Total Phosphorus TMDL for Chickasheen Brook, Barber Pond, and Yawgoo Pond, Rhode Island

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LIST OF ACRONYMS AND TERMS

BMP = Best management practice, the schedule of activities, prohibitions of practices, maintenance procedures, and other management practices to prevent or reduce the pollution of and impacts upon waters of the State. BMPs also include treatment requirements, operating procedures, and practices to control runoff, spillage or leaks, sludge or waste disposal, or drainage from raw material storage.

Clean Water Act = the Federal Water Pollution Act (33 U.S.C. § 1251) et seq. and all amendments thereto.

Designated uses = those uses specified in water quality standards for each water body, whether or not they are being attained. In no case shall assimilation or transport of pollutants be considered a designated use.

EPA = the United States Environmental Protection Agency.

Fecal coliform = bacteria found in the intestinal tracts of warm-blooded animals. Their presence in water or sludge is an indicator of pollution and possible contamination by pathogens, which are disease causing organisms.

LA = Load allocation, the portion of a receiving water's loading capacity that is allocated either to nonpoint sources of pollution or to natural background sources.

Loading capacity = means the maximum pollutant loading that a surface water can receive without violating water quality standards.

MOS = Margin of safety. Because bacteria levels are variable, it is possible that the specified reductions may not be adequate to allow water quality to meet standards. To account for this uncertainty, an additional reduction in bacteria levels beyond the required numeric bacteria concentration is specified. This can be achieved by using conservative assumptions, an explicitly allocated reduction, such as a level 10% below the standard, or a combination of both techniques.

Natural Background = all prevailing dynamic environmental conditions in a waterbody or segment, other than those human-made or human-induced. Natural background bacteria concentrations include contributions from wildlife and/or waterfowl. However contribution from animals and waterfowl that exist in an area because of human activities (e.g. feeding of birds) are not considered as part of the natural background.

Nonpoint source = any discharge of pollutants that does not meet the definition of point source in section 502.(14) of the Clean Water Act. Such sources are diffuse, and often associated with land use practices that carry pollutants to the waters of the state. They include but are not limited to, non-channelized land runoff, drainage, or snowmelt; atmospheric deposition; precipitation; and seepage.

Point source = any discernible, confined, and discrete conveyance, including but not limited to any pipe, ditch, channel, tunnel, conduit, well, discrete fissure, container, rolling stock, concentrated animal feeding operation or vessel, or other floating craft, from which pollutants are or may be discharged. This term does not include return flows from irrigated agriculture.

DEM = Rhode Island Department of Environmental Management

Runoff = water that drains from an area as surface flow.

RPD = Relative percent difference, expressed as the difference between observed and predicted values of a variable, divided by the observed value.

TMDL = Total maximum daily load, the amount of a pollutant that may be discharged into a waterbody without violating water quality standards. The TMDL is the sum of wasteload allocations for point sources, load allocations for nonpoint sources, and natural background. Also included is a margin of safety.

μg/L = a concentration unit of micrograms (one-millionth of a gram) pollutant (e.g. total phosphorus) per liter solution. One μg/L is equal to one-thousandth of a milligram per liter (mg/l). Hence, the total phosphorus standard of 0.025 mg/l = 25 μg/L.

Water quality standard = provisions of state or federal law which consist of designated use and water quality criteria for the waters of the state. Water quality standards also consist of an antidegradation policy. Rhode Island’s water quality regulations may be found at www.state.ri.us/dem/pubs/regs/index.htm#WR.

WLA = Waste load allocation, the portion of a receiving water’s loading capacity that is allocated to point sources of pollution.

ABSTRACT

Chickasheen Brook (waterbody ID number RI0008039), Yawgoo Pond (waterbody ID number RI0008039L-15-03) and Barber Pond (waterbody ID number RI0008039L-14) are located in the southern portion of the State of Rhode Island within the Towns of Exeter and South Kingstown (Figure 1.1). The surrounding watershed is not sewered and approximately 48 percent of the watershed is forested. Other land use consists of approximately 11 percent as low to medium density residential development (1/4- to 2-acre lots), 11 percent as agriculture, and a small amount (3 percent) as industrial/commercial use.

Chickasheen Brook from its headwaters to Yawgoo Pond is designated by the Rhode Island Department of Environmental Management (DEM) as a class A waterbody, suitable as a source of public drinking water supply, for primary and secondary contact recreational activities, and for fish and wildlife habitat. It is suitable for compatible industrial processes and cooling, hydropower, aquacultural uses, navigation, and irrigation and other agricultural uses and has good aesthetic value. The remainder of Chickasheen Brook, Yawgoo Pond, and Barber Pond are designated by DEM as Class B water bodies, suitable for primary and secondary recreation and fish and wildlife habitat.

The goals of this TMDL are to assess total phosphorus, chlorophyll-a, and dissolved oxygen concentrations within these water bodies, to identify and assess sources of the impairment, and to recommend mitigation measures to restore all designated uses.

At the points where it enters Yawgoo and Barber Ponds, Chickasheen Brook consistently exceeds the State's total phosphorus criterion of 0.025 mg/l (25 ug/l) and has excess algal growth. Yawgoo Pond consistently fails Class B standards for dissolved oxygen (instantaneous minimum dissolved oxygen content not less than 5.0 mg/l), total phosphorus (0.025 mg/l), and also has excess algal growth. Barber Pond also fails to meet the dissolved oxygen standard. As a result, these water bodies are listed in Group 2 on Rhode Island's 303(d) List of Impaired Waters.

The headwaters of Chickasheen Brook are located in a wetland (known locally as Maple Swamp) east of Route 2 and north of Yawgoo Valley Road in Exeter, Rhode Island. The brook flows approximately 1.6 miles from its headwaters to Yawgoo Pond and is conveyed through a culvert in a westerly direction under Route 2, flowing southwesterly through Arrow Swamp, passing through a culvert at Miskiania Trail, and proceeding southerly to Yawgoo Pond. Yawgoo Pond is approximately 143.4 acres, its deepest portion, 36 feet deep, is located in the center of the pond. The Chickasheen Brook outflow is located at the southeast section of the pond, where it flows southeasterly through a wetland for approximately 1,200 feet to its confluence with Mud Brook and another 400 feet where it flows diffusely into Barber Pond. Barber Pond is approximately 28.5 acres and the deepest portion is located northeast of the center of the pond, approximately 18 feet deep. Chickasheen Brook then exits the southeastern corner of Barber Pond.

The current phosphorus load in Chickasheen Brook at the point where it enters Yawgoo Pond was estimated to be 425 kg/yr. The allowable load in Chickasheen Brook where it discharges to the pond is 57 kg/yr. The current phosphorus load to Yawgoo Pond is 446 kg/yr; the allowable load is 78 kg/yr. The required load reductions for Chickasheen Brook (at Miskiania Trail) and Yawgoo Pond are therefore 368 kg/yr. Chickasheen Book continues out of Yawgoo Pond, flowing through a wetland area before discharging into Barber Pond. The brook contributes an estimated 96 kg of the 134 kg annual total phosphorus load to Barber Pond. The allowable load in the brook at the point of entry to the pond is 44 kg/yr, so a 54% load reduction is needed for Chickasheen Brook at its point of discharge to Barber Pond to meet the total phosphorus load target for the pond. The load reductions for Chickasheen Brook at the entry to Barber Pond and for Barber Pond are 52 kg/yr and 64 kg/yr, respectively. Identified or potential sources to the brook and ponds include the release of a phosphorus burden from wetland sediments, individual sewage disposal systems (ISDSs), storm runoff from adjacent roads, releases from historic land uses including two former shellfish operations, and wildlife.

The target total phosphorus concentration target for Chickasheen Brook is 22.5 ug/l at Miskiania Trail and 11.4 ug/l at the point of entry to Barber Pond. The target annual mean total phosphorus concentrations in Yawgoo and Barber Ponds are 11.4 ug/l and 10.6 ug/l, respectively. These targets are expected to produce lower loadings and concentrations than those seen during 1994 to 1997 when the condition of both ponds was significantly better.

