Historic Water Quality and Selected Biological Conditions of the Upper Merrimack River, New Hampshire

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1.0 Introduction

1.1 Purpose and Scope of Report

Public Service Company of New Hampshire (PSNH) owns and operates two separate electric generating units known together as Merrimack Station (Station) in Bow, New Hampshire. The Station functions as a base-loaded generating station, providing electricity to 475,000 customers. Merrimack Station withdraws and discharges once-through cooling water from the Merrimack River in compliance with a National Pollutant Discharge Elimination System (NPDES) permit (NPDES Permit NH0001465; Permit), which was last renewed by Region 1 of the United States Environmental Protection Agency (USEPA) on 25 June 1992.

Under §316(a) of the Clean Water Act (CWA), PSNH is entitled to pursue and receive a variance from otherwise applicable state or federal thermal water quality standards or requirements where it demonstrates (based upon information reasonably available) that the proposed alternative limits adequately "assure[s] the protection and propagation of a balanced, indigenous population of shellfish, fish and wildlife in and on the body of water into which the discharge is to be made …" 33 U.S.C. §1326(a); *see also* 40 C.F.R. §125.73. PSNH sought and has received its variance for the Station under §316(a) of the Clean Water Act (CWA), 33 U.S.C. §1326(a), and is now seeking continuation of the §316(a) variance for the Station as part of its renewal of the existing Permit.

This report has been prepared as a supporting document towards this permitting effort. This report characterizes the historic water quality and submerged aquatic vegetation conditions of the upper Merrimack River (defined as the stretch of the river between Franklin and Manchester, New Hampshire), from those records currently available, and compares this information to the more recent data collected by Normandeau Associates, Inc. (Normandeau) as part of long-term monitoring associated with the operation of the Station.

This report summarizes the condition of the upper Merrimack River prior to the commencement of operation of Unit II of the Station in 1968 and highlights the extensive contamination that was present at that time. This contamination significantly altered the river's water quality, especially with respect to nutrients, and had a corresponding impact on resident biota. While there is a notable lack of quantitative traditional water quality data for the pre-1968 period, there is sufficient anecdotal information to characterize the general water quality in the study area. Furthermore, pre-and post-Unit II operation data from 1967 through 1979 and occasional recent data is sufficient to establish historic water quality conditions in the vicinity of the Station and to document the substantially improved condition of the river since that date. Such improvement has likely resulted in corresponding changes to the river's indigenous aquatic populations.

1.2 Study Area

The Merrimack River Basin is located in central New England stretching from the White Mountains in New Hampshire south into northeast Massachusetts. The river originates at the confluence of the Pemigewasset and Winnipesaukee Rivers in Franklin, New Hampshire, flows south through New Hampshire, turns east/northeast shortly after entering Massachusetts and subsequently drains into the Atlantic Ocean at Newburyport, Massachusetts. The entire river basin drains 5,010 square miles, of which 3,800 are in New Hampshire. Major tributaries to the Merrimack River include the Pemigewasset, Contoocook, Souhegan, Nashua and Concord Rivers (USDI 1966).

2.0 Historic Review

To gain insight to the historical perspective of the Merrimack River's overall health, and to allow for a more complete understanding of how the river conditions presented as a "baseline" in the 1960's came about, this section presents a brief review of the use of the river and offers information on the sources of contamination coming from those uses.

2.1 Historical Context

The Merrimack River was the earliest polluted river of the United States (Wolf 1965). The Native Americans described the Merrimack River to the explorer Samuel De Champlain in 1605 as "bright, rapid water, a beautiful rolling river with pebbly bottom," (Meader 1869). A little over 200 years later, the extensive pollution levels were notoriously publicized by famed author Henry David Thoreau in 1839. Historic observations of this contamination give a picture of a river contaminated beyond our current comprehension: sewage so dense that a single drop contains "dangerous" levels of bacteria; coliform bacterial counts exceeding 1 million per 100 ml for several cities; toxic metals and wastes including phenol and cyanide found in the river; suspended solids covering the river bottom and decomposing, causing gas to bubble up "as if the river were cooking"; and a predominant smell of rotten egg from hydrogen sulfide, which can ruin painting on boats and houses (Wolf 1965).

The causes of this contamination are purely anthropomorphic. Accounts such as Meader's *The Merrimack River, its source and its tributaries*, written in 1869 to advertise New Hampshire as a place to relocate, publicized the river as "a vast system of mill privileges with excellent water power and an unfailing source of water. The amount of manufacturing along this stream is not equalled in the world." But the industrialization of the Merrimack River Valley in New Hampshire was detrimental to the river's water quality. Early saw and grist mills dumped byproducts such as sawdust, grain chaff and wood shavings into the river, while textile mills dumped cotton fibers, wool grease, washwater and human wastes. Other inputs of contamination included paper mills, machine building, tool and die manufacturing, wool scouring, silk preparation, dyeing, tanning, shoe manufacturing, paper production and food processing. These early conditions persisted well into the 20th century, with as much as fifteen percent of the unnatural color of the river at Lowell in the 1960's originating from the Franconia Paper Mill in Lincoln (Wolf 1965). In 1954 approximately 185 million gallons of water per day were taken from the Merrimack River for industrial use in Manchester, New Hampshire, and Lowell, Lawrence and Haverhill, in Massachusetts (USDI 1966).

Major landscape and lifestyle changes marked the 20th century, with the Merrimack River Valley transitioning from agricultural to urban-based lifestyle. For the 40-year period from 1880 to 1920, New England's population almost doubled to over 7 million. During the 19th century the population of New England increased 149 percent, to almost 14 million in 2000 (USGS 2003). A the turn of the 20th century, outbreaks of infectious diseases such as typhoid fever were common in urban areas that used polluted rivers for drinking water. As late as the mid-1960's more than 120 million gallons per day (Mgal/day) of untreated or minimally treated wastewater were discharged into the Merrimack River (USGS 2003).

Despite the significant amount of contamination in the river in New Hampshire, most public records focus on the river's condition in Massachusetts, only anecdotally referring to the conditions from New Hampshire as they approach the border between the states. In 1908 a report on the sanitary condition of the river was prepared by the Massachusetts Department of Health, Education and

Welfare (MDHEW) and was noted as the first of its kind. This report noted large quantities of wool scouring wastes, industrial wastes and raw sewage could be found in the river and that it was "considerably polluted at the point where it enters Massachusetts," (Durocher 1964). The Massachusetts Department of Public Health (previously MDHEW) again studied the river and issued a report in 1923-24, and 1928-29. The latter report indicated a marked reduction in wastes due to depressed businesses upstream in New Hampshire, but still noted the river as highly polluted. In 1936 and 1938 the Federal Works Progress Administration published reports on the Nashua and Merrimack Rivers, listing each significant sewerage and industrial discharge and their locations, noting that the river was "considerably polluted in its course through New Hampshire and too polluted for domestic water supply even after treatment when it entered Massachusetts," (Durocher 1964). These reports focused on the lower Merrimack and Nashua Rivers, and the Towns of Lowell, Haverhill, Lawrence, Nashua. Thomas R. Camp Consulting Engineers of Boston delivered report in 1947 noting that untreated sewage from New Hampshire would waste efforts in Massachusetts to clean it up for drinking and recreation (Durocher 1964). The US Department of Health, Education and Welfare (USDHEW) in 1965 determined it to be of federal concern due to interstate pollution and under the provisions of the Federal Water Pollution Control Act of 1948.

