised of larger fish (assumed to be more contaminated) than are most often taken as prey.

**Piscivorous Mammal Survival, Reproduction, and Neurological Effects** – Three measurement endpoints were evaluated for this assessment endpoint for Reach 3 (Table 4-62). The tissue chemistry endpoints (i.e., mink blood and fur) were weighted “moderate” and indicated “possible/undetermined” risk based on fur concentrations, and “unlikely/undetermined” risk based on blood concentrations. Note that blood and fur were collected from only one animal. The mink exposure modeling endpoint was weighted “moderate-high” and risk was noted as “possible/low-moderate.” Combined, these lines of evidence suggest that mercury contamination may be causing adverse effects in piscivorous mammals in Reach 3.

#### **4.3.2.2.1 Summary – Reach 3**

Overall, ecologically adverse effects from mercury contamination in Reach 3 are mixed for aquatic organisms (i.e., possible for benthic and unlikely for aquatic communities), but may be occurring in insectivorous and piscivorous birds and piscivorous mammals. Based on the available data, it is likely that if negative effects on the fish population are occurring, it is isolated to the larger (i.e., TL > 20 cm) fish. Given the uncertainties associated with the avian exposure modeling and the low magnitude of HQs for the piscivorous birds and piscivorous mammals, it is likely that the effects, if occurring, are not ecologically significant.

#### **4.3.2.2.3 Reach 4**

Table 4-63 depicts the WOE for Reach 4 for each of the assessment endpoints; the text below describes the potential risks.

**Benthic Invertebrate Community Structure, Survival, and Reproduction** – Three measurement endpoints were evaluated for this assessment endpoint for Reach 4 (Table 4-63). The field study measurement endpoint (i.e., the *Hexagenia* study) was weighted “moderate-high” and risk was indicated to be “unlikely/moderate.” The sediment and tissue chemistry endpoints (i.e., comparison of sediment concentrations with consensus-based values and comparison of crayfish tissue concentrations with CBRs) were weighted “low/moderate” and “moderate”, respectively. Risks were indicated to be “possible/high” based on sediment chemistry (note: 11/11 samples exceeded the TEC and 10/11 samples exceeded the PEC), but risk was indicated to be “unlikely/high” based on crayfish tissue chemistry. Combined, these lines of evidence suggest that mercury contamination may possibly be having an adverse effect

on the benthic community in Reach 4. It is possible that the toxicity expected based on sediment chemistry is not being expressed based on the tissue chemistry and field studies due to various issues with bioavailability.

**Fish Population Survival and Reproduction** – Two measurement endpoints were evaluated for this assessment endpoint for Reach 4 (Table 4-63). The tissue chemistry measurement endpoint (i.e., comparison of fish tissue concentrations with CBRs) was weighted “moderate-high” and indicated that risk is “unlikely/high” for all species/size class combinations, except for the yellow perch size class D and largemouth bass, which were noted as “possible/low-moderate.” Note that 85% of the fish tissue concentrations were below the NEL, and 15% of fish samples with concentrations greater than the NEL (but lower than the LEL) were TL > 20 cm. The water chemistry endpoint was weighted “low/moderate” and did not indicate risk (i.e., “unlikely/undetermined”) using the one available sample point. Combined, these lines of evidence suggest that it is not likely that mercury contamination is having an adverse effect on the overall fish community in Reach 4.

**Insectivorous Bird Survival, Reproduction, and Neurological Effects** – Four measurement endpoints were evaluated for this assessment endpoint for Reach 4 (Table 4-63). Three of these measurement endpoints were based on tissue chemistry (i.e., comparison of tissue concentrations with CBRs) for various tree swallow tissue types and were weighted “moderate-high.” The tree swallow blood and egg chemistry indicated “unlikely/undetermined” risk for the one 2003 sample and “unlikely/high” risk for the 2004 samples. Whereas, the tree swallow feather chemistry indicated that risk was “unlikely/undetermined” using the one 2003 sample point but “possible/low-moderate” using 2004 data.

The tree swallow modeling endpoint was weighted “moderate” and indicated that risk was “possible/moderate.” This designation was assigned based on total mercury HQs for the RME case based on the no-effects based TRV of 6.2 and based on the effect-based TRV of 6.0.

Combined, these lines of evidence suggest that mercury contamination may be causing limited adverse effects in tree swallows, and by extension, to other insectivorous birds foraging in Reach 4.

**Piscivorous Bird Survival, Reproduction, and Neurological Effects** – Three measurement endpoints were evaluated for this assessment endpoint for Reach 4 (Table 4-63). One of these measurement endpoints was based on tissue chemistry (i.e., comparison of hooded merganser

egg concentrations with CBRs) and was weighted “moderate-high” and indicated “possible/low-moderate” risks. The wildlife modeling endpoints were weighted “moderate” and indicated “possible/moderate” risk for the belted kingfisher and “unlikely/high” for the great blue heron. The kingfisher designation was assigned based on HQs for the RME case based on the no-effects based TRV of 1.0 and based on the effect-based TRV of 2.0. Combined, these lines of evidence suggest that mercury contamination may be causing adverse effects in smaller piscivorous birds foraging in Reach 4. However, the kingfisher exposure estimate is likely very conservative because kingfisher burrows were not found along the banks of the Sudbury River; foraging was observed in water bodies other than the Sudbury; and half of the fish portion of the dietary intake was comprised of larger fish (assumed to be more contaminated) than are most often taken as prey.

**Piscivorous Mammal Survival, Reproduction, and Neurological Effects** – Three measurement endpoints were evaluated for this assessment endpoint for Reach 4 (Table 4-63). The tissue chemistry endpoints (i.e., mink blood and fur) were weighted “moderate” and risk was not indicated (i.e., “unlikely/undetermined”). The mink exposure modeling endpoint was weighted “moderate-high” and risk was noted as “possible/low-moderate.” Combined, these lines of evidence suggest that mercury contamination is not likely causing adverse effects in piscivorous mammals in Reach 4.

#### **4.3.2.2.3.1 Summary – Reach 4**

Overall, ecologically adverse effects from mercury contamination in Reach 4 are mixed for aquatic organisms (i.e., possible for benthic and unlikely for aquatic communities), but may be occurring in insectivorous birds and smaller piscivorous birds. Based on the available data, it is likely that if negative effects on the fish population are occurring, it is isolated to the larger (i.e., TL > 20 cm) fish. Given the uncertainties associated with the risk estimates, the potential risks associated with smaller piscivorous birds are likely not ecologically significant. Adverse effects do not appear to be occurring in larger piscivorous birds (e.g., great blue heron) or in piscivorous mammals.

#### **4.3.2.2.4 Reach 5**

Table 4-64 depicts the WOE for Reach 5 for each of the assessment endpoints; the text below describes the potential risks.

**Benthic Invertebrate Community Structure, Survival, and Reproduction** – Two measurement endpoints were evaluated for this assessment endpoint for Reach 5 (Table 4-64). Both were chemistry endpoints (i.e., comparison of sediment concentrations with consensus-based values and comparison of crayfish tissue concentrations with CBRs) and were weighted “low/moderate” and “moderate”, respectively. Risks were indicated to be “possible/moderate” magnitude based on sediment chemistry (note: 7/10 samples exceeded the TEC and 5/10 samples exceeded the PEC), but risk was indicated to be “unlikely/high” based on crayfish tissue chemistry. Combined, these lines of evidence suggest mercury contamination may possibly be having an adverse effect on the benthic community in Reach 5. It is possible that the toxicity expected based on sediment chemistry is not being expressed based on the tissue chemistry due to various issues with bioavailability.

**Fish Population Survival and Reproduction** – Two measurement endpoints were evaluated for this assessment endpoint for Reach 5 (Table 4-64). The tissue chemistry measurement endpoint (i.e., comparison of fish tissue concentrations with CBRs) was weighted “moderate-high” and risk was “unlikely/undetermined” or “unlikely/high” for all species/size class combinations, except for the largemouth bass, which was noted as “possible/low-moderate.” Note that 90% of the fish tissue concentrations were below the NEL, and 10% of fish samples with concentrations greater than the NEL (but lower than the LEL) were TL > 20 cm. The water chemistry endpoint was weighted “low/moderate” and did not indicate risk (i.e., “unlikely/high”). Combined, these lines of evidence suggest that it is not likely that mercury contamination is having an adverse effect on the overall fish community in Reach 5.

**Insectivorous Bird Survival, Reproduction, and Neurological Effects** – Only one measurement endpoint was evaluated for this assessment endpoint for Reach 5 (Table 4-64); therefore, there is no true discussion of concurrence for this endpoint. The tree swallow exposure modeling measurement endpoint was weighted “moderate” and “possible/moderate” risk was indicated. This designation was determined from total mercury HQs for the RME case based on the no-effects based TRV of 2.2 and based on the effect-based TRV of 1.1.

**Piscivorous Bird Survival, Reproduction, and Neurological Effects** – Two measurement endpoints were evaluated for this assessment endpoint for Reach 5 (Table 4-64). Both of these measurement endpoints were based on wildlife receptor modeling (i.e., belted kingfisher and great blue heron) and were weighted “moderate.” “Possible/moderate” risk was indicated for the belted kingfisher, but risk was “unlikely/high” for the great blue heron. This designation for

belted kingfisher was determined from HQs for the RME case based on the no-effects based TRV of 2.3 and based on the effect-based TRV of 1.1. Combined, these lines of evidence suggest that mercury contamination may possibly be causing minimal adverse effects in smaller piscivorous birds foraging in Reach 5. However, the kingfisher exposure estimate is likely very conservative because kingfisher burrows were not found along the banks of the Sudbury River; foraging was observed in water bodies other than the Sudbury; and half of the fish portion of the dietary intake was comprised of larger fish (assumed to be more contaminated) than are most often taken as prey.

**Piscivorous Mammal Survival, Reproduction, and Neurological Effects** – Two measurement endpoints were evaluated for this assessment endpoint for Reach 5 (Table 4-64). The tissue chemistry endpoint (i.e., mink fur) was weighted “moderate;” risk was “possible/low-moderate.” The mink exposure modeling endpoint was weighted “moderate-high” and risk was noted as “possible/low-moderate.” Combined, these lines of evidence suggest that it is possible that mercury contamination is causing adverse effects in piscivorous mammals in Reach 5.

#### **4.3.2.2.4.1 Summary – Reach 5**

Overall, ecologically adverse effects from mercury contamination in Reach 5 are mixed for aquatic organisms (i.e., possible for benthic and unlikely for aquatic communities), but may be occurring in insectivorous birds, smaller piscivorous birds, and piscivorous mammals. Based on the available data, it is likely that if negative effects on the fish population are occurring, it is isolated to the larger (i.e., TL > 20 cm) fish. However, it is important to note that concentrations in size class D yellow perch from Reach 5 were not significantly different from those in the reference area (Reach 1; Table 4-6). Given the uncertainties associated with the risk estimates, the potential risk associated with smaller piscivorous birds and piscivorous mammals are likely not ecologically significant. Adverse effects do not appear to be occurring in larger piscivorous birds (e.g., great blue heron).

Note that the evidence for these conclusions is not as robust as for some other reaches as only one measurement endpoint was evaluated for insectivorous birds and that the results for all birds were based solely on exposure modeling. It is also important to note that while risk was possible for the benthic community in Reach 5, the sediment concentrations were not significantly different from those in the reference area (i.e., Reach 1; see Table 4-6). In addition, 41.5% of the dietary component assumed for the kingfisher consisted of fish (size class B) that had concentrations that were not statistically significant from the reference area

(i.e., Reach 1; see Table 4-16). Approximately 20% of the dietary component assumed for the mink consisted of fish (size class B and C) that were not statistically significant from the reference area.

#### **4.3.2.2.5                      Reach 6**

Table 4-65 depicts the WOE for Reach 6 for each of the assessment endpoints; the text below describes the potential risks.

**Benthic Invertebrate Community Structure, Survival, and Reproduction** – Three measurement endpoints were evaluated for this assessment endpoint for Reach 6 (Table 4-65). The field study measurement endpoint (i.e., the *Elliptio* study) was weighted “moderate-high” and risk was “possible/moderate.” The sediment and tissue chemistry endpoints (i.e., comparison of sediment concentrations with consensus-based values and comparison of crayfish tissue concentrations with CBRs) were weighted “low/moderate” and “moderate”, respectively. Risks were indicated to be “possible/high” based on sediment chemistry (note: 11/12 samples exceeded the TEC and 8/12 samples exceeded the PEC), but risk was indicated to be “unlikely/undetermined” based on the one crayfish tissue sample. Combined, these lines of evidence suggest that mercury contamination may be having an adverse effect on the benthic community in Reach 6. It is possible that the toxicity expected based on sediment chemistry is not being expressed based on the tissue chemistry due to various issues with bioavailability.

**Fish Population Survival and Reproduction** – Only one measurement endpoint was evaluated for this assessment endpoint for Reach 6 (Table 4-65); therefore, there is no true discussion of concurrence for this endpoint. The tissue chemistry measurement endpoint (i.e., comparison of fish tissue concentrations with CBRs) was weighted “moderate-high” and indicated that risk was “unlikely/undetermined” or “unlikely/high” for all species/size class combinations, except for the largemouth bass, which was noted as “possible/low-moderate.” Note that 95% of the fish tissue concentrations were below the NEL, and 5% of fish samples with concentrations greater than the NEL (but lower than the LEL) were TL > 20 cm.

**Insectivorous Bird Survival, Reproduction, and Neurological Effects** – Only one measurement endpoint was evaluated for this assessment endpoint for Reach 6 (Table 4-65); therefore, there is no true discussion of concurrence for this endpoint. The tree swallow exposure modeling measurement endpoint was weighted “moderate” and “possible/moderate”



risk was indicated. This designation was determined from total HQs for the RME case based on the no-effects based TRV of 6.2 and based on the effect-based TRV of 3.1.

**Piscivorous Bird Survival, Reproduction, and Neurological Effects** – Two measurement endpoints were evaluated for this assessment endpoint for Reach 6 (Table 4-65). Both of these measurement endpoints were based on wildlife receptor modeling (i.e., belted kingfisher and great blue heron) and were weighted “moderate.” Risk was “possible/low-moderate” for the belted kingfisher, and risk was “unlikely/high” for the great blue heron. Combined, these lines of evidence suggest that mercury contamination may possibly be causing minimal adverse effects in smaller piscivorous birds foraging in Reach 6, but likely is not causing adverse effects in larger piscivores. However, the kingfisher exposure estimate is likely very conservative because kingfisher burrows were not found along the banks of the Sudbury River; foraging was observed in water bodies other than the Sudbury; and half of the fish portion of the dietary intake was comprised of larger fish (assumed to be more contaminated) than are most often taken as prey.

**Piscivorous Mammal Survival, Reproduction, and Neurological Effects** – Only one measurement endpoint, mink exposure modeling, was evaluated for this assessment endpoint for Reach 6 (Table 4-65). The modeling measurement endpoint was weighted “moderate-high” and adverse effects from mink foraging in Reach 6 were “unlikely/high.”

#### **4.3.2.2.5.1 Summary – Reach 6**

Overall, ecologically adverse effects from mercury contamination in Reach 6 are mixed for aquatic organisms (i.e., possible for benthic and unlikely for aquatic communities), but may be occurring in insectivorous birds, and smaller piscivorous birds. Based on the available data, it is likely that if negative effects on the fish population are occurring, it is isolated to the larger (i.e., TL > 20 cm) fish. Given the uncertainties associated with the risk estimates, the potential risks associated with smaller piscivorous birds are likely not ecologically significant. Adverse effects do not appear to be occurring in larger piscivorous birds (e.g., great blue heron). Note that the evidence for these conclusions is not as robust as for some other reaches as only one measurement endpoint was evaluated for the aquatic community, insectivorous birds, and piscivorous mammals; and that the results for all birds and mammals were based solely on exposure modeling.

#### 4.3.2.2.6

#### Reach 7

Table 4-66 depicts the WOE for Reach 7 for each of the assessment endpoints; the text below describes the potential risks.

**Benthic Invertebrate Community Structure, Survival, and Reproduction** – Two measurement endpoints were evaluated for this assessment endpoint for Reach 7 (Table 4-66). Both were chemistry endpoints (i.e., comparison of sediment concentrations with consensus-based values and comparison of crayfish tissue concentrations with CBRs) and were weighted “low/moderate” and “moderate”, respectively. Risks were indicated to be “possible/moderate” based on sediment chemistry (note: 6/16 samples exceeded the TEC and 2/16 samples exceeded the PEC), but risk was indicated to be “unlikely/high” based on crayfish tissue chemistry. Combined, these lines of evidence suggest that mercury contamination may possibly be having an adverse effect on the benthic community in Reach 7. It is possible that the toxicity expected based on sediment chemistry is not being expressed based on the tissue chemistry due to various issues with bioavailability.

**Fish Population Survival and Reproduction** – Two measurement endpoints were evaluated for this assessment endpoint for Reach 7 (Table 4-66). The tissue chemistry measurement endpoint (i.e., comparison of fish tissue concentrations with CBRs) was weighted “moderate-high” and indicated risk was “unlikely/high” for all species/size class combinations, except for the largemouth bass, which was noted as “possible/low-moderate.” Note that 95% of the fish tissue concentrations were below the NEL, and 5% of fish samples with concentrations greater than the NEL (but lower than the LEL) were TL > 20 cm. The water chemistry endpoint was also weighted “low/moderate” and did not indicate risk (i.e., “unlikely/high”). Combined, these lines of evidence suggest that it is not likely that mercury contamination is having an adverse effect on the overall fish community in Reach 7.

**Herbivorous Bird Survival, Reproduction, and Neurological Effects** – Two measurement endpoints were evaluated for this assessment endpoint for Reach 7 (Table 4-66). Both of these measurement endpoints were based on tissue chemistry (i.e., comparison of tissue concentrations with CBRs) for wood duck blood and feathers. The tissue chemistry measurement endpoint was weighted “moderate-high” and risk was “unlikely/undetermined” for all tissue types.

**Insectivorous Bird Survival, Reproduction, and Neurological Effects** – Seven measurement endpoints were evaluated for this assessment endpoint for Reach 7 (Table 4-66). Six of these measurement endpoints were based on tissue chemistry (i.e., comparison of tissue concentrations with CBRs) for various species and tissue types. The endpoints based on tree swallow tissue were weighted “moderate-high;” the endpoints based on marsh bird tissue were weighted “moderate;” and the endpoint based on eastern kingbird tissue was weighted “low-moderate.” Tree swallow blood and egg chemistry indicated that risk was “unlikely/high”; whereas the feather chemistry was “possible/low-moderate.” Eastern kingbird egg risks were noted as “unlikely/high.” Marsh bird blood was always indicated to be of “unlikely/undetermined” or “unlikely/high” risk. Marsh bird feathers were indicated to be of “possible/undetermined” risk for the common yellowthroat and yellow warbler, “possible/low-moderate” risk for the song sparrow and swamp sparrow; but were of “unlikely/undetermined” risk for the northern waterthrush. The tree swallow modeling endpoint was weighted “moderate” and indicated that risk was “unlikely/high” based on total mercury HQs. Combined, these lines of evidence suggest that mercury contamination may possibly be causing minimal adverse effects in insectivorous birds foraging in Reach 7.

**Piscivorous Bird Survival, Reproduction, and Neurological Effects** – Four measurement endpoints were evaluated for this assessment endpoint for Reach 7 (Table 4-66). Two of these measurement endpoints were based on tissue chemistry (i.e., comparison of belted kingfisher blood and feather tissue concentrations with CBRs) and were weighted “moderate” and indicated that risks were “unlikely/high” and “possible/low-moderate,” respectively. The wildlife modeling endpoints were weighted “moderate” and indicated “possible/moderate” risk for the belted kingfisher and “unlikely/high” for the great blue heron. The designation for the belted kingfisher was determined from HQs for the RME case based on the no-effects based TRV of 2.4 and based on the effect-based TRV of 1.2. Combined, these lines of evidence suggest that mercury contamination may be causing low magnitude adverse effects in smaller piscivorous birds foraging in Reach 7. However, the kingfisher exposure estimate is likely very conservative because kingfisher burrows were not found along the banks of the Sudbury River; foraging was observed in water bodies other than the Sudbury; and half of the fish portion of the dietary intake was comprised of larger fish (assumed to be more contaminated) than are most often taken as prey.

**Piscivorous Mammal Survival, Reproduction, and Neurological Effects** – Three measurement endpoints were evaluated for this assessment endpoint for Reach 7 (Table 4-66).

The tissue chemistry endpoints (i.e., mink blood and fur) were weighted “moderate” and risk was not indicated (i.e., “unlikely/undetermined”). The mink exposure modeling endpoint was weighted “moderate-high” and risk was noted as “possible/low-moderate.” The designation was assigned based on HQs for the RME case based on the no-effects based TRV of 1.5 and based on the effect-based TRV of 0.61. Combined, these lines of evidence suggest that mercury contamination is not likely causing adverse effects in piscivorous mammals in Reach 7.

#### **4.3.2.2.6.1                      Summary – Reach 7**

Overall, ecologically adverse effects from mercury contamination in Reach 7 are mixed for aquatic organisms (i.e., possible for benthic and unlikely for aquatic communities) and insectivorous birds and unlikely for herbivorous waterfowl, but may be occurring in smaller piscivorous birds. Based on the available data, it is likely that if negative effects on the fish population are occurring, it is isolated to the larger (i.e., TL > 20 cm) fish. Ecologically significant adverse effects do not appear to be occurring in larger piscivorous birds (e.g., great blue heron) or in piscivorous mammals.

It is also important to note that while risk was possible for the benthic community in Reach 7, the sediment concentrations were not significantly different from those in the reference area (i.e., Reach 1; see Table 4-6). In addition, approximately 20% of the dietary component assumed for the mink consisted of fish (size classes C and D) that had concentrations that were not statistically significant from the reference area (i.e., Reach 1; see Table 4-16). It is important to note that risks for kingfisher feathers from the reference area (Charles River) were “possible/low-moderate.”

#### **4.3.2.2.7                      Reach 7-Heard Pond**

Table 4-67 depicts the WOE for Reach 7-Heard Pond for each of the assessment endpoints; the text below describes the potential risks.

**Benthic Invertebrate Community Structure, Survival, and Reproduction** – Only one measurement endpoint was evaluated for this assessment endpoint for Reach 7-Heard Pond (Table 4-67); therefore, there is no true discussion of concurrence for this endpoint. The sediment chemistry endpoint (i.e., comparison of sediment concentrations with consensus-based values) and was weighted “low/moderate.” Risks were indicated to be “possible/high” (note: 4/4 samples exceeded both the TEC the PEC).

**Fish Population Survival and Reproduction** – Only one measurement endpoint was evaluated for this assessment endpoint for Reach 7-Heard Pond (Table 4-67); therefore, there is no true discussion of concurrence for this endpoint. The tissue chemistry measurement endpoint (i.e., comparison of fish tissue concentrations with CBRs) was weighted “moderate-high” and risk was “unlikely/high” for all species/size class combinations.

**Insectivorous Bird Survival, Reproduction, and Neurological Effects** – Six measurement endpoints were evaluated for this assessment endpoint for Reach 7-Heard Pond (Table 4-67). Five of these measurement endpoints were based on tissue chemistry (i.e., comparison of tissue concentrations with CBRs) for various species and tissue types. The endpoints based on tree swallow tissue were weighted “moderate-high” and the endpoints based on marsh bird tissue were weighted “moderate.” Tree swallow blood indicated that risk was “possible/moderate,” feathers indicated that risk was “possible/low-moderate,” and egg chemistry indicated that risk was “unlikely/high.” Marsh bird (song and swamp sparrow) blood comparisons with CBRs indicated “unlikely/high” risk. The tree swallow modeling endpoint was weighted “moderate” and indicated “possible/moderate” risk. This designation was assigned based on total mercury HQs for the RME case based on the no-effects based TRV of 4.0 and based on the effect-based TRV of 2.0. Combined, these lines of evidence suggest that mercury contamination may be causing adverse effects in insectivorous birds foraging in Reach 7-Heard Pond.

**Piscivorous Bird Survival, Reproduction, and Neurological Effects** – Two measurement endpoints were evaluated for this assessment endpoint for Reach 7-Heard Pond (Table 4-67). Both of these measurement endpoints were based on wildlife receptor modeling (i.e., belted kingfisher and great blue heron) and were weighted “moderate.” Risk was not indicated (i.e., “unlikely/high”) for either endpoint. Combined, these lines of evidence suggest that mercury contamination is not causing adverse effects in piscivorous birds foraging in Reach 7-Heard Pond.

**Piscivorous Mammal Survival, Reproduction, and Neurological Effects** – Only one measurement endpoint, mink exposure modeling, was evaluated for this assessment endpoint for Reach 7-Heard Pond (Table 4-67). The modeling measurement endpoint was weighted “moderate-high” and risk was not indicated (i.e., “unlikely/high”) for mink foraging in Reach 7-Heard Pond.

#### 4.3.2.2.7.1

#### Summary – Reach 7-Heard Pond

Overall, ecologically adverse effects from mercury contamination in Reach 7-Heard Pond was indicated for the benthic community but not for the aquatic community. Ecological adverse effects may be occurring in insectivorous birds; but are not indicated for piscivorous birds and mammals. Note that the evidence for these conclusions is not as robust as for some other reaches as only one measurement endpoint was evaluated for each of the benthic and aquatic communities, and that the results for piscivorous birds and mammals were based solely on exposure modeling.

#### 4.3.2.2.8

#### Reach 8

Table 4-68 depicts the WOE for Reach 8 for each of the assessment endpoints; the text below describes the potential risks.

**Benthic Invertebrate Community Structure, Survival, and Reproduction** – Two measurement endpoints were evaluated for this assessment endpoint for Reach 8 (Table 4-68). The field study measurement endpoint (i.e., the *Hexagenia* study) was weighted “moderate-high” and noted risks were “unlikely/moderate.” The sediment chemistry endpoint (i.e., comparison of sediment concentrations with consensus-based values) was weighted “low/moderate” and indicated “possible/moderate” risk. Combined, these lines of evidence suggest that mercury contamination may possibly be having an adverse effect on the benthic community in Reach 8. It is possible that the toxicity expected based on sediment chemistry is not being expressed based on the field study due to various issues with bioavailability.

**Fish Population Survival and Reproduction** – Two measurement endpoints were evaluated for this assessment endpoint for Reach 8 (Table 4-68). The tissue chemistry measurement endpoint (i.e., comparison of fish tissue concentrations with CBRs) was weighted “moderate-high” and indicated risk was “unlikely/high” for all species/size class combinations, except for the largemouth bass, which was noted as “possible/moderate.” Note that 95% of the fish tissue concentrations were below the NEL, with 7 fish samples with concentrations greater than the NEL but lower than the LEL, and only 1 fish sample with a concentration greater than the LEL. All of the fish samples with concentrations greater than the NEL were TL > 20 cm. The water chemistry endpoint was weighted “low/moderate” and did not indicate risk (i.e., “unlikely/high”). Combined, these lines of evidence suggest that it is unlikely that mercury contamination is having an adverse effect on the overall fish community in Reach 8.

**Herbivorous Bird Survival, Reproduction, and Neurological Effects** – Three measurement endpoints were evaluated for this assessment endpoint for Reach 8 (Table 4-68). These measurement endpoints were based on tissue chemistry (i.e., comparison of tissue concentrations with CBRs) for wood duck blood, feathers, and eggs. The tissue chemistry measurement endpoint was weighted “moderate-high” and risk was “unlikely/undetermined” or “unlikely/high” for all tissue types.

**Insectivorous Bird Survival, Reproduction, and Neurological Effects** – Eight measurement endpoints were evaluated for this assessment endpoint for Reach 8 (Table 4-68). Seven of these measurement endpoints were based on tissue chemistry (i.e., comparison of tissue concentrations with CBRs) for various species and tissue types. The endpoints based on tree swallow tissue were weighted “moderate-high;” the endpoints based on marsh bird tissue were weighted “moderate;” and the endpoint based on eastern kingbird tissue was weighted “low-moderate.”

When comparing 2003 samples; tree swallow blood and eggs indicated that risk was “unlikely/high,” but feathers indicated a “possible/low-moderate” risk. Using 2004 concentrations, tree swallow blood indicated that risk was “possible/moderate,” feathers indicated that risk was “possible/low-moderate,” and egg chemistry indicated that risk was “unlikely/high.” Eastern kingbird egg risks were noted as “unlikely/high.” Redwing blackbird blood concentrations compared with CBRs indicated “possible/high” risk. Marsh bird blood was indicated to be “unlikely/high” risk for common yellowthroat, 2004 song sparrow concentrations, 2004 swamp sparrow concentrations, and yellow warblers. 2003 song sparrow blood concentrations indicated “possible/moderate” risk and 2003 swamp sparrows indicated “possible/low” risk. Marsh bird feathers were only collected in 2003 and were indicated to be of “possible/low-moderate” risk for the common yellowthroat, song sparrow, and swamp sparrow; but were of “possible/undetermined” risk based on the one yellow warbler sample.

The tree swallow modeling endpoint was weighted “moderate” and indicated that risk was “unlikely/high” based on the total mercury HQs. Combined, these lines of evidence suggest that mercury contamination may be causing adverse effects in some insectivorous birds foraging in Reach 8.

**Piscivorous Bird Survival, Reproduction, and Neurological Effects** – Eight measurement endpoints were evaluated for this assessment endpoint for Reach 8 (Table 4-68). Four of these measurement endpoints were based on tissue chemistry (i.e., comparison of tissue

concentrations with CBRs) and were weighted “moderate-high.” Kingfisher nestling blood (from Transfer Station Pit and Route 117 Pit) and one egg (from Route 117 Pit) indicated risk was “unlikely/undetermined.” The Transfer Station Pit had tissue concentrations indicating “possible/low-moderate” and “possible/undetermined” risk for blood and feathers, respectively. Macone’s Pile had tissue concentrations indicating “possible/low” and “possible/low-moderate” for blood and feathers, respectively. Route 117 Pit had tissue concentrations indicating “possible/low-moderate” and “possible/moderate” risk for blood and feathers, respectively.

Hooded merganser tissues also showed a mix of potential risks. Blood concentrations indicated “unlikely/undetermined” and “possible/low” risks in samples from 2004 and 2005, respectively. Feather concentrations indicated “possible/undetermined” and “possible/low-moderate” risks in samples from 2004 and 2005, respectively. Egg concentrations showed “possible/moderate” risks (sampled in 2005 only).

The wildlife modeling endpoints were weighted “moderate” and indicated “possible/moderate” risk for the belted kingfisher and “unlikely/high” risk for the great blue heron. The kingfisher designation was determined from HQs for the RME case based on the no-effects based TRV of 2.3 and based on the effect-based TRV of 1.2.

Combined, these lines of evidence suggest that mercury contamination may be causing low magnitude adverse effects in smaller piscivorous birds foraging in Reach 8. However, the kingfisher exposure estimate is likely very conservative because kingfisher burrows were not found along the banks of the Sudbury River; foraging was observed in water bodies other than the Sudbury; and half of the fish portion of the dietary intake was comprised of larger fish (assumed to be more contaminated) than are most often taken as prey. Lastly, the piscivorous bird diet was composed solely of fish (because crayfish data were not available in this reach); therefore dose estimates are likely overestimated because they are of a higher trophic level (and have higher mercury concentrations) than benthic invertebrates.

**Piscivorous Mammal Survival, Reproduction, and Neurological Effects** – Only one measurement endpoint, mink exposure modeling, was evaluated for this assessment endpoint for Reach 8 (Table 4-68). The modeling measurement endpoint was weighted “moderate-high” and noted the potential for “possible/moderate” risk for mink foraging in Reach 8. This designation was determined from HQs for the RME case based on the no-effects based TRV of 3.0 and based on the effect-based TRV of 1.2. Note that the mammal diet was composed solely of fish (because crayfish data were not available in this reach); therefore dose estimates



are likely overestimated because they are of a higher trophic level (and have higher mercury concentrations) than benthic invertebrates.

#### **4.3.2.2.8.1 Summary – Reach 8**

Overall, ecologically adverse effects from mercury contamination in Reach 8 are mixed for aquatic organisms (i.e., possible for benthic and unlikely for aquatic communities) and unlikely for herbivorous waterfowl, but may be occurring in insectivorous birds and smaller piscivorous birds. Based on the available data, it is likely that if negative effects on the fish population are occurring, it is isolated to the larger (i.e., TL > 20 cm) fish. Ecologically significant adverse effects do not appear to be occurring in larger piscivorous birds (e.g., great blue heron) or in piscivorous mammals.

Note that only one measurement endpoint was evaluated for piscivorous mammals. It is also important to note that while risk was possible for the benthic community in Reach 8, the sediment concentrations were not significantly different from those in the reference area (i.e., Charles River; see Table 4-6). In addition, it is important to note that for tree swallow feathers collected in the reference area in 2004, risks were “possible/low-moderate;” and risk for marsh birds feathers collected in the reference area were “possible/low-moderate” to “possible/moderate.” For hooded mergansers from the 2004 reference area (Charles River), risks were “possible/high” for blood and eggs and “possible/low-moderate” for feathers. Risks based on kingfisher feathers from the reference area (Charles River) were “possible/low-moderate.” Lastly, approximately 25% of the dietary component assumed for the mink consisted of fish (size class D) that had concentrations that were not statistically significant from the reference area (i.e., Reach 1; see Table 4-16).

#### **4.3.2.2.9 Reach 9**

Table 4-69 depicts the WOE for Reach 9 for each of the assessment endpoints; the text below describes the potential risks.

**Benthic Invertebrate Community Structure, Survival, and Reproduction** – Three measurement endpoints were evaluated for this assessment endpoint for Reach 9 (Table 4-69). The field study measurement endpoints (i.e., the *Hexagenia* and *Elliptio* studies) were weighted “moderate-high” and noted risks were “unlikely/moderate” for both endpoints. The sediment chemistry endpoint (i.e., comparison of sediment concentrations with consensus-based values) was weighted “low/moderate” and indicated “possible/high” risk. Risks were indicated to be of

“high” magnitude based on sediment chemistry (10/10 samples exceeded the TEC and 7/10 samples exceeded the PEC). Combined, these lines of evidence suggest that mercury contamination may possibly be having an adverse effect on the benthic community in Reach 9. It is possible that the toxicity expected based on sediment chemistry is not being expressed based on the field studies due to various issues with bioavailability.

**Fish Population Survival and Reproduction** – Only one measurement endpoint was evaluated for this assessment endpoint for Reach 9 (Table 4-69); therefore, there is no true discussion of concurrence for this endpoint. The tissue chemistry measurement endpoint (i.e., comparison of fish tissue concentrations with CBRs) was weighted “moderate-high” and indicated risk was “unlikely/high” for all species/size class combinations, except for the largemouth bass, which was noted as “possible/moderate.” Note that 90% of the fish tissue concentrations were below the NEL, with 4 fish samples with concentrations greater than the NEL but lower than the LEL, and only 1 fish sample with a concentration greater than the LEL. All of the fish samples with concentrations greater than the NEL were TL > 20 cm. (Figure 4-18).

**Insectivorous Bird Survival, Reproduction, and Neurological Effects** – Two measurement endpoints were evaluated for this assessment endpoint for Reach 9 (Table 4-69). One of these measurement endpoints was based on tissue chemistry (i.e., comparison of kingbird egg concentrations with CBRs) and was weighted “low-moderate.” The risk based on the tissue chemistry endpoint was “unlikely/high.” The tree swallow modeling endpoint was weighted “moderate” and indicated “possible/moderate” risk. This designation was assigned based on total mercury HQs for the RME case based on the no-effects based TRV of 2.2 and based on the effect-based TRV of 1.1. Combined, these lines of evidence suggest that mercury contamination may possibly be causing minimal adverse effects in some insectivorous birds foraging in Reach 9.

**Piscivorous Bird Survival, Reproduction, and Neurological Effects** – Two measurement endpoints were evaluated for this assessment endpoint for Reach 9 (Table 4-69). Both of these measurement endpoints were based on wildlife receptor modeling (i.e., belted kingfisher and great blue heron) and were weighted “moderate.” Risk was “possible/moderate” for the belted kingfisher, and risk was not indicated for the great blue heron (i.e., “unlikely/high”). The “possible/moderate” designation for the belted kingfisher was assigned based on HQs for the RME case based on the no-effects based TRV of 2.5 and based on the effect-based TRV of 1.2.

Combined, these lines of evidence suggest mercury contamination may be causing adverse effects in smaller piscivorous birds foraging in Reach 9, but likely is not causing adverse effects in larger piscivores. However, the kingfisher exposure estimate is likely very conservative because kingfisher burrows were not found along the banks of the Sudbury River; foraging was observed in water bodies other than the Sudbury; and half of the fish portion of the dietary intake was comprised of larger fish (assumed to be more contaminated) than are most often taken as prey. Lastly, the piscivorous bird diet was composed solely of fish (because crayfish data were not available in this reach); therefore dose estimates are likely overestimated because they are of a higher trophic level (and have higher mercury concentrations) than benthic invertebrates.

**Piscivorous Mammal Survival, Reproduction, and Neurological Effects** – Only one measurement endpoint, mink exposure modeling, was evaluated for this assessment endpoint for Reach 9 (Table 4-69). The modeling measurement endpoint was weighted “moderate-high” and “possible/moderate” risk was indicated. The designation was assigned based on HQs for the RME case based on the no-effects based TRV of 3.8 and based on the effect-based TRV of 1.5. The piscivorous mammal diet was composed solely of fish (because crayfish data were not available in this reach); therefore dose estimates are likely overestimated because they are of a higher trophic level (and have higher mercury concentrations) than benthic invertebrates.

#### **4.3.2.2.9.1 Summary – Reach 9**

Overall, ecologically adverse effects from mercury contamination in Reach 9 are possible for benthic communities, unlikely in aquatic communities (e.g., fish), and may be occurring in insectivorous birds, smaller piscivorous birds, and piscivorous mammals. Based on the available data, it is likely that if negative effects on the fish population are occurring, it is isolated to the larger (i.e., TL > 20 cm) fish. Given the uncertainties associated with the risk estimates, the potential risks associated with piscivorous mammals are likely not ecologically significant. Adverse effects do not appear to be occurring in larger piscivorous birds (e.g., great blue heron).

Note that the evidence for these conclusions is not as robust as for some other reaches as only one measurement endpoint was evaluated for the aquatic community and piscivorous mammals; and that the results for all birds and mammals were based solely on exposure modeling. Lastly, approximately 25% of the dietary component assumed for the mink consisted

of fish (size class D) that had concentrations that were not statistically significant from the reference area (i.e., Reach 1; see Table 4-16).

#### **4.3.2.2.10                      Reach 10**

Table 4-70 depicts the WOE for Reach 10 for each of the assessment endpoints; the text below describes the potential risks.

**Benthic Invertebrate Community Structure, Survival, and Reproduction** – Two measurement endpoints were evaluated for this assessment endpoint for Reach 10 (Table 4-70). The field study measurement endpoint (i.e., the *Elliptio* study) was weighted “moderate-high” and risk was “unlikely/moderate.” The sediment chemistry endpoint (i.e., comparison of sediment concentrations with consensus-based values) was weighted “low/moderate” and indicated “possible/moderate” risk (note: 7/10 samples exceeded the TEC and 2/10 samples exceeded the PEC). Combined, these lines of evidence suggest that it is not known if mercury contamination is having an adverse effect on the benthic community in Reach 10. It is possible that the toxicity expected based on sediment chemistry is not being expressed based on the field studies due to various issues with bioavailability.

**Fish Population Survival and Reproduction** – Only one measurement endpoint was evaluated for this assessment endpoint for Reach 10 (Table 4-70); therefore, there is no true discussion of concurrence for this endpoint. The tissue chemistry measurement endpoint (i.e., comparison of fish tissue concentrations with CBRs) was weighted “moderate-high” and indicated risk was “unlikely/high” for all species/size class combinations, except for the yellow perch size class A, which was noted as “possible/undetermined” and largemouth bass, which was noted as “possible/high.” Note that 90% of the fish tissue concentrations were below the NEL, with 4 fish samples with concentrations greater than the NEL but lower than the LEL, and only 2 fish samples had a concentration greater than the LEL. All of the fish samples with concentrations greater than the NEL were TL > 20 cm largemouth bass (Figure 4-19).

**Insectivorous Bird Survival, Reproduction, and Neurological Effects** – Two measurement endpoints were evaluated for this assessment endpoint for Reach 10 (Table 4-70). One of these measurement endpoints was based on tissue chemistry (i.e., comparison of kingbird egg concentrations with CBRs) and was weighted “low-moderate.” The risk based on the tissue chemistry endpoint was “unlikely/high.” The tree swallow modeling endpoint was weighted “moderate” and risk was “possible/low-moderate” based on total mercury HQs. Combined,

these lines of evidence suggest that mercury contamination may possibly be causing minimal adverse effects in insectivorous birds foraging in Reach 10.

**Piscivorous Bird Survival, Reproduction, and Neurological Effects** – Two measurement endpoints were evaluated for this assessment endpoint for Reach 10 (Table 4-70). Both of these measurement endpoints were based on wildlife receptor modeling (i.e., belted kingfisher and great blue heron) and were weighted “moderate.” Risk was “possible/moderate” for the belted kingfisher, and risk was “possible/low-moderate” for the great blue heron. The designation for the belted kingfisher was assigned based on HQs for the RME case based on the no-effects based TRV of 2.8 and based on the effect-based TRV of 1.4.

Combined, these lines of evidence suggest mercury contamination may be causing adverse effects in piscivorous birds foraging in Reach 10. However, the kingfisher exposure estimate is likely very conservative because kingfisher burrows were not found along the banks of the Sudbury River; foraging was observed in water bodies other than the Sudbury; and half of the fish portion of the dietary intake was comprised of larger fish (assumed to be more contaminated) than are most often taken as prey. Lastly, the piscivorous bird diet was composed solely of fish (because crayfish data were not available in this reach); therefore dose estimates are likely overestimated because they are of a higher trophic level (and have higher mercury concentrations) than benthic invertebrates.

**Piscivorous Mammal Survival, Reproduction, and Neurological Effects** – Only one measurement endpoint, mink exposure modeling, was evaluated for this assessment endpoint for Reach 10 (Table 4-70). The modeling measurement endpoint was weighted “moderate-high” and “possible/moderate” risk was indicated. The designation was assigned based on HQs for the RME case based on the no-effects based TRV of 4.6 and based on the effect-based TRV of 1.9. The piscivorous mammal diet was composed solely of fish (because crayfish data were not available in this reach); therefore dose estimates are likely overestimated because they are of a higher trophic level (and have higher mercury concentrations) than benthic invertebrates.

#### **4.3.2.2.10.1 Summary – Reach 10**

Overall, ecologically adverse effects from mercury contamination in Reach 10 may be occurring in benthic communities, aquatic communities (e.g., fish), insectivorous birds, piscivorous birds, and piscivorous mammals. Based on the available data, it is likely that if negative effects on the

fish population are occurring, it is isolated to the larger (i.e., TL > 20 cm) fish. Given the uncertainties associated with the risk estimates, the potential risks associated with piscivorous birds and piscivorous mammals are likely not ecologically significant.

Note that the evidence for these conclusions is not as robust as for some other reaches as only one measurement endpoint was evaluated for the aquatic community and piscivorous mammals; and that the results for piscivorous birds and mammals were based solely on exposure modeling. It is also important to note that while risk was undetermined for the benthic community in Reach 10, the sediment concentrations were not significantly different from those in the reference area (i.e., Reach 1; see Table 4-6).

#### **4.3.3 Incremental Risk**

Incremental Risk (IR), which is the risk attributable releases from the Nyanza Site, was not discussed in the risk characterization. Instead, the conclusions were based strictly on “reach-specific” risks without accounting for “background” risks. The latter were discussed in the risk estimation separate from site-specific risks and shown qualitatively in each of the risk summary tables but were not quantified in the Risk Description.

The issue of IR is important for two reasons: (1) Hg is a ubiquitous environmental contaminant due to region-wide atmospheric deposition, and (2) some of the reach-specific risks may drop (e.g., from risk scenario 6 (red) to risk scenario 5 (orange)) if background risks are considered. IR can be estimated by subtracting HQs developed for reference areas from the associated reach-specific HQs; the resulting difference is defined as the IR and can be interpreted as the risk resulting from site-related releases.

An IR analysis is only needed for the two highest risk scenarios (risk scenario 5 – orange, and risk scenario 6 – red). These two scenarios represent “possible” population risks with confidence levels of “high” or “moderate” and may be considered actionable. Risk Scenarios 1 through 4 represent risk levels that would not be considered actionable and therefore are not included in the IR analysis.

The IR calculations for endpoints with resulting risk scenarios of 5 or 6 are summarized by reach in Table 4-71. Table 4-71 dramatically illustrates a majority of the risk levels of concern within the study area are driven by mercury present as a result of anthropogenic mercury concentrations that are not site-related.

#### **4.4 Risk Conclusions**

The results of the 1999 BERA (Weston, 1999a) suggested that ecological risk might be present in Sudbury River Reaches 2, 3, 5, 6, 7, 8 and 9 due to mercury contamination in sediment and subsequent bioaccumulation in aquatic organisms. However, internal review comments to this BERA identified many data gaps that resulted in much uncertainty with the findings. Region 1 EPA developed a scope of work in March 2003 that identified an approach to address existing data gaps and reduce uncertainty when developing the final SBERA for Nyanza OU IV – Sudbury River. The primary objectives of the scope of work were to:

- accurately identify environmental bioaccumulation for mercury
- indicate where and what magnitude risks apply to what environmental receptors for which media, and
- otherwise provide data that is useful to the risk manager.

The scope of work for this SBERA broke the Sudbury River Reaches into 4 major decision target areas:

##### Primary target areas

- Reaches 2, 3, and 4 (primary reservoirs – note: Reach 2 is impounded at Mill Pond, but is not strictly a reservoir)
- Reach 8 – Great Meadows National Wildlife Refuge

##### Secondary target areas

- Reaches 5, 6, and 7 (flowing reaches)
- Reaches 9 and 10 (Fairhaven Bay and remainder of river)

For most reaches, all six assessment endpoints for this SBERA (see Table 2-68) were evaluated with two or more lines of evidence to assess risk using a WOE approach. Using a systematic WOE process integrated both the quality of the assessment and the magnitude of response for each line of evidence.

Using the risk criteria from Section 4.3 and comparing to concentrations at local reference areas and from regional data sources, only four lines of evidence showed a likelihood of adverse ecological effects above baseline: sediment mercury concentrations compared to benthic community TEC and PEC benchmarks; mercury levels in TL >20 cm fish compared with LEL reproductive CBRs, mercury levels in Reach 8 red-winged blackbird blood (collected in MA-1665-2008-F

2005) compared to a generic avian blood effect level, and mercury levels in hooded merganser eggs from Reaches 4 and 8 in 2005. The following discussion evaluates the confidence and uncertainty with these four lines of evidence and assesses the risks associated with the assessment endpoints related to these lines of evidence.

Mercury concentrations in sediment were compared to consensus-based sediment quality guidelines (TEC and PEC) by MacDonald et al. (2000). In the uncertainty analysis, many concerns were identified by using co-occurrence sediment quality benchmarks to assess specific sediment sample toxicity (O'Connor et al, 1998; O'Connor, 1999; Lee and Jones-Lee, 2002). Note also that the mercury TEC did not meet the authors' criteria of predicting no toxic effect in 75% of the samples evaluated (the mercury TEC was successful 34% of the time). The PEC was more successful in predicting toxic effects in test samples; however, the data set used for the PEC development only had 4 toxic samples. Also, this SBERA has cited many studies showing that total mercury in sediments do not correlate strongly with mercury bioavailability and subsequent trophic transfer. The *Elliptio* study showed lower growth, but no effect on survival, in Reaches 2 and 3. However, growth was not reduced in Reaches 9 and 10, which were used as surrogate reference areas. The two other lines of evidence used to evaluate impacts to the benthic community (i.e., the *Hexagenia* [Reaches 3, 4, 8, and 9] and crayfish tissue levels [Reaches 2 through 7]) did not show risk to the benthic community. Therefore, we believe it is wise to follow the advice of Chapman (1995) and others that these benchmarks should not be used for stand-alone decision making. It is concluded that risk to the benthic community in the Sudbury River is limited, given the lack of concurrence between measurement endpoints, the high degree of uncertainty associated with sediment benchmarks and the surface water data that indicate that methylation is mostly associated with the wetland areas bordering Reaches 7 and 8.

Except for 4 largemouth bass (size class D, > 20 cm) samples; one each from Reaches 8 and 9, and two from Reach 10, there were no exceedances of the reproductive LEL. In general, over 90% of all fish samples were less than the reproductive NEL. While mercury concentrations were typically higher in impacted reaches when compared to reference areas and regional background, it appears that potential adverse effect levels are limited to larger, older fish at a higher trophic level. These results are consistent with previous studies describing the biomagnification potential of mercury in aquatic systems; however, the data do not support a conclusion of population-level risk for fish based on reproductive impairment.



Redwing blackbird blood evaluated in this assessment was limited to 10 samples (4 juvenile and 6 adult) collected in August of 2005. All 10 samples exceeded the conservative avian blood CBR derived from field observations of loon chick behavior, where a strong correlation was found between higher blood mercury levels in chicks and less time riding parents' backs but more time spent preening. These behavioral changes resulted in increased energy expenditures which were not compensated for with a higher feeding rate or more begging to parents for food; suggesting a reduction in the overall fitness of the affected chicks.

A key factor to consider in the interpretation of the redwing blackbird data is that these birds were sampled well beyond the point in the season when reproduction and chick rearing occur. Most of the other insectivorous bird blood samples collected for this assessment were obtained in the spring and early summer (only 25% of the 235 insectivorous bird blood samples were collected as late as August). Such early-season blood samples may not reflect long-term, site-specific exposures; however, these samples do reflect exposure during nesting and are expected to be the best indicators of survival, growth, and reproductive effects. The results of the CBR comparisons to other insectivorous bird tissue data do not suggest much concern with this assessment endpoint. Blood samples collected later in the summer reflect long-term site exposure which would include periods of lower river flow and higher water temperatures when both methylmercury concentrations in surface waters and bioaccumulation increase. Without nesting season or reference data available there is no information that would indicate adverse impacts to the assessment endpoint resulting from the blackbird blood data. However, blackbird blood results do show mercury accumulation which may indicate potential late season effects after the blackbirds leave the study area. Any effects after the nesting season and their implications for bird population dynamics are unknown, because the state of the science offers little insight on the effects of high mercury on the ability of adults to successfully nest the following year. Re-sampling of the same birds between May and July have shown that adult mercury blood concentrations often increase during the summer in contaminated areas (Oksana Lane, BRI, November 21, 2007, Personal Communication). It is therefore possible that tree swallows follow the redwing blackbird pattern by further increasing their blood mercury levels later in the summer. This theory cannot be verified because it is unfeasible to capture adult swallows after their chicks have fledged. Overall, the available evidence does not suggest a population-level risk based on effects to reproductive endpoints.

Most of the hooded merganser eggs from Reaches 4 and 8 (n=2 and 21, respectively) in 2005 exceeded the no-effect level CBR (500 µg/kg). These results alone indicate that adverse

reproductive effects are possible for this piscivorous avian species. However, three of the four merganser egg samples collected at reference locations (Delaney Wildlife Management Area and Whitehall Reservoir) in 2005 also exceeded the no-effect CBR. These findings, while limited by a small sample size for the reference areas, suggest that mercury accumulation in merganser eggs may be a regional phenomenon and not strictly associated with Nyanza site-related discharges. Reference area data must be given a great deal of weight in this context because of the widely recognized regional problem of high fish tissue mercury caused by atmospheric deposition.

Overall, the results of this SBERA do not indicate that mercury contamination resulting from Nyanza Site discharges are likely to result in population-level risk to ecological receptors residing in or using the Sudbury River. The conservative assumptions built into this approach support this conclusion, even though there is an acknowledged amount of uncertainty with several of the lines of evidence used to evaluate the six assessment endpoints.

## SECTION 4 TABLES

**Table 4-1**

**Mussel Survival after 42 Days (Mid-test) and 84 Days (End-test) Exposure in the Sudbury River  
Operable Unit IV - Nyanza Chemical Dump Superfund Site  
Middlesex County, Massachusetts**

Reach/Reference Area	% Survival	
	42 Days	84 Days
Whitehall Reservoir	77	83
Reach 1	97	91
Reach 2	100	93
Reach 3	73	95
Reach 6	100	87
Reach 8	43	36
Reach 9	80	88
Reach 10	90	87
<b>Mean</b>	<b>82.5</b>	<b>82.5</b>

Note: % survival is relative to the portion of the total mussels at a given station that were examined, hence the apparent discrepancy.

Table 4-2

**Mussel Tissue Mercury Concentration**  
**Operable Unit IV - Nyanza Chemical Dump Superfund Site**  
**Middlesex County, Massachusetts**

Station	Growth Rate (mg/wk)	Total Hg (µg/kg WW)	Methyl Hg (µg/kg WW)	Total Hg (µg/kg DW)	Methyl Hg (µg/kg DW)	Inorganic Hg (µg/kg DW)	Total Hg Content (ng)	Methyl Hg Content (ng)	Inorganic Content (ng)	% MeHg
<b>Initial</b>	-	120 (20)	25 (1.66)	640 (103)	140 (9.29)	500	510 (125)	110 (18.2)	400	22
<b>Mid Test</b>										
Whitehall Reservoir	-24	99 (22.4)	-	750 (165)	-	-	370 (116)	-	-	-
Reach 1	-64	96 (17.7)	-	780 (179)	-	-	330 (66.3)	-	-	-
Reach 2	0	120 (9.60)	-	930 (79.4)	-	-	470 (60.0)	-	-	-
Reach 3	252	84 (8.02)	-	550 (47.1)	-	-	400 (54.3)	-	-	-
Reach 6	255	85 (7.81)	-	550 (70.0)	-	-	440 (56.4)	-	-	-
Reach 8	15	67 (13.6)	-	520 (104)	-	-	310 (66.5)	-	-	-
Reach 9	281	63 (8.66)	-	370 (60.6)	-	-	330 (45.2)	-	-	-
Reach 10	318	58 (6.46)	-	330 (31.9)	-	-	320 (50.7)	-	-	-
<b>End of Test</b>										
Whitehall Reservoir	-21	100 (5.43)	41 (4.19)	890 (85.5)	360 (46.7)	530	440 (70.4)	180 (28.5)	260	40
Reach 1	-38	110 (17.3)	33 (5.41)	850 (71.9)	260 (44.3)	600	440 (90.5)	130 (28.0)	310	30
Reach 2	23	130 (5.53)	43 (3.89)	950 (33.3)	320 (29.6)	640	550 (73.1)	180 (25.2)	370	33
Reach 3	185	100 (26.3)	38 (2.08)	690 (228)	260 (24.8)	430	570 (140)	220 (33.4)	350	38
Reach 6	198	78 (5.40)	29 (6.47)	520 (56)	200 (49.8)	320	390 (64.5)	150 (31.0)	240	38
Reach 8	46	94 (26.6)	27 (3.96)	590 (127)	170 (42.8)	420	450 (108)	150 (25.5)	350	33
Reach 9	270	69 (8.95)	24 (2.44)	400 (51.1)	140 (11.0)	260	430 (92.5)	150 (31.2)	280	34
Reach 10	303	62 (5.96)	24 (0.81)	340 (35.7)	130 (3.5)	210	430 (59.5)	170 (20.1)	260	39

- =Not Measured or Not Applicable

Note: Parenthetical values are ± standard deviation.

**Table 4-3**

**Mussel Study Significant Correlation Coefficients  
Operable Unit IV - Nyanza Chemical Dump Superfund Site  
Middlesex County, Massachusetts**

<b>Comparison</b>	<b>r value</b>
WAWW* growth vs. tissue total mercury concentration	-0.95
WAWW growth vs. tissue methylmercury concentration	-0.88
WAWW growth vs. tissue inorganic mercury concentration	-0.95
EOT** tissue weight vs. tissue total mercury concentration	-0.93
EOT tissue weight vs. tissue methylmercury concentration	-0.88
EOT tissue weight vs. tissue inorganic mercury concentration	-0.91
EOT shell length vs. tissue total mercury concentration	-0.94
EOT shell length vs. tissue methylmercury concentration	-0.85
EOT shell length vs. tissue inorganic mercury concentration	0.95
EOT shell weight vs. tissue total mercury concentration	-0.93
EOT shell weight vs. tissue methylmercury concentration	-0.87
EOT shell weight vs. tissue inorganic mercury concentration	-0.92

\* Whole-animal wet weight.

\*\* End of test.

Note: Critical r-value  $r_{0.05,(2),5}=0.755$ ; all correlations are significant at the 95-percent confidence level.

**Table 4-4**

**Comparison of Crayfish Concentrations with CBRs  
Operable Unit IV - Nyanza Chemical Dump Superfund Site  
Middlesex County, Massachusetts**

Reach/Reference Area	Maximum Detected Concentration (µg/kg WW)	HQ based on	
		Effects-based CBR <sup>a</sup>	No-effects-based CBR <sup>b</sup>
Reach 1	4.72E+01	1.45E-02	3.15E-02
Reach 2	7.45E+01	2.29E-02	4.97E-02
Reach 3	2.10E+02	6.46E-02	1.40E-01
Reach 4	3.62E+01	1.11E-02	2.41E-02
Reach 5	1.92E+02	5.91E-02	1.28E-01
Reach 6	2.97E+01	9.14E-03	1.98E-02
Reach 7	8.61E+01	2.65E-02	5.74E-02
Charles River	4.57E+01	1.41E-02	3.05E-02
Sudbury Reservoir	1.31E+01	4.03E-03	8.73E-03

<sup>a</sup>Effects-based Level: 3,250 µg/kg WW based on effects to growth and the ability to seek shelter (see Section 3.3.1.1.2).

<sup>b</sup>No-effects-based Level: 1,500 µg/kg WW based on effects to growth and the ability to seek shelter (see Section 3.3.1.1.2).

Table 4-5

**Summary of Exceeded TECs and PECs**  
**Operable Unit IV - Nyanza Chemical Dump Superfund Site**  
**Middlesex County, Massachusetts**

<b>Reach/Chemical</b>	<b>Frequency of TEC Exceedances</b>	<b>Number of TEC HQs &gt; 1 &lt; 10</b>	<b>Number of TEC HQs &gt; 10 &lt; 100</b>	<b>Number of TEC HQs &gt; 100 &lt; 1000</b>	<b>Frequency PEC Exceedances</b>	<b>Number of PEC HQs &gt; 1 &lt; 10</b>	<b>Number of PEC HQs &gt; 10 &lt; 100</b>
<b>Reach 1</b>							
Total Mercury	4 / 5	3	1	0	1 / 5	1	0
<b>Reach 2</b>							
Total Mercury	8 / 12	5	3	0	4 / 12	4	0
<b>Reach 3</b>							
Total Mercury	39 / 39	1	22	16	39 / 39	17	22
<b>Reach 3 - Focus Area</b>							
Total Mercury	15 / 15	6	9	0	10 / 15	10	0
<b>Reach 4</b>							
Total Mercury	11 / 11	1	10	0	10 / 11	8	2
<b>Reach 5</b>							
Total Mercury	7 / 10	5	2	0	5 / 10	5	0
<b>Reach 5 - Focus Area</b>							
Total Mercury	5 / 15	4	1	0	1 / 15	1	0
<b>Reach 6</b>							
Total Mercury	11 / 12	5	6	0	8 / 12	8	0
<b>Reach 7</b>							
Total Mercury	6 / 16	6	0	0	2 / 16	2	0
<b>Reach 7 - Heard Pond</b>							
Total Mercury	4 / 4	0	4	0	4 / 4	4	0
<b>Reach 8</b>							
Total Mercury	8 / 13	8	0	0	1 / 13	1	0
<b>Reach 9</b>							
Total Mercury	10 / 10	9	1	0	7 / 10	7	0
<b>Reach 10</b>							
Total Mercury	7 / 10	7	0	0	2 / 10	2	0
<b>Charles River</b>							
Total Mercury	5 / 7	5	0	0	0 / 7	0	0
<b>Sudbury Reservoir</b>							
Total Mercury	3 / 6	3	0	0	0 / 6	0	0

PEC = Probable effects concentration.

TEC = Threshold effects concentration.



**Table 4-6**

**Sediment Reference Comparisons  
Operable Unit IV - Nyanza Chemical Dump Superfund Site  
Middlesex County, Massachusetts**

Reach	Total Mercury
	Site Compared with Reference Concentrations
<b>Reach 1 Reference Area</b>	
2	NS (K)
5	NS (K)
7	NS (K)
10	NS (K)
<b>Charles River Reference Area</b>	
8	NS (A)
9	S (A)
<b>Sudbury Reservoir Reference Area</b>	
3	S (K)
4	S (A)
6	S (K)
7 - Heard Pond	S (A)

Notes:

Variances tested using Variance-Ratio Equal-Variance Test and Modified-Levene Equal Variance Test.

All tests run at (  $\alpha=0.05$ ).

A = Aspin-Welch Unequal Variance Test

K = Kolmogorov-Smirnov Test for Different Distributions.

NS = Not statistically different from reference.

S = Statistically significantly different from reference.

Table 4-7

**Yellow Perch and Largemouth Bass Fish Reference Comparisons  
Operable Unit IV - Nyanza Chemical Dump Superfund Site  
Middlesex County, Massachusetts**

Reach	Site Compared with Reference Concentrations				
	Total Mercury - Whole Body			Total Mercury - Fillet	
	Yellow Perch - Size Class A <sup>a</sup>	Yellow Perch - Size Class B <sup>a</sup>	Yellow Perch - Size Class C	Yellow Perch - Size Class D	Largemouth Bass
<b>Reach 1 Reference Area</b>					
2	S (E) (0.0132)	S (E) (0)	S (A) (0.008808)	S (A) (0.003541)	S (A) (0.015555)
5	S (K) (0)	NS (K) (0.5677)	NA	NS (K) (0.2999)	S (E) (0.000018)
7	S (K) (0.0242)	S (E) (0.006671)	NS (E) (0.775829)	NS (E) (0.318569) <sup>b</sup>	S (A) (0.001829)
<b>Charles River Reference Area</b>					
8	S (E) (0)	S (A) (0)	S (A) (0)	S (A) (0)	S (A) (0.000154)
9	S (E) (0.033608)	S (A) (0.000007)	S (A) (0.000001)	S (A) (0.000012)	S (A) (0.000778)
10	S (K) (0)	S (A) (0.000002)	S (A) (0)	S (A) (0.000379)	S (A) (0.004299)
<b>Sudbury Reservoir Reference Area</b>					
3	S (K) (0.0001)	S (A) (0)	S (A) (0)	S (A) (0.000007)	S (K) (0.0004)
4	S (A) (0.000001)	S (A) (0)	S (A) (0.000001)	S (A) (0.000002)	S (K) (0.0008)
6	S (A) (0)	S (A) (0.000001)	S (E) (0.002146)	S (A) (0.000161)	S (K) (0.0008)
7 - Heard Pond	S (E) (0.000004) <sup>b</sup>	S (A) (0.000029) <sup>b</sup>	S (A) (0.000209) <sup>b</sup>	S (E) (0.000397) <sup>b</sup>	S (K) (0.005) <sup>b</sup>

Notes:

Values in parenthesis represent probability level.

<sup>a</sup>Bluegill and pumpkinseed whole body data incorporated where appropriate when there was an insufficient yellow perch whole body sample size.

<sup>b</sup>Reference area found to be greater than the site.

A = Aspin-Welch Unequal Variance Test

E = Equal Variance t-Test

K = Kolmogorov-Smirnov Test for Different Distributions.

NA = Not analyzed due to insufficient sample size.

NS = Not statistically different from reference.

S = Statistically significantly different from reference.

**Table 4-8**

**Summary of Studies Used in the Comparison of Mercury Levels in Fish Collected from the Sudbury River with Those Collected from Regional Waterbodies  
Operable Unit IV, Nyanza Chemical Dump Superfund Site  
Middlesex County, Massachusetts**

<b>Study</b>	<b>Waterbody and Location</b>	<b>Period of Study</b>	<b>Fish Collected</b>	<b>Notes</b>
<i>Massachusetts Fish Tissue Mercury Studies: Long-Term Monitoring Results, 1999-2004.</i> MADEP, 2006	<ul style="list-style-type: none"> <li>20 lakes distributed throughout Massachusetts</li> <li>Some weighting towards NE Massachusetts</li> </ul>	<ul style="list-style-type: none"> <li>1999 through 2004</li> <li>½ of lakes sampled every other year</li> <li>Fish collected in spring</li> </ul>	From each lake: <ul style="list-style-type: none"> <li>30 yellow perch (fillet; 20- 25 cm TL)</li> <li>12 largemouth bass (fillet; range in size)</li> </ul>	Fillet samples analyzed for total mercury. Represents an update of previous investigations to determine the extent to which Hg contamination in fish statewide poses a risk to recreational anglers.
<i>Fish Mercury Levels in Northeastern Massachusetts Lakes.</i> MADEP, 2003	<ul style="list-style-type: none"> <li>26 lakes in NE Massachusetts</li> <li>Minimum size 10 acres</li> </ul>	<ul style="list-style-type: none"> <li>Spring collection, year of collection not stated in report</li> </ul>	From each lake: <ul style="list-style-type: none"> <li>9 yellow perch (fillet; 20-25 cm TL)</li> <li>9 largemouth bass (fillet; 30-36 cm TL)</li> </ul>	Study was designed to look at impact of Hg deposition from local sources (e.g., MSW incinerators) on surface water and the effects of emission reductions on water quality. Results indicated that fish from surface waters downwind of emission sources contained higher mercury levels. Reduction in emissions showing a trend of reducing Hg levels.

**Table 4-8, Continued**

**Summary of Studies Used in the Comparison of Mercury Levels in Fish Collected from the Sudbury River with Those Collected from  
Regional Waterbodies  
Operable Unit IV, Nyanza Chemical Dump Superfund Site  
Middlesex County, Massachusetts**

<b>Study</b>	<b>Waterbody and Location</b>	<b>Period of Study</b>	<b>Fish Collected</b>	<b>Notes</b>
<i>Fish Mercury Distribution in Massachusetts, USA Lakes.</i> Rose et al., 1999	<ul style="list-style-type: none"> <li>24 lakes not likely to have been impacted by non-point sources of mercury</li> <li>8 lakes from each of 3 ecoregions: <ul style="list-style-type: none"> <li>Green Mountain / Berkshire</li> <li>Narragansett/ Bristol</li> <li>Worcester/ Monadnock</li> </ul> </li> </ul>	Fall collection following summer spawning	From each lake: <ul style="list-style-type: none"> <li>9 yellow perch (fillet; 20-25 cm TL)</li> <li>9 largemouth bass (fillet; 30-36 cm TL)</li> <li>9 brown bullhead (fillet; 20-25 cm TL)</li> </ul>	Study was designed to look at regional water quality and Hg levels in fish from “unimpacted” lakes in Massachusetts. Note difference in season fish were collected.  Water quality properties of individual lakes appear to be more significant in affecting mercury levels in fish than do small-scale eco-regional differences.
<i>Fish Mercury Distribution in Massachusetts Lakes. Final Report. MADEP, 1997.</i>	<ul style="list-style-type: none"> <li>24 lakes not likely to have been impacted by non-point sources of mercury</li> <li>8 lakes from each of 3 ecoregions: <ul style="list-style-type: none"> <li>Green Mountain / Berkshire</li> <li>Narragansett/ Bristol</li> <li>Worcester/ Monadnock</li> </ul> </li> </ul>	Fall collection following summer spawning	From each lake: <ul style="list-style-type: none"> <li>9 yellow perch (fillet; 20-25 cm TL)</li> <li>9 largemouth bass (fillet; 30-36 cm TL)</li> <li>9 brown bullhead (fillet; 20-25 cm TL)</li> </ul>	Note: this is the study report of the paper presented by Rose et al., 1999.

**Table 4-8, Continued**

**Summary of Studies Used in the Comparison of Mercury Levels in Fish Collected from the Sudbury River with Those Collected from  
Regional Waterbodies  
Operable Unit IV, Nyanza Chemical Dump Superfund Site  
Middlesex County, Massachusetts**

<b>Study</b>	<b>Waterbody and Location</b>	<b>Period of Study</b>	<b>Fish Collected</b>	<b>Notes</b>
<i>Mercury in Freshwater Fish of Northeast North America – A Geographic Perspective Based on Fish Tissue Monitoring Databases.</i> Kammen et al., 2005.	<ul style="list-style-type: none"> <li>• Eastern Canada and Maritime Provinces and Northeastern United States (New York – Newfoundland)</li> <li>• 1,330 lakes</li> <li>• 136 reservoirs</li> <li>• 265 rivers</li> </ul>	<ul style="list-style-type: none"> <li>• Represents a synthesis of data from 24 different studies conducted after 1980</li> <li>• Season of collection varies</li> </ul>	13 species of fish analyzed – most robust dataset for yellow perch <ul style="list-style-type: none"> <li>• 2,888 YP fillet records</li> <li>• 841 YP whole body records</li> </ul>	Synthesis of databases from waterbodies in Northeast North America demonstrated large variability in Hg levels both across the landscape and within and between species of fish analyzed. Preliminary analysis demonstrated a positive correlation of mercury and water acidity and watershed size.

**Table 4-9**

**Surface Water Reference Comparisons  
Operable Unit IV - Nyanza Chemical Dump Superfund Site  
Middlesex County, Massachusetts**

Reach	Site Compared with Reference	
	Total Mercury	Methylmercury
<b>Reach 1 Reference Area</b>		
2	ND	ND
5	ND	ND
7	NS (K)	NS (K)
10	NA	NA
<b>Charles River Reference Area</b>		
8	S (A)	NS (K)
9	NA	NA

A = Aspin-Welch Unequal Variance Test

K = Kolmogorov-Smirnov Test for Different Distributions.

NA = Not analyzed.

ND = Not determined. Insufficient sample size.

NS = Not statistically different from reference.

S = Statistically significantly different from reference ( $p \leq 0.05$ ).