Historically, water quality degradation in Yawgoo Pond prompted the closure of upstream shellfish operations in 1990. Following the closures, water quality within Yawgoo Pond improved dramatically, returning to meso- to oligotrophic conditions. This recovery was short-lived, however, when in 1998 a dramatic increase in total phosphorus concentrations entering Yawgoo Pond from Chickasheen Brook caused excess algal blooms and a shift to cyanobacteria (blue-green algae) in the pond. The water quality impacts of this increase extended downstream to include Barber Pond. Based on windshield surveys conducted by the University of Rhode Island Watershed Watch (URIWW) Program, the most significant land use change observed within the upper watershed was the inundation of Arrow Swamp due to beaver activity.

The Arrow Swamp impoundment was eliminated by December 2001, however an impoundment was established downstream. Total phosphorus levels in Chickasheen Brook remained near their previous high values during 2002. It is apparent, however, that the impoundments are related to the increased release of previously bound phosphorus from the sediments of the swamp. DEM recommends that a strategy be developed to control phosphorus and algae blooms in Yawgoo and Barber Ponds by a consultant having expertise and experience in addressing similar situations. Possible management options include continued prevention of impoundments, controlled breaching, collection of duckweed, aeration, and alum application.

Recent (2002) groundwater data at the former Harbor Shellfish Inc. (HSI) site and surface water data collected in Chickasheen Brook upstream of Route 2 indicate that other phosphorus sources exist in the watershed. DEM recommends that monitoring of these historical sources be continued. The former HSI site apparently still contributes elevated phosphorus load to Arrow Swamp. The existence and potential role of sludge deposits in the former lagoons at this location should be evaluated. Because phosphorus concentrations in the brook at the station upstream of Route 2 are elevated above background, DEM recommends continued monitoring in this area.

The TMDL requires that Storm Water Management Program Plans (SWMPPs) be submitted by the Towns of Exeter and South Kingstown, and the Department of Transportation (DOT) for areas in the Chickasheen Brook and Barber Pond watersheds that are regulated by the Phase II Stormwater Program (Phase II). The SWMPPs must contain plans for implementation of the six minimum measurements required under Phase II. The installation of catch basins or another suitable BMP to treat runoff and stabilize soils in the area of the public boat launch adjacent to Route 2 near the Barber Pond outlet is also specified to prevent the overland conveyance of phosphorus in sheet flow entering Barber Pond and further sedimentation along that area of its shoreline.

This TMDL relies upon phased implementation to reach water quality goals. As remedial measures are implemented, the corresponding response in total phosphorus, dissolved oxygen, and algae (chlorophyll-a) concentrations will be measured. The water quality concentration targets are considered estimated levels that result in the attainment of designated uses. This TMDL will be considered implemented when the conditions necessary to support each water body's designated uses, as naturally occurs, are attained. More specifically, these conditions are algal abundance equivalent to a chlorophyll-a level less than 9 ug/l, a shift from blue-green algae as the dominant species, elimination of noxious plant accumulations in Chickasheen Brook, and return of dissolved oxygen conditions in the ponds to those seen in the 1950's. As appropriate, additional measures may be required if the designated uses are not met following implementation of the recommended remedial measures.

1.0 INTRODUCTION

Section 303(d) of the Clean Water Act and EPA's Water Quality Planning and Management Regulations (40 CFR Part 130) requires states to develop Total Maximum Daily Loads (TMDLs) for water bodies that are not meeting water quality standards. The objective of a TMDL is to establish water-quality-based limits for pollutant loadings that allow the impaired waterbody to meet standards. This TMDL addresses water quality impairments associated with excessive phosphorus loadings to water bodies in the headwaters of Chickasheen Brook, a sub-watershed of the Pawcatuck River watershed in southern Rhode Island.

1.1 Study Area

The study area includes Yawgoo Pond in Exeter and South Kingstown, RI, Barber Pond, in South Kingstown, and the reaches of Chickasheen Brook that drain to and connect the ponds. The upper Chickasheen Brook watershed showing the water bodies and their sub-watersheds is presented in Figure 1.1.

1.2 Pollutant of Concern

Water quality monitoring conducted by DEM and the University of Rhode Island Watershed Watch Program (URIWW) indicates that Chickasheen Brook is impaired for total phosphorus and noxious aquatic plants. Yawgoo Pond is impaired for total phosphorus, excess algal growth/chlorophyll-a, and hypoxia (low dissolved oxygen concentration). Barber Pond is impaired for hypoxia.

1.3 Priority Ranking

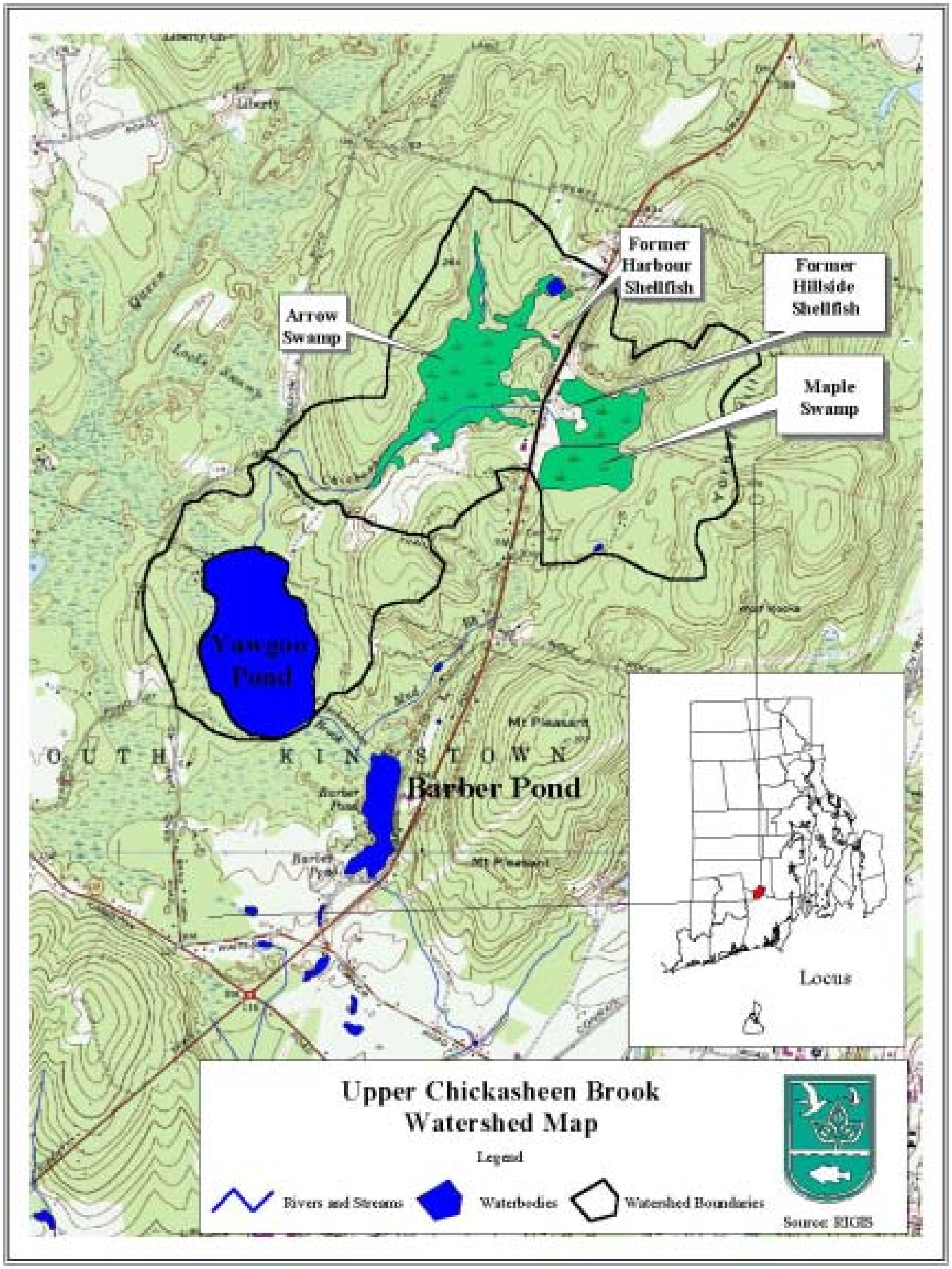
Yawgoo and Barber ponds are listed as Group 2 water bodies in the DEM 2002 303(d) List of Impaired Waters. Group 2 waters are those not meeting water quality standards, with TMDL development planned for the future. Chickasheen Brook was not listed in the DEM 2000 303(d) List of Impaired Waters, however, based on URIWW data, it is listed for total phosphorus in DEM’s 2002 303(d) List from its headwaters to the outflow of Barber Pond.