2.2 Sources of Contamination

The contamination of the Merrimack River occurred in step with the development of the river's towns and industries which originated during the late 18th and early 19th centuries. The effects of this have lasted well into the 20th century, as noted in the Normandeau water quality report from 1969, "…most of the (water quality) parameters were not dependent to a great deal on water flow…..the concentration of many chemical parameters are varying as the various industrial discharge slugs move down the river".

2.2.1 Wood and Paper Processing

During the late 1800s New Hampshire's farmlands were left behind as the farms of the Midwest began to produce food more abundantly, and the younger generation was able to find successful living conditions working in the towns along the river. Farmland previously tilled was allowed to develop into forests that were then heavily timbered, and those forests that had escaped cultivation also became an opportunity to make money. The country's growing need for lumber allowed rural New Hampshire to continue to survive (Wallace 2007). Among the first of such was the pulp-mill of the Winnipiseogee Paper Company, which was first built in 1868 for the grinding of poplar-wood in Franklin.

Sawmill waste includes sawmill chips, sawdust, wood shavings, sanding dust, and wastewater effluent can contain all these as well as wood preservation chemicals and pesticides leached or washed from the timber and soil. Current regulations require such wastes to be confined to log yards and ponds, but historically, all of these substances washed into the river (IFC 2007).

Waste water discharges for a pulp and paper mill contains solids, nutrients and dissolved organic matter, and unless at low levels these are classed as pollutants. Waste water may also be polluted with organo-chlorine compounds. Some of these are naturally occurring in the wood, but chlorine bleaching of the pulp produces far larger amounts (Environment Canada, 1991).

2.2.2 Wool/Textile/Cotton Fiber Mills

Textile mills use large amounts of water, consequently producing large amounts of wastewater that was channeled directly into the river prior to the enforcement of environmental regulations in the mid-1970's. The Franklin Mills began in 1863 and were located on the Pemigewassett River, just upstream from the confluence forming the Merrimack River mainstem. The A. W. Sulloway Company also milled on the river, producing hosiery, socks and flannel.

Wastes from the wool and textile industry released into the Merrimack River included biodegradable organic materials such as textile fibers, toxic organic compounds such as bleach and dyes, heavy metals, and oil/grease contaminants related to operation of the machinery. Included in this list is the untreated human waste from the hundreds of workers who essentially lived at the mills during typically twelve-hour shifts. As a comparative example, the Massachusetts Department of Health (MDH) reported in 1917 that the Lowell Bleachery discharged millions of gallons of waste "liquors" from washing, bleaching, and dyeing cloth on a daily basis into the Concord River, and U.S. Bunting daily dumped 300,000 gallons of wastewater from scouring wool, washing cloth, and dyeing stock.

Effects of textile effluent on the environment can be toxic with respect to fish, aquatic organisms and plants and bacteria. Suspended solids can clog fish gills, killing them directly or reducing their growth and reproductive rates. These solids can settle and coat the bottom sediments, altering the structure of the riverbed and disrupting the behavior of resident species. They can also reduce the amount of light penetrating the water, reducing the ability of algae to produce food and oxygen. This can also cause significant shifts in species dominance for macrophytes (EPA 1996).

Textile mills are also another input for elevated sulphates and phosphates, along with tanneries and pulp mills. Although not toxic to humans or plants at "normal" concentrations, sulphates are toxic at high concentrations. In addition, sulphates and phosphates have the ability to form strong acids which can disrupt the pH of the river environment (Wood and Bishop 1992).

2.2.3 Septic/Sewage

Human waste is one of the most significant inputs to the water quality of the river. As reported in 1964, no town on the mainstem of the Merrimack River in New Hampshire treated its wastes. (Wolf 1965). The list of towns discharging untreated sewage wastes included Allenstown, Concord, Franklin, Boscawen, Concord, Pembroke, Allenstown, and Hooksett. Additional sources of suspended solids from raw sewage included industries such as the Brezner Tanning Corporation in Boscawen and the Franconia Paper Corporation in Lincoln (USDI 1966).

Population

As the population living within the river basin expanded, particularly during the 1900s, large amounts of untreated septic and/or sewage waste flowed into the river daily. Population for the entire river basin in 1960 was estimated to be 1,072,000, of which 325,000 in New Hampshire. Twelve localities along the river accounted for 53% of the total basin population; those in NH were Manchester, 88, 282, Nashua, 39,096 and Concord, 28,991 (USDI 1966).

Major Tributaries to the Merrimack River and the population data for the largest towns they pass through and are consequently influenced by is listed in Table 1.

Table 1. Population of Larger Towns Located on Major Tributaries to the Upper Merrimack River (largest cities in bold)

Major Tributary	Affecting Towns	1960	1950	1940
Winnipesaukee				
	Laconia	**15,288**	**14,745**	**13,484**
	Belmont	1,953	1,611	1,374
	Tilton	3,266	3,212	1,738
	Northfield	3,027	2,626	1,543
	Meredith	2,434	2,222	2,192
	Gilford	2,043	1,251	996
	Franklin	**6,742**	**6,552**	**6,749**
Pemigewasset				
	Lincoln	1,228	1,415	1,560
	Campton	1,058	1,149	1,130
	Plymouth	**5,454**	**5,146**	**2,533**
	Ashland	2,700	2,814	1,460
	Bristol	1,470	1,586	1,632
Contoocook				
	Hopkinton	2,225	1,831	1,587
	Henniker	1,636	1,675	1,336
Turkey				
	Bow	1,340	1,052	942
	Concord	**28,991**	**27,988**	**27171**
Soucook				
	Loudon	1,194	1,012	920
	Pembroke	3,514	3,094	2,769
Suncook				
	Gilmanton	2,043	1,251	996
	Pittsfield	3,826	3,663	2,183
	Allenstown	3,202	1,540	1,673
	Suncook	2,318	NA	NA

From: NHOEP, online data, accessed November 4, 2011.

According to the U.S. Census Bureau from 1999, approximately 23 percent of the estimated 115 million occupied homes in the United States are served by onsite septic systems, a proportion that has changed little since 1970. At that time, New England states reported the highest proportion of homes served by onsite systems, with New Hampshire reporting approximately 50% of all homes are served by individual wastewater treatment systems (EPA 2000).

In 1947, the New England Interstate Water Pollution Control Commission was created in response to the act of Congress. This interstate agency includes Connecticut, Maine, Massachusetts, New Hampshire, New York, Rhode Island, and Vermont. Also in 1947, the NH legislature passed the state's first water pollution control act requiring towns and cities to protect water quality and created the Water Pollution Commission (NEIWPCC 2011). Few changes resulted, however, until 1974, when in response to the passage of the US Clean Water Act in 1972, the New Hampshire Water Supply and Pollution Control Commission (as it was named then) mandated secondary treatment for all wastewater discharges in the state (NEIWPCC 2011).

Effects

To give a perspective of input based on population data, humans excrete about 250 grams of solid waste per person per day, including 2000 million coliform and 450 million streptococci bacteria per person per day (Cumbler 2001). The average phosphate concentration found in raw sewage of 5.2 mg/L as compared to the average concentration in effluent from biological treatment was 0.5 mg/L. Per capita phosphate contributions from domestic raw sewage range from 3.3 to 7.5 x 10^{-3} per lb/day (Engelbrecht and Morgan 1959).

