

**2C Evaluation of Flow,  
Suspended Sediment,  
And Heavy Metals  
in the Aberjona River**

**DRAFT  
EVALUATION OF FLOW,  
SUSPENDED SEDIMENT, AND HEAVY METALS  
IN THE ABERJONA RIVER**

**REMEDIAL INVESTIGATION /FEASIBILITY STUDY**

**INDUSTRI-PLEX SITE  
WOBURN, MASSACHUSETTS**

**RESPONSE ACTION CONTRACT (RAC), REGION I**

**For  
U.S. Environmental Protection Agency**

**By  
Tetra Tech NUS, Inc.**

**EPA Contract No. 68-W6-0045  
EPA Work Assignment No. 116-RICO-0107  
TtNUS Project No. N4123**

**January 2005**



**TETRA TECH NUS, INC.**

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APPENDIX ON ATTACHED CD – Refer to Readme.txt files for CD organization

**LIST OF ACRONYMS**

As	Arsenic
CC	Composite Concentrations
CoC	Contaminant of Concern
Cr	Chromium
Cu	Copper
DO	Dissolved Oxygen
EPA	Environmental Protection Agency
Fe	Iron
FEMA	Federal Emergency Management Agency
GIS	Geographic Information System
GSIP	Groundwater/Surface water Investigation Plan
HBHA	Halls Brook Holding Area
Hg	Mercury
ICP	Inductively Coupled Plasma
ISCO	Company Name for a Manufacturer of Autosamplers
ISRT	Industri-Plex Site Remedial Trust
MDC	Metropolitan District Commission
Meas.	Measured
MIT	Massachusetts Institute of Technology
MSGRP RI	Multiple Source Groundwater Response Plan Remedial Investigation
MWRA	Massachusetts Water Resources Authority
NCDC	National Climatic Data Center
NERL	New England Regional Laboratory
ORP	Oxygen Reduction Potential
Pb	Lead
PVC	Polyvinyl Chloride
QA	Quality Assurance
QC	Quality Control
QL's	Quantitation Limits
RI/FS	Remedial Investigation/Feasibility Study
TSS	Total Suspended Solids
TtNUS	Tetra Tech NUS, Inc.

**LIST OF ACRONYMS (cont.)**

USGS	United States Geological Survey
USEPA	U.S. Environmental Protection Agency
YSI	Yellow Spring Instruments

**UNITS OF MEASURE**

%	Percent, parts per hundred
cm	Centimeter
cfs	Cubic feet per second
oC	Degrees Celsius
ft	Feet
gpd	Gallons per day
g/hr	Grams per hour
km	Kilometer
NTU	Nephelometric turbidity units
mi	Mile
mg	Milligrams
mg/L	Milligrams per liter
mgd	Million gallons per day
mg/kg	Mg of metal per kg of soil
mL	Milliliter
mm	Millimeter
mV	Milivolts
ug/L	Microgram per liter
uS/cm	microSiemens per centimeter (unit of conductivity)

## **E.0 EXECUTIVE SUMMARY**

A surface water monitoring program was implemented for the Aberjona River by Tetra Tech NUS, Inc. (TtNUS) for the U.S. Environmental Protection Agency (EPA) under Contract No. 68-W6-0045, Work Assignment No. 116-RICO-0107. The monitoring program included measurements of precipitation, streamflow, suspended sediment, and metals concentrations (dissolved and total), in addition to other physico-chemical parameters. A total of 11 monitoring stations were installed. Three monitoring stations (Stations 1, 2, and 4) were located within the drainage basin of Halls Brook, a major tributary to the northern reach of the Aberjona River. Five stations (Stations 3 and 5 through 8) were located along the main artery of the Aberjona River and three stations (Stations 9 through 11) were located downstream of the Aberjona River within the Mystic Lakes drainage basin (Figure ES-1).

The monitoring period for this study covered an 18-month time frame beginning May 2001 and ending October 2002. The measurements were semi-continuous for precipitation, streamflow, and several physico-chemical parameters (water temperature, specific conductivity, dissolved oxygen, pH, oxidation reduction potential, and turbidity). Water samples for metals analyses were collected during 16 baseflow events and 6 storm events. Composite samples were collected during storm events at eight of the monitoring stations and grab samples were collected hourly during storm events at two monitoring stations (Stations 4 and 8). One station, Station 11, was used to monitor only flow from a tributary to the Mystic Lakes.

Although samples collected through this study were analyzed for 23 elements, this report focuses on the results for six: arsenic, iron, chromium, copper, lead, and mercury. These metals/metalloids were chosen because they were considered to represent a possible health risk or, in the case of iron, they may impact the transport of metals that could represent a possible health risk. Among the six metals evaluated in this report, much of the discussions focus on arsenic since preliminary assessments suggest that this metalloid poses the greatest health risk.

Comparison of the hydrologic measurements with historical records indicates that the TtNUS monitoring period was consistent with overall average precipitation and river flow conditions. Both the average depth of rain and frequency of storms were similar between the 104-year record evaluated and the TtNUS period of record. Streamflow measured at TtNUS Station 8

was also consistent with the 63-year average streamflows measured at this site by the U.S. Geological Survey, with the exception of the timing of the spring snowmelt peak.

Semi-continuous measurements of physico-chemical parameters indicate that water temperature was very similar between stations and varied in a systematic fashion consistent with seasonal changes in climate. The highest levels of specific conductivity were observed during the winter months and were likely caused by runoff containing road salts. Dissolved oxygen concentrations also remained reasonably consistent throughout the length of the Aberjona River and were in many cases near saturation levels. The pH values measured at Stations 1 through 8 were very close to neutral (pH approximately 7); values at Stations 9 and 10 were elevated (pH approximately 8) in comparison with the other stations. The oxidation-reduction potential at all 10 stations monitored, except for Station 2, were positive. ORP readings at Station 2, downstream of the Halls Brook Holding Area (HBHA) Pond, were characterized by negative values. These negative values were likely caused by the anoxic nature of groundwater flowing into the HBHA Pond.

Total suspended solids (TSS) concentrations during baseflow conditions were consistently near 5 mg/L for all stations with the exception of Station 4, which was characterized by variable concentrations (4 to 110 mg/L) and an average of 23 mg/L. The elevated TSS concentrations at Station 4 were observed during the fall and early winter months. These elevated levels may be due to possible turnover of a small pond located immediately upstream of this station. During storm events, TSS concentrations were higher for all stations located along the Aberjona River with the exception of Station 4, again emphasizing the unique nature of sediment transport from this area. Stations exhibiting relatively high TSS concentrations during storm events included Station 1 (22 mg/L on average) and Station 8 (46 mg/L on average).

TSS fluxes increased at all stations during storm flow conditions. The most notable increases were observed at Stations 1 (21 kg/hr) and 8 (470 kg/hr). At these stations the TSS flux increased during storms by a factor of 40 (Station 1) to 70 (Station 8) times higher than those observed during baseflow conditions. These increases are a combined effect of increased flows and TSS concentrations observed at these stations during storm conditions.

Results from sample analyses indicate that metals transport was highly impacted by TSS concentrations. Spikes in metals concentrations were associated with spikes in TSS. The

association between TSS and metals concentrations was observed during baseflow conditions at Station 4, which was the only station characterized by large TSS spikes during low flows. These spikes in TSS were often accompanied by spikes in iron, indicating that the particulate phase at this station may be dominated by an iron oxide component. As a consequence of the TSS and iron spikes, the highest concentrations for all metals evaluated were often observed at Station 4 during baseflow conditions. The average total arsenic concentration during baseflow conditions at Station 4 was 37 µg/L, as compared to low concentrations (< 2 µg/L) observed at Station 1, the station located upstream of the Halls Brook Holding Area. Total metals concentrations typically decreased in concentration in the downstream direction past Station 4 during baseflow conditions.

Total arsenic concentrations were greatest at each station during storm flow conditions, with the exception of Stations 3, 4, and 5. The increase in total arsenic was due to an increase in suspended sediment transport during storm events, which resulted in an overall increase in particulate arsenic concentrations. Even though total arsenic concentrations decreased, on average, during storm events for Stations 3, 4, and 5, the total arsenic concentration measured at these stations was still the highest observed among all stations during storm event conditions. For example, the average total arsenic concentration at Station 4 during baseflow was 37 µg/L whereas during storm events the average concentration was 32 µg/L; which shows a net decrease in arsenic concentrations at this station from baseflow to storm conditions. The average total arsenic concentration at Station 8 during baseflow was 4.4 µg/L; whereas during storm events the average concentration at this station increased to 11 µg/L. Although the total arsenic concentration increased to 11 µg/L at Station 8 during storm events, this concentration was still less than the concentrations observed at Station 4 during baseflow and storm events.

For the other metals (iron, chromium, copper, lead and mercury), the highest concentrations were observed at Station 4 during baseflow conditions. During storm flow conditions the highest concentrations for these same metals were typically observed at Stations 1 and 8. The elevated concentrations at Stations 1 and 8 were likely due to the elevated TSS concentrations observed at these stations during storm events.

During baseflow conditions, metal fluxes typically increased from Station 1 to Station 2 to Station 4. The sum of the metal flux through Stations 4 and 3, both of which flow towards Station 5, was typically greater than the flux observed at Station 5, suggesting that metals were

depositing in areas immediately upstream of Station 5. A large fraction of the total metal flux observed at Station 8 can be accounted for by the fluxes observed at Stations upstream of Station 5. When the fluxes were normalized by the corresponding drainage areas ( $\text{g}/(\text{hr}\cdot\text{mi}^2)$ ), the highest normalized metal fluxes were consistently observed at Station 4 during baseflow conditions.

During storm flow conditions, a relatively large arsenic flux was observed at Station 2 on average. Iron flux was also high at Station 2, and increased systematically in the downstream direction from Station 5 to Station 8. The chromium, copper, and lead flux were generally elevated at Stations 1 and 8. When normalizing the storm flow metal fluxes on a drainage area basis ( $\text{g}/(\text{hr}\cdot\text{mi}^2)$ ), the largest storm flow arsenic and iron flux corresponded to Station 2. The largest normalized fluxes for chromium, copper, and lead during storm events corresponded to Stations 1 and 8. Stations 1 and 8 also corresponded to the largest normalized TSS fluxes during storm events.

Overall, the HBHA served as a concentrated source of arsenic during both baseflow and storm flow conditions (Figure ES-1). During baseflow, peaks in arsenic transport were associated with high TSS concentrations, which are hypothesized to occur during suspected turnover events within the HBHA wetland ponds. The metals from the HBHA area were transported downstream primarily in the particulate phase; during baseflow conditions some of these metals deposited within areas between Stations 3 / 4 and Station 5, most likely within the Wells G and H wetland. During storm flow conditions a large flushing of TSS was observed throughout the river and especially at Stations 1 and 8. Storm event flows at Stations 1 and 8 were characterized by elevated chromium, copper, and lead concentrations and fluxes, the source of which was likely from urban runoff. Regardless of the relatively high storm flow TSS at Stations 1 and 8, these stations were not considered to represent the primary concentrated source of arsenic. The HBHA represented the primary concentrated source of arsenic during both baseflow and storm flow to the Aberjona River, due to the elevated concentrations and normalized fluxes observed at Stations 2 and 4. Once metals were transported through the Aberjona River system, they were discharged to the Mystic Lakes where additional dilution and deposition of metals occurred, resulting in relatively low metals concentrations in the upper surface waters of these lakes. The metal concentrations observed from the upper surface waters of the Mystic Lakes were primarily in the dissolved phase, with the exception of iron, which was predominately in the particulate phase.

## 1.0 INTRODUCTION

This report describes the investigations and data evaluation to assess flow, suspended sediments, and heavy metals transport within the Aberjona River. This report was prepared by Tetra Tech NUS, Inc. (TtNUS), for the United States Environmental Protection Agency (EPA) under Contract No. 68-W6-0045, Work Assignment No. 116-RICO-0107 as part of the Multiple Source Groundwater Response Plan Remedial Investigation (MSGRP RI).

### 1.1 Background

Historically, the Aberjona River has been subject to contamination from several industrial chemicals including metals. Primary sources of metals within the watershed include former leather tanneries and chemical plants which operated predominately between the 1900s to the 1930s (Durant, et al., 1990). During this time, chrome-tanning was the primary process for treating animal hides. Evidence indicates that wastes from this process resulted in considerable discharges of chromium into the environment. Significant arsenic contamination has been associated with sulfuric acid and arsenical pesticide manufacturing (Aurilio, et al., 1995). A metal reconnaissance of the river bottom sediments (Knox, 1991) has revealed widespread distribution of metal contamination, including arsenic, chromium, and lead, along the Aberjona River. Two U.S. EPA Superfund sites are located within the watershed: the Industri-plex site located to the north, and the Well G&H site located within the central portion of the river.

Site-specific contamination of the Industri-plex site has been evaluated through the Groundwater/Surface Water Investigation Plan (GSIP) investigations. Area-wide contamination is currently under evaluation through the Multiple Source Groundwater Response Plan Remedial Investigation (MSGRP RI). Originally the MSGRP RI was to focus on the Industri-plex Superfund Site study area, which is located north to the Wilmington/Woburn town line, west to Route 38, east to Interstate 93 (I-93), and south to I-95. In 2002, the EPA merged a second study, which focused on evaluating the impacts to the river sediments from the Wells G&H site, into the original MSGRP RI, in an effort to evaluate contamination and risks for the entire Aberjona River. This merger expanded the study area to include the southern portion of the Aberjona River through the Wells G&H wetlands and ultimately incorporating the Mystic Lakes. This report focuses on evaluating surface water physical and chemical parameters in the

Aberjona River with an emphasis on evaluating factors that contribute to transport of metals. This evaluation was completed to support the MSGRP RI.

## **1.2 Objectives and Report Organization**

The purpose of this report is twofold. First, this report describes the pre-existing hydrometeorological monitoring network established for the Aberjona River and describes the data collection program established by TtNUS (Section 2.0). The second purpose of this report is to evaluate and discuss the monitoring data gathered with respect to the spatial origin of contamination, computation of metal fluxes at various points within the river system, and to describe factors that may contribute to metals transport. Physico-chemical data, such as precipitation, streamflow, and suspended sediments, are discussed in Section 3.0 followed by a discussion of metals data in Section 4.0. Discussions focus on describing metal concentrations and fluxes at the monitoring stations established for this study. An overall summary of the monitoring data along with conclusions are presented in Section 5.0. The individual measurements collected through this study along with files used to evaluate the data are available in the electronic appendices of this report.

## **2.0 MONITORING PROGRAM**

The monitoring program established for this study included evaluation of data from pre-existing hydrometeorological monitoring stations, including weather stations located in Reading, Massachusetts and a USGS flow monitoring station (Section 2.1). This data was extensively augmented through a set of 11 automated surface water monitoring stations constructed and maintained by TtNUS during an 18-month period beginning May 15, 2001 and ending October 29, 2002 (Section 2.2). Rainfall, stream velocity, water level, water temperature, specific conductivity, dissolved oxygen concentration, pH, oxidation-reduction potential, and turbidity were monitored at 10 of the 11 monitoring stations at 15-minute time intervals during the TtNUS monitoring period. Furthermore, samples for suspended sediment and metals concentrations (dissolved and total) were collected through a monitoring program designed to capture trends during baseflow and storm flow conditions (Section 2.3). Once these samples were collected, they were analyzed in the laboratory using standardized methods (Section 2.4). Additional information is provided in the attached CD. (Refer to the subdirectory called “\Chapter\_2\_Monitoring\_Program”.)

### **2.1 Pre-Existing Hydrometeorological Monitoring Stations**

The most significant pre-existing weather stations located within or near the Aberjona Watershed included the Reading – NCDC Weather Station which has monitored daily precipitation since 1957, and the Reading – 100 Acre Pumping Station, which has monitored daily precipitation since the late 1800s. Flow has been monitored since 1939 at the USGS station located near the outlet of the Aberjona River. See Figure 2-1 for the location of these pre-existing monitoring stations.

#### **2.1.1 Reading, Massachusetts Precipitation Monitoring Station**

There are two precipitation monitoring stations located within the Town of Reading, Massachusetts: the Reading – 100 Acre Pumping Station, and the Reading – NCDC Station. The Reading – NCDC Station possesses an extensive hourly precipitation record dating back to 1981 and is located within the northern boundary of the Aberjona Watershed.

#### 2.1.1.1 Reading – 100 Acre Pumping Station

Daily rainfall has been monitored at the water supply pumping station for the Town of Reading since 1899, and continues to be measured in an eight-inch diameter stainless-steel rain gauge. This station is located within one mile of the watershed boundary, at the end of Strout Ave, off of Grove Street in Reading. The data from this station are available from the *Town of Reading, Annual Reports*.

The historical records from this station, along with historical data collected at the Reading – NCDC Station (below), were utilized as benchmarks for the precipitation data. The statistics from the historical records were compared with the statistics of the data collected by the TtNUS monitoring network to determine whether or not the TtNUS period of record was representative of historical precipitation patterns.

#### 2.1.1.2 Reading – NCDC Station

The Reading-NCDC station consists of two rain gauges and an air temperature station. Hourly precipitation data from this station was compared with precipitation measurements at the TtNUS stations as an independent means of checking precipitation data collected through this study. Furthermore, the hourly temperatures measured at this station will eventually be incorporated into a computer model that will be developed for this study. The computer model will utilize temperature data when determining when rainfall versus snowfall occurred and in the algorithms that will be used to estimate snow accumulations and snowmelt.

This station is funded by the National Climatic Data Center (NCDC) and the voluntary data collection is conscientiously performed by Mr. R.E. Lautzenheiser, retired climatologist. The station is located at Mr. Lautzenheiser's home in his backyard at 35 Arcadia Avenue, Reading, Massachusetts. Data is available by writing Mr. Lautzenheiser directly or through the NCDC.

On February 11, 2003, TtNUS visited Mr. Lautzenheiser to view the Reading weather station. Mr. Lautzenheiser showed TtNUS the different gauges used to record precipitation and temperature. The first rain gauge is a standard rain gauge (installed in 1957) used to collect daily precipitation values. It consists of a metal cylinder about two feet deep with an eight-inch diameter opening. This rain gauge is used to confirm results of the primary rain gauge when

weather conditions are difficult to measure, (i.e. snow, freezing rain, wintry mix). A Frieze weighing bucket rain gauge (installed in 1981) is located about 10 yards from the thermograph housing box and used to collect hourly values; measurements are recorded on a rotary graph. Graph paper is replaced on the cylinder daily. Common anti-freeze is poured conservatively into the weighing bucket to melt the snow that accumulates in the bucket. A mark is made on the graph upon administering the anti-freeze so as not to confuse the anti-freeze with precipitation measurements. When snow piles up on top of the rain gauge it is allowed to fall in or melt.

There is a wood housing on four posts that shelters the thermograph, maximum and minimum thermometers, and a standard issue weather service thermometer that is wired to a digital display located in Mr. Lautzenheiser's home. The wooden housing is painted white, to reflect sunlight, and the sides are slatted to allow for air movement through the housing. The daily minimum thermometer is an alcohol-filled thermometer with a marker that stays at the lowest temperature reading until the thermometer is reset, by inverting. The daily maximum thermometer is a standard mercury filled, medical-type, thermometer that stays at the maximum temperature measured until it is tilted and reset. Hourly air temperature has been monitored at this station since 1957.

Rainfall values are recorded on official United States Department of Commerce log-sheets that represent the hourly accumulations for the entire month; there are 31 rows to represent the day of the month and 24 columns for the hours per day. At the right hand side of the table there is a column for the daily sums. This value is the sum of all the hourly accumulations throughout the day. Small inconsistencies were found in these summations upon inspection, which were corrected when the data were entered in digital format.

The rainfall data for the study period was provided to TtNUS by R.E. Lautzenheiser. Upon receiving the data TtNUS entered the data point values into an Excel file then converted those files to Textpad files to use for the data processing software developed specifically for this study. Data entry included manually entering the values hour-by-hour into a spreadsheet. In instances where the entries were indecipherable on the copies provided by Mr. Lautzenheiser, the value was back-calculated from the daily sum. Corrections to the paper copies were made using red ink. Where there were inconsistencies in the data, the daily summations were scrutinized and checked, to determine the correct data for entry into the Excel file.

Hourly temperature data was also received on photocopies of historic records from R.E. Lautzenheiser. The copies were of thermographs taken on a week-by-week basis. The values taken from the thermometer were manually transcribed on the thermograph traces to show calibration. Only the temperature measurements above freezing from May 2001 through October 2002 were entered into the spreadsheet. All temperatures, 32 degrees Fahrenheit and below, were represented by the value of -1. This is because the computer model will compute snowmelt contribution as a function of temperature. Temperatures at or below freezing are not used by the model since there will be no snowmelt at these temperatures. (The rates of snowmelt increase as the temperature increases past 32 degrees Fahrenheit.)

### **2.1.2 USGS Streamflow Monitoring Station**

The USGS monitoring station is located within the Town of Winchester, Massachusetts on the Aberjona River, approximately 2,600 feet upstream of the inlet to the Upper Mystic Lake and near the intersection of Mystic Avenue and the Mystic Valley Parkway. The flow measured at this station is considered to be representative of flow from the entire Aberjona River Watershed and the data are used by the Metropolitan District Commission (MDC) for operating the Amelia Earhardt Dam, located approximately 4.7 miles southeast of Station 8 along the Mystic River. Information about the monitoring station and hourly streamflow data requested by TtNUS were provided by the USGS in Northborough, Massachusetts.

The USGS monitoring station in Winchester, Massachusetts has been in operation since 1939. Flow control at this station is provided by a reinforced concrete Trenton-type weir, 44 feet long, with a shallow v-crest. The weir has flat sloping abutments flush with the banks. The lower water control submerges at about a 13 foot stage, above which the channel serves as the control (McDonough, 1983). A Friez FA-3 water level recorder was installed in April 1939 for the purpose of providing flow data. A rating curve is used to convert from water stage to flow at this station. The rating curve is established by measuring water depth and velocity at various points in the channel cross-section. Velocity measurements during calibration are made using Price current meters. In 1980 the chart recorder was replaced with a Fischer and Porter digital recorder set on a 15 minute punch cycle. The station was upgraded with satellite and telephone telemetry and a Sutron Heated Tipping-Bucket precipitation gauge (Sutron 8210 with satellite transmitting radio and telephone modem connection) in September 1998 with grant funding from

the Federal Emergency Management Agency (FEMA), in response to flooding that occurred in October 1996.

Flow at this station is based upon stream depth measurements. Stream depth is converted to flow using a rating curve. The river level is sensed through use of a stilling well located inside a concrete enclosure allowing river water to pass through intake pipes into the concrete well, used to dampen wave action. A float and counterweight system is used whereby a graduated steel tape goes from the float over a Sutron Shaft Encoder to the counterweight. The encoder converts float movement (and consequently shaft rotation) to water level, in hundredths of feet. A digital stage recorder records the stage every 15 minutes and transmits this data every 4 hours to the USGS receiving site. An in-stream reference sloping staff gauge is used to directly measure the river level, which is then compared with the level inside the stilling well as determined by the digital stage recorder.

An inside reference point mounted on the instrument shelf is also used to measure down to the water level inside the stilling well, which independently determines the level to which the digital recorder is set. Typically, the level inside the well is within 0.02 ft of the level outside the well as read on the staff gauge, which indicates that the intake pipes that transfer water between the river and the well are free of blockages. If the water level between inside and outside are different by more than about 0.05 ft, then intake blockages may have occurred and the flow data would require corrections, and if necessary, estimates. The marks on the outside staff gauge, as well as the inside reference mark and nearby reference marks outside the gauge house, are surveyed every 5 to 10 years to determine any vertical movement. The elevation surveys are done to an accuracy of 0.001 ft in order to have confidence in the published stage values to the nearest 0.01 ft.

The monitoring station is visited by USGS personnel approximately every 6-8 weeks for the purposes of calibrating the stage recorder and making a discharge measurement, which is used to calibrate the stage-discharge rating curve. Discharge measurements are made at varying flow rates throughout the year in order to calibrate the stage-discharge relation. Each measurement involves selecting a wading cross-section near the gauge that is perpendicular to streamflow. For flows too deep to wade, a nearby bridge is used and a portable crane is set up to lower the velocity meter in the water. The cross-section is then divided into approximately 25 to 30 subsections with each subsection having a discrete depth and velocity measurement. The

sum of the subsections equals the total discharge for that measurement, which is then paired with the mean gauge height during the time of the measurement. When the measured discharge for that gauge height varies by more than about 5 percent from the discharge determined by the existing stage-discharge relation (for that same gauge height), then a second discharge measurement is made at a different cross section using a different set of measuring equipment. If the second measurement supports the first, then a change to the stage-discharge relation has occurred and a correction is then required to adjust the computed flows to the new condition.

Daily mean discharge is computed by taking each 15-minute stage value (96 values during each day), assigning an equivalent discharge value (based on the stage-discharge rating) for each 15-minute stage value, summing the 96 individual discharge values, and then calculating the daily mean discharge for the 96 values. The daily mean gauge height is determined by selecting the gauge height value that corresponds to the daily mean discharge value. In other words, the daily mean gauge height is weighted by discharge and is not simply an average of the 96 stage values.

## **2.2            Location of TtNUS Stations**

The following sections list the locations of the monitoring stations installed by TtNUS for this study (2.2.1) and summarize the size of sub-basins contributing to each of the stations (2.2.2).

### **2.2.1            Description of Locations**

Eleven semi-automated surface monitoring stations were designed, installed and maintained by TtNUS for the purpose of gathering physical and chemical data for tracking contaminant contributions through the Halls Brook Holding Area (HBHA) and the Aberjona River. Stations were also installed downstream of the Aberjona River within the Mystic Lakes to observe contaminant concentrations transported through the surface waters of these lakes. Prior to the study, several possible station locations were evaluated. Considerations were given to the confluence of tributaries, location of watershed sub-basin boundaries, previous studies where similar stations have been established, locations of existing monitoring/gauging stations (i.e. United States Geological Survey and Industri-Plex Site Remedial Trust stations), access, stream channel configuration, and significant areas of deposition. Following a field reconnaissance trip with EPA, USGS, and TtNUS, the stations listed in Table 2-1 were selected.

Station locations are shown graphically in Figure 2-1. Close-up views of Stations 1 through 4 are provided in Figure 2-1a. Of note is that all stations, with the exception of Station 3, were downstream of one another.

Since the monitoring program was designed to track water sources from Halls Brook downstream through the Aberjona River and ultimately to the Mystic Lakes, flows from Station 1 flow towards Station 2, flows from Station 2 flow towards Station 4, flows from Station 5 flow towards Station 6 and so on. The flow from Station 3, which represents contributions from the upper reaches of the Aberjona River, enters the main “train” of monitoring stations immediately downstream of Station 4. Of note is that 3 stations (Stations 1, 2, and 4) were located within the Halls Brook Drainage Basin. Station 1 monitors flows from Halls Brook, upstream of the HBHA. Station 2 is immediately north of the outlet of the HBHA and Station 4 is located at the downstream end of the HBHA, immediately north of Mishawum Road.

Five stations were located along the main artery of the Aberjona River (Stations 3 and 5 through 8). Station 3 was located immediately upstream of the confluence with outflows from the HBHA. Station 5 was located downstream of the Wells G and H wetland. Station 6 was located downstream of the Cranberry Bog Conservation Area. Station 7 was located at Swanton Street immediately downstream of the Atlantic Gelatin withdrawal wells. Station 8 was located immediately adjacent to the USGS monitoring station, which is near the outlet of the Aberjona River.

The remaining 3 stations (Stations 9 through 11) were located within the drainage basin of the Upper and Lower Mystic Lakes. Stations 9 and 10 were located at the outlets of the Upper and Lower Mystic Lakes, respectively. Station 11 was located at the outlet of Mill Brook at the Lower Mystic Lake and installed for the sole purpose of resolving potential anomalies with flow at Station 10 should they occur. Subsequently, flow data from Station 11 was not needed and the data was not evaluated or presented as part of this study.

The upper portion of the Aberjona watershed was more intensely monitored than the lower portion, with gauging stations located closer to one another. The length of the river channel between the stations varied from 0.3 km between Stations 1 and 2 to almost 3 km between Stations 6 and 7 (Table 2-2). The lengths of the river between corresponding stations were obtained directly from the USGS topographic map using AutoCad.

## 2.2.2 Sub-basin Delineation for Each Station

Sub-basins contributing to each gauging station were determined by adding the corresponding primary and secondary sub-basins within the Aberjona Watershed. Primary sub-basins were those that had been defined in previous work for the Aberjona Watershed. Separation of the primary sub-basins into secondary basins was required to accommodate the geometry of the TtNUS monitoring network. Sub-basin delineations for the Aberjona Watershed are shown graphically in Figures 2-2 and 2-3.

### 2.2.2.1 Aberjona Watershed Boundary and Primary Sub-basins

Sub-basins delineate areas of the watershed that contribute surface water flows. The Aberjona Watershed boundary and primary sub-basins within the Aberjona Watershed were obtained from two sources: the Massachusetts Geographic Information System (GIS) and from a 2003 study performed by Vanasse, Hangen, Brustline, Inc. (VHB), which conducted an in-depth hydrologic study of the areas contributing to Halls Brook and the HBHA (VHB, 2003). The Massachusetts GIS is maintained by the Commonwealth's Office of Geographic and Environmental Information Office.

The primary sub-basins within the Massachusetts GIS database are numbered 1 through 16, and the numbering used in the current study is consistent with the Massachusetts GIS numbering scheme. Massachusetts GIS referenced the U.S. Geological Survey (USGS) as the source of the Aberjona Watershed and primary sub-basin boundaries. According to the USGS, the delineations were performed in the early 1980s by hand based solely on topographic divides. Very little ground-truthing was performed at the time. The VHB 2003 report provides details concerning stormwater flow paths and contributing areas within the northern part of the watershed. A considerable amount of ground-truthing was conducted by VHB and thus the sub-basin delineations from VHB are assumed to supersede the sub-basin delineations provided by the Massachusetts GIS database.

Overall, the sub-basin delineations were similar between the two sources of information, with the exception of flow within the southern part of the Middlesex Canal. The Middlesex Canal is located within the northwestern portion of the Aberjona Watershed, joins Halls Brook on its northern end, and then crosses I-95. Historically water on the south side of I-95 flowed in a

southerly direction whereas water on the north side of I-95 flowed in a northerly direction. The Massachusetts GIS sub-basin delineations were consistent with the historical configuration. However, in their ground-truthing, VHB found that a brick wall was placed on the south side of the Middlesex Canal causing water on the south side of I-95 to flow in a northern direction thereby significantly changing the drainage area of Halls Brook, which lies to the north of the Middlesex Canal (VHB, 2003). The sub-basin delineation within the current study is consistent with the VHB 2003 findings.