1.4 Applicable Water Quality Standards

Designated Uses

Chickasheen Brook is designated as a Class A waterbody from its headwaters to Yawgoo Pond. Class A water bodies are designated as sources of public drinking water supply, for primary and secondary contact recreational activities, and for fish and wildlife habitat and should have good aesthetic value. Chickasheen Brook from, and including Yawgoo and Barber Ponds, to its confluence with the Usquepaug River is designated as a Class B waterbody by the State of Rhode Island. Class B waters are designated for fish and wildlife habitat, primary and secondary contact recreation and shall be compatible for industrial processes and cooling, hydropower, aquacultural uses, navigation, and irrigation and other agricultural uses. Class B waters should have good aesthetic value.

Figure 1.1: Upper Chickasheen Brook Watershed, South Kingston and Exeter, Rhode Island.



Water Quality Criteria
The following criteria for nutrients, which include Total phosphorus and nitrogen, excerpted from Table 1 of DEM's Water Quality Regulations (DEM, 1997), apply to Chickasheen Brook, Yawgoo Pond, and Barber Pond:

> *10(a). Average Total phosphorus shall not exceed 0.025 mg/l in any lake, pond, kettlehole, or reservoir, and average Total P in tributaries at the point where they enter such bodies of water shall not cause exceedance of this phosphorus criteria, except as naturally occurs, unless the Director determines, on a site-specific basis, that a different value for phosphorus is necessary to prevent cultural eutrophication.*
>
> *10(b). None* [nutrients] *in such concentration that would impair any usages specifically assigned to said Class, or cause undesirable or nuisance aquatic species associated with cultural eutrophication, nor cause exceedance of the criterion of 10(a) above in a downstream lake, pond, or reservoir. New discharges of wastes containing phosphates will not be permitted into or immediately upstream of lakes or ponds. Phosphates shall be removed from existing discharges to the extent that such removal is or may become technically and reasonably feasible.*

Rule 10(b) states that nutrient concentrations in a waterbody (and hence loadings to the water body) shall not cause undesirable aquatic species (e.g. chlorophyll-a) associated with cultural vegetation. This narrative standard is designed to prevent the occurrence of excessive plant growth, whether as duckweed as is the case in Chickasheen Brook, or algal growth as is the case in Yawgoo Pond. The Department will follow guidelines set by the Nurnberg (1996) Trophic State Index to establish a limit for algal concentrations in Yawgoo Pond.

Barber and Yawgoo Ponds are considered to be warm water fish habitat (Alan Libby (Division of Fish and Wildlife), personal communication). The following standards apply for dissolved oxygen:

> *Warm Water Fish Habitat - Dissolved oxygen content of not less than 60% saturation, based on a daily average, and an instantaneous minimum dissolved oxygen concentration of at least 5.0 mg/l. The 7 day mean water column dissolved oxygen concentration shall not be less than 6 mg/l.*

Antidegradation Policy
Rhode Island's antidegradation policy requires that, at a minimum, the water quality necessary to support existing uses be maintained (see Rule 18, Tier 1 in the State of Rhode Island's Water Quality Regulations). If water quality for a particular parameter is of a higher level than necessary to support an existing use, that improved level of quality should be maintained and protected (see Rule 18, Tier 2 in the State of Rhode Island's Water Quality Regulations).

Numeric Water Quality Target

Historic shellfish processing operations in the Chickasheen Brook watershed are believed to be the primary source of phosphorus, causing water quality impairments in both Yawgoo and Barber Ponds. This TMDL sets numeric concentration targets for Chickasheen Brook of 0.0225 mg/l, which is equivalent to the state's water quality standard of 0.025 mg/l minus a 10% explicit margin of safety.

The resulting numeric concentration targets for Yawgoo and Barber Ponds establish the scale of the reductions necessary to support their designated uses. It may not be necessary, however, to attain the numeric targets specified to achieve the goal of supporting designated uses. This TMDL will be considered implemented when the conditions necessary to support each water body's designated uses, as naturally occurs, are attained. More specifically, these conditions are algal abundance equivalent to a chlorophyll-a level less than 9 ug/l, a shift from blue-green algae as the dominant species, elimination of noxious plant accumulations in Chickasheen Brook, and return of dissolved oxygen conditions in the ponds to those seen in the 1950's.

The numeric water quality targets are total phosphorus concentrations of 0.0114 mg/L for Yawgoo Pond, 0.0106 mg/l for Barber Pond, 0.0225 mg/l for Chickasheen Brook where it enters Yawgoo Pond, and 0.0114 mg/l for Chickasheen Brook where it enters Barber Pond. The TMDL must also ensure that the water quality criteria for dissolved oxygen and aquatic plant growth/algal abundance, as outlined above, are met. Reducing phosphorus is the most effective way to reduce algal abundance, because the growth of algae in freshwater environments is typically constrained by the availability of phosphorus. With algal abundance under control, the variability in dissolved oxygen levels (high daytime values, low nighttime values, and depressed oxygen levels following bloom crashes) will be reduced. As a consequence, dissolved oxygen and algae targets are not set explicitly by the TMDL. The Department believes that these criteria will be met by achieving the ambient phosphorus concentrations presented above.

2.0 DESCRIPTION OF THE STUDY AREA

The Chickasheen Brook watershed is a relatively small subwatershed of the Pawcatuck River located in the Towns of Exeter and South Kingstown in Rhode Island. The entire Chickasheen Brook encompasses approximately 4,260 acres, however, this TMDL only addresses the upper portion of the watershed, which encompasses approximately 2116 acres (3.3 mi^2). All subsequent references and descriptions of the Chickasheen Watershed will refer only to this upper portion of the watershed.

The length of Chickasheen Brook from its headwaters to the outflow of Barber Pond is approximately 3 miles. The headwaters of Chickasheen Brook originate in a swamp (known locally as Maple Swamp) located below the western slopes of Yorker Hill. The brook is conveyed under Route 2 through culverts, and it returns to channel flow on the western side of Route 2, flowing through Arrow Swamp in a southwesterly direction. The outflow to Arrow Swamp, located proximate to the end of Raymond Potter Road in Exeter, is constricted through an opening of a former raised farm/logging road. It was at this point that a beaver dam (estimated to be 2-4 years old) was located, causing the backwatering and flooding of Arrow Swamp. Subsequent to a property sale that included the area where the beaver dam was located, the landowner breached the dam and has maintained that breach. The beavers subsequently moved approximately 2,000 feet downstream to an old millpond and established a new dam and lodge. Chickasheen Brook continues flowing southwesterly through the downstream millpond and eventually flows through a culvert under Miskiania Trail. The brook continues southerly to the inflow of Yawgoo Pond.