The input of waste effluent to a river includes intestinal bacteria, some of which (i.e, Salmonella) may be pathogenic. The coliform bacteria content of raw and treated sewage indicates the density of sewage-associated bacteria, including disease-producing pathogens (USDI 1966). However the reduction in oxygen available to the biota of the system is the most important effect in terms of the system as a whole.

Wastewater benefits algal growth through the addition of excess phosphorus to the system where phosphorus is a limiting growth agent. Most temperate freshwaters are believed to be phosphorus-limited, although responses to both nitrogen and phosphorus have been documented (Francoeur 2001). Regardless, it is widely believed that sustained nutrient enrichment and subsequent enhancement of primary producers ultimately enhances secondary and tertiary productivity (deBruyn et al. 2003).

3.0 Historic Water Quality Records

Historic water quality and biological data come from a variety of sources and may reflect changing methods of sample collection and analyses.

3.1 USDI Report 1966

The Secretary of Health, Education and Welfare of Massachusetts called a conference in September 23, 1963 regarding pollution of interstate waters of the Merrimack and Nashua Rivers and their tributaries. A conference was held in February 11, 1964, and as a result, USDHEW established the Merrimack River Project to study the Merrimack River Basin. Although focus was on the evaluation of the adequacy of the pollution abatement measures proposed for the Merrimack River within Massachusetts, development of adequate data on the water quality of the Merrimack River and its tributaries in both states was also prioritized. As a result, in 1966 the US Department of the Interior Federal Water Pollution Control Administration produced a series of reports, including one focused on Physical, Chemical and Bacteriological Stream Studies for the Northeast Region of the Merrimack River (USDI 1966). Although a bulk of this report focuses on areas of the river below the Merrimack River Hydroelectric Project, applicable data from this report, collected in 1964-65, included sampling stations between river mile 115.70, at the confluence of the Pemigewasset and Winnipesaukee rivers, and 73.14 at the Amoskeag Dam in Manchester (Tables 2-4).

The Introduction to this report notes the sources of pollution (to the river) are mainly sewage and industrial waste that contain a variety of “obnoxious components”, including oxygen “demanding” materials which limit fish and aquatic life by removing dissolved oxygen (DO) from the water. Other “greasy substances” in the water form surface scums, settleable solids and sludge deposits, and other suspended materials can make the water turbid, limiting light penetration. Industrial wastes can contain chemical or toxic substances that can kill fish and aquatic organisms or promote slime growth.

The focus of this report for stream quality was on “sanitary water analysis” or temperature, DO, biochemical oxygen demand (BOD), and coliform bacteria. Limited nitrogen and phosphorus and industrial waste sampling was done. The river reaches above Concord (except for Sewalls Falls dam) were not sampled and are considered similar to the Concord reach (USDI 1966).

Because temperature is only significant in this case from a dissolved oxygen saturation standpoint, temperature is not presented in the following data tables. Table 2 presents dissolved oxygen from 1965. It is readily apparent the dissolved oxygen levels were often below 5.0 mg/l during June – September of 1965 throughout the entire East Concord to Manchester reach. Minimum dissolved oxygen values of 2.8 mg/l were measured in September 1965 at Garvins Falls dam, just upstream from the Station. Dissolved oxygen levels below 5.0 mg/l are considered detrimental to most temperate freshwater ecosystems.

Table 3 presents Biochemical Oxygen Demand (BOD) levels for the same time period and sampling stations. High BOD levels measured in the January – April period (uncontaminated waters in this area would be expected to have BOD levels <1.0 mg/l) indicate the relatively high level of organic material present in the river waters. Levels are high during the winter when biological activity is low, but lower during the summer when bacterial activity is high. Lower summer BODs combined with low dissolved oxygen levels during the same time are indicative of significant organic pollution in the river.

Table 2. Dissolved Oxygen (ppm) for the Upper Merrimack River from USDI 1966

Station	Jan-April 1965			Mid-June 1965			July/August 1965			September 1965		
	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg
FC 3.0 Sewalls Falls Dam	8.8	12.7	10.9	NA	NA	NA	NA	NA	NA	NA	NA	NA
FC 3.3 B&M RR Bridge, East Concord	NA	NA	NA	4.4	5.8	5.13	4.2	6.5	5.24	3.6	3.9	3.75
CH 0.0 Route 3 Bridge	NA	NA	NA	4.7	6.0	5.20	4.6	6.2	5.2	NA	NA	NA
CH 1.0 Garvins Falls Dam	8.8	12.6	10.77	3.7	5.2	4.3	3.9	5.6	4.83	2.8	3.7	3.37
CH 2.2 Suncook River	NA	NA	NA	NA	NA	NA	4.5	7.4	5.87	NA	NA	NA
HM 0.2 Hooksett Bridge	10.1	12.5	11.33	4.3	5.3	4.63	4.6	7.6	6.2	NA	NA	NA
HM 1.4 Messer Brook	NA	NA	NA	NA	NA	NA	4.2	7.3	5.77	NA	NA	NA
HM 2.9 Amoskeag Bridge	NA	NA	NA	3.6	5.0	4.23	4.1	7.9	5.89	NA	NA	NA
MN 0.0 Amoskeag Dam	8.6	12.3	10.77	NA	NA	NA	4.8	6.9	5.67	2.4	3.7	2.92
MN 2.0 Goffs Falls Bridge	9.9	12.5	11.23	4.2	5.4	4.71	1.4	5.0	3.73	2.3	3.0	2.55

Table 3. Biological Oxygen Demand (BOD, ppm) for the Upper Merrimack River from USDI 1966

Station	Jan-April 1965			Mid-June 1965			July/August 1965			Sept 1965		
	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg
FC 3.0 Sewalls Falls Dam	1.2	6.9	3.77	NA	NA	NA	NA	NA	NA	NA	NA	NA
FC 3.3 B&M RR Bridge, East Concord	NA	NA	NA	0.9	2.2	1.58	0.9	1.7	1.18	NA	NA	NA
CH 0.0 Route 3 Bridge	NA	NA	NA	1.8	2.3	2.08	0.7	1.8	1.29	NA	NA	NA
CH 1.0 Garvins Falls Dam	2.4	6.8	4.33	1.2	2.2	1.6	1.0	1.8	1.28	NA	NA	NA
CH 2.2 Suncook River	NA	NA	NA	NA	NA	NA	1.1	1.6	1.4	NA	NA	NA
HM 0.2 Hooksett Bridge	2.4	3.6	3.10	1.3	2.2	1.7	1.1	2.3	1.58	NA	NA	NA
HM 1.4 Messer Brook	NA	NA	NA	NA	NA	NA	0.8	2.0	1.28	NA	NA	NA
HM 2.9 Amoskeag Bridge	NA	NA	NA	1.7	2.0	1.83	1.0	2.0	1.31	NA	NA	NA
MN 0.0 Amoskeag Dam	2.0	3.2	2.6	NA	NA	NA	1.1	2.9	2.03	1.3	2.4	1.85
MN 2.0 Goffs Falls Bridge	4.2	6.4	5.4	2.2	5.0	3.49	2.6	4.5	3.65	4.2	4.6	4.4

Table 4. Nitrogen and Phosphate (mg/l) for the Upper Merrimack River from USDI 1966