#### 2.2.2.2 Secondary Sub-basins

Not all of the sub-basins coincided with the location of the TtNUS monitoring stations. For cases that did not coincide, secondary sub-basins were delineated. Sub-basin 13 was further sub-divided because a fraction of this sub-basin contributes directly to the Horn Pond Creek tributary whereas the remaining fraction of this sub-basin contributes directly towards the Aberjona River. This sub-basin was separated along the Boston and Maine Railroad into Sub-basin 13A (flows towards Horn Pond Creek) and Sub-basin 13B (flows towards the Aberjona River). Sub-basin 1 was sub-divided into five secondary sub-basins. Sub-basin 1C represents the portion of Sub-basin 1 that directly contributed to TtNUS Station 1. Sub-basin 1B represents the portion of Sub-basin 1 that directly contributed to TtNUS Station 2. Sub-basin 1B includes about 50 percent of the area drained by the tributary south of North and South Ponds. This tributary then flows towards the Regional Transportation Center and discharges into the north end of the HBHA Pond. This division of flow was completed around 1996 as part of the Industri-Plex Remedial Action soil remedy. The sub-basin delineation reflects this diversion of flow which prior to 1996 discharged directly to the Aberjona River.

Similarly Sub-basins 1D and 1A represent the portion of Sub-basin 1 that directly contributed to TtNUS Stations 4 and 3, respectively. Sub-basin 1E is the remaining area within Sub-basin 1 that did not contribute to TtNUS Stations 1 through 4. These five secondary sub-basins were identified through the stormwater flow paths shown on the VHB 2003 report.

The information provided within the VHB 2003 report was supplemented by the working knowledge of TtNUS staff. This working knowledge is based on oversight activities during construction of the soil remedy (cap) at the Industri-plex site; observations during numerous storm events over the past 15 years; completion of numerous soil, sediment, and surface water

sampling rounds around the HBHA; oversight during the design and construction of the I-93 Interchange (new Atlantic Avenue exit); review of wetland permits for commercial developments, including Target and Metro North Business Center; and review and oversight of drainage modifications to Commerce Way. The eastern sub-basin boundaries that extend almost to New Boston Street were estimated. TtNUS further checked these secondary sub-basin delineations at the Woburn City Engineers' Office through a review of city plans and drawings. Some drawings were found of the HBHA, although no street drainage drawings were available. The drawings that were reviewed confirmed that the sub-basin boundaries for Sub-basins 1D and 1E were an accurate interpretation of the drainage patterns in proximity to the HBHA. A point-value topographical map was used to verify that Sub-basins 1D and 1E drain into the Aberjona River, with 1D draining via the HBHA. It is assumed that sub-basin 1E does not flow towards the HBHA wetland area. This sub-basin is assumed to contribute directly to the Aberjona River.

The North Reservoir of the Winchester Waterworks, located outside and southeast of the Aberjona River Watershed boundary, showed a possible hydrologic connection to the Aberjona River through a stream shown on the USGS topographic map. As a result of this observation, the operation of the North Reservoir was confirmed by TtNUS during a visit on November 6, 2002 with the Winchester Town Engineer and the Winchester Conservation Officer. Winchester officials confirmed that the North Reservoir is surrounded by an earthen dike which physically separates the reservoir from the Aberjona Watershed. There is a small stream however, that originates in a small wetland area that is located just outside of the dike. This is the stream shown on the watershed map that eventually flows to the Aberjona River. The stream is within the Aberjona Watershed boundary, but the reservoir is not (see Figure 2-3). The reservoir does have an overflow structure that connects to this stream if the reservoir water elevation exceeds 158.08 feet mean sea level (msl). According to the Town Engineer, this has not happened in recent years and so, flow from the reservoirs of the Winchester Waterworks did not represent a contribution to the Aberjona Watershed during the modeling period.

### 2.2.2.3 Surface Areas Contributing to Each TtNUS Station

A module is defined as the area contributing directly to a particular gauging station. The water that falls within the boundaries of Module 1 contributes flow directly to Station 1, the water that falls within the boundaries of Module 2 contributes flow directly to Station 2, and so on. Primary

and secondary sub-basins were thus summed to define a particular module (Table 2-3, Figure 2-3).

Module 1 is the sum of Sub-basins 1C, 2, and 3. (This module includes the contributions to Station 1 from the Middlesex Canal, Halls Brook, and from the New Boston Street Drainway – East Drainage Ditch.) The area corresponding to Sub-basin 1B is the area corresponding to Module 2. Similarly the area corresponding to Sub-basin 1A is the area corresponding to Module 3 and Sub-basin 1D corresponds to Module 4. Module 5 is the sum of Sub-basins 1E and 5. Module 6 is the sum of Sub-basins 4 and 7. Module 7 is the sum of Sub-basins 6, 9, and 11. Module 8 is the sum of Sub-basins 12, 13B, and 15. Module 8 does not include the Woburn West Module which corresponds to the area within the southwestern part of the watershed that is drained by Horn Pond Creek.

The Woburn West Module was excluded from Module 8 because flows through this area are influenced by the reservoirs of the Horn Pond Creek tributary. These reservoirs influence the response of the tributary to storm events and this response is different from those observed by areas that contribute directly to the Aberjona River. The Woburn West module corresponds to the sum of Sub-basins 8, 10, 13A, and 14.

The cumulative areas to each station represent the total area that contributes surface water flows to that station. The cumulative surface area to Station 1 corresponds to the area of Module 1. For Station 2, the cumulative area corresponds to the area contributing to Station 1 plus the area of Module 2. Station 3 receives surface water flows from Module 3 only. Station 4 receives surface water flows from areas upstream of Station 2 plus those from Module 4. Station 5 receives flows from areas upstream of Stations 4 and 3 plus flows from Module 5. Station 6 receives flows from areas upstream of Station 5 plus from Module 6. Similarly, Station 7 receives surface water flows from areas upstream of Station 6 plus those from Module 7. Flows from the Woburn West Sub-basin enter the Aberjona River between Stations 7 and 8, and thus the contributing area to Station 8 is the sum of the cumulative area to Station 7, plus Module 8, plus the area corresponding to the Woburn West Sub-basin.

## **2.3 Equipment and Maintenance at Each Station**

The following sections (2.3.1 and 2.3.2) describe the equipment installed at each monitoring station and the maintenance of each station respectively.

### **2.3.1 Type of Equipment**

Each station was equipped with two ISCO automatic samplers, each fitted with 24 1-liter polyethylene bottles; one to collect a sample for total metals analysis and the second to serve as a backup unit in case of primary unit failure. Both samplers would engage at the same time when triggered by pre-set conditions based on flow, stage, and precipitation or were manually (remotely) activated. ISCO Model 6712 automatic samplers equipped with continuous data-logging instruments (YSI Model 6920 and ISCO Model 750, Area Velocity Flow Module) were installed at Stations 1 through 8 and at Station 10 (Table 2-4). In addition, a tipping bucket rain gauge with an 8-inch collector, manufactured by Stevens, Model TD3 – 0.01”T, was also installed to monitor rainfall at each station. At these stations velocity, stage, pH, conductivity, specific conductance, ORP, DO, temperature, turbidity, and rainfall were measured in 5-minute intervals and recorded in 15-minute intervals by the ISCO auto-sampler. The specific conductance measurements were corrected for temperature variations automatically by the YSI instrument. These readings were compensated to a temperature of 25 °C. The ORP measurements were referenced to a silver/silver-chloride electrode. No adjustments were made to convert the ORP values to an equivalent standard hydrogen electrode.

Flow and stage conditions were not monitored at Station 9 (located at the dam separating the Upper and Lower Mystic Lakes) due to the lack of an intact control structure. Water chemistry parameters were monitored by an YSI Model 6920 and rainfall was monitored by a Stevens Rain Gauge, Model TD3 - 0.01”T at this station. Station 11 (located on a small tributary to the Lower Mystic Lake) was only equipped with an ISCO Model 4250 Area Velocity Flow Meter. No other equipment was installed at this station. Station 11 only monitored level, velocity and flow.

The ISCO auto-samplers have the capability to be triggered when preset monitored conditions are met. For example, the auto-sampler could be set to begin sampling when precipitation rates reached a certain threshold (e.g. greater than 0.1 inches per hour), or when flow changed over a specified time interval, or when turbidity levels increased by a certain amount within a given

period. The auto-samplers could also be set to begin sampling based on a combination of parameters. In addition, each auto-sampler could be activated or shut-off manually or remotely by telephone. Generally, only Stations 1, 2 and 4, located at the furthest points upstream, were preset to automatically begin to collect samples (see Sections 2.3.2 and 2.3.3 for prescribed sampling program) once specific stage and rain conditions were met. Once activated, these stations would call TtNUS personnel and notify them that the sampling program had been initiated. TtNUS personnel would then remotely activate all remaining stations to begin their sampling program. This approach reduced extensive operation and maintenance activities due to false starts or localized rain events in the southern reaches of the watershed.

Flow and stage were continually measured using an ISCO Model 750 area-velocity flow module that was incorporated into the ISCO Model 6712 auto-sampler. Similar to the other monitoring instruments, all data was measured in 5-minute intervals and stored in 15-minute intervals by the ISCO auto-sampler. In order to calculate flow, TtNUS surveyed the river channel at each station and developed station-specific rating curves using the area-level option within the Flowlink software provided with the ISCO units. The rating curves developed were used by the ISCO stations for the collection of flow-weighted, composited, water samples. The rating curves used by the ISCO stations were different from those described in Section 2.4. The station flow profiles were periodically re-surveyed to see if the channel configuration had changed and the preliminary rating curves were updated accordingly. This allowed the auto-samplers to collect flow-weighted samples during a storm event.

Each station was solar powered and equipped with a cellular telephone for data retrieval and remote control of the auto-samplers. For site security, each station was installed on a concrete pad and enclosed within a chain link fence. All sampling and control equipment was installed inside of a lockable, steel, jobsite utility box (See Figures 2-4 and 2-5).

Typical methods for collecting grab samples from surface water require that either the sample be collected from a depth equal to 0.6 of the total water column or a depth-integrated sampler be used to collect the sample. Neither of these options were practical considering that the auto-samplers would be unattended during storm events and the sample intake could not be adjusted to conform to the fluctuating depth of the river. The ISRT's consultant, Roux Associates, had devised an alternative device using slotted PVC pipe with sampling ports incorporated into the side of the pipe. The slotted PVC pipe consisted of schedule 40 PVC, 2-inch diameter with

0.125-inch slots and 0.25-inch spacing between each slot. The pipe was positioned into the stream channel at a fixed location, as mentioned in the preceding paragraph. The premise of the operation was that water from the entire water column would enter the PVC pipe from the various slots and would mix to create a representative sample of the entire water column. Given that the river water-depths were generally less than 3 feet, this approach seemed to be a reasonable and viable alternative.

To evaluate this alternative sampling method, TtNUS collected surface water samples on May 21, 2001 using three sampling techniques simultaneously: a grab sample at 0.6 of total depth, a depth-integrated sample, and a sample through the ports of the slotted PVC pipe. Nine samples were collected at each of Stations 2 and 10. Samples were shipped to and analyzed by the EPA New England Regional Laboratory (NERL) for total suspended solids (TSS). The sample results (Table 2-5) indicate that there was very little variability between the sampling methods. As a result, the slotted PVC pipe was considered acceptable.

The sample intake for the sample stations consisted of a slotted PVC pipe located as close to the center of the river channel as possible. The PVC pipe was attached to a metal anchor fence post by cable ties. The fence post was positioned into the channel bottom and supported the PVC pipe above the channel bottom. Barbed fittings were inserted close to the base of the PVC pipe, approximately a few inches from the bottom of the pipe. Polyethylene tubing, consisting of 3/8-inch I.D. and 1/2-inch O.D. was connected to each of the barbed fittings. The sample tubing ran from the PVC pipe in the river channel, through galvanized steel conduit, into the utility box, and connected to the automatic samplers (Figure 2-5).

### **2.3.2 Maintenance of Monitoring Stations**

TtNUS maintained each monitoring instrument on a weekly basis including performing instrument calibrations as required. Data from the instruments was generally downloaded bi-weekly, tabulated, graphed, and evaluated for system performance, auto-sampler response, and changes in the riverine system.

Specific maintenance included cleaning, inspecting, and replacing parts of the YSI Model 6920 water quality meter, such as sample probes and cables. The performance of the turbidity probe of the YSI meter was periodically checked. This was done by comparing turbidity values to

readings taken with a HF Scientific Turbidimeter DR 15. Weekly inspections were conducted on the transducer, which monitored velocity and stage and was located within the center of the channel. This inspection included removing accumulated algae, sediment or debris from the transducer, which could have affected the velocity and level measurements, and manually measuring water levels over the transducer. The manual water level measurements were compared to the water levels measured by the transducer in order to monitor transducer performance. If the water levels differed, the level would be re-calibrated. On a monthly basis, the transducer elevation in the channel was surveyed in relation to a designated benchmark (the concrete pad of the sample station). The elevation of the transducer was routinely surveyed in order to ensure that the block which supported the transducer did not shift or settle. This survey was also an indication of a change in the shape of the channel configuration. If the survey elevations varied significantly from the previous survey elevations of the given transducer, the entire channel profile at that sample station was re-surveyed. The channel profiles for each station are included in the attached CD. (See file called "ManualFlowCalTables.xls" within the "/Rating\_Curve\_Evaluation" sub-directory.)

Other monitoring station maintenance included measuring water quality parameters along the channel cross section for each sample station. These readings were measured on a monthly basis with a YSI Model 6920 instrument, separate from the YSI instrument attached to the sample station. Readings were made in 2-foot intervals at the mid-point of the water column. These readings were an indication of mixing within the water column and also served as a check on the performance of the YSI instrument within the channel dedicated to the sample station. Occasionally, minor variances in turbidity and ORP readings were observed in comparison to the YSI instrument dedicated to the sample station. Generally, the readings were fairly consistent along the channel cross section as well as in comparison to the YSI instrument in the center of the channel dedicated to the sample station, which indicated that the channel was well mixed and the location of the YSI instrument dedicated to the sample station was appropriately located. The channel cross section water quality measurements (YSI check forms) are included in the attached CD for further detail. (See "ChannelCross\_YSICheck.pdf" in the "\Maintenance of SWStations" directory). It should be noted that prior to November 6, 2001 the conductivity and specific conductivity readings were inadvertently switched for the YSI instrument dedicated to the channel.

In addition, a flow calibration was conducted on the channel for each station. This calibration was initially performed on a monthly basis. After collecting a number of low flow calibration points, the flow calibration occurred only during high stream flow conditions in order to acquire high flow calibration points. This calibration was conducted to check flow readings of the ISCO auto-sampler and also to develop a flow rating curve for the sample station, which is described in further detail in Section 2.4

Miscellaneous maintenance tasks that were performed periodically included: changing sample tubing; changing pump head tubing and sample bottles; cleaning and inspecting the rain gauge; and calibrating the suction volume of the ISCO auto-sampler. Sample tubing for each station was replaced after each sample event. On some occasions, the sample tubing was changed during non-storm conditions. The tubing lines were changed prior to a storm event, after a considerable period of deployment when the tubing had acquired organic growth, or if the auto sampler inadvertently activated its sample program. The pump head tubing of the ISCO auto-sampler was either removed and replaced with new tubing after each storm event or decontaminated and reused if the tubing was still in serviceable condition. The decontamination procedure consisted of pumping deionized water through the tubing followed by a 10 percent nitric acid and deionized water solution, and lastly by deionized water only. The suction volume of the ISCO auto-sampler was calibrated to ensure that the volume of water purged was accurate. This calibration was performed according to the manufacturer's instructions. The calibration consisted of programming the sampler to collect a specific volume of water and measuring the amount of water the sampler actually purges with a graduated cylinder. The measured volume was entered into the sampler. The process continued until the sampler purged the correct volume for at least three consecutive purges.

## **2.4            Development of Rating Curves**

The rating curves were developed in two steps. The first step consisted of manually measuring depth and velocity along the cross section of the channel at each sampling station. Velocity measurements were measured with a Marsh – McBirney Flowmate 2000 velocity modified flow measurement meter. Both depth and velocity measurements were measured at 2-foot intervals along the width of the channel. Velocity measurements were measured at 0.6 of the total water column depth. These measurements were made at various times during the year and for

various channel conditions, such as low flow or baseflow conditions and during storm flow conditions.

In order to apply the depth and velocity measurements collected to an overall channel cross sectional average velocity, the velocities and depths were entered into a spreadsheet and computed. This computation was made according to standard procedures (Chow, et al., 1964; Linsley, et al., 1975). The area and discharge of each increment were calculated based on the measured depth and velocity and the width of each increment. The result of this technique was a flow-weighted average based on cross-sectional area, which is achieved by multiplying the cross-sectional area by the average velocity to calculate a discharge for each increment. The overall area, velocity, and flow were then calculated by the summation of each increment. The flow computed in this fashion is referred to herein as the “manually measured” flow.

The second step in developing the flow rating curves consisted of recording the level and velocity measurements made by the ISCO auto-sampler. Two water level/velocity measurements were obtained, one by reading the ISCO display in the field during the time of flow calibration, and another by reviewing the downloaded data from the auto-sampler for the time frame of the flow calibration. The downloaded level data from the auto-sampler was plotted versus the manually measured flow for each station for each flow calibration event and a flow rating curve was produced (Figures 2-6 and 2-7, and Table 2-6). It is important to note that the rating curves are based upon water level measurements downloaded from the ISCO auto-sampler only. Velocity measurements were not used in developing the rating curves since they did not contribute to an increase in the correlation between the “manually measured” flow and the computed flow given the ISCO values. The rating curves developed are thus used to determine flow rates for various stage conditions for each station and provide an accurate relationship between flow and stage. One flow rating curve has been produced for each station. However, for Station 10 a flow rating curve could not be developed because of observed flow reversals possibly due to tidal influences from Boston Harbor, which is approximately 5 miles from Station 10. In addition, a flow rating curve was not established for Station 9, because stage, velocity, and flow were not monitored at this station due to the disrepair of the dam.

For most stations the rating curves consisted of two relationships: one relationship which corresponded to low flows and was generally very flat (small change in flow per change in stage) and another relationship which corresponded to higher flows and was steeper (large

change in flow per change in stage) (Table 2-6; Figures 2-6 and 2-7). The “goodness of fit” or  $R^2$  for the steep curves was generally better than the goodness of fit for the flat portion of the rating curves. For Stations 1, 2, 3, 4, 5, 7 and 8, the goodness of fit for the steep curves was upwards of 0.9 indicating a very good fit (an  $R^2= 1$  being a perfect fit) and in some cases the  $R^2$  value was upwards of 0.97 indicating an excellent fit. The rating curves for Station 6 consisted of a single relationship. The relationship for Station 6 was linear and characterized by an  $R^2$  value of 0.93, again indicating a good fit.

The suitability of the rating curves can also be evaluated through graphs of manually measured flow and computed flow. Manually measured flow, as described above, corresponds to readings taken during flow calibration runs which required multiple depth and velocity measurements along the cross-section of the river. The computed flow corresponds to the flow provided by the rating curve given the ISCO level measurement during the time of flow calibration. As observed from Figures 2-8 and 2-9, the manual and computed flows fall very close to the 1:1 line for Stations 1 through 8, again indicating that the rating curves provide good estimates for flow given the water level measurements.

## **2.5 Sample Collection Procedures for Metals and Suspended Sediment Analysis**

The surface water monitoring program included collecting samples for suspended sediments, and dissolved and total metals analysis on a monthly basis during baseflow conditions (Section 2.5.1) and during six storm events (Section 2.5.3). In order to collect samples during storm events, parameters and their thresholds were established to initiate the auto-samplers. A description of these requirements is provided in Section 2.5.2.

### **2.5.1 Baseflow Sampling Procedures**

Monthly grab samples were collected at each station and submitted for total metals, dissolved metals, and TSS analyses. A total of 16 grab samples were collected from each station during baseflow conditions. Dissolved metals were operationally defined by filtering the water samples through 0.45 micron ( $\Phi$ m) pore size filters. The samples chosen to represent baseflow conditions could not be taken if a significant rain event had occurred within 3 to 5 days. In cases where a rain event had occurred prior to the scheduled sampling date, TtNUS would

evaluate flow conditions to verify that the river had returned to baseflow conditions before sampling.

The sample collection procedures for baseflow events followed the direct dip technique in accordance with the TtNUS SOP SA-1.2. This SOP is included in the attached CD. (See “TtNUS\_SW\_SOP.pdf” included in the “/SW\_Sample\_ProgramsandProcedures Directory”). This technique consists of collecting a grab sample from a depth of 0.6 of the total water column by dipping a sample bottle to the required depth and retrieving a sample. The sampling event included collecting QA/QC samples, such as duplicates and equipment blanks. Sample filtering was conducted in the field upon sample collection. It was also originally planned to filter the samples with an in-line system consisting of 1.0 and 0.45-micron filters, as highly turbid surface water was expected. However, the surface water was not excessively turbid and in most cases a 0.45  $\mu$ m filter was solely used to filter the sample. According to the Industri-Plex Quality Assurance Plan prepared by TtNUS, if the turbidity was 20 NTU or greater, both filters were used in-line to filter the sample. All sample filtering was conducted in the field by use of a peristaltic pump, sample dedicated disposable polyethylene tubing, and disposable filters.

Initially, the baseflow sampling events consisted of collecting 4-liter volumes for TSS analysis. The laboratory generally required only 1 liter for TSS analysis for samples collected during baseflow conditions. The additional sample volume was needed to analyze the total metal concentrations of the suspended solids mass. By providing a larger sample volume to the laboratory, a greater mass of suspended solids could be filtered from the sample. The suspended solids could then be dried and analyzed for total metal concentrations. However, despite the extra sample volume, the suspended solids mass collected was not sufficient to analyze for total metal concentration. As a result, the sample volume for TSS analysis was returned to the standard 1-liter volume for sample collection during baseflow conditions.

### **2.5.2 Initiation of ISCO Auto-samplers**

The initial goal of the storm sampling program was to capture storms greater than 2 inches in depth in the northern portion of the river. Since a 2-inch storm was not observed from April 2000 to May 2002, the threshold was reduced to 1-inch for the remainder of the study period from May 2002 to October 2002. It was also decided that Stations 1, 2, and 4 were the best stations to use for initiating the storm event sampling program. After evaluating the response of

river stage to 1-inch rain events for each station, and after evaluating the average change in level within 15 minutes and within 1 hour, the condition of a rise in level over a particular time period was determined to be a trigger for the samplers.

In addition to a rate of change in level, a rain condition was also used as a trigger. The rainfall trigger corresponded to more than 0.01-inches of rain in 1-hour. This additional condition ensured that the sampler was initiated due to a rain event and not due to some outside factor which may have temporarily increased the stage, such as wind driven waves or animal activity. The sample initiation conditions are presented in Table 2-7.

After receiving an automated alert call from Stations 1, 2, and 4 that they had been initiated, TtNUS personnel would call the remaining stations and remotely activate the sampling program.

All of the samplers were programmed to run until all 24 1-liter sample bottles were filled. In most cases, TtNUS personnel briefly interrupted the ISCO auto-samplers' program to add new bottles and then the program was re-engaged. This was done in order to capture the entire storm event, which for most of the storm events required more than 24 sample bottles.

### **2.5.3 Storm Flow Sampling Procedures**

Six storm events were sampled; two spring storms, two summer storms, and two fall storms. Since the intent of the program was to monitor and evaluate sediment and contaminant transport through the entire system, storms that did not geographically cover the northern portion of the study area (i.e. Stations 1 through 4), were ignored. Table 2-8 presents the general date and approximate overall size of the storm events sampled. A summary of rainfall for each storm event is presented in Figure 2-10. The distribution of total rainfall per sample station for each storm event is presented in Figure 2-11 and is based on rainfall measured at each TtNUS sample station.

The ISO auto-samplers at Stations 1, 2, 3, 5, 6, 7, and 10 collected composite samples based on flow-weighted criteria for each station. Samples were collected over the storm event beginning at the start of the storm, as indicated by the rising limb of the hydrograph, and continuing until the river approached baseflow conditions, as indicated by the falling limb of the hydrograph to approximately a 50 to 75 percent minimum of the falling limb of the hydrograph.

Refer to the attached CD for storm event hydrographs for each station. (See the “Appendices\ Chapter\_2\_Monitoring\_Program\ MaintenanceofSWStations\ Storm\_ hydrographs” directory.)

The flow-weighted criteria were based on a certain volume applicable for each sample station. This volume was determined by assessing different flow rates and volumes at each sample station for various rain events. Table 2-9 includes a summary of the flow determined for each sample station.

The ISCO auto-sampler offers several options for sample collection, including time paced (time-weighted), flow paced (flow-weighted), and grab. The sample type selected at most stations was the flow module volume option (flow-weighted). The specified volume, as previously described (see Table 2-9), was programmed into the ISCO auto-sampler program for each station. This specified volume is the amount of flow volume through the river between samples collected. In addition, data points of level and corresponding areas were programmed into the ISCO auto-sampler. The data points were based on the level readings recorded during the flow calibration events and the overall channel cross-sectional areas computed from the flow calibration. The data points entered allowed the ISCO auto-samplers to compute a flow rate and a flow volume. The samplers would collect an aliquot of sample when the transducer detected the specified amount of flow volume. Flow-weighted samples were collected in four 200-mL aliquots per 1-liter sample bottle. The 800-mL total per bottle was determined to be adequate, as it allowed for space within the sample bottle container to prevent overflowing if the auto-sampler should purge a greater sample aliquot volume than programmed. A detailed description of the sample program for each sample station is included in the attached CD. (See the “/SW\_Sample\_ProgramsandProcedures/ISCO Programs” directory)

Flow-weighted samples were not collected at Station 9. Instead, hourly samples were collected because the station did not monitor stage or velocity and therefore could not compute flow or a volume. Composite samples were collected at this station by retrieving a 200-mL aliquot of sample every hour (four aliquots per 1-liter sample bottle) beginning when the sample was initiated and continuing until the sampler was disabled.

Grab samples at Stations 4 and 8 were collected every hour once the sampling program had been initiated. However, due to budgetary constraints, only a portion of the samples were selected for analysis. Generally, the sample selection criterion for laboratory analysis was every

other sample during the rising limb, including the peak, and the first four hours of the peak of the hydrograph. Thereafter, every fourth sample was selected for analysis. The samples not selected were preserved and stored at TtNUS' offices for future consideration. Due to holding times, samples for TSS could not be stored. Following evaluation of the targeted sample results, other stored samples were also selected and analyzed to resolve or confirm inconsistencies or anomalies in the previous data. Each sample volume was 800-mL. This sample aliquot volume was determined to be sufficient volume for analysis and it allowed space within the 1-liter sample bottle container to prevent overfilling of the sample bottle container if the auto-sampler should purge a greater aliquot volume than programmed. For Stations 4 and 8, the samples collected in the primary ISCO sampler were used for total metals and TSS samples, and the samples collected in the secondary ISCO sampler were used for dissolved metals analyses.

After the storm ended and the river began to return to baseflow conditions, the auto-samplers were turned off. The end of storm sampling period was determined when the river flow was at 2 times the baseflow value (consisting of 50 percent of storm induced flow and 50 percent baseflow). This condition was calculated by noting the lowest flow rate,  $x$ , prior to the storm. Flow rates were based on the rating curves established for each station. Sampling ended when flow reached two times " $x$ ". For the sample stations where flow-weighted composite samples were collected, the samples collected within each bottle of the auto-sampler were composited into a single container, mixed, and aliquots were drawn off. An unpreserved aliquot was used for TSS analysis, a separate aliquot was filtered (0.45 micron filter) and preserved (nitric acid) for dissolved metals analysis, and preservative (nitric acid) was added to a third aliquot that was not filtered for total metals analysis.

For Station 4 and Station 8, where hourly grab samples were collected, the sample bottles within the primary auto-sampler were removed from the auto-sampler. Half of the sample volume, approximately 400 mL, was poured from each sample into a second sample bottle. This procedure of dividing the sample volumes separated each hourly grab sample into a sample for total metals analysis and a sample for TSS analysis. The sample bottles within the secondary auto-sampler were removed from the auto-sampler. These samples were field filtered upon collection for dissolved metals analysis. Field filtering consisted of pumping the sample volume through a new 0.45-micron disposable in-line filter using a peristaltic pump, and disposable silicone and polyethylene tubing. All samples for metals analysis were field-

preserved with concentrated nitric acid until the pH of the sample was less than 2.0. QA/QC samples, such as duplicates and equipment blanks, were also collected during each sample event.

## **2.6 Laboratory Methods for Sample Analysis**

Total and dissolved metals were analyzed by the laboratory according to the EPA contract laboratory program (CLP) statement of work Method ILM04.1 (inorganic low / medium 04.1). This method is based on the use of an inductively coupled plasma (ICP) spectrometer, which measures atomic emission by an optical spectroscopic technique. The ICP technique identifies elements within liquid samples after an acid digestion of the samples. A hydrochloric and nitric acid mix is used for the acid digestion for all metals with the exception of mercury, where a mix of sulfuric and nitric acid with potassium permanganate is used for acid digestion. The ICP instruments used were a Thermal Jarrel Ash Model P4 61 Trace (vacuum) and a Thermal Jarrel Ash Model P4 61 Trace (Nitrogen Purge). Analysis of mercury was based upon a cold vapor technique. The instrument used for mercury analysis was a Leeman Labs Model 1056A.

The TSS samples were analyzed according to the EPA Method 160.2 (USEPA, 1983). This method requires the determination of TSS by the non-filterable residue procedure which involves retaining a solid mass on a 2.1 cm diameter glass fiber filter disc and drying it to a constant weight at a temperature of 103 to 105 °C. The glass fiber filter used was a “Pro-weight Filter” manufactured by *Environmental Express*, catalog number F93447mm. The volume of sample specified by the method is between 100 to 300 mL of the sample volume. A total of 1.0 mg residue is required for analysis. If 1.0 mg was not received, an additional 100 mL of the sample was filtered. This process continued until the 1.0 mg residue was achieved.

Compu Chem performed the metals and TSS analyses. The detection limits applied are the achievable laboratory quantitation limits (QLs). The reported detection limit is the concentration below which the reported result is determined to be non-detected. The reported detection limit is based on two factors: the instrument detection limit (IDL), and blank actions that may be taken during a Tier II or Tier III data validation as described below.

- 1) IDL – The laboratory reports sample results down to the IDL for each metal. If the instrument sample result is greater than or equal to the IDL, the result is positive, and

the value of the result is reported. If the instrument sample result is less than the IDL, the result is non-detected (U), and the IDL is the reported value. Thus, the reported detection limit is the IDL of the instrument used. The IDLs for each instrument are determined based on the analysis of a standard solution. (The IDL is calculated as 3 times the average of the standard deviations obtained on 3 days of the results of seven measurements per day of the standard solution). The IDLs are re-determined at least quarterly and when the instrument is adjusted in any way that may affect the IDL.