Yawgoo Pond has a surface area of 143 acres and a maximum depth of 36 feet (Guthrie and Stolgitis, 1994). Volume estimates of Yawgoo Pond range from 2.27 x 10^6 m^3 (DEM, 2002) to 2.33 x 10^6 m^3 (Linda Green, personal communication) and annual pond outflow estimates range from 3.46 x 10^6 m^3/yr (Linda Green, personal communication) to 3.85 x 10^6 m^3/yr (DEM, 2002). This corresponds to a residence time between 215 and 246 days, where residence time is defined as the period of time required to replace the volume of water in the pond.

Chickasheen Brook exits Yawgoo Pond from the southeastern portion of the pond, flowing in a southeasterly direction to its confluence with Mud Brook and eventually Barber Pond. Barber Pond is approximately 25 acres and has a maximum depth of 18 feet (Guthrie and Stolgitis, 1994). Volume estimates of Barber Pond range from 3.35 x $10^5 m^3$ (Linda Green, personal communication) to 3.81 x $10^5 m^3$ (DEM, 2002) and annual pond outflow estimates range from 5.33 x 10^6 m^3/yr (Linda Green, personal communication) to 6.34 x 10^6 m^3/yr (DEM, 2002). This corresponds to a residence time between 22 and 23 days.

The dominant land use within the watershed is undeveloped (forests, wetlands, and open waters) occupying approximately 83 percent of the upper watershed. Residential land uses occupy approximately 10 percent of the upper watershed area with approximately 74 percent as medium density residential, 16 percent as medium-low density residential, and 10 percent as low density residential land use. The entire watershed is unsewered and generally served by private well water supplies. Figure 2.1 depicts land uses within the sub-watersheds of the upper Chickasheen Brook watershed. Table 2.1 summarizes the land uses within the watershed and selected sub-watersheds.

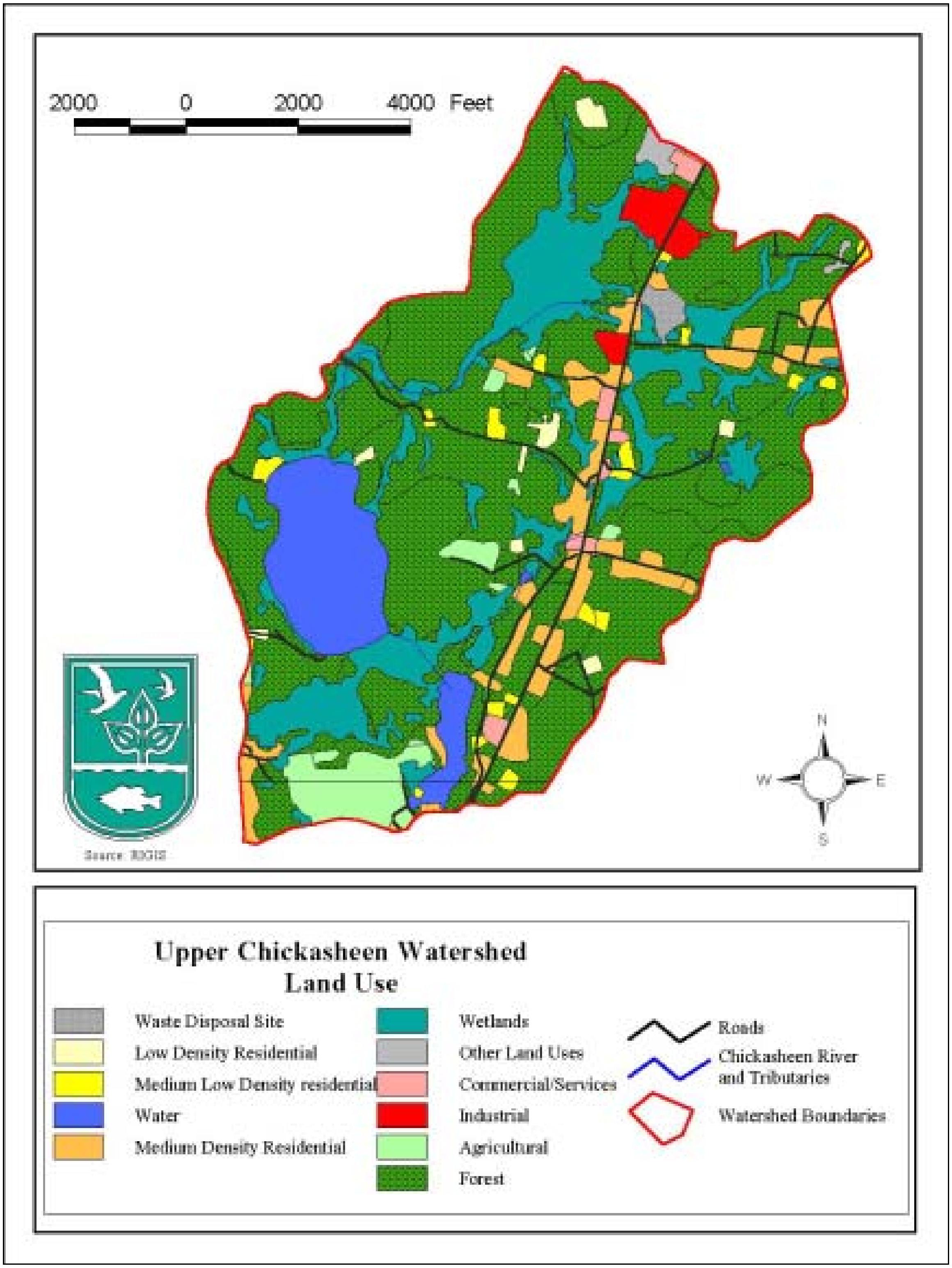
The upper Chickasheen watershed is underlain by glacial deposits consisting of till, outwash, ice-contact, and organic deposits. The glacial till deposits occur on Yorker Hill and Mt. Pleasant along the eastern watershed boundary and on the hills west of Arrow Swamp along the northwestern watershed boundary. These deposits form a thin (average thickness of 20 feet and maximum known thickness of 60 feet), discontinuous mantle over the bedrock and consists of boulders, sand, silt, and clay that are unconsolidated, poorly sorted, and unstratified.

The glacial outwash deposits occur in the lower-lying areas along Chickasheen Brook, and the open plain area north and south of Yawgoo Pond and west of Barber Pond. These deposits form a relatively thick mantle over the bedrock and reach a maximum known thickness of 122 feet. The outwash deposits consists of medium to coarse sand and gravel interbedded with fine sand, silt, and clay and are unconsolidated, generally well sorted and stratified. Both deposits generally yield water of good quality, but locally may contain excessive iron (Hahn, 1959). Ice-contact deposits, such as kame terraces consist of stratified sand and gravel deposited by a meltwater stream flowing between a melting glacier and a higher valley wall and left standing after the retreat of the glacier. These deposits are generally located along the side slopes of the hills.

Table 2.1: Land use in sub-watersheds of the upper Chickasheen Brook watershed (acres).

Description	Yawgoo Pond Subwatershed	Mud Brook Subwatershed	Barber Pond Subwatershed
Medium Density Residential	49.04	64.58	41.39
Medium Low Density Residential	18.53	8.82	7.09
Low Density Residential	11.66	6.42	2.39
Industrial	32.95	0	0
Commercial	4.95	11.06	4.25
Waste Disposal Sites	11.30	0	0
Open Space/Gravel Pits	11.20	0	0
Agriculture	6.15	14.11	57.61
Forest	772.26	325.83	124.72
Wetlands	227.05	122.51	8.39
Water	143	4.05	25

Figure 2.1: Land use within the upper Chickasheen watershed.



The swamp deposits of Maple Swamp and Arrow Swamp consist of organic peat and muck and inorganic silt and sand. These deposits are possibly underlain by the glacial deposits exposed around them.