Table 4-10

**Summary of HQs Calculated Using Effects-based TRVs  
Operable Unit IV - Nyanza Chemical Dump Superfund Site  
Middlesex County, Massachusetts**

Chemical	HQ/Receptor							
	RME				CTE			
	Tree Swallow	Belted Kingfisher	Great Blue Heron	Mink	Tree Swallow	Belted Kingfisher	Great Blue Heron	Mink
<i>Reach 1</i>								
Total Mercury	2.17E+00	NA	NA	NA	7.10E-01	NA	NA	NA
Methylmercury	7.60E-01	7.49E-01	3.35E-01	4.30E-01	2.49E-01	6.43E-01	2.73E-01	3.59E-01
<i>Reach 2</i>								
Total Mercury	3.68E+00	NA	NA	NA	1.46E+00	NA	NA	NA
Methylmercury	1.29E+00	1.16E+00	5.06E-01	6.28E-01	5.12E-01	1.03E+00	4.39E-01	5.27E-01
<i>Reach 3</i>								
Total Mercury	1.22E+01	NA	NA	NA	9.69E+00	NA	NA	NA
Methylmercury	4.28E+00	1.21E+00	6.13E-01	8.09E-01	3.39E+00	1.05E+00	5.21E-01	6.66E-01
<i>Reach 4</i>								
Total Mercury	5.96E+00	NA	NA	NA	4.35E+00	NA	NA	NA
Methylmercury	2.09E+00	1.03E+00	4.80E-01	5.60E-01	1.52E+00	8.99E-01	4.15E-01	4.60E-01
<i>Reach 5</i>								
Total Mercury	1.11E+00	NA	NA	NA	8.05E-01	NA	NA	NA
Methylmercury	3.90E-01	1.14E+00	4.69E-01	7.58E-01	2.82E-01	1.05E+00	4.22E-01	6.50E-01
<i>Reach 6</i>								
Total Mercury	3.12E+00	NA	NA	NA	1.78E+00	NA	NA	NA
Methylmercury	1.09E+00	6.64E-01	3.05E-01	4.48E-01	6.23E-01	5.91E-01	2.60E-01	3.77E-01
<i>Reach 7</i>								
Total Mercury	6.56E-01	NA	NA	NA	3.63E-01	NA	NA	NA
Methylmercury	2.30E-01	1.08E+00	4.21E-01	6.06E-01	1.27E-01	9.09E-01	3.53E-01	4.73E-01
<i>Reach 7 - Heard Pond</i>								
Total Mercury	2.04E+00	NA	NA	NA	1.76E+00	NA	NA	NA
Methylmercury	7.16E-01	1.12E-01	7.39E-02	2.40E-01	6.15E-01	1.02E-01	6.51E-02	1.99E-01
<i>Reach 8</i>								
Total Mercury	5.98E-01	NA	NA	NA	4.76E-01	NA	NA	NA
Methylmercury	2.09E-01	1.19E+00	5.01E-01	1.22E+00	1.66E-01	1.14E+00	4.71E-01	1.05E+00
<i>Reach 9</i>								
Total Mercury	1.10E+00	NA	NA	NA	9.44E-01	NA	NA	NA
Methylmercury	3.85E-01	1.24E+00	5.14E-01	1.52E+00	3.30E-01	1.11E+00	4.52E-01	1.18E+00
<i>Reach 10</i>								
Total Mercury	6.91E-01	NA	NA	NA	5.14E-01	NA	NA	NA
Methylmercury	2.42E-01	1.42E+00	6.11E-01	1.86E+00	1.80E-01	1.29E+00	5.42E-01	1.33E+00
<i>Charles River</i>								
Total Mercury	3.60E-01	NA	NA	NA	3.26E-01	NA	NA	NA
Methylmercury	1.26E-01	6.88E-01	2.85E-01	4.16E-01	1.14E-01	6.42E-01	2.66E-01	3.60E-01
<i>Sudbury Reservoir</i>								
Total Mercury	3.73E-01	NA	NA	NA	3.02E-01	NA	NA	NA
Methylmercury	1.31E-01	1.90E-01	1.15E-01	1.72E-01	1.06E-01	1.64E-01	9.73E-02	1.40E-01

NA = Not available.

Shading indicates HQ&gt;1.

Table 4-11

**Summary of HQs Calculated Using No-effects-based TRVs  
Operable Unit IV - Nyanza Chemical Dump Superfund Site  
Middlesex County, Massachusetts**

Chemical	HQ/Receptor							
	RME				CTE			
	Tree Swallow	Belted Kingfisher	Great Blue Heron	Mink	Tree Swallow	Belted Kingfisher	Great Blue Heron	Mink
<i>Reach 1</i>								
Total Mercury	4.30E+00	NA	NA	NA	1.41E+00	NA	NA	NA
Methylmercury	1.50E+00	1.48E+00	6.63E-01	1.08E+00	4.92E-01	1.27E+00	5.41E-01	8.97E-01
<i>Reach 2</i>								
Total Mercury	7.29E+00	NA	NA	NA	2.89E+00	NA	NA	NA
Methylmercury	2.55E+00	2.30E+00	1.00E+00	1.57E+00	1.01E+00	2.04E+00	8.68E-01	1.32E+00
<i>Reach 3</i>								
Total Mercury	2.42E+01	NA	NA	NA	1.92E+01	NA	NA	NA
Methylmercury	8.46E+00	2.40E+00	1.21E+00	2.02E+00	6.71E+00	2.08E+00	1.03E+00	1.66E+00
<i>Reach 4</i>								
Total Mercury	1.18E+01	NA	NA	NA	8.60E+00	NA	NA	NA
Methylmercury	4.13E+00	2.04E+00	9.49E-01	1.40E+00	3.01E+00	1.78E+00	8.21E-01	1.15E+00
<i>Reach 5</i>								
Total Mercury	2.20E+00	NA	NA	NA	1.59E+00	NA	NA	NA
Methylmercury	7.71E-01	2.25E+00	9.27E-01	1.89E+00	5.57E-01	2.07E+00	8.35E-01	1.62E+00
<i>Reach 6</i>								
Total Mercury	6.17E+00	NA	NA	NA	3.52E+00	NA	NA	NA
Methylmercury	2.16E+00	1.31E+00	6.03E-01	1.12E+00	1.23E+00	1.17E+00	5.15E-01	9.41E-01
<i>Reach 7</i>								
Total Mercury	1.30E+00	NA	NA	NA	7.19E-01	NA	NA	NA
Methylmercury	4.54E-01	2.14E+00	8.32E-01	1.51E+00	2.52E-01	1.80E+00	6.99E-01	1.18E+00
<i>Reach 7 - Heard Pond</i>								
Total Mercury	4.05E+00	NA	NA	NA	3.48E+00	NA	NA	NA
Methylmercury	1.42E+00	2.22E-01	1.46E-01	6.00E-01	1.22E+00	2.02E-01	1.29E-01	4.97E-01
<i>Reach 8</i>								
Total Mercury	1.18E+00	NA	NA	NA	9.41E-01	NA	NA	NA
Methylmercury	4.14E-01	2.35E+00	9.91E-01	3.04E+00	3.29E-01	2.25E+00	9.33E-01	2.63E+00
<i>Reach 9</i>								
Total Mercury	2.17E+00	NA	NA	NA	1.87E+00	NA	NA	NA
Methylmercury	7.61E-01	2.45E+00	1.02E+00	3.80E+00	6.54E-01	2.19E+00	8.95E-01	2.95E+00
<i>Reach 10</i>								
Total Mercury	1.37E+00	NA	NA	NA	1.02E+00	NA	NA	NA
Methylmercury	4.79E-01	2.81E+00	1.21E+00	4.64E+00	3.56E-01	2.55E+00	1.07E+00	3.33E+00
<i>Charles River</i>								
Total Mercury	7.13E-01	NA	NA	NA	6.46E-01	NA	NA	NA
Methylmercury	2.49E-01	1.36E+00	5.64E-01	1.04E+00	2.26E-01	1.27E+00	5.26E-01	8.99E-01
<i>Sudbury Reservoir</i>								
Total Mercury	7.38E-01	NA	NA	NA	5.98E-01	NA	NA	NA
Methylmercury	2.49E-01	3.76E-01	2.27E-01	4.30E-01	2.09E-01	3.25E-01	1.92E-01	3.49E-01

NA = Not available.

Shading indicates HQ&gt;1.



**Table 4-12**

**Summary of Analytical Variability as Estimated Using  
Relative Percent Difference between Duplicates  
Operable Unit IV - Nyanza Chemical Dump Superfund Site  
Middlesex County, Massachusetts**

Medium	RPD	
	Range	Average
<i><b>Total Mercury</b></i>		
Sediment	0.4 - 101	20
Crayfish*	0.5 - 12	5
Fish - Wholebody*	0.0 - 66	9
Fish - Fillet	0 - 37	9
Fish - Offal*	3 - 24	12
Bird Blood*	1.5 - 65	11
Bird Eggs*	0.3 - 27	8
Mink	123 - 123	123
All (without mink value)	0 - 101	11
<i><b>Methylmercury</b></i>		
Sediment	1.0 - 95	23
Crayfish*	8.8 - 24	15
Fish - Fillet	5 - 151	31
Fish - Offal*	0 - 57	18
All	0 - 151	22

RPD = Relative percent difference.

\*Method duplicate as opposed to field duplicate. Method duplicate obtained by analyzing two aliquots from the same sample.

**Table 4-13**

**Comparisons of Maximum and Average Whole Body Fish  
Tissue Total Mercury Concentrations (µg/kg WW)  
Operable Unit IV - Nyanza Chemical Dump Superfund Site  
Middlesex County, Massachusetts**

Reach/Species/ Size Class	SBERA		With Regressed Data	
	Maximum	Average	Maximum	Average
<i>Reach 2</i>				
BB - D	--	--	--	--
LB - D	565	392	1040	478
YB - D	--	--	--	--
YP - D	584	352	584	292
All Fish	584	228	1040	252
<i>Reach 3</i>				
BB - D	367	271	995	489
LB - D	895	658	1222	677
YB - D	487	487	553	457
YP - D	606	423	606	368
All Fish	895	279	1222	349
<i>Reach 4</i>				
BB - D	100	100	210	152
LB - D	617	506	629	496
YB - C	---	---	108	108
YB - D	312	245	312	241
YP - D	463	423	463	341
All Fish	617	216	629	250
<i>Reach 5</i>				
BB - D	170	154	229	128
LB - D	537	393	567	434
YB - D	163	163	163	163
YP - D	455	272	455	215
All Fish	537	218	567	227
<i>Reach 6</i>				
BB - D	103	103	103	103
LB - D	711	545	753	520
YB - D	321	311	374	265
YP - D	261	204	387	216
All Fish	711	154	753	209
<i>Reach 7</i>				
BB - D	129	117	272	157
LB - D	735	461	735	479
YB - D	280	280	399	258
YP - D	239	174	239	150
All Fish	735	183	735	213
<i>Reach 7 - Heard Pond</i>				
BB - D	--	--	--	--
LB - D	193	158	193	97
YB - D	100	92	100	81
YP - D	76	65	76	55
All Fish	193	38	193	47

**Table 4-13**

**Comparisons of Maximum and Average Whole Body Fish  
Tissue Total Mercury Concentrations (µg/kg WW)  
Operable Unit IV - Nyanza Chemical Dump Superfund Site  
Middlesex County, Massachusetts**

Reach/Species/ Size Class	SBERA		With Regressed Data	
	Maximum	Average	Maximum	Average
<i>Reach 8</i>				
BB - D	165	117	165	185
LB - D	1133	751	1133	683
YP - C	225	155	225	155
YB - D	465	358	465	309
YP - D	364	237	391	268
All Fish	1133	213	1133	291
<i>Reach 9</i>				
BB - D	192	176	192	150
LB - D	1275	935	1275	706
YB - D	--	--	--	--
YP - D	402	334	402	287
All Fish	1275	252	1275	282
<i>Reach 10</i>				
BB - D	123	123	585	185
LB - D	1270	1048	1270	683
YB - D	288	282	337	309
YP - C	259	204	259	202
YP - D	440	277	440	268
All Fish	1270	273	1270	291
<i>Reach 1</i>				
BB - D	--	--	--	--
LB - D	255	224	318	248
YB - D	555	399	555	399
YP - D	164	126	242	166
All Fish	555	138	555	158
<i>Charles River</i>				
BB - D	137	108	137	108
LB - D	414	336	414	294
YB - D	124	124	316	205
YP - D	169	160	169	133
All Fish	414	134	414	155
<i>Sudbury Reservoir</i>				
BB - D	185	185	185	184
LB - D	201	178	422	176
YP - C	113	64	113	67
YB - D	100	94	112	93
YP - D	105	84	105	79
All Fish	201	56	422	74

Table 4-14

**No Effect - HQ Summary for EPCs including Regressed Fish Data**  
**Operable Unit IV - Nyanza Chemical Dump Superfund Site**  
**Middlesex County, Massachusetts**

Chemical	HQ/Receptor							
	RME				CTE			
	Great Blue Heron		Mink		Great Blue Heron		Mink	
	SBERA	with Regressed Fish	SBERA	with Regressed Fish	SBERA	with Regressed Fish	SBERA	with Regressed Fish
<i>Reach 1</i>								
Methylmercury	6.6E-01	6.5E-01	1.1E+00	1.1E+00	5.4E-01	5.6E-01	9.0E-01	9.2E-01
<i>Reach 2</i>								
Methylmercury	1.0E+00	9.6E-01	1.6E+00	1.6E+00	8.7E-01	8.5E-01	1.3E+00	1.3E+00
<i>Reach 3</i>								
Methylmercury	1.2E+00	1.2E+00	2.0E+00	2.0E+00	1.0E+00	1.0E+00	1.7E+00	1.7E+00
<i>Reach 4</i>								
Methylmercury	9.5E-01	9.0E-01	1.4E+00	1.3E+00	8.2E-01	7.9E-01	1.1E+00	1.1E+00
<i>Reach 5</i>								
Methylmercury	9.3E-01	9.1E-01	1.9E+00	1.8E+00	8.3E-01	8.4E-01	1.6E+00	1.6E+00
<i>Reach 6</i>								
Methylmercury	6.0E-01	5.9E-01	1.1E+00	1.0E+00	5.2E-01	5.3E-01	9.4E-01	9.3E-01
<i>Reach 7</i>								
Methylmercury	8.3E-01	8.1E-01	1.5E+00	1.4E+00	7.0E-01	6.9E-01	1.2E+00	1.2E+00
<i>Reach 7 - Heard Pond</i>								
Methylmercury	1.5E-01	1.4E-01	6.0E-01	4.7E-01	1.3E-01	1.2E-01	5.0E-01	4.2E-01
<i>Reach 8</i>								
Methylmercury	9.9E-01	9.8E-01	3.0E+00	2.9E+00	9.3E-01	9.3E-01	2.6E+00	2.6E+00
<i>Reach 9</i>								
Methylmercury	1.0E+00	9.9E-01	3.8E+00	3.1E+00	8.9E-01	8.9E-01	3.0E+00	2.6E+00
<i>Reach 10</i>								
Methylmercury	1.2E+00	1.2E+00	4.6E+00	3.4E+00	1.1E+00	1.1E+00	3.3E+00	3.0E+00
<i>Charles River</i>								
Methylmercury	5.6E-01	5.7E-01	1.0E+00	9.9E-01	5.3E-01	5.3E-01	9.0E-01	8.9E-01
<i>Sudbury Reservoir</i>								
Methylmercury	2.3E-01	2.3E-01	4.3E-01	4.1E-01	1.9E-01	2.0E-01	3.5E-01	3.5E-01

Shading indicates HQ>1.

Table 4-15

**Effect - HQ Summary for EPCs including Regressed Fish Data**  
**Operable Unit IV - Nyanza Chemical Dump Superfund Site**  
**Middlesex County, Massachusetts**

Chemical	HQ/Receptor							
	RME				CTE			
	Great Blue Heron		Mink		Great Blue Heron		Mink	
	SBERA	with Regressed Fish	SBERA	with Regressed Fish	SBERA	with Regressed Fish	SBERA	with Regressed Fish
<i>Reach 1</i>								
Methylmercury	3.3E-01	3.3E-01	4.3E-01	4.5E-01	2.7E-01	2.8E-01	3.6E-01	3.7E-01
<i>Reach 2</i>								
Methylmercury	5.1E-01	4.9E-01	6.3E-01	6.4E-01	4.4E-01	4.3E-01	5.3E-01	5.4E-01
<i>Reach 3</i>								
Methylmercury	6.1E-01	5.9E-01	8.1E-01	8.0E-01	5.2E-01	5.1E-01	6.7E-01	6.8E-01
<i>Reach 4</i>								
Methylmercury	4.8E-01	4.5E-01	5.6E-01	5.3E-01	4.1E-01	4.0E-01	4.6E-01	4.5E-01
<i>Reach 5</i>								
Methylmercury	4.7E-01	4.6E-01	7.6E-01	7.3E-01	4.2E-01	4.2E-01	6.5E-01	6.4E-01
<i>Reach 6</i>								
Methylmercury	3.0E-01	3.0E-01	4.5E-01	4.2E-01	2.6E-01	2.7E-01	3.8E-01	3.7E-01
<i>Reach 7</i>								
Methylmercury	4.2E-01	4.1E-01	6.1E-01	5.7E-01	3.5E-01	3.5E-01	4.7E-01	4.7E-01
<i>Reach 7 - Heard Pond</i>								
Methylmercury	7.4E-02	7.0E-02	2.4E-01	1.9E-01	6.5E-02	6.2E-02	2.0E-01	1.7E-01
<i>Reach 8</i>								
Methylmercury	5.0E-01	5.0E-01	1.2E+00	1.2E+00	4.7E-01	4.7E-01	1.1E+00	1.0E+00
<i>Reach 9</i>								
Methylmercury	5.1E-01	5.0E-01	1.5E+00	1.2E+00	4.5E-01	4.5E-01	1.2E+00	1.1E+00
<i>Reach 10</i>								
Methylmercury	6.1E-01	5.9E-01	1.9E+00	1.4E+00	5.4E-01	5.3E-01	1.3E+00	1.2E+00
<i>Charles River</i>								
Methylmercury	2.9E-01	2.9E-01	4.2E-01	4.0E-01	2.7E-01	2.7E-01	3.6E-01	3.6E-01
<i>Sudbury Reservoir</i>								
Methylmercury	1.1E-01	1.2E-01	1.7E-01	1.7E-01	9.7E-02	9.9E-02	1.4E-01	1.4E-01

Shading indicates HQ>1.

Table 4-16

**Wildlife Exposure Fish Prey Data Set Reference Comparisons  
Operable Unit IV - Nyanza Chemical Dump Superfund Site  
Middlesex County, Massachusetts**

Reach	Total Mercury - Whole Body					
	Site Compared with Reference Concentrations					
	Size Class A	Size Class B	Size Class C	Size Class B and C	Size Class D	Size Class D (< 30 cm)
<b>Reach 1 Reference Area</b>						
2	S (E)	S (A)	S (A)	S (A)	S (K)	S (K)
5	S (K)	NS (K)	NS (E)	NS (E)	S (K)	NS (K)
7	S (K)	S (E)	NS (A)	NS (E)	NS (K)	NS (K)
10	S (K)	S (E)	S (E)	S (E)	S (K)	S (K)
<b>Charles River Reference Area</b>						
8	S (E)	S (A)	S (K)	S (K)	NS (K)	S (A)
9	S (E)	S (A)	S (A)	S (A)	NS (A)	S (A)
<b>Sudbury Reservoir Reference Area</b>						
3	S (K)	S (A)	S (A)	S (K)	S (A)	S (A)
4	S (K)	S (A)	S (A)	S (K)	S (A)	S (A)
6	S (K)	S (A)	S (E)	S (K)	S (A)	S (A)
7 - Heard Pond	S (K)	S (A)	S (A)	S (A)	NS (E)	NA

Notes:

Variances tested using Variance-Ratio Equal-Variance Test and Modified-Levene Equal Variance Test.  
All tests run at (  $\alpha=0.05$ ).

A = Aspin-Welch Unequal Variance Test

E = Equal Variance t-Test

K = Kolmogorov-Smirnov Test for Different Distributions.

NA = Not analyzed due to insufficient sample size.

NS = Not statistically different from reference.

S = Statistically significantly different from reference.

Table 4-17

**Summary of the Potential for Ecological Risk to Hexagenia Mayflies from Exposure to Sediments - July and September of 2004**  
**Operable Unit IV - Nyanza Chemical Dump Superfund Site**  
**Middlesex County, Massachusetts**

Reach	Test 1 (July 1994)					Test 2 (September 1994)				
	Mean TotHg in flies (µg/kg DW)*	Mean growth after 21 days (mm)*	Risk Scenario**	Population Risk?***	Confidence Level**	Mean TotHg in flies (µg/kg DW)*	Mean growth after 21 days (mm)*	Risk Scenario**	Population Risk?***	Confidence Level**
3	6,360 <sup>c</sup>	5.9 <sup>bc</sup>	2	unlikely	moderate	10,819 <sup>c</sup>	5.8 <sup>b</sup>	2	unlikely	moderate
4	5,182 <sup>c</sup>	6.1 <sup>bc</sup>	2	unlikely	moderate	4147 <sup>c</sup>	6.5 <sup>b</sup>	2	unlikely	moderate
8	759 <sup>b</sup>	4.9 <sup>ab</sup>	2	unlikely	moderate	762 <sup>b</sup>	6.3 <sup>b</sup>	2	unlikely	moderate
9	874 <sup>b</sup>	5.3 <sup>bc</sup>	2	unlikely	moderate	711 <sup>b</sup>	6.2 <sup>b</sup>	2	unlikely	moderate
<b>Reference Areas</b>										
Reach 1	149 <sup>a</sup>	6.2 <sup>c</sup>	1	unlikely	high	167 <sup>a</sup>	5.8 <sup>b</sup>	1	unlikely	high
Whitehall Reservoir	123 <sup>a</sup>	2.2 <sup>a</sup>	3	possible	low	171 <sup>a</sup>	2.3 <sup>a</sup>	3	possible	low
Hop Brook Wetland	not tested	not tested	--	--	--	not tested	not tested	--	--	--

Notes:

Reference areas compared with each other to determine Risk Scenario/Conclusion/Confidence Level.

Red highlighting indicates that risk of adverse effects is possible, with relatively high confidence only for the particular measurement endpoint, but does not account for the weight given to that measure of risk in the BERA. Other measures of potential risk for the same receptors may not support this conclusion, and remedial action decisions are based on the weight-of-evidence for all measurement endpoints for each ecological receptor.

\*Values with like footnotes indicate samples are not dissimilar based on statistical comparisons.

**\*\*Interpretive Ecological Risk Matrix**

Risk Scenario	Risk Case	Population Risk?	Confidence Level
1	Growth AND [TotHg] <sub>flies</sub> do not differ significantly from those observed in reference sediment	unlikely	high
2	Growth does not differ significantly from that in reference sediment BUT [TotHg] <sub>flies</sub> is significantly higher	unlikely	moderate
3	Growth differs significantly from that in reference sediment BUT does not appear related to [TotHg] <sub>flies</sub>	possible	low
4	Growth differs significantly from that in reference sediment and appears related to [TotHg] <sub>flies</sub>	possible	high

Table 4-18

**Summary of the Potential for Ecological Risk to Hexagenia Mayflies from Exposure to Sediments - May and September of 2005**  
**Operable Unit IV - Nyanza Chemical Dump Superfund Site**  
**Middlesex County, Massachusetts**

Reach	Test 3 (May 1995)					Test 4 (September 1995)				
	Mean TotHg in flies (µg/kg DW)*	Mean growth after 21 days (mm)*	Risk Scenario**	Population Risk?***	Confidence Level**	Mean TotHg in flies (µg/kg DW)*	Mean growth after 21 days (mm)*	Risk Scenario**	Population Risk?***	Confidence Level**
3	not tested	not tested	--	--	--	not tested	not tested	--	--	--
4	not tested	not tested	--	--	--	not tested	not tested	--	--	--
8-South Wetland	1,161 <sup>c</sup>	6.0 <sup>ab</sup>	2	unlikely	moderate	515 <sup>b</sup>	2.8 <sup>bc</sup>	3	possible	low
8-North Wetland	655 <sup>b</sup>	4.8 <sup>b</sup>	3	possible	low	539 <sup>b</sup>	1.5 <sup>c</sup>	3	possible	low
9	833 <sup>bc</sup>	6.1 <sup>ab</sup>	2	unlikely	moderate	492 <sup>b</sup>	5.7 <sup>a</sup>	2	unlikely	moderate
<b>Reference Areas</b>										
Reach 1	not tested	not tested	--	--	--	not tested	not tested	--	--	--
Whitehall Reservoir	not tested	not tested	--	--	--	not tested	not tested	--	--	--
Hop Brook Wetland	113 <sup>a</sup>	6.4 <sup>a</sup>	1	unlikely	high	98 <sup>a</sup>	4.0 <sup>ab</sup>	1	unlikely	high

Notes:

Reference areas compared with each other to determine Risk Scenario/Conclusion/Confidence Level.

Red highlighting indicates that risk of adverse effects is possible, with relatively high confidence only for the particular measurement endpoint, but does not account for the weight given to that measure of risk in the BERA. Other measures of potential risk for the same receptors may not support this conclusion, and remedial action decisions are based on the weight-of-evidence for all measurement endpoints for each ecological receptor.

\*Values with like footnotes indicate samples are not dissimilar based on statistical comparisons.

**\*\*Interpretive Ecological Risk Matrix**

Risk Scenario	Risk Case	Population Risk?	Confidence Level
1	Growth AND [TotHg] <sub>flies</sub> do not differ significantly from those observed in reference sediment	unlikely	high
2	Growth does not differ significantly from that in reference sediment BUT [TotHg] <sub>flies</sub> is significantly higher	unlikely	moderate
3	Growth differs significantly from that in reference sediment BUT does not appear related to [TotHg] <sub>flies</sub>	possible	low
4	Growth differs significantly from that in reference sediment and appears related to [TotHg] <sub>flies</sub>	possible	high



Table 4-19

**Summary of the Potential for Ecological Risk to Freshwater Mussels Exposed for 84 days  
Operable Unit IV - Nyanza Chemical Dump Superfund Site  
Middlesex County, Massachusetts**

Reach	Mean [TotHg] in Mussels (µg/kg DW)	% Survival*	Growth Rate (mg/week)*	Change in Tissue Weight* (g WW)	Risk Scenario**	Population Risk**	Confidence Level**
2	950	93 <sup>a</sup>	23 <sup>a</sup>	0.28 <sup>a</sup>	3	possible	moderate
3	690	95 <sup>a</sup>	185 <sup>b</sup>	1.81 <sup>b</sup>	3	possible	moderate
6	520	87 <sup>a</sup>	198 <sup>b</sup>	1.15 <sup>b</sup>	3	possible	moderate
9	400	88 <sup>a</sup>	270 <sup>c</sup>	2.32 <sup>c</sup>	2	unlikely	moderate
10	340	87 <sup>a</sup>	303 <sup>c</sup>	2.9 <sup>c</sup>	2	unlikely	moderate

Notes:

The data collected at the two reference locations (Reach 1 and Whitehall Reservoir) were compromised. Reaches 9 and 10 were used as "de facto reference stations" for comparisons because survival and growth metrics appeared to be high and were assumed to be acceptable. The Risk Matrix below reflects the interpretation of this study under these circumstances, as well as how the study would have been interpreted had the reference stations from the original study design produced acceptable results.

Reference areas compared with each other to determine Risk Scenario/Conclusion/Confidence Level.

Red highlighting indicates that risk of adverse effects is possible, with relatively high confidence only for the particular measurement endpoint, but does not account for the weight given to that measure of risk in the BERA. Other measures of potential risk for the same receptors may not support this conclusion, and remedial action decisions are based on the weight-of-evidence for all measurement endpoints for each ecological receptor.

\*Values with like footnotes indicate samples are not dissimilar based on statistical comparisons.

**\*\*Interpretive Ecological Risk Matrix**

Risk Scenario	Risk Case	Population Risk?	Confidence Level
1	Growth rate, change in tissue weight and survival are not significantly different from those measured in reference stations from original study design (had these been successful)	unlikely	high
2	Growth rate, change in tissue weight and survival are not significantly different from those measured in Reaches 9 and 10 (de facto reference because original reference stations failed)	unlikely	moderate
3	Growth rate, change in tissue weight, or survival is significantly different from those measured in Reaches 9 and 10 (de facto reference because original reference stations failed)	possible	moderate
4	Growth rate, change in tissue weight, or survival are significantly different from those measured in reference stations from original study design (had these been successful)	possible	high

Table 4-20

**Summary of the Potential for Ecological Risk to Crayfish  
Operable Unit IV - Nyanza Chemical Dump Superfund Site  
Middlesex County, Massachusetts**

Reach	Exposure Point Concentration (µg/kg)		Ecological Risk*				
	RME	CTE	RME Case	CTE Case	Risk Scenario	Population Risk?	Confidence Level
2	75	46	$N \leq 1$ & $L \leq 1$	$N \leq 1$ & $L \leq 1$	1	unlikely	high
3	210	55	$N \leq 1$ & $L \leq 1$	$N \leq 1$ & $L \leq 1$	1	unlikely	high
4	36	23	$N \leq 1$ & $L \leq 1$	$N \leq 1$ & $L \leq 1$	1	unlikely	high
5	192	98	$N \leq 1$ & $L \leq 1$	$N \leq 1$ & $L \leq 1$	1	unlikely	high
6	30	30	$N \leq 1$ & $L \leq 1$	$N \leq 1$ & $L \leq 1$	1	unlikely	undetermined**
7	86	50	$N \leq 1$ & $L \leq 1$	$N \leq 1$ & $L \leq 1$	1	unlikely	high
7 - Heard Pond	--	--	--	--	--	--	--
8	--	--	--	--	--	--	--
9	--	--	--	--	--	--	--
10	--	--	--	--	--	--	--
<b>Reference Areas</b>							
Reach 1	47	44	$N \leq 1$ & $L \leq 1$	$N \leq 1$ & $L \leq 1$	1	unlikely	high
Charles River	46	40	$N \leq 1$ & $L \leq 1$	$N \leq 1$ & $L \leq 1$	1	unlikely	high
Sudbury Reservoir	13	10	$N \leq 1$ & $L \leq 1$	$N \leq 1$ & $L \leq 1$	1	unlikely	high

Notes:

Concentration represents total mercury.

Red highlighting indicates that risk of adverse effects is possible, with relatively high confidence only for the particular measurement endpoint, but does not account for the weight given to that measure of risk in the BERA. Other measures of potential risk for the same receptors may not support this conclusion, and remedial action decisions are based on the weight-of-evidence for all measurement endpoints for each ecological receptor.

RME = Reasonable Maximum Exposure (in this case, the maximum detected concentration)

CTE = Central Tendency Exposure (in this case, the arithmetic mean concentration)

**\*Interpretive Ecological Risk Matrix**

Risk Scenario	RME Case	CTE Case	Population Risk?	Confidence Level
1	$N \leq 1$ & $L \leq 1$	$N \leq 1$ & $L \leq 1$	unlikely	high
2	$N > 1$ & $L \leq 1$	$N \leq 1$ & $L \leq 1$	unlikely	high
3	$N > 1$ & $L > 1$	$N \leq 1$ & $L \leq 1$	possible	low
4	$N > 1$ & $L \leq 1$	$N > 1$ & $L \leq 1$	possible	low/moderate
5	$N > 1$ & $L > 1$	$N > 1$ & $L \leq 1$	possible	moderate
6	$N > 1$ & $L > 1$	$N > 1$ & $L > 1$	possible	high

N = a hazard quotient based on dividing an RME or CTE by the NOAEL crayfish CBR for Hg (1,500 µg/kg)

L = a hazard quotient based on dividing an RME or CTE by the LOAEL crayfish CBR for Hg (3,250 µg/kg)

\*\* Confidence level noted as undetermined because only one sample available for use in assessment.

Table 4-21

**Summary of the Potential for Ecological Risk to Benthic Invertebrates from Exposure to Sediments  
Operable Unit IV - Nyanza Chemical Dump Superfund Site  
Middlesex County, Massachusetts**

Reach	Exposure Point Concentration (mg/kg)		Ecological Risk*				
	RME	CTE	RME Case	CTE Case	Risk Scenario	Population Risk?	Confidence Level
2	9.65	2.03	N>1 & L>1	N>1 & L>1	6	possible	high
3	44.9	15	N>1 & L>1	N>1 & L>1	6	possible	high
4	15.6	6.59	N>1 & L>1	N>1 & L>1	6	possible	high
5	3.2	1.05	N>1 & L>1	N>1 & L≤1	5	possible	moderate
6	9.76	2.53	N>1 & L>1	N>1 & L>1	6	possible	high
7	1.55	0.296	N>1 & L>1	N>1 & L≤1	5	possible	moderate
7 - Heard Pond	3.0	2.5	N>1 & L>1	N>1 & L>1	6	possible	high
8	1.19	0.473	N>1 & L>1	N>1 & L≤1	5	possible	moderate
9	1.9	1.21	N>1 & L>1	N>1 & L>1	6	possible	high
10	1.51	0.534	N>1 & L>1	N>1 & L≤1	5	possible	moderate
<b>Reference Areas</b>							
Reach 1	3.15	0.843	N>1 & L>1	N>1 & L≤1	5	possible	moderate
Charles River	0.341	0.237	N>1 & L≤1	N>1 & L≤1	4	possible	low/moderate
Sudbury Reservoir	0.402	0.199	N>1 & L≤1	N>1 & L≤1	4	possible	low/moderate

Notes:

Concentration represents total mercury.

Red highlighting indicates that risk of adverse effects is possible, with relatively high confidence only for the particular measurement endpoint, but does not account for the weight given to that measure of risk in the BERA. Other measures of potential risk for the same receptors may not support this conclusion, and remedial action decisions are based on the weight-of-evidence for all measurement endpoints for each ecological receptor.

RME = Reasonable Maximum Exposure (in this case, the maximum detected concentration)

CTE = Central Tendency Exposure (in this case, the arithmetic mean concentration)

**\*Interpretive Ecological Risk Matrix**

Risk Scenario	RME Case	CTE Case	Population Risk?	Confidence Level
1	N≤1 & L≤1	N≤1 & L≤1	unlikely	high
2	N>1 & L≤1	N≤1 & L≤1	unlikely	high
3	N>1 & L>1	N≤1 & L≤1	possible	low
4	N>1 & L≤1	N>1 & L≤1	possible	low/moderate
5	N>1 & L>1	N>1 & L≤1	possible	moderate
6	N>1 & L>1	N>1 & L>1	possible	high

N = a hazard quotient based on dividing an RME or CTE by the NOAEL sediment benchmark for Hg (0.18 mg/kg)

L = a hazard quotient based on dividing an RME or CTE by the LOAEL sediment benchmark for Hg (1.06 mg/kg)

Table 4-22

**Summary of the Potential for Ecological Risk to Fish  
Operable Unit IV - Nyanza Chemical Dump Superfund Site  
Middlesex County, Massachusetts**

Reach	Species	Size <sup>a</sup>	Exposure Point Concentration (µg/kg)		Ecological Risk*				
			RME	CTE	RME Case	CTE Case	Risk Scenario	Population Risk?	Confidence Level
2	sunfish	A	265	187	N≤1 & L≤1	N≤1 & L≤1	1	unlikely	high
2	sunfish	B	363	280	N≤1 & L≤1	N≤1 & L≤1	1	unlikely	high
2	bullhead	D	163	114	N≤1 & L≤1	N≤1 & L≤1	1	unlikely	high
2	yellow perch	A	--	--	--	--	--	--	--
2	yellow perch	B	259	222	N≤1 & L≤1	N≤1 & L≤1	1	unlikely	high
2	yellow perch	C	324	189	N≤1 & L≤1	N≤1 & L≤1	1	unlikely	high
2	yellow perch	D	584	352	N>1 & L≤1	N≤1 & L≤1	2	unlikely	high
2	LM bass	D	565	392	N>1 & L≤1	N>1 & L≤1	4	possible	low/moderate
3	sunfish	A	477	219	N>1 & L≤1	N≤1 & L≤1	2	unlikely	high
3	sunfish	B	--	--	--	--	--	--	--
3	bullhead	D	487	325	N>1 & L≤1	N≤1 & L≤1	2	unlikely	high
3	yellow perch	A	--	--	--	--	--	--	--
3	yellow perch	B	253	195	N≤1 & L≤1	N≤1 & L≤1	1	unlikely	high
3	yellow perch	C	350	260	N≤1 & L≤1	N≤1 & L≤1	1	unlikely	high
3	yellow perch	D	606	423	N>1 & L≤1	N>1 & L≤1	4	possible	low/moderate
3	LM bass	D	895	658	N>1 & L≤1	N>1 & L≤1	4	possible	low/moderate
4	sunfish	A	353	220	N≤1 & L≤1	N≤1 & L≤1	1	unlikely	high
4	sunfish	B	--	--	--	--	--	--	--
4	bullhead	D	312	208	N≤1 & L≤1	N≤1 & L≤1	1	unlikely	high
4	yellow perch	A	--	--	--	--	--	--	--
4	yellow perch	B	215	143	N≤1 & L≤1	N≤1 & L≤1	1	unlikely	high
4	yellow perch	C	200	156	N≤1 & L≤1	N≤1 & L≤1	1	unlikely	high
4	yellow perch	D	463	423	N>1 & L≤1	N>1 & L≤1	4	possible	low/moderate
4	LM bass	D	617	506	N>1 & L≤1	N>1 & L≤1	4	possible	low/moderate
5	sunfish	A	303	272	N≤1 & L≤1	N≤1 & L≤1	1	unlikely	high
5	sunfish	B	185	122	N≤1 & L≤1	N≤1 & L≤1	1	unlikely	high
5	bullhead	D	202	189	N≤1 & L≤1	N≤1 & L≤1	1	unlikely	high
5	yellow perch	A	--	--	--	--	--	--	--
5	yellow perch	B	--	--	--	--	--	--	--
5	yellow perch	C	158	138	N≤1 & L≤1	N≤1 & L≤1	1	unlikely	high
5	yellow perch	D	455	272	N>1 & L≤1	N≤1 & L≤1	2	unlikely	high
5	LM bass	D	537	393	N>1 & L≤1	N>1 & L≤1	4	possible	low/moderate
6	sunfish	A	197	130	N≤1 & L≤1	N≤1 & L≤1	1	unlikely	high
6	sunfish	B	132	111	N≤1 & L≤1	N≤1 & L≤1	1	unlikely	high
6	bullhead	D	321	242	N≤1 & L≤1	N≤1 & L≤1	1	unlikely	high
6	yellow perch	A	93	93	N≤1 & L≤1	N≤1 & L≤1	1	unlikely	undetermined**
6	yellow perch	B	108	87	N≤1 & L≤1	N≤1 & L≤1	1	unlikely	high
6	yellow perch	C	136	95	N≤1 & L≤1	N≤1 & L≤1	1	unlikely	high
6	yellow perch	D	261	204	N≤1 & L≤1	N≤1 & L≤1	1	unlikely	high
6	LM bass	D	711	545	N>1 & L≤1	N>1 & L≤1	4	possible	low/moderate
7	sunfish	A	269	188	N≤1 & L≤1	N≤1 & L≤1	1	unlikely	high
7	sunfish	B	--	--	--	--	--	--	--
7	bullhead	D	280	172	N≤1 & L≤1	N≤1 & L≤1	1	unlikely	high
7	yellow perch	A	404	245	N>1 & L≤1	N≤1 & L≤1	2	unlikely	high
7	yellow perch	B	205	152	N≤1 & L≤1	N≤1 & L≤1	1	unlikely	high
7	yellow perch	C	149	116	N≤1 & L≤1	N≤1 & L≤1	1	unlikely	high
7	yellow perch	D	239	174	N≤1 & L≤1	N≤1 & L≤1	1	unlikely	high
7	LM bass	D	735	461	N>1 & L≤1	N>1 & L≤1	4	possible	low/moderate
7 - Heard Pond	sunfish	A	--	--	--	--	--	--	--
7 - Heard Pond	sunfish	B	--	--	--	--	--	--	--
7 - Heard Pond	bullhead	D	100	92	N≤1 & L≤1	N≤1 & L≤1	1	unlikely	high
7 - Heard Pond	yellow perch	A	23	15	N≤1 & L≤1	N≤1 & L≤1	1	unlikely	high
7 - Heard Pond	yellow perch	B	29	20	N≤1 & L≤1	N≤1 & L≤1	1	unlikely	high
7 - Heard Pond	yellow perch	C	50	34	N≤1 & L≤1	N≤1 & L≤1	1	unlikely	high
7 - Heard Pond	yellow perch	D	76	65	N≤1 & L≤1	N≤1 & L≤1	1	unlikely	high
7 - Heard Pond	LM bass	D	193	158	N≤1 & L≤1	N≤1 & L≤1	1	unlikely	high
8	sunfish	A	303	217	N≤1 & L≤1	N≤1 & L≤1	1	unlikely	high
8	sunfish	B	216	197	N≤1 & L≤1	N≤1 & L≤1	1	unlikely	high
8	sunfish	C	349	271	N≤1 & L≤1	N≤1 & L≤1	1	unlikely	high
8	bullhead	D	465	197	N>1 & L≤1	N≤1 & L≤1	2	unlikely	high
8	yellow perch	A	201	175	N≤1 & L≤1	N≤1 & L≤1	1	unlikely	high
8	yellow perch	B	239	177	N≤1 & L≤1	N≤1 & L≤1	1	unlikely	high
8	yellow perch	C	225	155	N≤1 & L≤1	N≤1 & L≤1	1	unlikely	high
8	yellow perch	D	364	237	N≤1 & L≤1	N≤1 & L≤1	1	unlikely	high
8	LM bass	D	1130	751	N>1 & L>1	N>1 & L≤1	5	possible	moderate
9	sunfish	A	219	172	N≤1 & L≤1	N≤1 & L≤1	1	unlikely	high
9	sunfish	B	274	235	N≤1 & L≤1	N≤1 & L≤1	1	unlikely	high
9	bullhead	D	192	176	N≤1 & L≤1	N≤1 & L≤1	1	unlikely	high
9	yellow perch	A	--	--	--	--	--	--	--

Table 4-22

**Summary of the Potential for Ecological Risk to Fish  
Operable Unit IV - Nyanza Chemical Dump Superfund Site  
Middlesex County, Massachusetts**

Reach	Species	Size <sup>a</sup>	Exposure Point Concentration (µg/kg)		Ecological Risk*				
			RME	CTE	RME Case	CTE Case	Risk Scenario	Population Risk?	Confidence Level
9	yellow perch	B	199	165	N≤1 & L≤1	N≤1 & L≤1	1	unlikely	high
9	yellow perch	C	229	170	N≤1 & L≤1	N≤1 & L≤1	1	unlikely	high
9	yellow perch	D	402	334	N>1 & L≤1	N≤1 & L≤1	2	unlikely	high
9	LM bass	D	1270	935	N>1 & L>1	N>1 & L≤1	5	possible	moderate
10	sunfish	A	271	232	N≤1 & L≤1	N≤1 & L≤1	1	unlikely	high
10	sunfish	B	--	--	--	--	--	--	--
10	bullhead	D	288	229	N≤1 & L≤1	N≤1 & L≤1	1	unlikely	high
10	yellow perch	A	390	390	N>1 & L≤1	N>1 & L≤1	4	possible	undetermined**
10	yellow perch	B	259	199	N≤1 & L≤1	N≤1 & L≤1	1	unlikely	high
10	yellow perch	C	259	204	N≤1 & L≤1	N≤1 & L≤1	1	unlikely	high
10	yellow perch	D	440	277	N>1 & L≤1	N≤1 & L≤1	2	unlikely	high
10	LM bass	D	1270	1050	N>1 & L>1	N>1 & L>1	6	possible	high
<b>Reference Areas</b>									
Reach 1	sunfish	A	252	137	N≤1 & L≤1	N≤1 & L≤1	1	unlikely	high
Reach 1	sunfish	B	167	112	N≤1 & L≤1	N≤1 & L≤1	1	unlikely	high
Reach 1	bullhead	D	207	132	N≤1 & L≤1	N≤1 & L≤1	1	unlikely	high
Reach 1	yellow perch	A	--	--	--	--	--	--	--
Reach 1	yellow perch	B	--	--	--	--	--	--	--
Reach 1	yellow perch	C	123	113	N≤1 & L≤1	N≤1 & L≤1	1	unlikely	high
Reach 1	yellow perch	D	164	126	N≤1 & L≤1	N≤1 & L≤1	1	unlikely	high
Reach 1	LM bass	D	255	224	N≤1 & L≤1	N≤1 & L≤1	1	unlikely	high
Charles River	sunfish	A	187	145	N≤1 & L≤1	N≤1 & L≤1	1	unlikely	high
Charles River	sunfish	B	--	--	--	--	--	--	--
Charles River	bullhead	D	137	113	N≤1 & L≤1	N≤1 & L≤1	1	unlikely	high
Charles River	yellow perch	A	--	--	--	--	--	--	--
Charles River	yellow perch	B	122	105	N≤1 & L≤1	N≤1 & L≤1	1	unlikely	high
Charles River	yellow perch	C	123	104	N≤1 & L≤1	N≤1 & L≤1	1	unlikely	high
Charles River	yellow perch	D	169	160	N≤1 & L≤1	N≤1 & L≤1	1	unlikely	high
Charles River	LM bass	D	414	336	N>1 & L≤1	N≤1 & L≤1	2	unlikely	high
Sudbury Reservoir	sunfish	A	58	35	N≤1 & L≤1	N≤1 & L≤1	1	unlikely	high
Sudbury Reservoir	sunfish	B	--	--	--	--	--	--	--
Sudbury Reservoir	bullhead	D	185	124	N≤1 & L≤1	N≤1 & L≤1	1	unlikely	high
Sudbury Reservoir	yellow perch	A	30	26	N≤1 & L≤1	N≤1 & L≤1	1	unlikely	high
Sudbury Reservoir	yellow perch	B	45	33	N≤1 & L≤1	N≤1 & L≤1	1	unlikely	high
Sudbury Reservoir	yellow perch	C	113	64	N≤1 & L≤1	N≤1 & L≤1	1	unlikely	high
Sudbury Reservoir	yellow perch	D	105	84	N≤1 & L≤1	N≤1 & L≤1	1	unlikely	high
Sudbury Reservoir	LM bass	D	201	178	N≤1 & L≤1	N≤1 & L≤1	1	unlikely	high

Notes:

Concentration represents total mercury in whole fish.

Red highlighting indicates that risk of adverse effects is possible, with relatively high confidence only for the particular measurement endpoint, but does not account for the weight given to that measure of risk in the BERA. Other measures of potential risk for the same receptors may not support this conclusion, and remedial action decisions are based on the weight-of-evidence for all measurement endpoints for each ecological receptor.

RME = Reasonable Maximum Exposure (in this case, the maximum detected concentration)

CTE = Central Tendency Exposure (in this case, the arithmetic mean concentration)

<sup>a</sup>Size

Size A = ≤ 10 cm

Size B = 10 &lt; x ≤ 15 cm

Size C = 15 &lt; x ≤ 20 cm

Size D = &gt; 20 cm

**\*Interpretive Ecological Risk Matrix**

Risk Scenario	RME Case	CTE Case	Population Risk?	Confidence Level
1	N≤1 & L≤1	N≤1 & L≤1	unlikely	high
2	N>1 & L≤1	N≤1 & L≤1	unlikely	high
3	N>1 & L>1	N≤1 & L≤1	possible	low
4	N>1 & L≤1	N>1 & L≤1	possible	low/moderate
5	N>1 & L>1	N>1 & L≤1	possible	moderate
6	N>1 & L>1	N>1 & L>1	possible	high

N = a hazard quotient based on dividing an RME or CTE by the NOAEL fish Critical Body Residue (380 µg/kg)

L = a hazard quotient based on dividing an RME or CTE by the LOAEL fish Critical Body Residue (980 µg/kg)

\*\* Confidence level noted as undetermined because only one sample available for use in assessment.

Table 4-23

**Summary of the Potential for Ecological Risk to Aquatic Receptors from Exposure to Surface Water  
Operable Unit IV - Nyanza Chemical Dump Superfund Site  
Middlesex County, Massachusetts**

Reach	Exposure Point Concentration (ng/L)		Ecological Risk*				
	RME	CTE	RME Case	CTE Case	Risk Scenario	Population Risk?	Confidence Level
2	41.8	16.6	$N \leq 1$ & $L \leq 1$	$N \leq 1$ & $L \leq 1$	1	unlikely	high
3	5.89	5.89	$N \leq 1$ & $L \leq 1$	$N \leq 1$ & $L \leq 1$	1	unlikely	undetermined**
4	2.7	2.7	$N \leq 1$ & $L \leq 1$	$N \leq 1$ & $L \leq 1$	1	unlikely	undetermined**
5	1.59	1.59	$N \leq 1$ & $L \leq 1$	$N \leq 1$ & $L \leq 1$	1	unlikely	undetermined**
6	--	--	--	--	--	--	--
7	23.0	5.88	$N \leq 1$ & $L \leq 1$	$N \leq 1$ & $L \leq 1$	1	unlikely	high
7 - Heard Pond	--	--	--	--	--	--	--
8	15.0	9.61	$N \leq 1$ & $L \leq 1$	$N \leq 1$ & $L \leq 1$	1	unlikely	high
9	--	--	--	--	--	--	--
10	--	--	--	--	--	--	--
<b>Reference Areas</b>							
Reach 1	2.26	2.05	$N \leq 1$ & $L \leq 1$	$N \leq 1$ & $L \leq 1$	1	unlikely	high
Charles River	2.85	1.87	$N \leq 1$ & $L \leq 1$	$N \leq 1$ & $L \leq 1$	1	unlikely	high
Sudbury Reservoir	--	--	--	--	--	--	--

Notes:

Concentration represents total mercury.

Red highlighting indicates that risk of adverse effects is possible, with relatively high confidence only for the particular measurement endpoint, but does not account for the weight given to that measure of risk in the BERA. Other measures of potential risk for the same receptors may not support this conclusion, and remedial action decisions are based on the weight-of-evidence for all measurement endpoints for each ecological receptor.

RME = Reasonable Maximum Exposure (in this case, the maximum detected concentration)

CTE = Central Tendency Exposure (in this case, the arithmetic mean concentration)

**\*Interpretive Ecological Risk Matrix**

Risk Scenario	RME Case	CTE Case	Population Risk?	Confidence Level
1	$N \leq 1$ & $L \leq 1$	$N \leq 1$ & $L \leq 1$	unlikely	high
2	$N > 1$ & $L \leq 1$	$N \leq 1$ & $L \leq 1$	unlikely	high
3	$N > 1$ & $L > 1$	$N \leq 1$ & $L \leq 1$	possible	low
4	$N > 1$ & $L \leq 1$	$N > 1$ & $L \leq 1$	possible	low/moderate
5	$N > 1$ & $L > 1$	$N > 1$ & $L \leq 1$	possible	moderate
6	$N > 1$ & $L > 1$	$N > 1$ & $L > 1$	possible	high

N = a hazard quotient based on dividing an RME or CTE by the chronic surface water benchmark for Hg (910 ng/L)

L = a hazard quotient based on dividing an RME or CTE by the acute surface water benchmark for Hg (1,600 ng/L)

\*\* Confidence level noted as undetermined because only one sample available for use in assessment.

Table 4-24

**Summary of the Potential for Ecological Risk to Tree Swallows - 2003**  
**Operable Unit IV - Nyanza Chemical Dump Superfund Site**  
**Middlesex County, Massachusetts**

Reach	Lifestage	Tissue	Exposure Point Concentration (µg/kg)		Ecological Risk*				
			RME	CTE	RME Case	CTE Case	Risk Scenario	Population Risk?	Confidence Level
3	nestling	blood	48.1	35	N≤1 & L≤1	N≤1 & L≤1	1	unlikely	high
3	nestling	feather	--	--	--	--	--	--	--
3	--	egg	60	36	N≤1 & L≤1	N≤1 & L≤1	1	unlikely	high
3	adult	blood	512	258	N≤1 & L≤1	N≤1 & L≤1	1	unlikely	high
3	adult	feather	2690	1570	N>1 & L≤1	N>1 & L≤1	4	possible	low/moderate
4	nestling	blood	34	26	N≤1 & L≤1	N≤1 & L≤1	1	unlikely	high
4	nestling	feather	--	--	--	--	--	--	--
4	--	egg	49	49	N≤1 & L≤1	N≤1 & L≤1	1	unlikely	undetermined**
4	adult	blood	191	191	N≤1 & L≤1	N≤1 & L≤1	1	unlikely	undetermined**
4	adult	feather	794	794	N≤1 & L≤1	N≤1 & L≤1	1	unlikely	undetermined**
7	nestling	blood	--	--	--	--	--	--	--
7	nestling	feather	--	--	--	--	--	--	--
7	--	egg	131	107	N≤1 & L≤1	N≤1 & L≤1	1	unlikely	high
7	adult	blood	374	306	N≤1 & L≤1	N≤1 & L≤1	1	unlikely	high
7	adult	feather	1340	1266	N>1 & L≤1	N>1 & L≤1	4	possible	low/moderate
8	nestling	blood	--	--	--	--	--	--	--
8	nestling	feather	--	--	--	--	--	--	--
8	--	egg	212	135	N≤1 & L≤1	N≤1 & L≤1	1	unlikely	high
8	adult	blood	917	450	N>1 & L≤1	N≤1 & L≤1	2	unlikely	high
8	adult	feather	2520	1374	N>1 & L≤1	N>1 & L≤1	4	possible	low/moderate
<b>Reference Areas</b>									
Charles River	nestling	blood	--	--	--	--	--	--	--
Charles River	nestling	feather	--	--	--	--	--	--	--
Charles River	--	egg	257	137	N≤1 & L≤1	N≤1 & L≤1	1	unlikely	high
Charles River	adult	blood	996	511	N>1 & L≤1	N≤1 & L≤1	2	unlikely	high
Charles River	adult	feather	1560	1070	N>1 & L≤1	N≤1 & L≤1	2	unlikely	high
Sudbury Reservoir	nestling	blood	46	16.2	N≤1 & L≤1	N≤1 & L≤1	1	unlikely	high
Sudbury Reservoir	nestling	feather	--	--	--	--	--	--	--
Sudbury Reservoir	--	egg	157	61	N≤1 & L≤1	N≤1 & L≤1	1	unlikely	high
Sudbury Reservoir	adult	blood	171	120	N≤1 & L≤1	N≤1 & L≤1	1	unlikely	high
Sudbury Reservoir	adult	feather	2270	1510	N>1 & L≤1	N>1 & L≤1	4	possible	low/moderate

## Notes:

Concentration represents total mercury.

Red highlighting indicates that risk of adverse effects is possible, with relatively high confidence only for the particular measurement endpoint, but does not account for the weight given to that measure of risk in the BERA. Other measures of potential risk for the same receptors may not support this conclusion, and remedial action decisions are based on the weight-of-evidence for all measurement endpoints for each ecological receptor.

Mercury levels in bird blood and eggs are indicative of recent (site-specific) exposure to mercury. Mercury concentrations in bird feathers reflect more long-term exposures; therefore, may not be as strongly associated with site-related exposures or potential effects.

RME = Reasonable Maximum Exposure (in this case, the maximum detected concentration)

CTE = Central Tendency Exposure (in this case, the arithmetic mean concentration)

**\*Interpretive Ecological Risk Matrix**

Risk Scenario	RME Case	CTE Case	Population Risk?	Confidence Level
1	N≤1 & L≤1	N≤1 & L≤1	unlikely	high
2	N>1 & L≤1	N≤1 & L≤1	unlikely	high
3	N>1 & L>1	N≤1 & L≤1	possible	low
4	N>1 & L≤1	N>1 & L≤1	possible	low/moderate
5	N>1 & L>1	N>1 & L≤1	possible	moderate
6	N>1 & L>1	N>1 & L>1	possible	high

N = a hazard quotient based on dividing an RME or CTE by the Hg NOAEL for eggs (800 µg/kg for insectivores & 500 µg/kg for all other birds), blood (600 µg/kg) and feather (1,210 µg/kg)

L = a hazard quotient based on dividing an RME or CTE by the Hg LOAEL for eggs (1,600 µg/kg for insectivores & 1,000 µg/kg for all other birds), bird blood (1,250 µg/kg) and feather (9,100 µg/kg)

\*\* Confidence level noted as undetermined because only one sample available for use in assessment.

Table 4-25

**Summary of the Potential for Ecological Risk to Tree Swallows - 2004**  
**Operable Unit IV - Nyanza Chemical Dump Superfund Site**  
**Middlesex County, Massachusetts**

Reach	Lifestage	Tissue	Exposure Point Concentration (µg/kg)		Ecological Risk*				
			RME	CTE	RME Case	CTE Case	Risk Scenario	Population Risk?	Confidence Level
3	nestling	blood	--	--	--	--	--	--	--
3	nestling	feather	--	--	--	--	--	--	--
3	--	egg	308	86.4	N≤1 & L≤1	N≤1 & L≤1	1	unlikely	high
3	adult	blood	672	224	N>1 & L≤1	N≤1 & L≤1	2	unlikely	high
3	adult	feather	8560	2760	N>1 & L≤1	N>1 & L≤1	4	possible	low/moderate
4	nestling	blood	--	--	--	--	--	--	--
4	nestling	feather	--	--	--	--	--	--	--
4	--	egg	172	81.9	N≤1 & L≤1	N≤1 & L≤1	1	unlikely	high
4	adult	blood	470	253	N≤1 & L≤1	N≤1 & L≤1	1	unlikely	high
4	adult	feather	4390	2000	N>1 & L≤1	N>1 & L≤1	4	possible	low/moderate
7 - Heard Pond	nestling	blood	--	--	--	--	--	--	--
7 - Heard Pond	nestling	feather	--	--	--	--	--	--	--
7 - Heard Pond	--	egg	450	168	N≤1 & L≤1	N≤1 & L≤1	1	unlikely	high
7 - Heard Pond	adult	blood	1290	630	N>1 & L>1	N>1 & L≤1	5	possible	moderate
7 - Heard Pond	adult	feather	4540	2280	N>1 & L≤1	N>1 & L≤1	4	possible	low/moderate
8	nestling	blood	--	--	--	--	--	--	--
8	nestling	feather	--	--	--	--	--	--	--
8	--	egg	464	261	N≤1 & L≤1	N≤1 & L≤1	1	unlikely	high
8	adult	blood	1310	691	N>1 & L>1	N>1 & L≤1	5	possible	moderate
8	adult	feather	3530	2220	N>1 & L≤1	N>1 & L≤1	4	possible	low/moderate
<b>Reference Area</b>									
Charles River	nestling	blood	--	--	--	--	--	--	--
Charles River	nestling	feather	--	--	--	--	--	--	--
Charles River	--	egg	151	114	N≤1 & L≤1	N≤1 & L≤1	1	unlikely	high
Charles River	adult	blood	549	405	N≤1 & L≤1	N≤1 & L≤1	1	unlikely	high
Charles River	adult	feather	6030	2270	N>1 & L≤1	N>1 & L≤1	4	possible	low/moderate

## Notes:

Concentration represents total mercury.

Red highlighting indicates that risk of adverse effects is possible, with relatively high confidence only for the particular measurement endpoint, but does not account for the weight given to that measure of risk in the BERA. Other measures of potential risk for the same receptors may not support this conclusion, and remedial action decisions are based on the weight-of-evidence for all measurement endpoints for each ecological receptor.

Mercury levels in bird blood and eggs are indicative of recent (site-specific) exposure to mercury. Mercury concentrations in bird feathers reflect more long-term exposures; therefore, may not be as strongly associated with site-related exposures or potential effects.

RME = Reasonable Maximum Exposure (in this case, the maximum detected concentration)

CTE = Central Tendency Exposure (in this case, the arithmetic mean concentration)

**\*Interpretive Ecological Risk Matrix**

Risk Scenario	RME Case	CTE Case	Population Risk?	Confidence Level
1	N≤1 & L≤1	N≤1 & L≤1	unlikely	high
2	N>1 & L≤1	N≤1 & L≤1	unlikely	high
3	N>1 & L>1	N≤1 & L≤1	possible	low
4	N>1 & L≤1	N>1 & L≤1	possible	low/moderate
5	N>1 & L>1	N>1 & L≤1	possible	moderate
6	N>1 & L>1	N>1 & L>1	possible	high

N = a hazard quotient based on dividing an RME or CTE by the Hg NOAEL for eggs (800 µg/kg for insectivores & 500 µg/kg for all other birds), blood (600 µg/kg) and feather (1,210 µg/kg)

L = a hazard quotient based on dividing an RME or CTE by the Hg LOAEL for eggs (1,600 µg/kg for insectivores & 1,000 µg/kg for all other birds), bird blood (1,250 µg/kg) and feather (9,100 µg/kg)



Table 4-26

**Summary of the Potential for Ecological Risk to Tree Swallows Based on Food Chain Modeling  
Operable Unit IV - Nyanza Chemical Dump Superfund Site  
Middlesex County, Massachusetts**

Reach	Exposure Scenario		Ecological Risk*		
	RME	CTE	Risk Scenario	Population Risk?	Confidence Level
2	N>1 & L>1	N>1 & L>1	6	possible	high
3	N>1 & L>1	N>1 & L>1	6	possible	high
4	N>1 & L>1	N>1 & L>1	6	possible	high
5	N>1 & L>1	N>1 & L≤1	5	possible	moderate
6	N>1 & L>1	N>1 & L>1	6	possible	high
7	N>1 & L≤1	N≤1 & L≤1	2	unlikely	high
7 - Heard Pond	N>1 & L>1	N>1 & L>1	6	possible	high
8	N>1 & L≤1	N≤1 & L≤1	2	unlikely	high
9	N>1 & L>1	N>1 & L≤1	5	possible	moderate
10	N>1 & L≤1	N>1 & L≤1	4	possible	low/moderate
<b>Reference Areas</b>					
Reach 1	N>1 & L>1	N>1 & L≤1	5	possible	moderate
Charles River	N≤1 & L≤1	N≤1 & L≤1	1	unlikely	high
Sudbury Reservoir	N≤1 & L≤1	N≤1 & L≤1	1	unlikely	high

Notes:

HQs derived from modeled exposures to total mercury (see Tables 4-10 and 4-11).

Red highlighting indicates that risk of adverse effects is possible, with relatively high confidence only for the particular measurement endpoint, but does not account for the weight given to that measure of risk in the BERA. Other measures of potential risk for the same receptors may not support this conclusion, and remedial action decisions are based on the weight-of-evidence for all measurement endpoints for each ecological receptor.

RME = Reasonable Maximum Exposure

CTE = Central Tendency Exposure

**\*Interpretive Ecological Risk Matrix**

Risk Scenario	RME Case	CTE Case	Population Risk?	Confidence Level
1	N≤1 & L≤1	N≤1 & L≤1	unlikely	high
2	N>1 & L≤1	N≤1 & L≤1	unlikely	high
3	N>1 & L>1	N≤1 & L≤1	possible	low
4	N>1 & L≤1	N>1 & L≤1	possible	low/moderate
5	N>1 & L>1	N>1 & L≤1	possible	moderate
6	N>1 & L>1	N>1 & L>1	possible	high

N = a hazard quotient based on dividing an RME or CTE dose by the no effect TRV

L = a hazard quotient based on dividing an RME or CTE dose by the effect TRV

Table 4-27

**Summary of the Potential for Ecological Risk to Eastern Kingbirds - 2003**  
**Operable Unit IV - Nyanza Chemical Dump Superfund Site**  
**Middlesex County, Massachusetts**

Reach	Tissue	Exposure Point Concentration (µg/kg)		Ecological Risk*				
		RME	CTE	RME Case	CTE Case	Risk Scenario	Population Risk?	Confidence Level
7	egg	154	108	$N \leq 1$ & $L \leq 1$	$N \leq 1$ & $L \leq 1$	1	unlikely	high
7	blood	--	--	--	--	--	--	--
7	feather	--	--	--	--	--	--	--
8	egg	210	138	$N \leq 1$ & $L \leq 1$	$N \leq 1$ & $L \leq 1$	1	unlikely	high
8	blood	--	--	--	--	--	--	--
8	feather	--	--	--	--	--	--	--
9	egg	148	110	$N \leq 1$ & $L \leq 1$	$N \leq 1$ & $L \leq 1$	1	unlikely	high
9	blood	--	--	--	--	--	--	--
9	feather	--	--	--	--	--	--	--
10	egg	141	91	$N \leq 1$ & $L \leq 1$	$N \leq 1$ & $L \leq 1$	1	unlikely	high
10	blood	--	--	--	--	--	--	--
10	feather	--	--	--	--	--	--	--
<b>Reference Area</b>								
Charles River	egg	170	161	$N \leq 1$ & $L \leq 1$	$N \leq 1$ & $L \leq 1$	1	unlikely	high
Charles River	blood	--	--	--	--	--	--	--
Charles River	feather	--	--	--	--	--	--	--

## Notes:

Concentration represents total mercury.

Blood and feathers from adult birds.

Red highlighting indicates that risk of adverse effects is possible, with relatively high confidence only for the particular measurement endpoint, but does not account for the weight given to that measure of risk in the BERA. Other measures of potential risk for the same receptors may not support this conclusion, and remedial action decisions are based on the weight-of-evidence for all measurement endpoints for each ecological receptor.

RME = Reasonable Maximum Exposure (in this case, the maximum detected concentration)

CTE = Central Tendency Exposure (in this case, the arithmetic mean concentration)

**\*Interpretive Ecological Risk Matrix**

Risk Scenario	RME Case	CTE Case	Population Risk?	Confidence Level
1	$N \leq 1$ & $L \leq 1$	$N \leq 1$ & $L \leq 1$	unlikely	high
2	$N > 1$ & $L \leq 1$	$N \leq 1$ & $L \leq 1$	unlikely	high
3	$N > 1$ & $L > 1$	$N \leq 1$ & $L \leq 1$	possible	low
4	$N > 1$ & $L \leq 1$	$N > 1$ & $L \leq 1$	possible	low/moderate
5	$N > 1$ & $L > 1$	$N > 1$ & $L \leq 1$	possible	moderate
6	$N > 1$ & $L > 1$	$N > 1$ & $L > 1$	possible	high

N = a hazard quotient based on dividing an RME or CTE by the Hg NOAEL for eggs (800 µg/kg for insectivores & 500 µg/kg for all other birds), blood (600 µg/kg) and feather (1,210 µg/kg)

L = a hazard quotient based on dividing an RME or CTE by the Hg LOAEL for eggs (1,600 µg/kg for insectivores & 1,000 µg/kg for all other birds), bird blood (1,250 µg/kg) and feather (9,100 µg/kg)

Table 4-28

**Summary of the Potential for Ecological Risk to Red Wing Black Birds - 2005**  
**Operable Unit IV - Nyanza Chemical Dump Superfund Site**  
**Middlesex County, Massachusetts**

Reach	Tissue	Exposure Point Concentration (µg/kg)		Ecological Risk*				
		RME	CTE	RME Case	CTE Case	Risk Scenario	Population Risk?	Confidence Level
8	blood	9420	4060	N>1 & L>1	N>1 & L>1	6	possible	high
8	feather	--	--	--	--	--	--	--

Notes:

Concentration represents total mercury.

Blood and feathers from adult birds.

Red highlighting indicates that risk of adverse effects is possible, with relatively high confidence only for the particular measurement endpoint, but does not account for the weight given to that measure of risk in the BERA. Other measures of potential risk for the same receptors may not support this conclusion, and remedial action decisions are based on the weight-of-evidence for all measurement endpoints for each ecological receptor.

Mercury levels in bird blood and eggs are indicative of recent (site-specific) exposure to mercury. Mercury concentrations in bird feathers reflect more long-term exposures; therefore, may not be as strongly associated with site-related exposures or potential effects.

RME = Reasonable Maximum Exposure (in this case, the maximum detected concentration)

CTE = Central Tendency Exposure (in this case, the arithmetic mean concentration)

**\*Interpretive Ecological Risk Matrix**

Risk Scenario	RME Case	CTE Case	Population Risk?	Confidence Level
1	N≤1 & L≤1	N≤1 & L≤1	unlikely	high
2	N>1 & L≤1	N≤1 & L≤1	unlikely	high
3	N>1 & L>1	N≤1 & L≤1	possible	low
4	N>1 & L≤1	N>1 & L≤1	possible	low/moderate
5	N>1 & L>1	N>1 & L≤1	possible	moderate
6	N>1 & L>1	N>1 & L>1	possible	high

N = a hazard quotient based on dividing an RME or CTE by the Hg NOAEL for eggs (800 µg/kg for insectivores & 500 µg/kg for all other birds), blood (600 µg/kg) and feather (1,210 µg/kg)

L = a hazard quotient based on dividing an RME or CTE by the Hg LOAEL for eggs (1,600 µg/kg for insectivores & 1,000 µg/kg for all other birds), bird blood (1,250 µg/kg) and feather (9,100 µg/kg)

Table 4-29

**Summary of the Potential for Ecological Risk to Common Yellowthroats - 2003**  
**Operable Unit IV - Nyanza Chemical Dump Superfund Site**  
**Middlesex County, Massachusetts**

Reach	Tissue	Exposure Point Concentration (µg/kg)		Ecological Risk*				
		RME	CTE	RME Case	CTE Case	Risk Scenario	Population Risk?	Confidence Level
7	blood	203	203	$N \leq 1$ & $L \leq 1$	$N > 1$ & $L \leq 1$	1	unlikely	undetermined**
7	feather	1900	1900	$N > 1$ & $L \leq 1$	$N > 1$ & $L \leq 1$	4	possible	undetermined**
8	blood	437	182	$N \leq 1$ & $L \leq 1$	$N \leq 1$ & $L \leq 1$	1	unlikely	high
8	feather	6470	4600	$N > 1$ & $L \leq 1$	$N > 1$ & $L \leq 1$	4	possible	low/moderate
<b>Reference Area</b>								
Charles River	blood	338	197	$N \leq 1$ & $L \leq 1$	$N \leq 1$ & $L \leq 1$	1	unlikely	high
Charles River	feather	5960	5960	$N > 1$ & $L \leq 1$	$N > 1$ & $L \leq 1$	4	possible	undetermined**

## Notes:

Concentration represents total mercury.

Blood and feathers from adult birds.

Red highlighting indicates that risk of adverse effects is possible, with relatively high confidence only for the particular measurement endpoint, but does not account for the weight given to that measure of risk in the BERA. Other measures of potential risk for the same receptors may not support this conclusion, and remedial action decisions are based on the weight-of-evidence for all measurement endpoints for each ecological receptor.

Mercury levels in bird blood and eggs are indicative of recent (site-specific) exposure to mercury. Mercury concentrations in bird feathers reflect more long-term exposures; therefore, may not be as strongly associated with site-related exposures or potential effects.

RME = Reasonable Maximum Exposure (in this case, the maximum detected concentration)

CTE = Central Tendency Exposure (in this case, the arithmetic mean concentration)

**\*Interpretive Ecological Risk Matrix**

Risk Scenario	RME Case	CTE Case	Population Risk?	Confidence Level
1	$N \leq 1$ & $L \leq 1$	$N \leq 1$ & $L \leq 1$	unlikely	high
2	$N > 1$ & $L \leq 1$	$N \leq 1$ & $L \leq 1$	unlikely	high
3	$N > 1$ & $L > 1$	$N \leq 1$ & $L \leq 1$	possible	low
4	$N > 1$ & $L \leq 1$	$N > 1$ & $L \leq 1$	possible	low/moderate
5	$N > 1$ & $L > 1$	$N > 1$ & $L \leq 1$	possible	moderate
6	$N > 1$ & $L > 1$	$N > 1$ & $L > 1$	possible	high

N = a hazard quotient based on dividing an RME or CTE by the Hg NOAEL for eggs (800 µg/kg for insectivores & 500 µg/kg for all other birds), blood (600 µg/kg) and feather (1,210 µg/kg)

L = a hazard quotient based on dividing an RME or CTE by the Hg LOAEL for eggs (1,600 µg/kg for insectivores & 1,000 µg/kg for all other birds), bird blood (1,250 µg/kg) and feather (9,100 µg/kg)

\*\* Confidence level noted as undetermined because only one sample available for use in assessment.