- 2) Blank Actions – If a Tier II or Tier III data validation is performed, the detection limit for a sample result may be raised due to field or laboratory blank contamination. Blank action levels are calculated as 5 times the maximum blank concentrations. All positive results less than or equal to the action levels are changed to non-detected results (U). In this case, the reported detection limit has been raised from the IDL to the reported value.

Thus, the reported detection limit for a given metal may vary over time due to blank actions, the use of different laboratories or instruments, and the periodic re-determination of IDLs. A range of the reported detection limits for TSS and metals is provided in Table 2-10.

### **3.0 PHYSICO-CHEMICAL DATA**

This section focuses on discussing precipitation data (Section 3.1), streamflow data (Section 3.2), data collected using the YSI probes installed for this study (Section 3.3), and results from suspended sediment measurements (Section 3.4). Additional information is provided in the attached CD. (Refer to the subdirectory called “Chapter\_3\_Physico\_Chemical\_Data”.)

#### **3.1 Precipitation**

A large amount of historical precipitation data has been collected for the study watershed. This historical record is discussed in Section 3.1.1. Precipitation data are described in Section 3.1.2 for data collected by the TtNUS monitoring stations for the May 2001 to October 2002 period of record.

##### **3.1.1 Historical Rainfall Records at the Reading Station**

The data discussed in this section were obtained from the two rain gauging stations located in Reading, Massachusetts. The first station corresponds to the Reading – 100 Acre Pumping Station for the 1899 to 1956 period of record. The second rain gauge station corresponds to the Reading - NCDC station for the 1957 to 2002 period of record (Section 2.1.1 for a description of these stations).

###### *Yearly Rainfall Data*

The average yearly rainfall from 1899 through 2002 measured at the Reading weather stations was 43.5 inches, the standard deviation was 7.04 inches. The driest year during the period of record was 1965 with 27.1 inches of rain; the wettest year during the period of record was 1983 with 63.5 inches of rain (Figure 3-1).

###### *Monthly Rainfall Data*

The average monthly rainfall for the Reading weather stations was 3.63 inches, based on the 1899 through 2002 period of record (Table 3-1 and Figure 3-2). The average monthly rainfall as measured at the Reading weather stations does not vary significantly from month to month.

Historically the month receiving the most precipitation was November with an average accumulation of 4.10 inches, followed by March with a comparable average rainfall of 4.06 inches. July historically received the least amount of precipitation with an average rainfall of 3.31 inches, followed by August with 3.33 inches.

### *Storm Event Data*

Storm events were evaluated from the hourly precipitation record recorded by the Reading NCDC weather station, which was collecting hourly data between 1981 through the present. In order to evaluate this data, storms were defined as being separated by at least five hours without any precipitation and at least 0.02 inches of rain must fall during a five-hour period to meet storm event criteria. According to the historical rainfall data collected at the Reading weather station, 2,230 storms of 0.02 inches of accumulation or greater have occurred since 1981. Table 3-2 presents the number of larger storm events from 1981 through 2002; the averaged frequency of such storm events is also presented.

### **3.1.2 Data from the TtNUS ISCO Stations and Comparison to Reading Station Data**

#### *Yearly and Monthly Rainfall Data*

The TtNUS rainfall data was recorded in 15-minute intervals on data-logging instruments (ISCO Model 6712) at 10 TtNUS-installed monitoring stations. The period of record for the TtNUS Aberjona River study began May 15, 2001 and ended on October 29<sup>th</sup> 2002. Data were downloaded every two weeks and converted to Textpad files to be compatible with computer modeling software (Lahey Fortran and/or MatLab). The data were spliced into one spreadsheet then reviewed for missing data and anomalies. Erroneous data were identified through close inspection of the data and cross-referencing field notes concerning equipment maintenance. Erroneous data were typically caused by equipment malfunction or interference from wildlife. Error codes were inserted to fill in these data gaps. These error codes were later replaced through a computerized substitution routine for the rainfall data only. This substitution routine replaced the gaps in the rainfall data with a reasonable value from the next closest station. (For more details refer to the "\Error\_Log" and "\Rain\_Compare" subdirectories on the attached CD which are located under Appendices\Chapter\_3\_Physico-Chemical\_Data).

Table 3-1 provides a comparison between the monthly rainfall accumulations recorded at the Reading stations for the historical record (1899 to 2002) versus the TtNUS period of record (May 2001 to October 2002). The average rainfall recorded during 2001 and 2002, 3.8 inches and 4.18 inches, respectively, is slightly higher than the average for the entire historical 104 year period (3.63 inches).

In addition, the monthly average rainfall accumulation for the 18-month TtNUS monitoring period (3.52 inches) was extremely close to the monthly average rainfall accumulation for the same months of the historical 104-year record (3.56 inches). Thus, the TtNUS period of record as a whole is considered to be representative of average rainfall conditions for the Aberjona River watershed. The monthly precipitation for individual months during the TtNUS monitoring period were in some cases higher than the historical record (e.g. June 2001, August 2001, and May 2002) and in other cases the opposite was noted (e.g. September through November 2001). However, for the 18-month monitoring period as a whole, the TtNUS period of record is considered to be very near average precipitation conditions.

Monthly rainfall volumes measured at each of the 10 TtNUS stations follow a similar pattern (Figure 3-3 and Table 3-3). Not all stations recorded the exact same values, however. The differences between stations were primarily due to spatial variations in rainfall throughout the watershed. The largest differences in rainfall were noted during August 2001. In general, the Reading - NCDC station located in the northern part of the watershed recorded larger quantities of rainfall whereas Station 9 located at the southern end of the watershed generally recorded smaller quantities. From July 2002 through August 2002 the values for Stations 7 through 10 appear lower than the other stations, including the Reading - NCDC Station. By mid-September 2002 the plots for each station appear to converge to similar levels. It appears that storms during the summer months provide more precipitation to the northern part of the watershed than the southern part. Other factors that may impact the quantities of rainfall recorded at the stations include the way that each station handles snowfall. The Reading - NCDC station uses antifreeze to avoid the accumulation of snowfall on top of the gauges, whereas the snow at the TtNUS stations likely accumulated at the top of the gauge. For very large snowfalls this difference could have biased the TtNUS measurements toward the low end due to the inability of the gauges to accumulate large quantities of snow on top of them. The snowfall issue is probably insignificant since, according to temperature records, only a total of 1.08 inches of precipitation (rainfall equivalent depth of snow) fell during the winter of 2001.

Other possible causes of inconsistencies between rainfall monitoring stations, in addition to micrometeorological weather patterns and storm behavior, could be attributed to rain gauge obstructions such as leaves, bird guano, or other biological debris. Regular maintenance was performed on all stations and error codes were placed in the record in cases where known obstructions may have impacted the measurements.

The monthly rainfall records from the TtNUS Aberjona River monitoring Stations 1 through 10 and the Reading Weather Station are similar in shape; this consistency between stations supports the reliability of these measurements.

### *Storm Event Data*

Storm events were a significant factor in the TtNUS Aberjona River study. The initial goal was to capture storms greater than 2 inches in depth during different seasons (spring, summer, and fall). During the study, the goal was modified to capture storms greater than 1 inch in depth. TtNUS personnel decided whether to follow through with sampling of the surface water after the initial portion of the storm event met prescribed conditions for sampling (a set rate of rise in water depth and rainfall detection at Stations 1, 2, and 4). Storm predictions based on local forecasts and the proximity of storm events to one another influenced the decision to sample surface water during a particular storm event. ISCO units were controlled using a cell phone to dial each unit, enabling TtNUS personnel to initiate the ISCO sampling units or disable them if need be (see Section 2.5.2 for ISCO storm-event trigger settings). However, some storms may not have been captured due to poor weather forecasting and equipment failure.

Throughout the duration of the Aberjona River study there were 20 storm events with rainfall accumulation of 1-inch or greater. Table 3-4 outlines the occurrences of the storm events: 17 events were greater than 1 inch but less than 2 inches; two events were greater than 2 inches but less than 3 inches; and one event was greater than 3 inches, with the largest event occurring in August 2001 at 3.08 inches.

This frequency of storm events is consistent with historical records. From Tables 3-2 and 3-4, 15 storm events between 1 and 2 inches, 6 events between 2 and 3 inches, and 1.5 events greater than 3 inches would have been expected for an 18-month monitoring period. The actual frequency of storm events (17 events between 1 and 2 inches, 2 events between 2 and

3 inches, and 1 greater than 3 inches) is very close to the historical frequency of storm events with the exception of fewer 2 to 3 inch storm events. Overall, the correspondence between the frequency of storms between historical and the TtNUS monitoring period suggests that the TtNUS monitoring period is representative of average conditions, with fewer storms in the 2- to 3-inch range.

Storms events early in the TtNUS sampling effort were not captured due to the need to analyze storm hydrographs to determine the parameters for initiating the autosamplers. During the last 12 months of the TtNUS sampling period, 5 of the 13 storm events greater than 1 inch were captured. The storm capture rate is considered to be excellent due to the difficulties in predicting the entire depth of a storm based on the initial response of that storm.

## **3.2 Streamflow**

A large amount of historical streamflow data has been collected for the USGS station located at the south end of the Aberjona River. This historical record is discussed in Section 3.2.1. Streamflow data collected at the TtNUS monitoring stations for the May 2001 to October 2002 period of record are described in Section 3.2.2.

### **3.2.1 Historical Streamflow Records at the USGS Station**

Streamflow measurements for the Aberjona River have been recorded since 1939 by the USGS monitoring station located near the outlet of the river. For background and method of measurement at this station (see Section 2.1.2). Measurements are taken every 15 minutes. These readings are then averaged to provide hourly values. TtNUS monitoring stations also recorded streamflow data every 15 minutes and averaged the data using the same averaging routine used by the USGS.

#### **3.2.1.1 Yearly Streamflow Evaluation**

The historical data obtained from the USGS corresponds to the 1940 to 2002 period of record. The overall average yearly flow rate for the 42-year period of record was 29.7 cubic feet per second (cfs). Figure 3-4 shows yearly average streamflow, the average flow rate per decade and the overall average flow rate over the last 42 years of monitoring. A comparison of each

yearly average to the overall average indicates that streamflow is slowly increasing and more variable towards later years. While the decadal average precipitation has only slightly increased, the increase in streamflow is possibly due to increasing runoff development in the watershed where more pavement and storm water drainage structures have been constructed. Except for the high streamflows of the 1950's, the decade averages reflect this increasing trend of the flow rate in the Aberjona River.

#### 3.2.1.2 Monthly Streamflow Evaluation

The monthly distribution of streamflow was characterized by high flows during the spring and lower flows during the summer, with the lowest flows during August and September. The average monthly flow at the USGS station from 1940 to 2002 was 29.7 cfs. The maximum monthly flow rate generally occurred in March with an average flow of 65.5 cfs. The minimum monthly flow rates occur in August with an average of 10.1 cfs (Figure 3-5).

The distribution of monthly flows is influenced by precipitation, snowmelt, evapo-transpiration, and other seasonal variations in the climate. During the spring the average streamflow is generally higher due to snowmelt, spring rains, and bare frozen earth which allows for more runoff. Groundwater recharge also occurs during the spring which will impact groundwater contributions to the river. The snowmelt during the spring followed by increased evapo-transpiration during the summer is typically the primary cause of the decreasing trend in flow rates from March through September.

#### 3.2.1.3 Streamflow Evaluation During Storm Events

The daily streamflow rate was evaluated for the 1940 to 2002 period of record. Since hourly rainfall records were available from 1980 to 2002, precipitation event records were paired with flow data for storm events since 1980. The data were evaluated in 100 cfs increments with the exception of daily flow values less than 100 cfs which were evaluated in 20 cfs increments (Table 3-5). For the 1940 to 2002 period, the maximum average daily flow recorded was 1110 cfs. Nine days were characterized by average daily streamflows greater than 700 cfs (Table 3-6). There are two instances where extremely high streamflow events (>700 cfs) were documented on consecutive days, October 21st and 22nd, 1996 and March 22nd and 23rd, 2001. It is interesting to note that the majority of these large flow events occurred in more

recent years indicating that increased urbanization is resulting in a “flashier” river with higher peak flows. The rainfall associated with the large flow events typically occurred a day or two before the peak streamflow. These specific occurrences are also representative of long periods of precipitation with large accumulations of rain that include one or more storm events.

The majority of the time (53 percent), the daily streamflow at the USGS station was less than 20 cfs and 99 percent of the time the daily averaged streamflow was less than 200 cfs (Table 3-5).

### **3.2.2 Data from TtNUS ISCO Stations Compared with USGS Data**

The following sections provide a comparison between the streamflow measurements obtained from the TtNUS ISCO stations and the USGS station. Data are available for 17.5 months and thus, monthly streamflow data and hourly data are compared. No yearly comparisons are provided.

#### **3.2.2.1 Monthly Streamflow Data**

TtNUS Station 8 was installed next to the existing USGS monitoring station to establish an independent check of the streamflow measurements and methods. Monthly and hourly streamflow averages for all stations were calculated from 15-minute data. The corresponding overall average streamflow from the historical record was computed as 26.2 cfs which was very close to the average flow recorded by TtNUS Station 8, indicating that hydrologic conditions during the TtNUS monitoring period were consistent with historical averages. The only notable difference is the timing of the spring snowmelt event which typically occurs during March (Figure 3-6). However during the TtNUS monitoring period peak monthly average flows occurred during May. The magnitude of the historical peak monthly average flow (52.9 cfs) was very close to the magnitude of the peak monthly average flow measured at TtNUS Station 8 (61.4 cfs).

Comparison of the USGS measurements against the TtNUS Station 8 values for the same period of record (using data during times when both stations were functioning) indicates that the average flow recorded by TtNUS Station 8 was about 19 percent higher (24.8 cfs) than the average flow recorded at the USGS station (20.9 cfs). Average monthly streamflow for the USGS station and TtNUS Station 8 follow the same trend, with the highest flows during the spring of 2002 and the lowest flows between August and November 2001 (Figure 3-6 and Table

3-7). The lowest monthly average streamflow rates were measured at 4.7 cfs for TtNUS Station 8 and 3.6 cfs for the USGS station. The highest flow rates were measured during May 2002. For this month, TtNUS Station 8 measured a flow rate of 61.4 cfs and the USGS station measured a flow rate of 55.3 cfs.

As shown in Figure 3-6, TtNUS Station 8 recorded higher readings during the winter and spring months of 2002 as compared with the data recorded by the USGS station. The largest discrepancy was observed in February 2002 followed by March then April of 2002. These months also showed the highest streamflow averages. These differences may be due to differences in the rating curves established for each station. Typically, few calibration values are available at high flow rates due to their less frequent occurrence. Thus, there is greater uncertainty in the upper extremes of rating curves. This uncertainty may have contributed to the differences in the average monthly streamflow measured during the winter and spring months.

Monthly streamflow for all TtNUS stations and for the USGS stations are provided in Figure 3-7 and Table 3-8. All stations show higher flows during the spring of 2002 and lowest values from August through November 2001. The results indicate that streamflow generally increases in the downstream direction, with the exception of TtNUS Station 4, during the winter and spring months of 2002. Evaluation of groundwater level data collected for this study indicates that the surface water elevation at Station 4 is frequently higher than the groundwater elevation. This was observed for 10 of the 13 measurements taken between April and October 2002 and suggests that some surface water observed at Station 4 is lost to groundwater (See files within \Chapter\_3\_Physico-Chemical\_Data\Water\_Levels).

#### 3.2.2.2 Hourly Streamflow Data

TtNUS Station 8 and the USGS Station show very similar patterns for hourly streamflow (Figure 3-8). Peak values in streamflow between each station coincided in time as do the low flow values. Figure 3-9 emphasizes a time period during which the smaller peaks coincided for both Station 8 and the USGS station. The larger peaks on this graph however did not coincide as closely; the peaks measured by Station 8 are lower than the peak values from the USGS station. In contrast, Figure 3-10 emphasizes a time period during which the low flows measured by the USGS station were slightly lower than the flows measured by Station 8. Interestingly in this figure, the two large peaks show differing trends; Station 8 measured a larger peak flow for

one storm event and a lower peak flow (relative to the USGS value) for another storm event. This may be due to the differences in how the USGS rating curve was calculated versus the TtNUS rating curve.

Overall, the comparison indicates that Station 8 and the USGS station capture the same trends in streamflow. Both record peak flows and baseflows during the same time periods. The magnitude of the peaks and flows may differ on occasion. Overall the mass of water transported past each station (as observed from the average flow rates) was within 20 percent of each other.

### **3.3 Water Quality Data from YSI Probes**

The following sections include summaries of six parameters (water temperature, specific conductivity, dissolved oxygen concentration, pH, oxidation-reduction potential, and turbidity) that were monitored in 15-minute increments using YSI probes at each of the stations along the Aberjona River by TtNUS. The data were downloaded from ISCO remote sampling units to a database for tabulation and analysis. Monitoring of the Aberjona River for the six parameters was done to gain knowledge of the river's behavior and to evaluate possible trends or anomalies that could affect contaminant transport.

#### **3.3.1 Water Temperature**

As seen from the plot of average monthly temperature versus time (Figure 3-11, Table 3-9), the surface water temperature reflects a seasonal temperature pattern, with January and February being the coldest months and July and August being the warmest months. Water temperature readings are also affected by the depth of the water and the position of the temperature probe. Station 2, for example is very shallow compared with Stations 9 and 10. Therefore it is more significantly influenced by the air temperature and direct sunlight. Water temperature was consistently coldest at Station 1 (Halls Brook) and warmest at Stations 9 (Mystic Lake) and 10 (Mystic River). The greatest variance in water temperature between stations occurred in the summer, while the water temperature was almost the same throughout the river during the winter and spring months. The summer-time variations are most likely due to differences in sun exposure at each station since some are shaded by trees and various structures.

### 3.3.2 Specific Conductivity

Specific conductivity in freshwater ranges from 0 to 1,300  $\mu\text{S}/\text{cm}$ . Values above 1,300  $\mu\text{S}/\text{cm}$  water are considered brackish; there were four instances when average monthly specific conductivity rose to concentrations above the fresh water range: Station 3 during March 2002 (1,314  $\mu\text{S}/\text{cm}$ ), Station 7 during January 2002 (1,409  $\mu\text{S}/\text{cm}$ ), Station 8 during February 2002 (1,617  $\mu\text{S}/\text{cm}$ ), and Station 10 during February 2002 (1,365  $\mu\text{S}/\text{cm}$ ). The highest specific conductivity readings were observed during the months of January and February (Figure 3-12, Table 3-10). These high readings are likely due to road-salt runoff from winter road maintenance which can be carried to the river during storm events and snow melt.

### 3.3.3 Dissolved Oxygen Concentration

Dissolved oxygen (DO) concentrations varied from station to station. In general DO was highest during the winter months and lowest during the summer (Figure 3-13, Table 3-11). This trend is consistent with DO saturation values (Table 3-12) (Viessman and Hammer, 1998) which are higher at colder temperatures. The dissolved oxygen saturation values shown in Figure 3-13 correspond to the average monthly water temperature measured at each station. In general, DO concentrations varied in a similar pattern from station to station. Station 7 exhibited a monthly average reading during July 2001 (13 mg/L) and August 2001 (9.9 mg/L) that was not observed at any of the other stations. These elevated readings occurred after calibration of the YSI probe and may be due to a calibration offset or error. Also Station 8 exhibited a low reading (5.1 mg/L) in January 2002 that did not follow the general behavior of the other stations for that month. Also of note are a few other monthly averages (Station 1, February 2002: 15 mg/L; Station 9, January 2002: 15.3 mg/L; Station 9, August 2002: 11.4 mg/L) that were more than 2 mg/L above saturation values. The elevated DO concentrations during February 2002 at Station 1 occurred immediately after calibration of the DO probe and these elevated values may be due to a calibration error. The other elevated values occurred at Station 9. DO patterns at this station are unique in that relatively large variations were observed to occur with peak DO values during mid-day hours and lower values during the night. Station 9 is located immediately downstream of the Upper Mystic Lake. DO fluctuations at this station may be due to aquatic plant growth in the lake which results in elevated oxygen levels during times of maximum sunlight. In general DO concentrations at Station 9 were higher than at the other stations, in particular during the summer months.

### **3.3.4 pH**

The pH at Stations 1 through 8 was generally constant throughout the year at an average of 6.9, which is essentially neutral (Figure 3-14, Table 3-13). Stations 9 and 10 showed elevated pH measurements, in particular towards the end of the monitoring period, during August and September 2002. Stations 9 and 10 are located below the terminus of the Aberjona River and are thus affected by waters from other watersheds which may have higher pH values. The overall average pH at these two stations for the TtNUS period of record was a value of 8.

### **3.3.5 Oxidation-Reduction Potential (ORP)**

ORP values at Stations 1, and Stations 3 through 10 were generally within the 200 to 500 mV range, indicating generally toxic water conditions (Figure 3-15, Table 3-14). The primary exception to this trend were the low ORP values observed at Station 3 during July and August 2001; the ORP values dropped to between -130 and 100 mV. During these months dissolved oxygen values were also low at Station 3 (1.9 and 2.7 mg/L), which is consistent with the lower ORP values. Station 2 was characterized by consistently lower ORP values than the other stations, reflecting the more reducing conditions of the HBHA Pond. The highest monthly ORP value at Station 2 was observed during March 2002 (60 mV). During this time the other stations generally recorded their lowest values.

### **3.3.6 Turbidity**

Time series plots showed that turbidity readings tended to be very erratic in nature, and suggest that turbidity measurements were very sensitive to the frequency of probe calibration. As such, it is likely that the recorded turbidity values may not be representative of the turbidity for the Aberjona River during all times for which data are available; for this reason the data are not plotted. The overall average values for turbidity are provided, nevertheless, in Table 3-15. These average values appear to be high in comparison with turbidity measurements from other studies conducted on the Aberjona River (Solo-Gabriele and Perkins, 1997b). Although the turbidity data suggest generally elevated turbidity values at Station 5 during the summer of 2002 and Station 2 during the summer of 2001, this was not observed in the corresponding TSS measurements. Thus, turbidity measurements are not considered reliable over the long term.

### **3.3.7 Summary of Water Quality Data from YSI Probes**

During the Aberjona River study conducted by TtNUS, 10 ISCO sampling stations were programmed to record the measurements of six physico-chemical parameters (water temperature, specific conductance, dissolved oxygen concentration, pH, ORP, and turbidity) every 15 minutes. These records were stored by the ISCO stations and later downloaded and compiled by TtNUS.

Some parameters were observed to fluctuate in a systematic fashion whereas other parameters fluctuated in a more random fashion. Water temperature readings remained the most consistent among all the parameters measured. The greatest difference in water temperature readings between stations was observed in the summertime and is likely due to the effects of exposure of the water and temperature gauges to sunlight and shade. During the summer there are longer periods of sunshine due to longer days, and more obstructions from the presence of leaves on the trees. Specific conductivity remained fairly consistent between stations. The highest levels were observed during the winter months and were likely caused by road-salt runoff. Dissolved oxygen concentrations also remained reasonably consistent throughout the length of the Aberjona River and were in many cases near saturation levels. The pH measurements along the Aberjona River exhibit a consistent trend. From Stations 1 through 8, the pH measurements were all very close to neutral. The pH values at Stations 9 and 10 were elevated in comparison with the upstream stations. The oxidation-reduction potential measurements at all 10 stations except Station 2 were positive. ORP readings at Station 2, downstream of the Halls Brook Holding Area, were characterized by negative values. These negative values were likely caused by the anoxic nature of groundwater flowing into the pond. The turbidity readings followed no consistent pattern.

### **3.4 Suspended Sediments**

The following sections describe the suspended sediment data collected from the Aberjona River. Results corresponding to baseflow conditions for suspended sediment concentrations (Section 3.4.1) and fluxes (Section 3.4.2) are presented first, followed by a discussion of storm event conditions (Sections 3.4.3 and 3.4.4). Baseflow versus storm event TSS concentrations and fluxes are compared in Section 3.4.5. Vertical bars shown on each graph correspond to the range in values observed. Additional TSS graphs along with those included within this section,

are included in the attached CD. (See "TSS\_storm\_summaries.xls" and "TSS\_baseflow\_summaries.xls" within the "\suspended\_sediments" subdirectory.)

"Flux," expressed in units of mass per unit time, is useful for evaluating the suspended sediment mass that passes a particular station or is associated with a particular event. Flux was calculated by multiplying the average concentration by the flow rate at a specific sample date and time. The equation applied to determine arsenic flux was the following:

$$F = Q * C * (0.1019) \quad \text{eqn. 3-1}$$

Where F = flux (kg/hr)

Q = river flow rate (cfs)

C = TSS concentration (mg/L)

0.1019 = conversion factor (L·s·kg / (mg·ft<sup>3</sup>·hr))

The flow rate used in the equation was determined by the flow rating curve developed for each station. A detailed explanation of the development of the flow rating curves is included in Section 2.5. Please note that flux data are not provided for Stations 9 and 10 since flow rating curves were not developed for these two stations.

### 3.4.1 Baseflow TSS Concentrations

Samples corresponding to baseflow conditions were collected monthly starting in July 2001 for a total of 16 baseflow sampling events. The overall average TSS concentration and the range in variability for these samples were greatest at Station 4 for baseflow conditions (Figure 3-16). The average TSS at Station 4 was approximately 23 mg/L. Concentrations vary at this station from 4 mg/L to 110 mg/L. Average TSS concentrations for all of the other stations were approximately within the same range, near 5 mg/L. TSS at Station 7 was slightly higher (7 mg/L on average) and more variable than for Stations 1, 2, 3, 5, 6, 8 and 9. TSS at Station 10 was also slightly higher (6 mg/L on average).

The trend previously described above is also exhibited by Figure 3-17, which represents the TSS concentrations of each sample station per sample date. Station 4 exhibited significantly higher TSS concentrations for the following sampling events: 9/18/01 (54 mg/L), 11/19/01 (109 mg/L), and 12/17/01 (85 mg/L). These elevated TSS concentrations drive the higher overall

average TSS concentration in relation to the other sample stations. For example, excluding these three sample events, the average TSS concentration would be 8.6 mg/L for Station 4. A peak in TSS concentration was also present at Station 7 for the 7/14/02 sample event, which again drives a slightly higher overall average concentration in relation to the other sample stations. Again, excluding this one event, the average TSS concentration would be 4.6 mg/L for Station 7.

According to the overall average TSS concentrations per sample event (Figure 3-18), the greatest concentration for all stations as a whole occurred during the 11/19/01 sample event. The second greatest concentration occurred during the 12/17/01 event. The station-averaged concentrations for other sample dates were all relatively within the same range, with the exception of the 7/14/01 and 9/18/01 sample events which were slightly higher.

The elevated station-averaged TSS concentration observed on 7/14/01 was due primarily to the elevated concentration measured at Station 7 on that particular date. The elevated station-averaged TSS concentrations observed for the 9/18/01, 11/19/01, and the 12/17/01 sampling dates were primarily due to elevated concentrations observed at Station 4 (Figure 3-19). These dates correspond to the fall and winter months, suggesting a possible seasonal pattern in elevated TSS concentrations at Station 4. However, these elevated concentrations were not observed during the October 22, 2001 and October 25, 2002 sampling dates, suggesting that if these elevated TSS concentrations were seasonal in nature, then they are sporadic and not observed continuously during the fall and winter months. To evaluate this peculiar trend further, the TSS concentrations during baseflow conditions were plotted versus streamflow (Figure 3-20). As indicated earlier, TSS concentrations during baseflow conditions were generally in the 5 mg/L range with the exception of Station 4. Suspended sediment concentrations at Station 4 were as high as 109 mg/L. No relationship was observed between flow rate and suspended sediment concentration at Station 4.

### **3.4.2 Baseflow TSS Fluxes**

As mentioned above, TSS fluxes were computed by multiplying the TSS concentration by the flow rate. Of note is that not all data points had both a TSS concentration and a flow value and thus TSS flux values for each station and date may not be based upon a consistent set of data. It would thus be important to note this possible discrepancy when evaluating the data.

Results from the flux computations indicate that the TSS flux was highest on average at Station 8 during baseflow conditions (Figure 3-21 and Figure 3-22), driven primarily by the higher flow rate observed at this station. The TSS concentrations at Station 8 were within the range of 5 mg/L as previously discussed in Section 3.4.1 and shown by Figure 3-16 and Figure 3-17. The flux is also high at Stations 4, 6, and 7, and greater than the average flux observed at Stations 1, 2, 3 and 5 (Figures 3-21 and Figure 3-22). The higher average flux for Stations 6 and 7 can also be attributed to the higher flow rate, as the average TSS concentrations were also within the range of 5 mg/L as previously discussed in Section 3.4.1 and shown by Figure 3-16 and Figure 3-17. The higher TSS flux at Station 4 was due to the higher average TSS concentration observed at this station. The average TSS concentration at Station 4 was 21 mg/L, as previously discussed in Section 3.4.1. In addition, the TSS flux variability was greater at Stations 4, 6, 7, and 8, where the average TSS flux and TSS concentrations were higher (Figure 3-21).

Evaluating the data on a sampling date basis (Figures 3-23 and 3-24) indicates that TSS flux was generally higher during the winter and spring. This trend was likely due to higher flow rates during the winter and spring (see Figure 3-7). Similar to the concentration data, a peak was observed at Station 4 for the December 17, 2001 sample event, which was attributed to the high TSS concentration as previously discussed. Peaks were also observed at Stations 7 and 8, however, TSS concentrations were not elevated during the sample dates when these peaks occurred, and therefore these peaks were due to higher flow rates. Furthermore, the data indicate that variability was greater when the TSS flux was high, similar to the trend described above for TSS concentrations during baseflow.

### **3.4.3 Storm Event TSS Concentrations**

Storm event TSS concentrations for Stations 1, 2, 3, 5, 6, 7, and 10 correspond to the results from the composite sample analysis, which are flow-weighted composites based upon the flow rates measured by each ISCO station. Since hourly grab samples were collected at Stations 4 and 8, the results from these samples were converted into equivalent composite concentrations (CC) in units of mg/L, using a flow-weighted averaging routine consistent with the following expression:

$$CC = \frac{\sum(C * Q)}{\sum Q} \quad \text{eqn. 3-2}$$

where: Q = river flow rate at each sample interval (cfs)

C = TSS concentration at each sample interval (mg/L)

The flow rate used was obtained from the ISCO measurements and the flow rating curves developed for each sample station as described in Section 2.4. Flow measurements were not taken at Station 9, so the composite sample analyzed at this station is simply the mixture of hourly samples. See Section 2.5 for more details concerning the compositing procedure for different stations.