	September 1965			December 1965		
Station	Ammonia as N	Nitrate as N	Phosphate as PO4	Ammonia as N	Nitrate as N	Phosphate as PO4
FC 3.0 Sewalls Falls Dam	NA	NA	NA	NA	NA	NA
FC 3.3 B&M RR Bridge, East Concord	0.47	0.3	0.09	0.21	0.11	0.02
CH 0.0 Route 3 Bridge	NA	NA	NA	NA	NA	NA
CH 1.0 Garvins Falls Dam	0.57	0.3	0.15	0.16	0.10	0.03
CH 2.2 Suncook River	NA	NA	NA	NA	NA	NA
HM 0.2 Hooksett Bridge	NA	NA	NA	0.21	0.03	0.03
HM 1.4 Messer Brook	NA	NA	NA	NA	NA	NA
HM 2.9 Amoskeag Bridge	NA	NA	NA	NA	NA	NA
MN 0.0 Amoskeag Dam	1.10	0.20	0.20	NA	NA	NA
MN 2.0 Goffs Falls Bridge	1.4	0.3	0.84	0.16	0.06	0.10

Table 5. Total and Fecal Coliform Bacteria (per 100 ml) for the Upper Merrimack River from USDI 1966

	June 1965		July/August 1965		January to April 1965		May 1965		October 1965	
Station	Average Total Coliform	Average Fecal Coliform	Average Total Coliform	Average Fecal Coliform	Average Total Coliform	Average Fecal Coliform	Average Total Coliform	Average Fecal Coliform	Average Total Coliform	Average Fecal Coliform
FC 3.0 Sewalls Falls Dam	NA	NA	NA	NA	1,560	566	1,950	350	7,350	350
FC 3.3 B&M RR Bridge, East Concord	1,750	315	1,730	459	NA	NA	2,950	350	3,600	350
CH 0.0 Route 3 Bridge	9,500	1,300	16,100	2,650	NA	NA	27,500	7,500	24,400	12,550
CH 1.0 Garvins Falls Dam	5,500	870	6,350	1,400	20,000	3,470	43,500	4,500	92,000	12,550
CH 2.2 Suncook River	NA	NA	4,720	652	NA	NA	7,450	600	12,000	4,100
HM 0.2 Hooksett Bridge	2,240	385	2,060	367	8,600	4,900	6,400	1,050	4,800	1,130
HM 1.4 Messer Brook	NA	NA	505	71	NA	NA	10,900	950	3,300	200
HM 2.9 Amoskeag Bridge	1,330	260	2,660	869	6,680	2,900	2,000	500	2,100	377
MN 0.0 Amoskeag Dam	NA	NA	3,960	703	NA	NA	NA	NA	1,025	500
MN 2.0 Goffs Falls Bridge	42,200	6,080	249,000	18,600	103,000	17,700	45,000	15,000	850,000	722,000

Table 4 presents the available nutrient data that was collected during this study. Although not as comprehensive as dissolved oxygen and BOD, September 1965 clearly show substantially elevated ammonia + nitrate levels (approaching and exceeding 1 mg/l, Concord to Manchester) and total phosphorus levels (in excess of 0.1 mg/l and approaching 1 mg/l). Both nutrients indicate high levels of nutrient loading in the river.

Finally, Table 5 presents the total and fecal coliform levels that were present in the river during 1965. Although today's bacteria water quality standards are based on Escherichia coli (E. coli) instead of total and fecal coliform, it would not be unreasonable to conclude that few of the samples presented in Table 5 would be in compliance with E. coli standards. This river was without question heavily contaminated with raw sewage in 1965.

Early New Hampshire Water Use Classification and Quality Standards included Classes A-D for a river based primarily on dissolved oxygen, coliform bacteria, and pH, among other parameters. At the time of the report issuance, New Hampshire had not classified the Merrimack River but was expected to do so by June, 1967 according to the Federal water Pollution Control Act. Had the river been classified at that time, the data from this report would have supported a Class D rating.

3.2 Normandeau 1969

In 1969 The Institute for Research and Services at St. Anselm's College in Manchester, New Hampshire, led by Donald A. Normandeau, produced *The Effects of Thermal Releases on the Ecology of the Merrimack River* (Normandeau 1969). This report extensively cataloged the conditions of the river just upstream and below the Station, including physical parameters (temperature, river bottom sediments), chemical parameters (dissolved oxygen, pH, specific conductance), and biological parameters, including benthic, plankton, periphyton and fish studies. At the time the report was issued it was believed to be the most complete and comprehensive study characterizing such parameters of the Merrimack River in New Hampshire and is considered a "baseline" set of conditions for the purposes of this report in which to compare changing conditions over time (Table 6).

Table 6. Chemical Parameters of the Upper Merrimack River North of Generating Station at N-4, mg/l (Normandeau 1969)

Parameter	June-October 1967*	June- October 1968*
Organic Nitrogen and Ammonia	0.44	0.39
Nitrite	0.028	0.04
Nitrate	1.84	1.66
Total Phosphate	0.44	0.66
Chloride	11.73	11.21
Hardness	13.9	15.1
Calcium	4.9	4.84
BOD	2.28	1.84

*values represent the mean of twice weekly samples

The important information provided by Table 6 is that total nitrogen (organic N, ammonia and nitrate-nitrite) and total phosphorus are both significantly elevated over what would be expected in uncontaminated waters in in northeast rivers. This data provides evidence that the upper Merrimack River was highly enriched in the mid- to late 1960s.

The New Hampshire Water Use Classification for the Merrimack River was not provided in this report. However, similar to the USDI 1966 report, it is anticipated from the data provided that these waters would have been Class D.

3.3 Normandeau Associates, Inc. from 1969 to 1978

In the decade between 1969 and 1979, Normandeau Associates, Inc. (Normandeau) conducted an annual monitoring program for a variety of water quality and biological parameters as part of the condition of the NPDES permit. Data from these reports have been summarized in Table 7.

When compared to Table 2, it is clear that dissolved oxygen levels during 1971 – 1978 were substantially higher than during 1965, 1967 and 1968. During the mid-1960s, dissolved levels averaged in the mid-3 mg/l range during low flow conditions at Garvins Falls dam, while in the 1970s, values did not fall below 6.4 at Monitoring Station N-10. Clearly water quality was improving during the 1970s.

Nutrient concentrations from the mid- to late 1960s contrast sharply with those observed from 1971 through 1978. Nitrite, nitrate, orthophosphate, and total phosphate concentrations decreased by an order of magnitude from 1968 to 1971. Municipal and industrial pollution abatement activity in the upper Merrimack River basin prior to1971 was most likely responsible for this decrease in Hooksett Pond nutrient concentrations (Normandeau 1979). During 1971 to 1978, nutrient concentrations were relatively uniform and always substantially below 1960s levels.