Table 4-30

**Summary of the Potential for Ecological Risk to Northern Waterthrushes - 2003**  
**Operable Unit IV - Nyanza Chemical Dump Superfund Site**  
**Middlesex County, Massachusetts**

Reach	Tissue	Exposure Point Concentration (µg/kg)		Ecological Risk*				
		RME	CTE	RME Case	CTE Case	Risk Scenario	Population Risk?	Confidence Level
7	blood	--	--	--	--	--	--	--
7	feather	795	795	$N \leq 1$ & $L \leq 1$	$N \leq 1$ & $L \leq 1$	1	unlikely	undetermined**
<b>Reference Area</b>								
Charles River	blood	--	--	--	--	--	--	--
Charles River	feather	406	406	$N > 1$ & $L \leq 1$	$N > 1$ & $L \leq 1$	4	possible	undetermined**

Notes:

Concentration represents total mercury.

Blood and feathers from adult birds.

Red highlighting indicates that risk of adverse effects is possible, with relatively high confidence only for the particular measurement endpoint, but does not account for the weight given to that measure of risk in the BERA. Other measures of potential risk for the same receptors may not support this conclusion, and remedial action decisions are based on the weight-of-evidence for all measurement endpoints for each ecological receptor.

Mercury levels in bird blood and eggs are indicative of recent (site-specific) exposure to mercury. Mercury concentrations in bird feathers reflect more long-term exposures; therefore, may not be as strongly associated with site-related exposures or potential effects.

RME = Reasonable Maximum Exposure (in this case, the maximum detected concentration)

CTE = Central Tendency Exposure (in this case, the arithmetic mean concentration)

**\*Interpretive Ecological Risk Matrix**

Risk Scenario	RME Case	CTE Case	Population Risk?	Confidence Level
1	$N \leq 1$ & $L \leq 1$	$N \leq 1$ & $L \leq 1$	unlikely	high
2	$N > 1$ & $L \leq 1$	$N \leq 1$ & $L \leq 1$	unlikely	high
3	$N > 1$ & $L > 1$	$N \leq 1$ & $L \leq 1$	possible	low
4	$N > 1$ & $L \leq 1$	$N > 1$ & $L \leq 1$	possible	low/moderate
5	$N > 1$ & $L > 1$	$N > 1$ & $L \leq 1$	possible	moderate
6	$N > 1$ & $L > 1$	$N > 1$ & $L > 1$	possible	high

N = a hazard quotient based on dividing an RME or CTE by the Hg NOAEL for eggs (800 µg/kg for insectivores & 500 µg/kg for all other birds), blood (600 µg/kg) and feather (1,210 µg/kg)

L = a hazard quotient based on dividing an RME or CTE by the Hg LOAEL for eggs (1,600 µg/kg for insectivores & 1,000 µg/kg for all other birds), bird blood (1,250 µg/kg) and feather (9,100 µg/kg)

\*\* Confidence level noted as undetermined because only one sample available for use in assessment.

Table 4-31

**Summary of the Potential for Ecological Risk to Song Sparrows - 2003**  
**Operable Unit IV - Nyanza Chemical Dump Superfund Site**  
**Middlesex County, Massachusetts**

Reach	Tissue	Exposure Point Concentration (µg/kg)		Ecological Risk*				
		RME	CTE	RME Case	CTE Case	Risk Scenario	Population Risk?	Confidence Level
7	blood	192	99.1	$N \leq 1$ & $L \leq 1$	$N \leq 1$ & $L \leq 1$	1	unlikely	high
7	feather	8570	2240	$N > 1$ & $L \leq 1$	$N > 1$ & $L \leq 1$	4	possible	low/moderate
8	blood	1340	661	$N > 1$ & $L > 1$	$N > 1$ & $L \leq 1$	5	possible	moderate
8	feather	7790	3540	$N > 1$ & $L \leq 1$	$N > 1$ & $L \leq 1$	4	possible	low/moderate
<b>Reference Area</b>								
Charles River	blood	413	343	$N \leq 1$ & $L \leq 1$	$N \leq 1$ & $L \leq 1$	1	unlikely	high
Charles River	feather	13600	6070	$N > 1$ & $L > 1$	$N > 1$ & $L \leq 1$	5	possible	moderate

Notes:

Concentration represents total mercury.

Blood and feathers from adult birds.

Red highlighting indicates that risk of adverse effects is possible, with relatively high confidence only for the particular measurement endpoint, but does not account for the weight given to that measure of risk in the BERA. Other measures of potential risk for the same receptors may not support this conclusion, and remedial action decisions are based on the weight-of-evidence for all measurement endpoints for each ecological receptor.

Mercury levels in bird blood and eggs are indicative of recent (site-specific) exposure to mercury. Mercury concentrations in bird feathers reflect more long-term exposures; therefore, may not be as strongly associated with site-related exposures or potential effects.

RME = Reasonable Maximum Exposure (in this case, the maximum detected concentration)

CTE = Central Tendency Exposure (in this case, the arithmetic mean concentration)

**\*Interpretive Ecological Risk Matrix**

Risk Scenario	RME Case	CTE Case	Population Risk?	Confidence Level
1	$N \leq 1$ & $L \leq 1$	$N \leq 1$ & $L \leq 1$	unlikely	high
2	$N > 1$ & $L \leq 1$	$N \leq 1$ & $L \leq 1$	unlikely	high
3	$N > 1$ & $L > 1$	$N \leq 1$ & $L \leq 1$	possible	low
4	$N > 1$ & $L \leq 1$	$N > 1$ & $L \leq 1$	possible	low/moderate
5	$N > 1$ & $L > 1$	$N > 1$ & $L \leq 1$	possible	moderate
6	$N > 1$ & $L > 1$	$N > 1$ & $L > 1$	possible	high

N = a hazard quotient based on dividing an RME or CTE by the Hg NOAEL for eggs (800 µg/kg for insectivores & 500 µg/kg for all other birds), blood (600 µg/kg) and feather (1,210 µg/kg)

L = a hazard quotient based on dividing an RME or CTE by the Hg LOAEL for eggs (1,600 µg/kg for insectivores & 1,000 µg/kg for all other birds), bird blood (1,250 µg/kg) and feather (9,100 µg/kg)

Table 4-32

**Summary of the Potential for Ecological Risk to Song Sparrows - 2004**  
**Operable Unit IV - Nyanza Chemical Dump Superfund Site**  
**Middlesex County, Massachusetts**

Reach	Tissue	Exposure Point Concentration (µg/kg)		Ecological Risk*				
		RME	CTE	RME Case	CTE Case	Risk Scenario	Population Risk?	Confidence Level
7 - Heard Pond	blood	845	267	N>1 & L≤1	N≤1 & L≤1	2	unlikely	high
7 - Heard Pond	feather	--	--	--	--	--	--	--
8	blood	717	384	N>1 & L≤1	N≤1 & L≤1	2	unlikely	high
8	feather	--	--	--	--	--	--	--
<b>Reference Area</b>								
Charles River	blood	209	117	N≤1 & L≤1	N≤1 & L≤1	1	unlikely	high
Charles River	feather	--	--	--	--	--	--	--

## Notes:

Concentration represents total mercury.

Blood and feathers from adult birds.

Red highlighting indicates that risk of adverse effects is possible, with relatively high confidence only for the particular measurement endpoint, but does not account for the weight given to that measure of risk in the BERA. Other measures of potential risk for the same receptors may not support this conclusion, and remedial action decisions are based on the weight-of-evidence for all measurement endpoints for each ecological receptor.

Mercury levels in bird blood and eggs are indicative of recent (site-specific) exposure to mercury. Mercury concentrations in bird feathers reflect more long-term exposures; therefore, may not be as strongly associated with site-related exposures or potential effects.

RME = Reasonable Maximum Exposure (in this case, the maximum detected concentration)

CTE = Central Tendency Exposure (in this case, the arithmetic mean concentration)

**\*Interpretive Ecological Risk Matrix**

Risk Scenario	RME Case	CTE Case	Population Risk?	Confidence Level
1	N≤1 & L≤1	N≤1 & L≤1	unlikely	high
2	N>1 & L≤1	N≤1 & L≤1	unlikely	high
3	N>1 & L>1	N≤1 & L≤1	possible	low
4	N>1 & L≤1	N>1 & L≤1	possible	low/moderate
5	N>1 & L>1	N>1 & L≤1	possible	moderate
6	N>1 & L>1	N>1 & L>1	possible	high

N = a hazard quotient based on dividing an RME or CTE by the Hg NOAEL for eggs (800 µg/kg for insectivores & 500 µg/kg for all other birds), blood (600 µg/kg) and feather (1,210 µg/kg)

L = a hazard quotient based on dividing an RME or CTE by the Hg LOAEL for eggs (1,600 µg/kg for insectivores & 1,000 µg/kg for all other birds), bird blood (1,250 µg/kg) and feather (9,100 µg/kg)

Table 4-33

**Summary of the Potential for Ecological Risk to Swamp Sparrows - 2003**  
**Operable Unit IV - Nyanza Chemical Dump Superfund Site**  
**Middlesex County, Massachusetts**

Reach	Tissue	Exposure Point Concentration (µg/kg)		Ecological Risk*				
		RME	CTE	RME Case	CTE Case	Risk Scenario	Population Risk?	Confidence Level
7	blood	431	243	$N \leq 1$ & $L \leq 1$	$N \leq 1$ & $L \leq 1$	1	unlikely	high
7	feather	4880	2730	$N > 1$ & $L \leq 1$	$N > 1$ & $L \leq 1$	4	possible	low/moderate
8	blood	1450	541	$N > 1$ & $L > 1$	$N \leq 1$ & $L \leq 1$	3	possible	low
8	feather	5890	3570	$N > 1$ & $L \leq 1$	$N > 1$ & $L \leq 1$	4	possible	low/moderate
<b>Reference Area</b>								
Charles River	blood	423	306	$N \leq 1$ & $L \leq 1$	$N \leq 1$ & $L \leq 1$	1	unlikely	high
Charles River	feather	11400	4420	$N > 1$ & $L > 1$	$N > 1$ & $L \leq 1$	5	possible	moderate

Notes:

Concentration represents total mercury.

Blood and feathers from adult birds.

Red highlighting indicates that risk of adverse effects is possible, with relatively high confidence only for the particular measurement endpoint, but does not account for the weight given to that measure of risk in the BERA. Other measures of potential risk for the same receptors may not support this conclusion, and remedial action decisions are based on the weight-of-evidence for all measurement endpoints for each ecological receptor.

Mercury levels in bird blood and eggs are indicative of recent (site-specific) exposure to mercury. Mercury concentrations in bird feathers reflect more long-term exposures; therefore, may not be as strongly associated with site-related exposures or potential effects.

RME = Reasonable Maximum Exposure (in this case, the maximum detected concentration)

CTE = Central Tendency Exposure (in this case, the arithmetic mean concentration)

**\*Interpretive Ecological Risk Matrix**

Risk Scenario	RME Case	CTE Case	Population Risk?	Confidence Level
1	$N \leq 1$ & $L \leq 1$	$N \leq 1$ & $L \leq 1$	unlikely	high
2	$N > 1$ & $L \leq 1$	$N \leq 1$ & $L \leq 1$	unlikely	high
3	$N > 1$ & $L > 1$	$N \leq 1$ & $L \leq 1$	possible	low
4	$N > 1$ & $L \leq 1$	$N > 1$ & $L \leq 1$	possible	low/moderate
5	$N > 1$ & $L > 1$	$N > 1$ & $L \leq 1$	possible	moderate
6	$N > 1$ & $L > 1$	$N > 1$ & $L > 1$	possible	high

N = a hazard quotient based on dividing an RME or CTE by the Hg NOAEL for eggs (800 µg/kg for insectivores & 500 µg/kg for all other birds), blood (600 µg/kg) and feather (1,210 µg/kg)

L = a hazard quotient based on dividing an RME or CTE by the Hg LOAEL for eggs (1,600 µg/kg for insectivores & 1,000 µg/kg for all other birds), bird blood (1,250 µg/kg) and feather (9,100 µg/kg)



Table 4-34

**Summary of the Potential for Ecological Risk to Swamp Sparrows - 2004  
Operable Unit IV - Nyanza Chemical Dump Superfund Site  
Middlesex County, Massachusetts**

Reach	Tissue	Exposure Point Concentration (µg/kg)		Ecological Risk*				
		RME	CTE	RME Case	CTE Case	Risk Scenario	Population Risk?	Confidence Level
7 - Heard Pond	blood	703	350	N>1 & L≤1	N≤1 & L≤1	2	unlikely	high
7 - Heard Pond	feather	--	--	--	--	--	--	--
8	blood	957	454	N>1 & L≤1	N≤1 & L≤1	2	unlikely	high
8	feather	--	--	--	--	--	--	--

Notes:

Concentration represents total mercury.

Blood and feathers from adult birds.

Red highlighting indicates that risk of adverse effects is possible, with relatively high confidence only for the particular measurement endpoint, but does not account for the weight given to that measure of risk in the BERA. Other measures of potential risk for the same receptors may not support this conclusion, and remedial action decisions are based on the weight-of-evidence for all measurement endpoints for each ecological receptor.

Mercury levels in bird blood and eggs are indicative of recent (site-specific) exposure to mercury. Mercury concentrations in bird feathers reflect more long-term exposures; therefore, may not be as strongly associated with site-related exposures or potential effects.

RME = Reasonable Maximum Exposure (in this case, the maximum detected concentration)

CTE = Central Tendency Exposure (in this case, the arithmetic mean concentration)

**\*Interpretive Ecological Risk Matrix**

Risk Scenario	RME Case	CTE Case	Population Risk?	Confidence Level
1	N≤1 & L≤1	N≤1 & L≤1	unlikely	high
2	N>1 & L≤1	N≤1 & L≤1	unlikely	high
3	N>1 & L>1	N≤1 & L≤1	possible	low
4	N>1 & L≤1	N>1 & L≤1	possible	low/moderate
5	N>1 & L>1	N>1 & L≤1	possible	moderate
6	N>1 & L>1	N>1 & L>1	possible	high

N = a hazard quotient based on dividing an RME or CTE by the Hg NOAEL for eggs (800 µg/kg for insectivores & 500 µg/kg for all other birds), blood (600 µg/kg) and feather (1,210 µg/kg)

L = a hazard quotient based on dividing an RME or CTE by the Hg LOAEL for eggs (1,600 µg/kg for insectivores & 1,000 µg/kg for all other birds), bird blood (1,250 µg/kg) and feather (9,100 µg/kg)

Table 4-35

**Summary of the Potential for Ecological Risk to Yellow Warblers - 2003**  
**Operable Unit IV - Nyanza Chemical Dump Superfund Site**  
**Middlesex County, Massachusetts**

Reach	Tissue	Exposure Point Concentration (µg/kg)		Ecological Risk*				
		RME	CTE	RME Case	CTE Case	Risk Scenario	Population Risk?	Confidence Level
7	blood	68	53	$N \leq 1$ & $L \leq 1$	$N \leq 1$ & $L \leq 1$	1	unlikely	high
7	feather	1560	1560	$N > 1$ & $L \leq 1$	$N > 1$ & $L \leq 1$	4	possible	undetermined**
8	blood	63	55	$N \leq 1$ & $L \leq 1$	$N \leq 1$ & $L \leq 1$	1	unlikely	high
8	feather	11700	11700	$N > 1$ & $L > 1$	$N > 1$ & $L > 1$	6	possible	undetermined**
<b>Reference Area</b>								
Charles River	blood	48	19	$N \leq 1$ & $L \leq 1$	$N \leq 1$ & $L \leq 1$	1	unlikely	high
Charles River	feather	8870	3510	$N > 1$ & $L \leq 1$	$N > 1$ & $L \leq 1$	4	possible	low/moderate

## Notes:

Concentration represents total mercury.

Blood and feathers from adult birds.

Red highlighting indicates that risk of adverse effects is possible, with relatively high confidence only for the particular measurement endpoint, but does not account for the weight given to that measure of risk in the BERA. Other measures of potential risk for the same receptors may not support this conclusion, and remedial action decisions are based on the weight-of-evidence for all measurement endpoints for each ecological receptor.

Mercury levels in bird blood and eggs are indicative of recent (site-specific) exposure to mercury. Mercury concentrations in bird feathers reflect more long-term exposures; therefore, may not be as strongly associated with site-related exposures or potential effects.

RME = Reasonable Maximum Exposure (in this case, the maximum detected concentration)

CTE = Central Tendency Exposure (in this case, the arithmetic mean concentration)

**\*Interpretive Ecological Risk Matrix**

Risk Scenario	RME Case	CTE Case	Population Risk?	Confidence Level
1	$N \leq 1$ & $L \leq 1$	$N \leq 1$ & $L \leq 1$	unlikely	high
2	$N > 1$ & $L \leq 1$	$N \leq 1$ & $L \leq 1$	unlikely	high
3	$N > 1$ & $L > 1$	$N \leq 1$ & $L \leq 1$	possible	low
4	$N > 1$ & $L \leq 1$	$N > 1$ & $L \leq 1$	possible	low/moderate
5	$N > 1$ & $L > 1$	$N > 1$ & $L \leq 1$	possible	moderate
6	$N > 1$ & $L > 1$	$N > 1$ & $L > 1$	possible	high

N = a hazard quotient based on dividing an RME or CTE by the Hg NOAEL for eggs (800 µg/kg for insectivores & 500 µg/kg for all other birds), blood (600 µg/kg) and feather (1,210 µg/kg)

L = a hazard quotient based on dividing an RME or CTE by the Hg LOAEL for eggs (1,600 µg/kg for insectivores & 1,000 µg/kg for all other birds), bird blood (1,250 µg/kg) and feather (9,100 µg/kg)

\*\* Confidence level noted as undetermined because only one sample available for use in assessment.

Table 4-36

**Summary of the Potential for Ecological Risk to Hooded Merganser - 2003**  
**Operable Unit IV - Nyanza Chemical Dump Superfund Site**  
**Middlesex County, Massachusetts**

Reach	Lifestage	Tissue	Exposure Point Concentration (µg/kg)		Ecological Risk*				
			RME	CTE	RME Case	CTE Case	Risk Scenario	Population Risk?	Confidence Level
Reach 1 (Whitehall Reservoir)	NA	egg	326	326	N≤1 & L≤1	N≤1 & L≤1	1	unlikely	undetermined**
Reach 1 (Whitehall Reservoir)	nestling	blood	1130	1130	N>1 & L≤1	N>1 & L≤1	4	possible	undetermined**
Reach 1 (Whitehall Reservoir)	adult	blood	761	558	N>1 & L≤1	N≤1 & L≤1	2	unlikely	high
Delaney Reservoir	NA	egg	726	296	N>1 & L≤1	N≤1 & L≤1	2	unlikely	high
Delaney Reservoir	adult	blood	426	248	N≤1 & L≤1	N≤1 & L≤1	1	unlikely	high
Delaney Reservoir	adult	feather	17500	11900	N>1 & L>1	N>1 & L>1	6	possible	high

Notes:

Concentration represents total mercury.

Red highlighting indicates that risk of adverse effects is possible, with relatively high confidence only for the particular measurement endpoint, but does not account for the weight given to that measure of risk in the BERA. Other measures of potential risk for the same receptors may not support this conclusion, and remedial action decisions are based on the weight-of-evidence for all measurement endpoints for each ecological receptor.

Mercury levels in bird blood and eggs are indicative of recent (site-specific) exposure to mercury. Mercury concentrations in bird feathers reflect more long-term exposures; therefore, may not be as strongly associated with site-related exposures or potential effects.

RME = Reasonable Maximum Exposure (in this case, the maximum detected concentration)

CTE = Central Tendency Exposure (in this case, the arithmetic mean concentration)

**\*Interpretive Ecological Risk Matrix**

Risk Scenario	RME Case	CTE Case	Population Risk?	Confidence Level
1	N≤1 & L≤1	N≤1 & L≤1	unlikely	high
2	N>1 & L≤1	N≤1 & L≤1	unlikely	high
3	N>1 & L>1	N≤1 & L≤1	possible	low
4	N>1 & L≤1	N>1 & L≤1	possible	low/moderate
5	N>1 & L>1	N>1 & L≤1	possible	moderate
6	N>1 & L>1	N>1 & L>1	possible	high

N = a hazard quotient based on dividing an RME or CTE by the Hg NOAEL for eggs (800 µg/kg for insectivores & 500 µg/kg for all other birds), blood (600 µg/kg) and feather (1,210 µg/kg)

L = a hazard quotient based on dividing an RME or CTE by the Hg LOAEL for eggs (1,600 µg/kg for insectivores & 1,000 µg/kg for all other birds), bird blood (1,250 µg/kg) and feather (9,100 µg/kg)

\*\* Confidence level noted as undetermined because only one sample available for use in assessment.

Table 4-37

**Summary of the Potential for Ecological Risk to Hooded Merganser - 2004**  
**Operable Unit IV - Nyanza Chemical Dump Superfund Site**  
**Middlesex County, Massachusetts**

Reach	Tissue	Exposure Point		Ecological Risk*				
		Concentration (µg/kg)		RME Case	CTE Case	Risk Scenario	Population Risk?	Confidence Level
		RME	CTE					
8	egg	--	--	--	--	--	--	--
8	blood	21.2	21.2	N≤1 & L≤1	N≤1 & L≤1	1	unlikely	undetermined**
8	feather	7590	7590	N>1 & L≤1	N>1 & L≤1	4	possible	undetermined**

Notes:

Concentration represents total mercury.

Blood and feathers from adult birds.

Red highlighting indicates that risk of adverse effects is possible, with relatively high confidence only for the particular measurement endpoint, but does not account for the weight given to that measure of risk in the BERA. Other measures of potential risk for the same receptors may not support this conclusion, and remedial action decisions are based on the weight-of-evidence for all measurement endpoints for each ecological receptor.

Mercury levels in bird blood and eggs are indicative of recent (site-specific) exposure to mercury. Mercury concentrations in bird feathers reflect more long-term exposures; therefore, may not be as strongly associated with site-related exposures or potential effects.

RME = Reasonable Maximum Exposure (in this case, the maximum detected concentration)

CTE = Central Tendency Exposure (in this case, the arithmetic mean concentration)

**\*Interpretive Ecological Risk Matrix**

Risk Scenario	RME Case	CTE Case	Population Risk?	Confidence Level
1	N≤1 & L≤1	N≤1 & L≤1	unlikely	high
2	N>1 & L≤1	N≤1 & L≤1	unlikely	high
3	N>1 & L>1	N≤1 & L≤1	possible	low
4	N>1 & L≤1	N>1 & L≤1	possible	low/moderate
5	N>1 & L>1	N>1 & L≤1	possible	moderate
6	N>1 & L>1	N>1 & L>1	possible	high

N = a hazard quotient based on dividing an RME or CTE by the Hg NOAEL for eggs (800 µg/kg for insectivores & 500 µg/kg for all other birds), blood (600 µg/kg) and feather (1,210 µg/kg)

L = a hazard quotient based on dividing an RME or CTE by the Hg LOAEL for eggs (1,600 µg/kg for insectivores & 1,000 µg/kg for all other birds), bird blood (1,250 µg/kg) and feather (9,100 µg/kg)

\*\* Confidence level noted as undetermined because only one sample available for use in assessment.

Table 4-38

**Summary of the Potential for Ecological Risk to Hooded Merganser - 2005**  
**Operable Unit IV - Nyanza Chemical Dump Superfund Site**  
**Middlesex County, Massachusetts**

Reach	Tissue	Exposure Point Concentration (µg/kg)		Ecological Risk*				
		RME	CTE	RME Case	CTE Case	Risk Scenario	Population Risk?	Confidence Level
4	egg	816	657	N>1 & L≤1	N>1 & L≤1	4	possible	low/moderate
4	blood	--	--	--	--	--	--	--
4	feather	--	--	--	--	--	--	--
8	egg	1950	713	N>1 & L>1	N>1 & L≤1	5	possible	moderate
8	blood	1880	579	N>1 & L>1	N≤1 & L≤1	3	possible	low
8	feather	7480	4870	N>1 & L≤1	N>1 & L≤1	4	possible	low/moderate
<b>Reference Areas</b>								
Charles River	egg	2420	1580	N>1 & L>1	N>1 & L>1	6	possible	high
Charles River	blood	4270	2440	N>1 & L>1	N>1 & L>1	6	possible	high
Charles River	feather	8920	8920	N>1 & L≤1	N>1 & L≤1	4	possible	undetermined**
Sudbury Reservoir	egg	555	422	N>1 & L≤1	N≤1 & L≤1	2	unlikely	high
Sudbury Reservoir	blood	--	--	--	--	--	--	--
Sudbury Reservoir	feather	6440	6440	N>1 & L≤1	N>1 & L≤1	4	possible	undetermined**

## Notes:

Concentration represents total mercury.

Blood and feathers from adult birds.

Red highlighting indicates that risk of adverse effects is possible, with relatively high confidence only for the particular measurement endpoint, but does not account for the weight given to that measure of risk in the BERA. Other measures of potential risk for the same receptors may not support this conclusion, and remedial action decisions are based on the weight-of-evidence for all measurement endpoints for each ecological receptor.

Mercury levels in bird blood and eggs are indicative of recent (site-specific) exposure to mercury. Mercury concentrations in bird feathers reflect more long-term exposures; therefore, may not be as strongly associated with site-related exposures or potential effects.

RME = Reasonable Maximum Exposure (in this case, the maximum detected concentration)

CTE = Central Tendency Exposure (in this case, the arithmetic mean concentration)

**\*Interpretive Ecological Risk Matrix**

Risk Scenario	RME Case	CTE Case	Population Risk?	Confidence Level
1	N≤1 & L≤1	N≤1 & L≤1	unlikely	high
2	N>1 & L≤1	N≤1 & L≤1	unlikely	high
3	N>1 & L>1	N≤1 & L≤1	possible	low
4	N>1 & L≤1	N>1 & L≤1	possible	low/moderate
5	N>1 & L>1	N>1 & L≤1	possible	moderate
6	N>1 & L>1	N>1 & L>1	possible	high

N = a hazard quotient based on dividing an RME or CTE by the Hg NOAEL for eggs (800 µg/kg for insectivores & 500 µg/kg for all other birds), blood (600 µg/kg) and feather (1,210 µg/kg)

L = a hazard quotient based on dividing an RME or CTE by the Hg LOAEL for eggs (1,600 µg/kg for insectivores & 1,000 µg/kg for all other birds), bird blood (1,250 µg/kg) and feather (9,100 µg/kg)

\*\* Confidence level noted as undetermined because only one sample available for use in assessment.

Table 4-39

**Summary of the Potential for Ecological Risk to Wood Duck - 2003  
Operable Unit IV - Nyanza Chemical Dump Superfund Site  
Middlesex County, Massachusetts**

Reach	Tissue	Exposure Point Concentration (µg/kg)		Ecological Risk*				
		RME	CTE	RME Case	CTE Case	Risk Scenario	Population Risk?	Confidence Level
8	egg	221	77	$N \leq 1$ & $L \leq 1$	$N \leq 1$ & $L \leq 1$	1	unlikely	high
8	blood	50	36	$N \leq 1$ & $L \leq 1$	$N \leq 1$ & $L \leq 1$	1	unlikely	high
8	feather	--	--	--	--	--	--	--
<b>Reference Areas</b>								
Sudbury Reservoir	egg	53	53	$N \leq 1$ & $L \leq 1$	$N \leq 1$ & $L \leq 1$	1	unlikely	undetermined**
Sudbury Reservoir	blood	82	82	$N \leq 1$ & $L \leq 1$	$N \leq 1$ & $L \leq 1$	1	unlikely	undetermined**
Sudbury Reservoir	feather	--	--	--	--	--	--	--
Delaney Reservoir	egg	74	45	$N \leq 1$ & $L \leq 1$	$N \leq 1$ & $L \leq 1$	1	unlikely	high
Delaney Reservoir	blood	81	35	$N \leq 1$ & $L \leq 1$	$N \leq 1$ & $L \leq 1$	1	unlikely	high
Delaney Reservoir	feather	--	--	--	--	--	--	--

## Notes:

Concentration represents total mercury.

Blood and feathers from adult birds.

Red highlighting indicates that risk of adverse effects is possible, with relatively high confidence only for the particular measurement endpoint, but does not account for the weight given to that measure of risk in the BERA. Other measures of potential risk for the same receptors may not support this conclusion, and remedial action decisions are based on the weight-of-evidence for all measurement endpoints for each ecological receptor.

Mercury levels in bird blood and eggs are indicative of recent (site-specific) exposure to mercury. Mercury concentrations in bird feathers reflect more long-term exposures; therefore, may not be as strongly associated with site-related exposures or potential effects.

RME = Reasonable Maximum Exposure (in this case, the maximum detected concentration)

CTE = Central Tendency Exposure (in this case, the arithmetic mean concentration)

**\*Interpretive Ecological Risk Matrix**

Risk Scenario	RME Case	CTE Case	Population Risk?	Confidence Level
1	$N \leq 1$ & $L \leq 1$	$N \leq 1$ & $L \leq 1$	unlikely	high
2	$N > 1$ & $L \leq 1$	$N \leq 1$ & $L \leq 1$	unlikely	high
3	$N > 1$ & $L > 1$	$N \leq 1$ & $L \leq 1$	possible	low
4	$N > 1$ & $L \leq 1$	$N > 1$ & $L \leq 1$	possible	low/moderate
5	$N > 1$ & $L > 1$	$N > 1$ & $L \leq 1$	possible	moderate
6	$N > 1$ & $L > 1$	$N > 1$ & $L > 1$	possible	high

N = a hazard quotient based on dividing an RME or CTE by the Hg NOAEL for eggs (800 µg/kg for insectivores & 500 µg/kg for all other birds), blood (600 µg/kg) and feather (1,210 µg/kg)

L = a hazard quotient based on dividing an RME or CTE by the Hg LOAEL for eggs (1,600 µg/kg for insectivores & 1,000 µg/kg for all other birds), bird blood (1,250 µg/kg) and feather (9,100 µg/kg)

\*\* Confidence level noted as undetermined because only one sample available for use in assessment.

Table 4-40

**Summary of the Potential for Ecological Risk to Wood Duck - 2004**  
**Operable Unit IV - Nyanza Chemical Dump Superfund Site**  
**Middlesex County, Massachusetts**

Reach	Tissue	Exposure Point Concentration (µg/kg)		Ecological Risk*				
		RME	CTE	RME Case	CTE Case	Risk Scenario	Population Risk?	Confidence Level
7	egg	--	--	--	--	--	--	--
7	blood	52	52	$N \leq 1$ & $L \leq 1$	$N \leq 1$ & $L \leq 1$	1	unlikely	undetermined**
7	feather	541	541	$N \leq 1$ & $L \leq 1$	$N \leq 1$ & $L \leq 1$	1	unlikely	undetermined**
8	egg	--	--	--	--	--	--	--
8	blood	421	421	$N \leq 1$ & $L \leq 1$	$N \leq 1$ & $L \leq 1$	1	unlikely	undetermined**
8	feather	442	442	$N \leq 1$ & $L \leq 1$	$N \leq 1$ & $L \leq 1$	1	unlikely	undetermined**
<b>Reference Area</b>								
Sudbury Reservoir	egg	--	--	--	--	--	--	--
Sudbury Reservoir	blood	25	25	$N \leq 1$ & $L \leq 1$	$N \leq 1$ & $L \leq 1$	1	unlikely	undetermined**
Sudbury Reservoir	feather	298	298	$N \leq 1$ & $L \leq 1$	$N \leq 1$ & $L \leq 1$	1	unlikely	undetermined**

## Notes:

Concentration represents total mercury.

Blood and feathers from adult birds.

Red highlighting indicates that risk of adverse effects is possible, with relatively high confidence only for the particular measurement endpoint, but does not account for the weight given to that measure of risk in the BERA. Other measures of potential risk for the same receptors may not support this conclusion, and remedial action decisions are based on the weight-of-evidence for all measurement endpoints for each ecological receptor.

Mercury levels in bird blood and eggs are indicative of recent (site-specific) exposure to mercury. Mercury concentrations in bird feathers reflect more long-term exposures; therefore, may not be as strongly associated with site-related exposures or potential effects.

RME = Reasonable Maximum Exposure (in this case, the maximum detected concentration)

CTE = Central Tendency Exposure (in this case, the arithmetic mean concentration)

**\*Interpretive Ecological Risk Matrix**

Risk Scenario	RME Case	CTE Case	Population Risk?	Confidence Level
1	$N \leq 1$ & $L \leq 1$	$N \leq 1$ & $L \leq 1$	unlikely	high
2	$N > 1$ & $L \leq 1$	$N \leq 1$ & $L \leq 1$	unlikely	high
3	$N > 1$ & $L > 1$	$N \leq 1$ & $L \leq 1$	possible	low
4	$N > 1$ & $L \leq 1$	$N > 1$ & $L \leq 1$	possible	low/moderate
5	$N > 1$ & $L > 1$	$N > 1$ & $L \leq 1$	possible	moderate
6	$N > 1$ & $L > 1$	$N > 1$ & $L > 1$	possible	high

N = a hazard quotient based on dividing an RME or CTE by the Hg NOAEL for eggs (800 µg/kg for insectivores & 500 µg/kg for all other birds), blood (600 µg/kg) and feather (1,210 µg/kg)

L = a hazard quotient based on dividing an RME or CTE by the Hg LOAEL for eggs (1,600 µg/kg for insectivores & 1,000 µg/kg for all other birds), bird blood (1,250 µg/kg) and feather (9,100 µg/kg)

\*\* Confidence level noted as undetermined because only one sample available for use in assessment.

Table 4-41

**Summary of the Potential for Ecological Risk to Belted Kingfisher  
Operable Unit IV - Nyanza Chemical Dump Superfund Site  
Middlesex County, Massachusetts**

Reach	Lifestage	Tissue	Exposure Point Concentration (µg/kg)		Ecological Risk*				
			RME	CTE	RME Case	CTE Case	Risk Scenario	Population Risk?	Confidence Level
7	nestling	blood	766	514	N>1 & L≤1	N≤1 & L≤1	2	unlikely	high
7	nestling	feather	2990	2760	N>1 & L≤1	N>1 & L≤1	4	possible	low/moderate
7	--	egg	--	--	--	--	--	--	--
7	adult	blood	--	--	--	--	--	--	--
7	adult	feather	--	--	--	--	--	--	--
8 - Transfer Station Pit	nestling	blood	576	150	N≤1 & L≤1	N≤1 & L≤1	1	unlikely	high
8 - Transfer Station Pit	nestling	feather	--	--	--	--	--	--	--
8 - Transfer Station Pit	--	egg	--	--	--	--	--	--	--
8 - Transfer Station Pit	adult	blood	778	675	N>1 & L≤1	N>1 & L≤1	4	possible	low/moderate
8 - Transfer Station Pit	adult	feather	12400	12400	N>1 & L>1	N>1 & L>1	6	possible	undetermined**
8 - Macone's Pile	nestling	blood	--	--	--	--	--	--	--
8 - Macone's Pile	nestling	feather	--	--	--	--	--	--	--
8 - Macone's Pile	--	egg	--	--	--	--	--	--	--
8 - Macone's Pile	adult	blood	1330	496	N>1 & L>1	N≤1 & L≤1	3	possible	low
8 - Macone's Pile	adult	feather	6980	5400	N>1 & L≤1	N>1 & L≤1	4	possible	low/moderate
8 - Route 117 Pit	nestling	blood	246	104	N≤1 & L≤1	N≤1 & L≤1	1	unlikely	high
8 - Route 117 Pit	nestling	feather	--	--	--	--	--	--	--
8 - Route 117 Pit	--	egg	151	151	N≤1 & L≤1	N≤1 & L≤1	1	unlikely	undetermined**
8 - Route 117 Pit	adult	blood	1010	766	N>1 & L≤1	N>1 & L≤1	4	possible	low/moderate
8 - Route 117 Pit	adult	feather	10800	7390	N>1 & L>1	N>1 & L≤1	5	possible	moderate
<b>Reference Areas</b>									
Charles River	nestling	blood	--	--	--	--	--	--	--
Charles River	nestling	feather	--	--	--	--	--	--	--
Charles River	--	egg	--	--	--	--	--	--	--
Charles River	adult	blood	286	286	N≤1 & L≤1	N≤1 & L≤1	1	unlikely	undetermined**
Charles River	adult	feather	7180	7180	N>1 & L≤1	N>1 & L≤1	4	possible	undetermined**
Reach 1 (Whitehall Reservoir)	nestling	blood	--	--	--	--	--	--	--
Reach 1 (Whitehall Reservoir)	nestling	feather	--	--	--	--	--	--	--
Reach 1 (Whitehall Reservoir)	--	egg	--	--	--	--	--	--	--
Reach 1 (Whitehall Reservoir)	adult	blood	398	264	N≤1 & L≤1	N≤1 & L≤1	1	unlikely	high
Reach 1 (Whitehall Reservoir)	adult	feather	--	--	--	--	--	--	--

## Notes:

Concentration represents total mercury.

Red highlighting indicates that risk of adverse effects is possible, with relatively high confidence only for the particular measurement endpoint, but does not account for the weight given to that measure of risk in the BERA. Other measures of potential risk for the same receptors may not support this conclusion, and remedial action decisions are based on the weight-of-evidence for all measurement endpoints for each ecological receptor.

Mercury levels in bird blood and eggs are indicative of recent (site-specific) exposure to mercury. Mercury concentrations in bird feathers reflect more long-term exposures; therefore, may not be as strongly associated with site-related exposures or potential effects.

RME = Reasonable Maximum Exposure (in this case, the maximum detected concentration)

CTE = Central Tendency Exposure (in this case, the arithmetic mean concentration)

**\*Interpretive Ecological Risk Matrix**

Risk Scenario	RME Case	CTE Case	Population Risk?	Confidence Level
1	N≤1 & L≤1	N≤1 & L≤1	unlikely	high
2	N>1 & L≤1	N≤1 & L≤1	unlikely	high
3	N>1 & L>1	N≤1 & L≤1	possible	low
4	N>1 & L≤1	N>1 & L≤1	possible	low/moderate
5	N>1 & L>1	N>1 & L≤1	possible	moderate
6	N>1 & L>1	N>1 & L>1	possible	high

N = a hazard quotient based on dividing an RME or CTE by the Hg NOAEL for eggs (800 µg/kg for insectivores & 500 µg/kg for all other birds), blood (600 µg/kg) and feather (1,210 µg/kg)

L = a hazard quotient based on dividing an RME or CTE by the Hg LOAEL for eggs (1,600 µg/kg for insectivores & 1,000 µg/kg for all other birds), bird blood (1,250 µg/kg) and feather (9,100 µg/kg)

\*\* Confidence level noted as undetermined because only one sample available for use in assessment.



Table 4-42

**Summary of Ecological Risk to Belted Kingfishers Based on Food Chain Modeling  
Operable Unit IV - Nyanza Chemical Dump Superfund Site  
Middlesex County, Massachusetts**

Reach	Exposure Scenario		Ecological Risk*		
	RME	CTE	Risk Scenario	Population Risk?	Confidence Level
2	N>1 & L>1	N>1 & L>1	6	possible	high
3	N>1 & L>1	N>1 & L>1	6	possible	high
4	N>1 & L>1	N>1 & L≤1	5	possible	moderate
5	N>1 & L>1	N>1 & L>1	6	possible	high
6	N>1 & L≤1	N>1 & L≤1	4	possible	low/moderate
7	N>1 & L>1	N>1 & L≤1	5	possible	moderate
7 - Heard Pond	N≤1 & L≤1	N≤1 & L≤1	1	unlikely	high
8	N>1 & L>1	N>1 & L>1	6	possible	high
9	N>1 & L>1	N>1 & L>1	6	possible	high
10	N>1 & L>1	N>1 & L>1	6	possible	high
<b>Reference Areas</b>					
Reach 1	N>1 & L≤1	N>1 & L≤1	4	possible	low/moderate
Charles River	N>1 & L≤1	N>1 & L≤1	4	possible	low/moderate
Sudbury Reservoir	N≤1 & L≤1	N≤1 & L≤1	1	unlikely	high

## Notes:

HQs derived from modeled exposures to methylmercury (see Tables 4-10 and 4-11).

Red highlighting indicates that risk of adverse effects is possible, with relatively high confidence only for the particular measurement endpoint but does not account for the weight given to that measure of risk in the BERA. Other measures of potential risk for the same receptors may not support this conclusion, and remedial action decisions are based on the weight-of-evidence for all measurement endpoints for each ecological receptor.

RME = Reasonable Maximum Exposure

CTE = Central Tendency Exposure

**\*Interpretive Ecological Risk Matrix**

Risk Scenario	RME Case	CTE Case	Population Risk?	Confidence Level
1	N≤1 & L≤1	N≤1 & L≤1	unlikely	high
2	N>1 & L≤1	N≤1 & L≤1	unlikely	high
3	N>1 & L>1	N≤1 & L≤1	possible	low
4	N>1 & L≤1	N>1 & L≤1	possible	low/moderate
5	N>1 & L>1	N>1 & L≤1	possible	moderate
6	N>1 & L>1	N>1 & L>1	possible	high

N = a hazard quotient based on dividing an RME or CTE dose by the no effect TRV

L = a hazard quotient based on dividing an RME or CTE dose by the effect TRV

Table 4-43

**Summary of the Potential for Ecological Risk to Great Blue Herons Based on Food Chain Modeling  
Operable Unit IV - Nyanza Chemical Dump Superfund Site  
Middlesex County, Massachusetts**

Reach	Exposure Scenario		Ecological Risk*		
	RME	CTE	Risk Scenario	Population Risk?	Confidence Level
2	$N > 1$ & $L \leq 1$	$N \leq 1$ & $L \leq 1$	2	unlikely	high
3	$N > 1$ & $L \leq 1$	$N > 1$ & $L \leq 1$	4	possible	low/moderate
4	$N \leq 1$ & $L \leq 1$	$N \leq 1$ & $L \leq 1$	1	unlikely	high
5	$N \leq 1$ & $L \leq 1$	$N \leq 1$ & $L \leq 1$	1	unlikely	high
6	$N \leq 1$ & $L \leq 1$	$N \leq 1$ & $L \leq 1$	1	unlikely	high
7	$N \leq 1$ & $L \leq 1$	$N \leq 1$ & $L \leq 1$	1	unlikely	high
7 - Heard Pond	$N \leq 1$ & $L \leq 1$	$N \leq 1$ & $L \leq 1$	1	unlikely	high
8	$N \leq 1$ & $L \leq 1$	$N \leq 1$ & $L \leq 1$	1	unlikely	high
9	$N > 1$ & $L \leq 1$	$N \leq 1$ & $L \leq 1$	2	unlikely	high
10	$N > 1$ & $L \leq 1$	$N > 1$ & $L \leq 1$	4	possible	low/moderate
<b>Reference Areas</b>					
Reach 1	$N \leq 1$ & $L \leq 1$	$N \leq 1$ & $L \leq 1$	1	unlikely	high
Charles River	$N \leq 1$ & $L \leq 1$	$N \leq 1$ & $L \leq 1$	1	unlikely	high
Sudbury Reservoir	$N \leq 1$ & $L \leq 1$	$N \leq 1$ & $L \leq 1$	1	unlikely	high

Notes:

HQs derived from modeled exposures to methylmercury (see Tables 4-10 and 4-11).

Red highlighting indicates that risk of adverse effects is possible, with relatively high confidence only for the particular measurement endpoint but does not account for the weight given to that measure of risk in the BERA. Other measures of potential risk for the same receptors may not support this conclusion, and remedial action decisions are based on the weight-of-evidence for all measurement endpoints for each ecological receptor.

RME = Reasonable Maximum Exposure

CTE = Central Tendency Exposure

**\*Interpretive Ecological Risk Matrix**

Risk Scenario	RME Case	CTE Case	Population Risk?	Confidence Level
1	$N \leq 1$ & $L \leq 1$	$N \leq 1$ & $L \leq 1$	unlikely	high
2	$N > 1$ & $L \leq 1$	$N \leq 1$ & $L \leq 1$	unlikely	high
3	$N > 1$ & $L > 1$	$N \leq 1$ & $L \leq 1$	possible	low
4	$N > 1$ & $L \leq 1$	$N > 1$ & $L \leq 1$	possible	low/moderate
5	$N > 1$ & $L > 1$	$N > 1$ & $L \leq 1$	possible	moderate
6	$N > 1$ & $L > 1$	$N > 1$ & $L > 1$	possible	high

N = a hazard quotient based on dividing an RME or CTE dose by the no effect TRV

L = a hazard quotient based on dividing an RME or CTE dose by the effect TRV

Table 4-44

**Summary of the Potential for Ecological Risk to Mink  
Operable Unit IV - Nyanza Chemical Dump Superfund Site  
Middlesex County, Massachusetts**

Reach	Tissue	Exposure Point Concentration (µg/kg)		Ecological Risk*				
		RME	CTE	RME Case	CTE Case	Risk Scenario	Population Risk?	Confidence Level
3	blood	177	177	N≤1 & L≤1	N≤1 & L≤1	1	unlikely	undetermined**
3	fur	58600	58600	N>1 & L>1	N>1 & L>1	6	possible	undetermined**
4	blood	46	46	N≤1 & L≤1	N≤1 & L≤1	1	unlikely	undetermined**
4	fur	1230	1230	N≤1 & L≤1	N≤1 & L≤1	1	unlikely	undetermined**
5	blood	--	--	--	--	--	--	--
5	fur	18300	12260	N>1 & L≤1	N>1 & L≤1	4	possible	low/moderate
7	blood	93	93	N≤1 & L≤1	N≤1 & L≤1	1	unlikely	undetermined**
7	fur	1670	1670	N≤1 & L≤1	N≤1 & L≤1	1	unlikely	undetermined**

Notes:

Concentration represents total mercury.

Blood and fur from adult mink.

Red highlighting indicates that risk of adverse effects is possible, with relatively high confidence only for the particular measurement endpoint, but does not account for the weight given to that measure of risk in the BERA. Other measures of potential risk for the same receptors may not support this conclusion, and remedial action decisions are based on the weight-of-evidence for all measurement endpoints for each ecological receptor.

RME = Reasonable Maximum Exposure (in this case, the maximum detected concentration)

CTE = Central Tendency Exposure (in this case, the arithmetic mean concentration)

**\*Interpretive Ecological Risk Matrix**

Risk Scenario	RME Case	CTE Case	Population Risk?	Confidence Level
1	N≤1 & L≤1	N≤1 & L≤1	unlikely	high
2	N>1 & L≤1	N≤1 & L≤1	unlikely	high
3	N>1 & L>1	N≤1 & L≤1	possible	low
4	N>1 & L≤1	N>1 & L≤1	possible	low/moderate
5	N>1 & L>1	N>1 & L≤1	possible	moderate
6	N>1 & L>1	N>1 & L>1	possible	high

N = a hazard quotient based on dividing an RME or CTE by the Hg NOAEL for blood (630 µg/kg) and fur (7710 µg/kg)

L = a hazard quotient based on dividing an RME or CTE by the Hg LOAEL for blood (1500 µg/kg) and fur (19030 µg/kg)

\*\* Confidence level noted as undetermined because only one sample available for use in assessment.

Table 4-45

**Summary of Ecological Risk to Mink Based on Food Chain Modeling  
Operable Unit IV - Nyanza Chemical Dump Superfund Site  
Middlesex County, Massachusetts**

Reach	Exposure Scenario		Ecological Risk*		
	RME	CTE	Risk Scenario	Population Risk?	Confidence Level
2	$N > 1$ & $L \leq 1$	$N > 1$ & $L \leq 1$	4	possible	low/moderate
3	$N > 1$ & $L \leq 1$	$N > 1$ & $L \leq 1$	4	possible	low/moderate
4	$N > 1$ & $L \leq 1$	$N > 1$ & $L \leq 1$	4	possible	low/moderate
5	$N > 1$ & $L \leq 1$	$N > 1$ & $L \leq 1$	4	possible	low/moderate
6	$N > 1$ & $L \leq 1$	$N \leq 1$ & $L \leq 1$	2	unlikely	high
7	$N > 1$ & $L \leq 1$	$N > 1$ & $L \leq 1$	4	possible	low/moderate
7 - Heard Pond	$N \leq 1$ & $L \leq 1$	$N \leq 1$ & $L \leq 1$	1	unlikely	high
8	$N > 1$ & $L > 1$	$N > 1$ & $L > 1$	6	possible	high
9	$N > 1$ & $L > 1$	$N > 1$ & $L > 1$	6	possible	high
10	$N > 1$ & $L > 1$	$N > 1$ & $L > 1$	6	possible	high
<b>Reference Areas</b>					
Reach 1	$N > 1$ & $L \leq 1$	$N \leq 1$ & $L \leq 1$	2	unlikely	high
Charles River	$N > 1$ & $L \leq 1$	$N \leq 1$ & $L \leq 1$	2	unlikely	high
Sudbury Reservoir	$N \leq 1$ & $L \leq 1$	$N \leq 1$ & $L \leq 1$	1	unlikely	high

Notes:

HQs derived from modeled exposures to methylmercury (see Tables 4-10 and 4-11).

Red highlighting indicates that risk of adverse effects is possible, with relatively high confidence only for the particular measurement endpoint, but does not account for the weight given to that measure of risk in the BERA. Other measures of potential risk for the same receptors may not support this conclusion, and remedial action decisions are based on the weight-of-evidence for all measurement endpoints for each ecological receptor.

RME = Reasonable Maximum Exposure

CTE = Central Tendency Exposure

**\*Interpretive Ecological Risk Matrix**

Risk Scenario	RME Case	CTE Case	Population Risk?	Confidence Level
1	$N \leq 1$ & $L \leq 1$	$N \leq 1$ & $L \leq 1$	unlikely	high
2	$N > 1$ & $L \leq 1$	$N \leq 1$ & $L \leq 1$	unlikely	high
3	$N > 1$ & $L > 1$	$N \leq 1$ & $L \leq 1$	possible	low
4	$N > 1$ & $L \leq 1$	$N > 1$ & $L \leq 1$	possible	low/moderate
5	$N > 1$ & $L > 1$	$N > 1$ & $L \leq 1$	possible	moderate
6	$N > 1$ & $L > 1$	$N > 1$ & $L > 1$	possible	high

N = a hazard quotient based on dividing an RME or CTE dose by the no effect TRV

L = a hazard quotient based on dividing an RME or CTE dose by the effect TRV

**Table 4-46**

**Weighting of the Chemistry Lines of Evidence as a Measurement Endpoint for Benthic Invertebrate Community Structure, Survival, and Reproduction  
Operable Unit IV, Nyanza Chemical Dump Superfund Site  
Middlesex County, Massachusetts**

Attribute	Sediment	Crayfish Tissue	Rationale
<b>I. Relationship between Measurement and Assessment Endpoints</b>			
1. Degree of Association	L/M	M/H	Sediment chemistry is linked indirectly to biological processes; and therefore to the assessment endpoint. Tissue chemistry reflects site-specific bioavailability and represents a measurement more closely related to the site of action.
2. Stressor/Response	L/M	M	<p>Sediment quality criteria have a number of uncertainties, and are often developed from studies in which the receptor was exposed to more than one chemical stressor. Benchmark comparisons are useful screening tools, being able to predict conditions where no effect is expected, but are not highly predictive of the magnitude of effect on a site-specific basis. However, sediment is a sink for mercury and a better indicator of benthic invertebrate exposure than water. However, the cause-effect linkage between mercury sediment concentrations and adverse effects in benthic invertebrates is limited.</p> <p>Use of tissue chemistry accounts for bioavailability and integrates exposures from all pathways. However, the tissue benchmarks are limited by the number of long-term chronic endpoints for mercury toxicity in crayfish available in the literature; thereby requiring extrapolations from short-term and lethal endpoints.</p>
3. Utility of Measure	L/M	M	<p>Consensus-based sediment benchmarks are endorsed by regulatory bodies. However, the MacDonald et al. (2000) low-end value (TEC) for mercury only correctly predicted 34.5% of samples not to be toxic. The high-end value (PEC) is much more reliable, predicting toxicity in 100% of the cases.</p> <p>The literature review that was the basis of the CBR values was thorough, with stringent criteria for the inclusion of studies used as the basis for derivation of CBRs. No-effect CBR values were based on the median values from 9 studies with unbounded no-effects levels. The effect-based CBR was based on an unbounded effect value from one study. Crayfish tissue concentration data were not available for the lower portion of the study area (i.e., Reaches 8 through 10); therefore this line of evidence is not applicable to those reaches.</p>

**Table 4-46, Continued**

**Weighting of the Chemistry Lines of Evidence as a Measurement Endpoint for Benthic Invertebrate Community Structure, Survival, and Reproduction  
Operable Unit IV, Nyanza Chemical Dump Superfund Site  
Middlesex County, Massachusetts**

Attribute	Sediment	Crayfish Tissue	Rationale
<b>II. Data Quality</b>			
4. Quality of Data	M/H	M/H	The majority of sediment and all of the crayfish tissue data were validated. In these instances, requirements for accuracy, precision, and reproducibility were met.
<b>III. Study Design</b>			
5. Site Specificity	L/M	L/M	While the sediment and tissue data collected were site-specific, benchmarks were not. That is, the sediment benchmarks were based on a host of species, some of which would not be indigenous to the Sudbury River. Tissue residue data were also not available for crayfish indigenous to the site, or even the northeastern United States.
6. Sensitivity	L/M	M/H	Analytical techniques used can detect small differences in mercury concentrations. However, the Menzie et al. (1996) guidance recommends a moderate score for endpoints that can detect changes between 10- and 99-fold. There is approximately an order of magnitude difference between the sediment benchmarks used (i.e., 0.18 mg/kg TEC and 1.06 mg/kg PEC; MacDonald et al., 2000). In addition, the TEC is not as sensitive as it likely should be because only approximately 34% of the samples that were toxic were predicted to be so. For the crayfish tissue, true NOAELs and LOAELs were not available with which to derive CBRs. Because of this, it is likely that the actual NOAEL is higher than that used (1.5 mg/kg WW) and the actual LOAEL is likely lower than that used (3.25 mg/kg WW). Because of the slight differences between these two values (approximately 2-fold), the tissue comparison endpoint was given a moderate/high score.
7. Spatial Representativeness	M	M	Sediment chemistry samples were collected throughout all of the reaches of the Sudbury River, in a variety of habitats and substrates. However, due to the size of each reach, the number of samples collected provides moderate spatial coverage.  Tissue chemistry measurements were made only in areas in which crayfish were found. This excluded the lower reaches (i.e., Reach 8 through 10) of the Sudbury River. In addition, collection of crayfish was limited to areas within the upper reaches where habitat was most suitable for crayfish species. Other areas of the river provide suitable habitat for macroinvertebrates, but tissue residue levels are not expected to be as high in lower trophic level macroinvertebrates.

**Table 4-46, Continued**

**Weighting of the Chemistry Lines of Evidence as a Measurement Endpoint for Benthic Invertebrate Community Structure, Survival, and Reproduction  
Operable Unit IV, Nyanza Chemical Dump Superfund Site  
Middlesex County, Massachusetts**

<b>Attribute</b>	<b>Sediment</b>	<b>Crayfish Tissue</b>	<b>Rationale</b>
8. Temporal Representativeness	L/M	M	Two sediment sampling events occurred. One in October 2003 and one in October 2005. Sediment concentrations of methylmercury are cyclical and not expected to be the highest during this time period. However, although good data on seasonal sensitivity of the benthic community are not available, it is likely that it is correlated somewhat with the times of intimate exposure with the sediment (e.g., hibernation, metamorphosis) which does not occur at expected times of peak methylation. Because the sampling time and time of intimate exposure with the sediments is synoptic, the sediment chemistry endpoint was given a low to moderate score.  One crayfish sampling event occurred in October 2003. The no-effect CBR was based on survival and the effect-CBR was based on growth. Because survival is not seasonal, there is temporal overlap between the sampling time and the period during which effects would be expected to be manifested. Growth most likely is slowed by October, since the hibernation is near. However, in risk assessment, more weight is given to the comparisons based on no-effect toxicity values and the crayfish chemistry endpoint was given a moderate score.
9. Quantitative Measure	M	L/M	Sediment concentrations were quantitative and allowed for limited statistical comparisons to be made. Crayfish results were also quantitative but insufficient for employing statistical testing.
10. Standard Method	M	M	The methods used to obtain sediment and tissue concentrations followed established scientific protocols. The literature studies used to develop the benchmarks and CBRs were peer-reviewed. Consensus-based sediment values are derived using well established criteria. CBRs were developed using generally accepted methods. Using the hazard quotient method to determine the potential for ecological risk is well accepted, with acknowledgements of applicable uncertainties.
<b>Overall Endpoint Value</b>	L/M	M	---

L = low                      M = moderate                      H = high  
L/M = low-moderate      M/H = moderate-high

**Table 4-47**

**Weighting of the *Hexagenia* Study Line of Evidence as a Measurement Endpoint for Benthic Invertebrate Community Structure, Survival, and Reproduction  
Operable Unit IV, Nyanza Chemical Dump Superfund Site  
Middlesex County, Massachusetts**

Attribute	<i>Hexagenia</i> Study	Rationale
<b>I. Relationship between Measurement and Assessment Endpoints</b>		
1. Degree of Association	M	Laboratory toxicity and bioaccumulation tests help to isolate contaminant induced effects by controlling background factors such as temperature, DO, and pH; however, laboratory conditions do not incorporate naturally occurring site-specific environmental conditions. Measurement and assessment endpoints are directly linked; however, the level of ecological organization (i.e., individual <i>Hexagenia</i> larvae) is not the same as that of the assessment endpoint (i.e., benthic invertebrate community).
2. Stressor/Response	M	Endpoint response has been demonstrated in previous studies; however, the response is not correlated with the magnitude of exposure (i.e., total mercury concentration in sediments). In addition, there is an inability of sediment toxicity tests conducted on sediments with multiple stressors to link the observed toxicity to a specific stressor.
3. Utility of Measure	H	The use of <i>Hexagenia</i> nymphs as test organisms has been validated in laboratory tests (Fremling and Mauck, 1980; Henry et al., 1986), including bioaccumulation tests with inorganic- and methylmercury (Saouter et al., 1991a, b, c, 1993; Odin et al., 1994 and 1995).
<b>II. Data Quality</b>		
4. Quality of Data	H	Requirements for accuracy, precision, and reproducibility were met.
<b>III. Study Design</b>		
5. Site Specificity	M/H	The <i>Hexagenia</i> study is representative of the site since sediments are the main source of mercury contamination in the Sudbury River, sediments were obtained from the site, and <i>Hexagenia</i> are indigenous to the Sudbury River.
6. Sensitivity	H	The laboratory tests received a high rating because the tests were long in duration (21-day), included sensitive species, and sublethal endpoints. Furthermore, the replication included increased the statistical power of the analysis. In addition, analytical techniques used can detect small differences in mercury concentrations and mayfly growth.



**Table 4-47, Continued**

**Weighting of the *Hexagenia* Study Line of Evidence as a Measurement Endpoint for Benthic Invertebrate Community Structure, Survival, and Reproduction  
Operable Unit IV, Nyanza Chemical Dump Superfund Site  
Middlesex County, Massachusetts**

<b>Attribute</b>	<b><i>Hexagenia</i> Study</b>	<b>Rationale</b>
7. Spatial Representativeness	M/H	The sediment samples, containing the stressor (i.e., mercury) were obtained from different habitats in the Sudbury River; <i>Hexagenia</i> are found in the Sudbury River; and the <i>Hexagenia</i> larvae were exposed to the stressors in a laboratory set-up designed to mimic actual field conditions.
8. Temporal Representativeness	H	Measurements were collected during the same period that effects would be most clearly manifested and multiple tests, representing three different time periods of active methylmercury production in sediments, were performed.
9. Quantitative Measure	H	Results are quantitative and statistical tests were performed to determine significance. The use of infaunal test species with multiple test endpoints is particularly helpful in defining potential toxicity to the principal components and life stages of the benthic assemblage.
10. Standard Method	M/H	This method has been used in two peer-reviewed studies.
<b>Overall Endpoint Value</b>	M/H	---

L = low                      M = moderate                      H = high  
L/M = low-moderate      M/H = moderate-high

Table 4-48

**Weighting of the *Elliptio Complanata* Study Line of Evidence as a Measurement Endpoint for Benthic Invertebrate Community Structure, Survival, and Reproduction**  
**Operable Unit IV, Nyanza Chemical Dump Superfund Site**  
**Middlesex County, Massachusetts**

Attribute	<i>Elliptio</i> Study	Rationale
<b>I. Relationship between Measurement and Assessment Endpoints</b>		
1. Degree of Association	M	Measurement and assessment endpoints are directly linked; however, the level of ecological organization (i.e., individual <i>Elliptio</i> ) is not the same as that of the assessment endpoint (i.e., benthic invertebrate community).
2. Stressor/Response	M	Endpoint response has been demonstrated in previous studies; however, the correlation of the response versus magnitude of exposure was mixed. In addition, there is an inability of sediment toxicity tests conducted on sediments with multiple stressors to link the observed toxicity to a specific stressor.
3. Utility of Measure	M/H	Resident and transplanted populations of freshwater and marine bivalves have been used as biomonitors of environmental contamination for approximately 30 years (Bedford et al., 1968; Godsil and Johnson, 1968; Young et al., 1976; Eganhouse and Young 1978b; Phillips, 1980; McMahon, 1991). Mussels can integrate and accumulate bioavailable contaminants at concentrations orders of magnitude higher than those found in abiotic environmental media (Salazar and Salazar, 1995). <i>E. complanata</i> has been used in a number of transplant monitoring studies (Curry, 1977; Hinch and Green, 1989; Day et al., 1990; Koenig and Metcalfe, 1990; Kauss and Hamdy, 1991; Langdon, 1993). A study completed by Metcalfe-Smith et al., (1992) determined that <i>E. complanata</i> demonstrated a broader response range to mercury exposures than other species, suggesting that it may be more sensitive to changes in pollution status.
<b>II. Data Quality</b>		
4. Quality of Data	M/H	Laboratory quality assurance results were within the specified control limits; however, control stations did not perform as expected for growth rate and mercury accumulation. Standard reference materials analysis also fell within control limits for the initial and middle stages. The SRM percent recovery for methylmercury in the final stage was slightly below the control limits (86% versus 92%).
<b>III. Study Design</b>		
5. Site Specificity	H	The <i>Elliptio</i> study is highly site-specific since species endemic to the Sudbury River were tested <i>in situ</i> . Mussels were deployed throughout the study area and tests reflect natural ambient conditions.

**Table 4-48, Continued**

**Weighting of the *Elliptio Complanata* Study Line of Evidence as a Measurement Endpoint for Benthic Invertebrate Community Structure, Survival, and Reproduction  
Operable Unit IV, Nyanza Chemical Dump Superfund Site  
Middlesex County, Massachusetts**

<b>Attribute</b>	<b><i>Elliptio</i> Study</b>	<b>Rationale</b>
6. Sensitivity	M/H	Analytical techniques used can detect small differences in mercury concentrations and mussel growth. However, reference locations could not be used for comparisons due to poor growth and high mercury accumulation.
7. Spatial Representativeness	H	The mussel deployment locations met the five factors defined by Menzie et al. (1996) as critical for spatial representativeness (i.e., spatial overlap of study area, sampling site, stressors, receptors, and points of potential exposure). The eight deployment stations cover a range of habitats and exposure concentrations.
8. Temporal Representativeness	M	Measurements were collected at three points in time – initial, middle, and end stages of the experiment. The experiment was chronic (12 weeks) and was run June through September.
9. Quantitative Measure	M/H	Results are quantitative and statistical tests were performed to determine significance. Results were equivocal.
10. Standard Method	H	This method has been used in more than three peer-reviewed studies.
<b>Overall Endpoint Value</b>	M/H	---

L = low                      M = moderate                      H = high  
L/M = low-moderate      M/H = moderate-high

**Table 4-49**

**Weighting of the Chemistry Lines of Evidence as a Measurement Endpoint for Fish Population Survival and Reproduction  
Operable Unit IV, Nyanza Chemical Dump Superfund Site  
Middlesex County, Massachusetts**

Attribute	Surface Water	Fish Tissue	Rationale
<b>I. Relationship between Measurement and Assessment Endpoints</b>			
1. Degree of Association	L/M	M/H	Surface water chemistry is linked indirectly to biological processes; and therefore to the assessment endpoint. Tissue chemistry reflects site-specific bioavailability and represents a measurement more closely related to the site of action. However, the CBRs were derived from species not indigenous to the Sudbury River Watershed (although these non-native species have been observed in the Concord River Basin).
2. Stressor/Response	L	M	<p>Surface water criteria have a number of uncertainties, and are often developed from studies in which the receptor was exposed to more than one chemical stressor. Benchmark comparisons are useful screening tools, being able to predict conditions where no effect is expected, but are not highly predictive of the magnitude of effect on a site-specific basis. In addition, dissolved mercury concentrations in water tend to be low compared with sediment concentrations, thereby providing a lower exposure potential than that of mercury found in sediment. The most recent surface water benchmarks for mercury are based on food chain exposures to higher trophic level organisms (e.g., mink); therefore, older values that only considered effects on aquatic organisms were used.</p> <p>Use of tissue chemistry accounts for bioavailability and integrates exposures from all pathways. However, the tissue benchmarks are limited by the number of long-term chronic endpoints for mercury toxicity in fish available in the literature.</p>
3. Utility of Measure	L/M	M/H	<p>Comparing surface water concentrations to benchmarks is a well accepted tool for determining the potential for adverse effects, but cannot determine the probability or magnitude of effects. The availability of recent surface water data for the study area is somewhat limited.</p> <p>The literature review that was the basis of the CBR values was thorough, with stringent criteria for the inclusion of studies used as the basis for derivation of CBRs. Extensive fish tissue concentration data were available for the study area, being collected from all of the reaches and spanning several trophic levels.</p>

**Table 4-49, Continued**

**Weighting of the Chemistry Lines of Evidence as a Measurement Endpoint for Fish Population Survival and Reproduction  
Operable Unit IV, Nyanza Chemical Dump Superfund Site  
Middlesex County, Massachusetts**

Attribute	Surface Water	Fish Tissue	Rationale
<b>II. Data Quality</b>			
4. Quality of Data	M/H	H	<p>Surface water data were collected by a third party (USGS) and quality assurance/quality control procedures were not available. However, the data were validated and given the water quality programs employed by this agency, it is likely the data are of moderately high quality, and meet the useability requirements for risk assessment.</p> <p>For fish tissue data, all values were validated and requirements for accuracy, precision, and reproducibility were met.</p>
<b>III. Study Design</b>			
5. Site Specificity	L/M	L/M	While the surface water and tissue data collected were site-specific, benchmarks were not. Surface water benchmarks and fish tissue CBRs were derived from species not indigenous to the Sudbury River Watershed (although these non-native species have been observed in the Concord River Basin).
6. Sensitivity	L/M	M/H	<p>Analytical techniques used can detect small differences in mercury concentrations. Data on which the chronic surface water values were based are within an order of magnitude of each other, but may not be protective of more sensitive species for which insufficient data for inclusion in the derivation of the water quality value. Therefore, a low to moderate score was given to the surface water chemistry endpoint based on the Menzie et al. (1996) guidance that a moderate score for endpoints that can detect changes between 100- and 1000-fold.</p> <p>For the fish tissue, CBRs were derived based on reproductive no-effect and effect values from mummichog and fathead minnow studies. No-effects values used in the derivation ranged from 320 to 440 µg/kg ww with a final value of 380 µg/kg ww and effects values used in the derivation ranged from 680 to 1,360 with a final value of 980 µg/kg. Because of the minimal differences between the ranges of values used in the derivation of the CBRs (1.4- to 2-fold) and the minimal difference between the effect and no-effect values (approximately 3-fold), the tissue comparison endpoint was given a moderate/high score.</p>

**Table 4-49, Continued**

**Weighting of the Chemistry Lines of Evidence as a Measurement Endpoint for Fish Population Survival and Reproduction  
Operable Unit IV, Nyanza Chemical Dump Superfund Site  
Middlesex County, Massachusetts**

<b>Attribute</b>	<b>Surface Water</b>	<b>Fish Tissue</b>	<b>Rationale</b>
7. Spatial Representativeness	M	H	<p>The surface water samples, containing the stressor (i.e., mercury) were obtained from limited areas of the Sudbury River; however, sampling occurred in contaminated areas where aquatic organisms are expected to be exposed to concentrations of mercury and results are relatively similar to the findings reported from earlier, more extensive water sampling efforts.</p> <p>For the fish tissue samples, spatial coverage was excellent (i.e., samples were collected in each of the river reaches and proposed reference areas); a breadth of tissue types (i.e., whole body, fillet, and offal) were analyzed, and there was good overlap between the study area, sampling site, stressors, receptors, and potential points of exposure.</p>
8. Temporal Representativeness	L	L/M	<p>A single surface water sampling event occurred during October. Fall is not considered to be the season during which the effects associated with mercury concentrations in surface water would be most clearly manifested.</p> <p>Spawning season for fish in Massachusetts is generally late winter/early spring. Fish tissue concentrations were determined for fish collected in summer/early fall.</p>
9. Quantitative Measure	L/M	M/H	<p>Surface water results are quantitative but insufficient for employing statistical testing. Fish tissue concentrations were also quantitative and did allow for some statistical comparisons to be made.</p>
10. Standard Method	M	M/H	<p>The methods used to obtain surface water and tissue concentrations followed established scientific protocols. The literature studies used to develop the benchmarks and CBRs were peer-reviewed. AWQCs are derived using well established criteria. However, older values with lower limited of data requirements were used.</p> <p>CBRs were developed using generally accepted methods. Using the hazard quotient method to determine the potential for ecological risk is well accepted, with acknowledgements of applicable uncertainties.</p>
<b>Overall Endpoint Value</b>	L/M	M/H	---

L = low                      M = moderate                      H = high  
 L/M = low-moderate      M/H = moderate-high

**Table 4-50**

**Weighting of the Wood Duck Study Line of Evidence as a Measurement Endpoint for Herbivorous Bird Survival, Reproduction, and Neurological Effects  
Operable Unit IV, Nyanza Chemical Dump Superfund Site  
Middlesex County, Massachusetts**

Attribute	Wood Duck Study	Rationale
<b>I. Relationship between Measurement and Assessment Endpoints</b>		
1. Degree of Association	M/H	Tissue chemistry reflects site-specific bioavailability and represents a measurement more closely related to the site of action.
2. Stressor/Response	M	Use of tissue chemistry accounts for bioavailability and integrates exposures from all pathways. However, the tissue benchmarks are limited by the number of ecologically significant chronic endpoints for mercury toxicity in specific wood duck tissue (i.e., blood, feathers, and eggs) available in the literature; thereby requiring extrapolations from less than ideal studies (e.g., short-term, lethal endpoints, different species).
3. Utility of Measure	M	Comparisons of site-specific tissue concentrations with Critical Body Residues (CBRs) are an accepted line of evidence for use in determining potential ecological harm. However, only eggs and blood or blood and feathers were available from the same nest box (as opposed to having blood, feathers, and eggs).  The literature review that was the basis of the CBR values was thorough, with stringent criteria for the inclusion of studies used as the basis for derivation of CBRs.
<b>II. Data Quality</b>		
4. Quality of Data	H	For wood duck tissue data, all values were validated and requirements for accuracy, precision, and reproducibility were met.
<b>III. Study Design</b>		
5. Site Specificity	M/H	The wood duck tissue comparisons with CBRs met five factors under this attribute (i.e., representativeness of chemical data, environmental media, species, environmental conditions, and habitat types). Benchmarks derived were not specific to the Sudbury River.