Samples corresponding to storm flow conditions were analyzed for six storm events. These samples were collected during April 2002, May 2002, July 2002, August 2002, September 2002, and October 2002. The overall average TSS concentration during these storm events was greatest at Station 8, with an average concentration of 46 mg/L. The storm-composite concentrations for this station ranged from a low value of 17 mg/L to a high value of 83 mg/L (Figure 3-25). The overall storm averaged TSS concentrations for Stations 9 and 10 were in the 5 mg/L range which is the same range observed during baseflow conditions for these stations. Given the data collected it appears that concentrations at Stations 9 and 10 are relatively constant, in the 5 mg/L range, regardless of flow conditions. The overall average TSS concentrations for the remaining stations (Stations 1 through 7) are in the 6 to 22 mg/L range. With the exception of TSS at Station 4, these values are elevated over the typical values observed for these stations during baseflow conditions (5 mg/L). The observations at Station 4 are different than those at the other stations. At Station 4, TSS concentrations are typically higher during baseflow conditions than during storm flow conditions.

The elevated averaged TSS concentrations observed at Station 8 were primarily due to two storm events: the May 2002 and October 2002 events (Figure 3-26). Averaging the TSS concentrations across stations, the greatest storm event TSS concentrations occurred during the October 2002 storm (20 mg/L overall average) (Figure 3-27). The April 2002 storm (19 mg/L overall average) and the May 2002 storm (16 mg/L overall average) were also characterized by relatively high suspended sediment concentrations. The station-averaged TSS for the July 2002, August 2002, and September 2002 storm events were relatively within

the same range (near 9 mg/L). The high levels of the station-averaged TSS concentrations were driven primarily by the elevated concentrations observed at Station 8 (Figure 3-28).

Grab sample data collected during storms at Station 4 and 8 indicate that suspended sediment concentrations are elevated at Station 8 during storm flow conditions, in particular during the rising limb of the streamflow hydrograph (Figure 3-29). For example, this is especially evident for the October 2002 storm when plotted in time series (Figure 3-30). This behavior is different than that observed for Station 4 where suspended sediment concentrations are not as variable during storm flow conditions. Results from the storm composite samples at the remaining stations (Figure 3-31) indicate that for some stations, in particular for Stations 1, 2, and 3, the storm average composite suspended sediment concentrations were higher for larger storm averaged composite flows.

#### **3.4.4 Storm Event TSS Fluxes**

As mentioned above, TSS fluxes were computed by multiplying the TSS concentration by the flow rate. Of note is that not all data points had both a TSS concentration and a flow value and thus TSS flux values for each station and date may not be based upon a consistent set of data. In addition, the averaging periods for storm events were not necessarily the same for all stations. It is thus important to note these possible discrepancies when evaluating the data.

TSS flux during storm flow conditions was highest on average at Station 8 (Figure 3-32 and Figure 3-33). This was due to the high flow rates observed at this station (Figure 3-29) and was also due to the greatest average TSS concentration of 46 mg/L, as previously described in Section 3.4.3 and shown by Figure 3-25 and Figure 3-26. Elevated TSS concentrations at Station 8 occurred during the May 2002 storm event and the October 2002 storm event as previously discussed in Section 3.4.3 and shown by Figure 3-25 and Figure 3-26. These elevated concentrations are responsible for the elevated TSS fluxes observed on these dates. Overall, the average TSS flux tends to increase in the downstream direction from Station 1 through Station 8 (Figure 3-32 and Figure 3-33), which is consistent with increasing flow rates. The greater range of variability of flux for storm flow conditions tends to be more dependent upon greater variability in flow rates rather than greater variability in TSS concentrations.

Evaluating the data on a sampling date basis (Figure 3-34 and 3-35) indicates that there is no strong seasonal trend in the TSS flux during storm flow conditions across all stations. Similar to the concentration data, a peak is observed at Station 8 for the May 2002 storm event and the October 2002 storm event which is attributed to the high flows and TSS concentrations as previously discussed. The data also indicate that variability is greater for each storm event when the TSS flux is high, similar to the trend described above for TSS concentrations.

#### **3.4.5 Baseflow Versus Storm Event TSS Concentrations and Fluxes**

TSS concentrations varied between storm flow and baseflow conditions (Figure 3-36, Table 3-16). According to the data, overall average TSS concentrations are greatest during storm flow conditions, with the exception of Stations 4, 9 and 10. At Station 4, TSS concentrations on average, are about a factor of 2 higher during baseflow than during storm flow. Although TSS concentrations at Stations 9 and 10 are higher during baseflow conditions relative to concentrations observed during storm flow, the concentrations were within the range observed for the remaining stations. The TSS concentrations between baseflow and storm flows differ by a factor of 10 for Station 8, the largest difference observed for all of the stations. The baseflow and storm flow TSS concentrations were similar for Stations 5 and 9.

TSS fluxes increase at all stations during storm flow conditions (Table 3-16). The most notable increases were observed at Stations 1 and 8. At these stations the TSS flux increased during storm conditions by a factor of 40 (Station 1) to 70 (Station 8) times higher than those observed during baseflow conditions. These increases were a combined effect of increased flows and TSS concentrations observed at these stations during storm conditions. The increase in flow and TSS concentrations was likely due to tributary inflows during storm events. For example, Station 1 could be receiving additional inflows and sediments from the New Boston Street Drainway. The Horn Pond Creek tributary, which drains a large fraction of the Aberjona watershed, could also contribute significantly during storm flows at Station 8.

## **4.0 METALS DATA**

The metals reviewed for this study include: arsenic, iron, chromium, copper, lead, and mercury. Both total and dissolved metal concentrations were reviewed for baseflow (Section 4.1) and storm flow events (Section 4.2). Metals data for baseflow and storm flow conditions are compared in Section 4.3. A summary of the baseflow and storm flow data is provided in Section 4.4. Please note that the vertical bars shown in all of the subsequent graphs within this section correspond to the range of values observed. Also for averaging and plotting purposes, the concentrations of samples below the quantification limit were assumed at one-half the quantification limit value. Additional information for this section is provided in the attached CD. (Refer to the subdirectory called “\Section\_4\_Metals\_Data”).

### **4.1 Baseflow Data**

All data described in this section correspond to the 16 monthly grab samples collected during baseflow conditions. Grab samples were collected at each of the sample stations and were analyzed for total and dissolved metals as described in Section 2.0. Dissolved metals were operationally defined based upon the filtration method used. Concentrations and fluxes for arsenic are described in Sections 4.1.1 and 4.1.2. Concentrations and fluxes are also presented for iron (Sections 4.1.3 and 4.1.4), chromium (Sections 4.1.5 and 4.1.6), copper (Section 4.1.7 and 4.1.8), and lead (Section 4.1.9 and 4.1.10). Mercury concentrations are discussed in Section 4.1.11. Mercury fluxes are not plotted due to the large number of samples with concentrations measured at below quantification limits. Section 4.1.12 provides a comparison between metals concentrations and Section 4.1.13 provides a comparison between dissolved and total metals data. A summary of the metals data collected during baseflow conditions is provided in Section 4.1.14. Additional graphs are provided in the attached CD. (Go to the “\Baseflow\_metalsdata” within the directory called “\section\_4\_Metals\_Data”).

#### **4.1.1 Arsenic Concentrations**

According to the sample data, higher total concentrations of metals were observed at sample stations in the northern portion of the Aberjona River during baseflow conditions (Figure 4-1), with the exception of Station 1, which was immediately upstream of the HBHA. For total arsenic, the concentrations during baseflow were highest at Station 4 and was also high at

Stations 2, 3, and 5, which were located in drainage basin of the HBHA or within the northern part of the Aberjona River. The total arsenic concentrations decreased sequentially from Station 5 to Station 10. The range in variability in arsenic concentration was highest at Station 4 and was also high at Stations 2, 3, and 5. The range in variability in the total arsenic concentration during baseflow conditions decreased in the downstream direction from Station 4 to 10. In comparison to the overall average of TSS per sample station (Figure 3-16), the TSS concentration was also greatest at Station 4. However, unlike the average arsenic trend where concentrations were greater in the northern portion of the river, TSS concentrations did not vary much from the northern to southern portions of the river.

Dissolved arsenic concentrations increased slightly from Station 2 to 4 and then decreased in the downstream direction. Although the total arsenic concentration at Station 3 was not as large as that observed at Station 4, a relatively large proportion of the total arsenic at Station 3 was in the dissolved phase. This resulted in a relatively large dissolved arsenic concentration at this station relative to other stations. A majority of the total arsenic concentration was due to the particulate phase along the main “train” of stations from Station 2 to 4 and subsequently to Stations 5 and 6. Station 3 contributes to the dissolved arsenic burden of the river but this dissolved arsenic burden is small relative to the total arsenic observed at stations in its immediate vicinity. This observation is discussed further in the next section.

Figure 4-2 is a plot of the individual data points corresponding to the total average values plotted in Figure 4-1. Figure 4-2 again emphasizes the overall trend observed during baseflow conditions. The total arsenic concentrations appear to be greatest at Station 4 and elevated at Stations 2 and 3. The concentrations are relatively low at Station 1 and continuously decrease from Station 5 to Station 10. The highest concentrations were observed at Station 4 during November and December 2001. These two events drive the elevated concentrations observed at Station 4 during baseflow conditions. The average total arsenic concentration at Station 4 is 25.5 mg/L, not including the November and December 2001 events; the average total arsenic concentration is 37.1 mg/L if these two events are included.

The peak observed for total arsenic at Station 4 during the December 2001 sampling event was primarily due to a peak in the suspended sediment concentrations (85 mg/L) (Figure 4-3). For the 12/17/01 sample date, dissolved arsenic concentrations remained low. The total arsenic

concentrations during this sampling event were thus due to the elevated concentrations carried by the particulate phase.

Overall there was no clear seasonal trend in the total baseflow arsenic concentration (Figures 4-4 and 4-5). The only trend observed was that the variability in the baseflow arsenic concentration was typically larger when the average baseflow concentration was high. Most of the variability was due to variations observed at Station 4.

Further comparisons between TSS and arsenic concentrations for baseflow conditions indicate that there were elevated TSS and arsenic concentrations for the November 19, 2001 and the December 17, 2001 sample events for Station 4. The TSS concentrations for the other sample dates were all relatively low, as were the total arsenic concentrations. Thus when TSS concentrations were high, the total arsenic concentrations were also generally high. This relationship was not observed for the July 14, 2001 sample date where low arsenic concentrations were observed at Station 7 when TSS concentrations were elevated (Figure 4-6).

#### **4.1.2 Arsenic Fluxes**

Total arsenic flux during baseflow conditions was highest on average at Station 4 (Figure 4-7), which was primarily due to the high arsenic concentrations observed at this station (Figure 4-1). However, the total flux was also high at Station 2 and at Stations 5 through 8, greater than the average flux observed at Stations 1 and 3. The total arsenic flux appears to have decreased from Station 4 to 5, in particular if one considers that Station 5 receives the combined flux from Stations 4 and 3. If there was no deposition of arsenic between Stations 4 and 5, one would expect a total flux of 9.4 g/hr (2.7 g/hr from Station 3 plus 6.7 g/hr from Station 4 on average). However an average baseflow flux of 5.3 g/hr was observed at Station 5, which was about 40 percent less than what would have been expected if no deposition were to occur. The arsenic lost from Stations 4 to 5 could possibly have been deposited within the Wells G and H wetland located between these stations, an area known to contain high concentrations of arsenic within its sediments. A slight decrease in total flux (about 22 percent or about 1 g/hr less) was also noted on average from Station 5 to 6 and a slight increase in the arsenic flux was noted from Station 6 to 7 and from Station 7 to 8, on average. These slight increases and decreases were not as large as the loss noted between Stations 4 and 5. The elevated total flux values

observed at Stations 5 through 8 were primarily due to increasing flows in the downstream direction. Arsenic originating near Station 4 was generally diluted with additional water inflows in the downstream direction thereby decreasing the arsenic concentration but maintaining an elevated flux value. The large variability in the total arsenic flux observed at Station 4 appears to be due to the elevated arsenic concentrations observed at this station during the December 2001 sampling event (Figure 4-2 and Figure 4-8). Overall the data suggest that some of the arsenic flux was deposited in the area immediately upstream of Station 5. The primary source of the arsenic appears to have been from the HBHA.

With the exception of Station 3, the dissolved arsenic flux at each station represents less than 50 percent of the total arsenic flux, suggesting that the majority of the total flux was carried by the particulate phase. A large increase in the total arsenic flux between Station 2 and 4 was not accompanied by an increase in the dissolved arsenic flux, suggesting that particulates are responsible for the increase in arsenic flux between these stations.

Evaluating the data on a sampling date basis (Figure 4-9 and 4-10) indicates that there was no strong seasonal trend in the total arsenic flux during baseflow conditions across all stations. Similar to the concentration data, a peak observed at Station 4 for the December 17, 2001 sample event may also be attributed to the high TSS concentration and high total arsenic concentration observed on that sample date as previously discussed. Also the data indicate that variability was greater when the average arsenic flux was high, similar to the trend described above for arsenic concentrations during baseflow conditions.

#### **4.1.3 Iron Concentrations**

According to the sample data, higher total concentrations of iron occurred at Station 4, while the concentrations measured at the other sample stations decrease in the downstream direction with the lowest concentrations observed at Stations 9 and 10 (Figure 4-11). Also the data indicate an increase from Stations 1 to 2 to 4. The observed trends for total iron concentrations are further emphasized by Figure 4-12, which is a plot of the individual data points corresponding to the average values plotted in Figure 4-11. Total iron concentrations for the baseflow events ranged from detection limits to near 30,000 ug/L.

Dissolved iron concentrations increased slightly from Station 2 to 4 and then decreased in the downstream direction. Although the total iron concentration at Station 3 was not as large as that observed at Station 4, a relatively large proportion of the total iron at Station 3 was in the dissolved phase, resulting in a relatively large dissolved iron concentration at this station in comparison to other stations. As observed for arsenic, a majority of the total iron concentration was due to the particulate phase along the main “train” of stations from Station 2 to 4 and subsequently to Stations 5 through 10. Station 3 contributes iron in the dissolved phase but the dissolved iron is small relative to the total iron observed at other stations in its immediate vicinity.

Graphs of iron concentrations versus sampling dates (Figures 4-13 and 4-14) show no strong seasonal trend in iron concentration. The greatest average concentrations and greatest range of variability occurred during the 12/17/01 sample event. As was observed for arsenic, the high average concentration and high variability for the 12/17/01 event was due to the high concentration observed at Station 4 during that event. Elevated iron concentrations were also observed during the 8/23/01 and 11/19/01 events at Station 4.

#### **4.1.4 Iron Fluxes**

Total iron flux is highest on average at Station 8 (Figure 4-15), which was primarily due to the high flows observed at this station. The total flux on average for Stations 2 through 7 was between 400 to 1000 g/hr, however the highest iron flux was observed at Station 4 at 5233 g/hr. The lowest average flux occurred at Station 1 at 83 g/hr, where the lowest average iron concentration also occurred. The large amount of variability in the iron flux observed at Station 4 appears to be due primarily to the elevated iron concentrations observed at this station during the December 17, 2001 sampling event (Figure 4-12 and Figure 4-16).

For all stations, except for Station 3, a majority of the iron flux was carried by the particulate phase. At Station 3, the split between dissolved and “inferred particulate” flux was about 50:50.

Evaluating the data on a sampling date basis (Figure 4-13 and 4-14) indicates that there was no strong seasonal trend in the total iron flux during baseflow conditions across all stations. It appears that perhaps iron flux may have been higher during the winter and spring months on

average than during the summer and early fall. However, exceptions to this general observation are noted.

Similar to the concentration data, a peak observed at Station 4 for the December 17, 2001 sample event may also be attributed to the high TSS concentration and high total iron concentration on that sample date as previously discussed. Also the data indicate that variability was greater when the average iron flux was high, similar to the trend described above for arsenic concentrations during baseflow.

#### **4.1.5 Chromium Concentrations**

As observed for arsenic and iron previously, higher concentrations of total chromium occurred at Station 4 during baseflow conditions while the concentrations measured at the other sample stations were lower, on average (Figure 4-19). It appears that the concentrations were consistently low for Stations 1, 2, and 3, increased at Station 4, and continuously decreased from Stations 4 to 10. However, the concentrations were greater for Stations 5, 6, 7, and 8 than for Stations 1, 2, and 3. This trend is emphasized by Figure 4-20, which is a plot of the individual data points corresponding to the average values plotted in Figure 4-19. The range of chromium concentrations was from detection limits to near 90 ug/L. Also, similar to that observed for arsenic, the greatest concentration occurred on the 12/17/01 sample date at Station 4.

Dissolved chromium concentrations were relatively constant along the length of the river, on average. Higher total chromium concentrations observed at Stations 4 and 5 were due to higher particulate chromium concentrations.

Results by sampling dates are shown in Figures, 4-21 and 4-22. Based on these figures, it appears that the chromium concentrations were relatively consistent and did not vary much over the seasons. The greatest concentrations and greatest range of variability, which is consistent for most of the metals reviewed, occurred during the 12/17/01 sample event.

#### **4.1.6 Chromium Fluxes**

The total chromium flux values for Stations 4 and 5 through 8 were within the range of 1.6 to 2.8 g/hr. Total chromium flux was highest on average at Station 8 and lowest at Station 1

(Figure 4-23). The chromium flux appears to have increased from Stations 1 to 4, maintained the relatively same value at Stations 4 to 7, and slightly increased at Station 8. The large variability in the total chromium flux observed at Station 4 appears to be due primarily to the elevated chromium concentrations observed at this station during the December 17, 2001 sampling event (Figure 4-20 and Figure 4-24). A majority of the total chromium observed in the river, specifically at stations characterized by elevated chromium fluxes, was carried by the particulate phase.

Evaluating the data on a sampling date basis (Figure 4-25 and 4-26) indicates that there was no strong seasonal trend in the total chromium flux during baseflow conditions across all stations. Similar to the concentration data, a peak observed at Station 4 for the December 17, 2001 sample event may also be attributed to the high TSS concentration and high total chromium concentration on that sample date as previously discussed. Also the data indicate that variability was greater when the average chromium flux was high, similar to the trend described above for arsenic and iron concentrations during baseflow.

#### **4.1.7 Copper Concentrations**

According to the sample data, higher concentrations of copper occurred at Station 4, while the concentrations measured at the other sample stations are lower, on average (Figure 4-27). Also the data indicate a slight increase from Station 1 to 2, an increase at Station 4, low values contributed at Station 3, and a continuous decrease from Stations 4 to 10. This trend is emphasized by Figure 4-28, which is a plot of the individual data points corresponding to the average values plotted in Figure 4-27. The range of copper concentrations for the baseflow events was from 0 to 130 ug/L, which was slightly greater than the chromium concentrations. The highest concentration also occurred at Station 4 on the 12/17/01 sample date. In general the distribution between the dissolved and inferred particulate phase was roughly 50:50, with the exception of Station 4, where copper was more strongly partitioned towards the particulate phase. As observed for the other metals, for stations where total metals were relatively high, a larger proportion of the metals was carried by the particulate phase.

The data plotted by date are provided in Figures 4-29 and 4-30. Based on these figures, it appears that copper concentrations were relatively consistent and did not vary much over the

seasons. The greatest concentrations and greatest range of variability, which was consistent for most of the metals reviewed, occurred during the 12/17/01 sample event.

#### **4.1.8 Copper Fluxes**

Total copper flux is highest on average at Station 8 (Figure 4.31). This is primarily due to the high flow rate at this station rather than a high total copper concentration since the average copper concentration at Station 8 was less than the average concentrations at other stations (Figure 4-27). The total copper fluxes as measured at Stations 1 through 7 was consistently less than 4 g/hr (Figure 4-31). The copper flux appears to have increased from Station 1 (< 1g/hr) to 4 (3.3 g/hr), decreased from Stations 4 to 5, and increased from Stations 5 to 8, on average. The elevated flux values observed at Stations 5 through 8 were primarily due to increasing flows in the downstream direction. Copper originating near Station 4 was diluted with additional water inflows in the downstream direction, thereby decreasing the copper concentration but maintaining an elevated flux value. The large amount of variability in the copper flux observed at Station 4 appears to be due primarily to the elevated copper concentrations observed at this station during the December 2001 sampling event (Figure 4-28 and Figure 4-32), while the large variability in the copper flux at Station 8 appears to be due primarily to the elevated copper concentrations observed during the June 20, 2002 sampling event (Figure 4-28 and Figure 4-32). Roughly for stations characterized by elevated copper flux values, 50 percent of the copper flux was carried by the particulate phase with the exception of Station 4, where the particulate phase carried a greater proportion.

Evaluating the data on a sampling date basis (Figure 4-33 and 4-34) indicates that there was no strong seasonal trend in the total copper flux during baseflow conditions across all stations. Similar to the concentration data, a peak observed at Station 4 for the December 17, 2001 sample event may also be attributed to the high TSS concentration and high total copper concentration on that sample date as previously discussed. A peak was also observed at Station 8 for the June 20, 2002 sample date, which may be attributed to the high total copper concentration on that sample date. Also the data indicate that variability was greater when the average copper flux was high, similar to the trend described above for arsenic, iron, and chromium concentrations during baseflow.

#### **4.1.9 Lead Concentrations**

According to the sample data, higher concentrations of lead occur at Station 4, while the concentrations measured at the other sample stations were lower, on average (Figure 4-35). The data also indicate that lead concentrations were consistently low at Stations 1, 2, 3, 9 and 10. A notable increase in lead concentrations was observed from Stations 2 to 4 and concentrations generally decreased in the downstream direction. The increases in total lead concentrations along the length of the river were due to increases in particulate lead concentrations. Dissolved lead concentrations remained relatively constant along the length of the river. Individual data points corresponding to the averages plotted in Figure 4-35 are plotted in Figure 4-35. The range of lead concentrations for the baseflow events was from 0 to 60 ug/L. Similar to the other metals, the highest concentrations also occurred at Station 4 on the 12/17/01 sample date. Lead concentrations were also elevated during the November 19, 2001 sampling date at Stations 4, 6, and 8.

The data plotted by date for lead are shown in the Figures 4-37 and 4-38. Based on these figures, it appears that the metal's behavior during baseflow conditions was relatively consistent and did not vary much over the seasons, with the exception of elevated lead concentrations during the late fall and early winter of 2001. The greatest concentrations and greatest range of variability occurred during the 12/17/01 sample event, which is consistent for most of the metals reviewed.

#### **4.1.10 Lead Fluxes**

Total lead flux was highest on average at Station 8 (Figure 4-39), which was primarily due to the high flow rate at this station as well as the high lead concentrations observed at this station (Figure 4-35). The majority of the total lead flux observed at Station 8 was in the particulate phase. The lead flux appears to have increased from Stations 1 to 2 and from Stations 2 to 4. A net decrease in flux was observed between Stations 4 and 5. If no deposition of lead were to occur, the lead flux at Station 5 would be the sum of the flux at Stations 4 (1.5 g/hr) and 3 (0.3 g/hr). The flux at Station 5 was considerably less than the sum of the flux measured at Stations 3 and 4, suggesting that lead deposited between Stations 4 and 5. The elevated flux values observed at Stations 5 through 8 were primarily due to increasing flows in the downstream direction. Lead originating near Station 4 was diluted with additional water inflows

in the downstream direction thereby decreasing the lead concentration but maintaining an elevated flux value. The large amount of variability in the lead flux observed at Station 4 appears to be due primarily to the elevated lead concentrations observed at this station during the December 2001 sampling event, while the large amount of variability in the lead flux observed at Station 8 appears to be due primarily to elevated lead concentrations observed at this station during the June 2002 sampling event (Figure 4-36 and Figure 4-40).

Evaluating the data on a sampling date basis (Figure 4-41 and 4-42) indicates that there was no strong seasonal trend in the total lead flux during baseflow conditions across all stations. Similar to the concentration data, a peak observed at Station 4 for the December 17, 2001 sample event may also be attributed to the high TSS concentration and high total lead concentration on that sample date as previously discussed. Also similar to the concentration data, two peaks observed at Station 8, one for the February 15, 2002 sample event and one for the June 20, 2002 sample event, may be attributed to the high flow rates on these sample dates. On these dates the flow at Station 8 was high in comparison to the flow at the upstream stations. It is likely that during these sampling periods, the Woburn West sub-basin was contributing a significant amount of flow.

#### **4.1.11 Mercury Concentrations**

Based on Figures 4-43 and 4-44, there is no general trend that can be observed from the data. It should be noted that the mercury concentrations were very low, near or below the detection limits. As shown by Figure 4-44, the range in mercury concentrations was approximately from detection limits to 0.46 ug/L. The maximum value recorded during baseflow conditions was observed at Station 4.

The data plotted by sampling date is provided in Figures 4-45 and 4-46. Based on these figures, it appears that the metals' behavior was relatively consistent and did not vary much over the seasons. The greatest concentrations and greatest range of variability occurred during the November 19, 2001 and December 17, 2001 sampling events, which is consistent for most of the metals reviewed.

#### **4.1.12 Relationships and Trends Between Metals**

A comparison between metals concentrations during baseflow conditions is presented in Figures 4-47 through 4-50. Arsenic and iron are compared in Figures 4-47 and 4-48, and chromium, copper, lead, and mercury are compared in Figures 4-49 and 4-50. These figures display the results from the August 23, 2001 baseflow sampling event, which was considered to be representative of baseflow conditions.

The data (Figures 4-47 and 4-48) indicate that there was an apparent relationship between arsenic and iron in both the total and the dissolved phase. The two metals follow a similar pattern. When arsenic concentrations were elevated, iron concentrations were also elevated. Total arsenic and iron were elevated at Station 4. Station 4 was also characterized by the highest TSS concentration on average.

The highest total chromium, copper, and lead concentrations were also observed at Station 4 (Figure 4-49). No trends were observed for total mercury due to concentrations measured at or near detection limit values for the August 23, 2001 sampling event. Chromium, copper, iron, and lead were similar in that the dissolved concentrations were low in comparison with the total metals concentrations (Figure 4-50).

#### **4.1.13 Dissolved Versus Total Metals During Baseflow Conditions**

This section includes a discussion of dissolved versus total metals. The metals reviewed for these comparisons were arsenic, iron, chromium, copper, lead, and mercury. In addition, the fraction of the total metals that correspond to the dissolved phase was calculated and is discussed in this section. The fraction that corresponds to the dissolved phase was computed using two methods. The first method, represented by the first column in Table 4-1, excludes samples that were below the limit of quantification; the calculations used quantified data only from both the total and dissolved phase. The second method, represented by the second column, uses all data. Samples that were below the limit of quantification were set at one-half of the quantification limit value. The values plotted in the subsequent Figures 4-51 to 4-56 utilize all data including samples below the limit of quantification, which were subsequently set to one-half of the detection limit value. Discussion of the data shown in Table 4-1 is based on the Method 2 results since these are the fractions that correspond to Figures 4-51 to 4-56.

The computations for the percentages presented using Method 1 and Methods 2 in Table 4-1 are included in the attached CD. (See “fractionoftmindmall.xls” within the “\ComparisonofMetalsdata” directory for Method 1 and refer to the corresponding metals summary files located within “\Baseflow\_metalsdata” for Method 2.) The fractions computed using Method 1 and Method 2 were similar for most situations. Differences between fractions computed using Method 1 and Method 2 were observed for station and metal combinations corresponding to samples that were typically near or below quantification limit values for the majority of the measurements. Several below quantification limit values were observed for measurements of dissolved lead and mercury at all stations and for measurements of most metals at Stations 1, 9 and 10. Also, dissolved and particulate chromium concentrations were low at Station 8; as a result the fraction of metal within the dissolved phase was notably different between each Method and was sensitive to the one-half quantification limit value assigned to samples that were below analytical quantification limits. For example, at Station 8, 4 of the 16 total chromium concentrations and 12 of the 16 dissolved chromium concentrations were below quantification limits. The one-half of the quantification limit values for this station during baseflow varied from 0.95 to 2.6 ug/L for total chromium and from 0.25 to 1.05 ug/L for dissolved chromium. The differences in quantification limits between different sampling dates gives rise to fractions that are a function of laboratory analytical capabilities rather than true fractions observed from measurements. In these cases, results using Method 1 are considered to be more representative. However the number of samples used to compute fractions based on Method 1 are usually very small when the majority of the samples were below quantification limit values.

For arsenic, total concentrations were greater than the dissolved concentrations for each sample station during baseflow conditions, as expected (Figure 4-51). A similar pattern is displayed by iron, chromium, copper, and lead where the total concentration was greater than the dissolved concentration during baseflow conditions (Figure 4-52 through Figure 4-55). However, the relationship for mercury varies from station to station since many samples were measured at or below the limit of quantification. For Stations 1, 2, 3, 7, and 8, the total and dissolved mercury concentrations were computed as roughly equal to and near the limit of quantification. For Stations 4, 5, and 10, the total concentration is greater than the dissolved concentration, and for Stations 6 and 9 the dissolved concentration was computed as greater than the total concentration (Figure 4-56). This observation is likely an artifact due to the large number of values at or below the quantification limit for mercury.

Also the data (Figures 4-51 through 4-55) show a progression where the distribution of the metal shifts from total metals towards the dissolved phase as it proceeds downstream from Stations 4 to 10. For arsenic, 16 percent of the arsenic was in the dissolved phase at Station 4. This fraction systematically increased in the downstream direction and reached 100 percent at Station 10 (Table 4-1). This pattern is likely due to a combination of dilution and deposition of particulate arsenic as the water progresses from Station 4 to Station 10. In general, stations characterized by low arsenic concentrations (Stations 9, 10 and 1) were characterized by a larger fraction within the dissolved phase.

For iron, between 9 percent and 49 percent of the total iron was found within the dissolved phase. The lowest fraction occurred at Stations 4, 9, and 10 and the highest at Station 3. At Stations 9 and 10, this pattern is different than that observed for arsenic, because arsenic concentrations were generally almost entirely in the dissolved phase at Stations 9 and 10 whereas iron was predominantly in the particulate phase at Stations 9 and 10. Again the overall decrease in total iron concentrations between Stations 4 and 10 may be due to dilution and deposition of particulate iron during baseflow conditions.

For chromium, between 10 percent and 100 percent of the total chromium was found within the dissolved phase. The lowest fraction occurred at Station 4 and the highest at Stations 9 and 10. Again the progression of decreasing total concentrations is observed for chromium as the water progresses in a downstream direction from Station 4 to 10.

For copper, between 14 percent and 96 percent of the total copper was found within the dissolved phase. As observed for arsenic and chromium, the lowest fraction occurred at Station 4 and the highest at Stations 1 and 10.

For lead, the majority of the metal was in the dissolved phase for stations characterized by lower total lead concentrations (Stations 1, 2, 3, 9, and 10).

For mercury, most of the samples were below the limit of quantification. This resulted in a computed fraction where the majority of this metal was in the dissolved phase. However, this may be an artifact due to the inability to quantify this metal in most samples.

#### 4.1.14 Summary of Baseflow Data

Average metals concentrations during baseflow conditions are provided in Table 4-2. In general, higher concentrations of total arsenic were observed in the northern portion of the study area. This trend was also observed for the other metals reviewed: chromium, copper, iron, lead, and mercury. The highest concentrations for these metals were often observed at Station 4. Elevated total metals concentrations were also observed at Stations 2 and 5. Low total metals concentrations occurred at Station 1 and at Stations 9 and 10. The total metals concentrations increased from Station 1 to Station 2 to Station 4, where concentrations were greatest. [It is important to note that Station 3 did not receive flow from Station 2 and also that Station 4 received water from Stations 1 and 2, but not from Station 3.] The total metals concentrations generally sequentially decreased from Stations 4 to 10. Arsenic and iron concentrations followed a similar pattern.