Table 7. Merrimack River Data from Station N-10, Normandeau reports 1972-1979[1]

Date	DO (mg/l)		TPO4 (mg/l)	OPO4 (mg/l)	NO3 (mg/l)	NO2 (mg/l)
	Mean	Range				
1971	9.4	6.4-14.8	0.004	0.006	0.393	0.007
1972	9.9	8.0-13.7	0.037	0.028	0.149	0.007
1973	9.2	6.8-13.3	0.034	0.016	0.174	0.006
1974	9.5	6.7-13.8	0.042	0.022	0.261	0.006
1975	9.8	7.3-13.8	0.069	0.018	0.279	0.007
1976	10.1	7.3-13.4	0.021	0.006	0.126	0.002
1977	9.6	6.7-13.2	0.030	0.012	0.210	0.002
1978	9.3	6.6-13.9	0.019	0.008	0.116	0.005

[1]Data represent the means of weekly or monthly sampling conducted from April through October of each year

The New Hampshire Water Supply and Pollution Control Commission (NHWSPCC) in 1978 classified the Merrimack River from Concord, New Hampshire to the Massachusetts border as "less than C" due to non-attainment from high total coliform bacteria levels and low DO concentrations; water quality standards at that time required DO levels to be greater than 75% saturation and 6.0 mg/l for cold-water habitats, and pH as between 6.0 to 8.5, unless naturally occurring lower levels, to be classified as Class B. In addition, all surface waters within the Merrimack River basin were classified as Effluent Limited (EL), requiring secondary treatment of all wastewater discharges. NHWSPCC established 25 standard turbidity units as maximum acceptable for warm-water fisheries in Class B waters and ten turbidity units for cold-water fisheries. The 1979 Summary Report (Normandeau 1979) reports these standards were being met at that time.

The 1970's data includes 4 years of composition and relative abundances for the east and west ends of 35 transects in the Hooksett Pool, a total of 70 sampling stations (Normandeau 1972, Normandeau

1973, Normandeau 1974, Normandeau 1975; Figure 3-1). Thirty-five permanent transects (N10 through S24, including S0 at the discharge canal point of entry into the river) were sampled for Submerged Aquatic Vegetation (SAV) in June and August of 1971, 1972, 1973 and 1974. Each transect was sampled on the east and west ends for a total of 70 stations. At each station, the species composition and relative densities for each species were recorded. Data included both SAV and emergent deep-marsh species. Only the August data was used in the discussion presented in this report because most SAV are at their greatest biomass and in identifiable condition later in the growing season, and because August is more comparable with the 2002 and 2010 SAV data.

Dominant SAV species included pondweeds (*Potamogeton* species) and waterweed (*Elodea canadensis*, formerly *Anacharis canadensis*). and tapegrass (*Vallisineria americana*). Dominant emergent species included arrowarum (*Sagittaria* species), pickerelweed (*Pontedaria cordata*) and bulrush (*Scirpus* species). The pondweeds and waterweed were ubiquitous through most of the pool. The emergent species were more prevalent in the southern transects. Fifty-three of the 70 stations had vegetation present in 2 or more years, and 17 did not.

Average relative abundance for each station was estimated by qualitatively averaging the 4 years of relative abundance. Average relative abundance was classified as high if 2 or more years of data had one or more species that were very abundant and low if all years had low relative abundance or no SAV. Of the 70 stations, 33 had high relative SAV abundance; 15 had no or low relative abundances; and the remainder (22) had mixed or moderate relative abundances. The transects with high relative abundances were distributed in the northern and southern ends of the pool, as well as on the west shore above Merrimack Station and the east shore below the Suncook River junction. Transects with little or no SAV were clustered primarily in the Narrows and on the west shore of the southern reach.

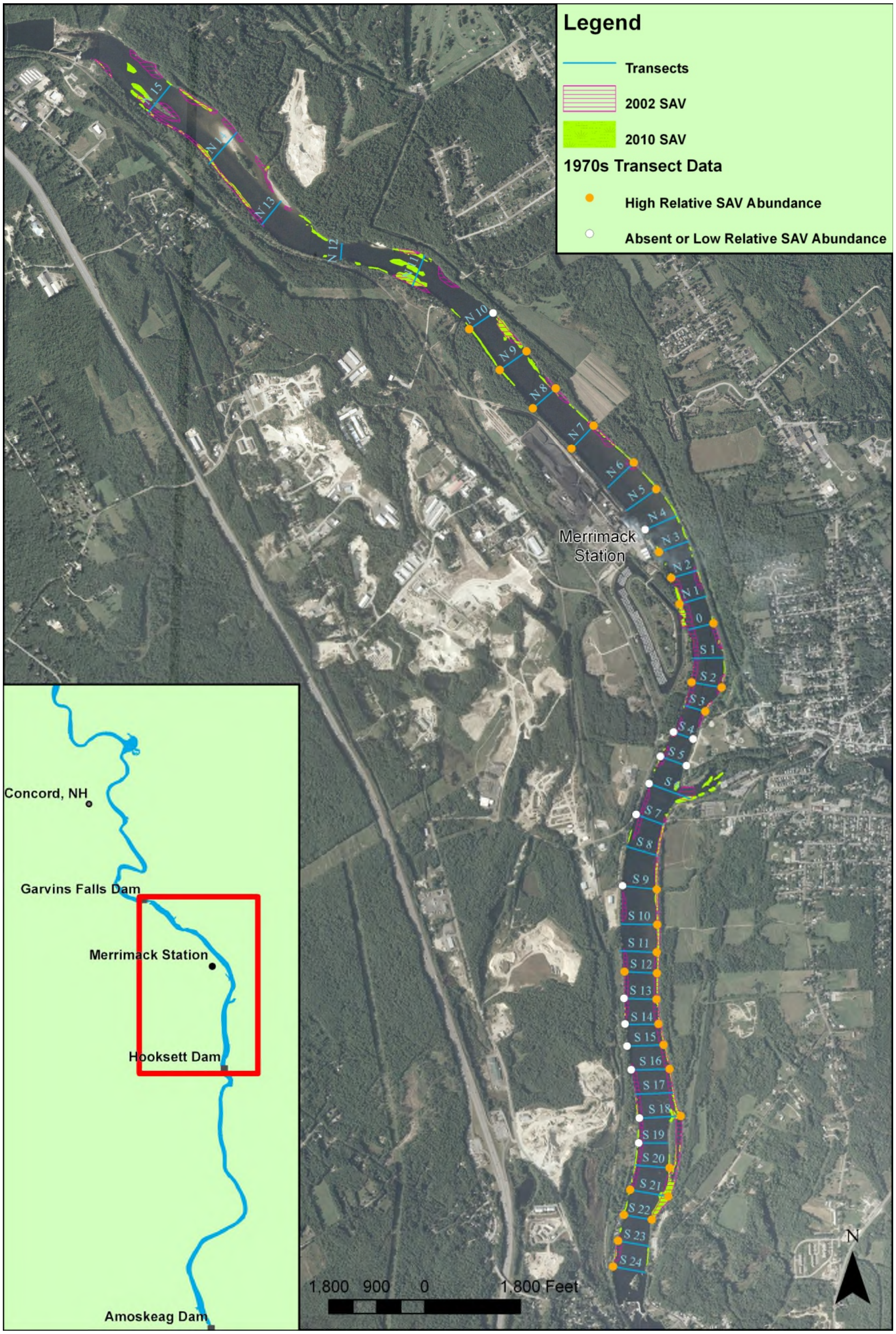

Figure 3-1. SAV locations for 1970s data, 2002 mapping and 2010 mapping in Hooksett Pool (Normandeau)

4.0 Current Water Quality

To examine the health of the river for comparison between the "baseline" in 1969 and current day, water quality data from 2003 and two SAV studies, from 2002 and 2010, have been utilized.