**Table 4-50, Continued**

**Weighting of the Wood Duck Study Line of Evidence as a Measurement Endpoint for Herbivorous Bird Survival, Reproduction, and Neurological Effects  
Operable Unit IV, Nyanza Chemical Dump Superfund Site  
Middlesex County, Massachusetts**

<b>Attribute</b>	<b>Wood Duck Study</b>	<b>Rationale</b>
6. Sensitivity	M	Analytical techniques used can detect small differences in mercury concentrations. The difference between the no-effect and effect-based CBRs for eggs was less than 2; however, concentration ranges on which the CBRs were based encompassed values approximately 84-fold different. In addition, blood and feather CBRs were only developed based on effects-based data with the ranges of concentrations spanning a difference of 8- to 36-fold (feathers and eggs, respectively). Therefore, a moderate score was given to the hooded merganser tissue endpoint based on the Menzie et al. (1996) guidance that a moderate score for endpoints that can detect changes between 10- and 99-fold.
7. Spatial Representativeness	M/H	Four of the five criteria defined by Menzie et al. (1996) were met for the tissue data: study area, location of stressors, location of representative species, and points of exposure. Duck boxes were only located in the primary target areas of the Sudbury River (i.e., Reaches 3, 4, 7, and 8) and reference areas.
8. Temporal Representativeness	M/H	Field study was conducted during two different breeding seasons of the wood duck (2003 and 2004).
9. Quantitative Measure	L/M	Results are quantitative but low sample sizes precluded the use of statistical testing.
10. Standard Method	M	The methods used to obtain tissue concentrations followed established scientific protocols. The literature studies used to develop the benchmarks and CBRs were peer-reviewed. CBRs were developed using generally accepted methods. Using the hazard quotient method to determine the potential for ecological risk is well accepted, with acknowledgements of applicable uncertainties.
<b>Overall Endpoint Value</b>	M/H	---

L = low  
L/M = low-moderate

M = moderate  
M/H = moderate-high

H = high



**Table 4-51**

**Weighting of the Tree Swallow Study Line of Evidence as a Measurement Endpoint for Insectivorous Bird Survival, Reproduction, and Neurological Effects  
Operable Unit IV, Nyanza Chemical Dump Superfund Site  
Middlesex County, Massachusetts**

Attribute	Tree Swallow Study	Rationale
<b>I. Relationship between Measurement and Assessment Endpoints</b>		
1. Degree of Association	M/H	Tissue chemistry reflects site-specific bioavailability and represents a measurement more closely related to the site of action.
2. Stressor/Response	M	Use of tissue chemistry accounts for bioavailability and integrates exposures from all pathways. However, the tissue benchmarks are limited by the number of ecologically significant chronic endpoints for mercury toxicity in specific tree swallow tissue (i.e., blood, feathers, and eggs) available in the literature; thereby requiring extrapolations from less than ideal studies (e.g., short-term, lethal endpoints, different species).
3. Utility of Measure	M/H	Comparisons of site-specific tissue concentrations with Critical Body Residues (CBRs) are an accepted line of evidence for use in determining potential ecological harm.  The literature review that was the basis of the CBR values was thorough, with stringent criteria for the inclusion of studies used as the basis for derivation of CBRs.
<b>II. Data Quality</b>		
4. Quality of Data	M/H	All of the 2003 tree swallow blood and egg data were validated to Tier II; whereas feathers were validated to either Tier II or Tier I. Because there were no significant issues in the data, it was decided not to validate all of the 2004 tree swallow data. Therefore, only some of the blood and egg data were validated and none of the feather data were. In these instances where validation occurred, requirements for accuracy, precision, and reproducibility were met.
<b>III. Study Design</b>		
5. Site Specificity	M/H	The tree swallow tissue comparisons with CBRs met five factors under this attribute (i.e., representativeness of chemical data, environmental media, species, environmental conditions, and habitat types). Benchmarks derived were not specific to the Sudbury River.
6. Sensitivity	M	Analytical techniques used can detect small differences in mercury concentrations. The difference between the no-effect and effect-based CBRs for eggs was less than 2; however, concentration ranges on which the CBRs were based encompassed values approximately 84-fold different. In addition, blood and feather CBRs were only

**Table 4-51, Continued**

**Weighting of the Tree Swallow Study Line of Evidence as a Measurement Endpoint for Insectivorous Bird Survival, Reproduction, and Neurological Effects**  
**Operable Unit IV, Nyanza Chemical Dump Superfund Site**  
**Middlesex County, Massachusetts**

Attribute	Tree Swallow Study	Rationale
		developed based on effects-based data with the ranges of concentrations spanning a difference of 8- to 36-fold (feathers and eggs, respectively). Therefore, a moderate score was given to the tree swallow tissue endpoint based on the Menzie et al. (1996) guidance that a moderate score for endpoints that can detect changes between 10- and 99-fold.
7. Spatial Representativeness	H	All five criteria for spatial representativeness (Menzie et al., 1996) were met for the tree swallow tissue data (i.e., spatial overlap of study area, sampling locations, location of stressors, location of representative species, and points of exposure). Tree swallow boxes were only located in the primary target areas of the Sudbury River (i.e., Reaches 3, 4, 7, and 8) and reference areas.
8. Temporal Representativeness	M/H	Field study was conducted during two different breeding seasons of the tree swallow (2003 and 2004).
9. Quantitative Measure	M	Results are quantitative but in most cases insufficient for employing statistical testing.
10. Standard Method	M/H	The methods used to obtain sediment and tissue concentrations followed established scientific protocols. The literature studies used to develop the CBRs were peer-reviewed. CBRs were developed using generally accepted methods. Using the hazard quotient method to determine the potential for ecological risk is well accepted, with acknowledgements of applicable uncertainties.
<b>Overall Endpoint Value</b>	M/H	---

L = low                      M = moderate                      H = high  
L/M = low-moderate      M/H = moderate-high

**Table 4-52**

**Weighting of the Eastern Kingbird Study Line of Evidence as a Measurement Endpoint for Insectivorous Bird Survival, Reproduction, and Neurological Effects  
Operable Unit IV, Nyanza Chemical Dump Superfund Site  
Middlesex County, Massachusetts**

Attribute	Eastern Kingbird Study	Rationale
<b>I. Relationship between Measurement and Assessment Endpoints</b>		
1. Degree of Association	L/M	Tissue chemistry reflects site-specific bioavailability and represents a measurement more closely related to the site of action; however, only kingbird eggs were collected to evaluate local mercury exposure.
2. Stressor/Response	M	Use of tissue chemistry accounts for bioavailability and integrates exposures from all pathways. However, the tissue benchmarks are limited by the number of ecologically significant chronic endpoints for mercury toxicity in eastern kingbird eggs available in the literature; thereby requiring extrapolations from less than ideal studies (e.g., short-term, lethal endpoints, different species).
3. Utility of Measure	M	Comparisons of site-specific tissue concentrations with Critical Body Residues (CBRs) are an accepted line of evidence for use in determining potential ecological harm. However, only eggs were available for comparisons (as opposed to the tree swallow, which had blood, feathers, and eggs).  The literature review that was the basis of the CBR values was thorough, with stringent criteria for the inclusion of studies used as the basis for derivation of CBRs.
<b>II. Data Quality</b>		
4. Quality of Data	L/M	Eastern kingbird eggs were collected opportunistically and therefore did not allow for a complete study area assessment of impacts to kingbirds. DQOs established for the sampling and analysis of other bird tissue samples were met by these data.
<b>III. Study Design</b>		
5. Site Specificity	L/M	The eastern kingbird tissue comparisons with CBRs only met three of the six factors considered under this attribute (i.e., representativeness of chemical data, environmental media, and species); therefore, a low-moderate value was assigned. Benchmarks derived were not specific to the Sudbury River, and environmental conditions and habitat types present throughout the study area were not evaluated.

**Table 4-52, Continued**

**Weighting of the Eastern Kingbird Study Line of Evidence as a Measurement Endpoint for Insectivorous Bird Survival, Reproduction, and Neurological Effects**  
**Operable Unit IV, Nyanza Chemical Dump Superfund Site**  
**Middlesex County, Massachusetts**

<b>Attribute</b>	<b>Eastern Kingbird Study</b>	<b>Rationale</b>
6. Sensitivity	M	Analytical techniques used can detect small differences in mercury concentrations. The difference between the no-effect and effect-based CBRs for eggs was less than 2; however, concentration ranges on which the CBRs were based encompassed values approximately 84-fold different. Therefore, a moderate score was given to the kingbird tissue endpoint based on the Menzie et al. (1996) guidance that a moderate score for endpoints that can detect changes between 10- and 99-fold.
7. Spatial Representativeness	L/M	Eastern kingbird eggs were collected opportunistically and finds were limited to the lower end of the Sudbury River.
8. Temporal Representativeness	M	Field study was conducted during the breeding season of the eastern kingbird, but is considered a single sampling event as only one reproductive cycle was measured.
9. Quantitative Measure	L/M	Results are quantitative but low sample sizes precluded the use of any statistical testing.
10. Standard Method	L/M	The methods used to obtain tissue concentrations followed established scientific protocols; however, no established sampling protocol was followed. The literature studies used to develop the benchmarks and CBRs were peer-reviewed. CBRs were developed using generally accepted methods. Using the hazard quotient method to determine the potential for ecological risk is well accepted, with acknowledgements of applicable uncertainties.
<b>Overall Endpoint Value</b>	L/M	---

L = low                      M = moderate                      H = high  
L/M = low-moderate      M/H = moderate-high

**Table 4-53**

**Weighting of the Marsh Bird Study Line of Evidence as a Measurement Endpoint for Insectivorous Bird Survival, Reproduction, and Neurological Effects  
Operable Unit IV, Nyanza Chemical Dump Superfund Site  
Middlesex County, Massachusetts**

Attribute	Marsh Bird Study	Rationale
<b>I. Relationship between Measurement and Assessment Endpoints</b>		
1. Degree of Association	M/H	Tissue chemistry reflects site-specific bioavailability and represents a measurement more closely related to the site of action.
2. Stressor/Response	M	Use of tissue chemistry accounts for bioavailability and integrates exposures from all pathways. However, the tissue benchmarks are limited by the number of ecologically significant chronic endpoints for mercury toxicity in specific marshbird tissue (i.e., blood and feathers) available in the literature; thereby requiring extrapolations from less than ideal studies (e.g., short-term, lethal endpoints, different species).
3. Utility of Measure	M	Comparisons of site-specific tissue concentrations with Critical Body Residues (CBRs) are an accepted line of evidence for use in determining potential ecological harm. However, only blood and feathers were available for comparisons (as opposed to the tree swallow, which had blood, feathers, and eggs).  The literature review that was the basis of the CBR values was thorough, with stringent criteria for the inclusion of studies used as the basis for derivation of CBRs.
<b>II. Data Quality</b>		
4. Quality of Data	M/H	All of the 2003 marsh bird blood and egg data were validated to Tier II; whereas feathers were validated to Tier I only. Redwing-blackbird blood and feathers were collected in 2005. Because there were no significant issues in the avian data that were validated in 2003 and 2004, it was decided not to validate 2005 data. In these instances where validation occurred, requirements for accuracy, precision, and reproducibility were met. Because the same field techniques, laboratory, and analytical methods were used for the Tier I and unvalidated data, it is assumed that these data are of moderate/high quality.
<b>III. Study Design</b>		
5. Site Specificity	M/H	The marsh bird tissue comparisons with CBRs met four of the six factors considered under this attribute (i.e., representativeness of chemical data, environmental media, species, environmental conditions, and habitat types). Benchmarks derived were not specific to the Sudbury River.

**Table 4-53, Continued**

**Weighting of the Marsh Bird Study Line of Evidence as a Measurement Endpoint for Insectivorous Bird Survival, Reproduction, and Neurological Effects  
Operable Unit IV, Nyanza Chemical Dump Superfund Site  
Middlesex County, Massachusetts**

<b>Attribute</b>	<b>Marsh Bird Study</b>	<b>Rationale</b>
6. Sensitivity	M	Analytical techniques used can detect small differences in mercury concentrations. The difference between the no-effect and effect-based CBRs for eggs was less than 2; however, concentration ranges on which the CBRs were based encompassed values approximately 84-fold different. In addition, blood and feather CBRs were only developed based on effects-based data with the ranges of concentrations spanning a difference of 8- to 36-fold (feathers and eggs, respectively). Therefore, a moderate score was given to the marshbird tissue endpoint based on the Menzie et al. (1996) guidance that a moderate score for endpoints that can detect changes between 10- and 99-fold.
7. Spatial Representativeness	M	Three of the five criteria defined by Menzie et al. (1996) were met for the tissue data: sampling locations, location of stressors, and location of representative species. However, marsh birds were collected from Reach 8 only.
8. Temporal Representativeness	M/H	Field study was conducted during two breeding seasons, except for red-winged blackbirds for which a concerted sampling effort was put forth during summer of 2005.
9. Quantitative Measure	L/M	Results are quantitative but low sample size frequently precluded the use of statistical testing.
10. Standard Method	M/H	The methods used to obtain tissue concentrations followed established scientific protocols. The literature studies used to develop the benchmarks and CBRs were peer-reviewed. CBRs were developed using generally accepted methods. Using the hazard quotient method to determine the potential for ecological risk is well accepted, with acknowledgements of applicable uncertainties.
<b>Overall Endpoint Value</b>	M	---

L = low                      M = moderate                      H = high  
L/M = low-moderate      M/H = moderate-high

**Table 4-54**

**Weighting of the Tree Swallow Modeled Exposure and Effects Line of Evidence as a Measurement Endpoint for Insectivorous Bird  
Survival, Reproduction, and Neurological Effects  
Operable Unit IV, Nyanza Chemical Dump Superfund Site  
Middlesex County, Massachusetts**

Attribute	Tree Swallow Modeling	Rationale
<b>I. Relationship between Measurement and Assessment Endpoints</b>		
1. Degree of Association	M	Exposure model used input parameters specific to the representative species, with the exception of the free metabolic rate for tree swallow which relied on an allometric equation based on a broader range of birds. The effects metrics were not specific to tree swallow.
2. Stressor/Response	M	The exposure modeling was species- and stressor-specific. The dose-response studies used to derive the effect metrics were not specific to the tree swallow.
3. Utility of Measure	M	Modeled exposure and effects procedures used are standardized and widely accepted, the primary limitation was lack of species-specific effects data, which increases uncertainty.
<b>II. Data Quality</b>		
4. Quality of Data	M/H	DQOs established for the sampling and analysis of tissue samples used in the exposure assessment were met. Other model parameters were derived from EPA (1993a) and other published journal articles and were tree swallow specific. The effects metrics were derived from published journal articles.
<b>III. Study Design</b>		
5. Site Specificity	M	Concentrations derived for biological tissue for use in exposure models were site-specific, as was the tree swallow body weight. Other exposure model parameters were not site-specific (e.g., free metabolic rate). The effects measures were laboratory-based and not site-specific.
6. Sensitivity	M	Modeled exposure and effects directly assessed exposure, but effects studies for tree swallow were not available, so no-effect and effect-based toxicity values for the most sensitive species was used.
7. Spatial Representativeness	L/M	Modeled exposures were based on sediment to biota regression equations developed for the site in the mid 1990's. Input sediment data was collected throughout the study area in 2003 and 2005. Some of the parameters used in the exposure model were taken from the literature and were not site-specific (e.g., gross energy). The effects assessment used toxicity studies conducted in laboratories.

**Table 4-54, Continued**

**Weighting of the Tree Swallow Modeled Exposure and Effects Line of Evidence as a Measurement Endpoint for Insectivorous Bird  
Survival, Reproduction, and Neurological Effects  
Operable Unit IV, Nyanza Chemical Dump Superfund Site  
Middlesex County, Massachusetts**

<b>Attribute</b>	<b>Tree Swallow Modeling</b>	<b>Rationale</b>
8. Temporal Representativeness	M	The collection of sediment and tissue data, used to derive concentrations input to the exposure model, did not completely overlap the reproductive cycle of tree swallows. The tree swallow body weight data was collected during the breeding season. It is unknown whether other input variables were collected during the tree swallow's breeding season. Effects studies did span the reproductive cycles of the birds studied.
9. Quantitative Measure	M	Results are quantitative but the hazard quotient approach provides a relative assessment of ecological concern and is inappropriate for employing statistical testing.
10. Standard Method	M/H	Generally accepted exposure and effects modeling procedures were followed. Using the hazard quotient method to determine the potential for ecological risk is well accepted, with acknowledgements of applicable uncertainties.
<b>Overall Endpoint Value</b>	M	---

L = low                      M = moderate                      H = high  
L/M = low-moderate      M/H = moderate-high



**Table 4-55**

**Weighting of the Belted Kingfisher Modeled Exposure and Effects Line of Evidence as a Measurement Endpoint for Piscivorous Bird  
Survival, Reproduction, and Neurological Effects  
Operable Unit IV, Nyanza Chemical Dump Superfund Site  
Middlesex County, Massachusetts**

Attribute	Kingfisher Modeling	Rationale
<b>I. Relationship between Measurement and Assessment Endpoints</b>		
1. Degree of Association	M	Exposure model used input parameters specific to the representative species, with the exception of the free metabolic rate for kingfisher which relied on an allometric equation based on a broader range of birds. The effects metrics were not specific to kingfisher.
2. Stressor/Response	M	The exposure modeling was species- and stressor-specific. The dose-response studies used to derive the effect metrics were not specific to the kingfisher.
3. Utility of Measure	M	Modeled exposure and effects procedures used are standardized and widely accepted, the primary limitation was lack of species-specific effects data, which reduces certainty.
<b>II. Data Quality</b>		
4. Quality of Data	M/H	DQOs established for the sampling and analysis of tissue samples used in the exposure assessment were met. Other model parameters were derived from EPA (1993a) and other published journal articles and were kingfisher specific. The effects metrics were derived from published journal articles.
<b>III. Study Design</b>		
5. Site Specificity	L/M	Biological tissue data used in exposure models were site-specific. Other exposure model parameters were not site-specific (e.g., body weight, free metabolic rate). The effects measures were laboratory-based and not site-specific.
6. Sensitivity	M	Modeled exposure and effects directly assessed exposure, but effects studies for the kingfisher were not available, so no-effect and effect-based toxicity values for the most sensitive species were used.
7. Spatial Representativeness	M	Modeled exposures relied on tissue data collected throughout the study area. Some of the parameters used in the exposure model were taken from the literature and were not site-specific (e.g., body weight, gross energy). The effects assessment used toxicity studies conducted in laboratories.

**Table 4-55, Continued**

**Weighting of the Belted Kingfisher Modeled Exposure and Effects Line of Evidence as a Measurement Endpoint for Piscivorous Bird  
Survival, Reproduction, and Neurological Effects  
Operable Unit IV, Nyanza Chemical Dump Superfund Site  
Middlesex County, Massachusetts**

<b>Attribute</b>	<b>Kingfisher Modeling</b>	<b>Rationale</b>
8. Temporal Representativeness	M	The collection of tissue data, used in the exposure model, did not completely overlap the reproductive cycle of kingfishers. It is unknown whether other input variables (e.g., body weight) were collected during the kingfisher's breeding season. Effects studies did span the reproductive cycles of the birds studied.
9. Quantitative Measure	M	Results are quantitative but the hazard quotient approach provides a relative assessment of ecological concern and is inappropriate for employing statistical testing.
10. Standard Method	M/H	Generally accepted exposure and effects modeling procedures were followed. Using the hazard quotient method to determine the potential for ecological risk is well accepted, with acknowledgements of applicable uncertainties.
<b>Overall Endpoint Value</b>	M	---

L = low                      M = moderate                      H = high  
 L/M = low-moderate      M/H = moderate-high

**Table 4-56**

**Weighting of the Great Blue Heron Modeled Exposure and Effects Line of Evidence as a Measurement Endpoint for Piscivorous Bird  
Survival, Reproduction, and Neurological Effects  
Operable Unit IV, Nyanza Chemical Dump Superfund Site  
Middlesex County, Massachusetts**

<b>Attribute</b>	<b>Great Blue Heron Modeling</b>	<b>Rationale</b>
<b>I. Relationship between Measurement and Assessment Endpoints</b>		
1. Degree of Association	M	Exposure model used input parameters specific to the representative species, with the exception of the free metabolic rate for heron which relied on an allometric equation based on a broader range of birds. The effects metrics were not specific to heron.
2. Stressor/Response	M/H	The exposure modeling was species- and stressor-specific. The dose-response studies used to derive the effect metrics were not specific to the heron, but was a closely related species – the great egret.
3. Utility of Measure	M	Modeled exposure and effects procedures used are standardized and widely accepted, the primary limitation was lack of species-specific effects data, which increases uncertainty.
<b>II. Data Quality</b>		
4. Quality of Data	M/H	DQOs established for the sampling and analysis of tissue samples used in the exposure assessment were met. Other model parameters were derived from EPA (1993a) and other published journal articles and were great blue heron specific. The effects metrics were derived from published journal articles.
<b>III. Study Design</b>		
5. Site Specificity	L/M	Biological tissue data used in exposure models were site-specific. Other exposure model parameters were not site-specific (e.g., body weight, free metabolic rate). The effects measures were laboratory-based and not site-specific.
6. Sensitivity	M	Modeled exposure and effects almost directly addressed the exposure-response relationship for the heron. Laboratory studies from which effects data were derived were conducted on a closely related species.
7. Spatial Representativeness	M	Modeled exposures relied on tissue data collected throughout the study area. Some of the parameters used in the exposure model were taken from the literature and were not site-specific (e.g., body weight, gross energy). The effects assessment used toxicity studies conducted in laboratories.

**Table 4-56, Continued**

**Weighting of the Great Blue Heron Modeled Exposure and Effects Line of Evidence as a Measurement Endpoint for Piscivorous Bird  
Survival, Reproduction, and Neurological Effects  
Operable Unit IV, Nyanza Chemical Dump Superfund Site  
Middlesex County, Massachusetts**

<b>Attribute</b>	<b>Great Blue Heron Modeling</b>	<b>Rationale</b>
8. Temporal Representativeness	M	The collection of tissue data, used in the exposure model, did not completely overlap the reproductive cycle of herons. It is unknown whether other input variables (e.g., body weight) were collected during the heron's breeding season. Effects studies did span the reproductive cycles of the birds studied.
9. Quantitative Measure	M	Results are quantitative but the hazard quotient approach provides a relative assessment of ecological concern and is inappropriate for employing statistical testing.
10. Standard Method	M/H	Generally accepted exposure and effects modeling procedures were followed. Using the hazard quotient method to determine the potential for ecological risk is well accepted, with acknowledgements of applicable uncertainties.
<b>Overall Endpoint Value</b>	M	---

L = low                      M = moderate                      H = high  
 L/M = low-moderate      M/H = moderate-high

**Table 4-57**

**Weighting of the Hooded Merganser Study Line of Evidence as a Measurement Endpoint for Piscivorous Bird Survival, Reproduction, and Neurological Effects  
Operable Unit IV, Nyanza Chemical Dump Superfund Site  
Middlesex County, Massachusetts**

<b>Attribute</b>	<b>Hooded Merganser Study</b>	<b>Rationale</b>
<b>I. Relationship between Measurement and Assessment Endpoints</b>		
1. Degree of Association	M/H	Tissue chemistry reflects site-specific bioavailability and represents a measurement more closely related to the site of action.
2. Stressor/Response	M	Use of tissue chemistry accounts for bioavailability and integrates exposures from all pathways. However, the tissue benchmarks are limited by the number of ecologically significant chronic endpoints for mercury toxicity in specific hooded merganser tissue (i.e., blood, feathers, and eggs) available in the literature; thereby requiring extrapolations from less than ideal studies (e.g., short-term, lethal endpoints, different species).
3. Utility of Measure	M/H	Comparisons of site-specific tissue concentrations with Critical Body Residues (CBRs) are an accepted line of evidence for use in determining potential ecological harm.  The literature review that was the basis of the CBR values was thorough, with stringent criteria for the inclusion of studies used as the basis for derivation of CBRs.
<b>II. Data Quality</b>		
4. Quality of Data	M/H	All of the 2003 and 2004 hooded merganser blood, feathers, and egg data were validated to Tier II; whereas none of the 2005 data were validated. Because there were no significant issues in the avian data that were validated in 2003 and 2004, it was decided not to validate 2005 data. In these instances where validation occurred, requirements for accuracy, precision, and reproducibility were met. Because the same field techniques and laboratory, and analytical methods were used for the Tier I and unvalidated data, it is assumed that these data are of moderate/high quality.
<b>III. Study Design</b>		
5. Site Specificity	M/H	The hooded merganser tissue comparisons with CBRs met five factors under this attribute (i.e., representativeness of chemical data, environmental media, species, environmental conditions, and habitat types). Benchmarks derived were not specific to the Sudbury River.

**Table 4-57, Continued**

**Weighting of the Hooded Merganser Study Line of Evidence as a Measurement Endpoint for Piscivorous Bird Survival, Reproduction, and Neurological Effects  
Operable Unit IV, Nyanza Chemical Dump Superfund Site  
Middlesex County, Massachusetts**

<b>Attribute</b>	<b>Hooded Merganser Study</b>	<b>Rationale</b>
6. Sensitivity	M	Analytical techniques used can detect small differences in mercury concentrations. The difference between the no-effect and effect-based CBRs for eggs was less than 2; however, concentration ranges on which the CBRs were based encompassed values approximately 84-fold different. In addition, blood and feather CBRs were only developed based on effects-based data with the ranges of concentrations spanning a difference of 8- to 36-fold (feathers and eggs, respectively). Therefore, a moderate score was given to the hooded merganser tissue endpoint based on the Menzie et al. (1996) guidance that a moderate score for endpoints that can detect changes between 10- and 99-fold.
7. Spatial Representativeness	M/H	Four of the five criteria defined by Menzie et al. (1996) were met for the tissue data: study area, location of stressors, location of representative species, and points of exposure. Duck boxes were only located in the primary target areas of the Sudbury River (i.e., Reaches 3, 4, 7, and 8) and reference areas.
8. Temporal Representativeness	M/H	Field study was conducted during 3 breeding seasons; however, merganser nest box occupation was limited in several reaches.
9. Quantitative Measure	L/M	Results are quantitative but low sample sizes frequently precluded the use of statistical testing.
10. Standard Method	M	The methods used to obtain tissue concentrations followed established scientific protocols. The literature studies used to develop the benchmarks and CBRs were peer-reviewed. CBRs were developed using generally accepted methods. Using the hazard quotient method to determine the potential for ecological risk is well accepted, with acknowledgements of applicable uncertainties.
<b>Overall Endpoint Value</b>	M/H	---

L = low                      M = moderate                      H = high  
L/M = low-moderate      M/H = moderate-high

**Table 4-58**

**Weighting of the Belted Kingfisher Study Line of Evidence as a Measurement Endpoint for Piscivorous Bird Survival, Reproduction, and Neurological Effects  
Operable Unit IV, Nyanza Chemical Dump Superfund Site  
Middlesex County, Massachusetts**

Attribute	Kingfisher Study	Rationale
<b>I. Relationship between Measurement and Assessment Endpoints</b>		
1. Degree of Association	M/H	Tissue chemistry reflects site-specific bioavailability and represents a measurement more closely related to the site of action.
2. Stressor/Response	M	Use of tissue chemistry accounts for bioavailability and integrates exposures from all pathways. However, the tissue benchmarks are limited by the number of ecologically significant chronic endpoints for mercury toxicity in specific belted kingfisher tissue (i.e., blood, feathers, and eggs) available in the literature; thereby requiring extrapolations from less than ideal studies (e.g., short-term, lethal endpoints, different species).
3. Utility of Measure	M/H	Comparisons of site-specific tissue concentrations with Critical Body Residues (CBRs) are an accepted line of evidence for use in determining potential ecological harm.  The literature review that was the basis of the CBR values was thorough, with stringent criteria for the inclusion of studies used as the basis for derivation of CBRs.
<b>II. Data Quality</b>		
4. Quality of Data	M/H	All of the kingfisher blood and egg data were validated to Tier II; whereas feathers were validated to Tier I only. In these instances where validation occurred, requirements for accuracy, precision, and reproducibility were met. Because the same field techniques, laboratory, and analytical methods were used for the Tier I and unvalidated data, it is assumed that these data are of moderate/high quality.
<b>III. Study Design</b>		
5. Site Specificity	M	Kingfisher nests were not located directly on the river. Nests were located in areas close enough to the Sudbury River to use the Sudbury for foraging. Numerous other waterbodies are available within the Sudbury River drainage that can also be foraged.

**Table 4-58, Continued**

**Weighting of the Belted Kingfisher Study Line of Evidence as a Measurement Endpoint for Piscivorous Bird Survival, Reproduction, and Neurological Effects**  
**Operable Unit IV, Nyanza Chemical Dump Superfund Site**  
**Middlesex County, Massachusetts**

Attribute	Kingfisher Study	Rationale
6. Sensitivity	M	Analytical techniques used can detect small differences in mercury concentrations. The difference between the no-effect and effect-based CBRs for eggs was less than 2; however, concentration ranges on which the CBRs were based encompassed values approximately 84-fold different. In addition, blood and feather CBRs were only developed based on effects-based data with the ranges of concentrations spanning a difference of 8- to 36-fold (feathers and eggs, respectively). Therefore, a moderate score was given to the belted kingfisher tissue endpoint based on the Menzie et al. (1996) guidance that a moderate score for endpoints that can detect changes between 10- and 99-fold.
7. Spatial Representativeness	M	Three of the five criteria defined by Menzie et al. (1996) were met for the tissue data: study area, location of stressors, and location of representative species. Some kingfisher nests were located in proximity to other waterbodies, and direct observation of foraging activity and exposure has to be assumed.
8. Temporal Representativeness	M	Field study was conducted during the breeding season of the belted kingfishers, but is considered a single sampling event as only one reproductive cycle was measured.
9. Quantitative Measure	L/M	Results are quantitative but low sample sizes precluded the use of statistical testing.
10. Standard Method	M/H	The methods used to obtain tissue concentrations followed established scientific protocols. The literature studies used to develop the benchmarks and CBRs were peer-reviewed. CBRs were developed using generally accepted methods. Using the hazard quotient method to determine the potential for ecological risk is well accepted, with acknowledgements of applicable uncertainties.
<b>Overall Endpoint Value</b>	M	---

L = low                      M = moderate                      H = high  
L/M = low-moderate      M/H = moderate-high



**Table 4-59**

**Weighting of the Mink Modeled Exposure and Effects Line of Evidence as a Measurement Endpoint for Piscivorous Mammal Survival, Reproduction, and Neurological Effects  
Operable Unit IV, Nyanza Chemical Dump Superfund Site  
Middlesex County, Massachusetts**

Attribute	Mink Modeling	Rationale
<b>I. Relationship between Measurement and Assessment Endpoints</b>		
1. Degree of Association	M/H	Exposure model used input parameters specific to the representative species, with the exception of the free metabolic rate for mink which relied on an allometric equation based on a broader range of mammals. The effects metrics were from mink studies.
2. Stressor/Response	H	The exposure modeling was species- and stressor-specific. Dose-response studies specific to mink were used to derive the effect metrics for mink.
3. Utility of Measure	H	Modeled exposure and effects procedures used are standardized and widely accepted. Dose-response effects were specific to mink and well defined for exposure to mercury.
<b>II. Data Quality</b>		
4. Quality of Data	M	DQOs established for the sampling and analysis of tissue samples used in the exposure assessment were met. Other model parameters were derived from EPA (1993a) and other published journal articles. The effects metrics were derived from published journal articles and details on the DQOs for effects metrics were not available.
<b>III. Study Design</b>		
5. Site Specificity	L/M	Biological tissue data used in exposure models were site-specific. Other exposure model parameters were not site-specific (e.g., body weight, free metabolic rate). The effects measures were laboratory-based and not site-specific.
6. Sensitivity	H	Modeled exposure and effects directly assessed exposure-response relationship for mink. Laboratory studies from which effects data were derived were stressor-specific and included reproductive endpoints, which previously have been shown to be sensitive to the effects of mercury.
7. Spatial Representativeness	M	Modeled exposures relied on tissue data collected throughout the study area. Some of the parameters used in the exposure model were taken from the literature and were not site-specific (e.g., body weight, gross energy). The effects assessment used toxicity studies conducted in laboratories.

**Table 4-59, Continued**

**Weighting of the Mink Modeled Exposure and Effects Line of Evidence as a Measurement Endpoint for Piscivorous Mammal Survival, Reproduction, and Neurological Effects  
Operable Unit IV, Nyanza Chemical Dump Superfund Site  
Middlesex County, Massachusetts**

<b>Attribute</b>	<b>Mink Modeling</b>	<b>Rationale</b>
8. Temporal Representativeness	M	The collection of tissue data, used in the exposure model, did not completely overlap the reproductive cycle of mink. Body weights used to determine the FMR were obtained during the spring (i.e., breeding season). Effects studies spanned the reproductive cycle of the mink.
9. Quantitative Measure	M	Results are quantitative but the hazard quotient approach provides a relative assessment of ecological concern and is inappropriate for employing statistical testing.
10. Standard Method	M/H	Generally accepted exposure and effects modeling procedures were followed. Using the hazard quotient method to determine the potential for ecological risk is well accepted, with acknowledgements of applicable uncertainties.
<b>Overall Endpoint Value</b>	M/H	---

L = low                      M = moderate                      H = high  
 L/M = low-moderate      M/H = moderate-high

**Table 4-60**

**Weighting of the Mink Study Line of Evidence as a Measurement Endpoint for Piscivorous Mammal Survival, Reproduction, and Neurological Effects  
Operable Unit IV, Nyanza Chemical Dump Superfund Site  
Middlesex County, Massachusetts**

Attribute	Mink Study	Rationale
<b>I. Relationship between Measurement and Assessment Endpoints</b>		
1. Degree of Association	M	Tissue chemistry reflects site-specific bioavailability and represents a measurement more closely related to the site of action.
2. Stressor/Response	M	Use of tissue chemistry accounts for bioavailability and integrates exposures from all pathways. However, the tissue benchmarks are limited by the number of ecologically significant chronic endpoints for mercury toxicity in specific mink tissue (i.e., blood, fur, brain, and liver) available in the literature; thereby requiring extrapolations from less than ideal studies (e.g., short-term, lethal endpoints, different species).
3. Utility of Measure	M/H	Comparisons of site-specific tissue concentrations with Critical Body Residues (CBRs) are an accepted line of evidence for use in determining potential ecological harm.  The literature review that was the basis of the CBR values was thorough, with stringent criteria for the inclusion of studies used as the basis for derivation of CBRs.
<b>II. Data Quality</b>		
4. Quality of Data	L/M	DQOs established for the sampling and analysis of blood, brain, and liver samples were met. Laboratory identified potential QA problems with highest detected fur concentration.
<b>III. Study Design</b>		
5. Site Specificity	L/M	The mink comparisons with CBRs met only three of the six factors considered under this attribute (i.e., representativeness of chemical data, environmental media, and species). Benchmarks derived were not specific to the Sudbury River, and the limited sample size did not reflect all environmental conditions or habitats present.

**Table 4-60, Continued**

**Weighting of the Mink Study Line of Evidence as a Measurement Endpoint for Piscivorous Mammal Survival, Reproduction, and Neurological Effects  
Operable Unit IV, Nyanza Chemical Dump Superfund Site  
Middlesex County, Massachusetts**

<b>Attribute</b>	<b>Mink Study</b>	<b>Rationale</b>
6. Sensitivity	M	Analytical techniques used can detect small differences in mercury concentrations. The difference between the no-effect and effect-based CBRs for blood was less than 2; however, concentration ranges on which the blood CBRs were based encompassed values approximately 75-fold different. The difference between the no-effect and effect-based CBRs for fur was approximately 3. The effect CBR of 19.0 ppm was roughly equal to a field-based CBR of 20 ppm for reduced survivorship. Therefore, a low/moderate score was given to the mink tissue endpoint based on the Menzie et al. (1996) guidance that a low/moderate for endpoints that can detect changes between 10- and 99-fold.
7. Spatial Representativeness	L/M	Two of the five criteria defined by Menzie et al. (1996) were met for the tissue data: study area and location of representative species. Only 3 blood and 6 fur samples were collected in a total of four reaches; therefore, the mink tissue samples do not spatially represent exposure to mink throughout the study area.
8. Temporal Representativeness	L	Field study was not conducted during the mink's breeding season, and is considered a single sampling event as only one year's worth of data was measured.
9. Quantitative Measure	L/M	Results are quantitative but low sample sizes precluded the use of statistical testing.
10. Standard Method	M	The methods used to obtain tissue concentrations followed established scientific protocols. The literature studies used to develop the benchmarks and CBRs were peer-reviewed but limited in number. CBRs were developed using generally accepted methods. Using the hazard quotient method to determine the potential for ecological risk is well accepted, with acknowledgements of applicable uncertainties.
<b>Overall Endpoint Value</b>	M	---

L = low

M = moderate

H = high

L/M = low-moderate

M/H = moderate-high

Table 4-61

**Summary of Ecological Risk Associated with Mercury - Reach 2**  
**Operable Unit IV - Nyanza Chemical Dump Superfund Site**  
**Middlesex County, Massachusetts**

Receptor Group/ Target Receptor (sampling year)	Lifestage or Size	Tissue Type	LOE <sup>a</sup>	Weight of Evidence <sup>b</sup>	Reach 2			Reference - Reach 1 (S1) or Sudbury Reservoir (SR) or as otherwise noted		
					Population Risk?	Confidence Level	Comment	Population Risk?	Confidence Level	Comment
<b><i>Benthic Invertebrates</i></b>										
generic	NA	NA	A.1	L/M	possible	high	sediment n = 12; 8 samples above TEC and 4 samples above PEC; sediment benchmarks are not site-specific; if median used as CTE, results would be "possible/moderate"	possible possible	moderate low/moderate	S1 n = 5 SR n = 6
<i>Elliptio</i> mussel	adult	whole mussel	B.2	M/H	possible	moderate	high Hg in mussels at start of test, high mortality and poor growth in reference mussels, variable flow and habitat conditions across reaches	unlikely	high	Reach 9 and Reach 10
crayfish	adult	whole crayfish	D.1	M	unlikely	high	n = 11	unlikely	high	S1 and SR (n = 3 for each)
<b><i>Fish<sup>c</sup></i></b>										
generic	NA	NA	A.2	L/M	unlikely	high	surface water n = 3	unlikely	high	S1 (SR = no data)
sunfish	A	whole fish	D.2	M/H	unlikely	high	n = 11	unlikely	high	S1 and SR
	B	whole fish	D.2	M/H	unlikely	high	n = 2	unlikely	high	S1 (SR = no data)
bullhead	D	whole fish	D.2	M/H	unlikely	high	n = 3	unlikely	high	S1 and SR
yellow perch	B	whole fish	D.2	M/H	unlikely	high	n = 11	unlikely	high	10 S1 sunfish from same size class used as surrogates; SR 13 yellow perch
	C	whole fish	D.2	M/H	unlikely	high	n = 13	unlikely	high	S1 and SR
	D	whole fish	D.2	M/H	unlikely	high	n = 6	unlikely	high	S1 and SR
largemouth bass	D	whole fish	D.2	M/H	possible	low/moderate	n = 6	unlikely	high	S1 and SR
<b><i>Birds</i></b>										
tree swallow	adult	NA	C.1	M	possible	high	RME/no effect HQ = 7.3; RME/effect HQ = 3.7; conservative modeling assumptions used, including adult insect prey concentrations estimated from sediment to larval insect regressions, assuming 100% of prey affected by mercury in Sudbury River, 100% bioavailability, and the use of a conservative, generic TRV	possible	moderate	S1; RME/no effect HQ = 4.3; RME/effect HQ = 2.2
								unlikely	high	SR

Table 4-61

**Summary of Ecological Risk Associated with Mercury - Reach 2  
Operable Unit IV - Nyanza Chemical Dump Superfund Site  
Middlesex County, Massachusetts**

Receptor Group/ Target Receptor (sampling year)	Lifestage or Size	Tissue Type	LOE <sup>a</sup>	Weight of Evidence <sup>b</sup>	Reach 2			Reference - Reach 1 (S1) or Sudbury Reservoir (SR) or as otherwise noted		
					Population Risk?	Confidence Level	Comment	Population Risk?	Confidence Level	Comment
belted kingfisher	adult	NA	C.1	M	possible	high	RME/no effect HQ = 2.3; RME/effect HQ = 1.2; conservative modeling assumptions used, including use of crayfish and fish prey items only, using fish from size classes that include specimens of greater length (and; therefore, higher concentrations) than typically ingested; 100% bioavailability; assuming all prey comes from the Sudbury River when burrows were not located along banks but further upland, and the use of a conservative, generic TRV	possible	low/moderate	S1
								unlikely	high	SR
great blue heron	adult	NA	C.1	M	unlikely	high		unlikely	high	S1 and SR
<b>Mammals</b>										
mink	adult	NA	C.2	M/H	possible	low/moderate		unlikely	high	S1 and SR

CBR = Critical body residue

CTE = Central tendency exposure (arithmetic mean)

HQ = Hazard quotient

LOAEL = Lowest-observable-adverse-effect-level

NA = Not applicable

NOAEL = No-observable-adverse-effect-level

RME = Reasonable maximum exposure (maximum for all but food chain modeling, where the lower of the maximum and 95% UCL was used)

tHg = Total mercury

TRV = Toxicity reference value

**Notes:**

Unlikely = Adverse population-level effects are unlikely to the receptors represented by the measurement endpoint.

Possible = There is a potential for adverse population-level effects to the receptors represented by the measurement endpoint.

Red highlighting indicates that risk of adverse effects is possible, with relatively high confidence only for the particular measurement endpoint, but does not account for the weight given to that measure of risk in the BERA. Other measures of potential risk for the same receptors may not support this conclusion, and remedial action decisions are based on the weight-of-evidence for all measurement endpoints for each ecological receptor.

<sup>a</sup>LOE = Line of Evidence:

A.1 = Comparison of CTE and RME sediment tHg concentration to threshold effect and probable effect concentrations.

A.2 = Comparison of CTE and RME surface water tHg concentration to acute and chronic surface water criteria.

B.2 = Field toxicity testing.

C.1 = Comparison of CTE and RME estimated daily doses of MeHg (tHg for tree swallows) to a NOAEL- and LOAEL-based bird TRV.

C.2 = Comparison of CTE and RME estimated daily doses of MeHg to a NOAEL- and LOAEL-based mammal TRV.

D.1 = Comparison of the CTE and RME wholebody crayfish tHg concentration to a no effect and effect tHg CBR.

D.2 = Comparison of the CTE and RME wholebody fish tHg concentration to a no effect and effect tHg CBR.

<sup>b</sup>Endpoint Weight:

L = Low

L-M = Low /Moderate

M = Moderate

M-H = Moderate/High

H = High

<sup>c</sup>Fish Size Classes:

Size A = ≤ 10 cm

Size B = 10 < x ≤ 15 cm

Size C = 15 < x ≤ 20 cm

Size D = >20 cm

Table 4-62

**Summary of Ecological Risk Associated with Mercury - Reach 3  
Operable Unit IV - Nyanza Chemical Dump Superfund Site  
Middlesex County, Massachusetts**

Receptor Group/ Target Receptor (sampling year)	Lifestage or Size Class	Tissue Type	LOE <sup>a</sup>	Weight of Evidence <sup>b</sup>	Reach 3			Sudbury Reservoir Reference (except when noted otherwise)		
					Population Risk?	Confidence Level	Comment	Population Risk?	Confidence Level	Comment
<b><i>Benthic Invertebrates</i></b>										
generic	NA	NA	A.1	L/M	possible	high	sediment n = 39; all samples exceed both TEC and PEC; sediment benchmarks are not site-specific	possible	low/moderate	n = 6
mayfly (July 1994)	juvenile	whole flies	B.1	M/H	unlikely	moderate	sediment n = 6	unlikely	high	Reach 1; n = 6
mayfly (September 1994)	juvenile	whole flies	B.1	M/H	unlikely	moderate	sediment n = 6	possible	low	Whitehall Reservoir; n = 6
								unlikely	high	Reach 1; n = 6
<i>Elliptio</i> mussel	adult	whole mussel	B.2	M/H	possible	moderate	high Hg in mussels at start of test, high mortality and poor growth in reference mussels, variable flow and habitat conditions across reaches	possible	low	Whitehall Reservoir; n = 6
								unlikely	high	Reach 9 and Reach 10
crayfish	adult	whole crayfish	D.1	M	unlikely	high	n = 19	unlikely	high	n = 3
<b><i>Fish<sup>c</sup></i></b>										
generic	NA	NA	A.2	L/M	unlikely	undetermined	surface water n = 1	--	--	no data
sunfish	A	whole fish	D.2	M/H	unlikely	high	n = 13	unlikely	high	n = 7
bullhead	D	whole fish	D.2	M/H	unlikely	high	n = 4	unlikely	high	n = 3
	B	whole fish	D.2	M/H	unlikely	high	n = 13	unlikely	high	n = 13
	C	whole fish	D.2	M/H	unlikely	high	n = 13	unlikely	high	n = 13
yellow perch	D	whole fish	D.2	M/H	possible	low/moderate	n = 3; if median used as CTE, results would be ""unlikely/high"	unlikely	high	n = 3
	largemouth bass	D	whole fish	D.2	M/H	possible	low/moderate	n = 4	unlikely	high
<b><i>Birds</i></b>										
tree swallow	adult	NA	C.1	M	possible	high	RME/no effect HQ = 24; RME/effect HQ = 12; conservative modeling assumptions used, including adult insect prey concentrations estimated from sediment to larval insect regressions, assuming 100% of prey affected by mercury in Sudbury River, 100% bioavailability, and the use of a conservative, generic TRV	unlikely	high	
tree swallow (2003)	nestling	blood	D.4	M/H	unlikely	high	n = 4	unlikely	high	n = 10
tree swallow (2003)	adult	blood	D.4	M/H	unlikely	high	n = 3	unlikely	high	n = 9
tree swallows (2004)	adult	blood	D.4	M/H	unlikely	high	n = 15	--	--	no data
tree swallow (2003)	NA	egg	D.3	M/H	unlikely	high	n = 4	unlikely	high	n = 14
tree swallow (2004)	NA	egg	D.3	M/H	unlikely	high	n = 21	--	--	no data
tree swallow (2003)	adult	feather	D.5	M/H	possible	low/moderate	n = 3; if median used as CTE, results would be ""unlikely/high"	possible	low/moderate	n = 9
tree swallows (2004)	adult	feather	D.5	M/H	possible	low/moderate	n = 15	--	--	no data

Table 4-62

**Summary of Ecological Risk Associated with Mercury - Reach 3  
Operable Unit IV - Nyanza Chemical Dump Superfund Site  
Middlesex County, Massachusetts**

Receptor Group/ Target Receptor (sampling year)	Lifestage or Size Class	Tissue Type	LOE <sup>a</sup>	Weight of Evidence <sup>b</sup>	Reach 3			Sudbury Reservoir Reference (except when noted otherwise)		
					Population Risk?	Confidence Level	Comment	Population Risk?	Confidence Level	Comment
belted kingfisher	adult	NA	C.1	M	possible	high	RME/no effect HQ = 2.4; RME/effect HQ = 1.2; conservative modeling assumptions used, including use of crayfish and fish prey items only, using fish from size classes that include specimens of greater length (and; therefore, higher concentrations) than typically ingested; 100% bioavailability; assuming all prey comes from the Sudbury River when burrows were not located along banks but further upland, and the use of a conservative, generic TRV	unlikely	high	
great blue heron	adult	NA	C.1	M	possible	low/moderate		unlikely	high	
<b>Mammals</b>										
mink	adult	NA	C.2	M/H	possible	low/moderate		unlikely	high	
	adult	blood	D.6	M	unlikely	undetermined	n = 1	--	--	no data
	adult	fur	D.7	M	possible	undetermined	n = 1; no effect HQ = 7.6; effect HQ = 3.1	--	--	no data

CBR = Critical body residue

CTE = Central tendency exposure (arithmetic mean)

HQ = Hazard quotient

LOAEL = Lowest-observable-adverse-effect-level

NA = Not applicable

NOAEL = No-observable-adverse-effect-level

RME = Reasonable maximum exposure (maximum for all but food chain modeling, where the lower of the maximum and 95% UCL was used)

tHg = Total mercury

TRV = Toxicity reference value

**Notes:**

Unlikely = Adverse population-level effects are unlikely to the receptors represented by the measurement endpoint

Possible = There is a potential for adverse population-level effects to the receptors represented by the measurement endpoint

Red highlighting indicates that risk of adverse effects is possible, with relatively high confidence only for the particular measurement endpoint, but does not account for the weight given to that measure of risk in the BERA. Other measures of potential risk for the same receptors may not support this conclusion, and remedial action decisions are based on the weight-of-evidence for all measurement endpoints for each ecological receptor.

Mercury levels in bird blood and eggs are indicative of recent (site-specific) exposure to mercury. Mercury concentrations in bird feathers reflect more long-term exposures; therefore, may not as strongly associated with site-related exposures or potential effects.

<sup>a</sup>LOE = Line of Evidence:

A.1 = Comparison of CTE and RME sediment tHg concentration to threshold effect and probable effect concentration

A.2 = Comparison of CTE and RME surface water tHg concentration to acute and chronic surface water criteria

B.1 = Laboratory toxicity testing

B.2 = Field toxicity testing

C.1 = Comparison of CTE and RME estimated daily doses of MeHg (tHg for tree swallows) to a NOAEL- and LOAEL-based bird TRV

C.2 = Comparison of CTE and RME estimated daily doses of MeHg to a NOAEL- and LOAEL-based mammal TRV

D.1 = Comparison of the CTE and RME wholebody crayfish tHg concentration to a no effect and effect tHg CBI

D.2 = Comparison of the CTE and RME wholebody fish tHg concentration to a no effect and effect tHg CBI

D.3 = Comparison of the CTE and RME bird egg tHg concentration to a no effect and effect tHg CBI

D.4 = Comparison of the CTE and RME bird blood tHg concentration to a no effect and effect tHg CBI

D.5 = Comparison of the CTE and RME feather tHg concentration to a no effect and effect tHg CBI

D.6 = Comparison of the CTE and RME mink blood tHg concentration to a no effect and effect tHg CBI

D.7 = Comparison of the CTE and RME tHg fur concentration to a no effect and effect tHg CBI

<sup>b</sup>Endpoint Weight:

L = Low

L-M = Low /Moderate

M = Moderate

M-H = Moderate/High

H = High

<sup>c</sup>Fish Size Classes:

Size A = ≤ 10 cm

Size B = 10 &lt; x ≤ 15 cm

Size C = 15 &lt; x ≤ 20 cm

Size D = &gt; 20 cm



Table 4-63

**Summary of Ecological Risk Associated with Mercury - Reach 4**  
**Operable Unit IV - Nyanza Chemical Dump Superfund Site**  
**Middlesex County, Massachusetts**

Receptor Group/ Target Receptor (sampling year)	Lifestage or Size	Tissue Type	LOE <sup>a</sup>	Weight of Evidence <sup>b</sup>	Reach 4			Sudbury Reservoir Reference (except when otherwise noted)		
					Population Risk?	Confidence Level	Comment	Population Risk?	Confidence Level	Comment
<b>Benthic Invertebrates</b>										
generic	NA	NA	A.1	L/M	possible	high	sediment n = 11; 11 samples above TEC and 10 samples above PEC; sediment benchmarks are not site-specific	possible	low/moderate	n = 6
mayfly (July 1994)	juvenile	whole flies	B.1	M/H	unlikely	moderate	sediment n = 6	unlikely	high	Reach 1; n = 6
mayfly (September 1994)	juvenile	whole flies	B.1	M/H	unlikely	moderate	sediment n = 6	possible	low	Whitehall Reservoir; n = 6
								unlikely	high	Reach 1; n = 6
								possible	low	Whitehall Reservoir; n = 6
crayfish	adult	whole crayfish	D.1	M	unlikely	high	n = 4	unlikely	high	n = 3
<b>Fish<sup>c</sup></b>										
generic	NA	NA	A.2	L/M	unlikely	undetermined	surface water n = 1	--	--	no data
sunfish	A	whole fish	D.2	M/H	unlikely	high	n = 13	unlikely	high	n = 7
bullhead	D	whole fish	D.2	M/H	unlikely	high	n = 4	unlikely	high	n = 3
yellow perch	B	whole fish	D.2	M/H	unlikely	high	n = 13	unlikely	high	n = 13
	C	whole fish	D.2	M/H	unlikely	high	n = 13	unlikely	high	n = 13
	D	whole fish	D.2	M/H	possible	low/moderate	n = 4	unlikely	high	n = 3
largemouth bass	D	whole fish	D.2	M/H	possible	low/moderate	n = 3	unlikely	high	n = 2
<b>Birds</b>										
tree swallow	adult	NA	C.1	M	possible	high	RME/no effect HQ = 12; RME/effect HQ = 6.0; conservative modeling assumptions used, including adult insect prey concentrations estimated from sediment to larval insect regressions, assuming 100% of prey affected by mercury in Sudbury River, 100% bioavailability, and the use of a conservative, generic TRV	unlikely	high	
tree swallow (2003)	nestling	blood	D.4	M/H	unlikely	high	n = 5	unlikely	high	n = 10
tree swallow (2003)	adult	blood	D.4	M/H	unlikely	undetermined	n = 1	unlikely	high	n = 9
tree swallows (2004)	adult	blood	D.4	M/H	unlikely	high	n = 10	--	--	no data
tree swallow (2003)	NA	egg	D.3	M/H	unlikely	undetermined	n = 1	unlikely	high	n = 14
tree swallows (2004)	NA	egg	D.3	M/H	unlikely	high	n = 14	--	--	no data
tree swallow (2003)	adult	feather	D.5	M/H	unlikely	undetermined	n = 1	possible	low/moderate	n = 9
tree swallows (2004)	adult	feather	D.5	M/H	possible	low/moderate	n = 10	--	--	no data
hooded merganser	NA	egg	D.3	M/H	possible	low/moderate	n = 2	unlikely	high	n = 2

Table 4-63

**Summary of Ecological Risk Associated with Mercury - Reach 4  
Operable Unit IV - Nyanza Chemical Dump Superfund Site  
Middlesex County, Massachusetts**

Receptor Group/ Target Receptor (sampling year)	Lifestage or Size	Tissue Type	LOE <sup>a</sup>	Weight of Evidence <sup>b</sup>	Reach 4			Sudbury Reservoir Reference (except when otherwise noted)		
					Population Risk?	Confidence Level	Comment	Population Risk?	Confidence Level	Comment
belted kingfisher	adult	NA	C.1	M	possible	moderate	RME/no effect HQ = 2.0; RME/effect HQ = 1.0; conservative modeling assumptions used, including use of crayfish and fish prey items only, using fish from size classes that include specimens of greater length (and; therefore, higher concentrations) than typically ingested; 100% bioavailability; assuming all prey comes from the Sudbury River when burrows were not located along banks but further upland, and the use of a conservative, generic TRV	unlikely	high	
great blue heron	adult	NA	C.1	M	unlikely	high		unlikely	high	
<b>Mammals</b>										
mink	adult	NA	C.2	M/H	possible	low/moderate		unlikely	high	
	adult	blood	D.6	M	unlikely	undetermined	n = 1	--	--	no data
	adult	fur	D.7	M	unlikely	undetermined	n = 1	--	--	no data

CBR = Critical body residue

CTE = Central tendency exposure (arithmetic mean)

HQ = Hazard quotient

LOAEL = Lowest-observable-adverse-effect-level

NA = Not applicable

NOAEL = No-observable-adverse-effect-level

RME = Reasonable maximum exposure (maximum for all but food chain modeling, where the lower of the maximum and 95% UCL was used)

tHg = Total mercury

TRV = Toxicity reference value

**Notes:**

Unlikely = Adverse population-level effects are unlikely to the receptors represented by the measurement endpoint.

Possible = There is a potential for adverse population-level effects to the receptors represented by the measurement endpoint.

Red highlighting indicates that risk of adverse effects is possible, with relatively high confidence only for the particular measurement endpoint, but does not account for the weight given to that measure of risk in the BERA. Other measures of potential risk for the same receptors may not support this conclusion, and remedial action decisions are based on the weight-of-evidence for all measurement endpoints for each ecological receptor.

Mercury levels in bird blood and eggs are indicative of recent (site-specific) exposure to mercury. Mercury concentrations in bird feathers reflect more long-term exposures; therefore, may not be as strongly associated with site-related exposures or potential effects.

<sup>a</sup>LOE = Line of Evidence:

A.1 = Comparison of CTE and RME sediment tHg concentration to threshold effect and probable effect concentrations.

A.2 = Comparison of CTE and RME surface water tHg concentration to acute and chronic surface water criteria.

B.1 = Laboratory toxicity testing.

C.1 = Comparison of CTE and RME estimated daily doses of MeHg (tHg for tree swallows) to a NOAEL- and LOAEL-based bird TRV.

C.2 = Comparison of CTE and RME estimated daily doses of MeHg to a NOAEL- and LOAEL-based mammal TRV.

D.1 = Comparison of the CTE and RME wholebody crayfish tHg concentration to a no effect and effect tHg CBR.

D.2 = Comparison of the CTE and RME wholebody fish tHg concentration to a no effect and effect tHg CBR.

D.3 = Comparison of the CTE and RME bird egg tHg concentration to a no effect and effect tHg CBR.

D.4 = Comparison of the CTE and RME bird blood tHg concentration to a no effect and effect tHg CBR.

D.5 = Comparison of the CTE and RME feather tHg concentration to a no effect and effect tHg CBR.

D.6 = Comparison of the CTE and RME mink blood tHg concentration to a no effect and effect tHg CBR.

D.7 = Comparison of the CTE and RME tHg fur concentration to a no effect and effect tHg CBR.

<sup>b</sup>Endpoint Weight:

L = Low

L-M = Low /Moderate

M = Moderate

M-H = Moderate/High

H = High

<sup>c</sup>Fish Size Classes:

Size A = ≤ 10 cm

Size B = 10&lt; x ≤15 cm

Size C = 15&lt; x ≤20 cm

Size D = &gt;20 cm

Table 4-64

**Summary of Ecological Risk Associated with Mercury - Reach 5  
Operable Unit IV - Nyanza Chemical Dump Superfund Site  
Middlesex County, Massachusetts**

Receptor Group/ Target Receptor (sampling year)	Lifestage or Size	Tissue Type	LOE <sup>a</sup>	Weight of Evidence <sup>b</sup>	Reach 5			Reach 1 Reference (except when noted otherwise)		
					Population Risk?	Confidence Level	Comment	Population Risk?	Confidence Level	Comment
<b><i>Benthic Invertebrates</i></b>										
generic	NA	NA	A.1	L/M	possible	moderate	sediment n = 10; 7 samples above TEC and 5 samples above PEC; sediment benchmarks are not site-specific	possible	moderate	n = 5
crayfish	adult	whole crayfish	D.1	M	unlikely	high	n = 17	unlikely	high	n = 3
<b><i>Fish<sup>c</sup></i></b>										
generic	NA	NA	A.2	L/M	unlikely	undetermined	surface water n = 1	unlikely	high	n = 4
sunfish	A	whole fish	D.2	M/H	unlikely	high	n = 13	unlikely	high	n = 11
	B	whole fish	D.2	M/H	unlikely	high	n = 11	unlikely	high	n = 10
bullhead	D	whole fish	D.2	M/H	unlikely	high	n = 3	unlikely	high	n = 2
yellow perch	C	whole fish	D.2	M/H	unlikely	high	n = 3	unlikely	high	n = 5
	D	whole fish	D.2	M/H	unlikely	high	n = 3	unlikely	high	n = 3
largemouth bass	D	whole fish	D.2	M/H	possible	low/moderate	n = 4	unlikely	high	n = 3
<b><i>Birds</i></b>										
tree swallow	adult	NA	C.1	M	possible	moderate	RME/no effect HQ = 2.2; RME/effect HQ = 1.1; conservative modeling assumptions used, including adult insect prey concentrations estimated from sediment to larval insect regressions, assuming 100% of prey affected by mercury in Sudbury River, 100% bioavailability, and the use of a conservative, generic TRV	possible	moderate	RME/no effect HQ = 4.3; RME/effect HQ = 2.2
belted kingfisher	adult	NA	C.1	M	possible	high	RME/no effect HQ = 2.3; RME/effect HQ = 1.1; conservative modeling assumptions used, including use of crayfish and fish prey items only, using fish from size classes that include specimens of greater length (and; therefore, higher concentrations) than typically ingested; 100% bioavailability; assuming all prey comes from the Sudbury River when burrows were not located along banks but further upland, and the use of a conservative, generic TRV	possible	low/moderate	
great blue heron	adult	NA	C.1	M	unlikely	high		unlikely	high	
<b><i>Mammals</i></b>										
mink	adult	NA	C.2	M/H	possible	low/moderate		unlikely	high	
	adult	fur	D.7	M	possible	low/moderate	2 fur samples. Note that one sample had a duplicate outside of the RPD; omitting this sample would result in unlikely/high.	---	---	no data

CBR = Critical body residue

CTE = Central tendency exposure (arithmetic mean)

HQ = Hazard quotient

<sup>b</sup>Endpoint Weight:

L = Low

Table 4-64

**Summary of Ecological Risk Associated with Mercury - Reach 5  
Operable Unit IV - Nyanza Chemical Dump Superfund Site  
Middlesex County, Massachusetts**

Receptor Group/ Target Receptor (sampling year)	Lifestage or Size	Tissue Type	LOE <sup>a</sup>	Weight of Evidence <sup>b</sup>	Reach 5			Reach 1 Reference (except when noted otherwise)		
					Population Risk?	Confidence Level	Comment	Population Risk?	Confidence Level	Comment

LOAEL = Lowest-observable-adverse-effect-level

NA = Not applicable

NOAEL = No-observable-adverse-effect-level

RME = Reasonable maximum exposure (maximum for all but food chain modeling, where the lower of the maximum and 95% UCL was used)

tHg = Total mercury

TRV = Toxicity reference value

L-M = Low /Moderate

M = Moderate

M-H = Moderate/High

H = High

<sup>c</sup>Fish Size Classes:

Size A = ≤ 10 cm

Size B = 10< x ≤15 cm

Size C = 15< x ≤20 cm

Size D = >20 cm

Notes:

Unlikely = Adverse population-level effects are unlikely to the receptors represented by the measurement endpoint.

Possible = There is a potential for adverse population-level effects to the receptors represented by the measurement endpoint.

Red highlighting indicates that risk of adverse effects is possible, with relatively high confidence only for the particular measurement endpoint, but does not account for the weight given to that measure of risk in the BERA. Other measures of potential risk for the same receptors may not support this conclusion, and remedial action decisions are based on the weight-of-evidence for all measurement endpoints for each ecological receptor.

<sup>a</sup>LOE = Line of Evidence:

A.1 = Comparison of CTE and RME sediment tHg concentration to threshold effect and probable effect concentrations.

A.2 = Comparison of CTE and RME surface water tHg concentration to acute and chronic surface water criteria.

C.1 = Comparison of CTE and RME estimated daily doses of MeHg (tHg for tree swallows) to a NOAEL- and LOAEL-based bird TRV .

C.2 = Comparison of CTE and RME estimated daily doses of MeHg to a NOAEL- and LOAEL-based mammal TRV.

D.1 = Comparison of the CTE and RME wholebody crayfish tHg concentration to a no effect and effect tHg CBR.

D.2 = Comparison of the CTE and RME wholebody fish tHg concentration to a no effect and effect tHg CBR.

D.7 = Comparison of the CTE and RME tHg fur concentration to a no effect and effect tHg CBR.

Table 4-65

**Summary of Ecological Risk Associated with Mercury - Reach 6  
Operable Unit IV - Nyanza Chemical Dump Superfund Site  
Middlesex County, Massachusetts**

Receptor Group/ Target Receptor (sampling year)	Lifestage or Size	Tissue Type	LOE <sup>a</sup>	WOE <sup>b</sup>	Reach 6			Sudbury Reservoir Reference (except when otherwise noted)		
					Population Risk?	Confidence Level	Comment	Population Risk?	Confidence Level	Comment
<b><i>Benthic Invertebrates</i></b>										
generic	NA	NA	A.1	L/M	possible	high	sediment n = 12; 11 samples above TEC and 8 samples above PEC; sediment benchmarks are not site-specific	possible	low/moderate	n = 6
<i>Elliptio</i> mussel	adult	whole mussel	B.2	M/H	possible	moderate	high Hg in mussels at start of test, high mortality and poor growth in reference mussels, variable flow and habitat conditions across reaches	unlikely	high	Reach 9 and Reach 10
crayfish	adult	whole crayfish	D.1	M	unlikely	undetermined	n = 1	unlikely	high	n = 3
<b><i>Fish<sup>c</sup></i></b>										
sunfish	A	whole fish	D.2	M/H	unlikely	high	n = 12	unlikely	high	n = 7
	B	whole fish	D.2	M/H	unlikely	high	n = 8	--	--	no data
bullhead	D	whole fish	D.2	M/H	unlikely	high	n = 3	unlikely	high	n = 3
yellow perch	A	whole fish	D.2	M/H	unlikely	undetermined	n = 1	unlikely	high	n = 6
	B	whole fish	D.2	M/H	unlikely	high	n = 2	unlikely	high	n = 13
	C	whole fish	D.2	M/H	unlikely	high	n = 13	unlikely	high	n = 13
	D	whole fish	D.2	M/H	unlikely	high	n = 3	unlikely	high	n = 3
largemouth bass	D	whole fish	D.2	M/H	possible	low	n = 3	unlikely	high	n = 2
<b><i>Birds</i></b>										
tree swallow	adult	NA	C.1	M	possible	high	RME/no effect HQ = 6.2; RME/effect HQ = 3.1;conservative modeling assumptions used, including adult insect prey concentrations estimated from sediment to larval insect regressions, assuming 100% of prey affected by mercury in Sudbury River, 100% bioavailability, and the use of a conservative, generic TRV	unlikely	high	
belted kingfisher	adult	NA	C.1	M	possible	low/moderate		unlikely	high	
great blue heron	adult	NA	C.1	M	unlikely	high		unlikely	high	
<b><i>Mammals</i></b>										
mink	adult	NA	C.2	M/H	unlikely	high		unlikely	high	

CBR = Critical body residue

CTE = Central tendency exposure (arithmetic mean)

HQ = Hazard quotient

LOAEL = Lowest-observable-adverse-effect-level

NA = Not applicable

NOAEL = No-observable-adverse-effect-level

RME = Reasonable maximum exposure (maximum for all but food chain modeling, where the lower of the maximum and 95% UCL was used)

tHg = Total mercury

TRV = Toxicity reference value

## Notes:

Unlikely = Adverse population-level effects are unlikely to the receptors represented by the measurement endpoint.

Possible = There is a potential for adverse population-level effects to the receptors represented by the measurement endpoint.

<sup>b</sup>Endpoint Weight:

L = Low

L-M = Low /Moderate

M = Moderate

M-H = Moderate/High

H = High

<sup>c</sup>Fish Size Classes:

Size A = ≤ 10 cm

Size B = 10 &lt; x ≤ 15 cm

Size C = 15 &lt; x ≤ 20 cm

Size D = &gt; 20 cm

Table 4-65

**Summary of Ecological Risk Associated with Mercury - Reach 6  
Operable Unit IV - Nyanza Chemical Dump Superfund Site  
Middlesex County, Massachusetts**

Receptor Group/ Target Receptor (sampling year)	Lifestage or Size	Tissue Type	LOE <sup>a</sup>	WOE <sup>b</sup>	Reach 6			Sudbury Reservoir Reference (except when otherwise noted)		
					Population Risk?	Confidence Level	Comment	Population Risk?	Confidence Level	Comment

Red highlighting indicates that risk of adverse effects is possible, with relatively high confidence only for the particular measurement endpoint, but does not account for the weight given to that measure of risk in the BERA. Other measures of potential risk for the same receptors may not support this conclusion, and remedial action decisions are based on the weight-of-evidence for all measurement endpoints for each ecological receptor.

<sup>a</sup>LOE = Line of Evidence:

A.1 = Comparison of CTE and RME sediment tHg concentration to threshold effect and probable effect concentrations.

B.2 = Field toxicity testing.

C.1 = Comparison of CTE and RME estimated daily doses of MeHg (tHg for tree swallows) to a NOAEL- and LOAEL-based bird TRV .

C.2 = Comparison of CTE and RME estimated daily doses of MeHg to a NOAEL- and LOAEL-based mammal TRV.

D.1 = Comparison of the CTE and RME wholebody crayfish tHg concentration to a no effect and effect tHg CBR.

D.2 = Comparison of the CTE and RME wholebody fish tHg concentration to a no effect and effect tHg CBR.