The soils that occur with the upper Chickasheen watershed and that formed over these deposits are summarized in Table 2.2. Soil restrictions for conventional septic system leaching fields range from slight to severe (Rector, 1981). According to Rector (1981), soils that are identified with slight restrictions are generally favorable for leaching fields and limitations are minor and easily overcome. Moderate restrictions have soil properties or site features that are unfavorable or difficult to overcome by special planning and design. Severe restrictions are so unfavorable or difficult to overcome that major soil reclamation, special designs, or intensive maintenance is needed. These restrictions are based only on the soil horizons between the depths of 18 and 72 inches. The soil properties and site features considered are those that affect the adsorption of the effluent and the ease of construction. The properties that affect the system's adsorption capacity are permeability, depth to seasonal high water table, depth to bedrock, and susceptibility to flooding. Stones, boulders, and shallowness to bedrock can interfere with installation of the adsorption fields.

Table 2.2: Soil mapping units within Upper Chickasheen Watershed grouped by surficial geology.

Mapping Unit Name	Soil Texture	Restrictions for ISDS
Areas of Glaciated Uplands Dominated by Deep Soils with a Friable Substratum		
Bridgehampton-Charlton Complex	Very stony	Moderate (large stones)
Canton and Charlton	Extremely-Very stony Fine sandy loam (fsl)	Moderate-Severe (large stones)
Narragansett	Very stony fsl	Moderate (large stones)
Areas of Outwash Plains, Terraces, Kames, and Eskers Dominated by Deep Soils with a Sandy and Gravelly Substratum		
Agawam	Fine sandy loam	Slight*
Bridgehamptom	Silt loam	Slight*
Enfield	Silt loam	Slight*
Merrimac	Sandy loam	Slight*
Ninigret	Fine sandy loam	Severe (wetness)
Raypol	Silt loam	Severe (wetness)
Scarboro	Mucky sandy loam	Severe (wetness)
Sudbury	Sandy loam	Severe (wetness)
Walpole	Sandy loam	Severe (wetness)
Areas of Inland Depressions and Low-Lying Positions Dominated by Organic Soils		
Adrian	Mucky	Severe (wetness and floods)
Carlisle	Mucky	Severe (wetness and floods)

*Excessive permeability may cause groundwater pollution.

3.0 PRESENT CONDITION OF THE WATERBODY

3.1 Current Water Quality Conditions

Current water quality conditions in the upper Chickasheen watershed are primarily based on observations made by the University of Rhode Island Cooperative Extension Watershed Watch Program (URIWW) program. Some additional information is available from historical site investigations in the area and by a University investigation made during the early 1990's.

The University of Rhode Island Cooperative Extension Watershed Watch Program (URIWW) has monitored water quality in Chickasheen Brook, Yawgoo Pond and Barber Pond since 1988. The URIWW Program is headed by the Department of Natural Resource Sciences at URI and is an institutional collaborative between DEM, URI, local sponsors, and the federal government. Program goals are to encourage active citizen participation in water quality protection, to educate the public about water quality issues, and to obtain multi-year surface water quality information. One of the aims of the program is to establish a long-term monitoring program for water bodies throughout the state.

The URIWW Program has routinely sampled for total phosphorus, chlorophyll-a, Secchi transparency depth, and dissolved oxygen. URIWW began sampling in Yawgoo and Barber Pond in 1998 and expanded into the upper Chickasheen as problems were encountered. A brief description of the stations sampled over the years is presented in Table 3.1. The station locations are shown in Figure 3.1. It is noteworthy that station 2 in Arrow Swamp was only sampled during the 1990 and 1999 sampling seasons. URIWW and DEM sampled the Arrow Swamp station in 1990 while the shellfish facilities were in operation. URIWW reoccupied this station again in 1999 after increases were again observed at downstream stations.

The URIWW results are compared to epilimnetic trophic state categories developed by Nurnberg (1996) listed in Table 3.2. It should be noted that the DEM total phosphorus criteria (25 µg/L) for ponds/lakes and the points where tributaries enter ponds/lakes is more stringent than the Nurnberg (1996) total phosphorus criteria for eutrophic conditions.

<u>Total phosphorus</u>

Total phosphorus is typically sampled on a monthly basis in Yawgoo and Barber Ponds between the months of May and November. Starting in the spring of 1988 through the fall of 1992, total phosphorus was monitored at the deepest area of the ponds at a depth of one meter. Subsequent to this time, samples have been collected at one and five meters below the surface. The URIWW phosphorus data are summarized for each station as

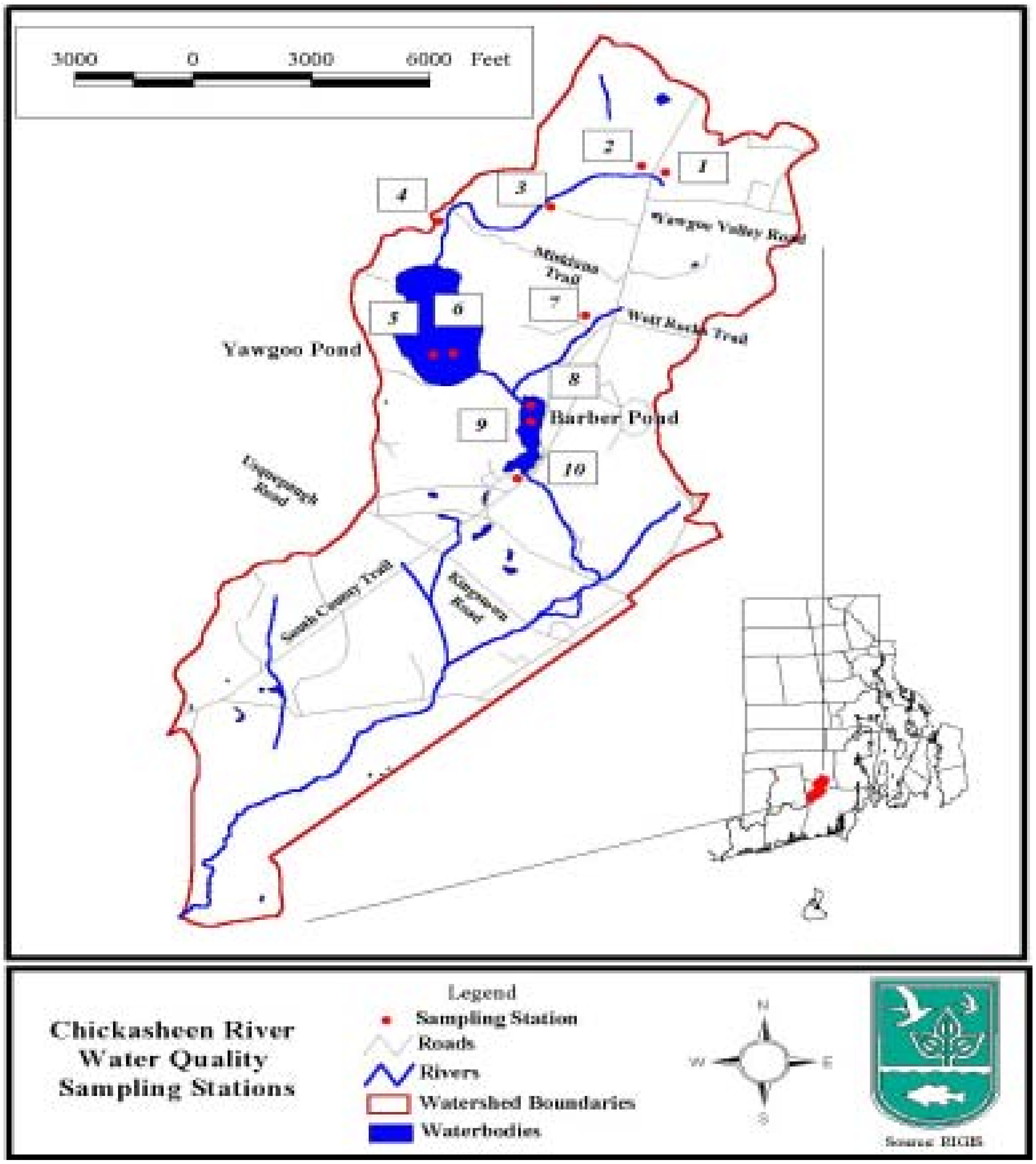
Table 3.1 URIWW sampling stations, locations, and rationale.