The majority of the metals as observed from the “flux” graphs appear to originate from drainage areas between Stations 1 and 2 and between Stations 2 and 4. Station 5 received the flux from Stations 4 and 3, however, the sum of the flux from Stations 4 and 3 was frequently higher than the flux observed at Station 5, suggesting that metals were depositing between Stations 4 and 5. Deposition likely occurred within the Wells G&H wetland, an area known to contain high concentrations of metals within the sediments. Fluxes were also observed to increase between Stations 7 and 8. The increase in flux from Stations 7 to 8 was primarily due to an increase in flow (Figure 3-7) and not to an increase in metals concentrations. The drainage area for Station 8 (24.2 mi<sup>2</sup>) was almost double the drainage area for Station 7 (13.9 mi<sup>2</sup>) and as a result flows increased significantly between these stations during certain times of the year.

A weak seasonal trend in metal flux was observed which was primarily associated with increases in flow through the Aberjona River. Although the sample collected during the December 2001 baseflow event had the highest observed metals concentrations, the flux on this date was not consistently the highest for all metals evaluated. Other baseflow sampling events, characterized by higher flow conditions, in particular higher flows at Station 8, were characterized by metal fluxes similar to that observed during December 2001, and in some cases were slightly higher on average. Higher flows occurred in the Aberjona River during the winter and spring of 2002 through the June 2002 baseflow sampling events (Figure 3-7). This

time period along with December 2001 were the months characterized by higher overall average fluxes in the river.

Metal fluxes observed at Station 4 were on average 6.7 g/hr for arsenic, 970 g/hr for iron, 2.1 g/hr for chromium, 3.3 g/hr for copper, and 1.5 g/hr for lead (Table 4-2a). Fluxes at the remaining stations (with the exception of Station 8) were typically lower than those observed at Station 4, even though flows at Station 4 were lower. Metal fluxes at Station 8 were measured at 5.5 g/hr for arsenic, 1380 g/hr for iron, 2.8 g/hr for chromium, 9.4 g/hr for copper, and 4.1 g/hr for lead. The increase in flux observed at Station 8 was primarily due to an increase in flow. On average the flow at Station 8 for these baseflow flux events was seven times higher than flow observed at Station 4 (14 cfs versus 2 cfs). However, the flux observed at Station 8 was considerably less than a factor of seven, again indicating that the increase in flux at Station 8 was due in large part to an increase in flow. In Table 4-2a, it is important to note that the computed fluxes correspond to samples for which flow data were available since flux is computed as the product of concentration and flow. Flow data were not available for the July 2001 baseflow sampling event for all stations, nor was flow data available: at Stations 2, 3, 7 and 8 for the August 2001 event; at Stations 4, 5, and 6 for the September 2001 event; at Station 5 for the November 2001 event; and at Station 2 for the September and October 2002 sampling events.

As expected, the total metals concentrations were greater than the dissolved metals concentrations for all samples collected where concentrations were generally above limits of quantification. With the exception of iron at Stations 9 and 10, dissolved arsenic, chromium, copper, and lead represent a larger fraction of the total metals concentration when total concentrations were low. For iron, dissolved metals concentrations were low when the total concentrations were low.

The distribution of the metal flux between the dissolved and "inferred particulate" phases was dependent upon the relative concentrations observed. When the total metal concentrations were low, the dissolved phase represented a larger proportion of the flux. However, when total metal concentrations were high, the metals were more strongly partitioned towards the particulate phase which accounted for the majority of the flux. Exceptions to this trend include the relatively large proportion of dissolved arsenic and dissolved iron at Station 3, which in turn account for a relatively large proportion of the flux observed at this station. Although the

dissolved phase accounted for the majority of the arsenic and iron flux at Station 3, the flux observed at this station was less than that observed at Stations 4 and 8.

#### 4.2 Storm Flow Data

The storm flow data were collected during storm events using various methods. Flow-weighted composite samples were collected at Stations 1, 2, 3, 5, 6, 7, and 10 for total and dissolved metals and for total suspended solids. Grab samples were collected every hour for Stations 4, 8, and 9. Grab samples were analyzed individually for Stations 4 and 8 to provide the distribution of metals throughout the duration of the storm. Grab samples collected at Station 9 were composited together prior to analysis. In order to provide a consistent comparison between the composite samples and the grab samples collected at Stations 4 and 8, data obtained from these grab samples were converted into a numerical equivalent composite sample. This conversion was based upon the following equation, which was consistent with the flow-weighting scheme used to collect the samples at stations 1, 2, 3, 5, 6, 7, and 10.

$$CC = \frac{\sum(C * Q)}{\sum Q} \quad \text{eqn. 4.2}$$

Where CC = flow weighted composite concentration

(mg/L for TSS or ug/L for metals)

Q = river flow rate at each sample interval (cfs)

C = concentration at each sample interval

(mg/L for TSS or ug/L for metals)

The following sections include a discussion of arsenic concentrations (Section 4.2.1) and fluxes (Section 4.2.2). Concentrations and fluxes for iron, chromium, copper, and lead are discussed in Sections 4.2.3 through 4.2.6. Mercury concentrations are discussed in Section 4.2.7. Mercury fluxes are not presented due to the large number of samples that were below detection limits. The flux discussion for arsenic is much more detailed than those for the other metals. In addition to summarizing the metals fluxes on a storm by storm basis, arsenic flux values associated with individual grab samples are plotted for Stations 4 and 8. A comparison between metals for the May 2002 storm event, the largest storm event monitored, is provided in Section

4.2.8 and a comparison between dissolved and total metals is provided in Section 4.2.9. A summary of the storm flow data is provided in Section 4.2.10.

#### **4.2.1 Arsenic Concentrations**

In general, total arsenic concentrations during storm flow conditions decreased from the northern part of the river to the southern part, from Stations 2 through 10 (Figure 4-57). However, this trend is not a perfect linear trend. There were some peaks and lows observed from station to station. The average total arsenic concentrations during storm events appear to be highest at Station 2 and also high at Station 4. Peaks associated with individual storm composites were observed in the 30 ug/L range at Stations 3, 6, and 8 (upper bar on Figure 4-57). The storm composite concentrations at Stations 7 and 8 appear to be approximately equal, on average, and low in comparison with the upstream reaches of the river. The range in variability was greatest at Station 2, where the average concentration was greatest. The range of variability was also high at Station 4 and slightly high at Station 8.

In comparison to the overall average of TSS concentrations per sample station during storm events (Figure 3-25 and superimposed on Figure 4-57), there was an inverse relationship between TSS concentrations and arsenic concentrations. TSS concentrations were generally higher during storm conditions for the stations located in the southern portion of the river and lower for the stations in the northern portion of the river, while for arsenic, the concentrations were higher for sample stations located within the northern portion of the river and lower for the southern portion of the river. For example, the highest average arsenic concentration occurred at Station 2, although the average TSS concentration for Station 2 was low. The highest average TSS concentration occurred at Station 8, while the average arsenic concentration was low at Station 8. The average TSS and arsenic concentrations observed at both Stations 9 and 10 were consistently low.

Dissolved arsenic concentrations were generally highest at Stations 2 and 4, with dissolved arsenic concentrations decreasing in the downstream direction. Unlike baseflow conditions, the dissolved concentration at Station 3 was relatively low in comparison to concentrations observed at other stations. A majority of the total arsenic concentration was observed in the “inferred particulate” phase.

Individual total average values per storm event are plotted in Figure 4-58. Similar to the previous graph, Figure 4-57, storm event arsenic concentrations were highest at Station 2 and Station 4 with the exception of the August 2002 storm event. For the August 2002 storm event there was an auto-sampler malfunction at Station 2 in which the samplers did not initiate or collect samples. The total arsenic concentrations appear to be greatest for the May 2002 storm, followed by the October 2002 storm event, and the September 2002 storm event. It is interesting to note that the May 2002 storm event was characterized by the greatest amount of rainfall (2.80 inches) and the October 2002 event was characterized by the second greatest amount of rainfall (1.48 inches) suggesting that total arsenic concentrations increased with storm size.

The total arsenic concentrations during storm events are plotted by date in Figures 4-59 and 4-60. These graphs show that the highest average total arsenic concentrations occurred during the May 2002 storm event. The May 2002 storm event had the greatest total arsenic concentration and also the greatest range of variability. The October 2002 storm event had the second greatest total arsenic concentrations and range in variability followed by the September 2002 storm event. In comparison to the average TSS concentrations per storm event (Figure 3-27), both the May 2002 storm and the October 2002 storm had elevated average TSS concentrations. Furthermore, in comparison to the overall average arsenic concentrations (Figure 4-59), there were elevated TSS concentrations for the May 2002 storm event and the October 2002 storm event. However, the elevated TSS concentrations occurred at Station 8 (Figure 3-28) for both storm events, whereas the elevated total arsenic concentrations occurred at Station 2 (Figure 4-60).

Arsenic concentrations during the May 2002 storm event were highest at Stations 2 and 4 for both total arsenic and dissolved arsenic in surface water. Total arsenic concentrations at Stations 2 and 4 were 81.5 ug/L and 55.6 ug/L (Figure 4-61), respectively. Dissolved arsenic concentrations at Stations 2 and 4 were 27.4 ug/L and 25.6 ug/L, respectively. At Station 3 the total arsenic concentration was lower at 7.5 ug/L and the dissolved arsenic concentration dropped to 1 ug/L. After Station 4, the concentration of both total and dissolved arsenic dropped sequentially to 2 ug/L at Stations 9 and 10.

#### 4.2.2 Arsenic Flux

Arsenic flux was calculated by multiplying the average arsenic concentration by the flow rate during a storm event as provided in equation 3-1 at the beginning of Section 3.3. The flow rate used was determined using the flow rating curve developed for each station. A detailed explanation of the development of the flow rating curves is included in Section 2.4. The time over which averaging occurred corresponded to the times when the autosamplers were activated for composite sample collection for Stations 1, 2, 3, 5, 6, and 7. For Stations 4 and 8, data included in the averaging procedure corresponded to times during which samples were collected. The end of the storm event corresponded to the time when streamflow reached two times the baseflow value. Fluxes were not computed at Stations 9 and 10 because flow was not measured at these stations. It is important to note that on occasion flow data and/or concentration data were not available. For these situations, the flux value was not computed.

The overall average flux per sample station is summarized in Figure 4-62 for storm conditions. This figure shows that the highest total storm flow flux was measured at Station 8 and the range in variability was also high at this station. The arsenic flux was high at Station 2 and decreased at Station 4, on average, suggesting some deposition of arsenic within the wetlands in the southern part of the HBHA. A decrease in the dissolved arsenic flux was also observed between Stations 2 and 4. The observed total flux at Station 5 appears to be very close to the sum of the flux from Stations 4 and 3, on average, suggesting minimal net deposition in the areas upstream of Station 5 during storm conditions. This observation is different than that observed during baseflow conditions which suggested that deposition of metals from the HBHA occurs upstream of Station 5. From Stations 5 to 8, a net increase in total arsenic flux was observed, whereas the dissolved arsenic flux remained relatively constant. About one-half of the total arsenic flux observed during storm conditions at Station 8 can be accounted for by the storm induced flux at Station 2. Overall, the total arsenic flux during storms was greater at the stations within the southern part of the river and a greater proportion of the flux in the southern part of the river was due to the particulate phase. Figure 4-63 shows the pattern of arsenic flux at each sample station according to each storm event.

The greatest overall total arsenic flux, as well as the greatest variability, occurred for the May 2002 event (Figure 4-64). The second largest storm event sampled, the October 2002 event (1.5 inches), was characterized by the second highest arsenic fluxes and the second largest

range in arsenic fluxes. These results suggest that arsenic fluxes generally increase with the size of the storm event.

Although concentrations were typically lower at downstream stations, the arsenic flux was higher. In essence, arsenic was transported downstream and the concentration was diluted by additional water. This additional water carried arsenic with it but at lower concentrations, resulting in a net increase in the flux in the downstream direction. Figure 4-65 shows the pattern of arsenic flux for each storm event as observed at each station. The greatest arsenic flux occurred during the May 2002 event at Station 8. The large flux for the May 12, 2002 event was likely due to the relatively large storm event (2.8 inches) which resulted in large river flow values on that date. At Station 8, the metal concentrations for this storm event were also unusually high on the rising limb of the hydrograph for 2 of the 22 samples collected (240 and 430 ug/L). These two samples accounted for more than one-half of the flux observed for this event at Station 8. The second greatest arsenic flux occurred during the October 2002 event at Station 6, which was analyzed as a composite sample. Although the metal concentration was highest at Station 2 for the October 2002 event, the flux was not computed for Station 2 due to the lack of a flow value for this station for this event.

A comparison of arsenic flux between Stations 4 and 8 (which collected hourly grab samples) is shown in Figures 4-66 through 4-71. These graphs show a comparison between arsenic concentration, flow, and arsenic flux between Stations 4 and 8 for each storm event. The comparison shows that the arsenic concentrations were greater at Station 4 than Station 8, and that the flow was greater at Station 8 than Station 4.

For the April 2002 storm event, the arsenic flux at Station 8 was consistently greater than the arsenic flux at Station 4 throughout the duration of the storm (Figure 4-66). This was also true of the August 2002 storm event (Figure 4-69). The May 2002 storm event (Figure 4-67) was characterized by an unusually large initial peak in arsenic fluxes at Station 8 suggesting a flushing effect. In general for the May 2002 storm event, when the arsenic flux was elevated at Station 8 it was low at Station 4 and vice versa. Of interest is the sudden drop in arsenic concentration at Station 4 during hour 65. One explanation for this drop is a possible flow reversal at Station 4 where flows from Station 3 (characterized by lower arsenic concentrations) temporarily backed up and flowed towards Station 4. Review of the velocity record at Station 4 shows a sudden drop in velocity on May 14, 2002 at hour 12:30 to 0.13 ft/s from 5.9 ft/s.

Reversals in flow direction as indicated by negative velocity values are also observed at this station on May 15, 2002. Sporadic occurrences of negative velocities are also noted at Station 2 after the peak of the May 2002 storm. Arsenic flux values during the July 2002, September 2002, and October 2002 storm events (Figures 4-68, 4-70, 4-71) were characterized by similar sized peaks in arsenic fluxes. These events were also characterized by similar rainfall depths (1.1 to 1.5 inches).

#### **4.2.3 Iron Concentrations and Fluxes**

The sample data indicate that the highest concentrations of iron during storm events occurred at Station 2, on average (Figure 4-72). Dissolved iron generally represented a small fraction of the total with the highest concentrations observed at Stations 2 and 4. Similarly, total iron concentrations decreased in the downstream direction from Station 2 through Station 10, although increases are observed at Stations 6 and 8. This trend is further illustrated by Figure 4-73, which is a plot of the individual data points corresponding to the average values plotted in Figure 4-72. Each storm shows a general decreasing trend in the downstream direction with the exception of the May 2002, which shows a spike in iron at Station 8. The range of iron concentrations observed during storm events was from detection limits at Station 10 to 9,000 ug/L during the May 2002 storm event at Station 8. This elevated “equivalent composite” concentration was largely affected by two samples collected on the rising limb of the hydrograph which were characterized by unusually elevated iron concentrations (77,100 ug/L and 145,000 ug/L). Without these two data points, the average of the remaining 20 samples would be 3,000 ug/L, which is more consistent with the general trend observed along the length of the river. For all stations collectively, the iron concentrations were highest during the May 2002 storm. This is shown by Figures 4-74 and 4-75. The highest concentrations for this storm event were observed at Stations 2 and 8.

Similar to arsenic flux, iron flux was also calculated by multiplying the average iron concentration for a storm event by the average flow rate during the same storm event. The overall average iron flux per sample station is summarized by Figure 4-76 for storm conditions. This figure shows that the total flux was highest at Station 8 and the range in variability was also high. The iron flux was slightly elevated on average at Station 2, decreased at Station 4, and then continually increased through Station 8. Overall, the iron flux was greater at the stations within the southern part of the river and the majority of the iron flux was transported by the

particulate phase. Figure 4-77 shows the pattern of total iron flux at each sample station according to each storm event.

The greatest overall total iron flux as well as the greatest variability occurred for the May 2002 event (Figure 4-78). The large flux for the May 12, 2002 event was likely due to the relatively large storm event (2.8 inches), which resulted in large river flow values on that date as well as elevated average iron concentrations at Station 8 (Figure 4-79). The elevated iron fluxes at Station 8 during this storm event were strongly affected by 2 of the 22 samples collected during this event (77 mg/L and 145 mg/L). These two samples accounted for two-thirds of the flux observed at this station for this event. The April 2002 event (0.97 inches) was characterized by the second highest iron fluxes and the second largest iron flux, closely followed by the October 2002 event (1.5 inches).

#### **4.2.4 Chromium Concentrations and Fluxes**

The average storm event chromium concentrations ranged from near detection limits at Stations 9 and 10 to 60 ug/L at Station 8 during the May 2002 event. The sample data indicate that the highest concentrations of chromium occurred at Stations 6 and 8, on average, during storm events (Figure 4-80). A larger proportion of the chromium was carried by the particulate phase for stations characterized by elevated chromium concentrations. Overall, dissolved chromium concentrations were relatively constant along the length of the river. Total concentrations decreased from Stations 1 to 2, gradually increased from Station 2 to Station 6, decreased at Station 7, increased at Station 8, and decreased at Stations 9 and 10.

This trend is further illustrated by Figure 4-81, which is a plot of the individual data points corresponding to the average values plotted in Figure 4-80. The increase observed in the average chromium concentration at Station 8 was strongly influenced by the May 2002 storm event where the highest concentration of chromium was observed. Excluding this storm, the trend would show a more consistent peak at Station 6 and a general decrease in chromium in the downstream direction. Also, similar to arsenic, the highest chromium concentration occurred during the May 2002 storm event. However, the highest concentration for chromium occurred at Station 8 rather than Station 2, where the highest arsenic concentration occurred (Refer to Figure 4-58). The high chromium concentration at Station 8 during the May 2002 was due to two unusually elevated chromium concentration values on the rising limb of the

hydrograph (574 ug/L and 1070 ug/L). Without these two points, the remaining 20 samples average to 17 ug/L, rather than 59 ug/L if these two points are included. For all stations collectively, the highest chromium concentrations were observed during the May 2002 storm. This event was also characterized by the greatest variability between stations (Figures 4-82 and 4-83).

Similar to the arsenic and iron fluxes, chromium flux was also calculated by multiplying the average chromium concentration by the flow rate, as provided in equation 3-1 at the beginning of Section 3.3. The overall average chromium flux per sample station is summarized by Figure 4-84 for storm conditions. This figure shows that the flux was highest at Station 8 and the range in variability was also high at this station. The chromium flux was relatively constant from Station 1 to Station 4, the total flux increased from Stations 4 to 6, slightly decreased from Stations 6 to 7, and increased to Station 8, on average. Overall, the chromium flux was greater at the stations at the southern part of the river, similar to the trend in arsenic and iron fluxes, and a majority of the flux within the southern part of the river was associated with the particulate phase. Figure 4-85 shows the pattern of chromium flux at each sample station according to each storm event. The higher fluxes at Station 8 are due to the combined effects of elevated chromium concentrations (Figure 4-80) and flow at this station.

The greatest overall chromium flux as well as the greatest variability occurred for the May 2002 event (Figure 4-86). The large flux for the May 12, 2002 event was likely due to the relatively large storm event (2.8 inches), which resulted in large river flow values on that date, plus the unusually high chromium concentrations measured for two samples collected at Station 8 during the rising limb of the streamflow hydrograph. These two samples (574 ug/L and 1070 ug/L) accounted for over two-thirds of the chromium flux. The second largest storm event sampled, the October 2002 event (1.5 inches), was characterized by the third highest chromium flux and the second largest range in variability. The April 2002 storm event was the smallest storm event sampled (0.97 inches) but was characterized by the second highest chromium flux and the third largest range in variability. No clear trend was observed with storm size for chromium flux, with the exception of the relatively high flux observed at Station 8 during the May 2002 event, which was the largest storm event sampled.

#### 4.2.5 Copper Concentrations and Fluxes

The range of copper concentrations for storm composites was from near detection limits at Stations 9 and 10 to 120 ug/L at Station 6 during the April 2002 event. The variation in copper concentrations along the length of the river was very similar to that for chromium (compare Figures 4-80 and Figure 4-88) with the exception that a larger proportion of copper was within the dissolved phase. In the case of copper, the highest total concentrations, on average, occurred at Station 6, and the second highest at Station 8 (Figure 4-88). Total copper concentrations decreased from Stations 1 to 2 and remained within the same range from Station 2 to Station 5. Total concentrations increased at Station 6, decreased at Station 7, increased again at Station 8 and decreased at Stations 9 and 10. This trend is emphasized by Figure 4-89, which is a plot of the individual data points corresponding to the average values plotted in Figure 4-88.

For all stations collectively, the highest copper concentrations were observed during the April 2002 storm event. This event was also characterized by the greatest range of variability (Figures 4-90 and 4-91) and by the highest storm-composite concentration as observed at Station 6.

The overall average copper flux per sample station is summarized by Figure 4-92 for storm conditions. Results from individual storm events are provided in Figure 4-93. These figures show that the total flux and variability were highest at Station 8, similar to that observed for arsenic, iron, and chromium fluxes. The copper flux was relatively constant from Stations 1 to 4 and continually increased from Stations 4 to 8. Overall, the copper flux was greater at the stations within the southern part of the river and a larger proportion of the flux was due to transport within the particulate phase. Although the copper flux increased in the downstream direction (Figure 4-92), the average copper concentrations did not continuously increase in the downstream direction but varied from station to station (Figure 4-88). The higher fluxes at Station 8 were due to the combined effects of elevated copper concentrations and higher flows at this station.

The greatest overall copper flux as well as the greatest variability occurred for the May 2002 event (Figures 4-94 and 4-95). The large flux for the May 12, 2002 event was likely due to the relatively large storm event (2.8 inches), which resulted in large river flows on that date, plus

unusually high total copper concentrations on the rising limb of the streamflow hydrograph. The unusually high total copper concentrations were associated with 2 of the 22 samples collected at Station 8 during this storm (800 ug/L and 1,320 ug/L). These two samples accounted for two-thirds of the flux at Station 8 during the May 2002 storm. The April 2002 storm event was the smallest storm sampled (0.97 inches) and was characterized by the second highest copper flux and the second largest range in copper flux. The second largest storm event sampled was the October 2002 event (1.5 inches) which included the third highest copper flux and the third largest range of copper flux, which were only slightly greater than the flux and range in flux for the July 2002, August 2002, and September 2002 storm events.

#### **4.2.6 Lead Concentrations and Fluxes**

The range of total lead concentrations was from near detection limits at Station 9 and 10 to 90 ug/L for the storm-composite sample at Station 8 during the May 2002 storm. The storm-composite concentrations at all the stations were usually below 20 ug/L, with the exception of the May 2002 equivalent-composite sample measured at Station 8. On average, the highest concentrations of lead occurred at Station 8 (Figure 4-96). There were also elevated levels of lead at Station 6 in comparison to the lead concentrations at the other sample stations. The observed trend was as follows: lead concentrations decreased on average from Stations 1 to 2 and remained within the same range from Station 2 to Station 5; the concentrations increased at Station 6, slightly decreased at Station 7, increased again at Station 8, and decreased at Stations 9 and 10. The dissolved lead concentrations were generally constant along the length of the river and the variability observed in lead concentrations between stations was due to variability in the particulate lead concentration. In general, stations characterized by elevated lead levels were also characterized by a large proportion of the lead within the particulate phase. The trend in total lead concentrations is further emphasized by Figure 4-97, which is a plot of the individual data points corresponding to the average values plotted in Figure 4-96.

For all stations collectively, the May 2002 storm event had the greatest total lead concentrations and also the greatest range of variability (Figures 4-98 and 4-99). As for the other metals, the large lead flux observed at Station 8 during the May 2002 event was due to the large flow rates associated with this event and unusually high lead concentrations for 2 of the 22 samples collected at Station 8 during the rising limb of the streamflow hydrograph (770 ug/L and 1,420

ug/L). Omission of these two values would decrease the average total lead concentration for this event from 83 ug/L to 27 ug/L.

The overall average lead flux per sample station is summarized by Figure 4-100 for storm conditions. Figure 4-101 shows the pattern of lead flux at each sample station according to each storm event. These figures show that the flux and variability was highest at Station 8, similar to that observed for arsenic, iron, chromium, and copper fluxes. The lead flux was relatively constant from Stations 1 to 4 and continually increased from Stations 4 to 8. Overall, the total lead flux was greater at the stations within the southern part of the river and a larger proportion of the flux at these stations was carried by the particulate phase. The elevated flux at Station 8 was due to the combined effects of elevated flow and concentration (Figure 4-96).

The greatest overall lead flux as well as the greatest variability occurred for the May 2002 event (Figures 4-102 and 4-103). The large flux for the May 12, 2002 event was due to the relatively large storm event (2.8 inches), which resulted in large river flows, plus the unusually high lead concentrations observed during the rising limb of the hydrograph (770 ug/L and 1,420 ug/L). These two sampling points account for roughly two-thirds of the lead flux observed at Station 8 during the May 2002 storm. The April 2002 storm event was the smallest storm sampled (0.97 inches) and was characterized by the second highest lead flux and the second largest range in lead flux. The second largest storm event sampled was the October 2002 event (1.5 inches) which included the third highest lead flux and the fourth largest range of lead flux. The lead flux from the October 2002 storm event was only slightly greater than the flux of the July 2002, August 2002, and September 2002 storm events.

#### **4.2.7 Mercury Concentrations**

The highest concentrations of mercury were observed at Stations 6 and 8, on average, during storm events (Figure 4-104). It should be noted that the range in mercury concentrations was very low, and in most cases the concentrations were below the detection limit (about 0.1 ug/L) for most sample dates. For averaging purposes, samples that measured below detection limits were set to one-half the detection limit value. As shown by Figure 4-105, the mercury concentrations ranged from below detection limits (plotted at 0.05 ug/L) to 0.24 ug/L. The following trend was observed: mercury concentrations are at detection limits for Stations 1 to 3; slightly elevated at Stations 4, 5, and 6; at detection limits at Station 7; slightly elevated at

Station 8; and at detection limits at Stations 9 and 10. Elevated mercury concentrations were primarily associated with the particulate phase. The greatest equivalent-composite mercury concentration occurred during the May 2002 storm event at Station 8 (Figures 4-106 and 4-107). This elevated composite concentration was strongly influenced by one sample, 3.7 ug/L, which was collected on the rising limb of the streamflow hydrograph. Omission of this sampling point from the 18 that were analyzed results in a decrease in the equivalent-composite concentration from a value of 0.24 ug/L to 0.16 ug/L.

#### **4.2.8 Comparison Between Metals for the May 2002 Storm Event**

More specific details of the total metals behavior for the May 2002 storm event are presented in Figures 4-108 through 4-115. The May 2002 storm was selected for further evaluation because it was the largest storm event sampled during the monitoring period. Figure 4-108 includes the storm average per station for arsenic and iron, as well as TSS, flow and arsenic flux. As shown by this graph, stations with high total arsenic concentrations (Stations 2, 4 and to a lesser extent Station 8) were also characterized by high total iron concentrations. This trend is consistent throughout all of the storm events. The relationship between total arsenic and iron is further illustrated in Figure 4-108a which shows  $R^2$  values upwards of 0.9 between total arsenic and total iron for the hourly values measured at Stations 4 and 8. Of note is that the relationship between total arsenic and total iron concentrations was steeper at Station 4 than at Station 8 indicating that a relatively small increase in total iron at Station 4 was accompanied by a relatively large increase in total arsenic. The increase in total arsenic concentration was not as large for Station 8 given the same increase in total iron concentration.

Figure 4-109 includes dissolved arsenic and dissolved iron concentrations, as well as flow. The dissolved iron concentration did not follow the same trend as the total iron concentration for Station 8. Although the highest total iron concentration was observed at Station 8, the dissolved iron concentration at this station was relatively low. The elevated iron concentrations observed at Station 8 were probably associated with elevated TSS concentrations.

More specific details of the metals behavior for chromium, copper, lead, and mercury for the May 2002 storm event are presented by Figures 4-110 and 4-111. Figure 4-110 includes total metal results for copper, chromium, mercury, and lead, as well as TSS and flow. Figure 4-111 includes dissolved metals results for chromium, copper, lead and mercury, as well as flow. As

shown by the total metals data, elevated concentrations did occur at Station 8 (Figure 4-110). The total metals concentrations for the sample stations other than Station 8 were within the same range, from the analytical quantification limits to 15 ug/L, while the concentrations at Station 8 were as high as 80 ug/L. Again as mentioned earlier, the elevated concentrations observed at Station 8 during the May 2002 storm were due in large part to 2 of 22 samples characterized by unusually elevated metals concentrations. Similarly, elevated flow and TSS also occurred at Station 8. In contrast, as shown by the dissolved metals data in Figure 4-111, concentrations were very low, ranging from the analytical quantification limits to 5 ug/L. There does not appear to be an apparent trend for the dissolved phase. Similar to arsenic and iron, however, the total metals concentrations appear to be associated with elevated TSS.

Hourly grab sample data collected during the May 2002 storm event at Station 4, clearly shows a relationship between arsenic and iron. The two metals follow a parallel pattern as shown in Figure 4-112. There is no clear relationship for the other metals based on the hourly grab samples collected at Station 4 (Figure 4-113). Hourly grab sample data collected during the May 2002 storm at Station 8 (Figure 4-114), shows an association between arsenic and iron. Both are characterized by an extremely large initial peak of total arsenic and iron concentrations at the beginning of the storm event followed by a sharp decline. All metals and TSS appear to follow this pattern (Figures 4-114 and 4-115). Apparently a strong “flushing effect” occurred at Station 8 during this event.

#### **4.2.9 Storm Event Dissolved Versus Total Metals**

This section compares the total and dissolved concentrations for the metals, arsenic, chromium, copper, lead, iron, and mercury. The fraction of the total metals that corresponds to the dissolved phase was calculated based on the comparison of total and dissolved metal concentrations (Table 4-3). This fraction was computed using two methods. The first method, represented by the first column in Table 4-3, excludes samples that were below the limit of quantification and the calculations used quantified data only from both the total and dissolved phases. The second method, represented by the second column, utilized all data. Samples that were below the limit of quantification were set at one-half the quantification limit value. For discussion purposes the data corresponding to the second computation method are described in this section. In general the results from both computation methods were consistent with one

another except for stations characterized by very low metals concentrations (e.g. Stations 1, 9 and 10) for which many samples collected were either near or below the limit of quantification.