Table 4-66

**Summary of Ecological Risk Associated with Mercury - Reach 7  
Operable Unit IV - Nyanza Chemical Dump Superfund Site  
Middlesex County, Massachusetts**

Receptor Group/ Target Receptor (sampling year)	Lifestage or Size	Tissue Type	LOE <sup>a</sup>	WOE <sup>b</sup>	Reach 7			otherwise; Charles River = CR and Sudbury Reservoir = SR)		
					Population Risk?	Confidence Level	Comment	Population Risk?	Confidence Level	Comment
<b>Benthic Invertebrates</b>										
generic	NA	NA	A.1	L/M	possible	moderate	sediment n = 16; 6 samples above TEC and 2 samples above PEC; sediment benchmarks are not site-specific; if median used as CTE, results would be "possible/low"; if 95% UCL used as RME, results would be "possible/low-moderate"; if median/95% UCL combined used, results = "unlikely/high"	possible	moderate	n = 5
crayfish	adult	whole crayfish	D.1	M	unlikely	high	n = 7	unlikely	high	n = 3
<b>Fish<sup>c</sup></b>										
generic	NA	NA	A.2	L/M	unlikely	high	surface water n = 10	unlikely	high	n = 4
sunfish	A	whole fish	D.2	M/H	unlikely	high	n = 7	unlikely	high	n = 11
bullhead	D	whole fish	D.2	M/H	unlikely	high	n = 3	unlikely	high	n = 2
yellow perch	A	whole fish	D.2	M/H	unlikely	high	n = 3	unlikely	high	11 sunfish from same size class
	B	whole fish	D.2	M/H	unlikely	high	n = 13	unlikely	high	10 sunfish from same size class
	C	whole fish	D.2	M/H	unlikely	high	n = 13	unlikely	high	n = 5
	D	whole fish	D.2	M/H	unlikely	high	n = 4	unlikely	high	n = 3
largemouth bass	D	whole fish	D.2	M/H	possible	low/moderate	n = 4	unlikely	high	n = 3
<b>Birds</b>										
tree swallow	adult	NA	C.1	M	unlikely	high		possible	moderate	RME/no effect HQ = 4.3;
tree swallow (2003)	adult	blood	D.4	M/H	unlikely	high	n = 5	unlikely	high	CR; n = 15
tree swallow (2003)	NA	egg	D.3	M/H	unlikely	high	n = 8	unlikely	high	CR; n = 15
tree swallow (2003)	adult	feather	D.5	M/H	possible	low/moderate	n = 5	unlikely	high	CR; n = 16
eastern kingbird	NA	egg	D.3	L/M	unlikely	high	n = 6	unlikely	high	CR; n = 5
song sparrow (2003)	adult	blood	D.4	M	unlikely	high	n = 9	unlikely	high	CR; n = 4
swamp sparrow (2003)	adult	blood	D.4	M	unlikely	high	n = 3	unlikely	high	CR; n = 6
yellow throat (2003)	adult	blood	D.4	M	unlikely	undetermined	n = 1	unlikely	high	CR; n = 2
yellow warbler (2003)	adult	blood	D.4	M	unlikely	high	n = 2	unlikely	high	CR; n = 4
song sparrow (2003)	adult	feather	D.5	M	possible	low/moderate	n = 9; if median used as CTE, results would be "unlikely/high"	possible	moderate	CR; n = 4
swamp sparrow (2003)	adult	feather	D.5	M	possible	low/moderate	n = 2	possible	moderate	CR; n = 6
waterthrush (2003)	adult	feather	D.5	M	unlikely	undetermined	n = 1	possible	undetermined	CR; n = 1
yellow throat (2003)	adult	feather	D.5	M	possible	undetermined	n = 1	possible	undetermined	CR; n = 1
yellow warbler (2003)	adult	feather	D.5	M	possible	undetermined	n = 1	possible	low/moderate	CR; n = 4
wood duck (2004)	adult	blood	D.4	M/H	unlikely	undetermined	n = 1	unlikely	undetermined	SR; n = 1
wood ducks (2004)	adult	feather	D.5	M/H	unlikely	undetermined	n = 1	unlikely	undetermined	SR; n = 1

Table 4-66

**Summary of Ecological Risk Associated with Mercury - Reach 7  
Operable Unit IV - Nyanza Chemical Dump Superfund Site  
Middlesex County, Massachusetts**

Receptor Group/ Target Receptor (sampling year)	Lifestage or Size	Tissue Type	LOE <sup>a</sup>	WOE <sup>b</sup>	Reach 7			otherwise; Charles River = CR and Sudbury Reservoir = SR)		
					Population Risk?	Confidence Level	Comment	Population Risk?	Confidence Level	Comment
belted kingfisher	adult	NA	C.1	M	possible	moderate	RME/no effect HQ = 2.1; RME/effect HQ = 1.1; conservative modeling assumptions used, including use of crayfish and fish prey items only, using fish from size classes that include specimens of greater length (and; therefore, higher concentrations) than typically ingested; 100% bioavailability; assuming all prey comes from the Sudbury River when burrows were not located along banks but further upland, and the use of a conservative, generic TRV	possible	low/moderate	
belted kingfisher	nestling	blood	D.4	M	unlikely	high	n = 2 (1 nest)	unlikely	undetermined	CR; n = 1
belted kingfisher	nestling	feather	D.5	M	possible	low/moderate	n = 2 (1 nest)	possible	undetermined	CR; n = 1
great blue heron	adult	NA	C.1	M	unlikely	high		unlikely	high	
<b>Mammals</b>										
mink	adult	NA	C.2	M/H	possible	low/moderate		unlikely	high	
	adult	blood	D.6	M	unlikely	undetermined	n = 1	---	---	no data
	adult	fur	D.7	M	unlikely	undetermined	n = 1	---	---	no data

CBR = Critical body residue

CTE = Central tendency exposure (arithmetic mean)

HQ = Hazard quotient

LOAEL = Lowest-observable-adverse-effect-level

NA = Not applicable

NOAEL = No-observable-adverse-effect-level

RME = Reasonable maximum exposure (maximum for all but food chain modeling, where the lower of the maximum and 95% UCL was used)

tHg = Total mercury

TRV = Toxicity reference value

<sup>b</sup>Endpoint Weight:

L = Low

L-M = Low /Moderate

M = Moderate

M-H = Moderate/High

H = High

<sup>c</sup>Fish Size Classes:

Size A = ≤ 10 cm

Size B = 10< x ≤15 cm

Size C = 15< x ≤20 cm

Size D = >20 cm

**Notes:**

Unlikely = Adverse population-level effects are unlikely to the receptors represented by the measurement endpoint.

Possible = There is a potential for adverse population-level effects to the receptors represented by the measurement endpoint.

Red highlighting indicates that risk of adverse effects is possible, with relatively high confidence only for the particular measurement endpoint, but does not account for the weight given to that measure of risk in the BERA. Other measures of potential risk for the same receptors may not support this conclusion, and remedial action decisions are based on the weight-of-evidence for all measurement endpoints for each ecological receptor.

Mercury levels in bird blood and eggs are indicative of recent (site-specific) exposure to mercury. Mercury concentrations in bird feathers reflect more long-term exposures; therefore, may not be as strongly associated with site-related exposures or potential effects.

<sup>a</sup>LOE = Line of Evidence:

A.1 = Comparison of CTE and RME sediment tHg concentration to threshold effect and probable effect concentrations.

A.2 = Comparison of CTE and RME surface water tHg concentration to acute and chronic surface water criteria.

C.1 = Comparison of CTE and RME estimated daily doses of MeHg (tHg for tree swallows) to a NOAEL- and LOAEL-based bird TRV .

C.2 = Comparison of CTE and RME estimated daily doses of MeHg to a NOAEL- and LOAEL-based mammal TRV.

D.1 = Comparison of the CTE and RME wholebody crayfish tHg concentration to a no effect and effect tHg CBR.

D.2 = Comparison of the CTE and RME wholebody fish tHg concentration to a no effect and effect tHg CBR.

D.3 = Comparison of the CTE and RME bird egg tHg concentration to a no effect and effect tHg CBR.

D.4 = Comparison of the CTE and RME bird blood tHg concentration to a no effect and effect tHg CBR.

D.5 = Comparison of the CTE and RME feather tHg concentration to a no effect and effect tHg CBR.

D.6 = Comparison of the CTE and RME mink blood tHg concentration to a no effect and effect tHg CBR.

D.7 = Comparison of the CTE and RME tHg fur concentration to a no effect and effect tHg CBR.



Table 4-67

**Summary of Ecological Risk Associated with Mercury - Reach 7 Heard Pond  
Operable Unit IV - Nyanza Chemical Dump Superfund Site  
Middlesex County, Massachusetts**

Receptor Group/ Target Receptor (sampling year)	Lifestage or Size	Tissue Type	LOE <sup>a</sup>	WOE <sup>b</sup>	Reach 7- Heard Pond			Sudbury Reservoir Reference		
					Population Risk?	Confidence Level	Comment	Population Risk?	Confidence Level	Comment
<b>Benthic Invertebrates</b>										
generic	NA	NA	A.1	L/M	possible	high	sediment n = 4; all samples exceed both TEC and PEC; sediment benchmarks are not site-specific	possible	low/moderate	n = 6
<b>Fish<sup>c</sup></b>										
bullhead	D	whole fish	D.2	M/H	unlikely	high	n = 3	unlikely	high	n = 3
yellow perch	A	whole fish	D.2	M/H	unlikely	high	n = 13	unlikely	high	n = 6
	B	whole fish	D.2	M/H	unlikely	high	n = 13	unlikely	high	n = 13
	C	whole fish	D.2	M/H	unlikely	high	n = 13	unlikely	high	n = 13
	D	whole fish	D.2	M/H	unlikely	high	n = 3	unlikely	high	n = 3
largemouth bass	D	whole fish	D.2	M/H	unlikely	high	n = 3	unlikely	high	n = 2
<b>Birds</b>										
tree swallow	adult	NA	C.1	M	possible	high	RME/no effect HQ = 4.1; RME/effect HQ = 2.0; conservative modeling assumptions used, including adult insect prey concentrations estimated from sediment to larval insect regressions, assuming 100% of prey affected by mercury in Sudbury River, 100% bioavailability, and the use of a conservative, generic TRV	unlikely	high	
tree swallow (2004)	adult	blood	D.4	M/H	possible	moderate	n = 19; if median used as CTE, results would be "possible/low"; if 95% UCL used as RME, results would be "possible/low-moderate"; if median/95% UCL combined used, results = "unlikely/high"	--	--	no data
tree swallow (2004)	NA	egg	D.3	M/H	unlikely	high	n = 22	--	--	no data
tree swallow (2004)	adult	feather	D.5	M/H	possible	low/moderate	n = 20	--	--	no data
song sparrow (2004)	adult	blood	D.4	M	unlikely	high	n = 5	--	--	no data
swamp sparrow (2004)	adult	blood	D.4	M	unlikely	high	n = 7	--	--	no data
belted kingfisher	adult	NA	C.1	M	unlikely	high		unlikely	high	
great blue heron	adult	NA	C.1	M	unlikely	high		unlikely	high	
<b>Mammals</b>										
mink	adult	NA	C.2	M/H	unlikely	high		unlikely	high	

CBR = Critical body residue

CTE = Central tendency exposure (arithmetic mean)

HQ = Hazard quotient

LOAEL = Lowest-observable-adverse-effect-level

NA = Not applicable

NOAEL = No-observable-adverse-effect-level

RME = Reasonable maximum exposure (maximum for all but food chain modeling, where the lower of the maximum and 95% UCL was used)

tHg = Total mercury

TRV = Toxicity reference value

**Notes:**

Unlikely = Adverse population-level effects are unlikely to the receptors represented by the measurement endpoint.

Possible = There is a potential for adverse population-level effects to the receptors represented by the measurement endpoint.

<sup>b</sup>Endpoint Weight:

L = Low

L-M = Low /Moderate

M = Moderate

M-H = Moderate/High

H = High

<sup>c</sup>Fish Size Classes:

Size A = ≤ 10 cm

Size B = 10 &lt; x ≤ 15 cm

Size C = 15 &lt; x ≤ 20 cm

Size D = &gt; 20 cm

Table 4-67

**Summary of Ecological Risk Associated with Mercury - Reach 7 Heard Pond  
Operable Unit IV - Nyanza Chemical Dump Superfund Site  
Middlesex County, Massachusetts**

Receptor Group/ Target Receptor (sampling year)	Lifestage or Size	Tissue Type	LOE <sup>a</sup>	WOE <sup>b</sup>	Reach 7- Heard Pond			Sudbury Reservoir Reference		
					Population Risk?	Confidence Level	Comment	Population Risk?	Confidence Level	Comment

Red highlighting indicates that risk of adverse effects is possible, with relatively high confidence only for the particular measurement endpoint, but does not account for the weight given to that measure of risk in the BERA. Other measures of potential risk for the same receptors may not support this conclusion, and remedial action decisions are based on the weight-of-evidence for all measurement endpoints for each ecological receptor.

Mercury levels in bird blood and eggs are indicative of recent (site-specific) exposure to mercury. Mercury concentrations in bird feathers reflect more long-term exposures; therefore, may not be as strongly associated with site-related exposures or potential effects.

<sup>a</sup>LOE = Line of Evidence:

- A.1 = Comparison of CTE and RME sediment tHg concentration to threshold effect and probable effect concentrations.
- C.1 = Comparison of CTE and RME estimated daily doses of MeHg (tHg for tree swallows) to a NOAEL- and LOAEL-based bird TRV .
- C.2 = Comparison of CTE and RME estimated daily doses of MeHg to a NOAEL- and LOAEL-based mammal TRV.
- D.2 = Comparison of the CTE and RME wholebody fish tHg concentration to a no effect and effect tHg CBR.
- D.3 = Comparison of the CTE and RME bird egg tHg concentration to a no effect and effect tHg CBR.
- D.4 = Comparison of the CTE and RME bird blood tHg concentration to a no effect and effect tHg CBR.
- D.5 = Comparison of the CTE and RME feather tHg concentration to a no effect and effect tHg CBR.

Table 4-68

**Summary of Ecological Risk Associated with Mercury - Reach 8  
Operable Unit IV - Nyanza Chemical Dump Superfund Site  
Middlesex County, Massachusetts**

Receptor Group/ Target Receptor (sampling year)	Lifestage or Size Class	Tissue Type	LOE <sup>a</sup>	Endpoint Weight <sup>b</sup>	Reach 8			Charles River Reference (except when otherwise noted)		
					Population Risk?	Confidence Level	Comment	Population Risk?	Confidence Level	Comment
<b><i>Benthic Invertebrates</i></b>										
generic	NA	NA	A.1	L/M	possible	moderate	sediment n = 13; 8 samples above TEC and 1 sample above PEC; sediment benchmarks are not site-specific	possible	low/moderate	n = 7
mayfly (July 1994)	juvenile	whole flies	B.1	M/H	unlikely	moderate	sediment n = 6	unlikely possible	high low	Reach 1; n = 6 Whitehall Reservoir; n = 6
mayfly (September 1994)	juvenile	whole flies	B.1	M/H	unlikely	moderate	sediment n = 6	unlikely possible	high low	Reach 1; n = 6 Whitehall Reservoir; n = 6
<b><i>Fish<sup>c</sup></i></b>										
generic	NA	NA	A.2	L/M	unlikely	high	surface water n = 14	unlikely	high	n = 16
sunfish	A	whole fish	D.2	M/H	unlikely	high	n = 34	unlikely	high	n = 12
	B	whole fish	D.2	M/H	unlikely	high	n = 6	--	--	no data
	C	whole fish	D.2	M/H	unlikely	high	n = 5	--	--	no data
bullhead	D	whole fish	D.2	M/H	unlikely	high	n = 6	unlikely	high	n = 3
yellow perch	A	whole fish	D.2	M/H	unlikely	high	n = 34	unlikely	high	12 sunfish from same size class used as surrogates
	B	whole fish	D.2	M/H	unlikely	high	n = 50	unlikely	high	n = 13
	C	whole fish	D.2	M/H	unlikely	high	n = 30	unlikely	high	n = 13
	D	whole fish	D.2	M/H	unlikely	high	n = 10	unlikely	high	n = 3
largemouth bass	D	whole fish	D.2	M/H	possible	moderate	n = 6; conservative generic CBR used, bass concentrations for > 20 cm only and impacts to smaller breeding fish and therefore, to entire bass population unknown.	unlikely	high	n = 3
<b><i>Birds</i></b>										
tree swallow	adult	NA	C.1	M	unlikely	high		unlikely	high	
tree swallow (2003)	adult	blood	D.4	M/H	unlikely	high	n = 16	unlikely	high	n = 15
tree swallows (2004)	adult	blood	D.4	M/H	possible	moderate	n =14; only one sample had concentrations greater than effect-based CBR	unlikely	high	n = 6
tree swallow (2003)	NA	egg	D.3	M/H	unlikely	high	n = 22	unlikely	high	n = 15
tree swallow (2004)	NA	egg	D.3	M/H	unlikely	high	n = 13	unlikely	high	n = 9
tree swallow (2003)	adult	feather	D.5	M/H	possible	low/moderate	n = 16; if median used as CTE, results would be ""unlikely/high"	unlikely	high	n = 16
tree swallows (2004)	adult	feather	D.5	M/H	possible	low/moderate	n = 14	possible	low/moderate	n = 6
eastern kingbird	NA	egg	D.3	L/M	unlikely	high	n = 8	unlikely	high	n = 5
redwing blackbird (2005)	adult	blood	D.4	M	possible	high	n = 10	--	--	no data
song sparrow (2003)	adult	blood	D.4	M	possible	moderate	n = 4; if median used as CTE, results would be "possible/low"	unlikely	high	n = 4
song sparrow (2004)	adult	blood	D.4	M	unlikely	high	n = 8	unlikely	high	n = 10

Table 4-68

**Summary of Ecological Risk Associated with Mercury - Reach 8  
Operable Unit IV - Nyanza Chemical Dump Superfund Site  
Middlesex County, Massachusetts**

Receptor Group/ Target Receptor (sampling year)	Lifestage or Size Class	Tissue Type	LOE <sup>a</sup>	Endpoint Weight <sup>b</sup>	Reach 8			Charles River Reference (except when otherwise noted)		
					Population Risk?	Confidence Level	Comment	Population Risk?	Confidence Level	Comment
swamp sparrow (2003)	adult	blood	D.4	M	possible	low	n = 5; if 95% UCL used as RME, results would be "unlikely/high"	unlikely	high	n = 6
swamp sparrow (2004)	adult	blood	D.4	M	unlikely	high	n = 8	--	--	no data
yellow throat (2003)	adult	blood	D.4	M	unlikely	high	n = 4	unlikely	high	n = 2
yellow warblers (2003)	adult	blood	D.4	M	unlikely	high	n = 2	unlikely	high	n = 4
song sparrow (2003)	adult	feather	D.5	M	possible	low/moderate	n = 5	possible	moderate	n = 4
swamp sparrow (2003)	adult	feather	D.5	M	possible	low/moderate	n = 5	possible	moderate	n = 6
yellow throat (2003)	adult	feather	D.5	M	possible	low/moderate	n = 3	possible	undetermined	n = 1
yellow warbler (2003)	adult	feather	D.5	M	possible	undetermined	n = 1; only feather sample of all "marsh birds" that had a concentration exceeding the effect-based CBR	possible	low/moderate	n = 4
wood duck (2003)	adult	blood	D.4	M/H	unlikely	high	n = 4	unlikely	high	Delaney Reservoir; n = 5
wood duck (2004)	adult	blood	D.4	M/H	unlikely	undetermined	n = 1	--	--	no data
wood duck (2003)	NA	egg	D.3	M/H	unlikely	high	n = 4	unlikely	high	Delaney Reservoir; n = 7
wood ducks (2004)	adult	feather	D.5	M/H	unlikely	undetermined	n = 1	--	--	no data
hooded merganser (2004)	adult	blood	D.4	M/H	unlikely	undetermined	n = 1	--	--	no data
hooded merganser (2005)	adult	blood	D.4	M/H	possible	low	n = 8; if 95% UCL used as RME, results would be "unlikely/high"	possible	high	n = 2
hooded merganser (2005)	NA	egg	D.3	M/H	possible	moderate	n = 21; only one sample had concentrations greater than the effect-based CBR	possible	high	n = 2
hooded merganser (2004)	adult	feather	D.5	M/H	possible	undetermined	n = 1	--	--	no data
hooded merganser (2005)	adult	feather	D.5	M/H	possible	low/moderate	n = 5	possible	undetermined	n = 1
belted kingfisher	adult	NA	C.1	M	possible	high	RME/no effect HQ = 2.4; RME/effect HQ = 1.2; conservative modeling assumptions used, including use of fish prey items only, using fish from size classes that include specimens of greater length (and; therefore, higher concentrations) than typically ingested; 100% bioavailability; assuming all prey comes from the Sudbury River when burrows were not located along banks but further upland, and the use of a conservative, generic TRV	possible	low/moderate	
belted kingfisher	nestling	blood	D.4	M	unlikely	high	n = 13 (2 nests; Transfer Station and Route 117 Pit)	--	--	no data
belted kingfisher	adult	blood	D.4	M	possible	low/moderate	Transfer Station Pit; n = 2 and Route 117 Pit; n = 3	unlikely	undetermined	Charles River; n = 1
					possible	low	Macone's Pile; n = 3	unlikely	high	Whitehall Reservoir; n = 2
belted kingfisher	NA	egg	D.3	M	unlikely	undetermined	Route 117 Pit; n = 1	--	--	no data
belted kingfisher	adult	feather	D.5	M	possible	undetermined	Transfer Station Pit; n = 1; burrows were not located along banks but further upland, actual source of prey not known	possible	undetermined	n = 1
					possible	low/moderate	Macone's Pile; n = 2			
					possible	moderate	Route 117 Pit; n = 2; burrows were not located along banks but further upland, actual source of prey not known			
great blue heron	adult	NA	C.1	M	unlikely	high		unlikely	high	

Table 4-68

**Summary of Ecological Risk Associated with Mercury - Reach 8  
Operable Unit IV - Nyanza Chemical Dump Superfund Site  
Middlesex County, Massachusetts**

Receptor Group/ Target Receptor (sampling year)	Lifestage or Size Class	Tissue Type	LOE <sup>a</sup>	Endpoint Weight <sup>b</sup>	Reach 8			Charles River Reference (except when otherwise noted)		
					Population Risk?	Confidence Level	Comment	Population Risk?	Confidence Level	Comment
Mammals										
mink	adult	NA	C.2	M/H	possible	high	RME/no effect HQ = 3.0; RME/effect HQ = 1.2; conservative modeling assumptions used, including assuming 100% of diet is aquatic and all mercury in diet is bioavailable	unlikely	high	

CBR = Critical body residue

CTE = Central tendency exposure (arithmetic mean)

HQ = Hazard quotient

LOAEL = Lowest-observable-adverse-effect-level

NA = Not applicable

NOAEL = No-observable-adverse-effect-level

RME = Reasonable maximum exposure (maximum for all but food chain modeling, where the lower of the maximum and 95% UCL was used)

tHg = Total mercury

TRV = Toxicity reference value

<sup>b</sup>Endpoint Weight:

L = Low

L-M = Low /Moderate

M = Moderate

M-H = Moderate/High

H = High

<sup>c</sup>Fish Size Classes:

Size A = ≤ 10 cm

Size B = 10 < x ≤ 15 cm

Size C = 15 < x ≤ 20 cm

Size D = > 20 cm

**Notes:**

Unlikely = Adverse population-level effects are unlikely to the receptors represented by the measurement endpoint

Possible = There is a potential for adverse population-level effects to the receptors represented by the measurement endpoint

Red highlighting indicates that risk of adverse effects is possible, with relatively high confidence only for the particular measurement endpoint, but does not account for the weight given to that measure of risk in the BERA. Other measures of potential risk for the same receptors may not support this conclusion, and remedial action decisions are based on the weight-of-evidence for all measurement endpoints for each ecological receptor.

Mercury levels in bird blood and eggs are indicative of recent (site-specific) exposure to mercury. Mercury concentrations in bird feathers reflect more long-term exposures; therefore, may be as strongly associated with site-related exposures or potential effects.

<sup>a</sup>LOE = Line of Evidence:

A.1 = Comparison of CTE and RME sediment tHg concentration to threshold effect and probable effect concentration

A.2 = Comparison of CTE and RME surface water tHg concentration to acute and chronic surface water criteria

B.1 = Laboratory toxicity testing.

B.2 = Field toxicity testing.

C.1 = Comparison of CTE and RME estimated daily doses of MeHg (tHg for tree swallows) to a NOAEL- and LOAEL-based bird TRV

C.2 = Comparison of CTE and RME estimated daily doses of MeHg to a NOAEL- and LOAEL-based mammal TRV

D.2 = Comparison of the CTE and RME wholebody fish tHg concentration to a no effect and effect tHg CBF

D.3 = Comparison of the CTE and RME bird egg tHg concentration to a no effect and effect tHg CBF

D.4 = Comparison of the CTE and RME bird blood tHg concentration to a no effect and effect tHg CBF

D.5 = Comparison of the CTE and RME feather tHg concentration to a no effect and effect tHg CBF

Table 4-69

**Summary of Ecological Risk Associated with Mercury - Reach 9  
Operable Unit IV - Nyanza Chemical Dump Superfund Site  
Middlesex County, Massachusetts**

Receptor Group/ Target Receptor (sampling year)	Lifestage or Size	Tissue Type	LOE <sup>a</sup>	WOE <sup>b</sup>	Reach 9			Charles River Reference (except when otherwise noted)		
					Population Risk?	Confidence Level	Comment	Population Risk?	Confidence Level	Comment
<b><i>Benthic Invertebrates</i></b>										
generic	NA	NA	A.1	L/M	possible	high	sediment n = 10; 10 samples above TEC and 7 samples above PEC; sediment benchmarks are not site-specific	possible	low/moderate	n = 7
mayfly (July 1994)	juvenile	whole flies	B.1	M/H	unlikely	moderate	sediment n = 6	unlikely	high	Reach 1; n = 6
mayfly (September 1994)	juvenile	whole flies	B.1	M/H	unlikely	moderate	sediment n = 6	possible	low	Reservoir; n = 6
								unlikely	high	Reach 1; n = 6
								possible	low	Reservoir; n = 6
mayfly (May 1995)	juvenile	whole flies	B.1	M/H	unlikely	moderate	sediment n = 9	unlikely	high	Hop Brook Wetland; n = 9
mayfly (September 1995)	juvenile	whole flies	B.1	M/H	unlikely	moderate	sediment n = 9	unlikely	high	Hop Brook Wetland; n = 9
<i>Elliptio</i> mussel	adult	whole mussel	B.2	M/H	unlikely	moderate	used as reference area; high Hg in mussels at start of test, high mortality and poor growth in reference mussels, variable flow and habitat conditions across reaches	---	---	
<b><i>Fish<sup>c</sup></i></b>										
sunfish	A	whole fish	D.2	M/H	unlikely	high	n = 7	unlikely	high	n = 12
	B	whole fish	D.2	M/H	unlikely	high	n = 7	--	--	no data
bullhead	D	whole fish	D.2	M/H	unlikely	high	n = 3	unlikely	high	n = 3
yellow perch	B	whole fish	D.2	M/H	unlikely	high	n = 4	unlikely	high	n = 13
	C	whole fish	D.2	M/H	unlikely	high	n = 13	unlikely	high	n = 13
	D	whole fish	D.2	M/H	unlikely	high	n = 3	unlikely	high	n = 3
largemouth bass	D	whole fish	D.2	M/H	possible	moderate	n = 3; conservative generic CBR used, bass concentrations for > 20 cm only and impacts to smaller breeding fish and therefore, to entire bass population	unlikely	high	n = 3
<b><i>Birds</i></b>										
tree swallow	adult	NA	C.1	M	possible	moderate	RME/no effect HQ = 2.2; RME/effect HQ = 1.1; conservative modeling assumptions used, including adult insect prey concentrations estimated from sediment to larval insect regressions, assuming 100% of prey affected by mercury in Sudbury River, 100% bioavailability, and the use of a conservative, generic TRV	unlikely	high	
eastern kingbird	NA	egg	D.3	L/M	unlikely	high	n = 2	unlikely	high	n = 5

Table 4-69

**Summary of Ecological Risk Associated with Mercury - Reach 9  
Operable Unit IV - Nyanza Chemical Dump Superfund Site  
Middlesex County, Massachusetts**

Receptor Group/ Target Receptor (sampling year)	Lifestage or Size	Tissue Type	LOE <sup>a</sup>	WOE <sup>b</sup>	Reach 9			Charles River Reference (except when otherwise noted)		
					Population Risk?	Confidence Level	Comment	Population Risk?	Confidence Level	Comment
belted kingfisher	adult	NA	C.1	M	possible	high	RME/no effect HQ = 2.5; RME/effect HQ = 1.2; conservative modeling assumptions used, including use of fish prey items only, using fish from size classes that include specimens of greater length (and; therefore, higher concentrations) than typically ingested; 100% bioavailability; assuming all prey comes from the Sudbury River when burrows were not located along banks but further upland, and the use of a conservative, generic TRV	possible	low/moderate	
great blue heron	adult	NA	C.1	M	unlikely	high		unlikely	high	
<b>Mammals</b>										
mink	adult	NA	C.2	M/H	possible	high	RME/no effect HQ = 3.8; RME/effect HQ = 1.5; conservative modeling assumptions used, including assuming 100% of diet is aquatic and all mercury in diet is bioavailable	unlikely	high	

CBR = Critical body residue

CTE = Central tendency exposure (arithmetic mean)

HQ = Hazard quotient

LOAEL = Lowest-observable-adverse-effect-level

NA = Not applicable

NOAEL = No-observable-adverse-effect-level

RME = Reasonable maximum exposure (maximum for all but food chain modeling, where the lower of the maximum and 95% UCL was used)

tHg = Total mercury

TRV = Toxicity reference value

**Notes:**

Unlikely = Adverse population-level effects are unlikely to the receptors represented by the measurement endpoint.

Possible = There is a potential for adverse population-level effects to the receptors represented by the measurement endpoint.

Red highlighting indicates that risk of adverse effects is possible, with relatively high confidence only for the particular measurement endpoint, but does not account for the weight given to that measure of risk in the BERA. Other measures of potential risk for the same receptors may not support this conclusion, and remedial action decisions are based on the weight-of-evidence for all measurement endpoints for each ecological receptor.

Mercury levels in bird blood and eggs are indicative of recent (site-specific) exposure to mercury. Mercury concentrations in bird feathers reflect more long-term exposures; therefore, may not be as strongly associated with site-related exposures or potential effects.

<sup>a</sup>LOE = Line of Evidence:

A.1 = Comparison of CTE and RME sediment tHg concentration to threshold effect and probable effect concentrations.

B.1 = Laboratory toxicity testing.

C.1 = Comparison of CTE and RME estimated daily doses of MeHg (tHg for tree swallows) to a NOAEL- and LOAEL-based bird TRV.

C.2 = Comparison of CTE and RME estimated daily doses of MeHg to a NOAEL- and LOAEL-based mammal TRV.

D.2 = Comparison of the CTE and RME wholebody fish tHg concentration to a no effect and effect tHg CBR.

D.3 = Comparison of the CTE and RME bird egg tHg concentration to a no effect and effect tHg CBR.

<sup>b</sup>Endpoint Weight:

L = Low

L-M = Low /Moderate

M = Moderate

M-H = Moderate/High

H = High

<sup>c</sup>Fish Size Classes:

Size A = ≤ 10 cm

Size B = 10 &lt; x ≤ 15 cm

Size C = 15 &lt; x ≤ 20 cm

Size D = &gt;20 cm

Table 4-70

**Summary of Ecological Risk Associated with Mercury - Reach 10**  
**Operable Unit IV - Nyanza Chemical Dump Superfund Site**  
**Middlesex County, Massachusetts**

Receptor Group/ Target Receptor (sampling year)	Lifestage or Size	Tissue Type	LOE <sup>1</sup>	WOE <sup>2</sup>	Reach 10			Reach 1 Reference (except when noted otherwise)		
					Population Risk?	Confidence Level	Comment	Population Risk?	Confidence Level	Comment
<b><i>Benthic Invertebrates</i></b>										
generic	NA	NA	A.1	L/M	possible	moderate	sediment n = 10; 7 samples above TEC and 2 samples above PEC; sediment benchmarks are not site-specific	possible	moderate	n = 5
<i>Elliptio</i> mussel	adult	whole mussel	B.2	M/H	unlikely	moderate	used as reference area; high Hg in mussels at start of test, high mortality and poor growth in reference mussels, variable flow and habitat conditions across reaches	---	---	no data
<b><i>Fish<sup>c</sup></i></b>										
sunfish	A	whole fish	D.2	M/H	unlikely	high	n = 12	unlikely	high	n = 11
bullhead	D	whole fish	D.2	M/H	unlikely	high	n = 3	unlikely	high	n = 2
yellow perch	A	whole fish	D.2	M/H	possible	undetermined	n = 12	unlikely	high	11 sunfish from same size class
	B	whole fish	D.2	M/H	unlikely	high	n = 13	unlikely	high	10 sunfish from same size class
	C	whole fish	D.2	M/H	unlikely	high	n = 13	unlikely	high	n = 5
	D	whole fish	D.2	M/H	unlikely	high	n = 3	unlikely	high	n = 3
largemouth bass	D	whole fish	D.2	M/H	possible	high	n = 3; conservative generic CBR used, bass concentrations for > 20 cm only and impacts to smaller breeding fish and therefore, to entire bass population	unlikely	high	n = 3
<b><i>Birds</i></b>										
tree swallow	adult	NA	C.1	M	possible	low/moderate		possible	moderate	RME/no effect HQ = 4.3; RME/effect HQ = 2.2
eastern kingbird	NA	egg	D.3	L/M	unlikely	high	n = 6	unlikely	high	Charles River; n = 5
belted kingfisher	adult	NA	C.1	M	possible	high	RME/no effect HQ = 2.8; RME/effect HQ = 1.4; conservative modeling assumptions used, including use of fish prey items only, using fish from size classes that include specimens of greater length (and; therefore, higher concentrations) than typically ingested; 100% bioavailability; assuming all prey comes from the Sudbury River when burrows were not located along banks but further upland, and the use of a conservative, generic TRV	possible	low/moderate	
great blue heron	adult	NA	C.1	M	possible	low/moderate		unlikely	high	



Table 4-70

**Summary of Ecological Risk Associated with Mercury - Reach 10**  
**Operable Unit IV - Nyanza Chemical Dump Superfund Site**  
**Middlesex County, Massachusetts**

Receptor Group/ Target Receptor (sampling year)	Lifestage or Size	Tissue Type	LOE <sup>1</sup>	WOE <sup>2</sup>	Reach 10			Reach 1 Reference (except when noted otherwise)		
					Population Risk?	Confidence Level	Comment	Population Risk?	Confidence Level	Comment
Mammals										
mink	adult	NA	C.2	M/H	possible	high	RME/no effect HQ = 4.6; RME/effect HQ = 1.9; conservative modeling assumptions used, including assuming 100% of diet is aquatic and all mercury in diet is bioavailable	unlikely	high	

CBR = Critical body residue

CTE = Central tendency exposure (arithmetic mean)

HQ = Hazard quotient

LOAEL = Lowest-observable-adverse-effect-level

NA = Not applicable

NOAEL = No-observable-adverse-effect-level

RME = Reasonable maximum exposure (maximum for all but food chain modeling, where the lower of the maximum and 95% UCL was used)

tHg = Total mercury

TRV = Toxicity reference value

**Notes:**

Unlikely = Adverse population-level effects are unlikely to the receptors represented by the measurement endpoint.

Possible = There is a potential for adverse population-level effects to the receptors represented by the measurement endpoint.

Red highlighting indicates that risk of adverse effects is possible, with relatively high confidence only for the particular measurement endpoint, but does not account for the weight given to that measure of risk in the BERA. Other measures of potential risk for the same receptors may not support this conclusion, and remedial action decisions are based on the weight-of-evidence for all measurement endpoints for each ecological receptor.

Mercury levels in bird blood and eggs are indicative of recent (site-specific) exposure to mercury. Mercury concentrations in bird feathers reflect more long-term exposures; therefore, may not be as strongly associated with site-related exposures or potential effects.

<sup>a</sup>LOE = Line of Evidence:

A.1 = Comparison of CTE and RME sediment tHg concentration to threshold effect and probable effect concentrations.

C.1 = Comparison of CTE and RME estimated daily doses of MeHg (tHg for tree swallows) to a NOAEL- and LOAEL-based bird TRV.

C.2 = Comparison of CTE and RME estimated daily doses of MeHg to a NOAEL- and LOAEL-based mammal TRV.

D.2 = Comparison of the CTE and RME wholebody fish tHg concentration to a no effect and effect tHg CBR.

D.3 = Comparison of the CTE and RME bird egg tHg concentration to a no effect and effect tHg CBR.

<sup>b</sup>Endpoint Weight:

L = Low

L-M = Low /Moderate

M = Moderate

M-H = Moderate/High

H = High

<sup>c</sup>Fish Size Classes:

Size A = ≤ 10 cm

Size B = 10< x ≤15 cm

Size C = 15< x ≤20 cm

Size D = >20 cm

Table 4-71

**Incremental Risk for Endpoints with Results Indicating Risk Scenarios 5 or 6<sup>a</sup>**  
**Operable Unit IV - Nyanza Chemical Dump Superfund Site**  
**Middlesex County, Massachusetts**

Receptor/Reach	Mercury Form	Matched Reference Location	Medium or Exposure	Hazard Quotients								Incremental Risk <sup>b</sup>			
				Site				Reference				NOAEL			
				NOAEL		LOAEL		NOAEL		LOAEL		NOAEL		LOAEL	
				RME	CTE	RME	CTE	RME	CTE	RME	CTE	RME	CTE	RME	CTE
<b>Benthic Invertebrates</b>															
Reach 2	tHg	Reach 1	sediment	53.61	11.28	9.10	1.92	17.50	4.68	2.97	0.80	36.1	6.6	6.1	1.1
Reach 3	tHg	Sudbury Reservoir	sediment	249.44	83.33	42.36	14.15	2.23	1.11	0.38	0.19	247.2	82.2	42.0	14.0
Reach 4	tHg	Sudbury Reservoir	sediment	86.67	36.61	14.72	6.22	2.23	1.11	0.38	0.19	84.4	35.5	14.3	6.0
Reach 5	tHg	Reach 1	sediment	17.78	5.83	3.02	0.99	17.50	4.68	2.97	0.80	<1	1.2	<1	<1
Reach 6	tHg	Sudbury Reservoir	sediment	54.22	14.06	9.21	2.39	2.23	1.11	0.38	0.19	52.0	13.0	8.8	2.2
Reach 7	tHg	Reach 1	sediment	8.61	1.64	1.46	0.28	17.50	4.68	2.97	0.80	<1	<1	<1	<1
Reach 7-Heard Pond	tHg	Sudbury Reservoir	sediment	16.67	13.89	2.83	2.36	2.23	1.11	0.38	0.19	14.4	12.8	2.5	2.2
Reach 8	tHg	Charles River	sediment	6.61	2.63	1.12	0.45	1.89	1.32	0.32	0.22	4.7	1.3	<1	<1
Reach 9	tHg	Charles River	sediment	10.56	6.72	1.79	1.14	1.89	1.32	0.32	0.22	8.7	5.4	1.5	<1
Reach 10	tHg	Reach 1	sediment	8.39	2.97	1.42	0.50	17.50	4.68	2.97	0.80	<1	<1	<1	<1
<b>Tree Swallows</b>															
Reach 2	tHg	Reach 1	food chain modeling	7.29	2.89	3.68	1.46	4.30	1.41	2.17	0.71	3.0	1.5	1.5	<1
Reach 3	tHg	Sudbury Reservoir	food chain modeling	24.20	19.20	12.20	9.69	0.74	0.60	0.37	0.30	23.5	18.6	11.8	9.4
Reach 4	tHg	Sudbury Reservoir	food chain modeling	11.80	8.06	5.96	4.35	0.74	0.60	0.37	0.30	11.1	7.5	5.6	4.0
Reach 5	tHg	Reach 1	food chain modeling	2.20	1.59	1.11	0.81	4.30	1.41	2.17	0.71	<1	<1	<1	<1
Reach 6	tHg	Sudbury Reservoir	food chain modeling	6.17	3.52	3.12	1.78	0.74	0.60	0.37	0.30	5.4	2.9	2.7	1.5
Reach 7-Heard Pond	tHg	Sudbury Reservoir	food chain modeling	4.05	3.48	2.04	1.76	0.74	0.60	0.37	0.30	3.3	2.9	1.7	1.5
Reach 7-Heard Pond	tHg	Sudbury Reservoir	adult blood-2004	2.15	1.05	1.03	0.50	NA	NA	NA	NA	---c	---c	---c	---c
Reach 8	tHg	Charles River	adult blood-2004	2.18	1.15	1.05	0.55	0.92	0.68	0.44	0.32	1.3	<1	<1	<1
Reach 9	tHg	Charles River	food chain modeling	2.17	1.87	1.10	0.94	0.71	0.65	0.36	0.33	1.5	1.2	<1	<1
<b>Belted Kingfisher</b>															
Reach 2	MeHg	Reach 1	food chain modeling	2.30	2.04	1.16	1.03	1.48	1.27	0.75	0.64	<1	<1	<1	<1
Reach 3	MeHg	Sudbury Reservoir	food chain modeling	2.40	2.08	1.21	1.05	0.38	0.33	0.19	0.16	2.0	1.8	1.0	<1
Reach 4	MeHg	Sudbury Reservoir	food chain modeling	2.04	1.78	1.03	0.90	0.38	0.33	0.19	0.16	1.7	1.5	<1	<1
Reach 5	MeHg	Reach 1	food chain modeling	2.25	2.10	1.14	1.05	1.48	1.27	0.75	0.64	<1	<1	<1	<1
Reach 7	MeHg	Reach 1	food chain modeling	2.14	1.80	1.08	0.91	1.48	1.27	0.75	0.64	<1	<1	<1	<1
Reach 8	MeHg	Charles River	food chain modeling	2.35	2.25	1.19	1.14	1.36	1.27	0.69	0.64	<1	<1	<1	<1
Reach 8 - Transfer Station Pit	tHg	Charles River	adult feather	10.25	10.25	1.36	1.36	5.93	5.93	0.79	0.79	4.3	4.3	<1	<1
Reach 8 - Route 117 Pit	tHg	Charles River	adult feather	8.93	6.11	1.19	0.81	5.93	5.93	0.79	0.79	3.0	<1	<1	<1
Reach 9	MeHg	Charles River	food chain modeling	2.45	2.19	1.24	1.11	1.36	1.27	0.69	0.64	1.1	<1	<1	<1
Reach 10	MeHg	Reach 1	food chain modeling	2.81	2.55	1.42	1.29	1.48	1.27	0.75	0.64	1.3	1.3	<1	<1
<b>Hooded Merganser</b>															
Reach 8	tHg	Charles River	egg (2005)	3.90	1.43	1.95	0.71	4.84	3.16	2.42	1.58	<1	<1	<1	<1
<b>Red-winged Blackbird</b>															
Reach 8	tHg	Charles River	adult blood (2005)	15.70	6.77	7.54	3.25	NA	NA	NA	NA	---c	---c	---c	---c
<b>Song Sparrow</b>															
Reach 8	tHg	Charles River	adult blood (2003)	2.23	1.10	1.07	0.53	0.69	0.57	0.33	0.27	1.5	<1	<1	<1
<b>Yellow Warbler</b>															
Reach 8	tHg	Charles River	adult feather (2003)	9.67	9.67	1.29	1.29	7.33	2.90	0.97	0.39	2.3	6.8	<1	<1
<b>Mink</b>															
Reach 3	tHg	Sudbury Reservoir	fur	7.60	7.60	3.08	3.08	NA	NA	NA	NA	---c	---c	---c	---c
Reach 8	MeHg	Charles River	food chain modeling	3.04	2.63	1.22	1.05	1.04	0.89	0.42	0.36	2.0	1.7	<1	<1
Reach 9	MeHg	Charles River	food chain modeling	3.80	2.95	1.52	1.18	1.04	0.89	0.42	0.36	2.8	2.1	1.1	<1
Reach 10	MeHg	Reach 1	food chain modeling	4.64	3.33	1.86	1.33	1.08	0.90	0.43	0.36	3.6	2.4	1.4	<1
<b>Largemouth Bass</b>															
Reach 8	tHg	Charles River	whole fish	2.97	1.98	1.15	0.77	1.09	0.88	0.42	0.34	1.9	1.1	<1	<1
Reach 9	tHg	Charles River	whole fish	3.34	2.46	1.30	0.95	1.09	0.88	0.42	0.34	2.3	1.6	<1	<1
Reach 10	tHg	Reach 1	whole fish	3.34	2.76	1.30	1.07	0.67	0.59	0.26	0.23	2.7	2.2	1.0	<1

**Interpretive Ecological Risk Matrix**

Risk Scenario	RME Case	CTE Case	Population Risk?	Confidence Level
5	N>1 & L>1	N>1 & L<1	possible	moderate
6	N>1 & L>1	N>1 & L>1	possible	high

CTE - Central tendency exposure

MeHg = Methylmercury

NA - Not available

RME - Reasonable maximum exposure

tHg = Total mercury

Sediment benchmark Hg NOAEL = 0.18 mg/kg; LOAEL = 1.06 mg/kg

Fish CBR NOAEL = 380 µg/kg; LOAEL = 980 µg/kg

Bird blood CBR NOAEL = 600 µg/kg; LOAEL = 1,250 µg/kg

Bird feather CBR NOAEL = 1,200 µg/kg; LOAEL = 9,100 µg/kg

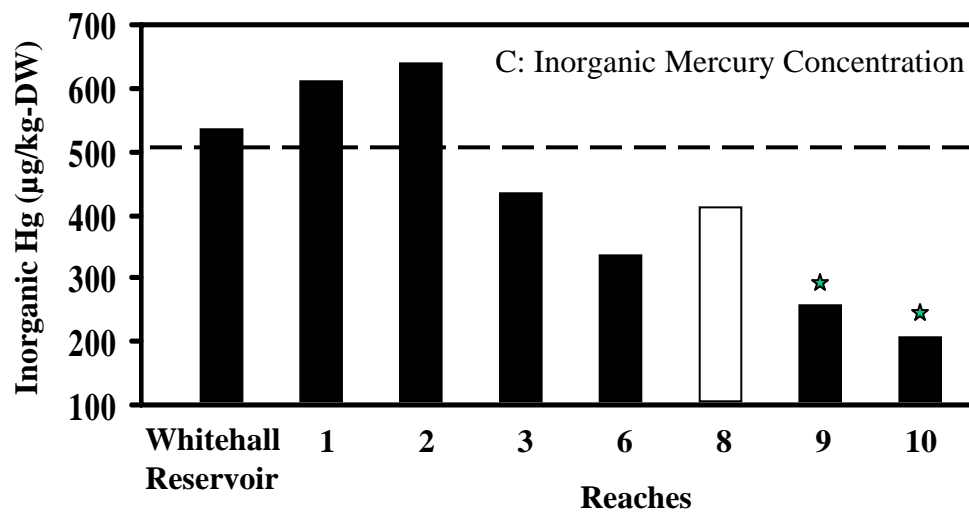
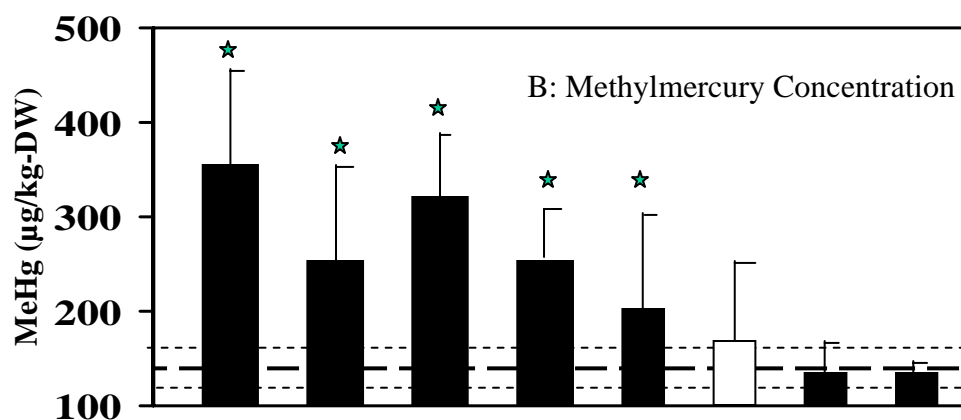
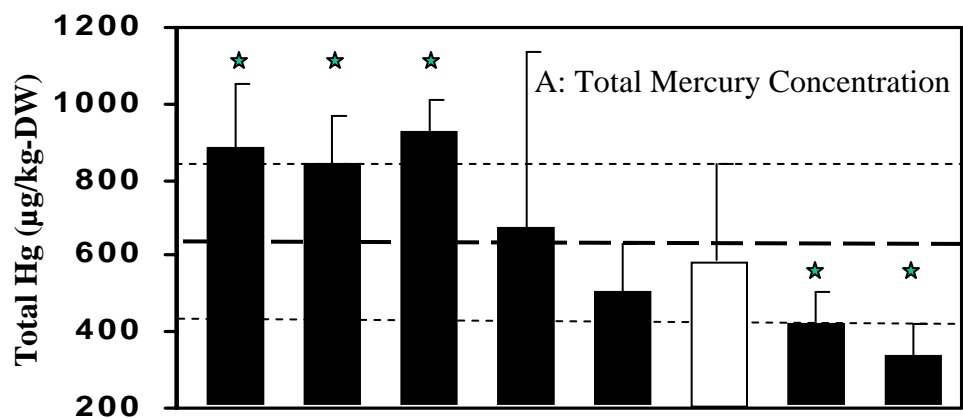
Bird egg (generic) CBR NOAEL = 500 µg/kg; LOAEL = 1,000 µg/kg

Mink fur CBR NOAEL = 7,700 µg/kg; LOAEL = 19,000 µg/kg

<sup>b</sup>The incremental risk is the hazard quotient for the Site minus the hazard quotient for the matched reference location.<sup>c</sup>--- = IR could not be calculated because reference data not available.

Red highlighting indicates that risk of adverse effects is possible, with relatively high confidence only for the particular measurement endpoint, but does not account for the weight given to that measure of risk in the BERA. Other measures of potential risk for the same receptors may not support this conclusion, and remedial action decisions are based on the weight-of-evidence for all measurement endpoints for each ecological receptor.

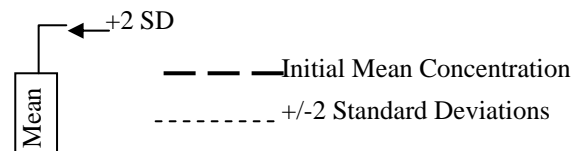
## SECTION 4 FIGURES



**Legend**

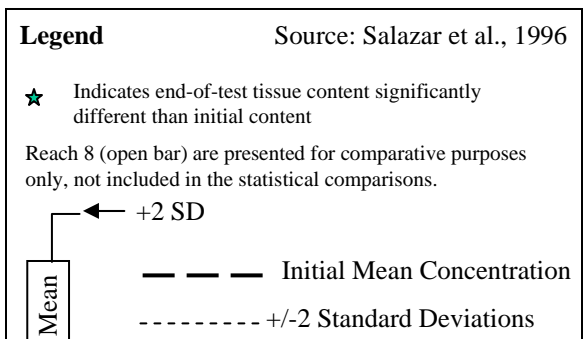
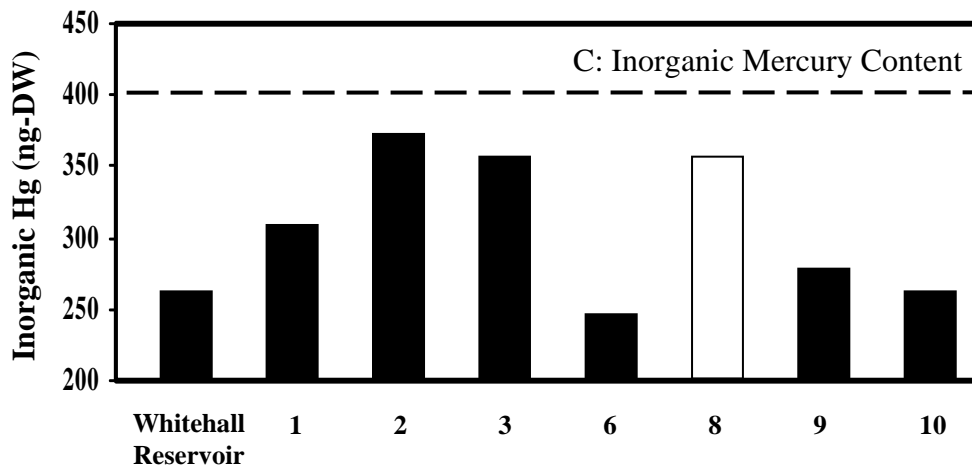
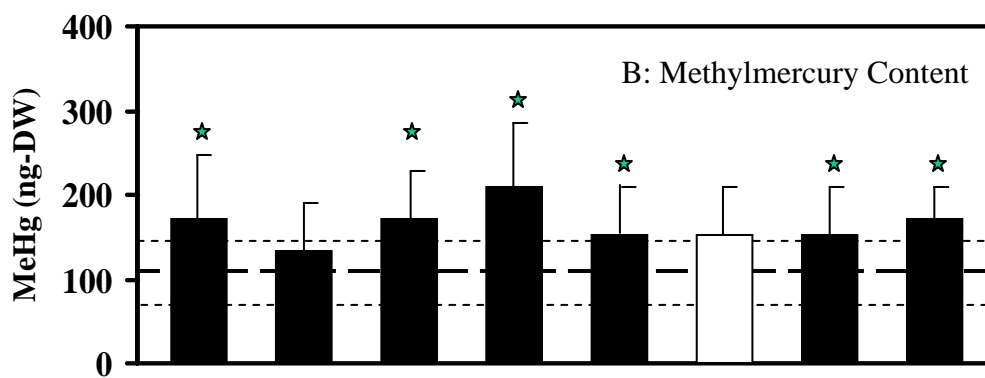
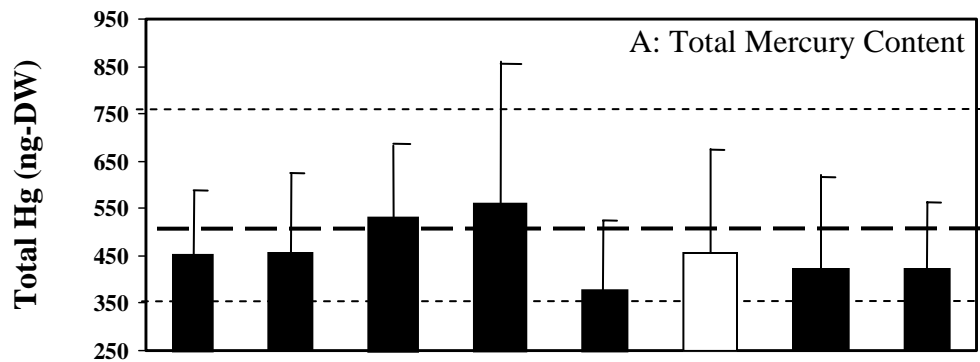
★ Indicates end-of-test tissue concentration significantly different than initial concentration

Reach 8 (open bar) are presented for comparative purposes only, not included in the statistical comparisons.



**Nyanza Superfund Site OU IV  
Sudbury River Mercury Contamination**

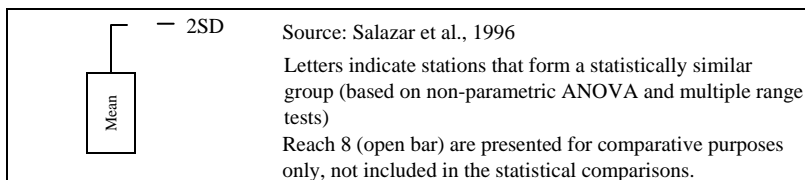
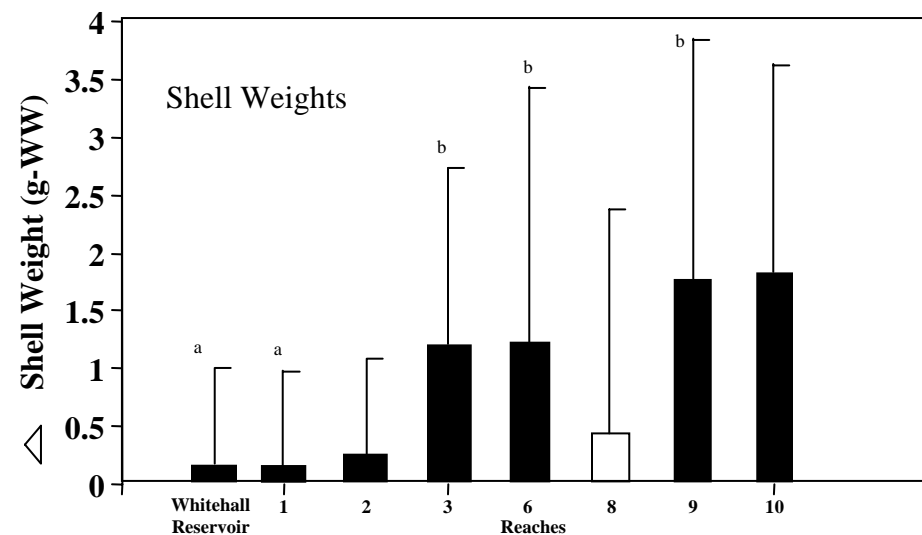
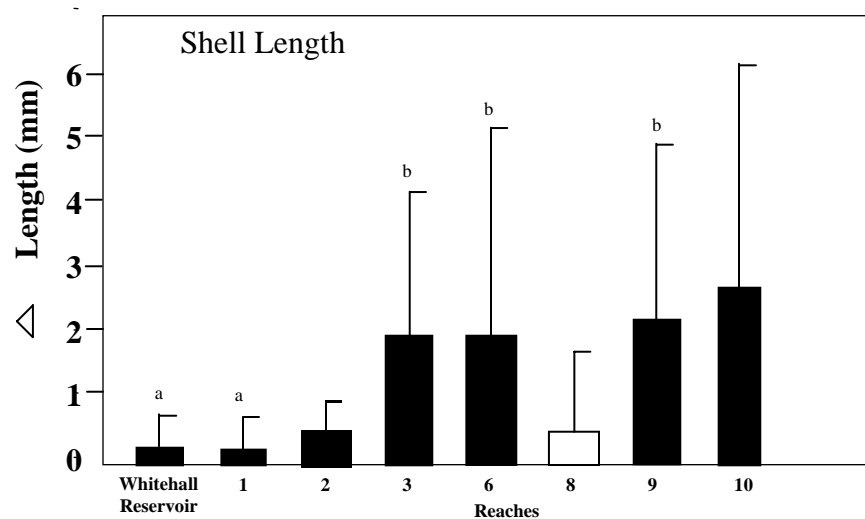
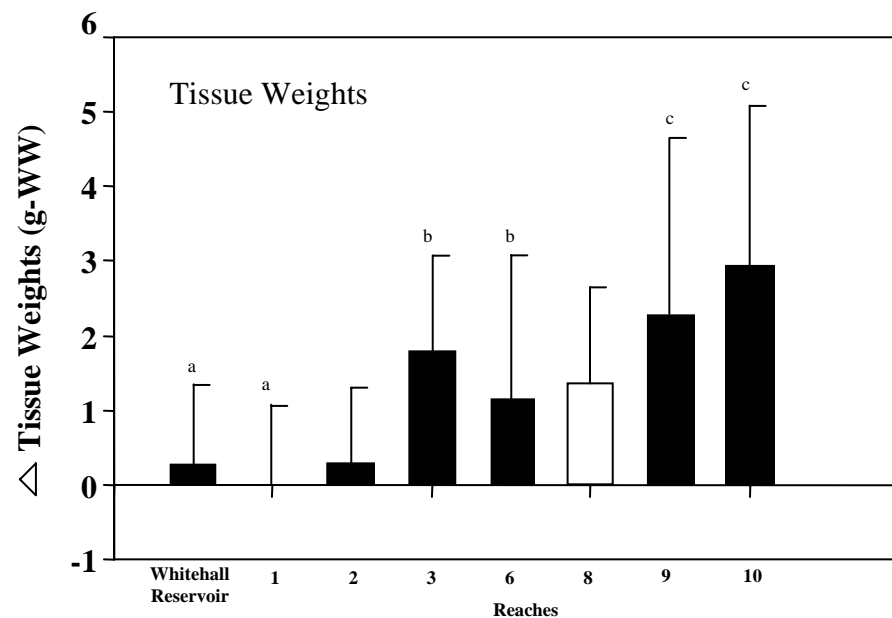
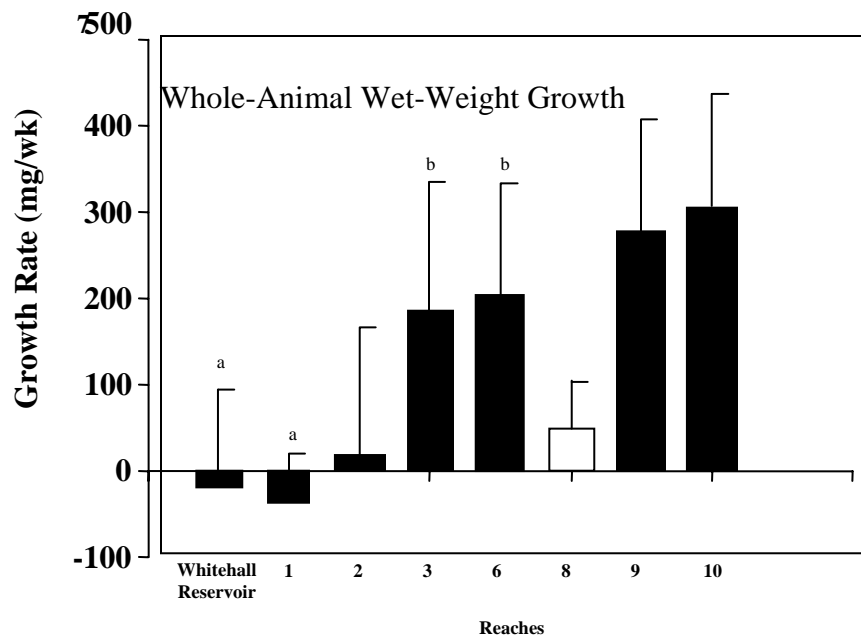
**Figure 4-1  
Initial and End of Test Mussel Tissue  
Concentration**



Reaches

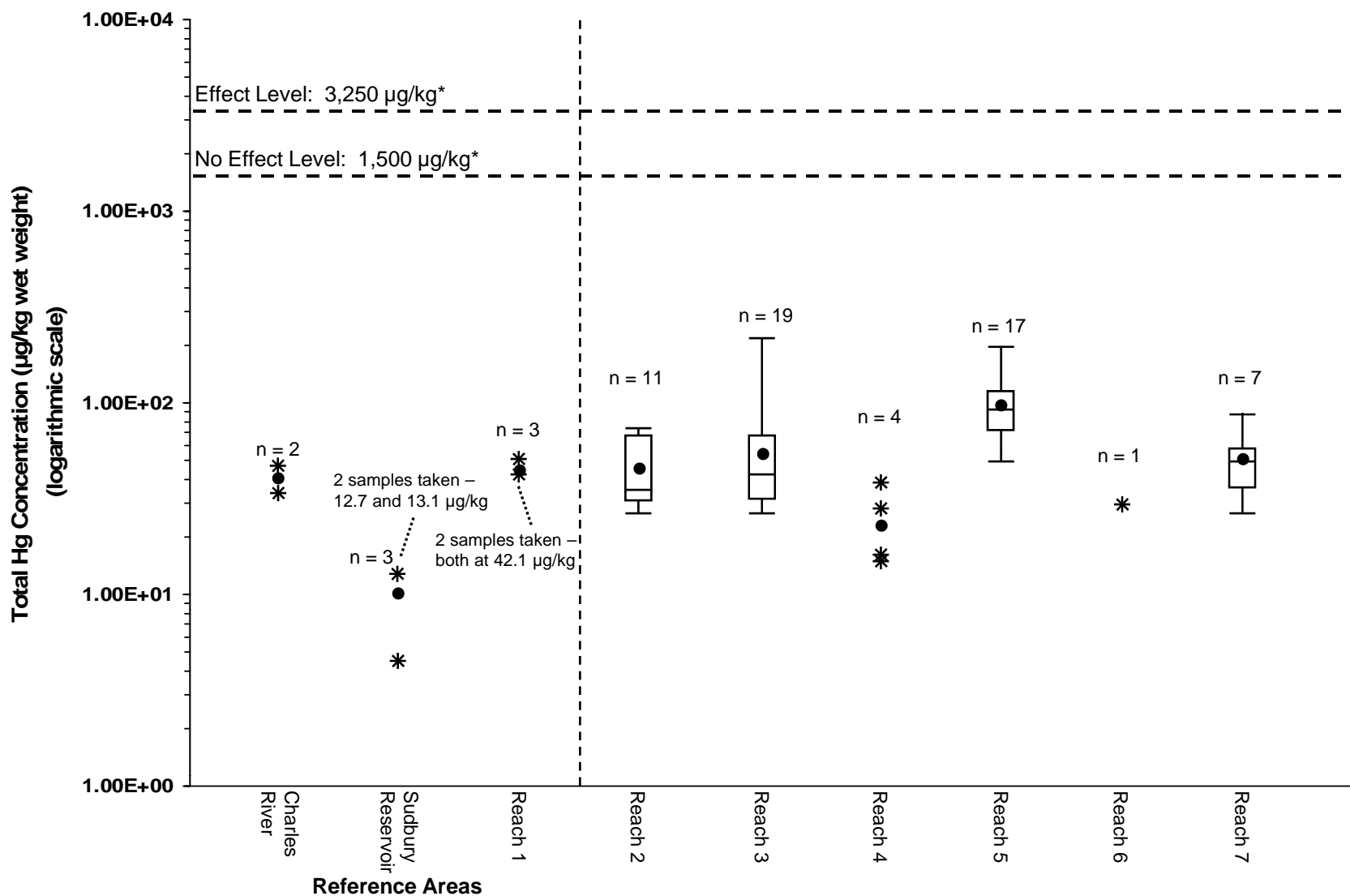
**Nyanza Superfund Site OU IV  
Sudbury River Mercury Contamination**

**Figure 4-2  
Initial and End of Test Mussel Tissue  
Contents**



**Nyanza Superfund Site OU IV  
Sudbury River Mercury Contamination**

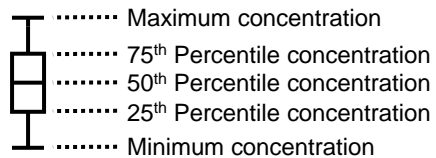
**Figure 4-3  
Mussel Growth Parameters**



#### Legend:

\* - Whole body crayfish sample  
(includes individual whole body and  
composites)

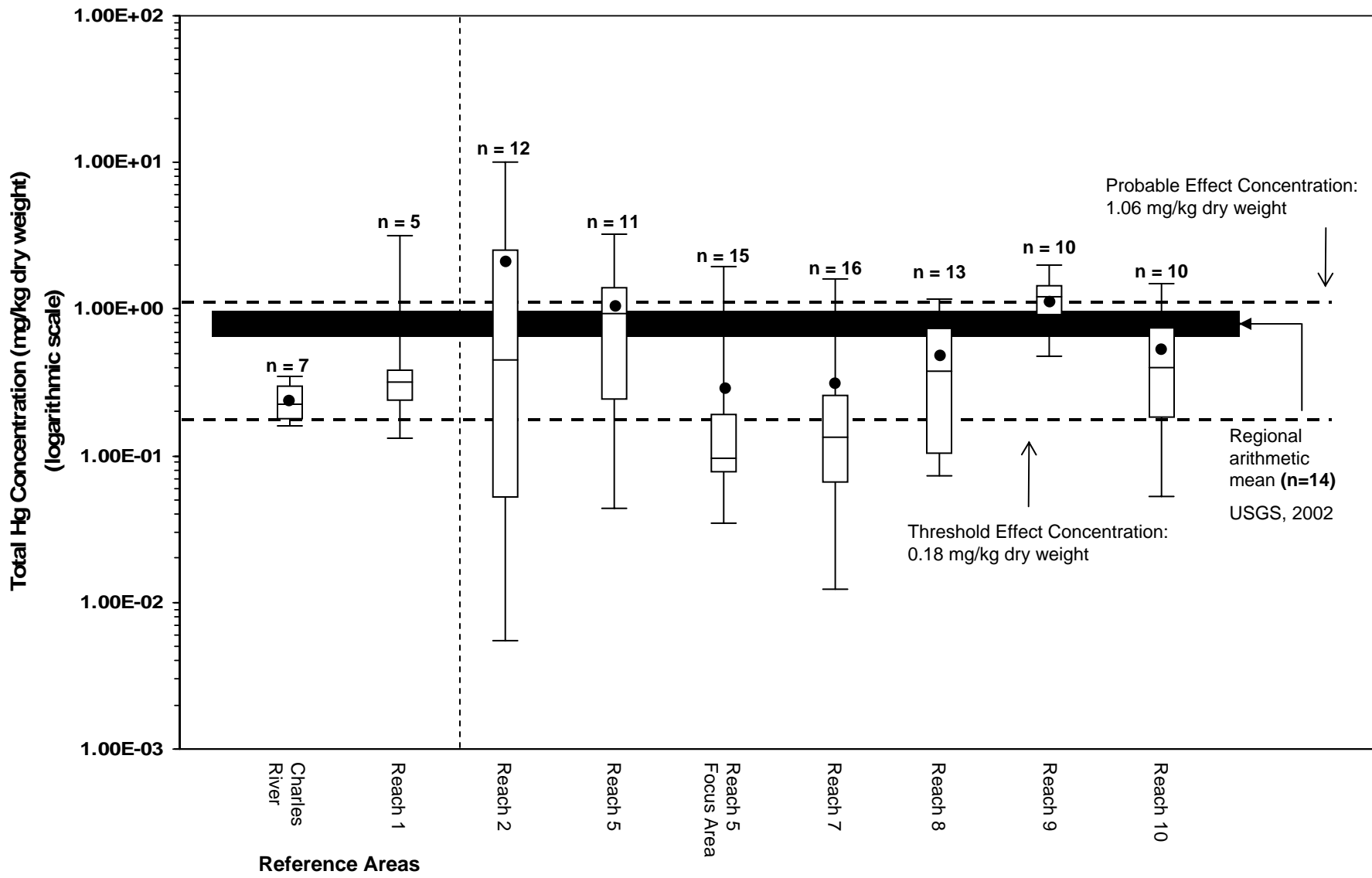
● - Mean Concentration



\*CBR based on crayfish growth and the ability to seek shelter (see Section 3.3.1.1.2).

#### *Nyanza Superfund Site OU IV Sudbury River Mercury Contamination*

**Figure 4-4**  
**Total Mercury Concentrations in**  
**2003 Whole Body Crayfish Samples Compared with CBRs**



**Legend:**

..... Maximum concentration  
 ..... 75<sup>th</sup> Percentile concentration  
 ..... 50<sup>th</sup> Percentile concentration  
 ..... 25<sup>th</sup> Percentile concentration  
 ..... Minimum concentration

● - Mean Concentration

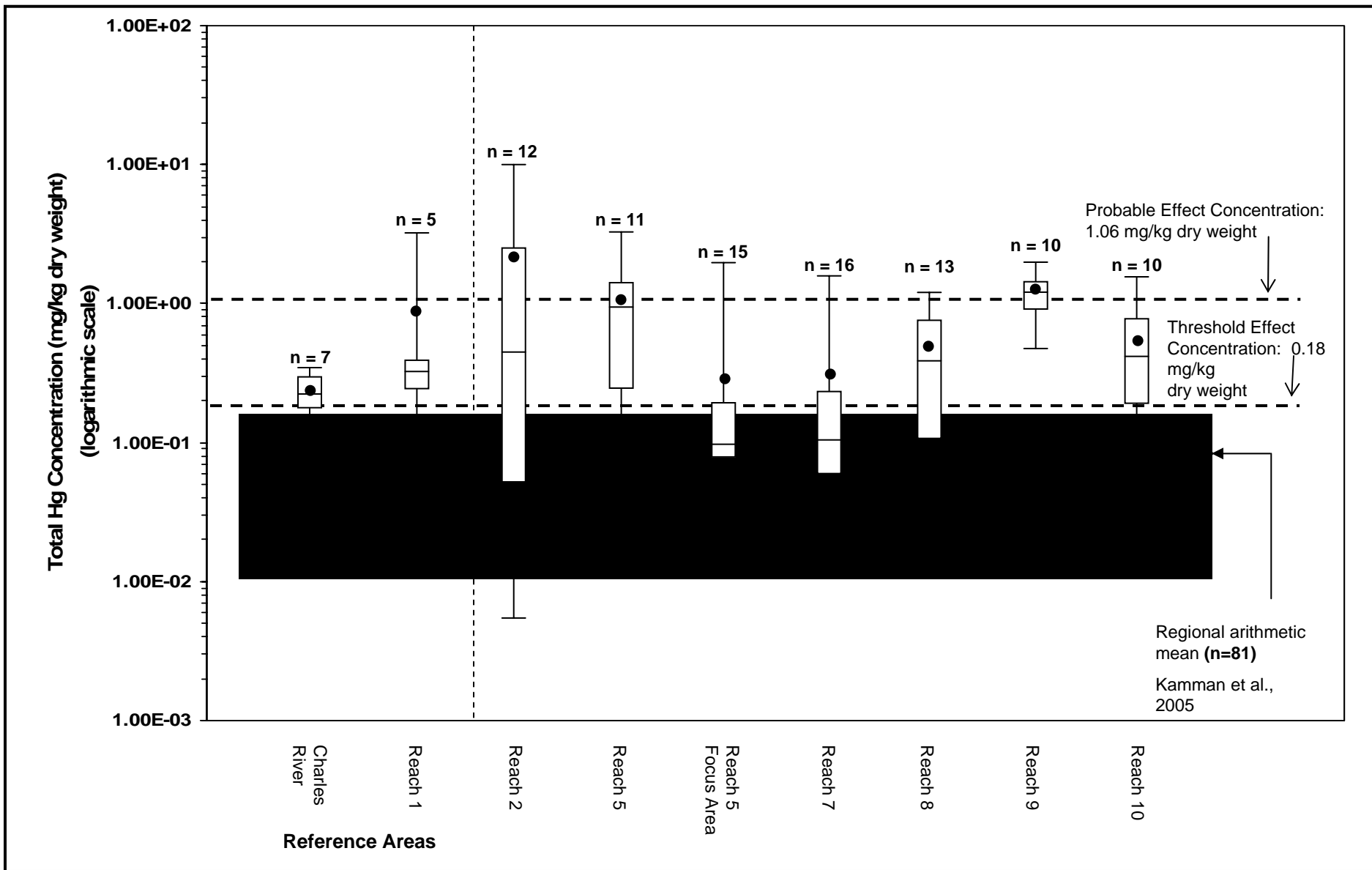
+ one S.E.  
 Arithmetic mean of regional value  
 - one S.E.