ID	Name	Location	Rationale
CHK-01	Route 2	East side of Route 2 (upstream) of culvert under road	Characterize water quality in headwaters
CHK-02	Arrow Swamp	West side of Route 2 (downstream) of culvert under road	Characterize water quality entering Arrow Swamp
CHK-03	Potter Road	Residential property at end of Potter Road	Characterize water quality exiting Arrow Swamp
CHK-04	Miskiania Trail	At 36-inch RCP culvert under Miskiania Trail, approximately 2000 feet upstream of Yawgoo Pond	Approximate water quality entering Yawgoo Pond
CHK-05	Yawgoo Pond-Shallow	At deepest portion of pond (approximately center of pond), 1 meter below water surface	Characterize water quality in epilimnion
CHK-06	Yawgoo Pond-Deep	At deepest portion of pond (approximately center of pond), 4-7 meters below water surface	Characterize water quality in the hypolimnion
CHK-07	Mud Brook	Upstream side of approximately 12-inch culvert under driveway, off Barber Pond Road	Characterize water quality in the Mud Brook sub-watershed
CHK-08	Barber Pond-Shallow	At deepest portion of pond (approximately northeast of center), 1 meter below surface	Characterize water quality in epilimnion
CHK-09	Barber Pond-Deep	At deepest portion of pond (approximately northeast of center), 5 meters below surface	Characterize water quality in hypolimnion
CHK-10	Barber Pond outlet	At upstream side of culvert headwall on west side of Route 2	Characterize water quality exiting pond

Table 3.2 Nurnberg (1996) trophic state categories based on summer epilimnetic water quality.

Analyte/Trophic Index	Oligotrophic	Mesotrophic	Eutrophic	Hypereutrophic
Total phosphorus (µg/L)	<10	10 - 30	31 - 100	>100
Chlorophyll-a (µg/L)	<3.5	3.5 – 9	9.1 - 25	>25
Secchi Disk Transparency (m)	>4	2 - 4	1 –2.1	<1
Anoxic Factor (d/yr)	0 - 20	20 - 40	40 - 60	>61

Figure 3.1: URIWW sampling stations in upper portion of the Chickasheen Brook watershed.



means by calendar year and as means for the months of July through September during the summer season in Tables 3.3 and 3.4. Phosphorus concentrations in both ponds are typically higher at the 5m depth than at the surface over the course of the year. In Yawgoo Pond, the mean of samples collected during 1998 - 2002 at the 1 m and 5 m depths are 25.0 ug/l and 55.3 ug/l respectively over the period of record between 1988-2002. Summer season concentrations at the 1 m depth are comparable to the calendar year mean at the 1 m depth, however concentrations increase significantly at the 5 m depth during the summer. The corresponding summer season means are 27.0 ug/l and 75.8 ug/l, at 1 m and 5 m respectively.

Phosphorus concentrations are somewhat lower in Barber Pond, but the trends with season and depth are similar. The mean of samples collected during 1998 - 2002 at the 1 m and 5 m depths are 18.1ug/l and 19.8 ug/l, respectively. During the summer, the 1 m and 5 m mean concentrations increase to 21.3 ug/l and 28.3 ug/l, respectively.

Trends in the year-to-year means over the period of record are shown for the two ponds in Figures 3.2 and 3.3. Averages for each calendar year, typically for samples collected during the months of May through November, are shown as bars. Summer season data for the months of July through September are shown as lines in the figures. For Yawgoo Pond, Figure 3.2 shows elevated (approximately 25 ug/l or greater) annual mean total phosphorus concentrations from 1988 to 1990 and from 1997 through 2002. Peak values are seen at the surface and bottom in 1990 and 2001; both surface and bottom means exceed the 25 ug/l water quality criterion during 1990, 2001, and 2002. The 5m depth annual mean concentration is 104.6 ug/l (N=7) in 2001, while the summer season mean is 156.3 ug/l (N=4). Both values exceed the maximum range of the chart in the figure.

Barber Pond phosphorus concentrations in Figure 3.3 follow a similar temporal trend, however peak concentrations are significantly lower. Annual mean concentrations violate the phosphorus criterion only at the bottom depth during 1990 and 2001, as do the summer season surface and bottom depth means. The highest annual mean concentration of 55.3 ug/l (N=3) occurred at the bottom in 1990. The highest annual mean concentrations at the surface station are 23 and 24 ug/l during 1990 and 2001, respectively.

URIWW began sampling Chickasheen Brook in 1989. Data for the station at Miskiania Trail in Figure 3.4 characterizes the annual trend in total phosphorus concentrations downstream of the swamp from 1989 through 2002. This station is located approximately 2000 feet upstream of the point where the brook empties into Yawgoo Pond and approximates the concentrations that enter the pond. Between 1989 – 1997, annual mean values were somewhat greater than 25 ug/l, with the exception of two significantly higher peaks (75 and 93 ug/l) during 1989 – 1990. The summer season values are generally higher during this period, with peak values of 99 and 109 ug/l during 1989 and 1990. Starting in 1998, levels increased dramatically to near or above 200 ug/l, reaching a peak value of 328 ug/l in 1999. Values were again typically higher during the summer, with the peak value of 371 ug/l again in 1999.

Supplemental monitoring was started at stations further upstream in Chickasheen Brook by URIWW in 1989. As Table 3.3 shows, the stations at Route 2 and Miskiania trail were sampled most frequently, with a lesser number of samples at Potter Road. Figure 3.5 shows the trend in mean total phosphorus concentration by station along Chickasheen Brook during the two periods when concentrations were elevated at Miskiania Trail in Figure 3.4. The 1990 - 1991 data show nearly level to decreasing concentrations from the headwaters to the Miskiania Trail station. Total phosphorus concentrations are somewhat elevated, (79 ug/l) at the upstream station at Route 2, and decline to 73 ug/l at Miskiania

Table 3.3: Annual mean total phosphorus and number of samples by station in the study area (URIWW).

	Year 1988		Year 1989		Year 1990		Year 1991		Year 1992		Year 1993		Year 1994		Year 1995		Year 1996		Year 1997		Year 1998		Year 1999		Year 2000		Year 2001		Year 2002		Year 1998 - 2002	
	Mean	N	Mean	N	Mean	N	Mean	N	Mean	N	Mean	N	Mean	N	Mean	N	Mean	N	Mean	N	Mean	N	Mean	N	Mean	N	Mean	N	Mean	N	Mean	N
Shickasheen @ Rt 2			55.7	3	114.7	9	43.1	9	58.6	16	58.0	5	71.0	8	44	5	49.5	4	62.0	2	96.5	6	61.4	7	54.3	4	56.5	12	61.9	6	65.0	35
Shickasheen @ Potter Rd.					84.8	4	54.0	3															536.4	7			366.0	1	205.0	3	430.5	11
Shickasheen @ Arrow Swamp																							633.3	6			260.0	2			540.0	8
Shickasheen @ Miskiania			75.3	4	93.1	19	38.1	11	39.4	17	51.7	9	31.4	16	28	8	27.3	4	28.3	3	198.2	6	328.0	9	255.3	5	174.3	16	251.7	12	233.9	48
Shickasheen @ Yawgoo			106.1	14	43	1															462	1					197	1			329.5	2
Yawgoo Pond @ 1m @ deep spot	24.7	3	23.0	16	32.5	17	17.3	12	14.3	19	12.8	9	14.4	17	13	12	14.3	4	13.3	3	18.0	6	19.5	10	23.3	8	34.7	10	29.0	4	25.0	38
Yawgoo Pond @ 5m @deep spot			33.7	13	36.6	16	14.0	10	11.9	16	16.0	6	19.9	14	24	11	16.3	4	25.7	3	38.3	6	44.5	11	38.4	6	104.6	7	49.0	4	55.3	34
Mud Brook			21.3	3	19.7	7	9.7	11	10.2	19	10.0	9	11.0	16	13	9	10.8	4	13.0	3	20.8	4	8.4	9	14.5	4	19.8	14	15.6	9	15.9	40
Barber Pond @1m @deep spot	14.0	3			23.0	4	16.0	3	16.0	1			17.3	4	13	3	10.0	3	10.7	3	12.7	3	21.0	1	16.3	3	24.0	3	18.5	2	18.1	12
Barber Pond @5 m @deep spot					55.3	3	22.3	3	16.0	1					12	3	6.0	3	17.3	3	16.0	2	16.0	1	12.3	3	28.3	3	24.0	2	19.8	11
Shickasheen@ Barber Outlet					30.3	7	18.3	8	10.3	13	9.0	7	14.1	15	11	8	13.0	3	8.5	2			9.2	6	22.0	4	25.6	14	25.0	9	22.0	33
Shickasheen @ rte 138, S side															19	1			89.5	2	42.0	6			57.5	2	28.5	11	31.6	7	34.7	26