For arsenic, between 14 percent and 88 percent of the total arsenic was found within the dissolved phase. The lowest fractions occurred at Stations 3 and 8 and the highest at Station 9. Iron was more strongly partitioned toward the particulate phase. For iron, between 5 percent and 19 percent of the total iron was found within the dissolved phase. The lowest fraction occurred at Stations 8 and 9, and the highest at Stations 4 and 5. For chromium, between 7 percent and 75 percent of the total chromium was found within the dissolved phase. The lowest fraction occurred at Station 8 and the highest at Station 9. For copper, between 18 percent and 78 percent of the total copper was found within the dissolved phase. The lowest fraction occurred at Station 8 and the highest fraction occurred at Stations 9 and 10. For lead, between 6 percent and 100 percent of the total lead was computed as within the dissolved phase. The lowest fraction occurred at Station 8. The high fractions computed at Stations 9 and 10 may be an artifact due to the majority of samples being below the detection limit. Many of the mercury concentrations were below the detection limit for all sample stations, with the exception of Stations 4 and 8. For Station 4, 71 percent of the total mercury was found within the dissolved phase; for Station 8, 50 percent of the total mercury was found within the dissolved phase.

The distribution of dissolved versus total metals is shown graphically by station in Figures 4-116 through 4-121. In general the graphs show that the majority of the metals (with the exception of iron) tended to partition towards the dissolved phase for Stations 9 and 10, both of which were characterized by low metals concentrations. Iron, at Stations 9 and 10, was more strongly partitioned towards the particulate phase. The graphs also show that metals at Station 8 were more strongly partitioned towards the particulate phase. This may be due to the relatively high TSS concentrations observed at this station during storm events. As discussed in the previous section: elevated arsenic and iron concentrations were observed at Station 2; elevated chromium, copper, and lead were observed at Stations 6 and 8; and lead was also elevated at Station 1. In general the higher the metal concentration the more strongly the metal was partitioned towards the particulate phase, suggesting that TSS plays an important role in metals transport through the Aberjona River watershed.

#### 4.2.10 Summary of Storm Flow Metals Data

Overall, metals concentrations during storm flow conditions are summarized in Table 4-4. As expected, the total metals concentrations were greater than the dissolved metals concentrations. Total metals concentrations were typically highest at Stations 2, 4, and 8 and generally lowest at Stations 1, 9, and 10 (with the exception of total lead at Station 1). Mercury concentrations were generally below detection limits throughout the river.

Some trends in storm flow metals concentrations were observed along the length of the river. Arsenic concentrations during storm events generally decreased from Station 2 to Station 10. Iron concentrations decreased in a similar fashion as arsenic concentrations, with the exception of elevated levels of iron observed at Stations 6 and 8. Elevated concentrations of copper and chromium were not observed in the northern reaches of the watershed. Copper and chromium concentrations were generally elevated at Stations 6 and 8 during storm conditions. Iron concentrations were generally elevated at Station 8. As mentioned above, the lowest total metal concentrations for all metals were observed at Stations 9 and 10.

Overall, the highest concentrations of metals were observed during the May 2002 storm event, which was also the largest of the six storm events sampled. The metal concentrations observed for this event were dominated by the very high concentrations observed for two samples collected at Station 8 during the rising limb of the hydrograph. The unusually high concentrations observed for these two samples greatly influenced the flux observed during this event, accounting for as much as two-thirds of the overall flux for the event. In general, the highest metal flux values were observed at Station 8, due to a combined effect of increased flow and, in some cases, elevated metals concentrations (e.g. chromium, copper, lead and mercury). In general the metal flux was variable throughout the river, with Station 8 typically recording the highest fluxes during storm conditions (Table 4-4a). It appears that the area between Station 7 and 8 may account for much of the metal flux (and TSS flux) observed at Station 8 during storm flow conditions, in particular for iron, chromium, copper and lead. The contributing area between Stations 7 and 8 was very large representing almost half of the drainage area to Station 8.

In general, metals were more strongly partitioned toward the particulate phase when total metal concentrations were high, suggesting that TSS plays an important role in the transport of metals through the river. This was observed during both storm flow and baseflow conditions.

#### **4.3 Graphical Comparison of Baseflow Versus Storm Flow Metal Concentrations**

Metals concentrations do differ between baseflow and storm flow conditions. As shown by Figure 4-122, the total arsenic concentrations were greater during baseflow conditions for Stations 3, 4, and 5. For all other sample stations, the total arsenic concentrations were highest during storm flow conditions. The highest total arsenic concentrations were observed at Stations 2 and 4. Generally storm flow conditions resulted in higher dissolved arsenic concentrations than baseflow conditions, with the exception of Station 3 (Figure 4-123).

As shown by Figure 4-124, the total iron concentrations were greater during baseflow conditions for Stations 3, 4, 5, 9, and 10. For all of the other stations, the total iron concentrations were greater during storm flow conditions. As shown by Figure 4-125, dissolved iron concentrations are greater during baseflow conditions at Station 3 and 5. For the remaining stations, the dissolved concentrations are roughly the same between baseflow and storm flow.

As shown by Figures 4-126, 4-128, and 4-130, total chromium, copper, and lead concentrations were highest during storm flow conditions at Stations 1, 6, 7, and 8. These same metals concentrations were higher during baseflow conditions at Station 4. Results show that dissolved chromium, copper, and iron concentrations (Figures 4-127, 4-129, and 4-131) were lower than the total concentrations. No clear trend was observed for dissolved chromium, copper, and lead concentrations with the exception that dissolved chromium, copper, and lead concentrations were generally higher during storm flow conditions for Stations 1, 6, 7, and 8,

For mercury (Figures 4-132 and 4-133), many of the samples were at or near quantification limits. For Station 4 during baseflow and storm flow conditions, and for Stations 6 and 8 during storm flow conditions, mercury was measured above quantification limits more often than for other stations.

Strong correlations were observed between total arsenic and total iron concentrations for a particular station (Figure 4-134). The higher the total iron concentration the higher the total

arsenic concentration. The relationships were generally “steeper” toward the northern portion of the watershed where increases in iron concentrations were accompanied by larger increases in arsenic. At Station 8, an increase in total iron was associated with an increase in arsenic, but the rate of increase was not as high as in the northern portions of the watershed.

Similar relationships were evaluated between “inferred” particulate arsenic concentration (total minus dissolved) and TSS (Figure 4-135). The correlations were not as strong as those observed between total arsenic and total iron. In general, as TSS concentrations increase, “inferred” particulate arsenic concentrations also increase. As observed in Figure 4-134, the rate of increase between TSS and “inferred” particulate arsenic is steeper for Stations 2 and 4 versus that for Station 8.

#### **4.4 Summary of Baseflow and Storm Flow Data**

Overall, higher total arsenic concentrations were observed at stations within the HBHA (Stations 2 and 4) (Table 4-6). Total iron concentrations were more variable. In addition to elevated concentrations at Stations 2 and 4, iron was also elevated at Station 3, and at Station 5 during baseflow conditions and Stations 6 and 8 during storm flow conditions, on average. Total chromium, copper, and lead concentrations were similar in that the highest average concentrations were observed at Station 4 during baseflow. During storm flow conditions, the highest concentrations for these metals were observed at Stations 1, 6, and 8. TSS concentrations were also elevated during storm flows for these stations. The elevated total metals concentrations observed at Stations 1, 6, and 8 during storm events were likely due to the elevated TSS concentrations. Similarly, TSS concentrations were elevated during baseflow conditions for Station 4. These elevated TSS concentrations likely contributed to the elevated total arsenic concentrations observed at that station. Metals concentrations were consistently low at Stations 9 and 10.

Dissolved metals were similar between baseflow and storm flow conditions (Table 4-7), with the exception of Station 3 for arsenic and iron, where much higher dissolved concentrations were observed during baseflow conditions. In general, dissolved metals concentrations were generally uniform throughout all of the stations, with the exception of elevated dissolved arsenic and dissolved iron at Station 3 during baseflow conditions and elevated dissolved copper during storm flow conditions at Station 6. Also of note were the very low dissolved iron concentrations

observed at Stations 9 and 10, relative to the concentrations observed for stations within the Aberjona River watershed.

Total metals concentrations were generally elevated when TSS concentrations were elevated, in particular during baseflow conditions. However, the overall average TSS concentrations in comparison to the overall average arsenic concentrations differs for storm events. The May 2002 and the October 2002 storm events have the greatest overall average arsenic concentrations and the greatest overall average TSS concentrations but the sample stations in which each occurs is different. The highest overall average arsenic concentration is observed at Station 2, while the highest overall average TSS concentration is observed at Station 8.

The overall fraction of total metals that correspond to the dissolved phase for arsenic, chromium, copper, iron, lead, and mercury differs between baseflow and storm flow conditions (Table 4-8). The fractions were calculated by summing the averages from each station for each specific metal and then taking the sum of the dissolved metals averages and dividing it by the sum of the total metals average for both baseflow and storm flow conditions. The fraction of metals in the dissolved phase tends to be less for storm flow conditions in comparison to baseflow conditions for all metals reviewed. The lower fraction for storm flow conditions indicates that particulates play a role in transporting metals during storm events since TSS are generally elevated during storm flow conditions.

Metal fluxes (g/hr) were higher during storm flow conditions than during baseflow conditions (Table 4-9). The increase in metal flux was due to the increase in flow rates during storm events and in some cases increases in total metals concentrations. With the exception of Station 4, TSS concentrations (and consequently TSS flux) were also elevated during storm events and indirectly affect the flux computations by resulting in greater total metals concentrations.

## 5.0 SUMMARY AND CONCLUSIONS

An extensive monitoring program was implemented to measure transport of water, suspended sediments and metals through the Aberjona River watershed. The monitoring program included 11 automated surface water monitoring stations constructed and maintained by TtNUS during an 18-month period beginning May 2001 and ending October 2002. Ten of these 11 stations were programmed to record the measurements of nine physico-chemical parameters (rainfall, stream velocity, water level, water temperature, specific conductance, dissolved oxygen concentration, pH, ORP, and turbidity) every 15 minutes. At these same stations, samples for suspended sediment and metals (dissolved and total) were collected and analyzed through a monitoring program designed to capture trends during baseflow and storm flow conditions. Samples were collected during 16 baseflow events and 6 storm events. Storm events ranged in size from 1 to 2.8 inches of rainfall. Metals evaluated in this report included arsenic, iron, chromium, copper, lead and mercury, although additional metals were measured. In addition to the TtNUS monitoring program, a considerable amount of historical precipitation and streamflow data were also compiled for the watershed. Evaluation of this historical data indicates that hydrologic conditions during the TtNUS monitoring period were typical of average conditions. The only exception was the timing of the summer low flows and the spring peak flows, which were delayed by two months during the TtNUS monitoring period.

### 5.1 Watershed Geometry

Three of the 11 monitoring stations (Stations 1, 2, and 4) were located within the drainage basin of Halls Brook, a major tributary along the northern portion of the Aberjona River. Five stations (Stations 3 and 5 through 8) were located along the main artery of the Aberjona River and three stations (Stations 9 through 11) were located downstream of the Aberjona River within the Mystic Lakes drainage basins (Figure 2-1). Of note is that Station 3 received upstream flows from the Aberjona River only. Station 4 received flows upstream from the HBHA. Flows that pass through Station 3 and 4, joined after these stations and flowed towards Station 5. Thus the main “train” stations originate within Halls Brook and runs downstream in the following order, Station 1, 2, 4, 5, 6, 7, and 8. Flows from Station 3 join flows from Station 4 between Stations 4 and 5. The density of monitoring stations was higher within the northern part of the watershed. The drainage areas between stations were smaller in the northern part of the watershed in comparison with the southern part (Table 5-1). Station 11 was installed in Mill Brook, a tributary

to the lower portion of the Lower Mystic Lake. Only flow was monitored at the station in the event anomalies were detected at Station 10. Subsequently, data from this station was not required or evaluated in this study.

## **5.2 Physico-Chemical Factors Measured Semi-Continuously**

The total amount of rainfall measured during the 18-month monitoring period was 53 inches, on average. Less rainfall was generally observed at the stations located south of the watershed boundary. Overall average flow measured at Station 8 was 26 cfs. Both rainfall and streamflow were typical of average conditions for the watershed when compared with historical records. In general, flows were observed to increase in the downstream direction, with the exception of flows between Stations 2 and 4. The drainage area normalized flow for each station was within 0.9 to 1.4 cfs/mi<sup>2</sup> (Table 5-1).

Water temperature varied in a consistent fashion on a seasonal basis. On average, slightly warmer water temperatures were measured toward the southern part of the watershed. Specific conductivity was observed to increase during the winter months, presumably due to roadway salting activities during this season. Dissolved oxygen levels were also higher during the winter months, presumably due to the higher equilibrium saturation levels in colder waters. pH was fairly consistent throughout the seasons. pH at the stations located within the Aberjona River watershed was generally near 7. Outside of the Aberjona River watershed, but within the Mystic Lakes watershed, pH was slightly higher, near 8. In general, positive ORP values were observed at all stations with the exception of water at Station 2, which was characterized by negative ORP values (silver/silver-chloride reference), on average (Table 5-1).

## **5.3 Evaluation of TSS Data**

The data showed that TSS concentrations during baseflow conditions were roughly 5 mg/L on average for all stations, with the exception of Station 4 (Table 5-2). The TSS characteristics at Station 4 were unique; during baseflow conditions TSS was subject to significant variability (4 to 110 mg/L) that was not observed at other stations. The overall average TSS concentration at Station 4 during baseflow conditions was 21 mg/L, which was a factor of 4 greater than that observed at the remaining stations.

In general, higher TSS concentrations were observed at each station during storm events, with the exceptions of Stations 4, 9, and 10. The highest average storm event TSS concentration was observed at Station 8 (46 mg/L). Larger storm events at this station resulted in larger average TSS concentrations. Storm event averages for Stations 1 through 7 ranged from 6 to 22 mg/L. TSS concentrations at Stations 9 and 10 remained relatively constant at 4 mg/L during storm events. Thus, suspended sediment concentrations were not largely affected by flow conditions at these stations, possibly because they were located downstream of the Mystic Lakes which serve to buffer changes in suspended sediment concentrations. TSS behavior at Station 4 was again unique; the average concentration during storm flow conditions (13 mg/L) was lower than the average TSS concentration during baseflow conditions (21 mg/L). The opposite was observed for the other stations located along the Aberjona River. The HBHA wetland immediately upstream of Station 4, including HBHA Wetland Pond No. 3, may play a role in the unique characteristics of TSS observed at this station.

During baseflow conditions, TSS fluxes generally increased in the downstream direction with the exception of the area between the Stations 3/4 confluence and Station 5, where TSS fluxes decreased presumably due to the deposition of suspended sediment in this area (Table 5-3). For stations at which flows were measured (Stations 1 through 8), an increase in the TSS flux was noted between baseflow and storm flow conditions. TSS fluxes were notably high at Station 8 during storm flow conditions, indicating a strong TSS flushing effect at this station during storm conditions. This strong flushing effect was noted, even when the TSS flux was normalized by the drainage area contributing to this station (Table 5-4). One factor that may have influenced storm event TSS concentrations (as well as metal concentrations) at this station may be the capture of the "first flush". This station had a very large drainage area, much larger than stations upstream, and was thus slower to respond during storm events. The probability of capturing the first flush was higher at this station relative to the others, as a result of a slower response. The highest TSS and metals concentrations observed in the river were associated with the very first samples collected during the May 2002 storm event. These samples drove the higher overall TSS concentrations and fluxes at Station 8 during storm conditions.

As part of a 1995 monitoring program established through MIT, Solo-Gabriele collected TSS data from July 1991 through May 1993 at locations south of the Stations 3/4 confluence through Station 8. The TSS observed during the TtNUS monitoring period was consistent with the earlier data. Both data sets show that TSS concentrations were consistently at about 5 mg/L

throughout the length of the Aberjona River during baseflow conditions. During storm events increases in TSS concentrations were observed during both studies at Station 8. The increase in the TSS concentration during the rising limb of the hydrograph, however, was larger during the TtNUS monitoring period (recorded peak value of 1,980 mg/L) than during the monitoring period corresponding to the MIT study (recorded peak value of 90 mg/L). Regardless of the differences in the magnitude of the TSS peaks, the response after the peaks was very similar between both time periods. After the peak, TSS concentrations were observed in both studies to decline rapidly on the falling limb of the streamflow hydrograph. Also, Solo-Gabriele (1995) estimated that the overall TSS flux (baseflow and storm flow combined) at the outlet of the Aberjona River was between 30 and 70 kg/hr. The average measured TSS flux during the TtNUS monitoring period was 7 kg/hr during baseflow conditions and 470 kg/hr during storm flow conditions.

#### **5.4 Evaluation of Arsenic Data**

Baseflow data indicate that arsenic concentrations were higher in the northern portion of the Aberjona River (Table 5-2), in particular at Station 4 (37 ug/L on average), which was characterized by concentrations that were more variable relative to other stations. Spikes in metals concentrations at Station 4 were associated with spikes in suspended sediment concentrations indicating that elevated levels of metals at this station were associated with the particulate phase. Low total arsenic concentrations (< 2 ug/L) occurred at Station 1 and at Stations 9 and 10. The total arsenic concentrations increased from Station 1 to Station 2 (20 ug/L) to Station 4 (37 ug/l) during baseflow conditions. Concentrations observed at Station 3 were also elevated on average (19 ug/L). After Station 4, total arsenic concentrations sequentially decreased in the downstream direction during baseflow conditions.

The average total arsenic concentration observed during storm events was lower for Stations 3, 4, and 5 than during baseflow conditions. For all the other sampling stations, total arsenic concentrations were greatest during storm flow conditions. The increase in total arsenic for the other stations was due to an increase in suspended sediment transport during storm events, which resulted in an overall increase in the particulate arsenic concentration.

During baseflow conditions, a decrease in the arsenic flux was noted in the area between Stations 3/4 confluence and Station 5 (Table 5-3). The arsenic flux observed at Station 4 was

estimated at 6.7 g/hr and at Station 3 was estimated at 2.7 g/hr. The sum of these fluxes (9.4 g/hr) was almost a factor of two times higher than the flux observed at Station 5 (5.3 g/hr), suggesting that arsenic was depositing in the area upstream of Station 5. The Wells G&H wetland was one likely location, since this wetland is known to contain very high metals concentrations within its sediments. The flux during baseflow conditions remained between 4 and 6 g/hr through Station 8, located at the outlet of the watershed.

During storm flow conditions, arsenic fluxes increase considerably due to higher flows and TSS fluxes. The arsenic flux was estimated at 70 g/hr at Station 2 as compared to 110 g/hr at Station 8. Measured arsenic fluxes were lower between these stations. When normalizing the total arsenic flux at Station 2 during storm flow conditions, Station 2 contributed the largest flux (23 g/(hr\*mi<sup>2</sup>). This relatively large contribution may have been due, in part, to the relatively large amount of water that was discharged by the corresponding drainage area (1.4 cfs/mi<sup>2</sup>) (Table 5-4).

Arsenic data for surface water were available during the TtNUS monitoring period from the Industri-Plex Site Remedial Trust (ISRT), which collected separate samples for arsenic analysis. The location of two ISRT stations coincided with the location of the TtNUS stations (Stations 2 and 4). Although samples were not split between TtNUS and ISRT, samples were collected during the same general time periods between August 2000 and March 2004. Average dissolved arsenic concentrations between the ISRT and TtNUS studies were within 20 percent of each other. Average total arsenic concentration measured at TtNUS Station 2 was within 40 percent of the average value measured by ISRT. The average total arsenic concentration measured at TtNUS Station 4 was approximately two times higher than the average value measured by ISRT. (See \Chapter\_4\_Metals\_Data\ComparisonofMetalsdata\Arsenic Compare \_ISRT.xls)

General trends observed in the arsenic data were also consistent with the data collected through the MIT monitoring network approximately 10 years ago (Solo-Gabriele, 1995). The location of two of the MIT stations coincided with the location of two TtNUS stations (Stations 6 and 8). Overall, the highest concentrations of arsenic from both monitoring networks were observed within the northern sections of the watershed, and the measured arsenic concentrations at Stations 6 and 8 were within the same order of magnitude. The dissolved arsenic concentrations observed during the MIT monitoring period at Station 6 were between 3

and 7 ug/L. This was consistent with the average observed by TtNUS (2.7 ug/L during baseflow and 4 ug/L during storm flow). Total arsenic observed through the MIT monitoring network was on the order of 8 ug/L. Again this was consistent with the average observed by TtNUS (5 ug/L during baseflow and 17 ug/L during stormflow). At TtNUS Station 8, it appears that the particulate arsenic contribution may have increased between the two study periods. Dissolved arsenic concentrations were similar between each study (at 3 ug/L for Solo-Gabriele, 1995, and 1.5 to 2 ug/L for the TtNUS monitoring period). Particulate arsenic at Station 8 was at about 1 ug/L for the Solo-Gabriele, 1995 study. For the TtNUS period, the inferred particulate concentration was on the order of 3 to 9 ug/L. As a result, it appears that the particulate flux of arsenic may have increased at Station 8 during the past 10 years. This may be associated with the higher storm event TSS peaks observed at this station during the more recent TtNUS study.

### **5.5 Evaluation of Other Metals (Iron, Chromium, Copper, Lead, and Mercury)**

A strong association was generally observed between total iron and total arsenic concentrations, with both metals exhibiting similar patterns in fluctuations; both were highly correlated when data from a particular station or storm event were considered. One possible scenario for transport of arsenic is that during baseflow conditions, arsenic and iron entered the river through groundwater primarily within the northern reaches of the watershed. Once within the river, some of the arsenic precipitated along with iron and deposited within the river bottom. This precipitate was then flushed out of the system during storm flows.

For Stations 1, 2, 6, 7, and 8, metals concentrations were typically highest during storm flow conditions versus baseflow conditions. Metals concentrations at Station 4 were consistently higher during baseflow relative to storm flow. Overall, elevated metals concentrations were observed at Station 4 during baseflow conditions accounting for the highest average for iron for storm flow and baseflow combined. For chromium, copper, and lead, the highest concentrations were observed at Stations 1, 6, and 8 during storm flow conditions (Table 5-2). Typically mercury concentrations observed within the river were at or near detection limits. However, on occasion, mercury concentrations were observed above the detection limit at Station 4 during baseflow conditions and at Station 8 during storm flow conditions. Metals concentrations were typically the lowest at Stations 9 and 10 during baseflow and storm flow conditions. The low concentrations observed at Stations 9 and 10 was likely due to the deposition of suspended sediments within the Mystic Lakes.

Metal fluxes were typically higher during storm flow conditions relative to baseflow conditions. This increase was due to increases in flow and TSS fluxes during storm events. The largest drainage-area normalized chromium, copper, and lead fluxes were observed at Stations 1 and 8. The largest drainage-area normalized fluxes for these same metals were observed at Station 4 during baseflow conditions.

## **5.6**            **Overall Summary**

During the TtNUS monitoring period, the primary concentrated source of arsenic to the Aberjona River entered the river within the HBHA. Some of the arsenic that was transported from the HBHA was deposited during baseflow conditions in the area between the Stations 3/4 confluence and Station 5, presumably within the Wells G & H wetland. During storm events, metal fluxes increased due to increased transport of particulate metals. Particulate metals transported during storms likely came from metals previously deposited within the river system and metals deposited within drainage areas contributing to the river system.

Although the primary concentrated source of arsenic originates within the HBHA, areas upstream of the HBHA and the areas between Station 7 and 8 represented a concentrated source of copper, chromium, and lead during storm conditions. The source of the copper and lead during storms is currently unknown but was likely associated with urban runoff. Sources of chromium could also be associated with urban runoff or with discharges from the Olin Chemical Company site, located upstream of Halls Brook and connected by the East Drainage Ditch and New Boston Street Drainway.

Once the metals were transported through the Aberjona River system, they were likely diluted with inflows from the Mystic Lakes watershed and a portion of the metals was likely deposited within the Mystic Lakes. As a result, the surface waters of the Mystic Lakes were characterized by low metals concentrations relative to the concentrations observed within the upper reaches of the Aberjona River watershed.

## TABLES

**TABLE 2-1  
LOCATION OF TTNUS MONITORING STATIONS  
DRAFT EVALUATION OF FLOW, SUSPENDED SEDIMENT,  
AND HEAVY METALS IN THE ABERJONA RIVER  
INDUSTRI-PLEX SITE  
WOBURN, MASSACHUSETTS**

Station	Location
1	Halls Brook, upstream of discharge into Halls Brook Holding Area (HBHA)
2	HBHA, outlet of north pond (downstream gradient of Industri-Plex Site)
3	Aberjona River (AR) prior to discharge control structure at Mishawum Road and confluence with Halls Brook
4	HBHA outlet at Mishawum Road
5	AR at Salem Street bridge, downstream of Wells G&H Site and 38-acre wetlands (Woburn)
6	AR downstream of Montvale Avenue, adjacent to Citizens Bank and McDonalds (Woburn)
7	AR at Swanton Street bridge (Winchester)
8	AR at USGS gaging station, Mystic Valley Parkway (Winchester)
9	Upper Mystic Lake outlet, Medford Boat Club (Arlington)
10	Lower Mystic Lake outlet, High Street (Rt. 60) bridge (Medford)
11	Outlet of Mill Brook into the Lower Mystic Lake (Arlington)

**TABLE 2-2  
DISTANCE ALONG RIVER BETWEEN STATIONS  
DRAFT EVALUATION OF FLOW, SUSPENDED SEDIMENT,  
AND HEAVY METALS IN THE ABERJONA RIVER  
INDUSTRI-PLEX SITE  
WOBURN, MASSACHUSETTS**

Begin Gaging Station	End Gaging Station	Length (km)	Length (mi)
1	2	0.29	0.18
2	4	0.93	0.58
4	5	1.57	0.98
5	6	1.78	1.11
6	7	2.95	1.83
7	8	1.66	1.03
8	9	2.66	1.65
9	10	1.37	0.85
SUM		13.21	8.21

**TABLE 2-3  
SUB-BASIN AND MODULE SUMMARY  
DRAFT EVALUATION OF FLOW, SUSPENDED SEDIMENT,  
AND HEAVY METALS IN THE ABERJONA RIVER  
INDUSTRI-PLEX SITE  
WOBURN, MASSACHUSETTS**

<b>Modules</b>	<b>Sub-Basins</b>	<b>Individual Area (km<sup>2</sup>)</b>	<b>Individual Area (mi<sup>2</sup>)</b>	<b>Total Module Area (mi<sup>2</sup>)</b>	<b>Cumulative Area to Station (mi<sup>2</sup>)</b>
1	1C	1.38	0.53	2.56	2.56
	2	2.14	0.82		
	3	3.11	1.20		
2	1B	1.17	0.45	0.45	3.01
3	1A	6.92	2.67	2.67	2.67
4	1D	0.44	0.17	0.17	3.18
5	1E	0.12	0.05	1.51	7.36
	5	3.78	1.46		
6	4	4.14	1.60	2.03	9.39
	7	1.12	0.43		
7	6	5.40	2.08	4.48	13.87
	9	2.19	0.85		
	11	4.01	1.55		
8	12	1.15	0.44	0.95	24.20
	13B	0.86	0.33		
	15	0.44	0.17		
Woburn West	8	7.68	2.97	9.39	Not Applicable
	10	7.31	2.82		
	13A	2.41	0.93		
	14	6.91	2.67		
Sum				24.20	

**TABLE 2-4  
DESCRIPTION OF EQUIPMENT USED AT EACH MONITORING STATION  
DRAFT EVALUATION OF FLOW, SUSPENDED SEDIMENT,  
AND HEAVY METALS IN THE ABERJONA RIVER  
INDUSTRI-PLEX SITE  
WOBURN, MASSACHUSETTS**

<b>Station</b>	<b>ISCO Auto-sampler</b>	<b>ISCO Area Velocity Flow Module/Meter</b>	<b>YSI Multi-Parameter Probe</b>	<b>Steven Rain Gage</b>
1-8	Model 6712	Model 750	Model 6920	Model TD3 – 0.01”T
9	Model 6712	none	Model 6920	Model TD3 – 0.01”T
10	Model 6712	Model 750	Model 6920	Model TD3 – 0.01”T
11	none	Model 4250	none	none

**TABLE 2-5  
SUMMARY OF TSS RESULTS FROM THE EVALUATION OF  
ALTERNATIVE SAMPLING METHODS  
DRAFT EVALUATION OF FLOW, SUSPENDED SEDIMENT,  
AND HEAVY METALS IN THE ABERJONA RIVER  
INDUSTRI-PLEX SITE  
WOBURN, MASSACHUSETTS**

<b>Field Sample No.</b>	<b>Sample Method</b>	<b>TSS (mg/L)</b>	<b>Field Sample No.</b>	<b>Sample Method</b>	<b>TSS (mg/L)</b>
IP0001-A	Station 10 PVC Pipe	5.5	IP0004-A	Station 2 PVC Pipe	ND <sup>a</sup>
IP0002-A	Station 10 Grab	5.2	IP0005-A	Station 2 Grab	ND
IP0003-A	Station 10 Depth-Integrated Sampler	4.8	IP0006-A	Station 2 Depth-Integrated Sampler	ND
IP0001-B	Station 10 PVC Pipe	5.4J	IP0004-B	Station 2 PVC Pipe	ND
IP0002-B	Station 10 Grab	6.8	IP0005-B	Station 2 Grab	ND
IP0003-B	Station 10 Depth-Integrated Sampler	ND	IP0006-B	Station 2 Depth-Integrated Sampler	ND
IP0001-C	Station 10 PVC Pipe	4.8	IP0004-C	Station 2 PVC Pipe	ND
IP0002-C	Station 10 Grab	6	IP0005-C	Station 2 Grab	ND
IP0003-C	Station 10 Depth-Integrated Sampler	4.4	IP0006-C	Station 2 Depth-Integrated Sampler	ND

<sup>a</sup> Not Detected

**TABLE 2-6**  
**RATING CURVE RELATIONSHIPS FOR STATIONS 1 THROUGH 8**  
**DRAFT EVALUATION OF FLOW, SUSPENDED SEDIMENT,**  
**AND HEAVY METALS IN THE ABERJONA RIVER**  
**INDUSTRI-PLEX SITE**  
**WOBURN, MASSACHUSETTS**

Station	Rating Curve Used	R <sup>2</sup>
1	for levels <= 0.832, flow = 0.81 for levels > 0.832, flow = 17.38(level) – 13.66	N/A <sup>a</sup> 0.98
2	for levels <= 0.855, flow = 0.56 (level) + 0.47 for levels > 0.855, flow = 16.56 (level) – 13.22	0.01 0.92
3	for levels <= 0.711, flow = 0.41 (level) + 0.28 for levels > 0.711, flow = 15.8 (level) – 10.65	0.01 0.97
4	for levels <= 0.442, flow = 3.57 (level) – 0.33 for levels > 0.442, flow = 9.31 (level) – 2.89	0.51 0.91
5	for levels <= 1.07, flow = 2.52 for levels > 1.07, flow = 50.76 (level) – 51.65	N/A 0.99
6	flow = 20.03 (level) – 24.74	0.93
7	for levels <= 1.03, flow = 0.18 (level) + 3.70 for levels > 1.03, flow = 70.36 (level) – 68.90	0.0004 0.996
8	for levels <= 1.57, flow = 5.08 [(level) <sup>4.51</sup> ] for levels > 1.57, flow = 108.47 (level) – 131.96	0.96 0.99