4.1 Merrimack River Watershed Assessment Study, 2003

The Merrimack River Watershed Assessment Study (2003) was a jointly funded effort between federal, state and local communities of Manchester and Nashua, New Hampshire, and Lowell, Lawrence and Haverhill, Massachusetts (ACOE 2004). The Environmental Protection Agency (EPA), New Hampshire Department of Environmental Services (NHDES), and U.S. Geological Survey (USGS) all provided technical assistance to the U.S. Army Corps of Engineers (ACOE) New England District for this study. This study is authorized by Section 729 of Water Resources Development Act (WRDA) of 1986 entitled "Study of Water Resources Needs of River Basins and Regions" as amended by Section 202 of WRDA 2000 and by Section 437 of WRDA 2000 entitled "Merrimack River Basin, Massachusetts and New Hampshire."

This body of data, although primarily focused on a study area below Manchester, included two sampling points above the Station. Because of the thoroughness of the sampling plan, this body of data is useful in comparison of historic and current water quality parameters. Appendices A-H of this report provides a complex picture of the river's health, and are loosely summarized herein for comparison to historic data. Data collection occurred over the summer and fall of 2003 and is summarized in Table 8. Although limited in terms of sampling frequency, these data show that all sampled locations had low levels of bacteria and nutrients, parameters that were substantially elevated during the mid-'60s.

Table 8. Water Quality Data for Upper Merrimack River (ACOE 2004)[1]

Stations	June 30, 2003			August 20, 2003			September 12, 2003		
	C001	C002	M001	C001	C002	M001	C001	C002	M001
DO (ppm)	NA	NA	NA	7.67	NA	NA	NA	NA	NA
E coli (CFU/100ml)	<10	80	70	80	60	80	30	30	20
Fecal Coliform (Col/100ml)	10	120	40	60	300	150	30	20	50
DO (mg/l)	NA	NA	NA	NA	8	NA	NA	7.1	NA
BOD 5 (mg/l)	NA	NA	<2	NA	NA	<2	NA	NA	12
Ammonia as N (mg/l)	NA	NA	<1	NA	NA	<1	NA	NA	<1
Nitrite (mg/l)	NA	NA	NA	NA	NA	<0.2	NA	NA	<0.2
Nitrate as N (mg/l)	NA	NA	0.22	NA	NA	0.089	NA	NA	0.19
Total Phosphorus (mg/l)	NA	NA	0.025	NA	NA	0.05	NA	NA	0.044
TKN (mg/l)	NA	NA	1.1	NA	NA	1.7	NA	NA	<1
Chlorophyll-a (ug/l)	NA	NA	3.4	NA	NA	0.8	NA	NA	1.0

Since 1991, the surface waters of New Hampshire have been classified by the state legislature (RSA 485-A:8) as either Class A or Class B. Class A waters are considered to be of the highest quality and considered optimal for use as water supplies after adequate treatment. Sewage discharges are prohibited in these waterbodies. Class B waters are considered acceptable for fishing, swimming, and other recreational purposes, and for use as water supplies after adequate treatment has been applied. Prior to 1991, some waterbodies were in a Class C category and were considered usable only for non-contact recreational purposes such as fishing and boating, and for some industrial purposes. All Class C waterbodies were legislatively upgraded to Class B in 1991; thus, since that date the Merrimack River has been classified as Class B waters.

4.2 SAV Studies 2002 and 2010

Semi-quantitative SAV data were collected in Hooksett Pool by Normandeau in 2002 and 2010 (Normandeau 2003, Normandeau 2011; Figure 3-1). Because the data collection methods varied from that done in the 1970's, they are detailed below:

In-river mapping was performed in 2002 using a boat-based GPS system to delineate the limits of aquatic beds in the Hooksett Pool as well as the Garvin Falls and Amoskeag pools. The mapping was performed on September 24 and 25, and October 1, 2002, and resulted in a series of 8 maps, of which Hooksett Pool was depicted on Sheets 3-5 (Normandeau 2003). No published data set accompanied the maps. The text included qualitative descriptions of the dominant species in each pool, and a relative density of SAV within each pool. Using National Wetland Inventory maps, the terrestrial wetlands within ¼ mile of the river were also shown.

In 2010 SAV mapping was performed in the course of side-scan sonar surveys to document aquatic habitat cover types in the Hooksett Pool between September 16 and October 25 (Normandeau 2011). Sonar data was collected using a Humminbird™ 1197c side imaging unit in conjunction with a Trimble GeoXT™ dGPS to provide the precise coordinate information necessary for geo-referencing captured images. Sonar classifications of all habitat types, including SAV, were verified while in the field. Verification consisted of visual assessment within shallow water habitats and/or clear water conditions as well as pole and ponar grab samples for deeper water areas. The verification qualitatively indicated that SAV beds that were low-growing, low density or flattened by the current were underestimated.

The aquatic beds in 2002 comprised 49.9 acres, or 11.7% of the total habitat of the pool, based on the total of 423.5 acres of habitat mapped within Hooksett Pool during the 2010 survey. The 2002 report describes all beds as "moderate to low densities". SAV species were generally described for Hooksett Pool as including Nuttall's waterweed (*Elodea nutallii*), tapegrass, two pondweeds (*Potamogeton epihydrus* and *P. spirillus*), and coontail (*Ceratophyllum demersum*).

In 2010, 21.3 acres were SAV, or 5.0% of the total 423.5 acres of habitat. The majority (17.2 acres; 80.8 %) of the SAV was observed to occur over portions of Hooksett Pool characterized by the sand/silt/clay habitat type, which comprised 90.2% of the substrates of the pool.

5.0 Results and Analysis/Discussion

The goal of this report was to examine the water quality and biological data, where available, and determine what changes, if any, had occurred from the mid-1960s to present. Towards this goal, available data has been summarized and presented in the tables above to track some of the defining water quality parameters that influence biological characteristics of rivers. Table 9 provides a summary of all data that was collected, averaged across time to facilitate comparison of changing water quality conditions during the period of investigation.

5.1 Dissolved Oxygen (DO) and Biological Oxygen Demand (BOD)

DO values have steadily increased from 1965 to the present, reflecting a number of changes in the river: the increased in number of wastewater treatment plants higher in the watershed, the passage of the US Clean Water Act in 1972 which required not only increased wastewater treatment facilities for towns but also a reduction in industrial use of the river for release of raw effluent. In 1974, in response to the passage of the US Clean Water Act in 1972, the New Hampshire Water Supply and Pollution Control Commission (as it was named then) mandated secondary treatment for all wastewater discharges in the state (NEIWPCC 2011). At that time there were no secondary treatment facilities in the watershed and all towns discharged minimally or un-treated effluent into the river.

Table 9 shows DO increasing over time. The value from 2003 is an average of three summer data points, as opposed to the data from 1972-78 which average over a longer season and include winter values, when DO is higher, which raises the average. Comparison of the summer DO level from 2003, 7.59 mg/l, to the summer DO levels from 1965 of 5.38 and 3.15 mg/l for July-August and September, respectively, shows a substantial increase in DO over the 38 year period.

The 1969 Normandeau report states that heavily polluted rivers, such as the Merrimack, generally have an abundance of dissolved substances that impose oxygen demand (BOD) resulting from biodegradation of organic wastes by microbiota. Daily fluctuations of DO of as much as 50% can occur due to variations in temperature and flows. Daytime DO may be above 5 and as high as 10 ppm, but may fall as low as 1 ppm at night. Normal DO for 1967 was 6-8.5 ppm while in 1968 it ranged from 4.8 ppm (in September, low flow conditions) to 10.5 ppm in June. Even though average daily DO was generally greater than 5 ppm during 1967 and 1968, instantaneous values were at times considerably less and in fact fell to 3.4 and 1.0 ppm during the early morning hours on September 8 and 22, 1968, respectively. Large diurnal changes in DO levels are indicative of a nutrient enriched systems and resulting enhanced primary productivity.