Table 3.4: Summer season mean total phosphorus and number of samples by station in the study area (URIWW).

	Year 1988		Year 1989		Year 1990		Year 1991		Year 1992		Year 1993		Year 1994		Year 1995		Year 1996		Year 1997		Year 1998		Year 1999		Year 2000		Year 2001		Year 2002		Year 1998 - 2002	
	Mean	N	Mean	N	Mean	N	Mean	N	Mean	N	Mean	N	Mean	N	Mean	N	Mean	N	Mean	N	Mean	N	Mean	N	Mean	N	Mean	N	Mean	N	Mean	N
Shickasheen @ Rt 2			57.0	1	144.5	2	53.7	3	81.3	7	93.0	2	43.5	2			102.0	1			76.5	2	40.5	2	67.0	2	62.6	5	61.9		61.9	11
Shickasheen @ Potter Rd.							112.0	1															500.3	3					205.0	2	359.0	5
Shickasheen @ Arrow Swamp																							645.5	2			130.0	1			473.7	3
Shickasheen @ Miskiania			99.0	2	108.9	8	48.2	5	48.8	9	46.5	4	40.4	7	39	3	45.0	1	46.0	1	179.5	2	371.3	4	333.9	3	167.3	8	251.7	4	240.9	21
Shickasheen @ Yawgoo			118.1	11																												
Yawgoo Pond @ 1m @ deep spot	11.0	1	22.3	12	29.5	8	15.3	6	15.3	9	16.5	4	15.4	7	13	6	20.0	1	19.0	1	19.5	2	19.0	4	23.6	5	40.5	5	29.0	2	27.0	18
Yawgoo Pond @ 5m @deep spot			36.6	10	45.5	8	13.5	4	14.1	7	21.7	3	22.8	8	29	6	24.0	1	51.0	1	47.0	2	56.8	5	48.8	4	156.3	4	49.0	2	75.8	17
Mud Brook			27.0	1	25.5	2	14.2	5	11.8	9	9.3	4	15.1	7	11	4	19.0	1	11.0	1	18.5	2	10.0	4	20.5	2	18.1	7	15.6	4	15.3	19
Barber Pond @1m @deep spot	9.0	1			30.0	2	13.0	1					18.0	2	12	1	10.0	1	14.0	1	8.0	1			21.0	1	33.0	1	18.5	1	21.3	4
Barber Pond @5 m @deep spot					69.5	2	15.0	1							7	1	2.0	1	34.0	1					9.0	1	39.0	1	24.0	1	28.3	3
Shickasheen@ Barber Outlet					30.8	6	25.5	4	12.0	7	9.5	2	12.0	7	10	3	18.0	1					10.5	2	21.0	3	30.9	6	25.0	4	24.3	15
Shickasheen @ rte 138, S side															19	1			54.0	1	74.0	2			57.5	2	29.7	6	31.6	2	42.4	12

Figure 3.2 Mean total phosphorus concentrations in Yawgoo Pond (1988-2002).

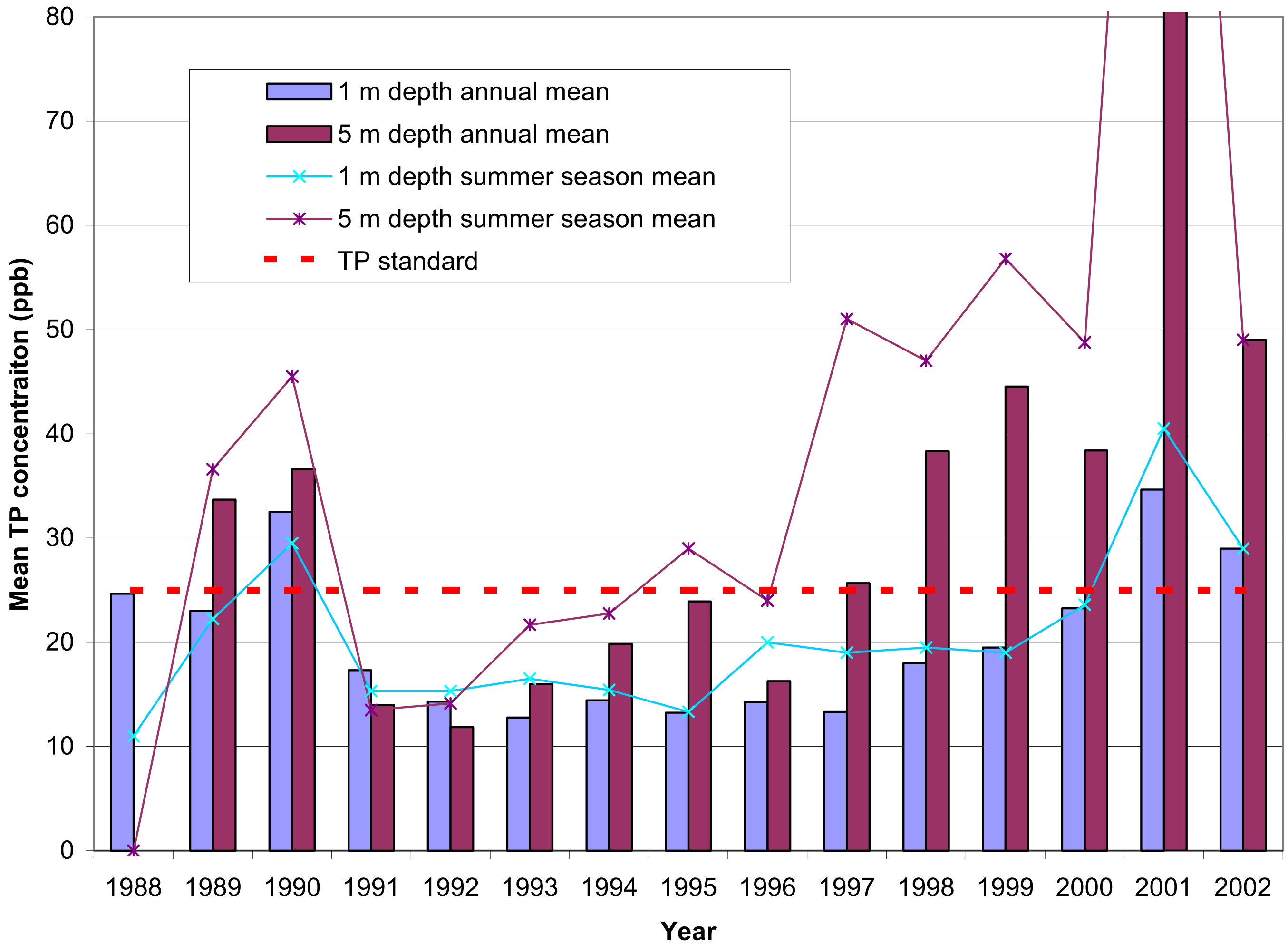


Figure 3.3: Mean total phosphorus concentrations in Barber Pond (1988-2002).