<sup>a</sup> N/A = Not Applicable

**TABLE 2-7**  
**SAMPLER INITIATION CONDITIONS PER STATION**  
**DRAFT EVALUATION OF FLOW, SUSPENDED SEDIMENT,**  
**AND HEAVY METALS IN THE ABERJONA RIVER**  
**INDUSTRI-PLEX SITE**  
**WOBURN, MASSACHUSETTS**

Sample Station	Level Condition	Rain Condition
Station 1	Rise of 0.24 ft/hr	Above 0.01" in 1 hour
Station 2	Rise of 0.14 ft/hr	Above 0.01" in 1 hour
Station 4	Rise of 0.07 ft/hr	Above 0.01" in 1 hour

**TABLE 2-8  
TOTAL RAINFALL PER STORM EVENT  
DRAFT EVALUATION OF FLOW, SUSPENDED SEDIMENT,  
AND HEAVY METALS IN THE ABERJONA RIVER  
INDUSTRI-PLEX SITE  
WOBURN, MASSACHUSETTS**

<b>Storm Name</b>	<b>Begin Date/Time of Storm Event</b>	<b>End Date/Time of Storm Event</b>	<b>Total Rainfall Measured at the Reading-NCDC Weather Station</b>
April, 2002	4/25/02 15:00	4/26/02 00:00	0.97 inches
May, 2002	5/12/02 01:00	5/14/02 04:00	2.80 inches
July, 2002	7/23/02 14:00	7/24/02 01:00	1.15 inches
August, 2002	8/29/02 06:00	8/30/02 03:00	1.26 inches
September, 2002	9/23/02 23:00	9/24/02 06:00	1.12 inches
October, 2002	10/16/02 07:00	10/16/02 20:00	1.48 inches

**TABLE 2-9  
FLOW PER SAMPLE STATION FOR AUTO-SAMPLER PROGRAMS  
DRAFT EVALUATION OF FLOW, SUSPENDED SEDIMENT,  
AND HEAVY METALS IN THE ABERJONA RIVER  
INDUSTRI-PLEX SITE  
WOBURN, MASSACHUSETTS**

<b>Sample Station</b>	<b>Flow Volume</b>
1	50,000 cubic feet
2	50,000 cubic feet
3	50,000 cubic feet
4	Not Applicable – Hourly Samples
5	80,000 cubic feet
6	80,000 cubic feet
7	195,000 cubic feet
8	Not Applicable – Hourly Samples
9	Not Applicable – Hourly Samples
10	195,000 cubic feet
11	No Water Quality Samples Collected at this Station

**TABLE 2-10  
DETECTION LIMITS FOR METALS AND TSS AS OBSERVED FROM  
THE DATA SET COLLECTED FOR THIS STUDY  
DRAFT EVALUATION OF FLOW, SUSPENDED SEDIMENT,  
AND HEAVY METALS IN THE ABERJONA RIVER  
INDUSTRI-PLEX SITE  
WOBURN, MASSACHUSETTS**

Analytes	Detection Limit	
	Minimum (µg/L)	Maximum (µg/L)
Arsenic, Dissolved	1.2	13
Arsenic, Total	1.2	13.6
Chromium, Dissolved	0.4	3.6
Chromium, Total	0.4	14.4
Copper, Dissolved	0.6	11.8
Copper, Total	1.8	19.8
Iron, Dissolved	8.6	282
Iron, Total	48.1	234
Lead, Dissolved	0.7	5.1
Lead, Total	0.7	9.5
Mercury, Dissolved	0.1	0.43 <sup>a</sup>
Mercury, Total	0.1	0.42 <sup>b</sup>
Total Suspended Solids	1,000	5,000

<sup>a</sup>Detection limit of 0.43 ug/L for only 1 sample.  
The next highest maximum value was 0.17 ug/L

<sup>b</sup>Detection limit of 0.42 ug/L for only 1 sample.  
The next highest maximum value was 0.22 ug/L

**TABLE 3-1**  
**COMPARISON OF THE MONTHLY AVERAGE RAINFALL FROM 1899 THROUGH 2002**  
**TO THE MONTHLY AVERAGE RAINFALLS FOR 2001 AND 2002**  
**AS MEASURED AT THE READING –NCDC STATION**  
**DRAFT EVALUATION OF FLOW, SUSPENDED SEDIMENT,**  
**AND HEAVY METALS IN THE ABERJONA RIVER**  
**INDUSTRI-PLEX SITE**  
**WOBURN, MASSACHUSETTS**

	<b>104 Year Average (in.)</b>	<b>2001 Monthly Average (in.)</b>	<b>2002 Monthly Average (in.)</b>
January	3.76	2.71	<b>3.82</b>
February	3.37	2.66	<b>2.34</b>
March	4.06	12.8	<b>4.14</b>
April	3.86	1.31	<b>3.95</b>
May	3.39	<b>1.85<sup>a</sup></b>	<b>7.23</b>
June	3.41	<b>7.67</b>	<b>3.36</b>
July	3.31	<b>2.63</b>	<b>2.08</b>
August	3.33	<b>6.27</b>	<b>2.46</b>
September	3.66	<b>1.89</b>	<b>3.35</b>
October	3.36	<b>1.20</b>	<b>4.56</b>
November	4.10	<b>1.01</b>	6.02
December	3.94	<b>3.58</b>	6.86
Overall	3.63	3.8	4.18

<sup>a</sup> Bolded values are representative of those months included in the TtNUS Aberjona River study.

**TABLE 3-2**  
**FREQUENCY AND MAGNITUDE OF STORM EVENTS FROM 1981 THROUGH 2002**  
**DRAFT EVALUATION OF FLOW, SUSPENDED SEDIMENT,**  
**AND HEAVY METALS IN THE ABERJONA RIVER**  
**INDUSTRI-PLEX SITE**  
**WOBURN, MASSACHUSETTS**

<b>Storm Event</b>	<b>Number of Storms</b>	<b>Avg. Number of Events per Year</b>
Events greater than 1"	302	10.5
Events greater than 2"	89	3.29
Events greater than 3"	29	1.29

**TABLE 3-3  
 AVERAGE MONTHLY RAINFALL MEASURED AT EACH TTNUS SAMPLING STATION AS  
 COMPARED WITH READING – NCDC STATION RECORDS  
 DRAFT EVALUATION OF FLOW, SUSPENDED SEDIMENT,  
 AND HEAVY METALS IN THE ABERJONA RIVER  
 INDUSTRI-PLEX SITE  
 WOBURN, MASSACHUSETTS**

<b>Month</b>	<b>Station 1 (in.)</b>	<b>Station 2 (in.)</b>	<b>Station 3 (in.)</b>	<b>Station 4 (in.)</b>	<b>Station 5 (in.)</b>	<b>Station 6 (in.)</b>	<b>Station 7 (in.)</b>	<b>Station 8 (in.)</b>	<b>Station 9 (in.)</b>	<b>Station 10 (in.)</b>	<b>Reading NCDC (in.)</b>
May 01 <sup>a</sup>	1.25	1.24	1.21	1.21	1.20	2.01	1.61	1.61	1.43	1.75	1.75
Jun 01	8.24	8.24	8.69	8.69	8.69	8.66	8.83	7.06	7.21	7.21	7.67
Jul 01	2.55	2.86	2.88	2.88	2.54	2.37	2.41	2.50	1.99	1.73	2.63
Aug 01	1.59	3.38	3.55	3.55	2.95	3.39	4.74	5.34	3.62	3.46	6.27
Sep 01	1.67	1.60	1.44	1.44	1.49	1.70	2.05	1.79	1.41	1.77	1.89
Oct 01	1.06	0.98	0.99	0.99	1.01	0.93	0.94	0.91	0.83	0.80	1.20
Nov 01	1.15	1.00	1.01	1.01	0.93	0.73	1.05	0.79	0.66	0.66	0.94
Dec 01	3.68	2.93	3.22	3.22	3.11	3.16	3.32	3.15	2.57	3.38	3.58
Jan 02	2.90	2.75	2.99	2.99	2.97	2.86	3.24	2.87	2.13	2.78	3.82
Feb 02	2.36	2.30	2.37	2.37	2.20	2.48	2.75	2.20	1.79	2.18	2.29
Mar 02	3.91	3.96	4.04	4.04	4.23	4.34	4.24	3.77	3.82	4.15	4.14
Apr 02	3.78	4.19	3.75	3.72	3.87	3.66	3.96	3.55	3.15	3.15	3.87
May 02	6.99	7.05	7.68	7.76	7.70	7.91	8.07	6.21	5.9	5.86	7.23
Jun 02	3.14	3.02	3.37	3.39	3.36	3.33	3.84	3.76	3.14	2.50	3.36
Jul 02	2.23	2.23	2.24	2.32	2.14	2.39	1.65	1.56	1.46	1.23	2.08
Aug 02	2.39	2.35	2.41	2.45	2.59	2.59	2.70	2.38	2.06	1.37	2.46
Sep 02	3.25	3.20	3.11	3.23	3.54	3.11	3.68	3.78	3.78	3.25	3.35

<sup>a</sup> May 2001 includes only 15 days of data.

<sup>b</sup> Data gaps were substituted with data from the closest station.

**TABLE 3-4**  
**DATES WHEN ONE-INCH OR GREATER STORM EVENTS OCCURRED DURING THE TTNUS**  
**PERIOD OF RECORD**  
**DRAFT EVALUATION OF FLOW, SUSPENDED SEDIMENT,**  
**AND HEAVY METALS IN THE ABERJONA RIVER**  
**INDUSTRI-PLEX SITE**  
**WOBURN, MASSACHUSETTS**

<b>Date of Storm Event</b>	<b>Amount of Rain (inches)</b>
6/01/01	1.30
6/17/01	2.53
6/30/01	1.24
8/03/01	3.08
8/10/01	1.31
8/12/01	1.45
12/17/01	1.15
1/13/02	1.06
1/31/02	1.24
3/26/02	1.04
3/31/02	1.21
5/12/02	<b>2.80<sup>a</sup></b>
5/17/02	1.22
5/29/02	1.41
6/06/02	1.10
7/23/02	<b>1.15</b>
8/29/02	<b>1.26</b>
9/22/02	<b>1.12</b>
10/16/02	<b>1.48</b>
10/25/02	1.83

<sup>a</sup> Bolded rain amounts are storm events that triggered a sample round. One sample round was collected in April 2002 for an event slightly less than one inch (0.97 in).

**TABLE 3-5**  
**RANGES OF STREAMFLOW RATES MEASURED AT THE USGS STATION FOR THE 1940 TO 2002**  
**PERIOD OF RECORD**  
**DRAFT EVALUATION OF FLOW, SUSPENDED SEDIMENT,**  
**AND HEAVY METALS IN THE ABERJONA RIVER**  
**INDUSTRI-PLEX SITE**  
**WOBURN, MASSACHUSETTS**

<b>Streamflow Rate (cfs)</b>	<b>Days Within Range from 1940 to 2002</b>	<b>Average Number of Days Per Year Within Range</b>
0<rate<=20	12305	195.73
20<rate<=40	5185	82.47
40<rate<=60	2477	39.40
60<rate<=80	1263	20.09
80<rate<=100	646	10.28
100<rate<=200	871	13.85
200<rate<=300	127	2.02
300<rate<=400	37	0.59
400<rate<=500	16	0.25
500<rate<=600	5	0.08
600<rate<=700	6	0.10
>700	9	0.14

**TABLE 3-6**  
**THE NINE HIGHEST STREAMFLOW EVENTS (DAILY MAXIMUM) RECORDED AT THE USGS**  
**ABERJONA RIVER MONITORING STATION SINCE 1940**  
**DRAFT EVALUATION OF FLOW, SUSPENDED SEDIMENT,**  
**AND HEAVY METALS IN THE ABERJONA RIVER**  
**INDUSTRI-PLEX SITE**  
**WOBURN, MASSACHUSETTS**

<b>Date of High Streamflow</b>	<b>Daily Average Streamflow (cfs)</b>	<b>Beginning Date of Precipitation Event</b>	<b>Magnitude of Precipitation Event</b>
October 7, 1962	732	No Record <sup>a</sup>	No Record
January 25, 1979	830	No Record	No Record
January 26, 1979	951	No Record	No Record
April 7, 1987	780	4/4/1987	6.0 inches
October 21, 1996	1070	10/19/1996	10.1 inches
October 22, 1996	786	"	Continued Event <sup>b</sup>
June 14, 1998	1020	6/12/1998	7.27 inches
March 22, 2001	961	3/21/2001	5.43 inches
March 23, 2001	1110	"	Continued Event

<sup>a</sup> Hourly storm data not available from the Reading weather station since data was not recorded in hourly increments at this time.

<sup>b</sup> Significant streamflow events that include multiple days of constant rain and multiple storm events.

**TABLE 3-7**  
**MONTHLY AVERAGE STREAMFLOW COMPARISON BETWEEN**  
**USGS STATION AND TTNUS STATION 8**  
**DRAFT EVALUATION OF FLOW, SUSPENDED SEDIMENT,**  
**AND HEAVY METALS IN THE ABERJONA RIVER**  
**INDUSTRI-PLEX SITE**  
**WOBURN, MASSACHUSETTS**

<b>Mo/Yr</b>	<b>USGS<sup>a</sup>, (cfs)</b>	<b>Station 8, (cfs)</b>
May-01	16.39	18.23
Jun-01	44.31	42.99
Jul-01	42.40	38.91
Aug-01	6.35	6.38
Sep-01	6.55	7.95
Oct-01	4.38	5.93
Nov-01	3.58	4.69
Dec-01	10.84	13.38
Jan-02	11.59	14.34
Feb-02	15.88	33.17
Mar-02	31.11	40.39
Apr-02	36.47	44.24
May-02	55.33	61.36
Jun-02	36.27	43.23
Jul-02	9.67	11.51
Aug-02	6.09	7.37
Sep-02	9.79	11.83
Overall Average	20.99	24.79

<sup>a</sup> Data Evaluated Include Only Those Hourly Data Points When Both Stations Were Operating

**TABLE 3-8  
 AVERAGE MONTHLY STREAMFLOW AS RECORDED AT THE USGS STATION AND EACH  
 OF THE 8 TTNUS MONITORING STATIONS FOR THE ABERJONA RIVER  
 DRAFT EVALUATION OF FLOW, SUSPENDED SEDIMENT,  
 AND HEAVY METALS IN THE ABERJONA RIVER  
 INDUSTRI-PLEX SITE  
 WOBURN, MASSACHUSETTS**

Date	Station 1 <sup>b</sup> (cfs)	Station 2 (cfs)	Station 3 (cfs)	Station 4 (cfs)	Station 5 (cfs)	Station 6 (cfs)	Station 7 (cfs)	Station 8 (cfs)	USGS (cfs)
Jun-01	NA <sup>a</sup>	NA	3.22	3.54	NA	NA	23.31	42.88	44.23
Jul-01	NA	NA	1.26	2.07	5.26	NA	20.06	39.32	42.74
Aug-01	2.15	NA	2.14	2.41	7.41	NA	9.17	NA	6.36
Sep-01	0.99	0.93	0.84	NA	NA	NA	5.4	7.96	6.55
Oct-01	0.99	1.00	0.94	1.30	3.14	3.72	6.54	5.94	4.38
Nov-01	0.82	0.84	1.37	1.01	2.76	3.49	6.9	4.78	3.58
Dec-01	1.72	3.14	3.02	2.38	6.31	7.46	7.82	13.41	10.83
Jan-02	1.87	5.82	4.04	2.42	5.58	7.56	8.19	14.34	11.58
Feb-02	2.71	8.22	5.07	3.04	7.3	10.7	10.97	33.15	15.69
Mar-02	4.09	7.59	6.34	4.14	12.38	13.52	22.73	40.48	30.32
Apr-02	4.16	7.24	6.85	4.12	9.42	15.41	27.25	44.29	35.19
May-02	5.51	9.63	8.57	4.90	14.99	21.28	34.66	61.38	53.15
Jun-02	3.38	4.41	5.29	4.18	6.23	12.25	21.21	43.39	34.06
Jul-02	1.23	1.05	1.08	2.40	3.05	1.02	7.3	11.55	9.55
Aug-02	1.03	0.70	0.85	1.65	2.57	0.72	5.72	7.38	6.1
Sep-02	1.25	NA	1.17	2.33	2.53	1.45	6.14	11.85	9.78
Max	5.51	9.63	8.57	4.90	14.99	21.28	34.66	61.38	53.15
Min	0.82	0.70	0.84	1.01	2.53	0.72	5.40	4.78	3.58
Avg	2.28	4.21	3.25	2.79	6.35	8.22	13.96	25.47	20.26

<sup>a</sup>Not Available

<sup>b</sup>Period of Record May Differ Between Stations.

**TABLE 3-9**  
**AVERAGE MONTHLY WATER TEMPERATURE AT EACH TTNUS MONITORING STATION**  
**DRAFT EVALUATION OF FLOW, SUSPENDED SEDIMENT,**  
**AND HEAVY METALS IN THE ABERJONA RIVER**  
**INDUSTRI-PLEX SITE**  
**WOBURN, MASSACHUSETTS**

Date	Station 1 (°C)	Station 2 (°C)	Station 3 (°C)	Station 4 (°C)	Station 5 (°C)	Station 6 (°C)	Station 7 (°C)	Station 8 (°C)	Station 9 (°C)	Station 10 (°C)
Jun-01	NA <sup>a</sup>	NA	20.3	22.5	NA	20.8	20.5	21.3	23.3	NA
Jul-01	NA	NA	20.7	23.4	22.8	21.4	21.4	22.0	24.7	24.8
Aug-01	20.6	NA	21.7	24.5	23.5	22.7	22.2	22.5	26.0	25.7
Sep-01	7.3	20.2	18.2	NA	NA	NA	19.0	19.2	22.6	22.0
Oct-01	11.5	13.7	12.7	12.1	12.8	12.5	12.6	13.1	15.7	15.3
Nov-01	7.5	8.7	8.9	8.0	7.8	8.0	8.1	8.9	NA	10.0
Dec-01	4.2	5.5	5.5	4.8	4.2	4.4	4.4	5.4	6.6	6.9
Jan-02	2.1	3.7	3.3	2.6	2.4	2.4	2.3	3.3	2.4	2.9
Feb-02	3.2	4.3	4.1	3.9	3.6	3.5	3.5	3.9	3.1	3.2
Mar-02	5.9	6.3	6.4	6.5	6.3	6.6	6.2	6.3	5.5	5.6
Apr-02	11.5	12.0	11.8	12.7	12.4	11.8	11.9	12.1	12.2	11.9
May-02	14.1	14.3	14.4	15.4	15.3	14.9	14.5	14.9	15.1	14.7
Jun-02	17.7	19.2	18.8	20.5	19.8	19.1	18.6	19.4	21.2	21.1
Jul-02	20.7	23.8	21.4	25.0	23.7	22.4	22.2	22.6	26.0	25.6
Aug-02	20.6	24.2	20.5	24.9	24.4	22.1	22.6	22.5	26.2	25.6
Sep-02	17.7	22.5	18.0	20.6	19.6	19.4	19.0	20.0	22.0	21.6

<sup>a</sup>Not Available

**TABLE 3-10**  
**MONTHLY AVERAGE SPECIFIC CONDUCTIVITY AT EACH TTNUS MONITORING STATION**  
**DRAFT EVALUATION OF FLOW, SUSPENDED SEDIMENT,**  
**AND HEAVY METALS IN THE ABERJONA RIVER**  
**INDUSTRI-PLEX SITE**  
**WOBURN, MASSACHUSETTS**

Date	Station 1 (uS/cm)	Station 2 (uS/cm)	Station 3 (uS/CM)	Station 4 (uS/CM)	Station 5 (uS/CM)	Station 6 (uS/CM)	Station 7 (uS/CM)	Station 8 (uS/CM)	Station 9 (uS/CM)	Station 10 (uS/CM)
Jun-01	NA <sup>a</sup>	495	501	452	NA	593	490	528	616	NA
Jul-01	NA	590	642	579	670	568	563	527	478	514
Aug-01	524	794	620	562	638	623	603	588	473	536
Sep-01	478	762	675	NA	NA	NA	581	551	464	513
Oct-01	483	890	608	508	773	815	634	691	538	611
Nov-01	450	1101	552	451	820	758	721	682	NA	617
Dec-01	621	766	749	646	879	756	1002	794	643	685
Jan-02	1139	954	1025	959	1079	1162	<b>1409<sup>b</sup></b>	1266	689	722.
Feb-02	809	1006	897	916	1039	1016	1177	<b>1617</b>	1171	<b>1365</b>
Mar-02	652	677	<b>1314</b>	700	716	885	894	749	885	868
Apr-02	571	635	984	539	574	684	644	537	703	697
May-02	497	521	478	434	468	530	482	419	576	603
Jun-02	486	522	509	388	458	612	600	521	453	479
Jul-02	514	576	567	548	454	700	640	535	520	485
Aug-02	420	641	515	529	657	665	650	593	551	541
Sep-02	366	581	587	573	573	584	547	526	543	567

<sup>a</sup>Not Available.

<sup>b</sup>Bolded values show monthly averages above the fresh water range for specific conductivity.

**TABLE 3-11  
 AVERAGE MONTHLY DISSOLVED OXYGEN CONCENTRATION IN THE  
 ABERJONA RIVER AT EACH TTNUS MONITORING STATION  
 DRAFT EVALUATION OF FLOW, SUSPENDED SEDIMENT,  
 AND HEAVY METALS IN THE ABERJONA RIVER  
 INDUSTRI-PLEX SITE  
 WOBURN, MASSACHUSETTS**

<b>Date</b>	<b>Station 1 (mg/L)</b>	<b>Station 2 (mg/L)</b>	<b>Station 3 (mg/L)</b>	<b>Station 4 (mg/L)</b>	<b>Station 5 (mg/L)</b>	<b>Station 6 (mg/L)</b>	<b>Station 7 (mg/L)</b>	<b>Station 8 (mg/L)</b>	<b>Station 9 (mg/L)</b>	<b>Station 10 (mg/L)</b>
Jun-01	NA	3.6	3.5	4.0	NA	2.3	5.8	5.4	10.1	NA
Jul-01	NA	4.0	1.9	5.2	3.9	3.7	13.0	1.8	6.1	1.9
Aug-01	4.3	3.6	2.7	3.9	4.0	2.9	9.9	3.9	5.5	8.5
Sep-01	4.9	7.5	3.3	NA	NA	NA	3.9	4.2	5.4	8.2
Oct-01	5.0	5.7	4.0	9.6	8.3	6.8	5.6	5.3	10.0	10.2
Nov-01	5.4	7.0	4.9	8.8	8.4	8.3	6.6	7.2	NA	8.8
Dec-01	9.4	9.1	8.0	9.9	10.6	9.8	11.4	10.2	11.8	10.1
Jan-02	11.8	9.2	9.9	10.6	10.6	12.3	13.3	5.1	15.3	12.8
Feb-02	15.3	9.4	10.0	9.7	11.8	11.5	13.3	12.6	14.1	13.9
Mar-02	8.9	11.7	10.7	11.8	11.1	13.2	12.0	11.6	13.9	13.9
Apr-02	9.1	5.5	8.1	11.1	10.2	5.3	8.7	9.5	12.9	12.6
May-02	8.4	9.0	7.2	9.0	8.4	7.6	10.1	9.4	12.3	11.5
Jun-02	6.0	5.8	3.4	5.9	5.7	5.4	6.4	7.1	10.8	9.2
Jul-02	2.4	5.3	2.5	3.2	4.9	4.0	2.7	4.7	9.8	6.5
Aug-02	3.2	9.6	3.8	3.9	5.0	4.4	6.2	7.4	11.4	7.3
Sep-02	4.4	3.5	3.4	4.2	4.2	5.7	6.9	6.0	8.0	9.0

<sup>a</sup>Not Available.

**TABLE 3-12**  
**SATURATION VALUES OF DISSOLVED OXYGEN GIVEN AVERAGE WATER TEMPERATURE**  
**OBSERVED IN THE ABERJONA RIVER**  
**DRAFT EVALUATION OF FLOW, SUSPENDED SEDIMENT,**  
**AND HEAVY METALS IN THE ABERJONA RIVER**  
**INDUSTRI-PLEX SITE**  
**WOBURN, MASSACHUSETTS**

<b>Date</b>	<b>Avg. Water Temp. (°C)</b>	<b>Dissolved Oxygen (mg/L)</b>
Jun-01	22.9	8.3
Jul-01	22.7	8.3
Aug-01	23.3	8.3
Sep-01	19.8	8.7
Oct-01	13.2	10.1
Nov-01	8.4	11.2
Dec-01	5.2	12.1
Jan-02	2.7	12.7
Feb-02	3.6	12.4
Mar-02	6.1	11.8
Apr-02	12.0	10.3
May-02	14.8	9.7
Jun-02	19.5	8.7
Jul-02	23.3	8.3
Aug-02	23.4	8.3
Sep-02	20.0	8.7

**TABLE 3-13**  
**MONTHLY AVERAGE PH AT EACH TTNUS MONITORING STATION ON THE ABERJONA RIVER**  
**DRAFT EVALUATION OF FLOW, SUSPENDED SEDIMENT,**  
**AND HEAVY METALS IN THE ABERJONA RIVER**  
**INDUSTRI-PLEX SITE**  
**WOBURN, MASSACHUSETTS**

Date	Station 1 (pH units)	Station 2 (pH units)	Station 3 (pH units)	Station 4 (pH units)	Station 5 (pH units)	Station 6 (pH units)	Station 7 (pH units)	Station 8 (pH units)	Station 9 (pH units)	Station 10 (pH units)
Jun-01	NA <sup>a</sup>	6.75	6.84	6.82	NA	6.85	6.84	6.85	7.68	NA
Jul-01	NA	6.75	7.03	6.98	6.89	6.78	6.93	7.01	7.66	7.52
Aug-01	7.04	6.81	6.71	6.89	6.90	7.04	6.79	6.99	7.78	8.14
Sep-01	6.85	6.93	6.82	NA	NA	NA	6.65	6.8	7.99	8.21
Oct-01	6.87	6.79	6.73	7.28	7.03	7.04	7.13	6.87	7.76	7.81
Nov-01	6.74	6.82	6.57	7.16	6.99	7.1	7.04	6.95	NA	7.54
Dec-01	6.64	6.70	6.63	6.86	6.99	7.01	7.08	6.99	7.55	7.40
Jan-02	7.09	6.55	6.77	6.79	7.03	6.98	7.19	7.42	7.55	7.57
Feb-02	7.05	6.81	6.90	7.04	7.05	7.03	7.29	7.30	7.77	7.94
Mar-02	7.03	6.74	6.81	6.98	6.98	7.11	7.32	7.29	7.42	7.90
Apr-02	7.04	6.81	6.71	6.83	6.73	7.17	7.22	7.27	7.82	7.93
May-02	6.99	6.39	6.60	6.70	6.61	6.91	7.06	7.00	8.03	7.87
Jun-02	6.98	6.78	6.75	6.75	6.59	6.85	6.99	7.04	8.20	8.04
Jul-02	7.11	6.69	6.63	7.05	6.53	6.90	7.12	6.82	8.38	8.56
Aug-02	6.96	6.79	6.61	7.22	6.92	6.95	7.06	7.04	9.39	8.63
Sep-02	6.87	7.51	6.52	7.04	6.71	6.84	6.77	6.87	9.11	8.66

<sup>a</sup>Not Available.

**TABLE 3-14**  
**MONTHLY AVERAGE ORP VALUES FOR EACH TTNUS MONITORING STATION ALONG THE ABERJONA RIVER**  
**DRAFT EVALUATION OF FLOW, SUSPENDED SEDIMENT,**  
**AND HEAVY METALS IN THE ABERJONA RIVER**  
**INDUSTRI-PLEX SITE**  
**WOBURN, MASSACHUSETTS**

Date	Station 1 (mV)	Station 2 (mV)	Station 3 (mV)	Station 4 (mV)	Station 5 (mV)	Station 6 (mV)	Station 7 (mV)	Station 8 (mV)	Station 9 (mV)	Station 10 (mV)
Jun-01	NA	4.3	364	422	NA	469	465	470	367	NA
Jul-01	NA	4.2	93	440	300	479	448	457	413	450
Aug-01	478	-1.8	-132	424	441	495	479	426	394	373
Sep-01	490	-89	422	NA	NA	NA	509	505	344	405
Oct-01	376	-143	418	252	440	462	466	487	370	408
Nov-01	299	-192	392	347	404	404	403	419	NA	400
Dec-01	259	-185	362	400	443	384	424	445	337	390
Jan-02	225	-32	445	431	485	355	350	402	371	382
Feb-02	215	-26	424	413	407	306	307	405	336	333
Mar-02	128	60	374	184	334	256	290	254	271	247
Apr-02	143	-94	268	203	223	168	317	313	265	275
May-02	225	-127	262	248	219	362	332	383	245	298
Jun-02	255	-240	337	254	221	256	229	365	212	242
Jul-02	263	-168	276	285	218	246	302	398	217	213
Aug-02	299	-134	230	272	212	318	359	358	154	214
Sep-02	319	-261	131	324	170	389	412	397	242	271

<sup>a</sup>Not Available.

**TABLE 3-15**  
**MONTHLY AVERAGE TURBIDITY FOR EACH TTNUS MONITORING STATION ALONG THE ABERJONA RIVER**  
**DRAFT EVALUATION OF FLOW, SUSPENDED SEDIMENT,**  
**AND HEAVY METALS IN THE ABERJONA RIVER**  
**INDUSTRI-PLEX SITE**  
**WOBURN, MASSACHUSETTS**

<b>Date</b>	<b>Station 1 (ntu)</b>	<b>Station 2 (ntu)</b>	<b>Station 3 (ntu)</b>	<b>Station 4 (ntu)</b>	<b>Station 5 (ntu)</b>	<b>Station 6 (ntu)</b>	<b>Station 7 (ntu)</b>	<b>Station 8 (ntu)</b>	<b>Station 9 (ntu)</b>	<b>Station 10 (ntu)</b>
Jun-01	NA	427	386	13	NA	77	114	21	0.94	NA
Jul-01	NA	449	193	17	28	38	82	6.9	5.8	20
Aug-01	79	461	85	294	140	14	121	21	7.6	3.0
Sep-01	42	170	44	NA	NA	NA	108	24	1.1	24
Oct-01	22	101	58	31	261	22	8.1	120	2.2	3.2
Nov-01	19	86	205	85	23	7.7	4.2	188	NA	2.0
Dec-01	333	145	112	22	59	12	14	72.2	1.7	18
Jan-02	362	421	10	18	36	8.6	16	304	1.8	2.3
Feb-02	225	39	9.9	22	45	10	16	157	2.8	2.0
Mar-02	234	52	23.8	15	5.5	20	5.7	95	2.5	2.7
Apr-02	62	48	3.5	37	3.9	469	2.2	135	1.6	1.1
May-02	14	67	3.8	143	170	4.2	18	146	0.2	0.3
Jun-02	16	58	1.3	10	186	72	12	58	1.1	2.5
Jul-02	87	38	268	291	337	6.3	5.9	180	0.3	2.2
Aug-02	8.4	13	133	98	434	221	3.5	75	101	1.5
Sep-02	62	18	166	147	404	7.3	4.0	11	215	2.8

<sup>a</sup>Not Available.