As noted in Table 7, average DO values from 1971 to 1978 ranged between 9.2 and 9.8 with an average of 9.5 ppm. Minimum DO values during this timeframe did not fall below the low 6s. These higher values are indicative of improved water quality conditions that are expected to be associated with the implementation upriver wastewater treatment improvements.

Table 9. Summary of Water Quality Characteristics, 1965-2003, Upper Merrimack River

	DO (ppm)	BOD (ppm)	Ammonia as N (mg/l)	Nitrite as N (mg/l)	Nitrate as N (mg/l)	TOP/PO4 (mg/l)	Fecal coliform (per 100 ml)	Total coliform (per 100 ml)
1965	Winter: Low, high, average- 10.77, 11.33, 11.0 Mid-June: Low, high, average- 4.23, 5.2, 4.7 Summer: Low, high, average- 3.73, 6.2, 5.38 September: Low, high, average- 2.55, 3.75, 3.15	Winter: Low, high, average- 2.6, 5.4, 3.8 Mid-June: Low, high, average- 1.58, 3.49, 2.05 Summer: Low, high, average- 1.18, 3.65, 1.67 September: Low, high, average- 1.85, 4.4, 3.13	September: Low, high, average- 0.47, 1.1, 0.89 December: Low, high, average- 0.16, 0.21, 0.19		September: Low, high, average- 0.2, 0.3, 0.28 December: Low, high, average- 0.03, 0.11, 0.08	September: Low, high, average- 0.09, 0.84, 0.32 December: Low, high, average- 0.02, 0.10, 0.05	Summer: Low, high, average- 71, 18,600, 2,332 Winter/Spring: Low, high, average- 350, 15,000, 4,310 October: Low, high, average- 200, 722,000, 75,410	Summer: Low, high, average- 505, 249,000, 23,307 Winter/Spring: Low, high, average- 1560, 103,000, 20,535 October: Low, high, average- 1,025, 850,000, 100,058
June-October 1967		2.28	0.44	0.028	1.84	0.44		
June-October 1968		1.84	0.39	0.04	1.66	0.66		
1971	9.4			0.007	0.393	0.004		
1972	9.8			0.007	0.149	0.037		
1973	9.2			0.006	0.174	0.034		
1974	9.5			0.006	0.261	0.042		
1975	9.7			0.007	0.279	0.069		
1976	9.5			0.002	0.126	0.021		
1977	NA			0.002	0.210	0.030		
1978	9.5			0.005	0.116	0.019		
2003	Summer: 7.59	Low: <2 High: 12	<1	<0.2	0.170	0.040	Low: 10 High: 300 Average: 86.7	

5.2 Eutrophication in Rivers

Eutrophication results from nutrients such as nitrates and phosphates which results in enhanced primary production. Resulting phytoplankton blooms can contribute large diurnal changes in dissolve oxygen levels from supersaturated conditions during the late afternoon timeframe to values approaching zero during the pre-dawn hours. Eutrophication favors growth of plants such as algae and plankton over complex plants (Carpenter, Caraco and Smith, 1998), and algal blooms limit sunlight available to bottom dwellers and plants. Eutrophication can decrease biodiversity and change species composition and dominance. It can increase growth of gelatinous zooplankton, decrease epiphytic algae and benthic algae, and change macrophyte biomass and composition (Smith, Tilman and Nekola 1999). Total nitrogen and phosphorus values, indicators of trophic state, have all significantly decreased over time in the upper Merrimack River as shown in Table 9, reflecting the decreases in untreated domestic and industrial wastes released into the river and mirroring other Northeastern rivers according to a study done by USGS in 2003. Figure 5-1 presents the mid-1960s to late 1970s trend of nutrients in the Merrimack River and especially depicts the dramatic decrease that occurred in nitrogen and phosphorus levels between 1970 and 1971. The nitrate level from 2003 for the Merrimack River of 0.17 mg/l is well below these values.

Phosphorus in the Upper Merrimack River reached a high of 0.66 mg/l in 1968, and has declined since then. Values from 1972 to 2003 have varied from a low of 0.019 mg/l in 1978 to a high of 0.069 mg/l in 1975, with no significant increase or decrease. In 2003 the reported phosphorous level (0.04 mg/l) remained in the range of values reported during the 1970s.

Today, nutrient levels in the upper Merrimack River are an order of magnitude less than levels measured in the 1960s. Even so, concentrations are still elevated over what would be expected for rivers unimpacted by wastewater discharge.

5.3 Biological Parameters

5.3.1 Bacteria

Fecal coliform bacteria decreased significantly since 1965. As noted in Tables 5 and 9, fecal coliform bacteria averaged 41,026 units per 100 ml in 1965 (averaged across stations and months) while in 2003 the average was approximately 300 units per 100 ml. The averages from 1965 reported in Table 9 are slightly higher than expected due to the inclusion of sampling below Manchester in the averages; this sampling station consistently reported bacterial counts an order of magnitude higher than those above it, reflecting the influence of Manchester wastes (Table 5). The marked decrease in bacteria in the upper Merrimack River reflects the effects of continuing improvement in wastewater treatment.

5.3.2 Macroinvertebrates

From USDI 1966, benthic organisms were "totally absent" in the lower 57 miles of the river; less than 15 miles of the total 115 miles of the Merrimack River that was studied contained benthic organisms.

The Normandeau report (1969) includes data on biological parameters, including benthic, plankton, periphyton and fish studies. Of note, large variations in mussel density were found, with the section of the river south of the Station discharge canal more productive than to the north. Additional benthic studies showed variety in macrofauna at all stations. This area of the Merrimack River was