Note: Site-specific data presented includes only flowing areas.

**Nyanza Superfund Site OU IV  
Sudbury River Mercury Contamination**

**Figure 4-5  
Total Mercury Concentrations in 2003 & 2005 Sediment  
Compared with Regional Values from Rivers (USGS, 2002)**





**Legend:**

..... Maximum concentration  
 ..... 75<sup>th</sup> Percentile concentration  
 ..... 50<sup>th</sup> Percentile concentration  
 ..... 25<sup>th</sup> Percentile concentration  
 ..... Minimum concentration

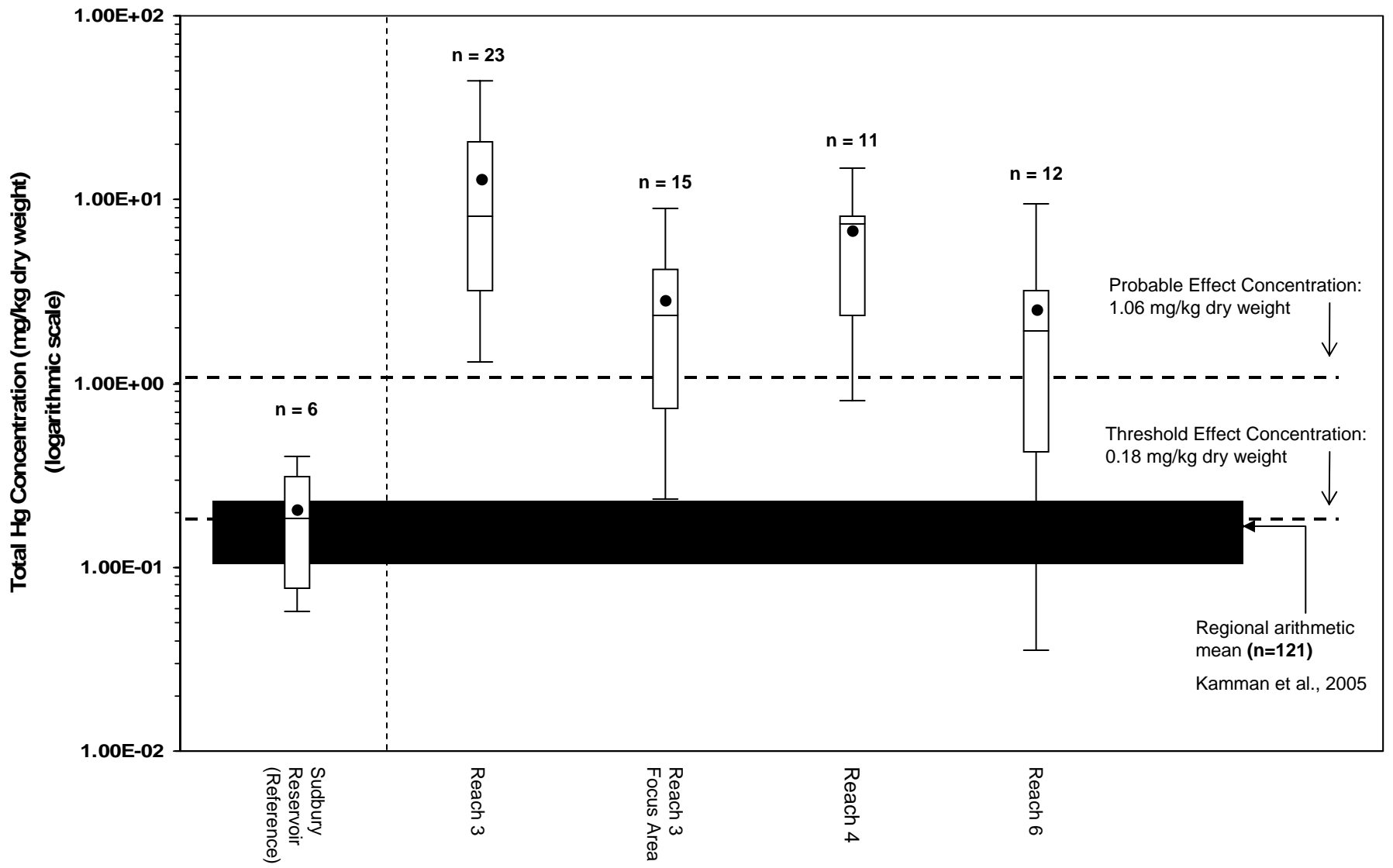
● - Mean Concentration

Note: Site-specific data presented includes only flowing areas.

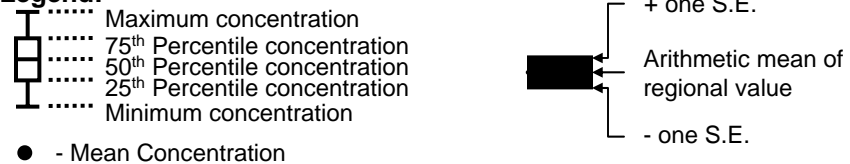
+ one S.E.  
 Arithmetic mean of regional value  
 - one S.E.

**Nyanza Superfund Site OU IV  
Sudbury River Mercury Contamination**

**Figure 4-6  
Total Mercury Concentrations in 2003 & 2005 Sediment Compared  
with Regional Values from Rivers (Kamman et al., 2005)**



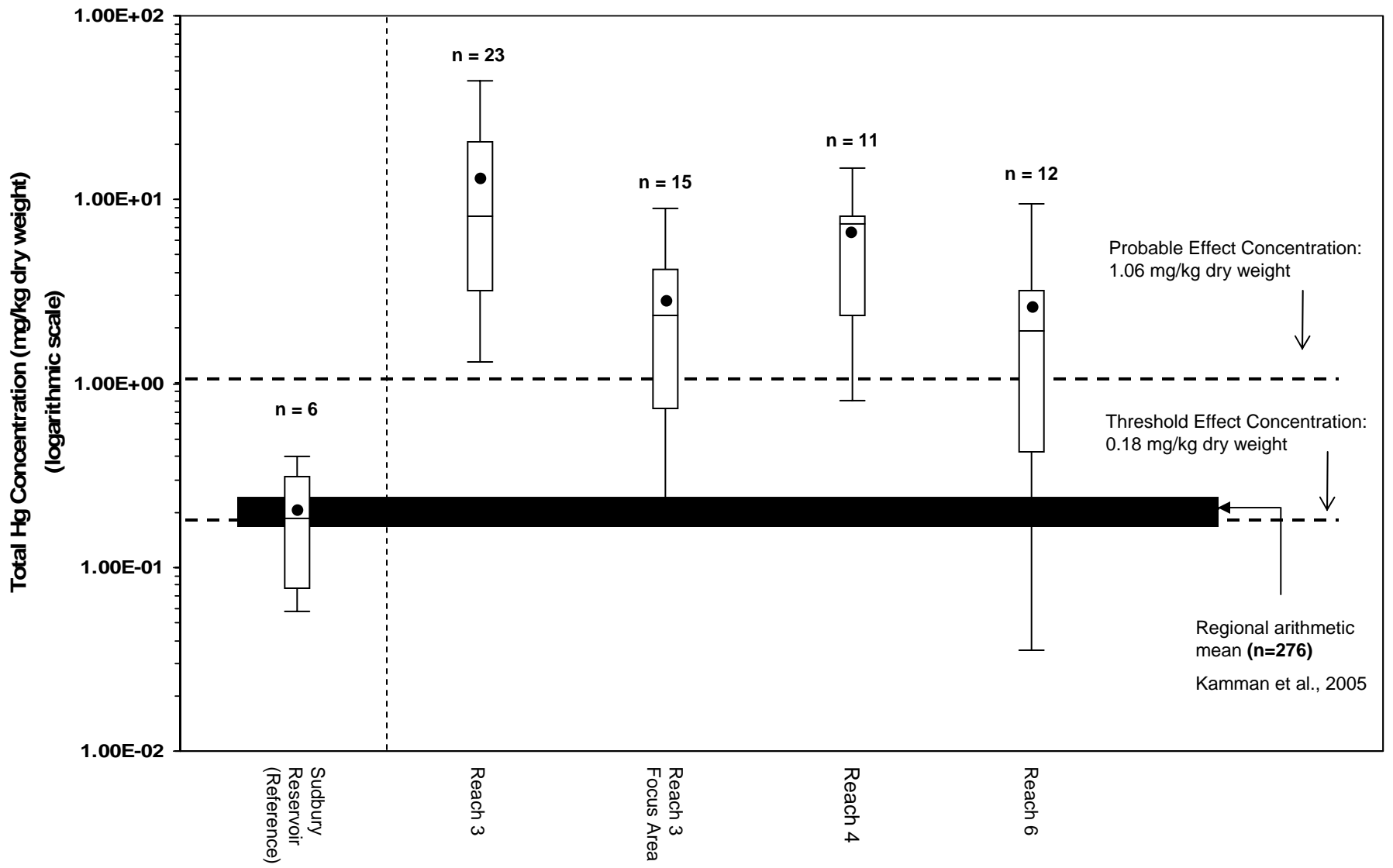
**Legend:**



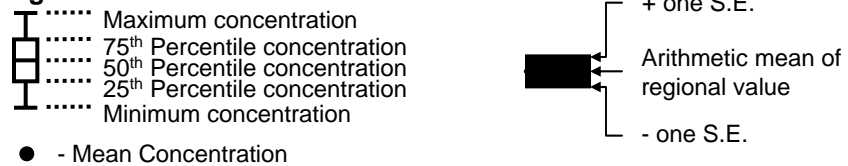
Note: Site-specific data presented includes only impounded areas.

**Nyanza Superfund Site OU IV  
Sudbury River Mercury Contamination**

**Figure 4-7  
Total Mercury Concentrations in 2003 & 2005 Sediment Compared  
with Regional Values from Reservoirs (Kamman et al., 2005)**



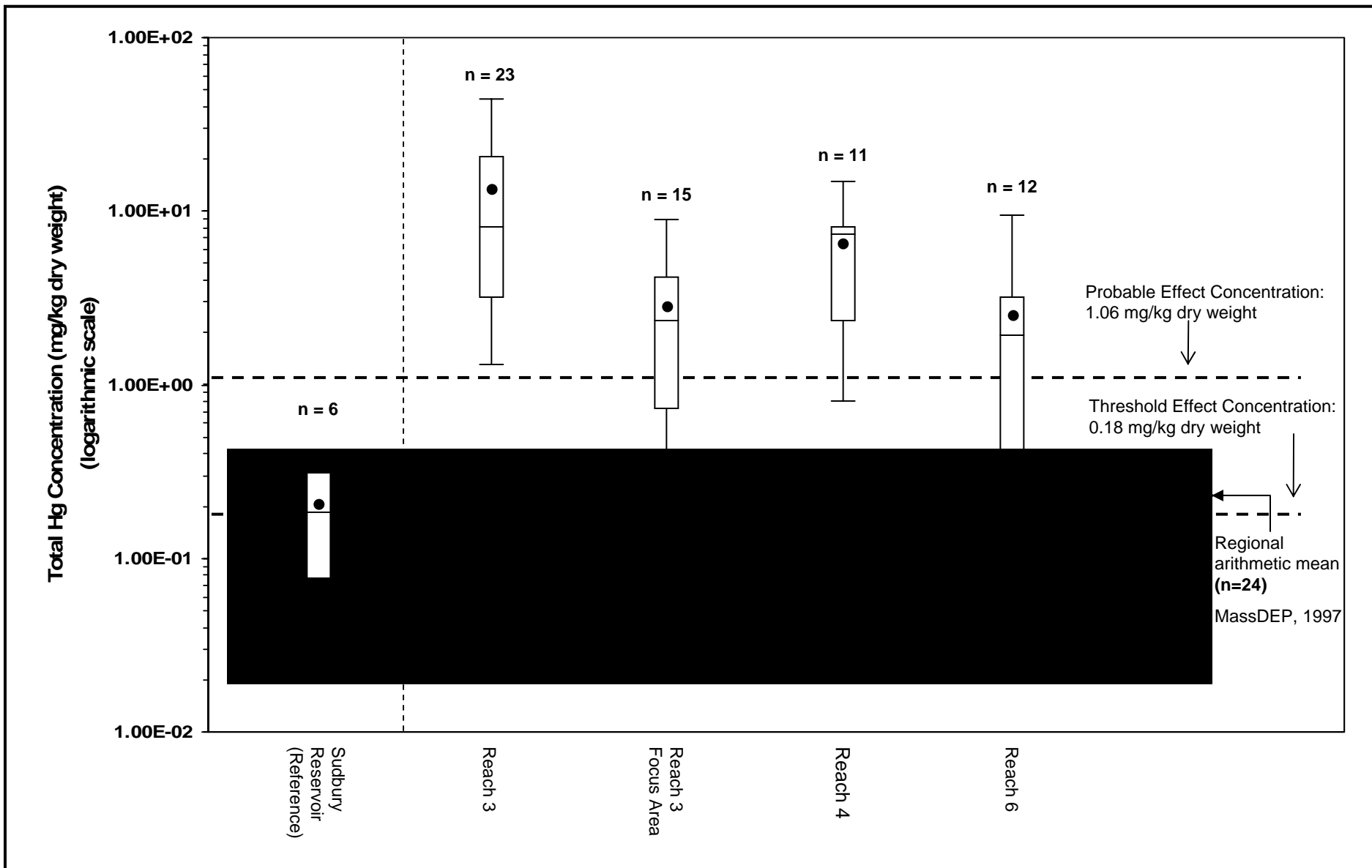
**Legend:**



Note: Site-specific data presented includes only impounded areas.

**Nyanza Superfund Site OU IV  
Sudbury River Mercury Contamination**

**Figure 4-8  
Total Mercury Concentrations in 2003 & 2005 Sediment Compared  
with Regional Values from Lakes (Kamman et al., 2005)**



#### Legend:

..... Maximum concentration  
 ..... 75<sup>th</sup> Percentile concentration  
 ..... 50<sup>th</sup> Percentile concentration  
 ..... 25<sup>th</sup> Percentile concentration  
 ..... Minimum concentration

● - Mean Concentration

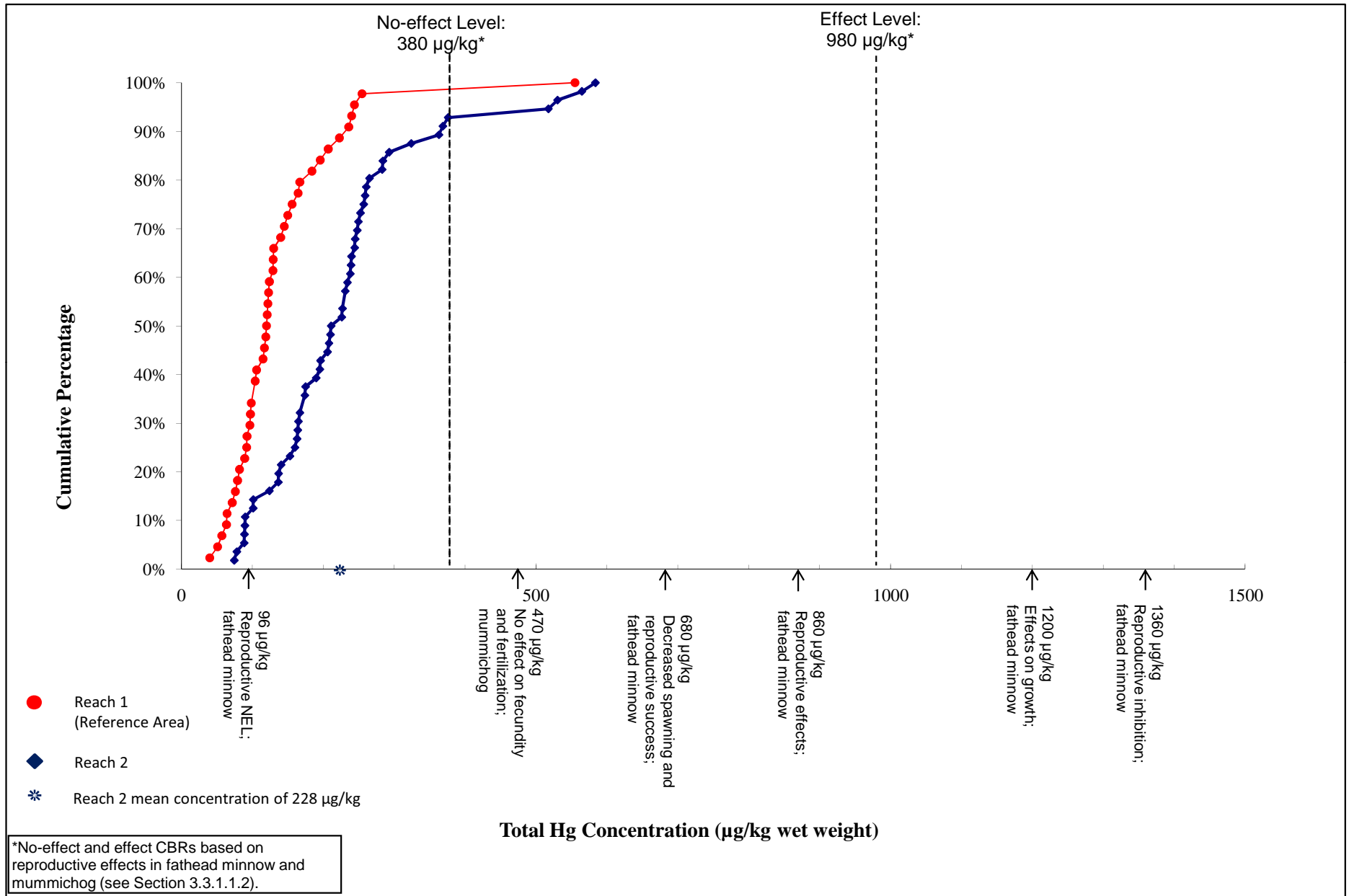
Note: Site-specific data presented includes only impounded areas.

+ one S.E.  
 Arithmetic mean of regional value  
 - one S.E.

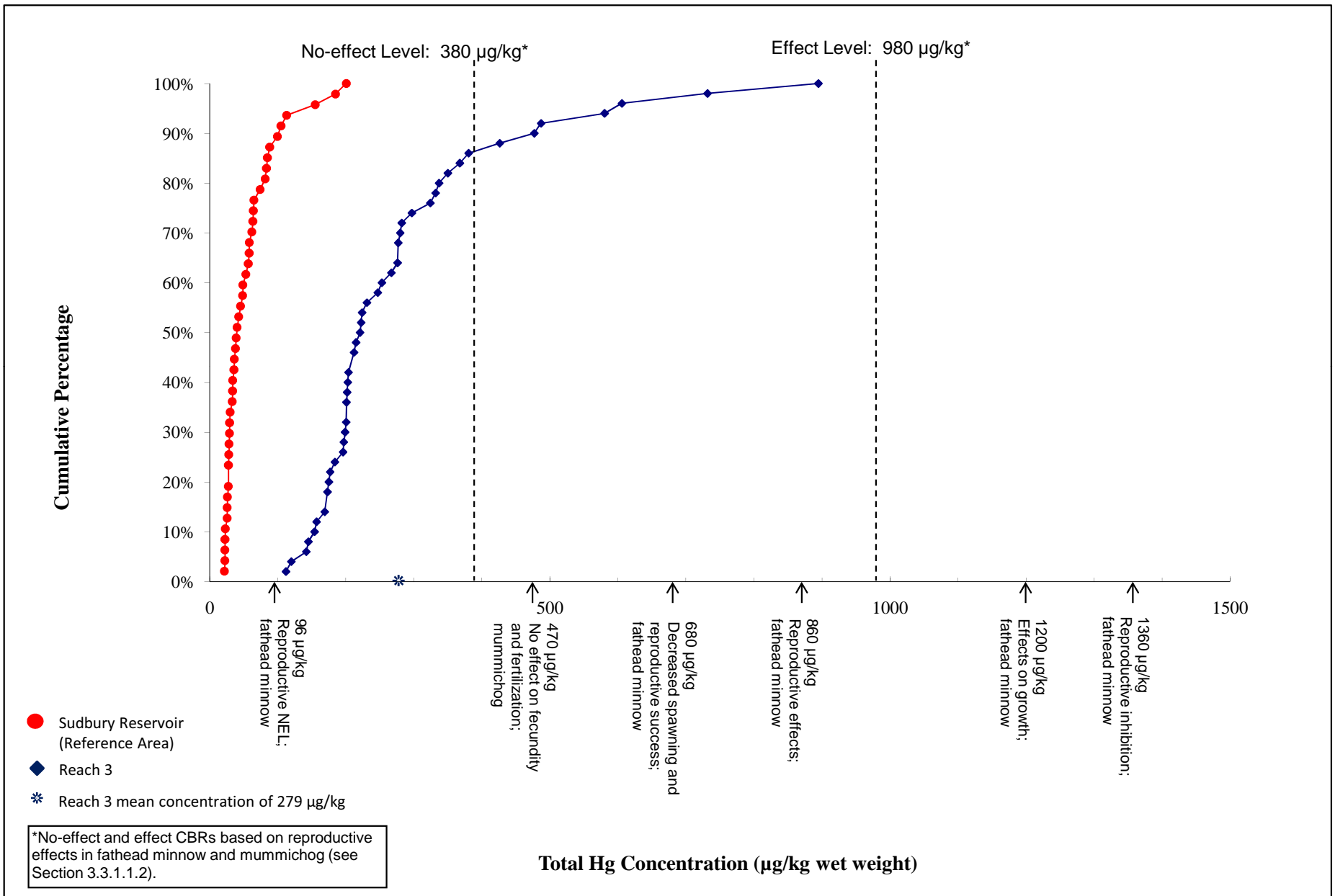
#### Nyanza Superfund Site OU IV Sudbury River Mercury Contamination

**Figure 4-9**  
**Total Mercury Concentrations in 2003 & 2005 Sediment Compared with Regional Values from Lakes (MassDEP, 1997)**

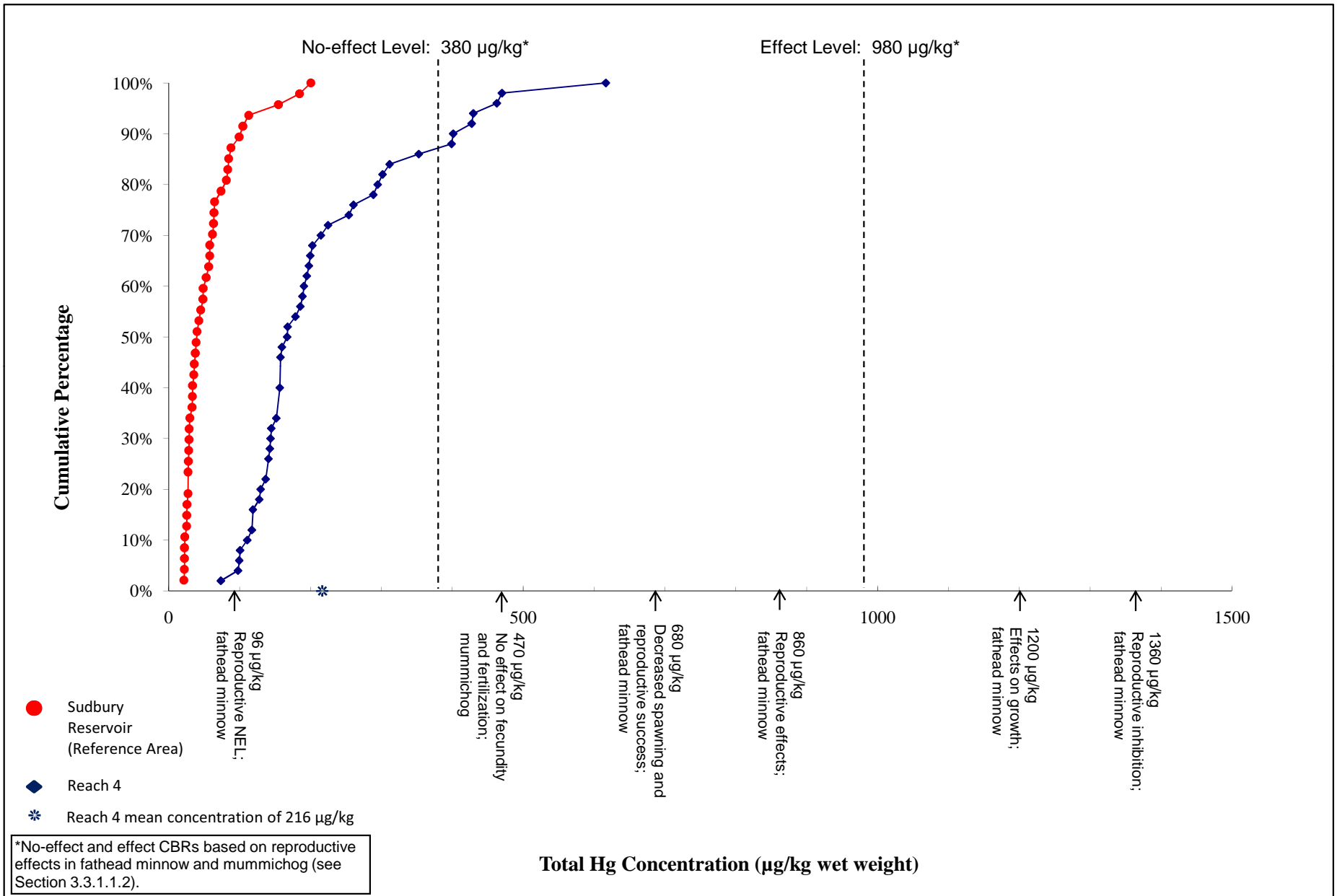
**Figure 4-10**  
**Cumulative Frequency Distribution of Total Mercury Concentrations in Fish from Reach 2**  
*Nyanza Superfund Site OU IV*  
**Sudbury River Mercury Contamination**



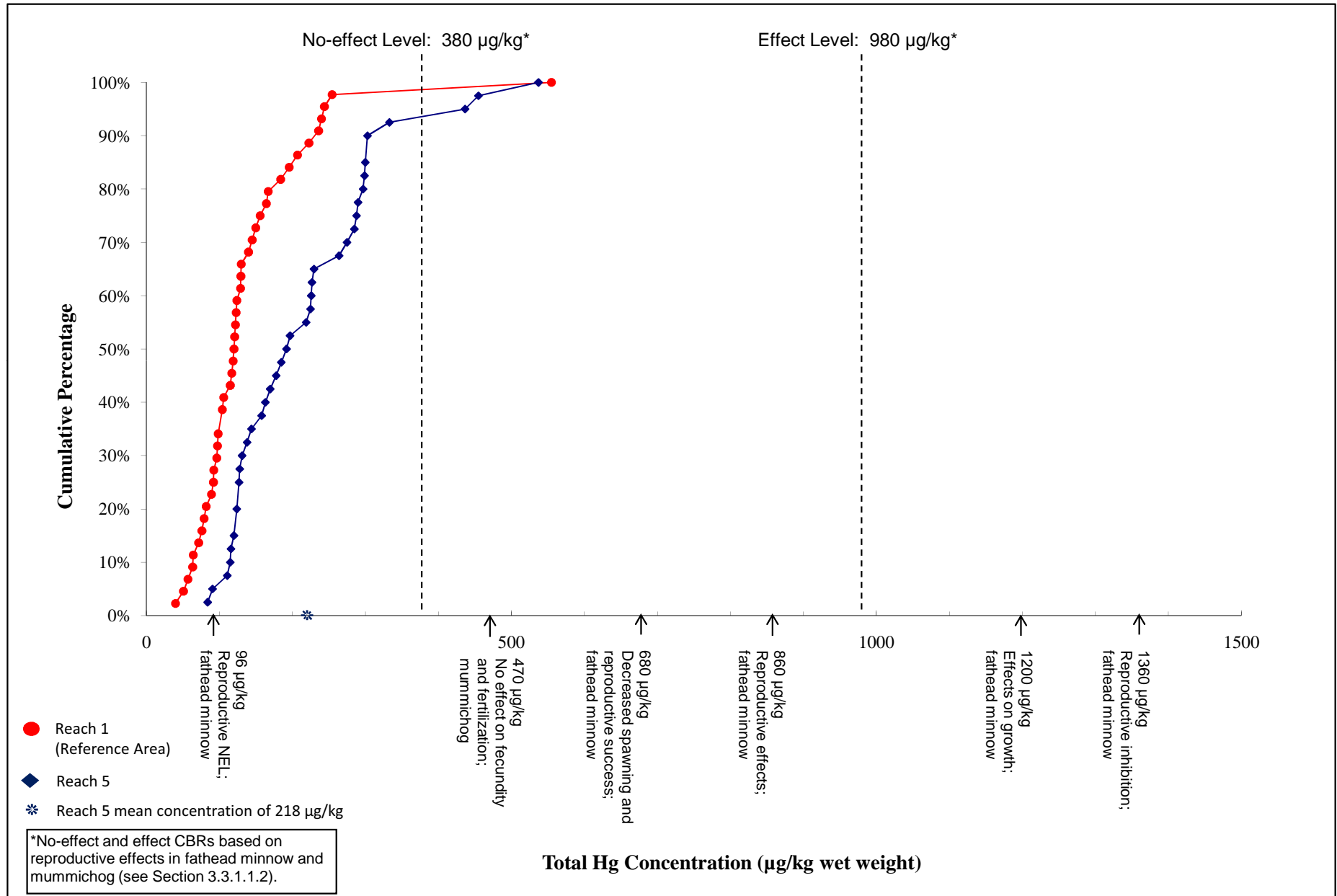
**Figure 4-11**  
**Cumulative Frequency Distribution of Total Mercury Concentrations in Fish from Reach 3**  
*Nyanza Superfund Site OU IV*  
**Sudbury River Mercury Contamination**



**Figure 4-12**  
**Cumulative Frequency Distribution of Total Mercury Concentrations in Fish from Reach 4**  
*Nyanza Superfund Site OU IV*  
**Sudbury River Mercury Contamination**

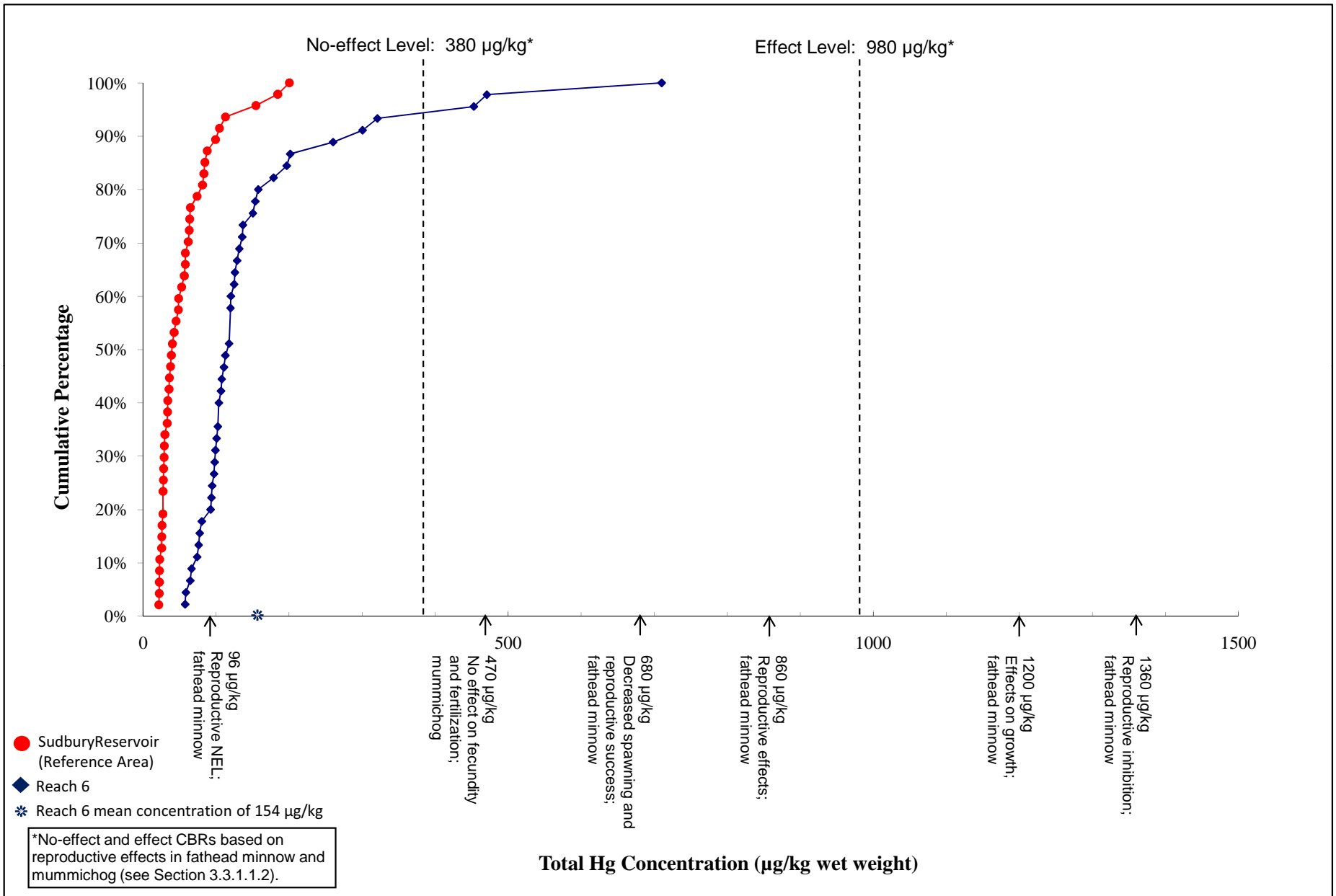


**Figure 4-13**  
**Cumulative Frequency Distribution of Total Mercury Concentrations in Fish from Reach 5**  
**Nyanza Superfund Site OU IV**  
**Sudbury River Mercury Contamination**

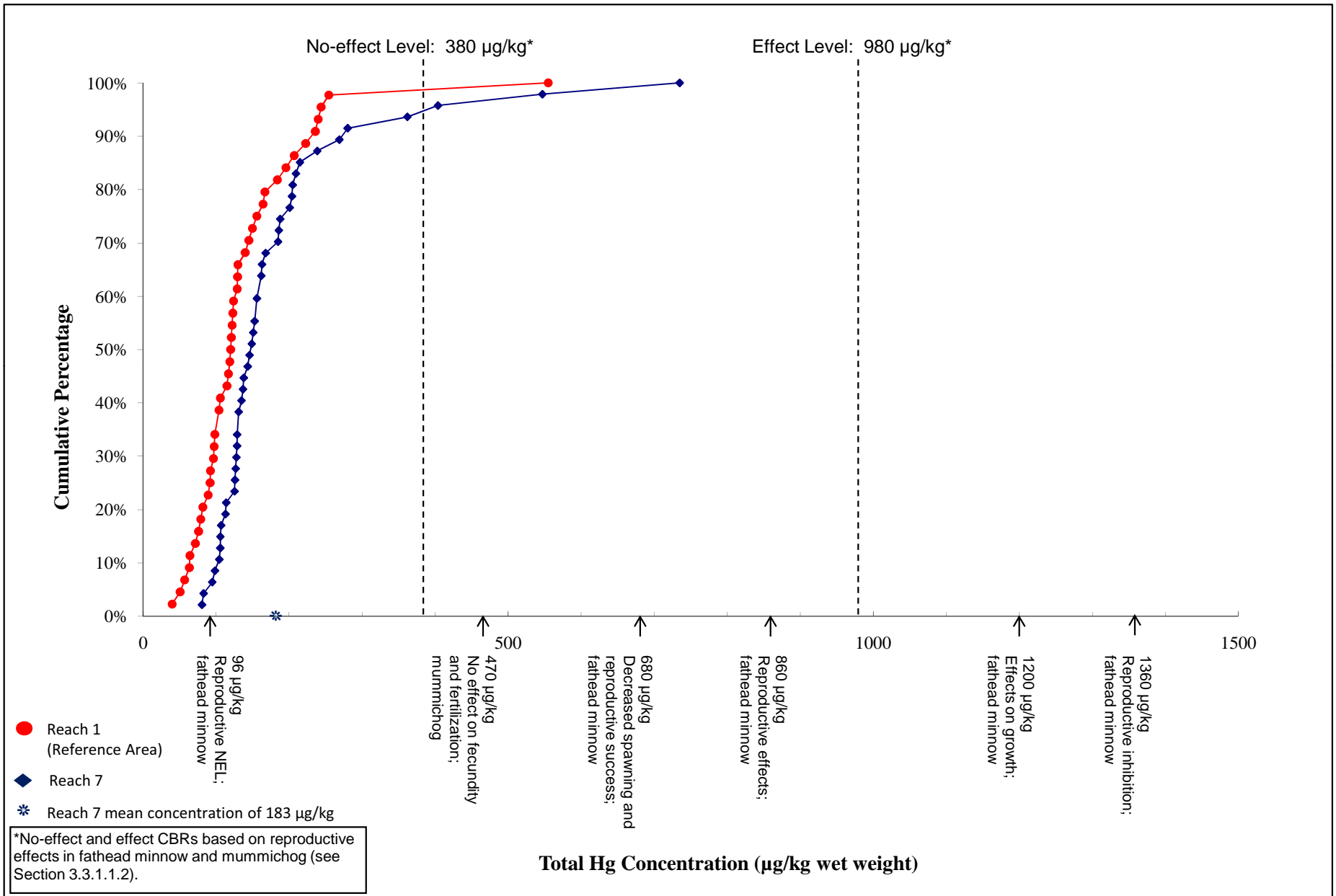




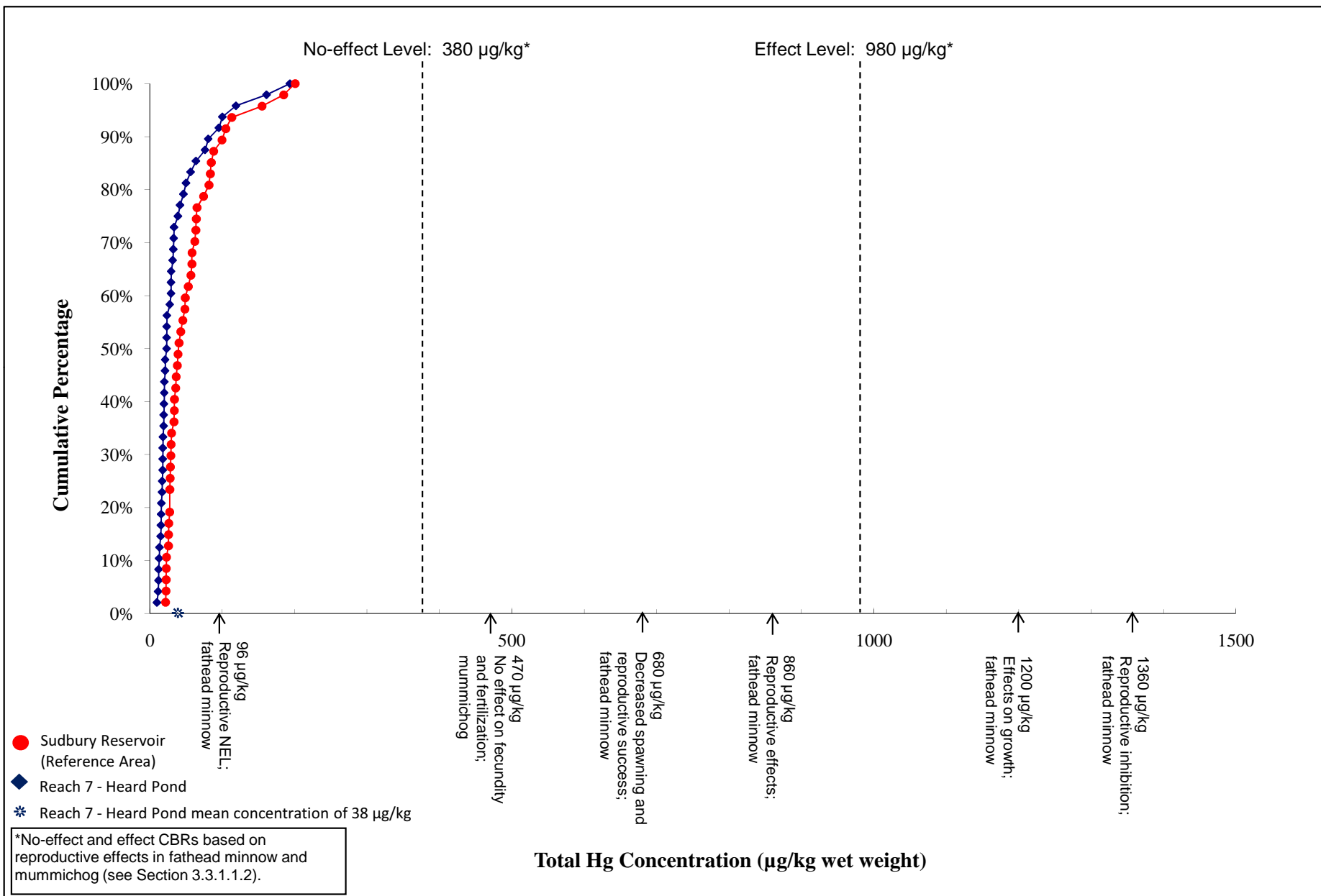
**Figure 4-14**  
**Cumulative Frequency Distribution of Total Mercury Concentrations in Fish from Reach 6**  
**Nyanza Superfund Site OU IV**  
**Sudbury River Mercury Contamination**



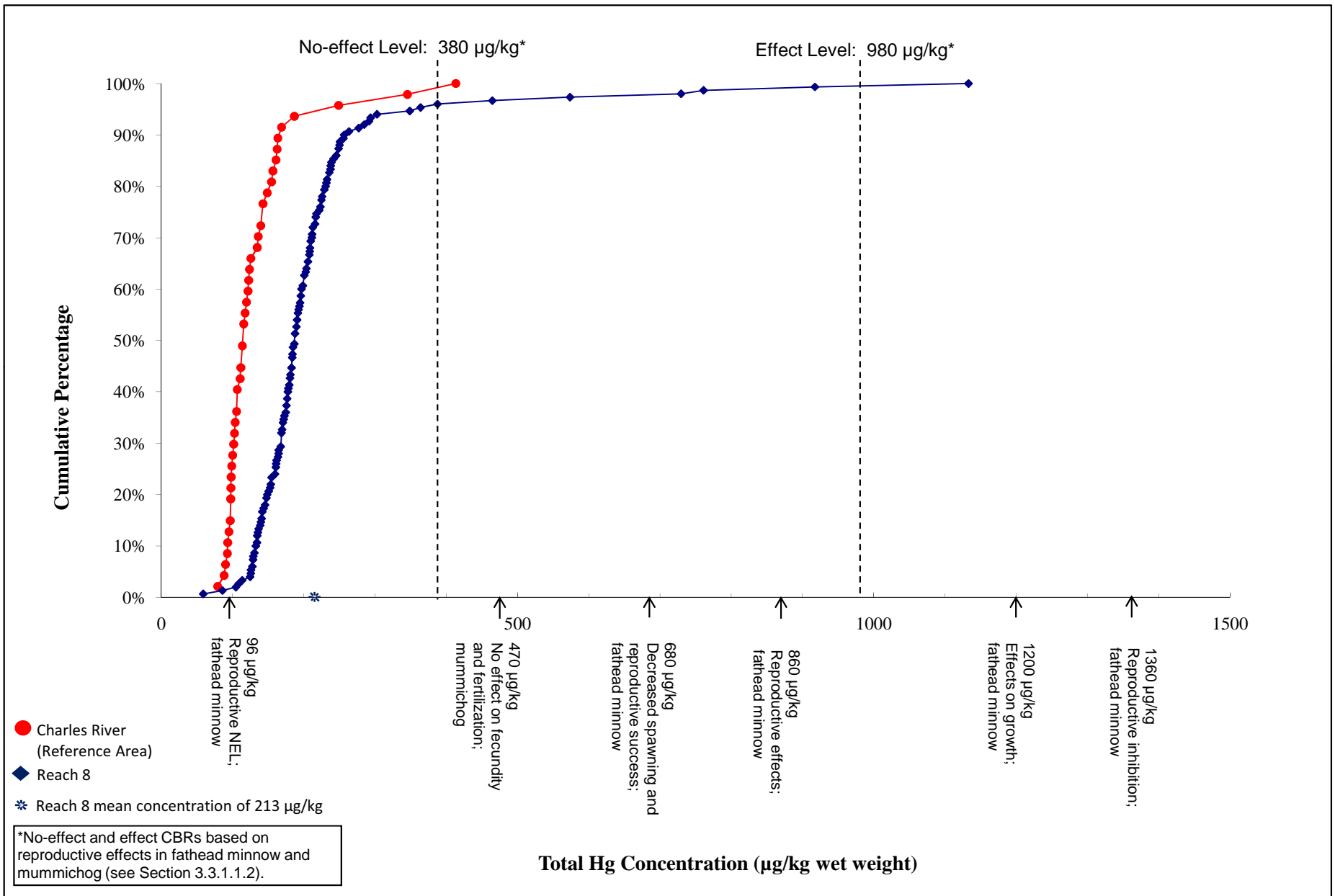
**Figure 4-15**  
**Cumulative Frequency Distribution of Total Mercury Concentrations in Fish from Reach 7**  
**Nyanza Superfund Site OU IV**  
**Sudbury River Mercury Contamination**



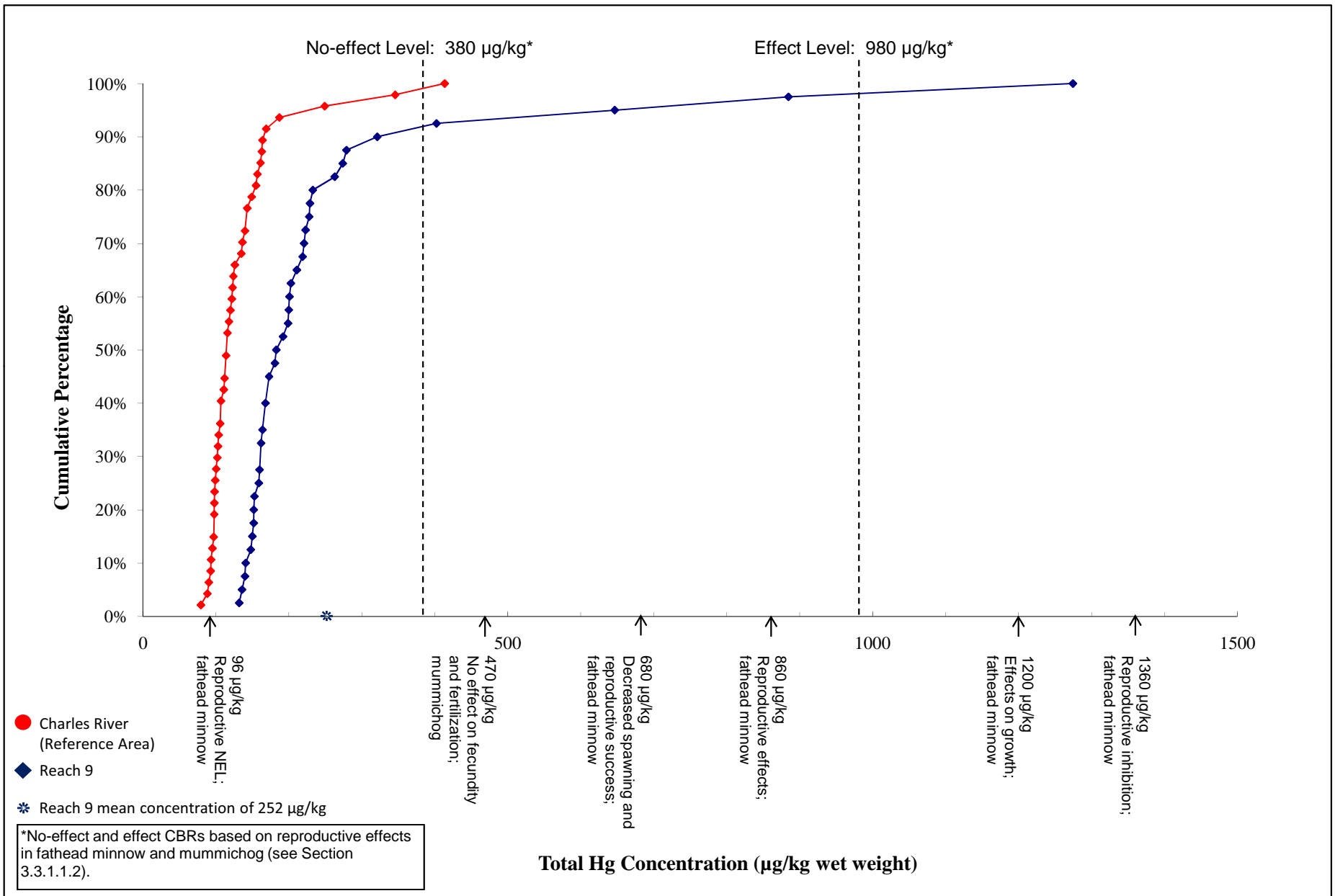
**Figure 4-16**  
**Cumulative Frequency Distribution of Total Mercury Concentrations in Fish from Reach 7 - Heard Pond**  
*Nyanza Superfund Site OU IV*  
**Sudbury River Mercury Contamination**



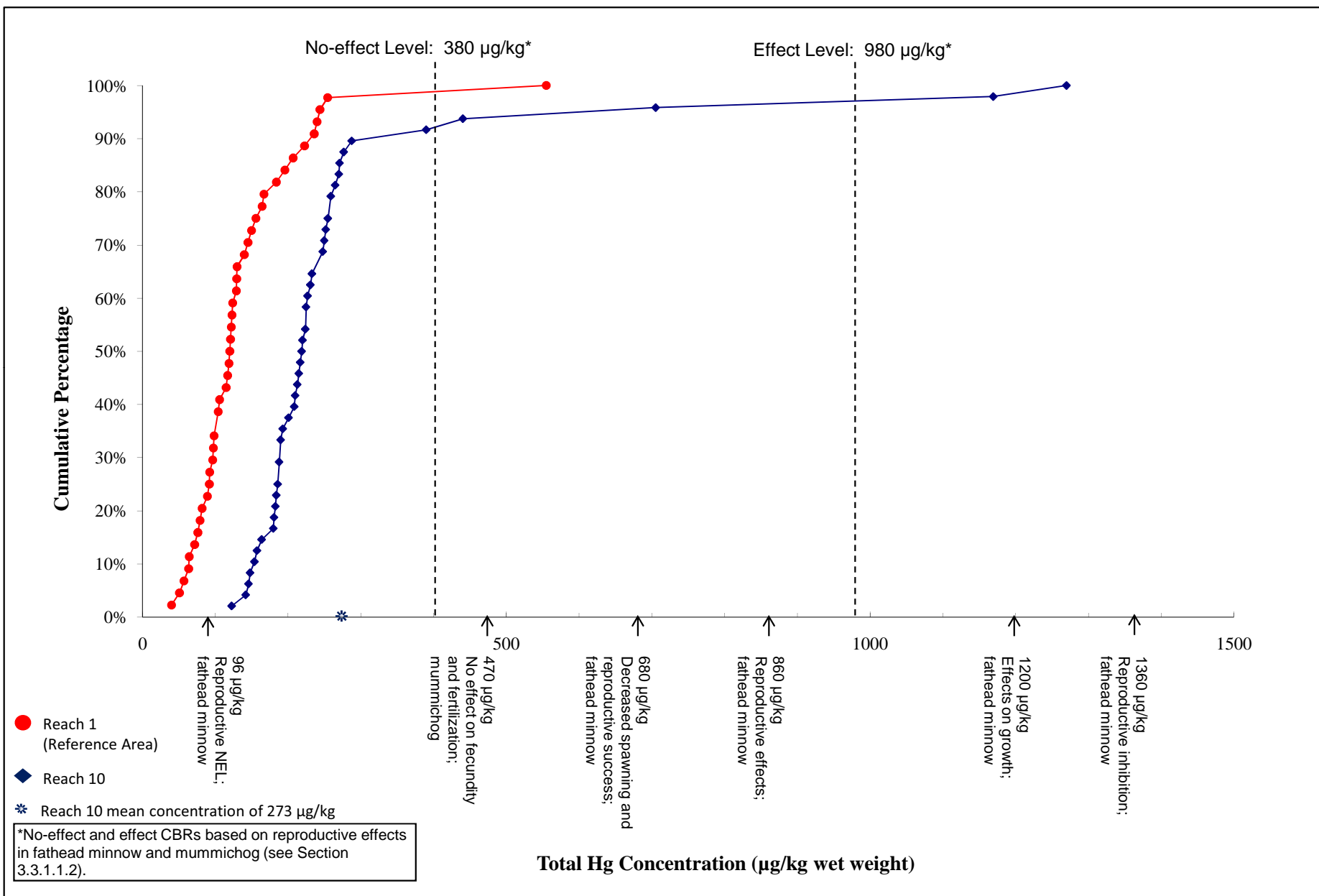
**Figure 4-17**  
**Cumulative Frequency Distribution of Total Mercury Concentrations in Fish from Reach 8**  
**Nyanza Superfund Site OU IV**  
**Sudbury River Mercury Contamination**

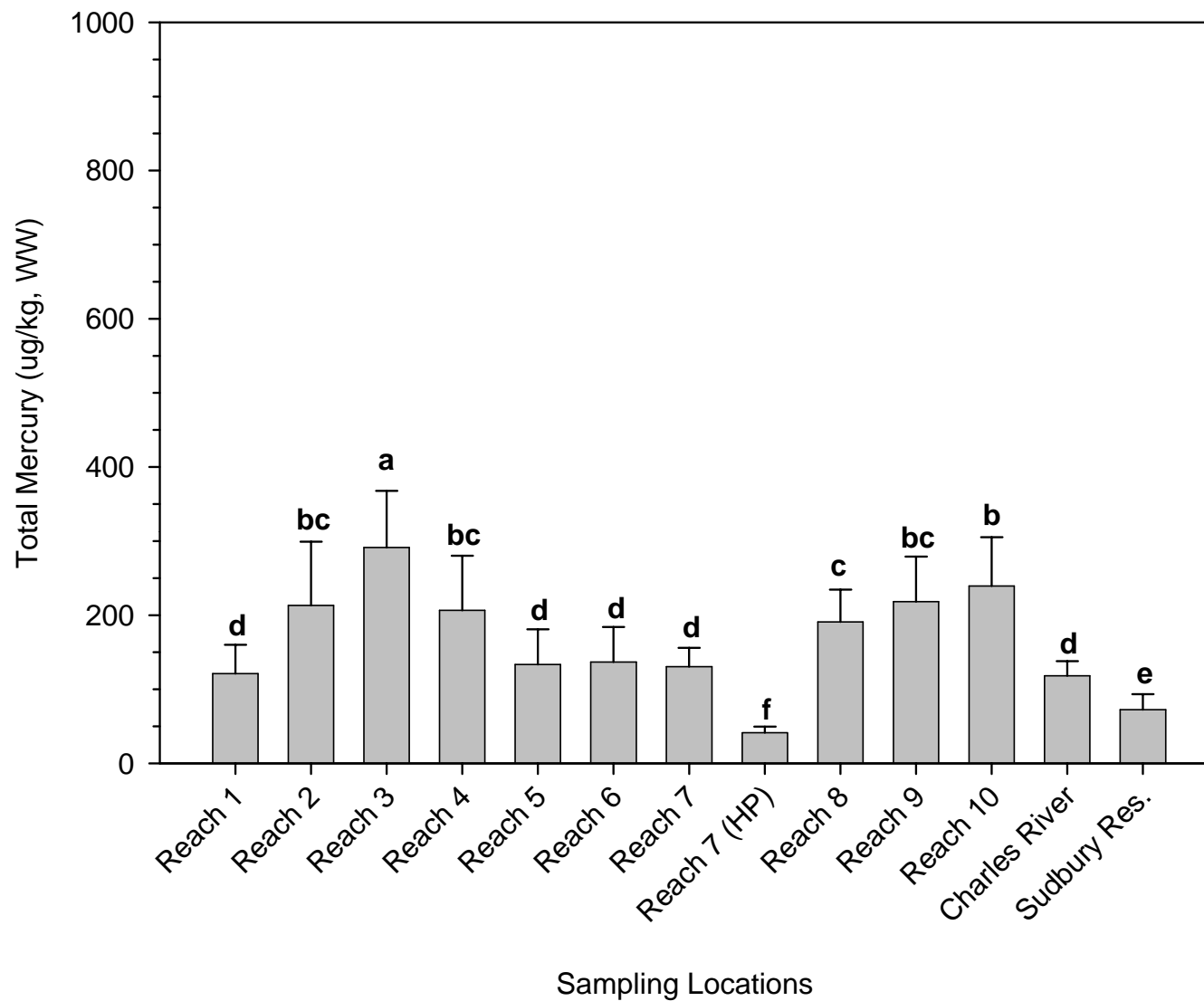


**Figure 4-18**  
**Cumulative Frequency Distribution of Total Mercury Concentrations in Fish from Reach 9**  
*Nyanza Superfund Site OU IV*  
**Sudbury River Mercury Contamination**



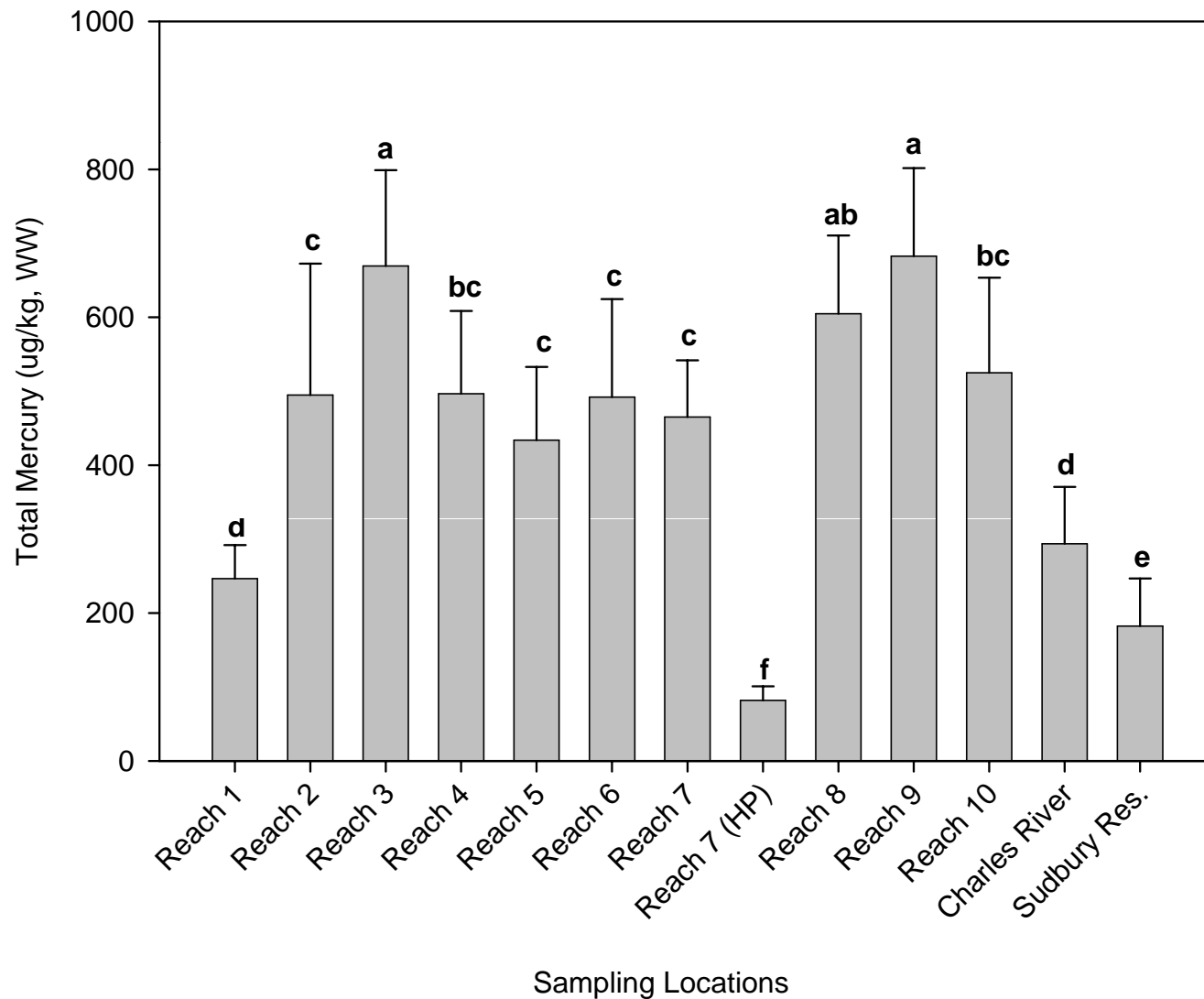
**Figure 4-19**  
**Cumulative Frequency Distribution of Total Mercury Concentrations in Fish from Reach 10**  
**Nyanza Superfund Site OU IV**  
**Sudbury River Mercury Contamination**





**Note: Sampling stations with the same letter are not significantly different from each other ( $p > 0.05$ ).**

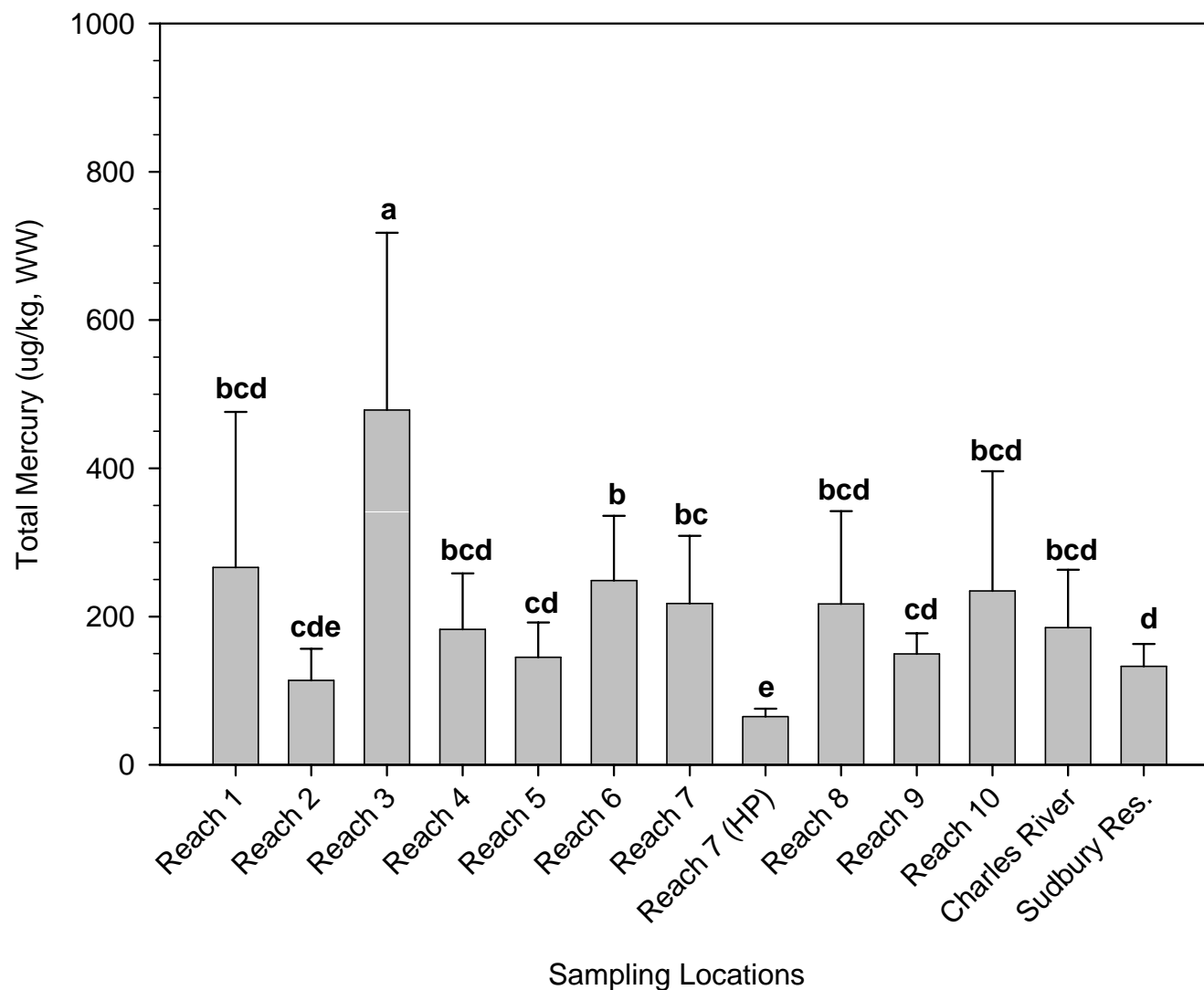
***Nyanza Superfund Site OU IV  
Sudbury River Mercury Contamination  
Figure 4-20  
Comparing Total Hg (Mean  $\pm$  1 S.D.) in Length-Normalized,  
Whole Yellow Perch Collected from the Sudbury River and  
Reference Locations***



**Note: Sampling stations with the same letter are not significantly different from each other ( $p>0.05$ ).**

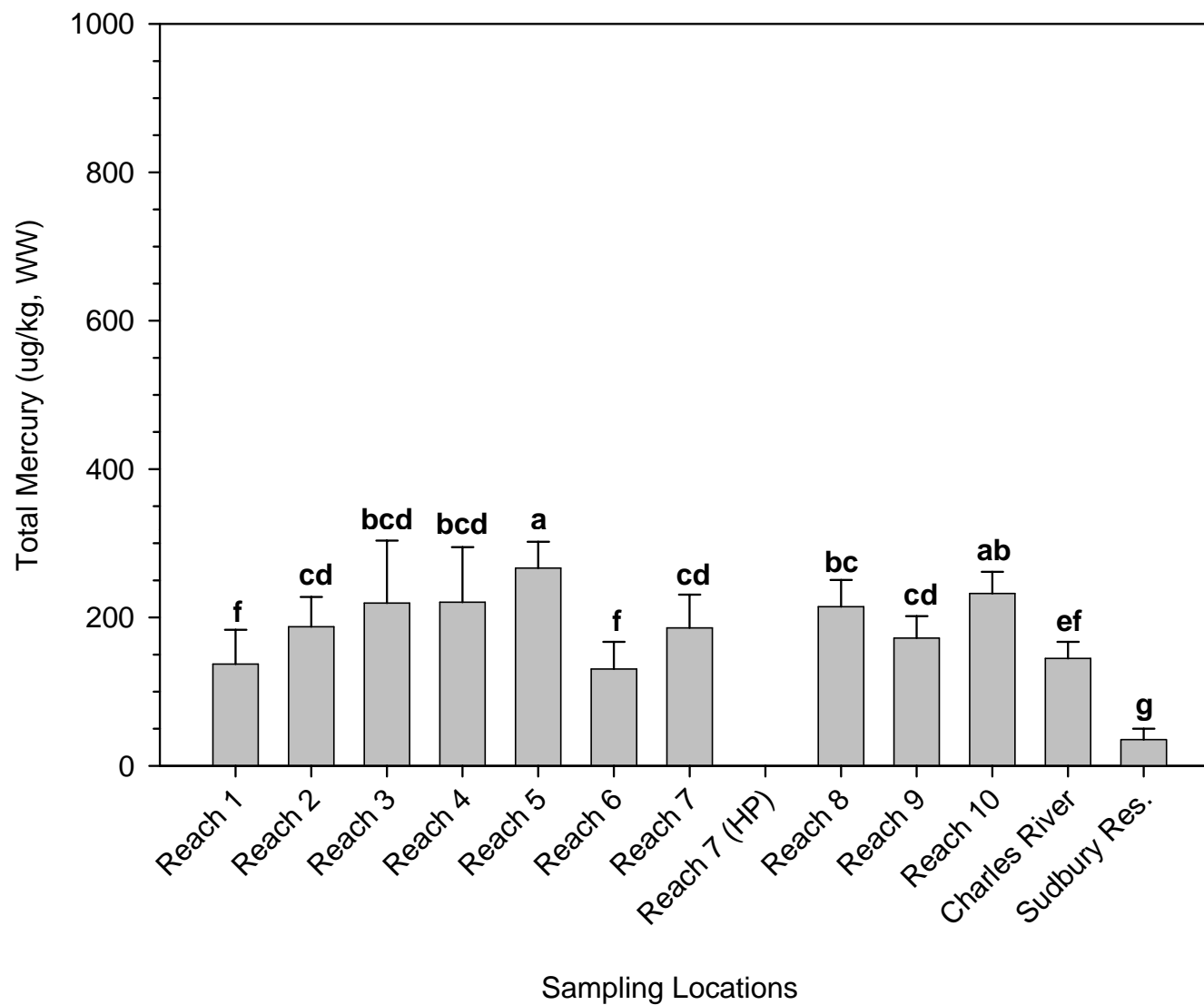
***Nyanza Superfund Site OU IV  
Sudbury River Mercury Contamination  
Figure 4-21  
Comparing Total Hg (Mean  $\pm$  1 S.D.) in Size-Normalized,  
Whole Largemouth Bass Collected from the Sudbury River  
and Reference Locations***