**TABLE 3-16**  
**AVERAGE TSS CONCENTRATIONS AND FLUXES DURING BASEFLOW AND STORM EVENTS**  
**DRAFT EVALUATION OF FLOW, SUSPENDED SEDIMENT,**  
**AND HEAVY METALS IN THE ABERJONA RIVER**  
**INDUSTRI-PLEX SITE**  
**WOBURN, MASSACHUSETTS**

Station	Flow (cfs) <sup>a</sup>		TSS <sup>b</sup> (mg/L)		TSS (kg/hr)	
	Baseflow	Storm Flow	Baseflow	Storm Flow	Baseflow	Storm Flow
1	0.9	8.9	4.4	21.6	0.5	20.8
2	2.4	13.0	4.8	12.6	1.1	16.4
3	2.0	10.4	4.7	8.1	0.6	6.2
4	1.9	6.6	22.5	12.7	3.2	8.3
5	2.8	25.6	6.0	6.8	1.6	22.2
6	4.1	27.0	4.6	17.1	2.1	50.7
7	7.3	49.2	7.4	10.3	3.9	60.7
8	13.6	75.8	4.5	46.1	6.7	468.1
9	NM <sup>c</sup>	NM	4.1	3.8	NM	NM
10	NM	NM	6.1	3.8	NM	NM

<sup>a</sup> Average flows shown correspond to times when samples were analyzed for TSS. Slight differences in storm event average flows may be noted between TSS and metals for Stations 4 and 8 since not all samples collected at these stations during storm flow were analyzed for both metals and TSS due to differences in allowable holding times. Some samples analyzed from Station 4 and 8 were retrieved from the sample archive and these samples could not longer be analyzed for TSS because of extended holding times.

<sup>b</sup> Concentrations set at ½ quantification limit for samples measuring below the quantification limit. Flux computations are based upon ½ quantification limit values for samples measuring below the quantification limit.

<sup>c</sup>NM = Not Measured

**TABLE 4-1**  
**FRACTION OF THE TOTAL METALS THAT CORRESPOND TO THE DISSOLVED PHASE FOR**  
**EACH SAMPLE STATION FOR OVERALL BASEFLOW CONDITIONS**  
**DRAFT EVALUATION OF FLOW, SUSPENDED SEDIMENT,**  
**AND HEAVY METALS IN THE ABERJONA RIVER**  
**INDUSTRI-PLEX SITE**  
**WOBURN, MASSACHUSETTS**

Station	Fraction of Total Metals that Correspond to the Dissolved Phase <sup>a</sup>											
	Arsenic		Iron		Chromium		Copper		Lead		Mercury	
	Method 1	Method 2	Method 1	Method 2	Method 1	Method 2	Method 1	Method 2	Method 1	Method 2	Method 1	Method 2
1	44%	72%	41%	31%	48%	39%	67%	53%	ND <sup>b</sup>	40%	ND	100%
2	25%	24%	23%	18%	77%	71%	77%	82%	ND	45%	ND	100%
3	65%	63%	49%	49%	81%	69%	55%	58%	ND	74%	ND	100%
4	15%	16%	11%	9%	9%	10%	11%	14%	54%	11%	ND	56%
5	32%	28%	26%	21%	20%	19%	47%	35%	42%	25%	ND	83%
6	29%	24%	22%	20%	36%	29%	32%	46%	ND	24%	ND	GT
7	38%	35%	30%	22%	30%	29%	57%	56%	ND	28%	ND	100%
8	31%	34%	27%	21%	70%	27%	53%	59%	ND	21%	ND	83%
9	GT <sup>c</sup>	94%	ND	13%	ND	100%	88%	96%	ND	93%	ND	GT
10	67%	100%	19%	9%	72%	70%	GT	GT	ND	81%	ND	71%

<sup>a</sup> The fractions were calculated using two methods. The first method, represented by the first column, excludes samples that were below the limit of quantification and the data used in the calculations corresponded to those for which quantification occurred within both total and dissolved phase. The second method, represented by the second column, utilizes all data. Samples that were below the limit of quantification were set at ½ the quantification limit value.

<sup>b</sup> ND = No samples exceeded the limit of quantification for both the dissolved and total analyses and so the fraction could not be computed.

<sup>c</sup> GT = Greater than. In these cases the distribution of metals between the dissolved versus total was computed as greater than 100%. This occurred for stations with the lowest metals concentrations, which in many cases were near instrument quantification limits and where analytical errors tend to be higher on a % basis.

**TABLE 4-2  
 AVERAGE METALS CONCENTRATIONS DURING BASEFLOW CONDITIONS FOR  
 STATIONS 1 THROUGH 10  
 DRAFT EVALUATION OF FLOW, SUSPENDED SEDIMENT,  
 AND HEAVY METALS IN THE ABERJONA RIVER  
 INDUSTRI-PLEX SITE  
 WOBURN, MASSACHUSETTS**

Station	As (ug/L)		Fe (ug/L)		Cr (ug/L)		Cu (ug/L)		Pb (ug/L)		Hg (ug/L)	
	Dissolved	Total										
1	1.3	1.8	266	868	0.7	1.8	1.8	3.4	0.93	2.31	0.05	0.05
2	4.9	20.2	346	1933	1.2	1.7	4.9	6.0	0.77	1.72	0.05	0.05
3	12.1	19.2	1177	2404	0.9	1.3	1.5	2.6	0.76	1.03	0.05	0.05
4	6.0	37.1	487	5266	1.1	11.5	2.4	17.4	0.83	7.87	0.05	0.09
5	5.6	20.1	524	2448	1.4	7.2	1.8	5.1	0.84	3.35	0.05	0.06
6	2.7	11.1	293	1463	1.2	4.2	2.1	4.6	0.77	3.24	0.07	0.06
7	2.0	5.7	247	1127	0.9	3.1	2.5	4.5	0.77	2.73	0.05	0.05
8	1.5	4.4	220	1031	0.6	2.2	3.0	5.1	0.76	3.64	0.05	0.06
9	1.7	1.8	17	132	0.5	0.5	2.5	2.6	0.76	0.82	0.06	0.05
10	1.4	1.4	16	183	0.7	1.0	2.4	2.2	0.77	0.95	0.05	0.07

Concentrations Assumed at ½ Detection Limit for Samples Measuring Below Detection

**TABLE 4-2A  
 AVERAGE TOTAL AND DISSOLVED METAL FLUX DURING BASEFLOW CONDITIONS  
 FOR STATIONS 1 THROUGH 8  
 DRAFT EVALUATION OF FLOW, SUSPENDED SEDIMENT,  
 AND HEAVY METALS IN THE ABERJONA RIVER  
 INDUSTRI-PLEX SITE  
 WOBURN, MASSACHUSETTS**

Station	Flow (cfs)	As (g/hr)		Fe (g/hr)		Cr (g/hr)		Cu (g/hr)		Pb (g/hr)	
		Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved <sup>a</sup>	Total
1	0.9	0.1	0.2	26	83	0.1	0.2	0.2	0.4	0.1	0.2
2	2.4	1.4	3.8	113	440	0.2	0.4	1.3	1.6	0.2	0.5
3	2.0	1.9	2.7	218	410	0.1	0.2	0.3	0.7	0.1	0.3
4	1.9	1.0	6.7	109	970	0.2	2.1	0.5	3.3	0.2	1.5
5	2.8	1.5	5.3	144	660	0.4	1.9	0.5	1.5	0.2	0.9
6	4.1	1.1	4.1	161	580	0.5	1.6	1.0	2.1	0.3	1.3
7	7.3	1.5	4.4	202	830	0.6	2.1	1.9	3.8	0.5	1.8
8	13.6	1.8	5.5	346	1380	0.6	2.8	5.4	9.4	1.0	4.1

Flux was computed for samples where both concentrations and flows were measured. Samples measured below quantification limits were set at ½ quantification limit values.

<sup>a</sup> The majority of dissolved lead concentrations were below detection limits, so flux values provided were not measured directly and represent estimates.

**TABLE 4-3**  
**FRACTION OF THE TOTAL METALS THAT CORRESPOND TO THE DISSOLVED PHASE FOR EACH**  
**SAMPLE STATION FOR STORM FLOW CONDITIONS**  
**DRAFT EVALUATION OF FLOW, SUSPENDED SEDIMENT,**  
**AND HEAVY METALS IN THE ABERJONA RIVER**  
**INDUSTRI-PLEX SITE**  
**WOBURN, MASSACHUSETTS**

Station	Fraction of Total Metals that Correspond to the Dissolved Phase <sup>a</sup>											
	Arsenic		Iron		Chromium		Copper		Lead		Mercury	
1	ND <sup>a</sup>	34%	17%	11%	16%	16%	36%	25%	34%	8%	ND <sup>b</sup>	100%
2	22%	21%	12%	11%	49%	52%	53%	38%	23%	26%	ND	100%
3	33%	14%	18%	11%	34%	33%	60%	38%	32%	30%	ND	100%
4	32%	27%	27%	18%	39%	29%	41%	33%	87%	27%	92%	71%
5	33%	25%	21%	19%	23%	18%	ND	31%	ND	22%	ND	83%
6	27%	20%	17%	14%	12%	11%	43%	39%	ND	9%	ND	63%
7	39%	29%	18%	17%	19%	21%	44%	41%	27%	13%	ND	100%
8	14%	18%	4%	6%	6%	7%	9%	18%	3%	6%	71%	50%
9	GT <sup>c</sup>	74%	ND	5%	ND	75%	74%	78%	ND	56%	ND	100%
10	72%	88%	ND	11%	66%	67%	48%	78%	ND	100%	ND	100%

<sup>a</sup> The fractions were calculated using two methods. The first method, represented by the first column, excludes samples that were below the limit of quantification and the data used in the calculations corresponded to those for which quantification occurred within both total and dissolved phase. The second method, represented by the second column, utilizes data for all samples. Samples that were below the limit of quantification were set at ½ the quantification limit value.

<sup>b</sup> ND = No samples exceeded the limit of quantification for both the dissolved and total analyses and so the fraction could not be computed.

<sup>c</sup> In these cases the distribution of metals between the dissolved versus total was computed as greater than 100%. This occurred for stations with the lowest metals concentrations, which in many cases were near instrument detection limits and where analytical errors tend to be higher on a % basis.

**TABLE 4-4  
 AVERAGE METALS CONCENTRATIONS DURING STORM FLOW CONDITIONS  
 FOR STATIONS 1 THROUGH 10  
 DRAFT EVALUATION OF FLOW, SUSPENDED SEDIMENT,  
 AND HEAVY METALS IN THE ABERJONA RIVER  
 INDUSTRI-PLEX SITE  
 WOBURN, MASSACHUSETTS**

Station	As (ug/L)		Fe (ug/L)		Cr (ug/L)		Cu (ug/L)		Pb (ug/L)		Hg (ug/L)	
	Dissolved	Total										
1	1.2	3.5	198	1830	1.5	9.5	4.3	17	1.1	13	0.05	0.05
2	10	48	444	3910	1.6	3.1	3.0	7.8	0.9	3.5	0.05	0.05
3	2.1	15	209	1880	1.0	3.0	2.3	6.1	0.8	2.7	0.05	0.05
4	8.7	32	521	2870	1.2	4.1	2.7	8.3	0.9	3.3	0.05	0.07
5	3.7	15	304	1630	1.2	6.8	2.2	7.0	0.8	3.6	0.05	0.06
6	4.0	20	342	2520	1.7	15	12	31	0.8	9.2	0.05	0.08
7	2.8	9.5	241	1450	1.2	5.6	6.1	15	0.9	7.1	0.05	0.05
8	2.0	11	157	2800	1.0	15	4.7	26	1.5	24	0.05	0.10
9	1.7	2.3	7.0	130	0.3	0.4	1.8	2.3	0.5	0.9	0.05	0.05
10	1.4	1.6	6.1	54	0.6	0.9	1.4	1.8	0.6	0.6	0.05	0.05

Concentrations Set at ½ Detection Limit for Samples Measuring Below Detection

**TABLE 4-5  
 AVERAGE TOTAL AND DISSOLVED METAL FLUX DURING STORM FLOW CONDITIONS FOR STATIONS 1 THROUGH 8  
 DRAFT EVALUATION OF FLOW, SUSPENDED SEDIMENT,  
 AND HEAVY METALS IN THE ABERJONA RIVER  
 INDUSTRI-PLEX SITE  
 WOBURN, MASSACHUSETTS**

Station	Flow (cfs)	As (g/hr)		Fe (g/hr)		Cr (g/hr)		Cu (g/hr)		Pb (g/hr)	
		Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total
1	8.9	1.1	3.2	214	1,700	1.6	9.4	3.5	15.0	1.1	12.0
2	13.0	22.9	67.9	1,118	4,930	2.0	3.2	3.5	9.5	1.5	4.9
3	10.4	1.6	15.3	267	2,060	1.3	3.7	2.5	7.6	0.9	3.2
4	6.7	7.2	23.7	430	2,020	0.9	2.8	1.8	5.4	0.6	2.1
5	25.6	16.2	44.8	1,392	4,860	3.4	19.1	5.1	19.8	2.1	9.5
6	27.0	14.5	58.6	1,291	7,330	5.3	42.5	35.3	94.7	1.9	27.0
7	49.2	19.4	60.0	1,734	8,510	7.3	34.9	32.6	91.6	6.6	43.9
8	76.3	17.4	106.8	1,563	29,700	9.0	177.3	36.6	281.5	12.1	262.2

Flux was computed for samples where both concentrations and flows were measured. Samples measured below quantification limits were set at ½ quantification limit values.

**TABLE 4-6  
 AVERAGE TOTAL METALS AND TSS CONCENTRATIONS DURING BASEFLOW AND STORM FLOW  
 CONDITIONS FOR STATIONS 1 THROUGH 10  
 DRAFT EVALUATION OF FLOW, SUSPENDED SEDIMENT,  
 AND HEAVY METALS IN THE ABERJONA RIVER  
 INDUSTRI-PLEX SITE  
 WOBURN, MASSACHUSETTS**

Station	TSS (mg/L)		Total As (ug/L)		Total Fe (ug/L)		Total Cr (ug/L)		Total Cu (ug/L)		Total Pb (ug/L)		Total Hg (ug/L)	
	Baseflow	Storm Flow	Baseflow	Storm Flow	Baseflow	Storm Flow	Baseflow	Storm Flow	Baseflow	Storm Flow	Baseflow	Storm Flow	Baseflow	Storm Flow
1	4.4	21.6	1.8	3.5	868	1830	1.8	9.5	3.4	17	2.31	13	0.05	0.05
2	4.8	12.6	20.2	48	1933	3910	1.7	3.1	6.0	7.8	1.72	3.5	0.05	0.05
3	4.7	8.1	19.2	15	2404	1880	1.3	3.0	2.6	6.1	1.03	2.7	0.05	0.05
4	22.5	12.7	37.1	32	5266	2870	11.5	4.1	17.4	8.3	7.87	3.3	0.09	0.07
5	6.0	6.8	20.1	15	2448	1630	7.2	6.8	5.1	7.0	3.35	3.6	0.06	0.06
6	4.6	17.1	11.1	20	1463	2520	4.2	15	4.6	31	3.24	9.2	0.06	0.08
7	7.4	10.3	5.7	9.5	1127	1450	3.1	5.6	4.5	15	2.73	7.1	0.05	0.05
8	4.5	46.1	4.4	11	1031	2800	2.2	15	5.1	26	3.64	23.6	0.06	0.10
9	4.1	3.8	1.8	2.3	132	130	0.5	0.4	2.6	2.3	0.82	0.9	0.05	0.05
10	6.1	3.8	1.4	1.6	183	54	1.0	0.9	2.2	1.8	0.95	0.6	0.07	0.05

Concentrations Set at ½ Detection Limit for Samples Measuring Below Detection

**TABLE 4-7**  
**AVERAGE DISSOLVED METALS CONCENTRATIONS DURING BASEFLOW AND**  
**STORM FLOW CONDITIONS FOR STATIONS 1 THROUGH 10**  
**DRAFT EVALUATION OF FLOW, SUSPENDED SEDIMENT,**  
**AND HEAVY METALS IN THE ABERJONA RIVER**  
**INDUSTRI-PLEX SITE**  
**WOBURN, MASSACHUSETTS**

Station	Dissolved As (ug/L)		Dissolved Fe (ug/L)		Dissolved Cr (ug/L)		Dissolved Cu (ug/L)		Dissolved Pb (ug/L)		Dissolved Hg (ug/L)	
	Baseflow	Storm Flow										
1	1.3	1.2	266	198	0.7	1.5	1.8	4.3	0.9	1.1	0.05	0.05
2	4.9	10.4	346	444	1.2	1.6	4.9	3.0	0.8	0.9	0.05	0.05
3	12.1	2.1	1177	209	0.9	1.0	1.5	2.3	0.8	0.8	0.05	0.05
4	6.0	8.7	487	521	1.1	1.2	2.4	2.7	0.8	0.9	0.05	0.05
5	5.6	3.7	524	304	1.4	1.2	1.8	2.2	0.8	0.8	0.05	0.05
6	2.7	4.0	293	342	1.2	1.7	2.1	12.1	0.8	0.8	0.07	0.05
7	2.0	2.8	247	241	0.9	1.2	2.5	6.1	0.8	0.9	0.05	0.05
8	1.5	2.0	220	157	0.6	1.0	3.0	4.7	0.8	1.5	0.05	0.05
9	1.7	1.7	17	7.0	0.5	0.28	2.5	1.8	0.8	0.5	0.06	0.05
10	1.4	1.4	16	6.1	0.7	0.60	2.4	1.4	0.8	0.6	0.05	0.05

Concentrations Set at ½ Detection Limit for Samples Measuring Below Detection

**TABLE 4-8**  
**OVERALL FRACTION OF TOTAL METALS THAT CORRESPOND TO THE DISSOLVED PHASE**  
**DRAFT EVALUATION OF FLOW, SUSPENDED SEDIMENT,**  
**AND HEAVY METALS IN THE ABERJONA RIVER**  
**INDUSTRI-PLEX SITE**  
**WOBURN, MASSACHUSETTS**

<b>Metal</b>	<b>Baseflow</b>	<b>Storm Flow</b>
Arsenic	42%	29%
Chromium	37%	18%
Copper	42%	31%
Iron	25%	15%
Lead	42%	10%
Mercury	ND <sup>a</sup>	81%

<sup>a</sup> ND = Majority of samples were below the detection limit.

<sup>b</sup> Values below detection limits were excluded from the averages and the samples used in the calculations were those where detection occurred within both total and dissolved phases.

Fractions by station are provided in Tables 4-1 and 4-3.

**TABLE 4-9**  
**TOTAL METAL FLUXES DURING BASEFLOW AND STORM FLOW CONDITIONS FOR STATIONS 1 THROUGH 8**  
**DRAFT EVALUATION OF FLOW, SUSPENDED SEDIMENT,**  
**AND HEAVY METALS IN THE ABERJONA RIVER**  
**INDUSTRI-PLEX SITE**  
**WOBURN, MASSACHUSETTS**

Station	Flow (cfs)		TSS (kg/hr)		As (g/hr)		Fe (g/hr)		Cr (g/hr)		Cu (g/hr)		Pb (g/hr)	
	Baseflow	Storm Flow	Baseflow	Storm Flow	Baseflow	Storm Flow	Baseflow	Storm Flow	Baseflow	Storm Flow	Baseflow	Storm Flow	Baseflow	Storm Flow
1	0.9	8.9	0.5	20.8	0.2	3.2	83	1,700	0.2	9.4	0.4	15.0	0.2	12.0
2	2.4	13.0	1.1	16.4	3.8	67.9	440	4,930	0.4	3.2	1.6	9.5	0.5	4.9
3	2.0	10.4	0.6	6.2	2.7	15.3	410	2,060	0.2	3.7	0.7	7.6	0.3	3.2
4	1.9	6.7	3.2	8.3	6.7	23.7	970	2,020	2.1	2.8	3.3	5.4	1.5	2.1
5	2.8	25.6	1.6	22.2	5.3	44.8	660	4,860	1.9	19.1	1.5	19.8	0.9	9.5
6	4.1	27.0	2.1	50.7	4.1	58.6	580	7,330	1.6	42.5	2.1	94.7	1.3	27.0
7	7.3	49.2	3.9	60.7	4.4	60.0	830	8,510	2.1	34.9	3.8	91.6	1.8	43.9
8	13.6	76.3	6.7	468.1	5.5	106.8	1,380	29,700	2.8	177.3	9.4	281.5	4.1	262.2

Flux was computed for samples where both concentrations and flows were measured. Samples measured below quantification limits were set at ½ quantification limit values. The flow measurements listed correspond to flow measurements for which metals samples were collected and analyzed and may not correspond to the flow measurements corresponding to when samples for when TSS were analyzed.

**TABLE 5-1**  
**SUMMARY OF GEOMETRICAL AND PHYSICO-CHEMICAL MEASUREMENTS FOR EACH TTNUS MONITORING STATION**  
**DRAFT EVALUATION OF FLOW, SUSPENDED SEDIMENT,**  
**AND HEAVY METALS IN THE ABERJONA RIVER**  
**INDUSTRI-PLEX SITE**  
**WOBURN, MASSACHUSETTS**

Measurement	Station									
	1	2	3	4	5	6	7	8	9	10
<b>Watershed Geometry</b>										
Drainage Area between Current Station and Previous One (mi <sup>2</sup> )	2.56	0.45	2.67	0.17	1.51	2.03	4.48	10.34	NC <sup>a</sup>	NC
Total Drainage Area to Station (mi <sup>2</sup> )	2.56	3.01	2.67	3.18	7.36	9.39	13.87	24.2	NC	NC
Distance between Current Station and Previous One (mi)	NA	0.18	NA	0.58	0.98	1.11	1.83	1.03	1.65	0.85
<b>Physico-Chemical Parameters<sup>b</sup></b>										
Rainfall (in) <sup>c</sup>	52.1	53.3	55.0	55.3	54.5	55.6	59.1	53.2	47.2	47.2
Flow (cfs)	2.3	4.2	3.3	2.8	6.4	8.2	14	26	NM <sup>a</sup>	NM
Drainage Area Normalized Flow (cfs/mi <sup>2</sup> )	0.89	1.40	1.22	0.88	0.86	0.88	1.01	1.05	NM	NM
Water Temperature (°C)	12	14	14	15	14	14	14	15	17	16
Specific Conductivity (uS/cm)	572	719	701	586	700	730	682	695	620	654
Dissolved Oxygen (mg/L)	7	7	5	7	8	7	8	7	10	10
pH	6.9	6.8	6.7	7.0	6.9	7.0	7.0	7.0	8.0	8.0
ORP (mV)	284	-102	292	327	323	357	381	405	303	327

<sup>a</sup> NC= Not Computed, NM = Not Measured.

<sup>b</sup> As measured for the TtNUS P.O.R. Note that the times corresponding to measurements may be different between different stations. Averages were computed by first computing the monthly averages and then averaging the results for each month.

<sup>c</sup> Data gaps were substituted with data from the closest station

**TABLE 5-2  
 AVERAGE TOTAL SUSPENDED SEDIMENTS AND TOTAL METALS CONCENTRATIONS AT EACH STATION  
 DURING BASEFLOW AND STORM FLOW CONDITIONS  
 DRAFT EVALUATION OF FLOW, SUSPENDED SEDIMENT,  
 AND HEAVY METALS IN THE ABERJONA RIVER  
 INDUSTRI-PLEX SITE  
 WOBURN, MASSACHUSETTS**

Parameter Measured		Station									
		1	2	3	4	5	6	7	8	9	10
TSS (mg/L)	Baseflow	4.4	4.8	4.7	22.5	6.0	4.6	7.4	4.5	4.1	6.1
	Storm Flow	21.6	12.6	8.1	12.7	6.8	17.1	10.3	46.1	3.8	3.8
Total As (ug/L)	Baseflow	1.8	20.2	19.2	37.1	20.1	11.1	5.7	4.4	1.8	1.4
	Storm Flow	3.5	48	15	32	15	20	9.5	11	2.3	1.6
Total Fe (ug/L)	Baseflow	868	1933	2404	5266	2448	1463	1127	1031	132	183
	Storm Flow	1830	3910	1880	2870	1630	2520	1450	2800	130	54
Total Cr (ug/L)	Baseflow	1.8	1.7	1.3	11.5	7.2	4.2	3.1	2.2	0.5	1
	Storm Flow	9.5	3.1	3	4.1	6.8	15	5.6	15	0.4	0.9
Total Cu (ug/L)	Baseflow	3.4	6	2.6	17.4	5.1	4.6	4.5	5.1	2.6	2.2
	Storm Flow	17	7.8	6.1	8.3	7	31	15	26	2.3	1.8
Total Pb (ug/L)	Baseflow	2.31	1.72	1.03	7.87	3.35	3.24	2.73	3.64	0.82	0.95
	Storm Flow	13	3.5	2.7	3.3	3.6	9.2	7.1	23.6	0.9	0.6
Total Hg (ug/L)	Baseflow	0.05	0.05	0.05	0.09	0.06	0.06	0.05	0.06	0.05	0.07
	Storm Flow	0.05	0.05	0.05	0.07	0.06	0.08	0.05	0.1	0.05	0.05

Concentrations Assumed at ½ Detection Limit for Samples Measuring Below Detection

**TABLE 5-3**  
**ESTIMATED AVERAGE FLOW, TOTAL SUSPENDED SEDIMENT FLUX, AND TOTAL METALS FLUX**  
**AT EACH STATION DURING BASEFLOW AND STORM FLOW CONDITIONS**  
**DRAFT EVALUATION OF FLOW, SUSPENDED SEDIMENT,**  
**AND HEAVY METALS IN THE ABERJONA RIVER**  
**INDUSTRI-PLEX SITE**  
**WOBURN, MASSACHUSETTS**

		Station							
		1	2	3	4	5	6	7	8
Flow (cfs)	Baseflow	0.9	2.4	2	1.9	2.8	4.1	7.3	14
	Storm Flow	8.9	13	10	6.7	26	27	49	76
TSS (kg/hr)	Baseflow	0.5	1.1	0.6	3.2	1.6	2.1	3.9	6.7
	Storm Flow	21	16	6	8	22	51	61	468
Total As (g/hr)	Baseflow	0.2	3.8	2.7	6.7	5.3	4.1	4.4	5.5
	Storm Flow	3.2	68	15	24	45	59	60	107
Total Fe (g/hr)	Baseflow	83	440	410	970	660	580	830	1,380
	Storm Flow	1,700	4,930	2,060	2,020	4,860	7,330	8,510	29,700
Total Cr (g/hr)	Baseflow	0.2	0.4	0.2	2.1	1.9	1.6	2.1	2.8
	Storm Flow	9.4	3.2	3.7	2.8	19.1	42.5	34.9	177
Total Cu (g/hr)	Baseflow	0.4	1.6	0.7	3.3	1.5	2.1	3.8	9.4
	Storm Flow	15	9.5	7.6	5.4	19.8	94.7	91.6	282
Total Pb (g/hr)	Baseflow	0.2	0.5	0.3	1.5	0.9	1.3	1.8	4.1
	Storm Flow	12	4.9	3.2	2.1	9.5	27	43.9	262

Flux was computed for samples where both concentrations and flows were measured. Samples measured below quantification limits were set at ½ quantification limit values. The flow measurements listed for Stations 4 and 8 correspond to flow measurements for which metals samples were collected and analyzed and may not correspond to the flow measurements corresponding to when samples for when TSS were analyzed.

**TABLE 5-4**  
**ESTIMATED AVERAGE FLOW, TOTAL SUSPENDED SEDIMENT FLUX, AND TOTAL METALS FLUX**  
**NORMALIZED BY DRAINAGE AREA FOR EACH STATION DURING BASEFLOW**  
**AND STORM FLOW CONDITIONS**  
**DRAFT EVALUATION OF FLOW, SUSPENDED SEDIMENT,**  
**AND HEAVY METALS IN THE ABERJONA RIVER**  
**INDUSTRI-PLEX SITE**  
**WOBURN, MASSACHUSETTS**

		Station							
		1	2	3	4	5	6	7	8
Flow, cfs/mi <sup>2</sup>	Baseflow	0.4	0.8	0.7	0.6	0.4	0.4	0.5	0.6
	Storm Flow	3.5	4.3	3.7	2.1	3.5	2.9	3.5	3.1
TSS, kg/(hr·mi <sup>2</sup> )	Baseflow	0.2	0.4	0.2	1.0	0.2	0.2	0.3	0.3
	Storm Flow	8.2	5.3	2.2	2.5	3.0	5.4	4.4	19.3
Total As, g/(hr·mi <sup>2</sup> )	Baseflow	0.1	1.3	1.0	2.1	0.7	0.4	0.3	0.2
	Storm Flow	1.3	22.6	5.6	7.5	6.1	6.3	4.3	4.4
Total Fe, g/(hr·mi <sup>2</sup> )	Baseflow	32	146	154	305	90	62	60	57
	Storm Flow	664	1638	772	635	660	781	614	1230
Total Cr g/(hr·mi <sup>2</sup> )	Baseflow	0.1	0.1	0.1	0.7	0.3	0.2	0.2	0.1
	Storm Flow	3.7	1.1	1.4	0.9	2.6	4.5	2.5	7.3
Total Cu g/(hr·mi <sup>2</sup> )	Baseflow	0.2	0.5	0.3	1.0	0.2	0.2	0.3	0.4
	Storm Flow	5.9	3.2	2.8	1.7	2.7	10.1	6.6	11.7
Total Pb g/(hr·mi <sup>2</sup> )	Baseflow	0.1	0.2	0.1	0.5	0.1	0.1	0.1	0.2
	Storm Flow	4.7	1.6	1.2	0.7	1.3	2.9	3.2	10.8

Flux was computed for samples where both concentrations and flows were measured. Samples measured below quantification limits were set at ½ quantification limit values. The flow measurements listed correspond to flow measurements for which metals samples were collected and analyzed and may not correspond to the flow measurements corresponding to when samples for when TSS were analyzed.

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