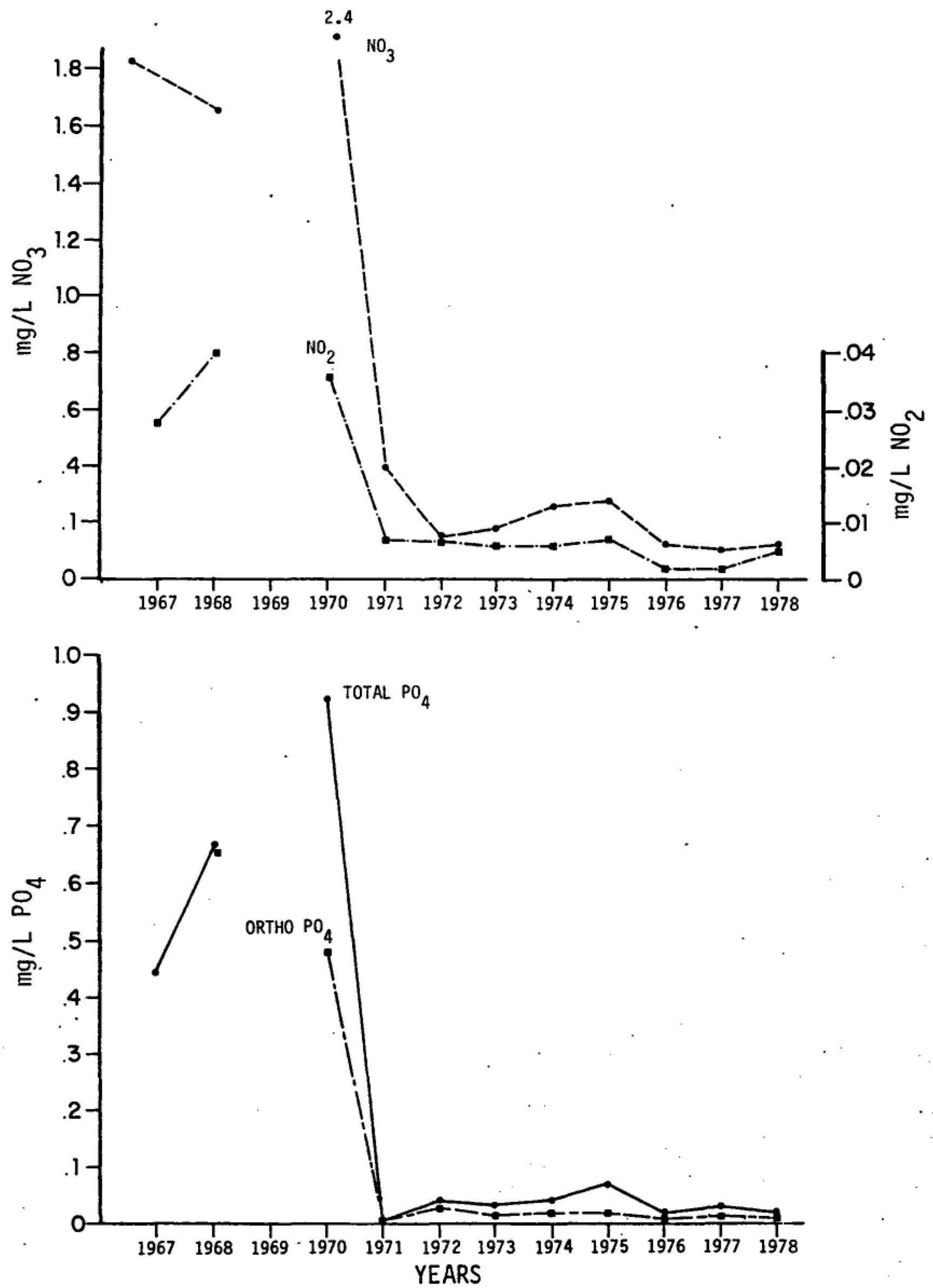

Figure 5-1. Seasonal Mean Nutrient Concentrations in Hooksett Pond - 1967-1978 (Merrimack River Summary Report, Normandeau 1979)

characterized as being in a stage of moderate recovery from past pollution. River plankton identified in Normandeau 1969 was described as being transient and having considerable fluctuation in species composition and numbers between river sections; such observations were affected by parameters such as flow, temperature, availability of dissolved nutrients, and BOD. Much of the plankton is believed to have come from lakes and ponds which empty into the Merrimack River. Changes in water quality are reflected in plankton. (Normandeau 1969)

In contrast to USDI 1966, sampling conducted by the Upper Merrimack River Local Advisory Committee, Merrimack River Watershed Council and NH Department of Environmental Services was published in "The State of the Upper Merrimack River 1995-1997". As noted in this 2000 UMRLAC report, representatives of sensitive taxa were found to be present at all eleven sites that were sampled between Franklin and Bow. Although sensitive species declined downstream of Concord, the report indicated that the cause for the decline was probably due to a reduction in habitat suitability (sites are all impounded to a certain extent) rather water quality. Field chemistry parameters supported this statement and fell within acceptable ranges established for NH surface waters. Clearly, significant changes in aquatic biota have occurred in the upper Merrimack River since the mid-1960s.

5.3.3 Submerged Aquatic Vegetation (SAV)

Looking at presence-absence only, a decline in overall extent of SAV in Hooksett pool is implied between the 1970's data and the 2002 and 2010 data. In the 1970's, 53 of the 70 stations (76%) had vegetation present in 2 or more years, and 17 did not. In 2002, 42 (60%) stations occurred within mapped beds, and 28 did not. In 2010, 35 (50%) stations fell within mapped beds and 35 did not, however this data set is known to underrepresent the low density and low-growth form SAV beds.

The qualitative statement referring to the 2002 beds as having low to moderate density also implies a decline in SAV, compared to the multiple stations with very high abundances of SAV in the 1970s data. This comparison is qualitative only, due to the differences in sampling techniques and available data.

The distribution of the SAV in Hooksett Pool appears driven primarily by microsite conditions of substrate, current and exposure, as evidenced by the relatively even distribution of SAV above and below the discharge canal. The 2010 habitat data found that 80% of the SAV occurred in sand/silt/clay substrates. Beds were most prevalent in the north and south ends of the pool, where the river is wider and currents are presumably less. Beds were also more extensive in protected coves or the lee of islands such as below Garvin Falls, the discharge canal, and the junction with the Suncook River. Where current velocities are highest, such as the Narrows and the outer bends in the river, SAV is either absent or confined to narrow linear beds along the shore.

While the 1970s data indicate an absence in SAV at the discharge canal outlet in 1972-74, this is most likely disturbance-related from the 1972 canal dredging. In 1971, an aquatic spike rush (*Eleocharis* sp) was considered very abundant on the west side of Station 0 at the discharge outlet. No SAV were recorded in 1972, the year of the dredging, and the two subsequent years. Large SAV beds were mapped in this location in the 2002 and 2010 sampling efforts indicating the area has recovered, although species composition is not known. Immediately downstream of the discharge canal, the SAV on both sides of the river remain similar in species composition and densities to other stations in Hooksett Pool.

6.0 Summary and Conclusion

The Merrimack River was substantially polluted due to anthropomorphic input since the early 1800's. The diversity and abundance of those organisms living in and on the river reflected this polluted state. Over the past 200 years, the changing socio-economic structure of the people living within the watershed resulted in the decline of those historic industries that used the river for disposing of wastes such as wool, fiber, wood and paper processing. At the same time, awareness was growing regarding the impaired state of our nation's water resources and protective enforcement measures developed both at the federal and state levels, including New Hampshire's first water pollution control act in 1947 requiring towns and cities to protect water quality, and in 1974 when New Hampshire mandated secondary treatment for all wastewater discharges in the state (NEIWPCC 2011) as a result of the passage of the US Clean Water Act in 1972.

The Merrimack River has been in a continuing state of recovery probably since the decline in its river-based manufacturing, but according to available data, certainly since the early 1970's. Water quality and biological conditions along the Upper Merrimack, above the Station, have improved considerably in the last 40 years and are expected to continue to do so as stricter wastewater treatment requirement, such as additional nutrient control, continue to be implemented.

As discussed in this report, the indicators of improved water quality are:

- Increased Dissolved Oxygen (DO) levels across all seasons, but especially during periods of high temperature/low flow. Occurrence of DO levels less than 5 mg/l have been essentially eliminated from the upper Merrimack River;
- Decreased Biochemical Oxygen Demand (BOD) reflective of decreases in dissolved and suspended organic matter in the river;
- Reductions in eutrophication caused by very high levels of nitrogen and phosphorus;
- Reductions in total and fecal coliform and E. coli concentrations, indicative of improved treatment levels at wastewater treatment facilities within the watershed;
- Increased diversity and abundance of macroinvertebrate, indicative of the absence of concentrated sources of pollution;
- Continued presence, albeit variable in location and density, of SAV beds required for fish habitat; and,
- Improved overall quality as evidenced by the change in classification from the equivalent of Class D to Class B.

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