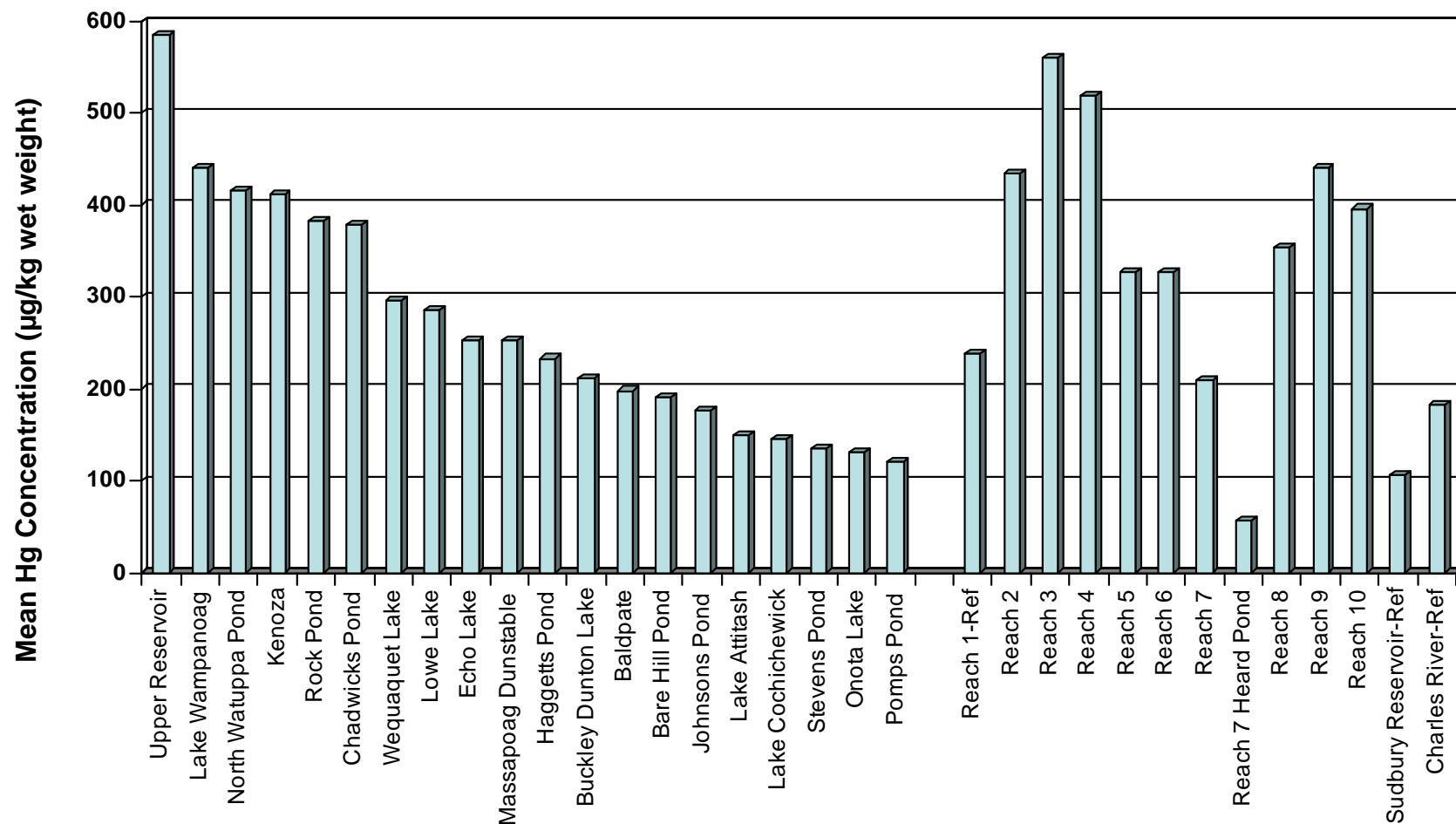
**Note: Sampling stations with the same letter are not significantly different from each other ( $p>0.05$ ).**

***Nyanza Superfund Site OU IV  
Sudbury River Mercury Contamination  
Figure 4-22  
Comparing Total Hg (Mean  $\pm$  1 S.D.) in Size-Normalized,  
Whole Bullheads Collected from the Sudbury River and  
Reference Locations***



**Note: Sampling stations with the same letter are not significantly different from each other ( $p>0.05$ ).**

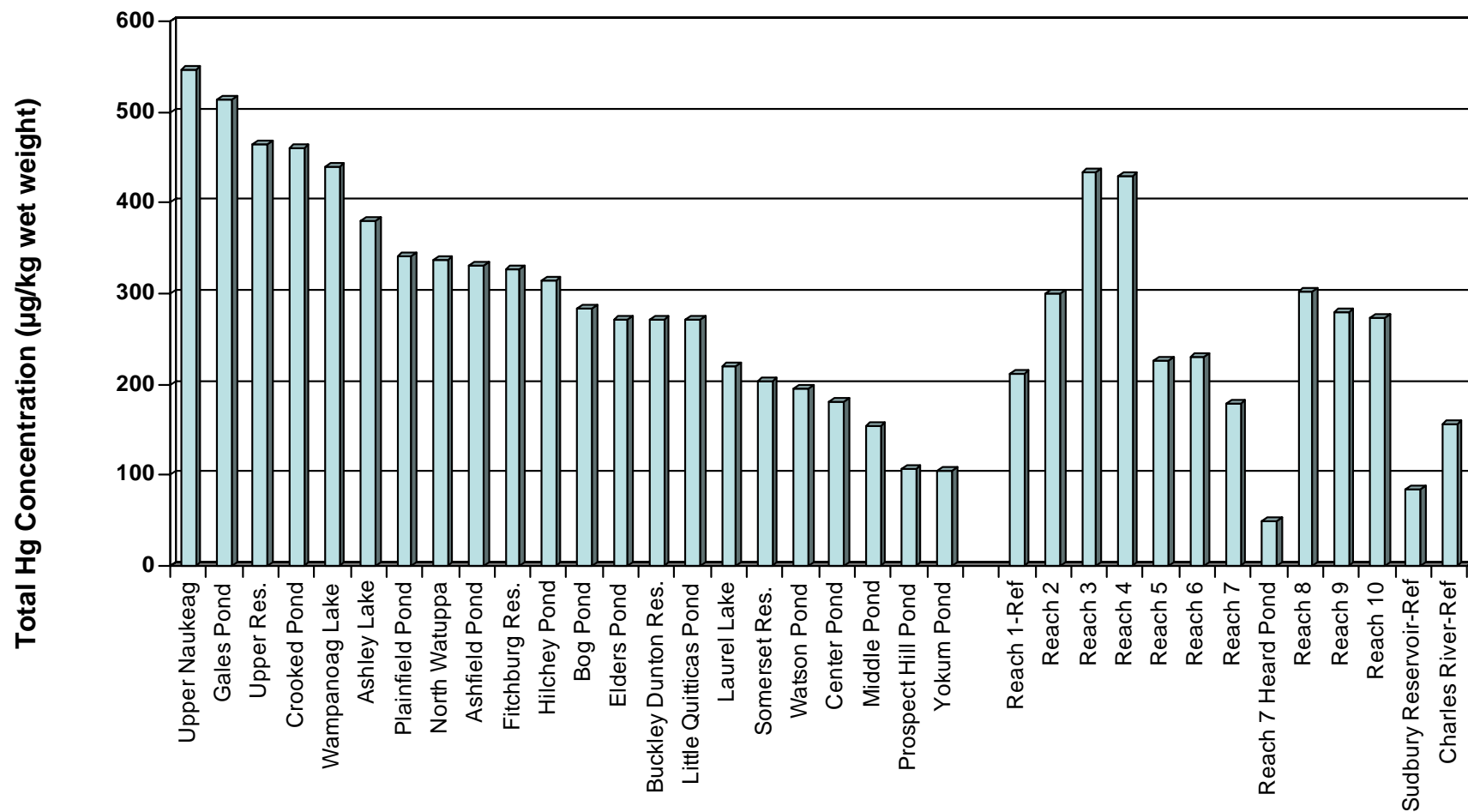
**Nyanza Superfund Site OU IV  
Sudbury River Mercury Contamination  
Figure 4-23  
Comparing Total Hg (Mean  $\pm$  1 S.D.) in Whole Sunfish (5-10 cm) Collected from the Sudbury River and Reference Locations**



**Regional vs. Site-Specific Areas**

Note: Site-specific data presented includes flowing areas.  
Source: Massachusetts DEP, 2006

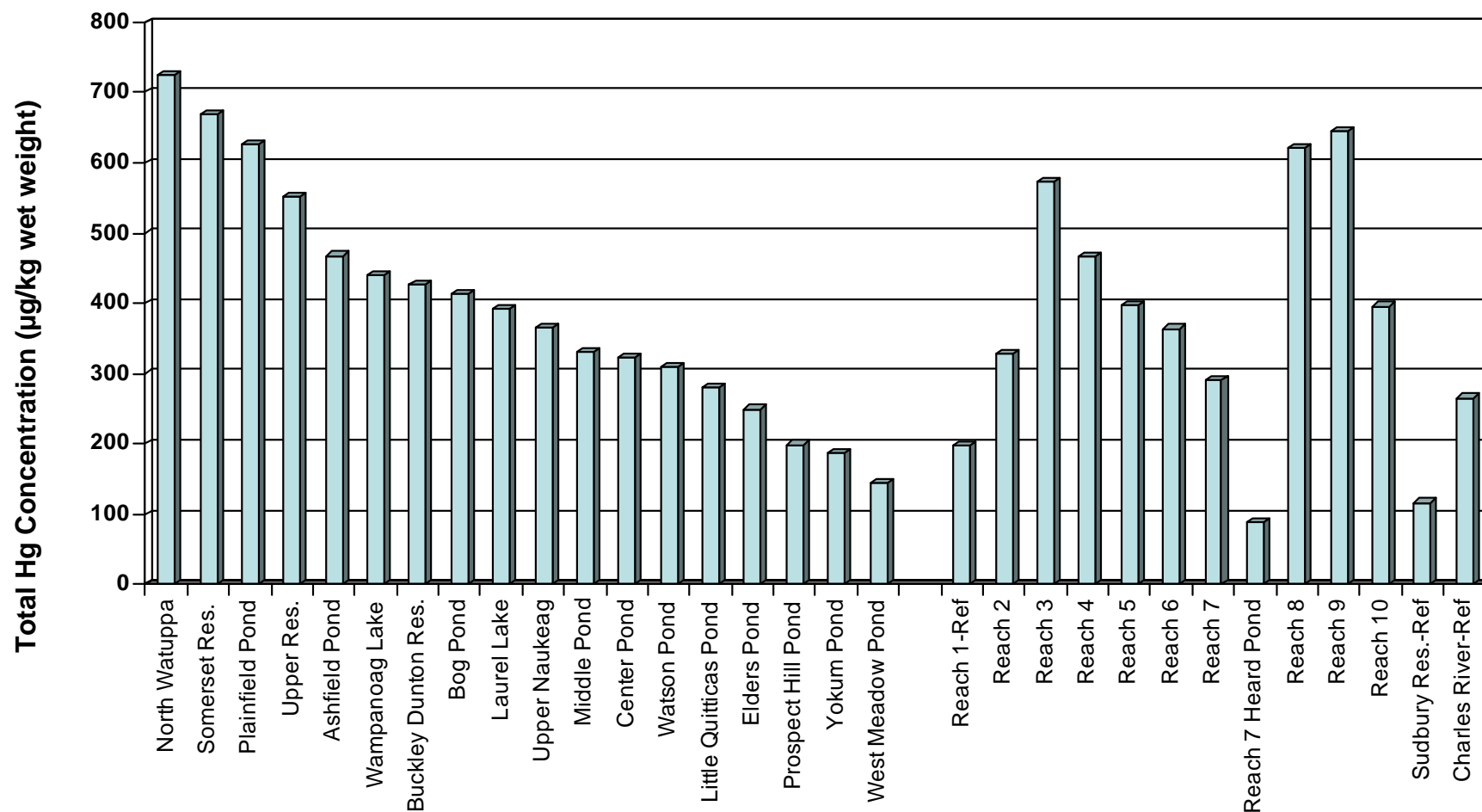
**Nyanza Superfund Site OU IV**  
**Sudbury River Mercury Contamination**  
**Figure 4-24**  
**Comparison of Mean Mercury Concentrations in Axial**  
**Muscle of Yellow Perch (>20 cm) from the Sudbury River**  
**and Regional Waters ( Mass. DEP, 2006)**



Regional vs. Site-Specific Areas

Note: Site-specific data presented includes flowing areas.  
Source: Rose et al., 1999

**Nyanza Superfund Site OU IV**  
**Sudbury River Mercury Contamination**  
**Figure 4-25**  
**Comparison of Mean Mercury Concentrations in Axial**  
**Muscle of Yellow Perch (>20 cm) from the Sudbury**  
**River and Regional Waters (Rose et al., 1999)**



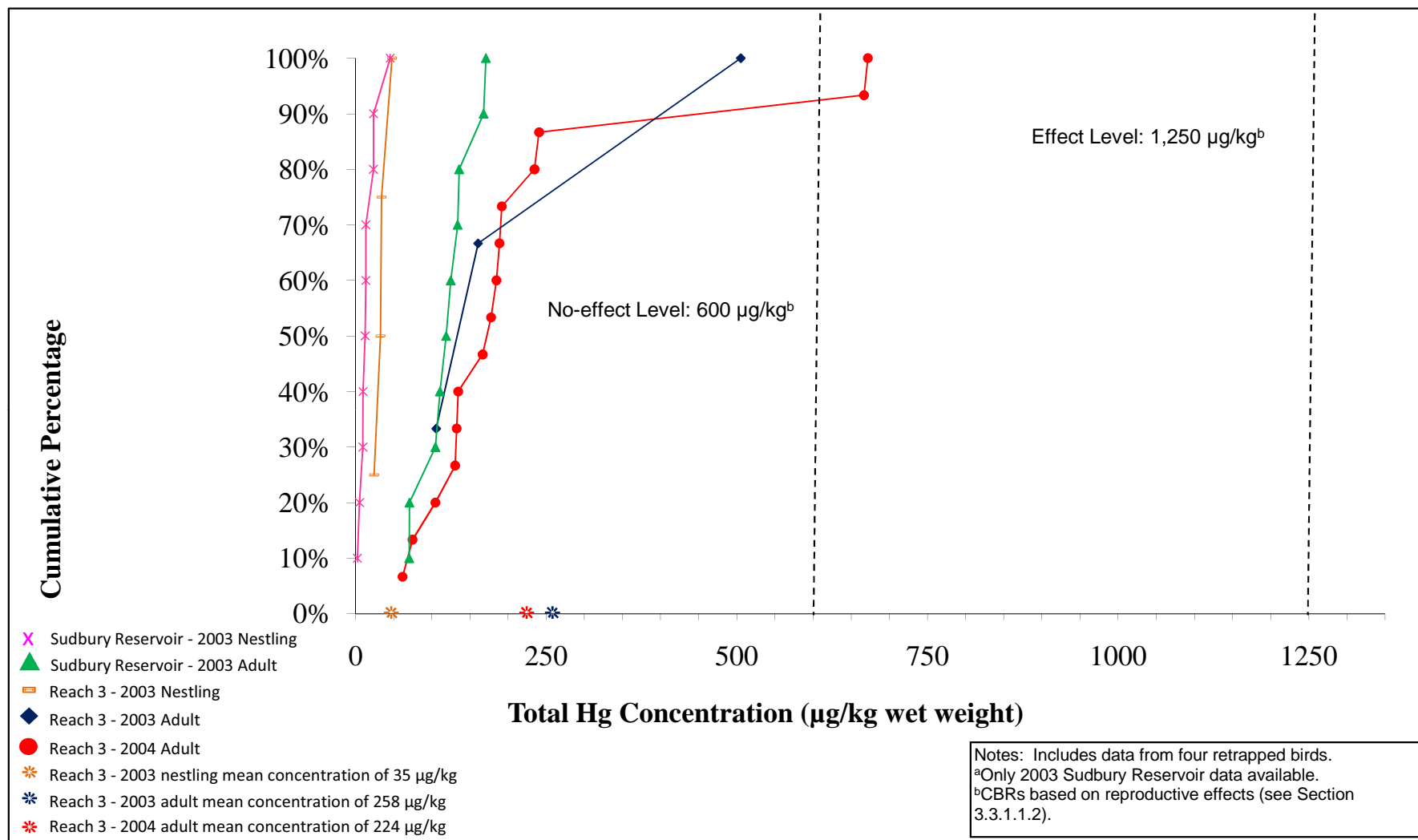
**Regional vs. Site-Specific Areas**

Note: Site-specific data presented includes only flowing areas.  
Source: Rose et al., 1999

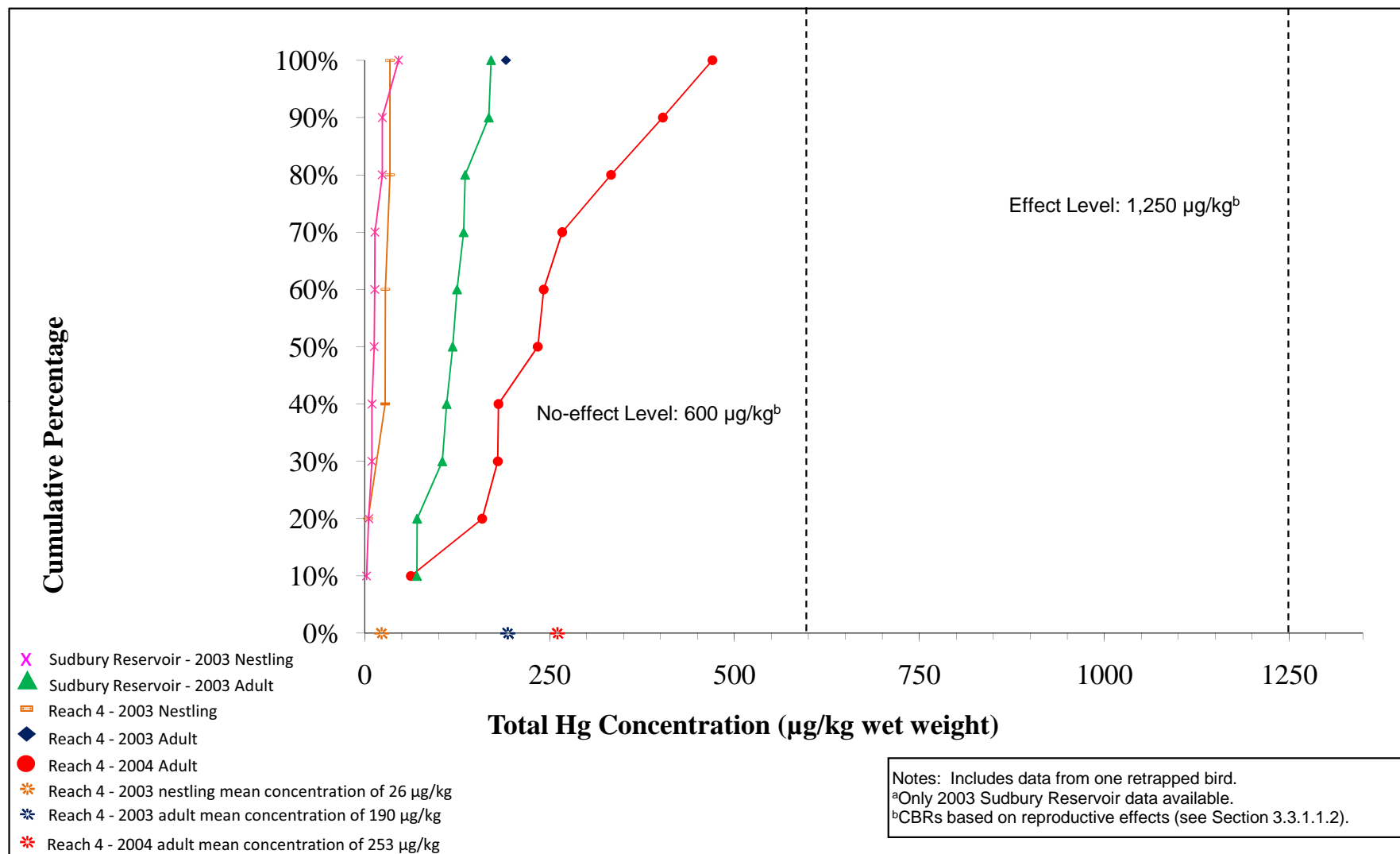
***Nyanza Superfund Site OU IV  
Sudbury River Mercury Contamination***

**Figure 4-26  
Average Mercury Concentrations in Largemouth Bass Axial  
Muscle from the Sudbury River and Regional Waters**

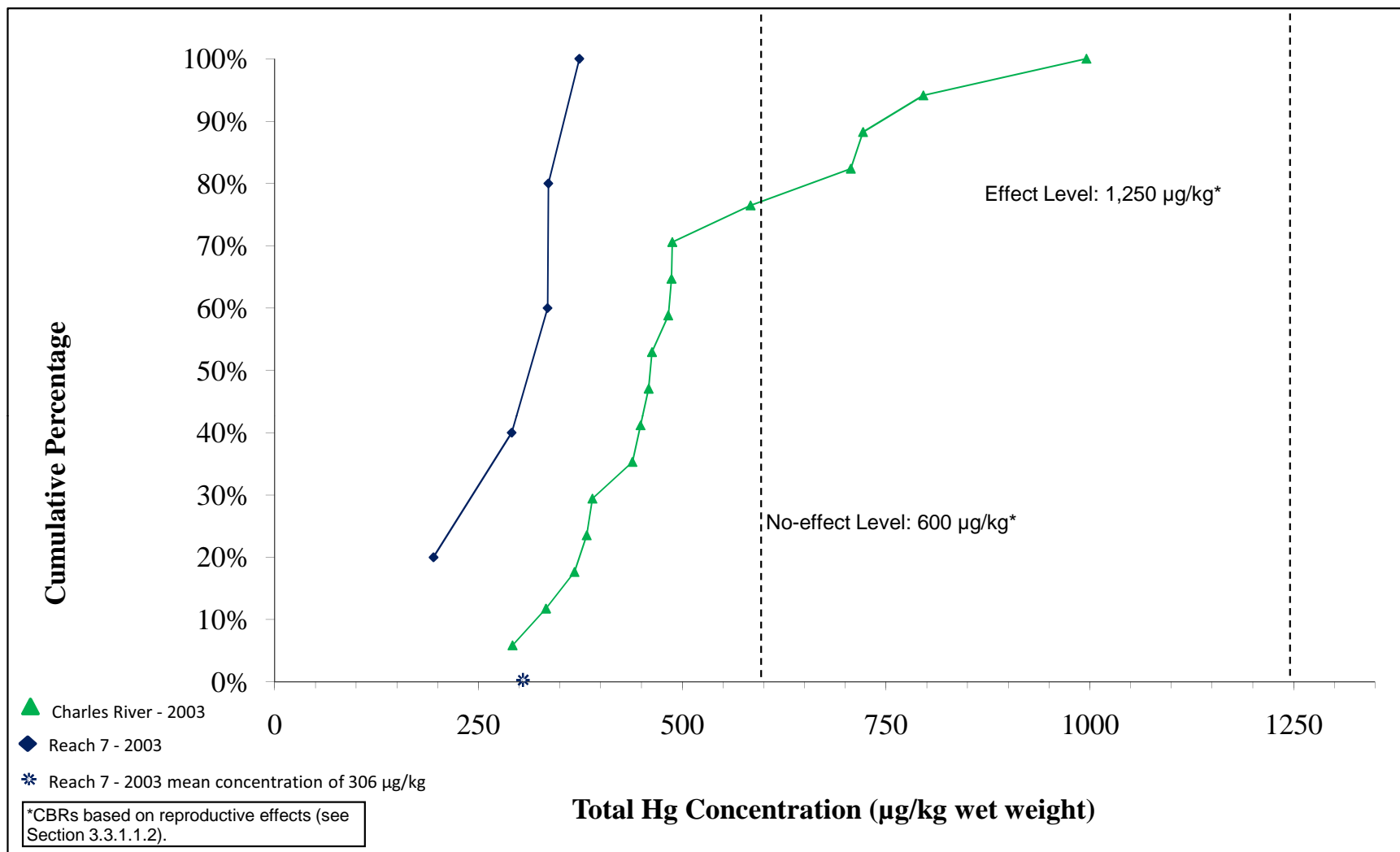
**Figure 4-27**  
**Cumulative Frequency Distribution of Total Mercury Concentrations in 2003 and 2004 Nestling**  
**and Adult Tree Swallow Blood from Reach 3 and Sudbury Reservoir Reference Area<sup>a</sup>**  
*Nyanza Superfund Site OU IV Sudbury River Mercury Contamination*



**Figure 4-28**  
**Cumulative Frequency Distribution of Total Mercury Concentrations in 2003 and 2004 Nestling**  
**and Adult Tree Swallow Blood from Reach 4 and Sudbury Reservoir Reference Area<sup>a</sup>**  
*Nyanza Superfund Site OU IV Sudbury River Mercury Contamination*

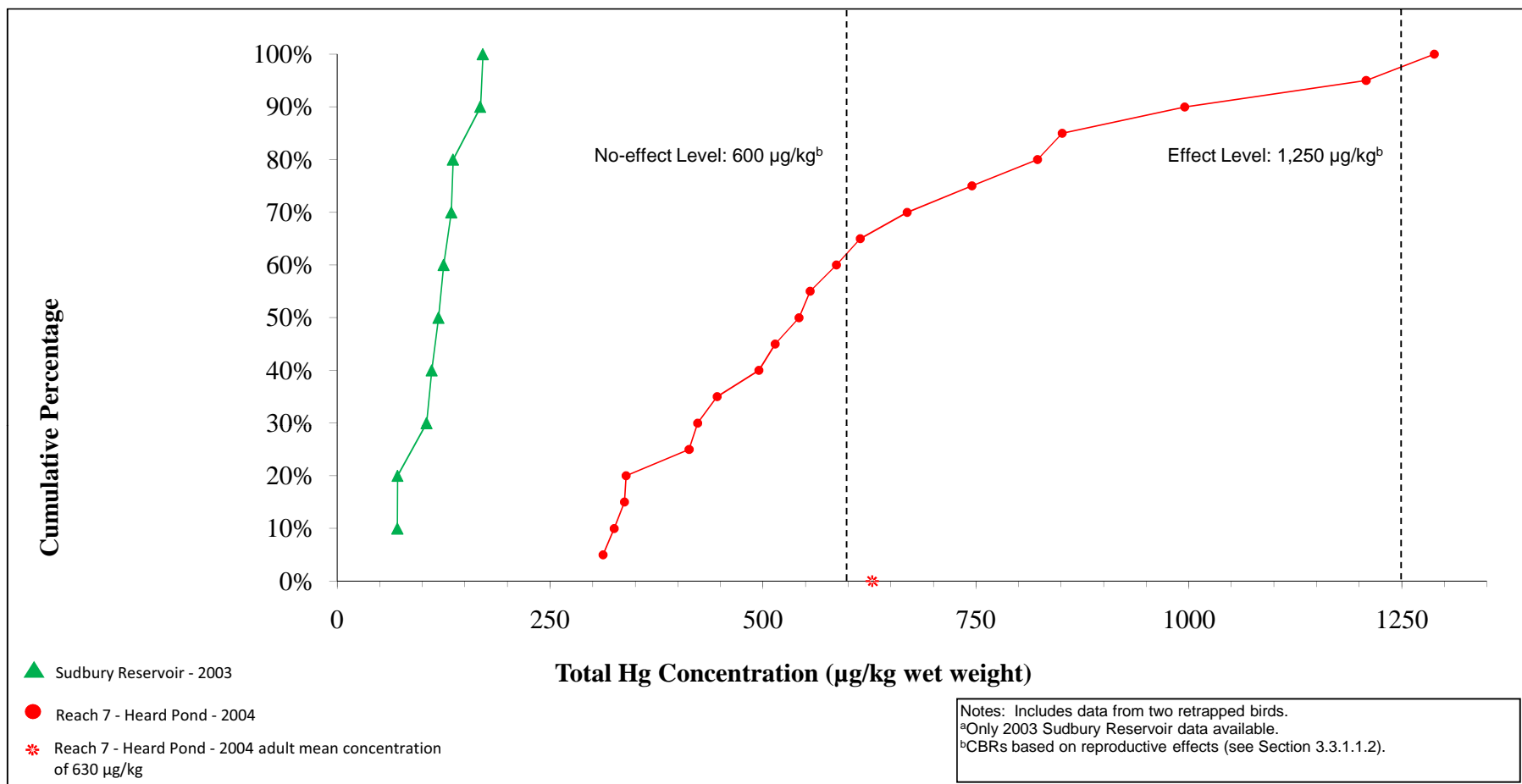


**Figure 4-29**  
**Cumulative Frequency Distribution of Total Mercury Concentrations in 2003 Tree Swallow Blood from Reach 7 and Charles River Reference Area**  
*Nyanza Superfund Site OU IV*  
*Sudbury River Mercury Contamination*

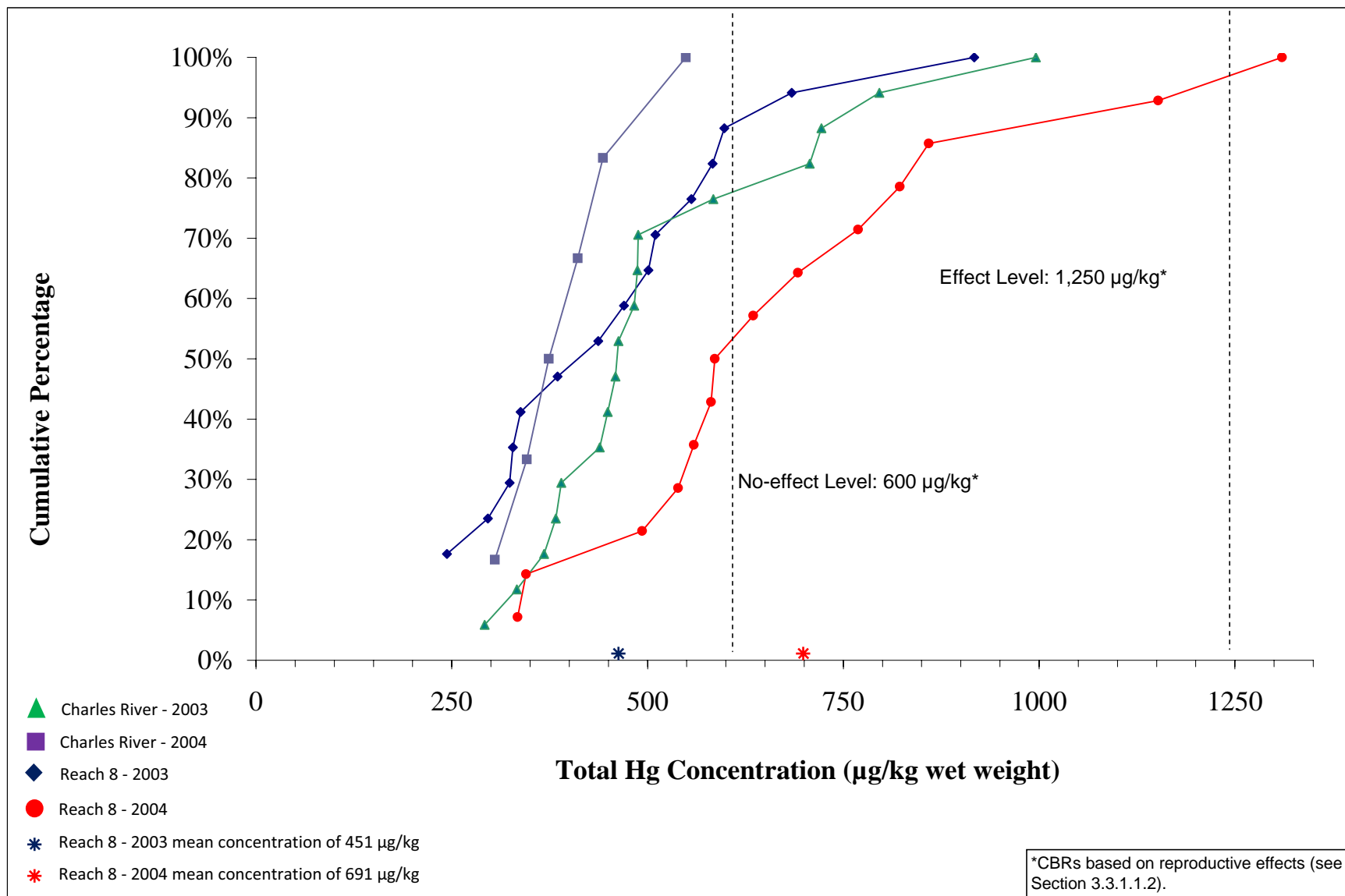




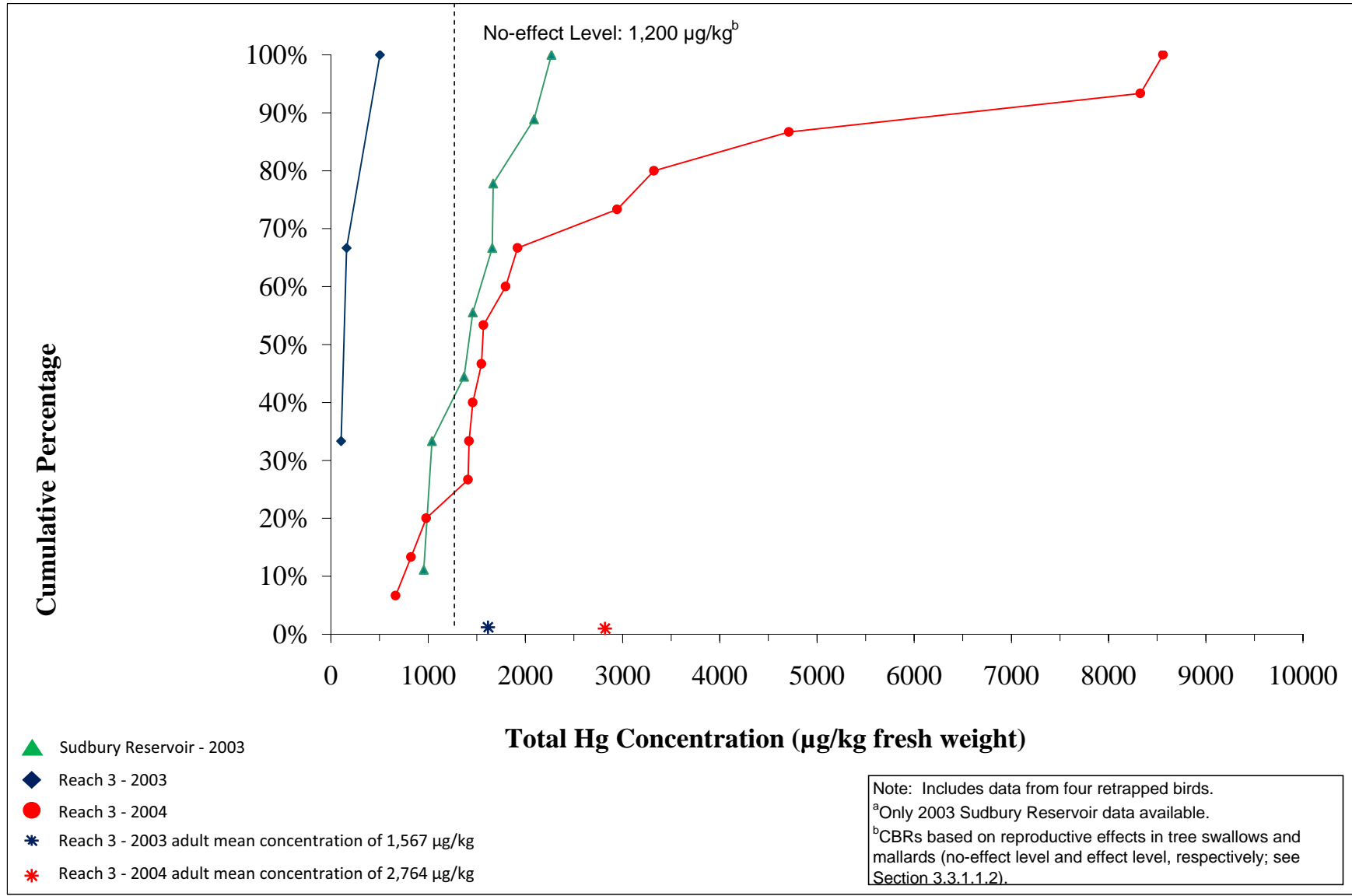
**Figure 4-30**  
**Cumulative Frequency Distribution of Total Mercury Concentrations in 2004**  
**Adult Tree Swallow Blood from Reach 7 - Heard Pond and Sudbury Reservoir Reference Area<sup>a</sup>**  
**Nyanza Superfund Site OU IV**  
**Sudbury River Mercury Contamination**



**Figure 4-31**  
**Cumulative Frequency Distribution of Total Mercury Concentrations in 2003 and 2004 Adult Tree Swallow Blood from Reach 8 and Charles River Reference Area**  
*Nyanza Superfund Site OU IV*  
**Sudbury River Mercury Contamination**



**Figure 4-32**  
**Cumulative Frequency Distribution of Total Mercury Concentrations in 2003 and 2004**  
**Adult Tree Swallow Feathers from Reach 3 and Sudbury Reservoir Reference Area<sup>a</sup>**  
**Nyanza Superfund Site OU IV Sudbury River Mercury Contamination**



**Figure 4-33**  
**Cumulative Frequency Distribution of Total Mercury Concentrations in 2003 and 2004**  
**Adult Tree Swallow Feathers from Reach 4 and Sudbury Reservoir Reference Area<sup>a</sup>**  
**Nyanza Superfund Site OU IV Sudbury River Mercury Contamination**

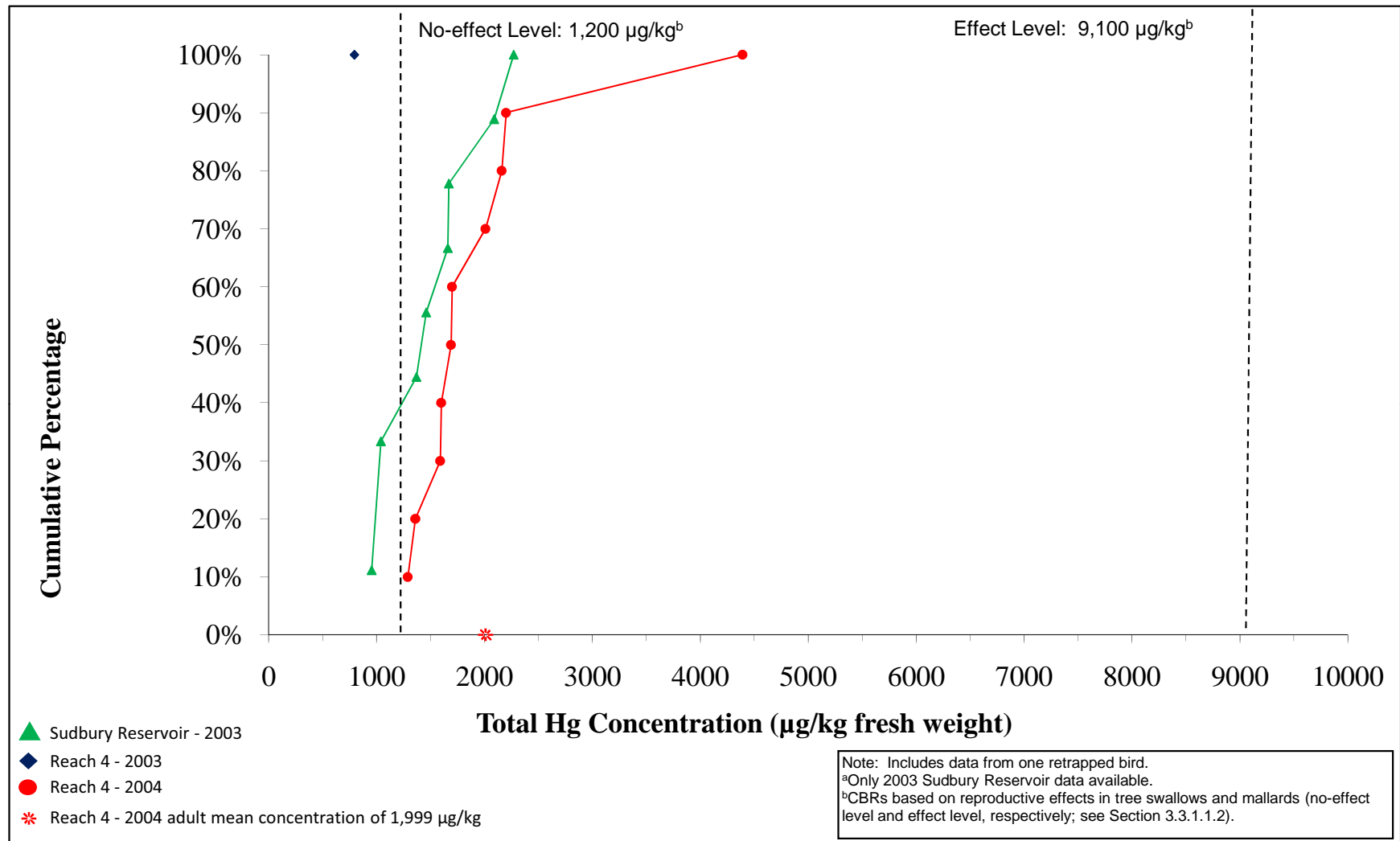
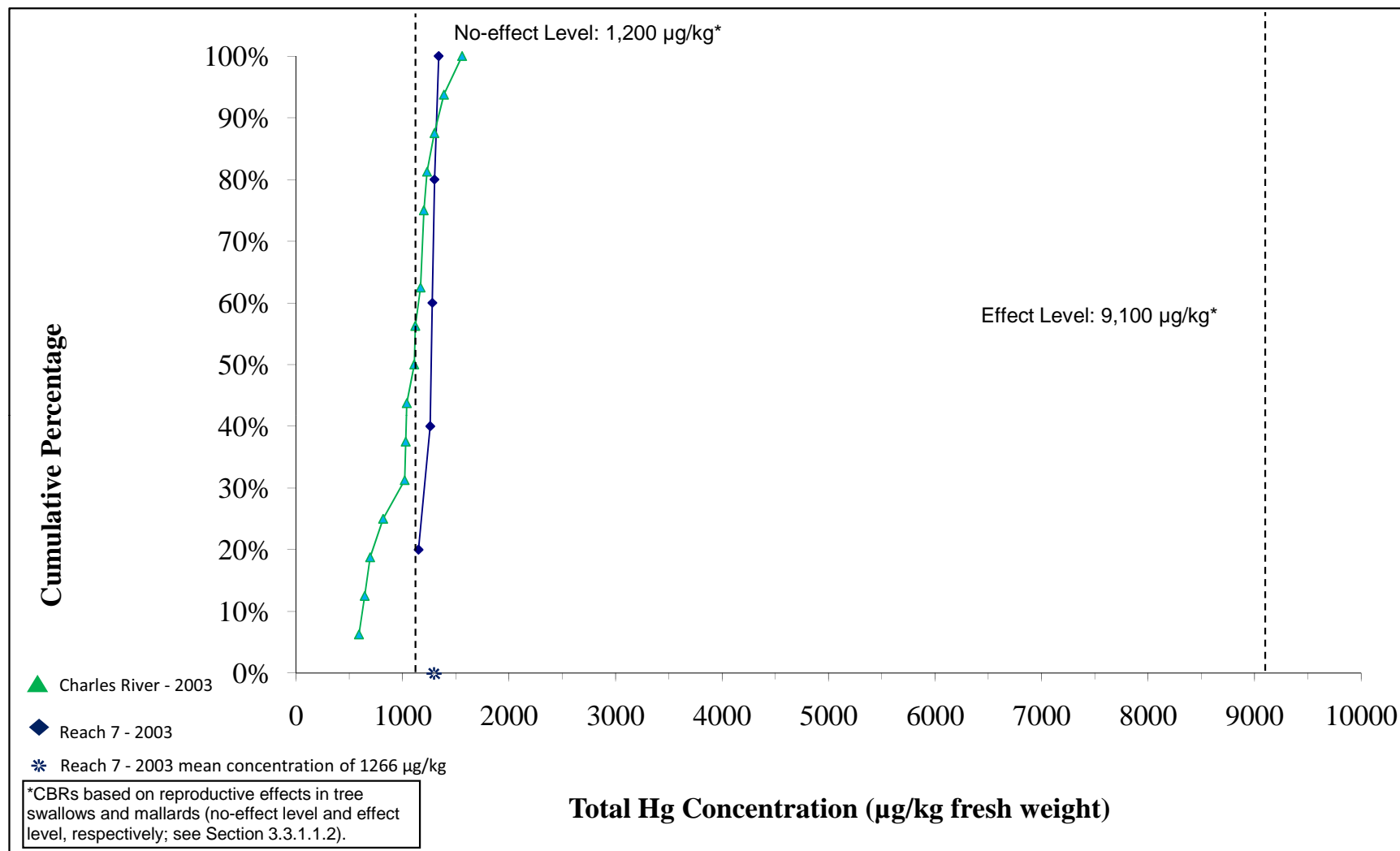
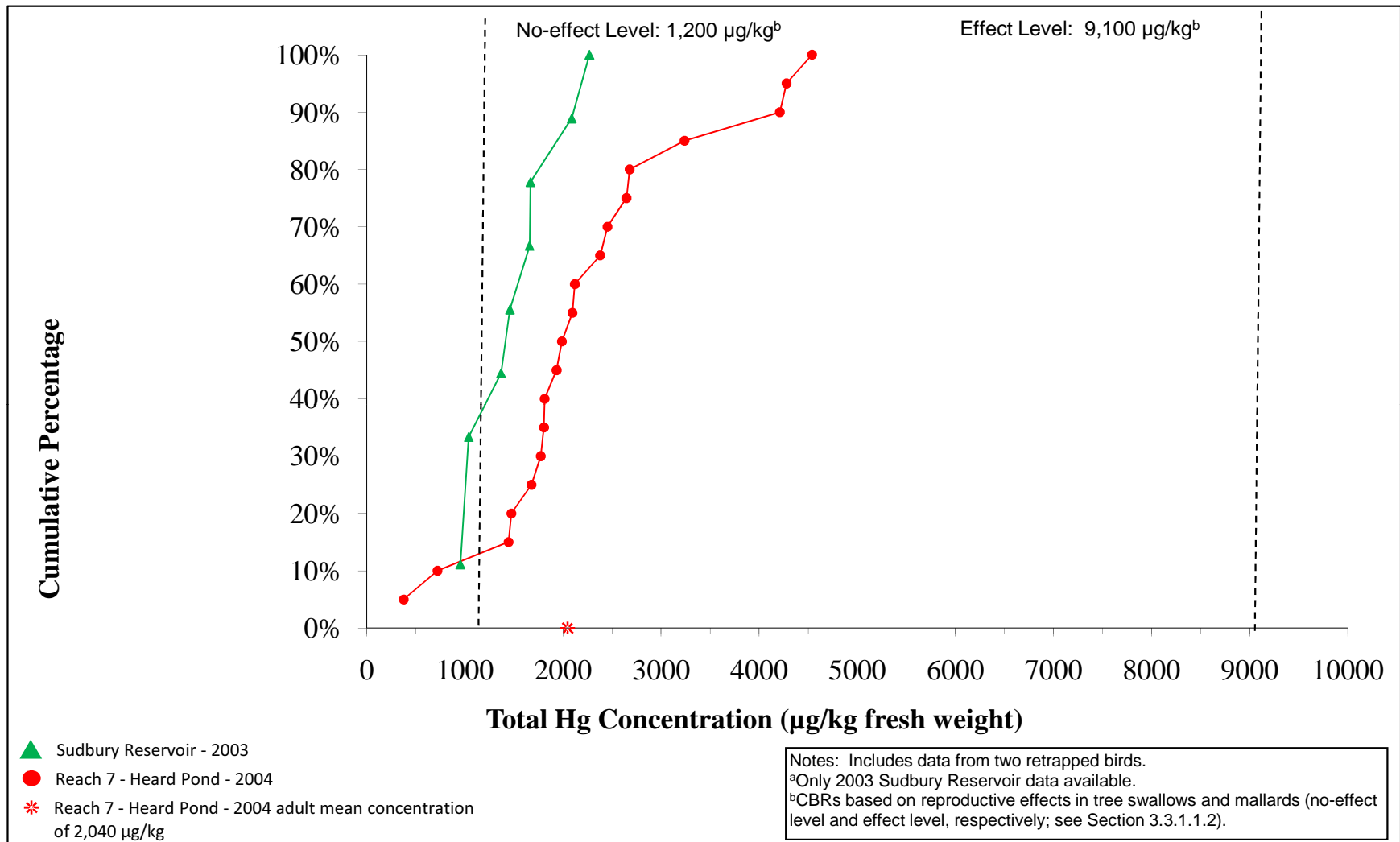


Figure 4-34

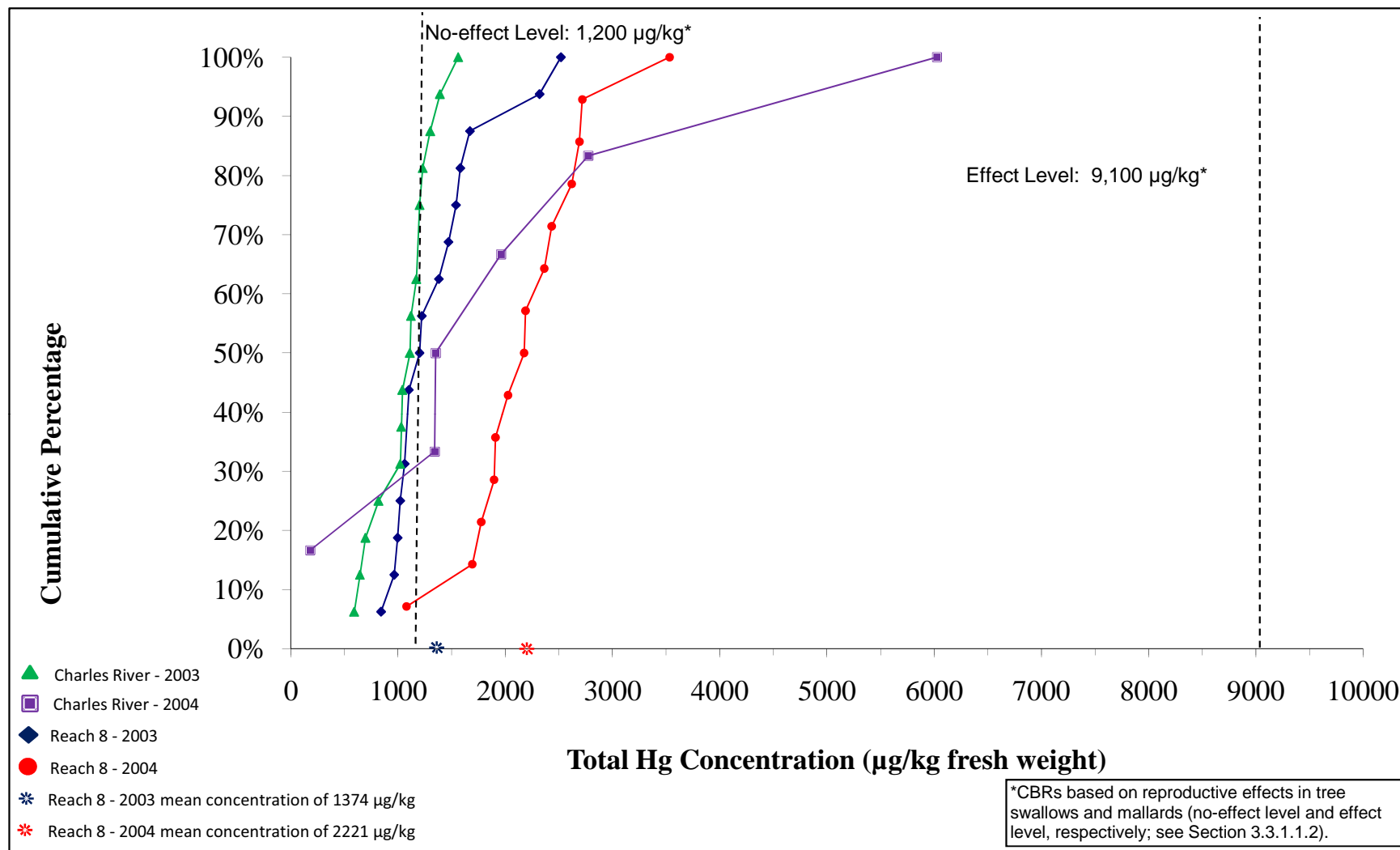
Cumulative Frequency Distribution of Total Mercury Concentrations in 2003 Tree Swallow Feathers from Reach 7 and Charles River Reference Area  
*Nyanza Superfund Site OU IV*  
*Sudbury River Mercury Contamination*



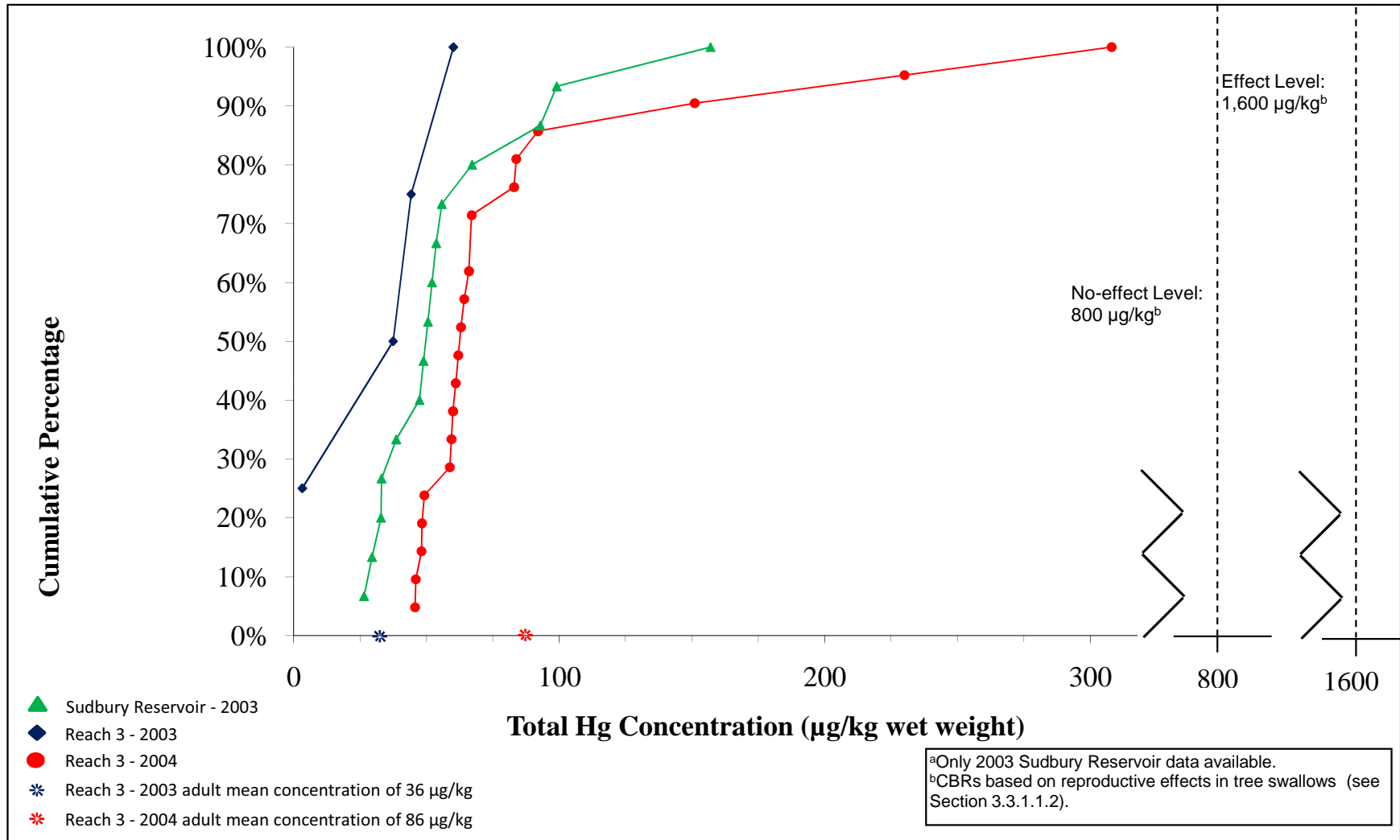
**Figure 4-35**  
**Cumulative Frequency Distribution of Total Mercury Concentrations in 2003 and 2004**  
**Adult Tree Swallow Feathers from Reach 7 - Heard Pond and Sudbury Reservoir Reference Area<sup>a</sup>**  
***Nyanza Superfund Site OU IV Sudbury River Mercury Contamination***



**Figure 4-36**  
**Cumulative Frequency Distribution of Total Mercury Concentrations in 2003 and 2004 Tree Swallow Feathers from Reach 8 and Charles River Reference Area**  
*Nyanza Superfund Site OU IV*  
**Sudbury River Mercury Contamination**

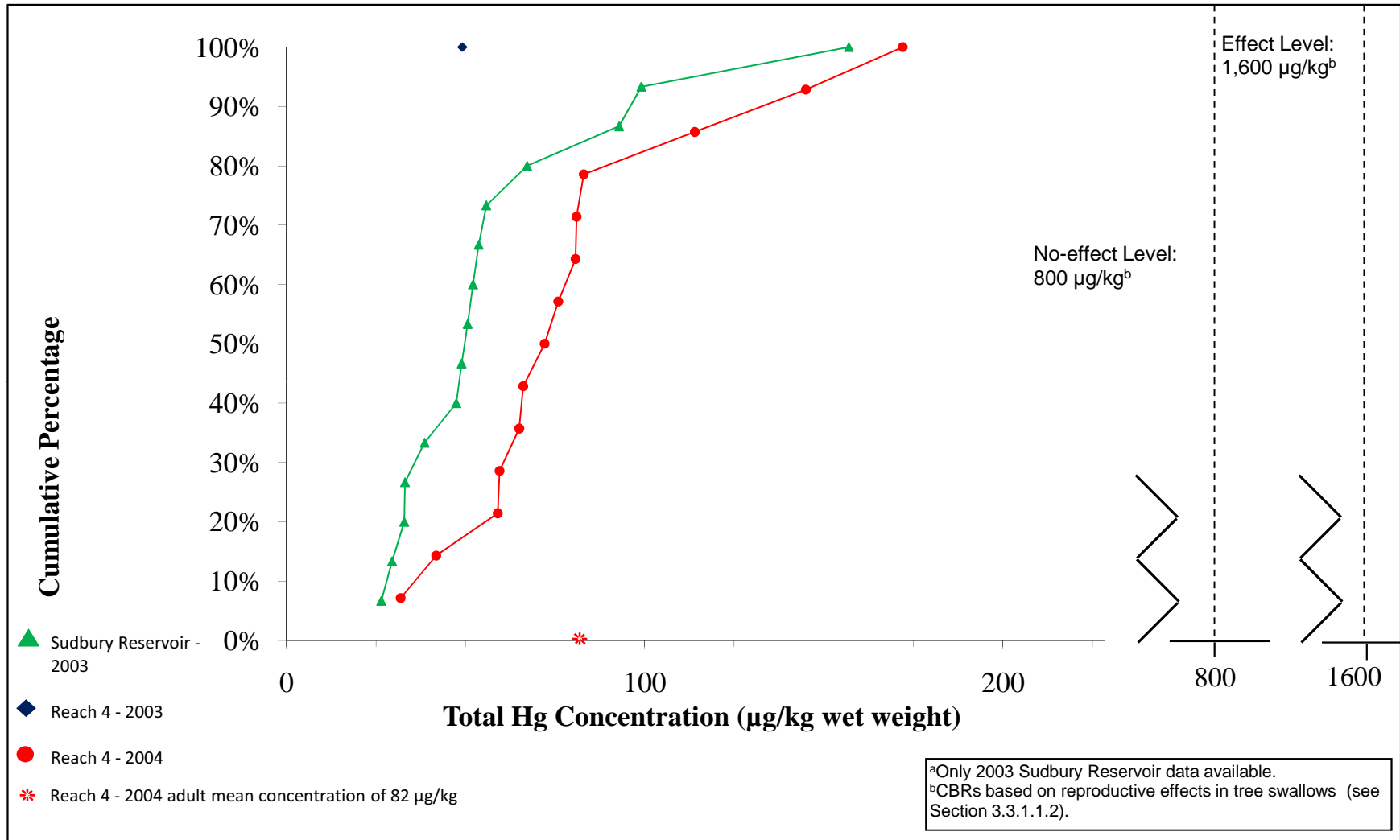


**Figure 4-37**  
**Cumulative Frequency Distribution of Total Mercury Concentrations in 2003 and 2004**  
**Tree Swallow Eggs from Reach 3 and Sudbury Reservoir Reference Area<sup>a</sup>**  
*Nyanza Superfund Site OU IV*  
**Sudbury River Mercury Contamination**

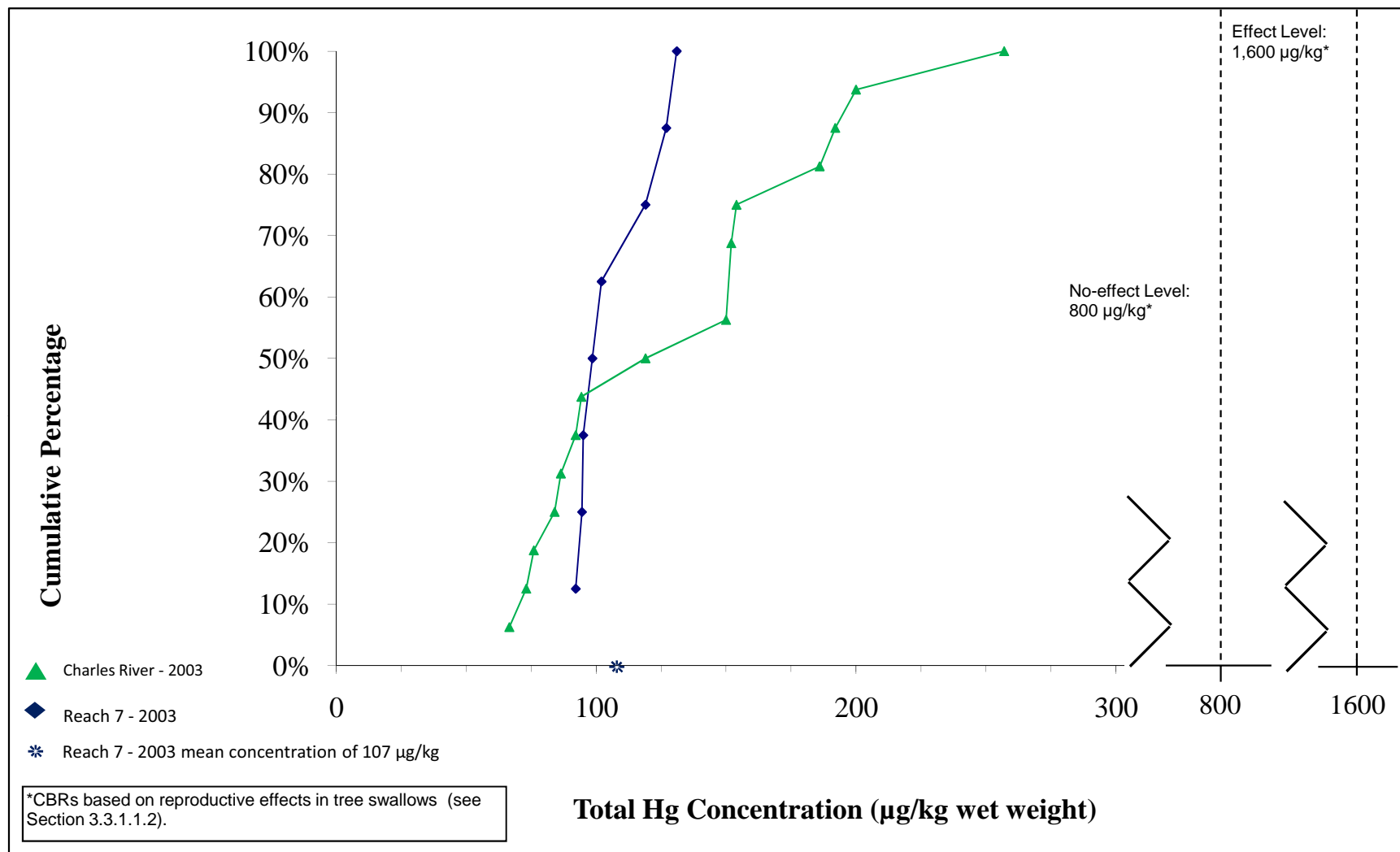




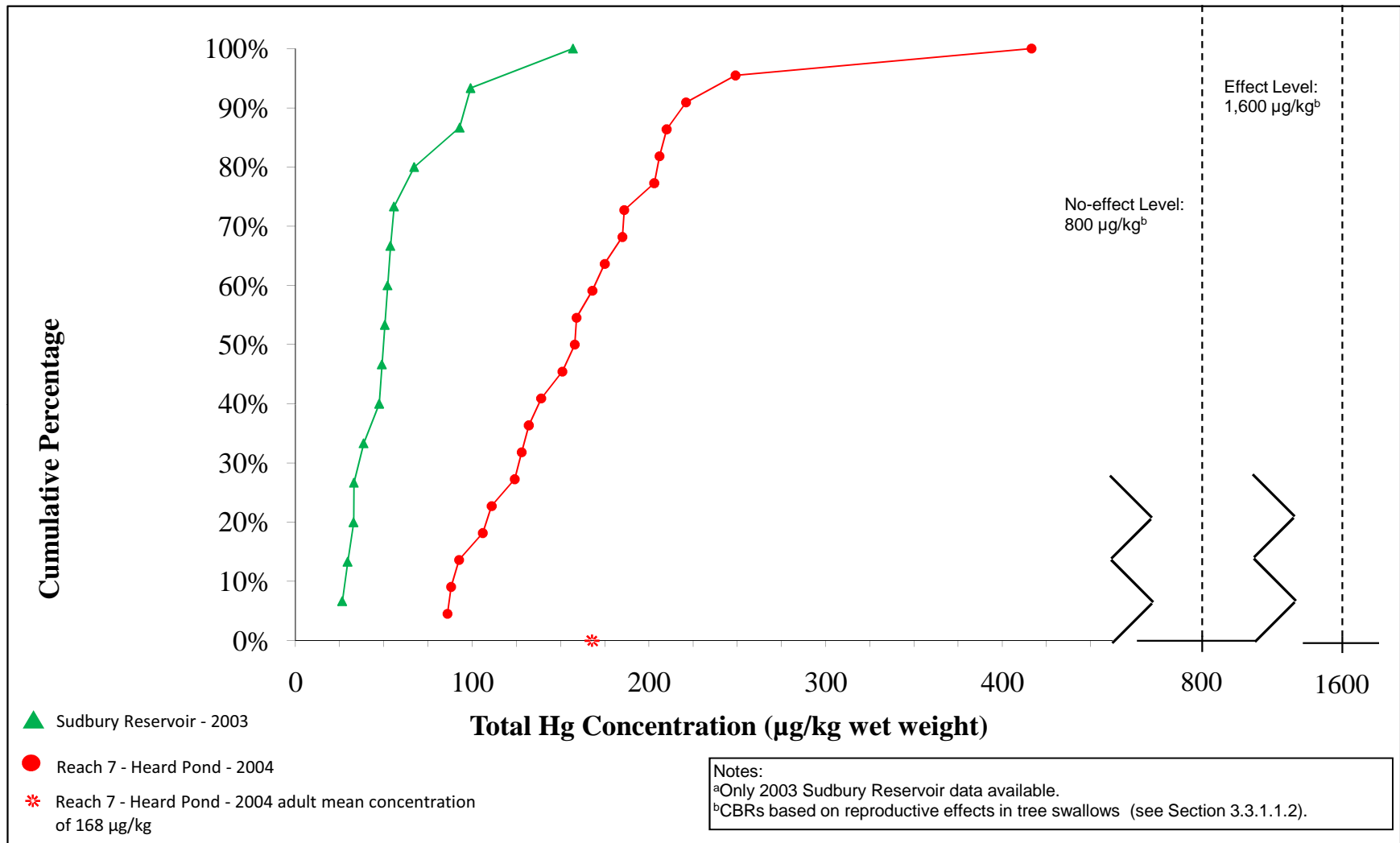
**Figure 4-38**  
**Cumulative Frequency Distribution of Total Mercury Concentrations in 2003 and 2004**  
**Tree Swallow Eggs from Reach 4 and Sudbury Reservoir Reference Area<sup>a</sup>**  
*Nyanza Superfund Site OU IV*  
*Sudbury River Mercury Contamination*



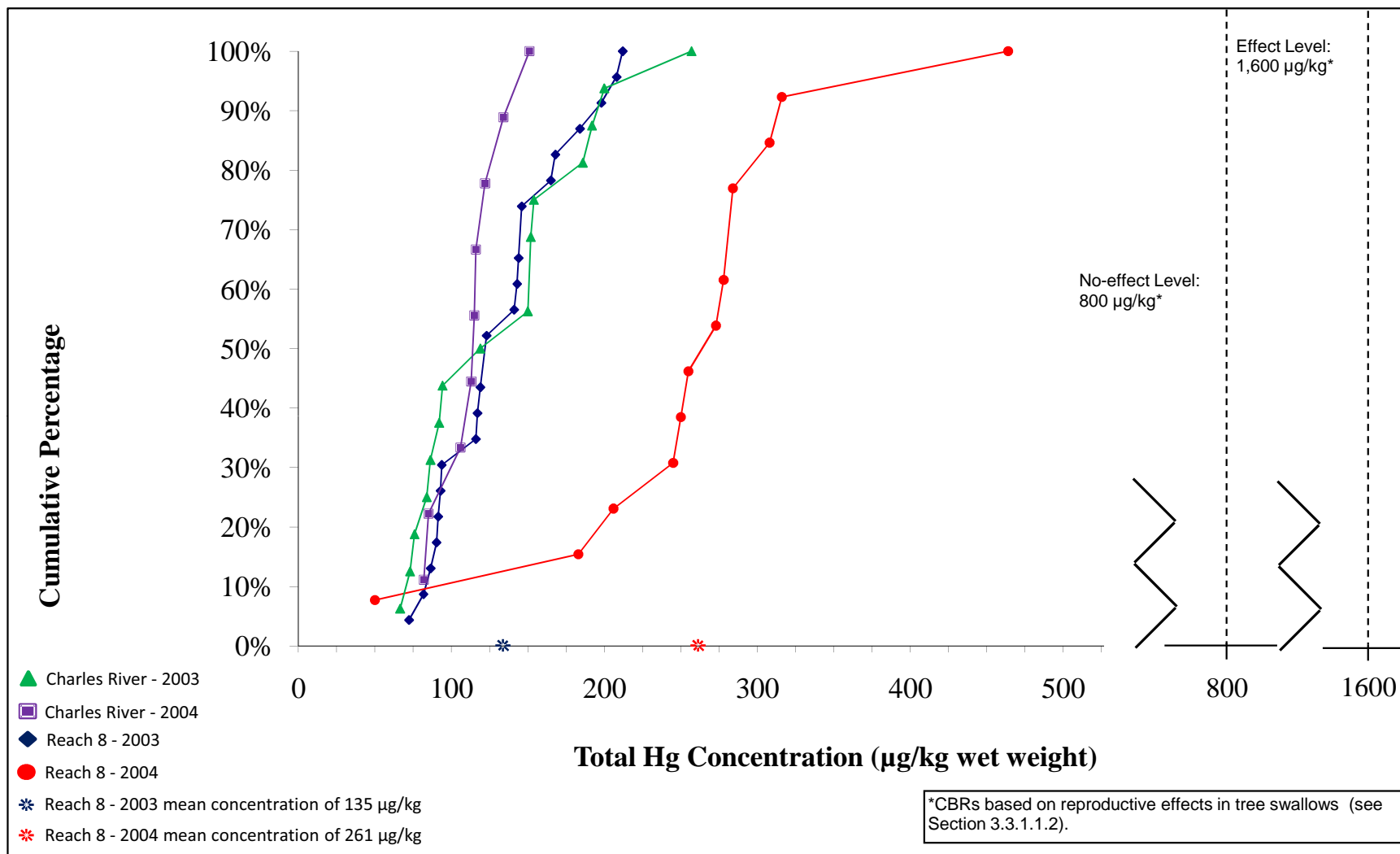
**Figure 4-39**  
**Cumulative Frequency Distribution of Total Mercury Concentrations in 2003 Tree Swallow Eggs from Reach 7 and Charles River Reference Area**  
*Nyanza Superfund Site OU IV*  
*Sudbury River Mercury Contamination*

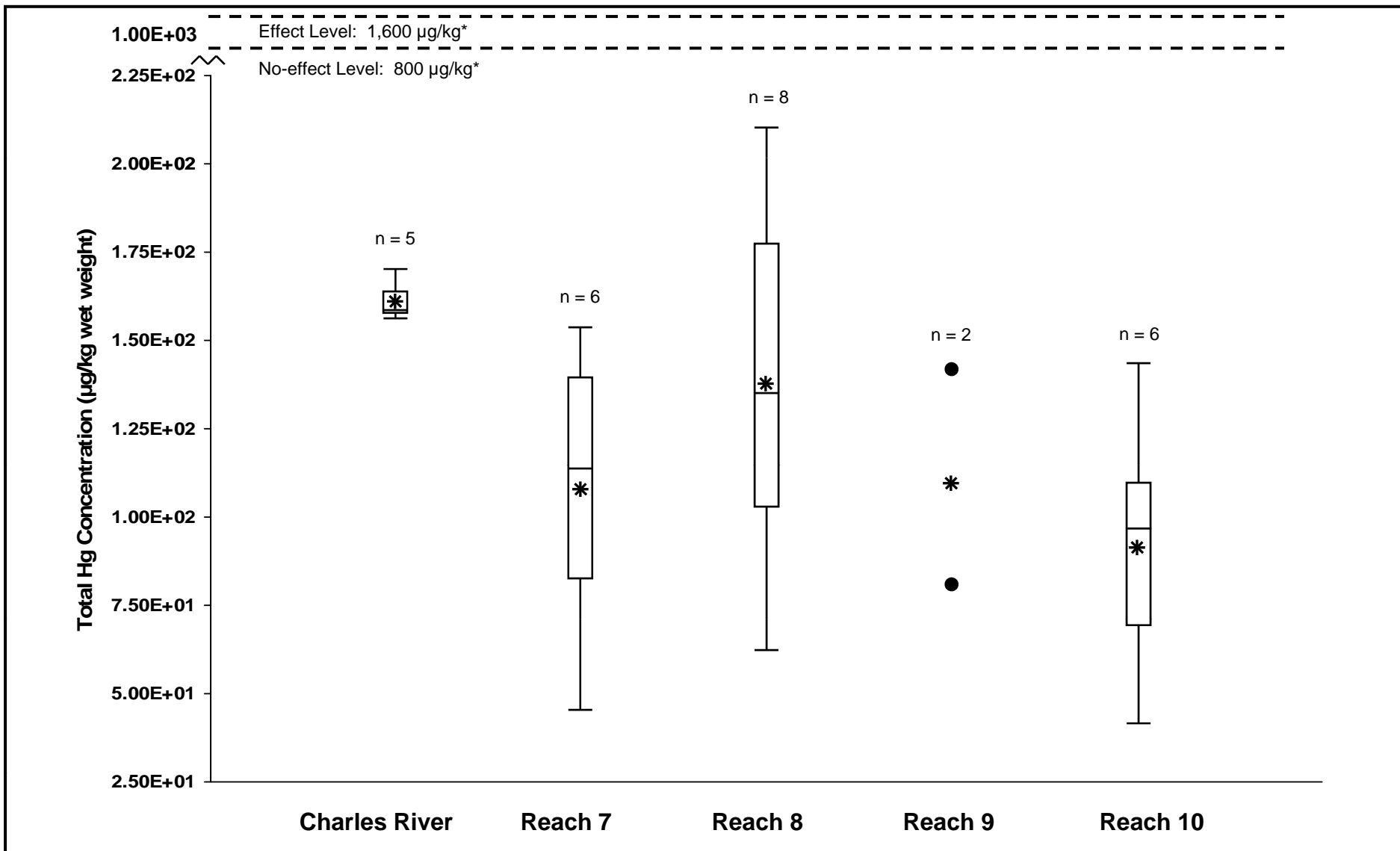


**Figure 4-40**  
**Cumulative Frequency Distribution of Total Mercury Concentrations in 2004**  
**Tree Swallow Eggs from Reach 7 - Heard Pond and Sudbury Reservoir Reference Area<sup>a</sup>**  
**Nyanza Superfund Site OU IV Sudbury River Mercury Contamination**



**Figure 4-41**  
**Cumulative Frequency Distribution of Total Mercury Concentrations in 2003 and 2004 Tree Swallow Eggs from Reach 8 and Charles River Reference Area**  
*Nyanza Superfund Site OU IV*  
*Sudbury River Mercury Contamination*

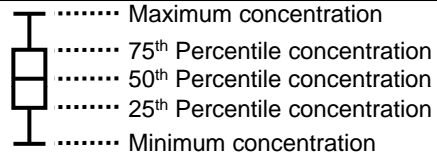




**Legend:**

● - Egg sample

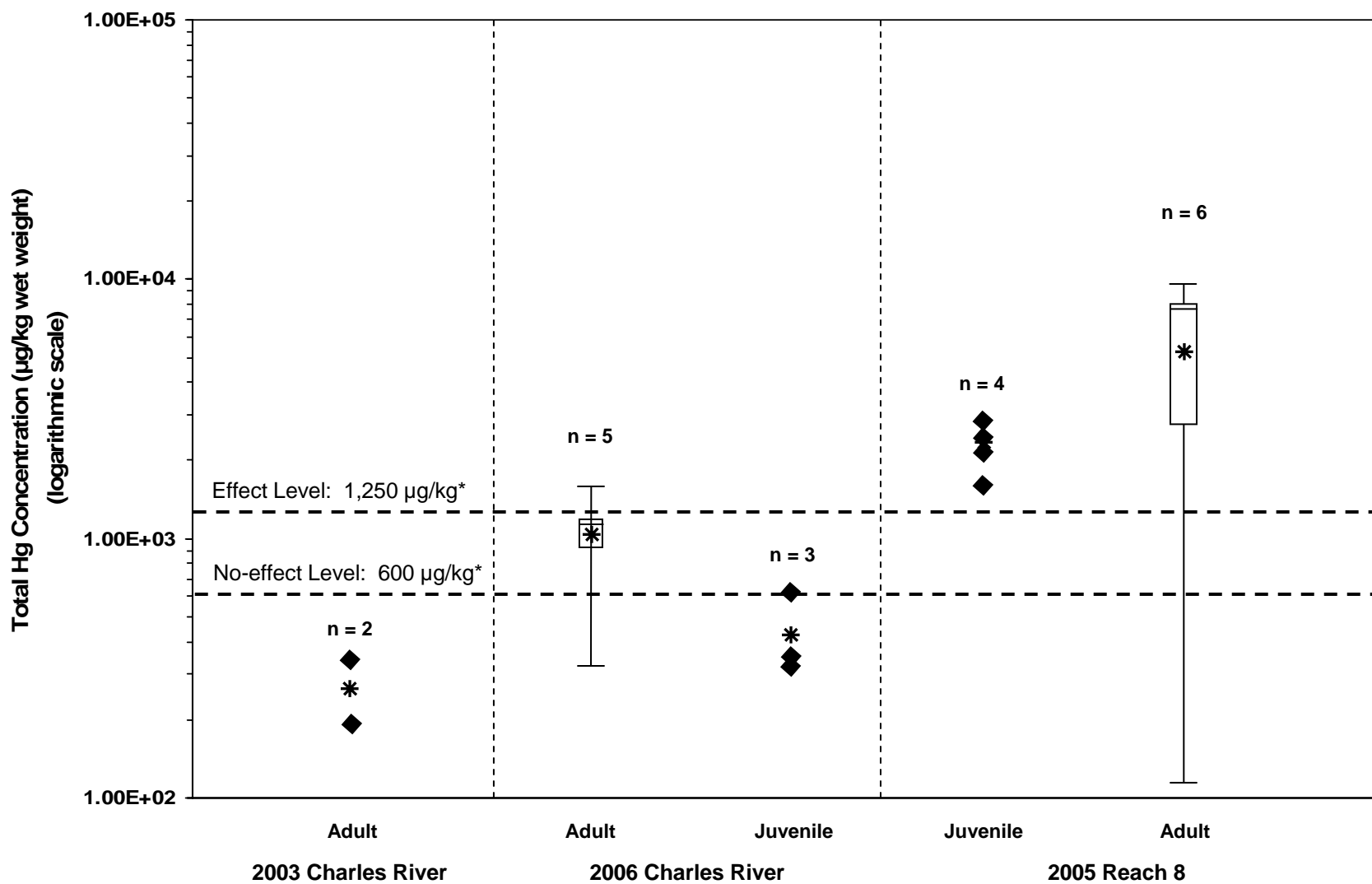
\* - Mean Concentration



\*CBRs based on reproductive effects (see Section 3.3.1.1.2).

***Nyanza Superfund Site OU IV  
Sudbury River Mercury Contamination***

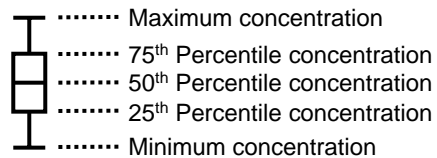
**Figure 4-42  
Total Mercury Concentrations in 2003  
Eastern Kingbird Egg Samples Compared with CBRs**



**Legend:**

◆ - Blood sample

\* - Mean Concentration

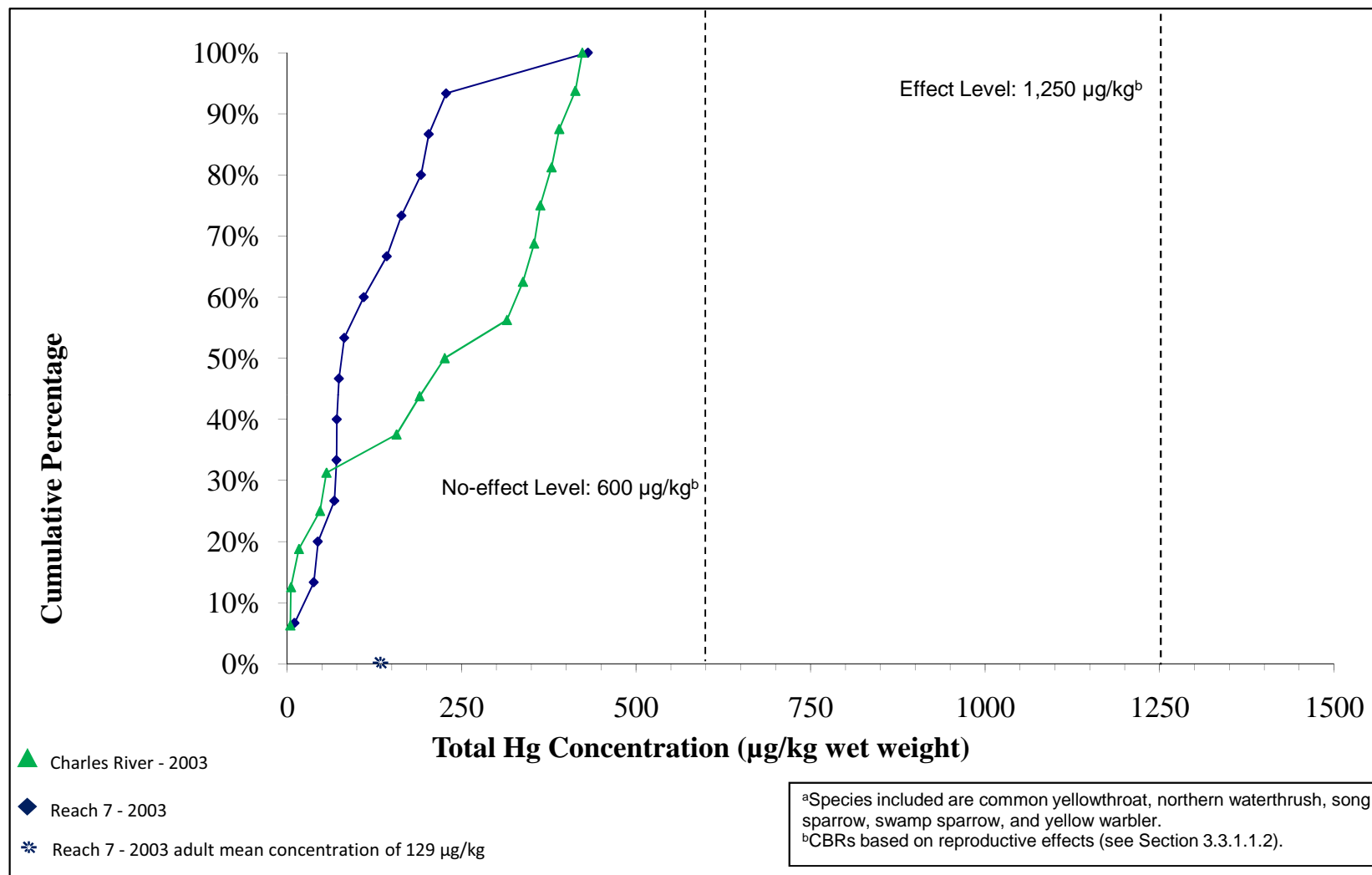


\*CBRs based on reproductive effects (see Section 3.3.1.1.2).

***Nyanza Superfund Site OU IV  
 Sudbury River Mercury Contamination***

**Figure 4-43  
 Total Mercury Concentrations in 2003, 2005, and 2006  
 Red-Winged Blackbird Blood Samples Compared with CBRs**

**Figure 4-44**  
**Cumulative Frequency Distribution of Total Mercury Concentrations in 2003 Marsh Bird<sup>a</sup> Blood from Reach 7 and Charles River**  
**Reference Area**  
*Nyanza Superfund Site OU IV*  
*Sudbury River Mercury Contamination*



**Figure 4-45**  
**Cumulative Frequency Distribution of Total Mercury Concentrations in 2004 Marsh Bird<sup>a</sup> Blood from Reach 7 - Heard Pond**  
**Nyanza Superfund Site OU IV**  
**Sudbury River Mercury Contamination**

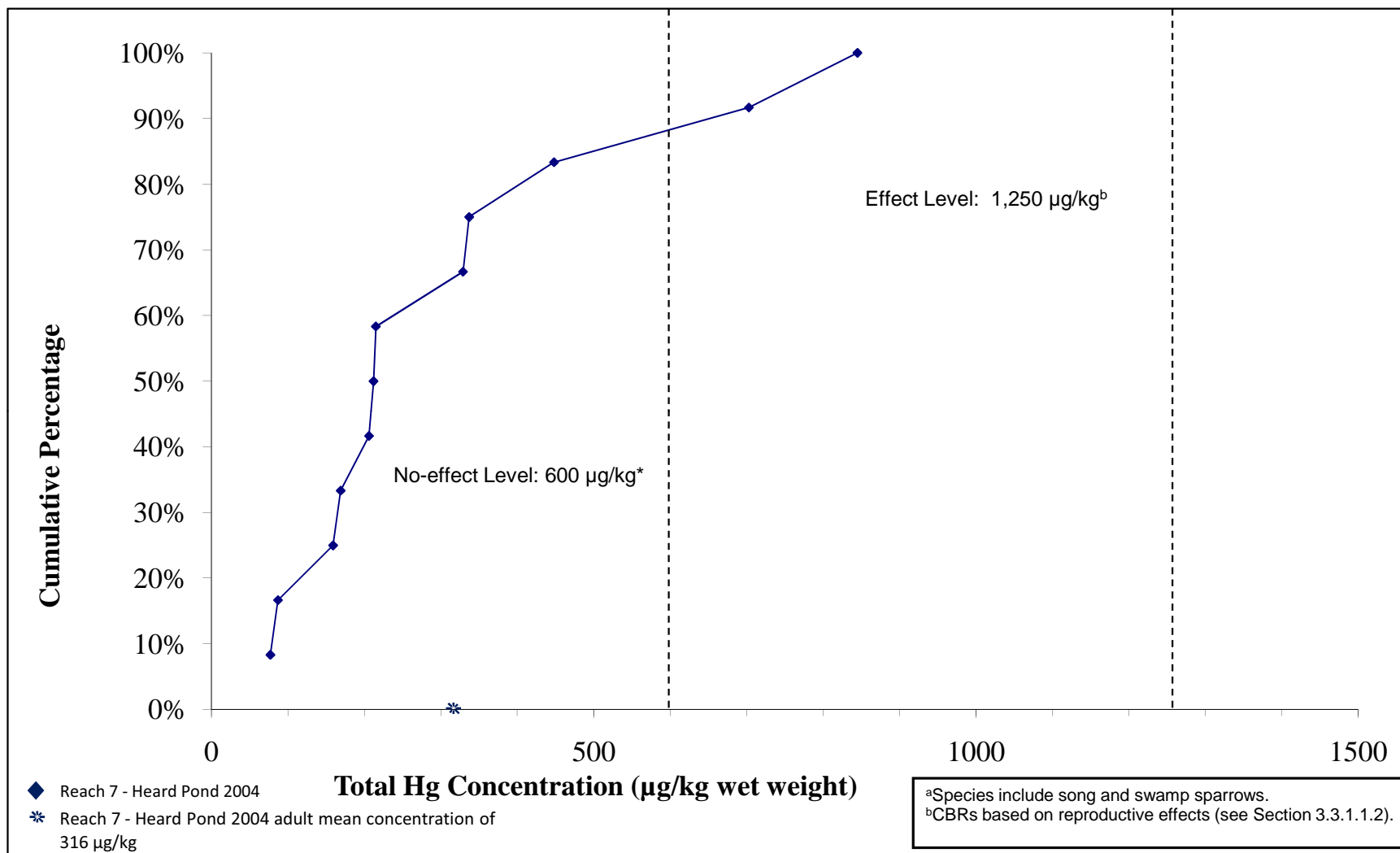




Figure 4-46

Cumulative Frequency Distribution of Total Mercury Concentrations in 2003 and 2004 Marsh Bird<sup>a</sup> Blood from Reach 8 and Charles River  
Reference Area

*Nyanza Superfund Site OU IV*  
*Sudbury River Mercury Contamination*

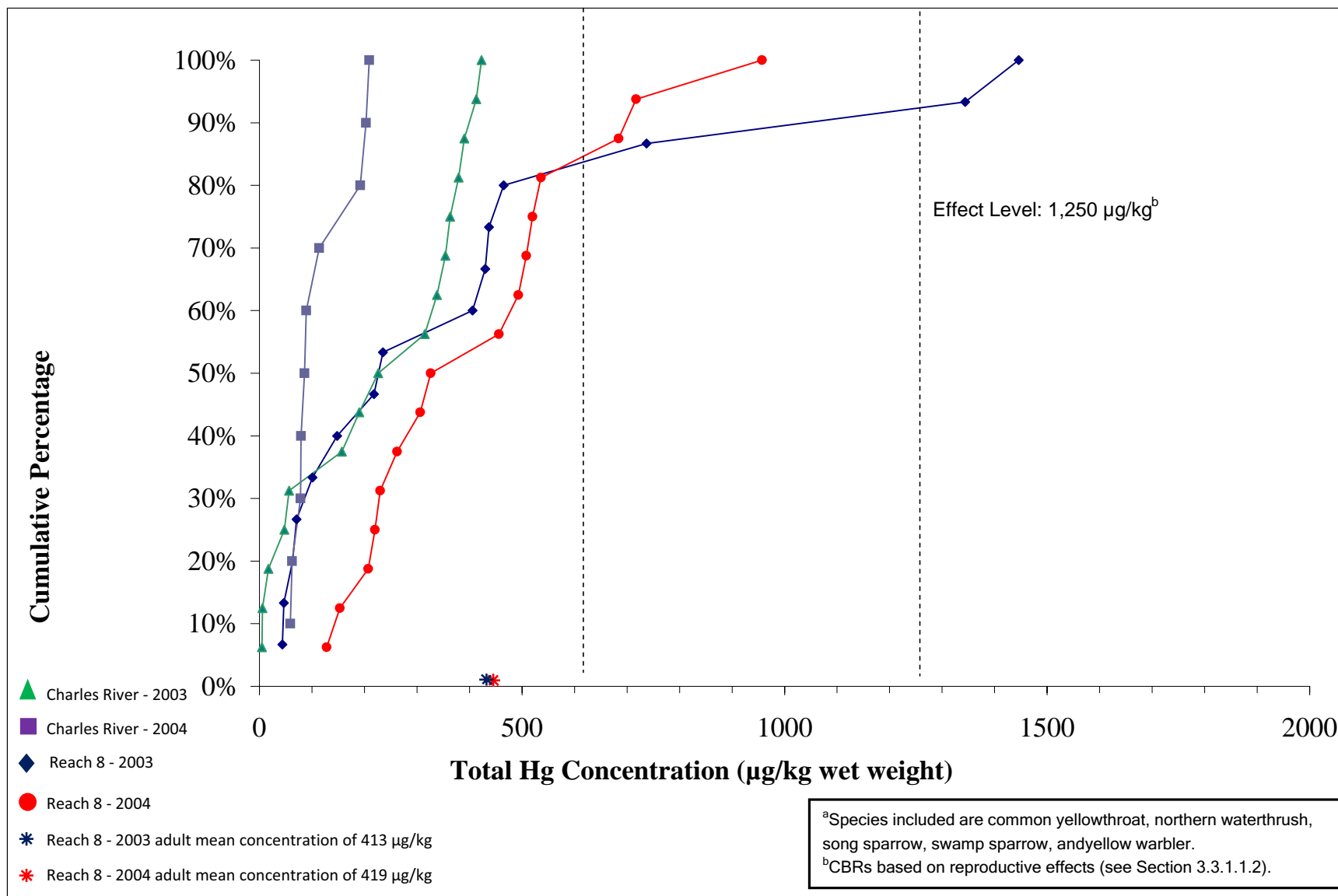


Figure 4-47

Cumulative Frequency Distribution of Total Mercury Concentrations in 2003 Marsh Bird<sup>a</sup> Feathers from Reach 7 and Charles River Reference Area

*Nyanza Superfund Site OU IV  
Sudbury River Mercury Contamination*

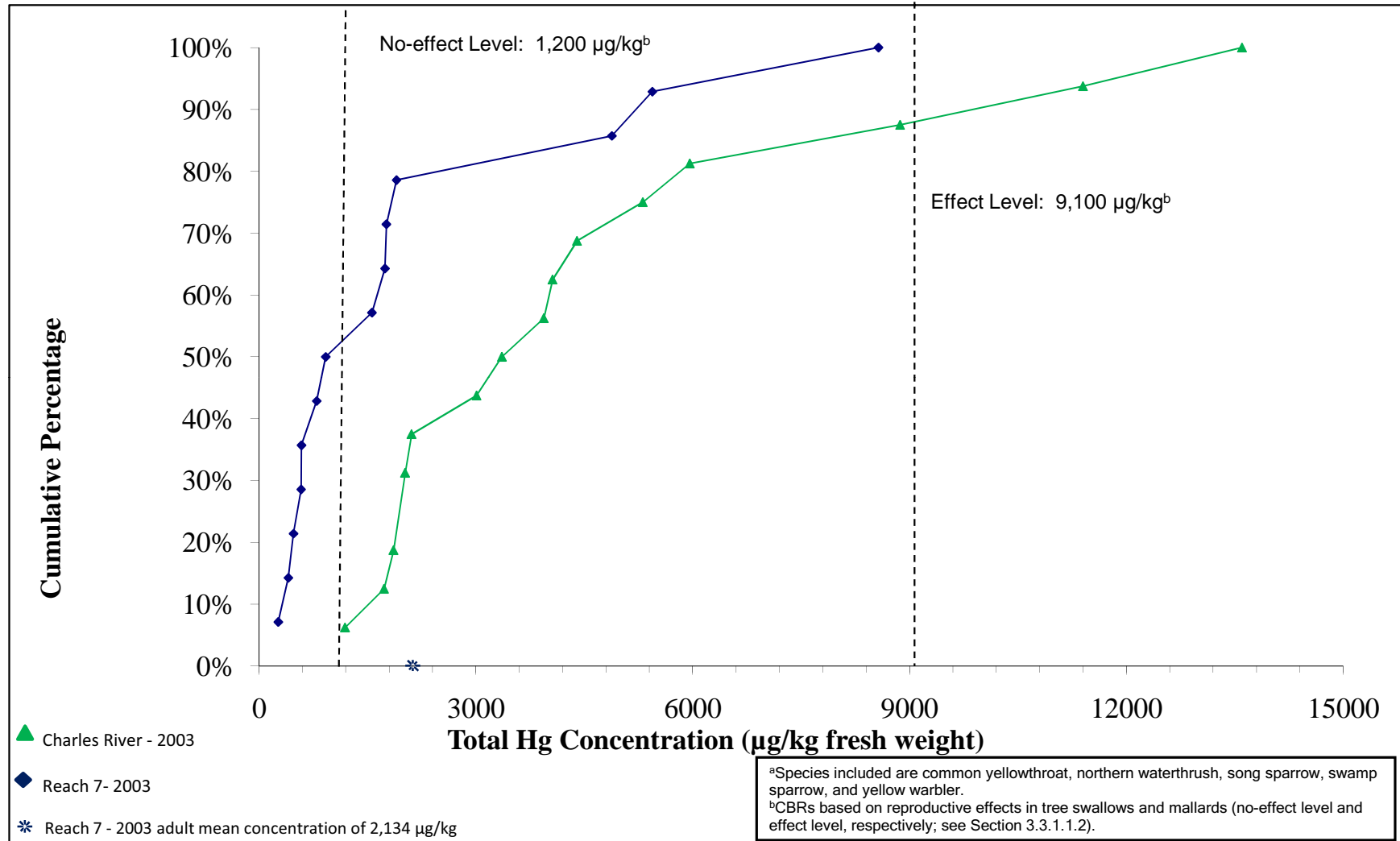
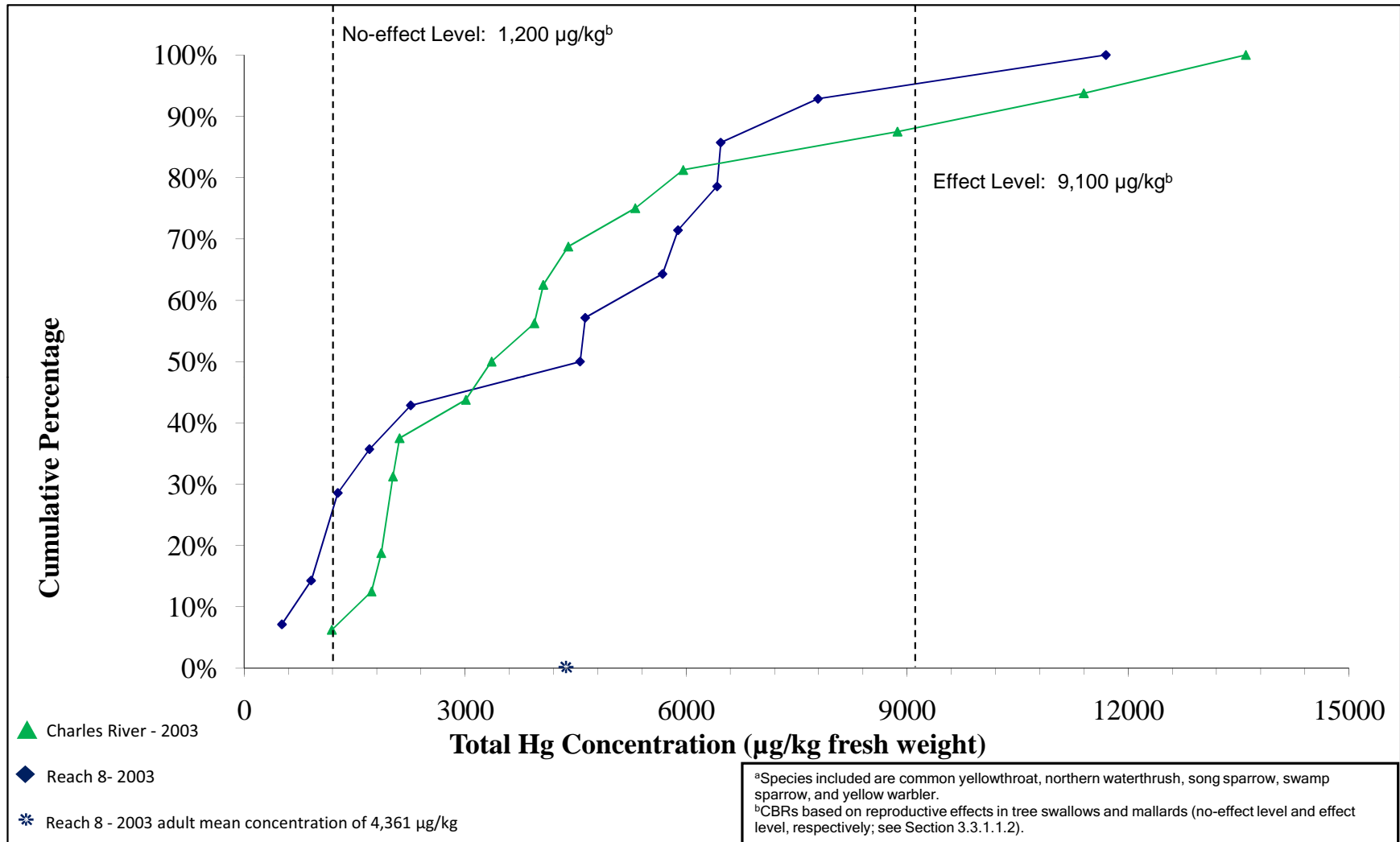
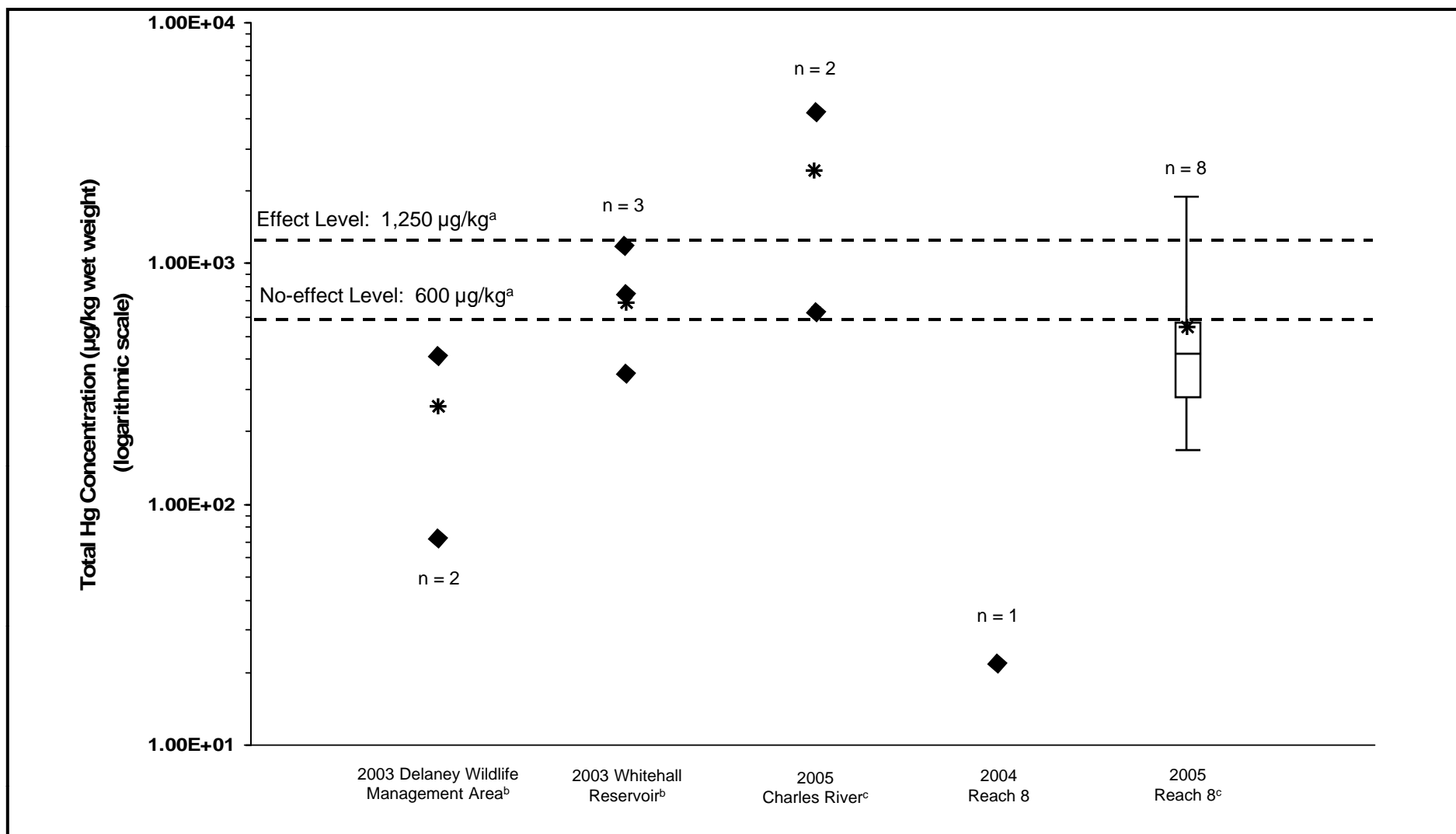


Figure 4-48

Cumulative Frequency Distribution of Total Mercury Concentrations in 2003 Marsh Bird<sup>a</sup>Feathers from Reach 8 and Charles River Reference Area  
 Nyanza Superfund Site OU IV  
 Sudbury River Mercury Contamination

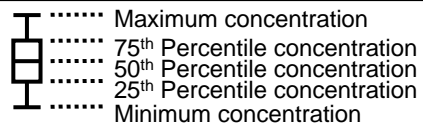




**Legend:**

◆ - Blood sample

\* - Mean Concentration



Note: all blood samples from adult birds except for one sample in Whitehall Reservoir.

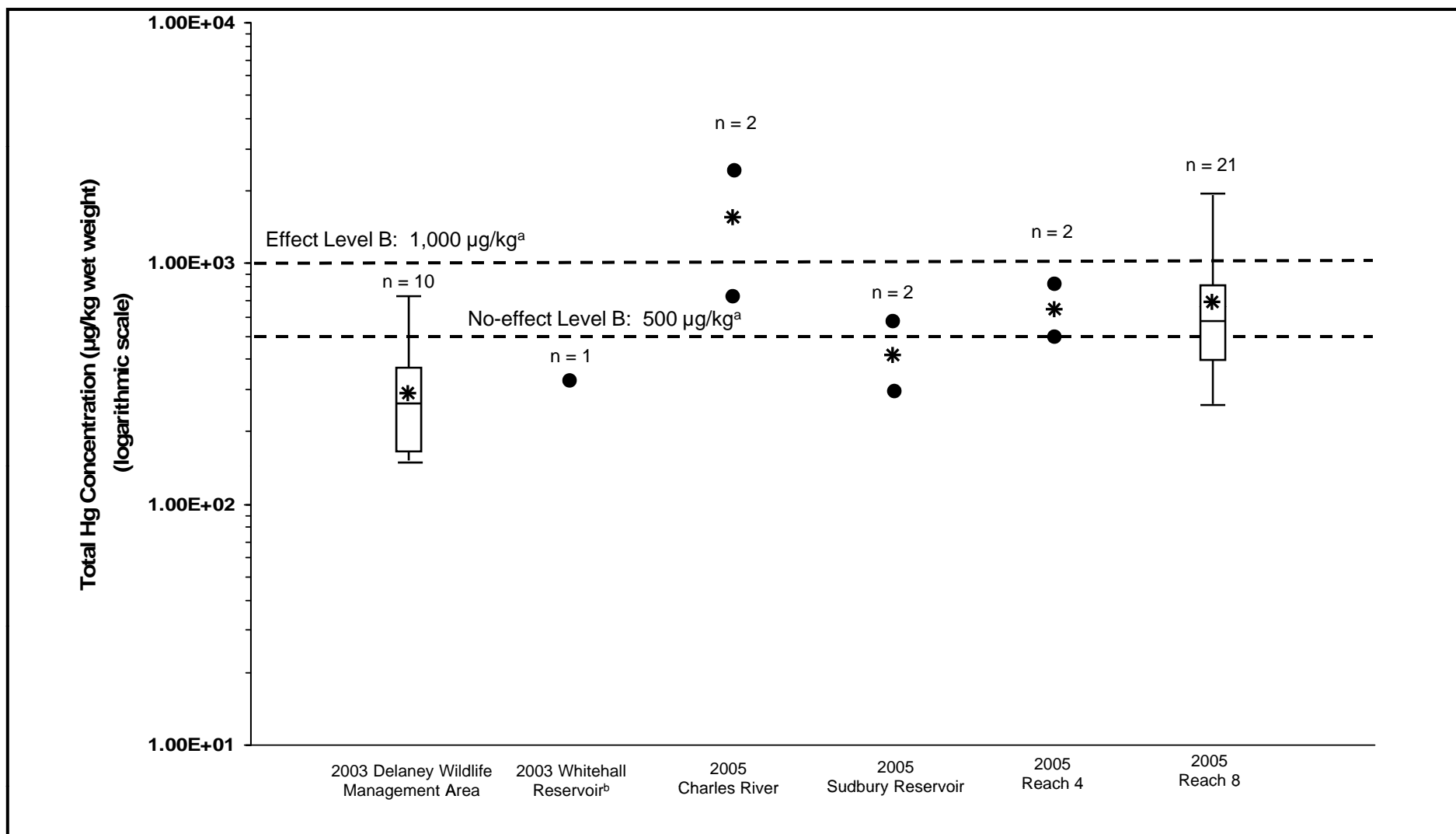
<sup>a</sup>CBRs based on reproductive effects (see Section 3.3.1.1.2).

<sup>b</sup>No comparable site data collected in 2003.

<sup>c</sup>Includes data from retrapped birds (Charles River – 1 sample; Reach 8 – 4 samples).

**Nyanza Superfund Site OU IV  
Sudbury River Mercury Contamination**

**Figure 4-49  
Total Mercury Concentrations in 2003, 2004, and 2005  
Hooded Merganser Blood Samples  
Compared with CBRs**



**Legend:**

● - Egg sample

\* - Mean Concentration

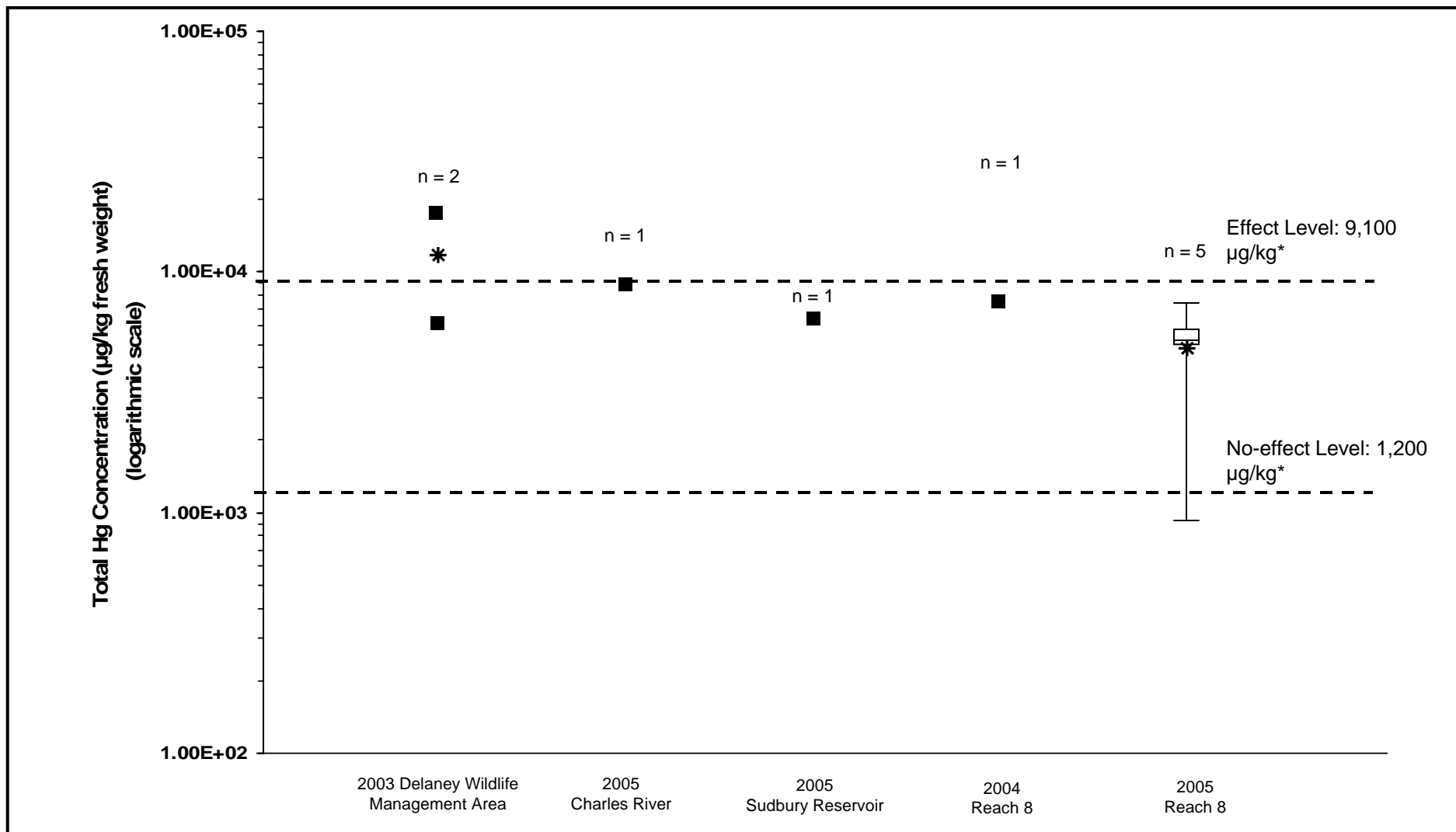
..... Maximum concentration  
 ..... 75<sup>th</sup> Percentile concentration  
 ..... 50<sup>th</sup> Percentile concentration  
 ..... 25<sup>th</sup> Percentile concentration  
 ..... Minimum concentration

<sup>a</sup>CBRs based on reproductive effects (see Section 3.3.1.1.2).

<sup>b</sup>Includes data from a retrapped bird.

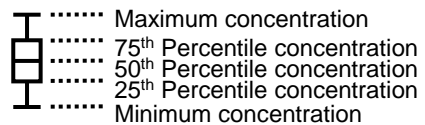
***Nyanza Superfund Site OU IV  
Sudbury River Mercury Contamination***

**Figure 4-50  
Total Mercury Concentrations in 2003 and 2005  
Hooded Merganser Egg Samples  
Compared with CBRs**



**Legend:**

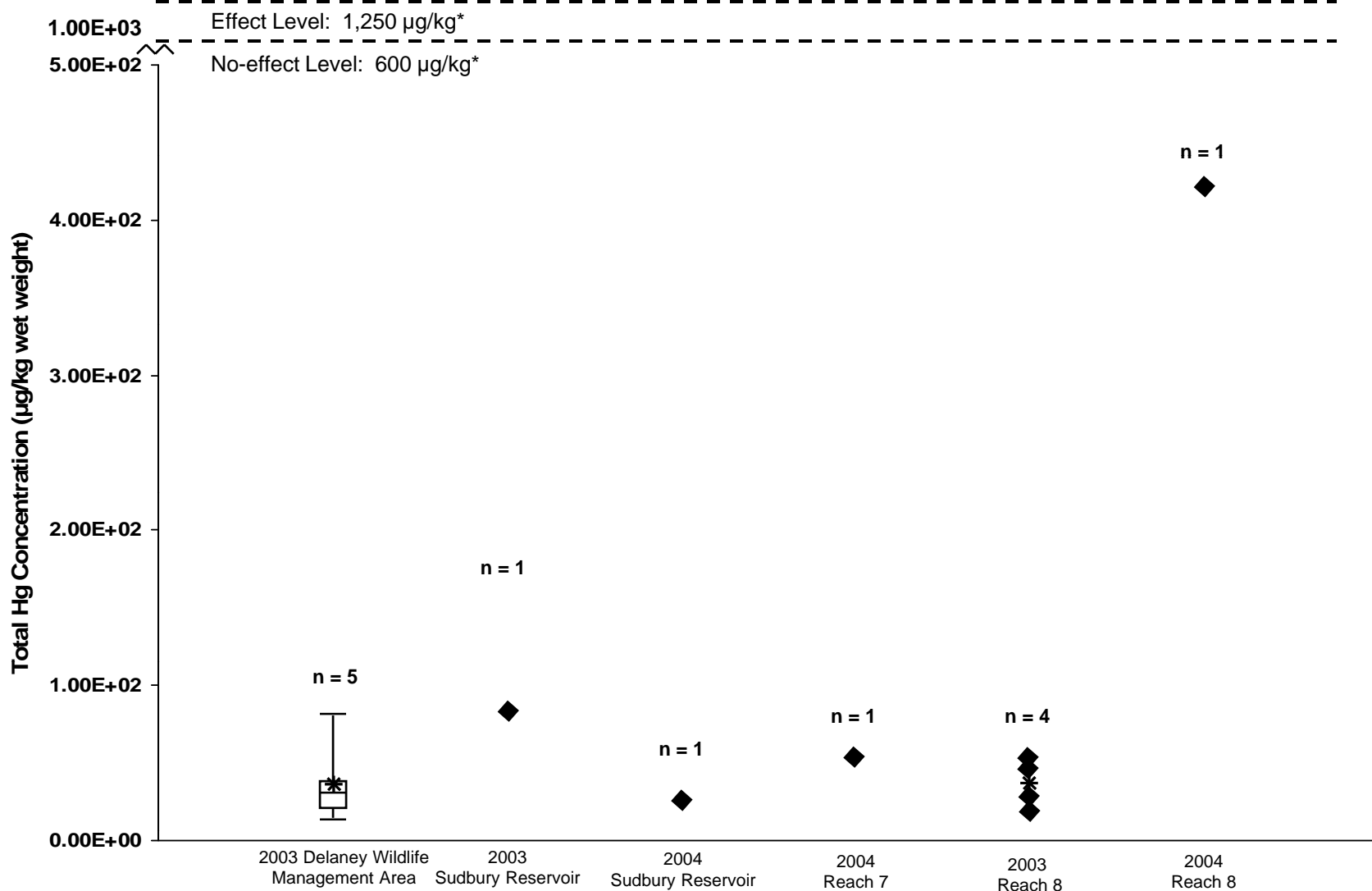
- - Feather sample
- \* - Mean Concentration



\*CBRs based on reproductive effects in tree swallows and mallards (no-effect level and effect level, respectively; see Section 3.3.1.1.2).

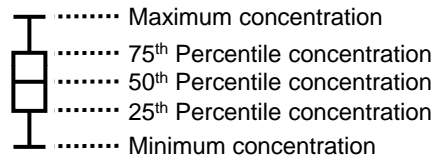
***Nyanza Superfund Site OU IV  
Sudbury River Mercury Contamination***

**Figure 4-51  
Total Mercury Concentrations in 2003, 2004, and 2005  
Hooded Merganser Feather Samples  
Compared with CBRs**



**Legend:**

- ◆ - Blood sample
- \* - Mean Concentration

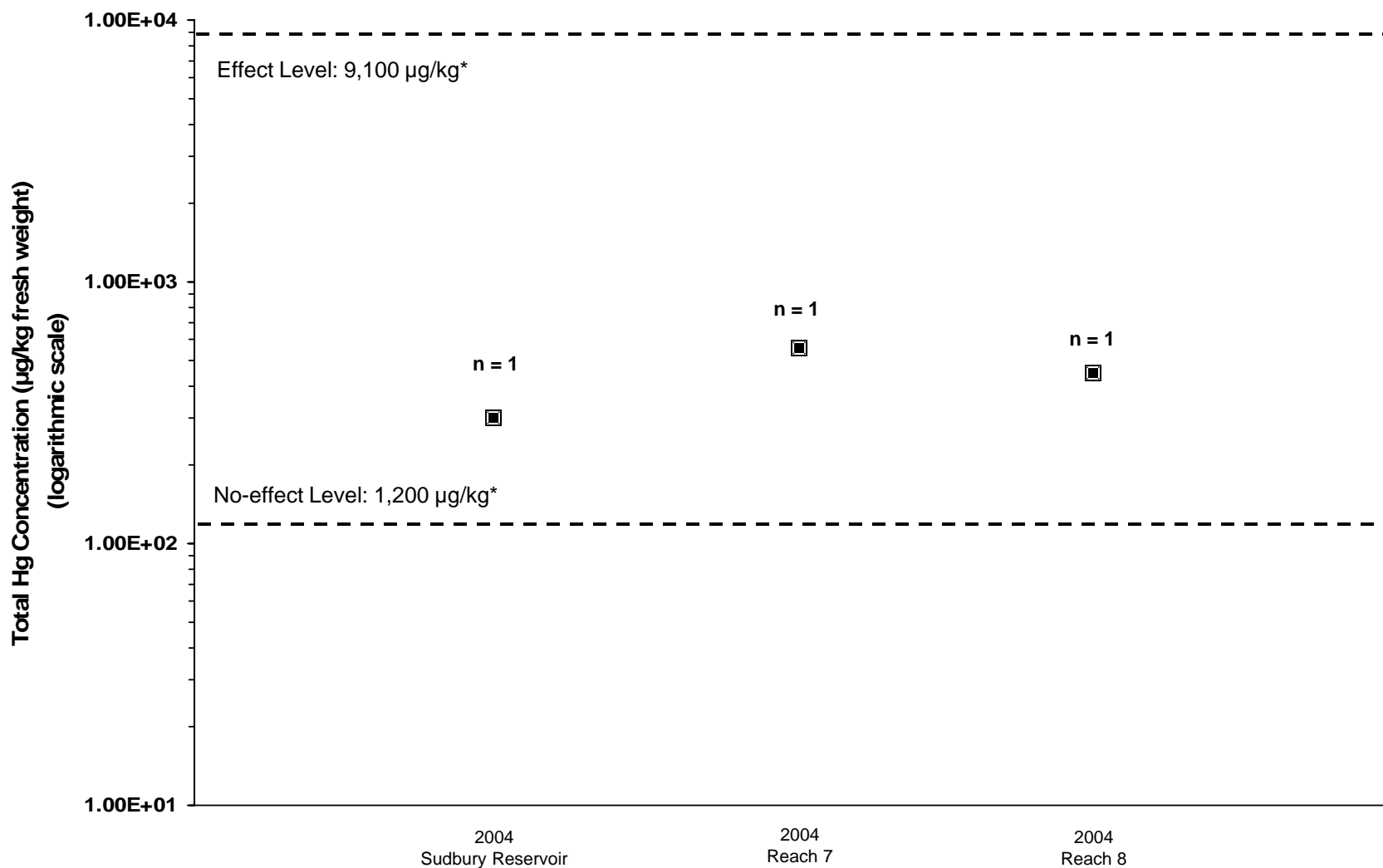


Note: all blood samples from adult birds.

\*CBRs based on reproductive effects (see Section 3.3.1.1.2).

***Nyanza Superfund Site OU IV  
Sudbury River Mercury Contamination***

**Figure 4-52  
Total Mercury Concentrations in 2003 and 2004  
Wood Duck Blood Samples Compared with CBRs**



**Legend:**

■ - Feather sample

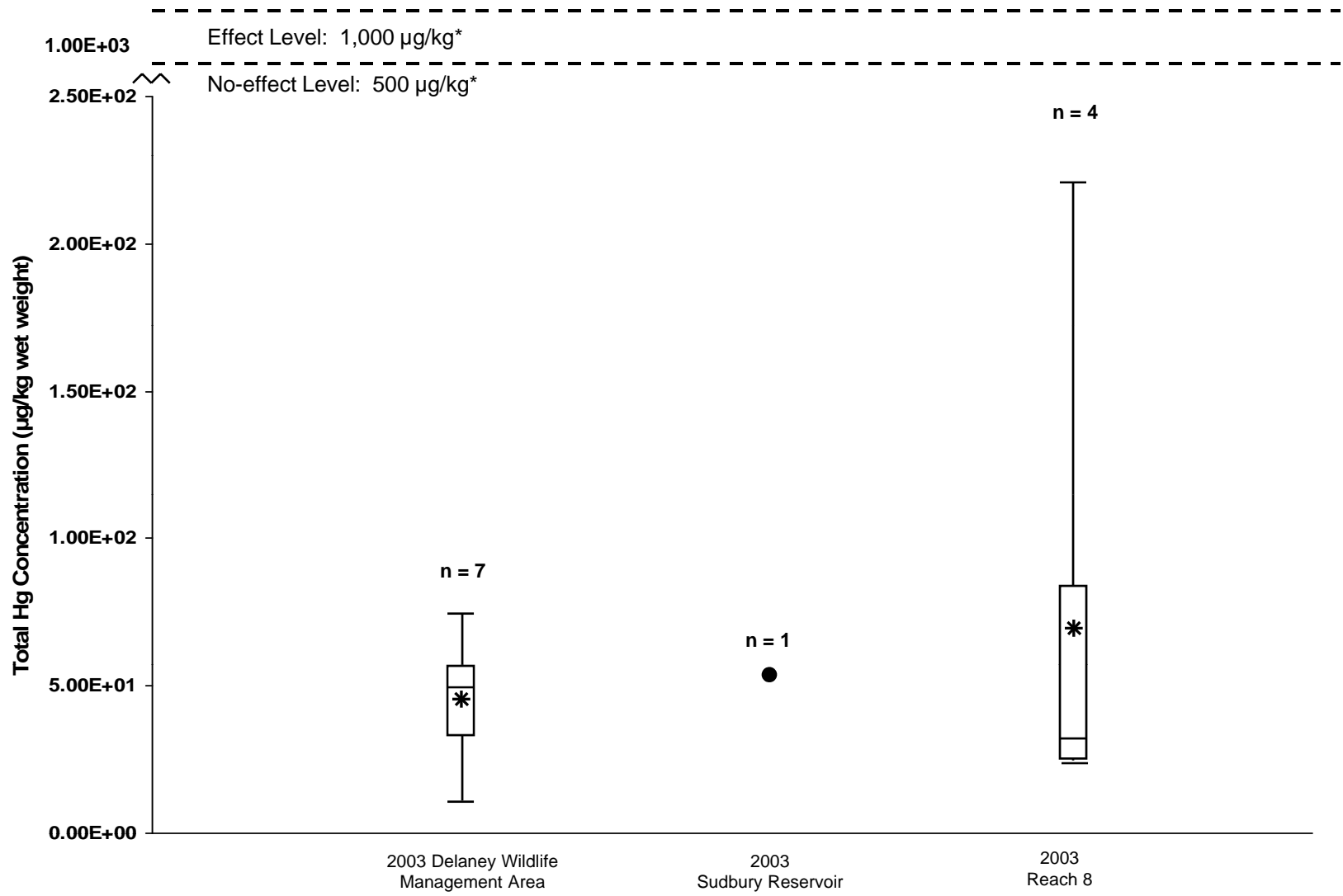
Note: all samples from adult birds.

\*CBRs based on reproductive effects in mallards (effect; see Section 3.3.1.1.2) or on reproductive effects in tree swallows (no-effect; see Section 3.3.1.1.2).

***Nyanza Superfund Site OU IV  
Sudbury River Mercury Contamination***

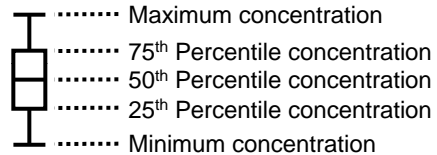
**Figure 4-53  
Total Mercury Concentrations in 2004 Wood Duck  
Feather Samples Compared with CBRs**





**Legend:**

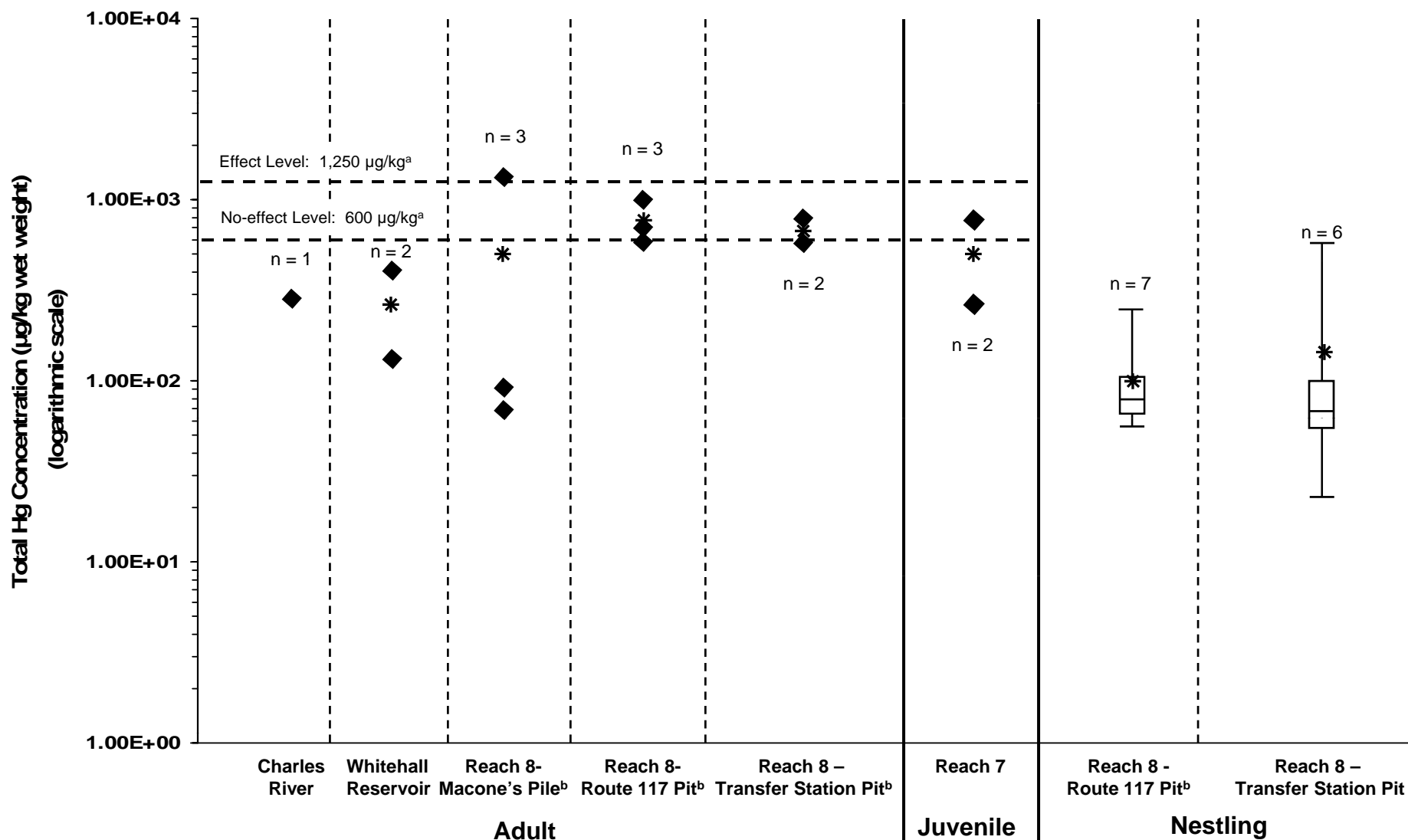
- - Egg sample
- \* - Mean Concentration



\*CBRs based on reproductive effects (see Section 3.3.1.1.2).

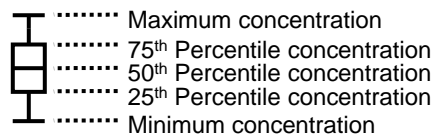
***Nyanza Superfund Site OU IV  
Sudbury River Mercury Contamination***

**Figure 4-54  
Total Mercury Concentrations in 2003  
Wood Duck Egg Samples Compared with CBRs**



**Legend:**

- ◆ - Adult blood sample
- ◆ - Juvenile blood sample
- \* - Mean Concentration

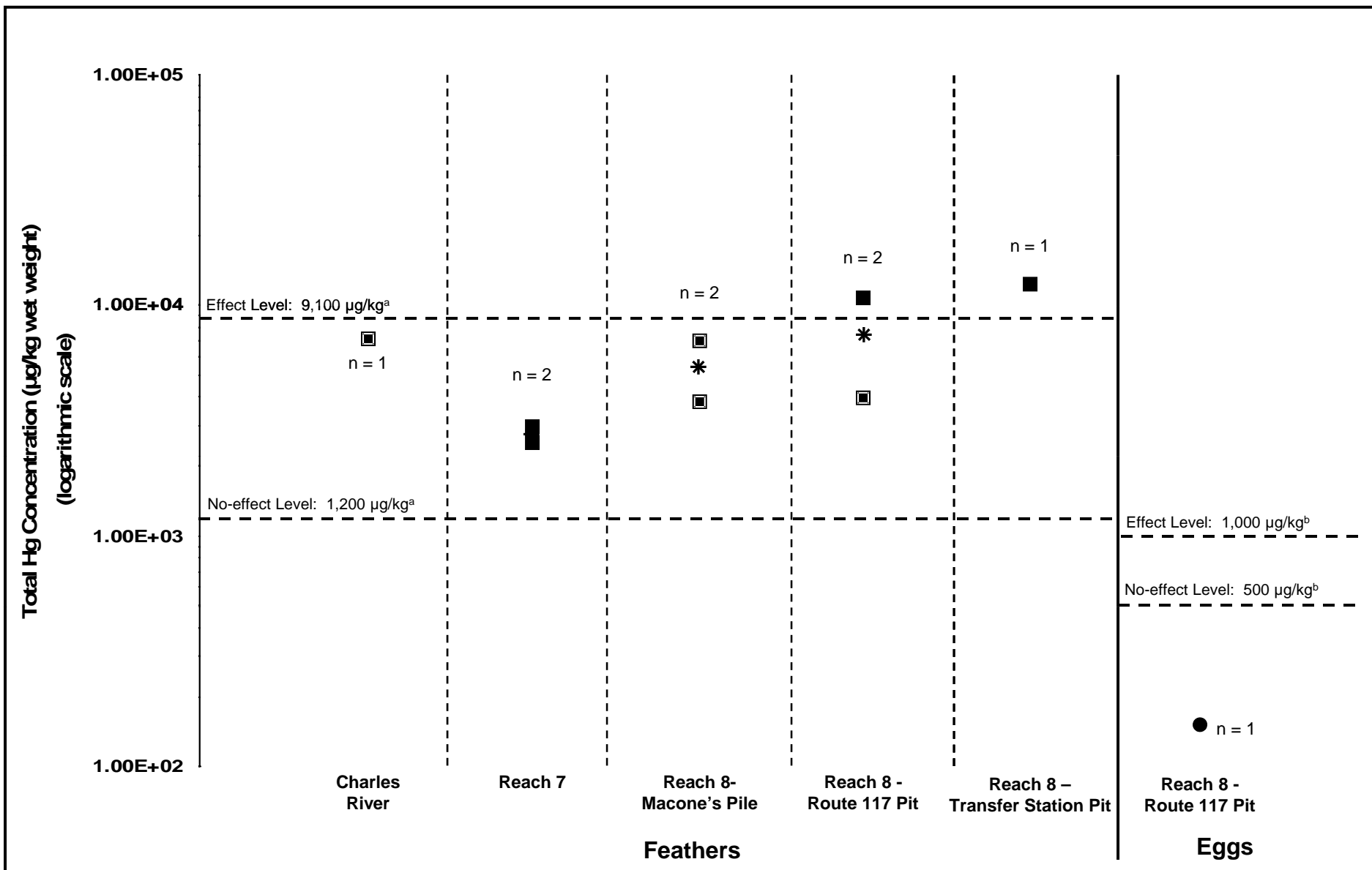


<sup>a</sup>CBRs based on reproductive effects (see Section 3.3.1.1.2).

<sup>b</sup>Includes data from retrapped birds (Macone's – 1 adult; Route 117 Pit – 1 nestling and 1 adult; Transfer Station Pit – 1 Adult).

**Nyanza Superfund Site OU IV  
Sudbury River Mercury Contamination**

**Figure 4-55  
Total Mercury Concentrations in 2003  
Belted Kingfisher Blood Samples Compared with CBRs**



**Legend:**

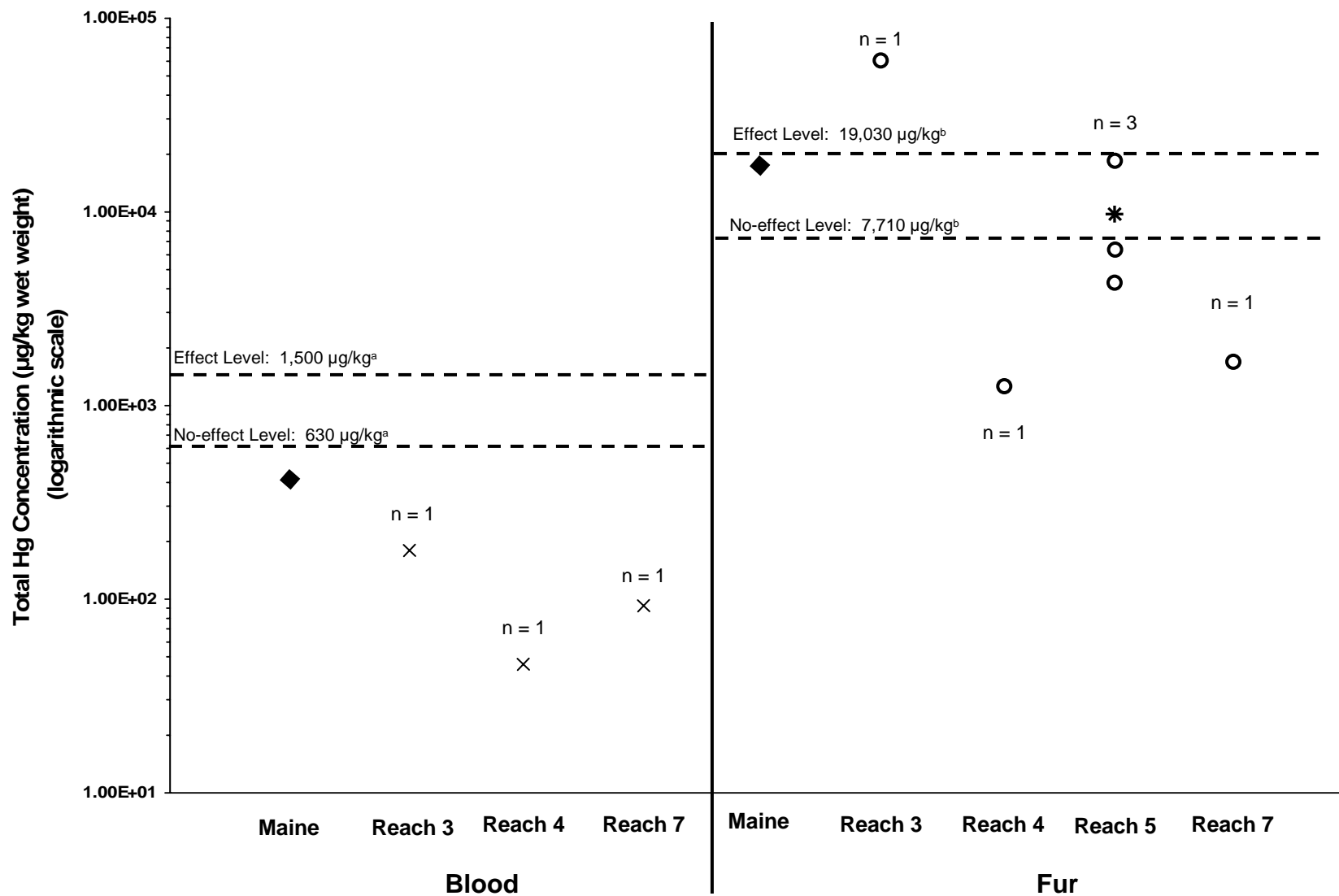
- - Adult feather sample
- - Juvenile feather sample
- - Egg sample
- \* - Mean Concentration

<sup>a</sup>CBRs based on reproductive effects in mallards (effect; see Section 3.3.1.1.2) or on reproductive effects in tree swallows (no-effect; see Section 3.3.1.1.2).

<sup>b</sup>CBRs based on a review paper (see Section 3.3.1.1.2).

**Nyanza Superfund Site OU IV  
Sudbury River Mercury Contamination**

**Figure 4-56  
Total Mercury Concentrations in 2003 Belted Kingfisher  
Feather and Egg Samples Compared with CBRs**



**Legend:**

X - Blood sample

O - Fur sample

\* - Mean Concentration

◆ - Regional Value (based on 1 value for blood and mean of 90 values for fur; see Appendix A.5)

<sup>a</sup>Effect level CBR based on % viable deliveries in the macaque (Burbacher et al., 1988). No-effect level CBR based on neurotoxicity in mink (see Section 3.3.1.1.2).

<sup>b</sup>CBRs based on changes in litter size (Halbrook et al., 1997).

**Nyanza Superfund Site OU IV  
Sudbury River Mercury Contamination**

**Figure 4-57  
Total Mercury Concentrations in 2003  
Mink Blood and Fur Samples Compared with CBRs**

## **SECTION 5**

## **REFERENCES**

## 5.0 REFERENCES

- Albano, D. 2000. *A Behavioral Ecology of the Belted Kingfisher (Ceryle alcyon)*. PhD dissertation, University of Massachusetts, Amherst, MA.
- ALCOA. 1996. *Draft Ecological Risk Assessment Problem Formulation for Mercury: Lavaca Bay/Point Comfort Superfund Site*. April 1996.
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