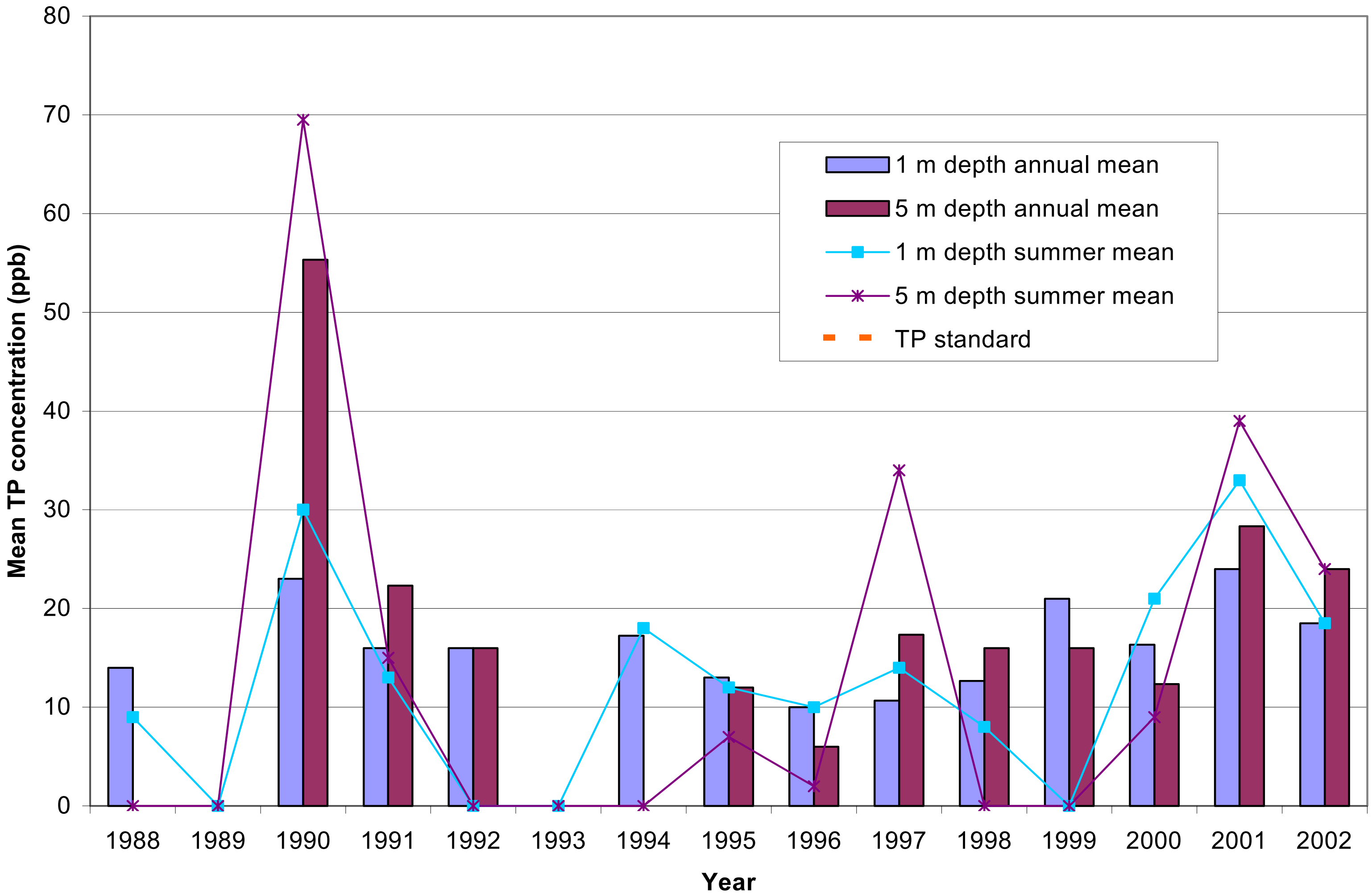
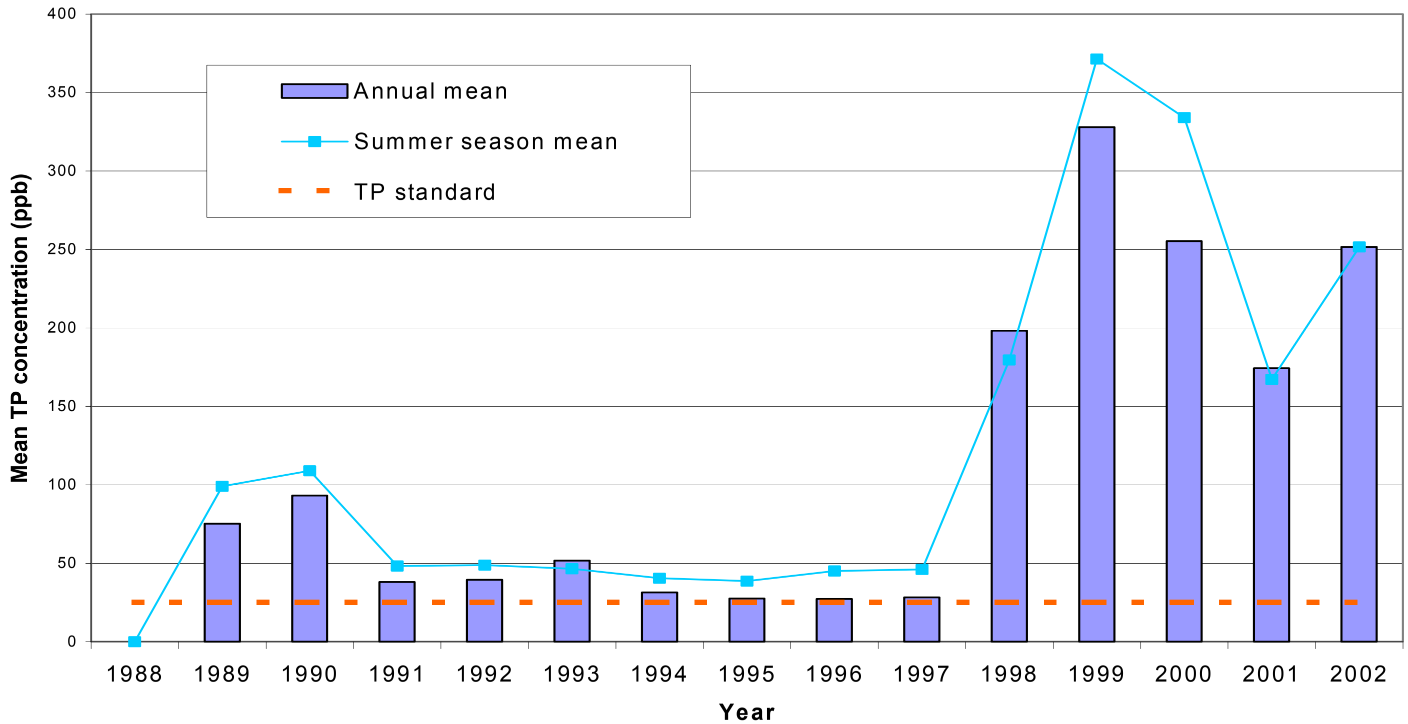


Figure 3.4: Mean total phosphorus concentrations in Chickasheen Brook at Miskiania Trail (1993-2002).



Trail. Total phosphorus concentrations remain somewhat elevated, 65 ug/l at Route 2 between 1998 – 2002, but increase significantly downstream. At the Potter Road station, the mean concentration of water emptying from Arrow Swamp into Chickasheen Brook is 430 ug/l. The mean concentration in the brook at Miskiania Trail is 234 ug/l.

Chlorophyll-a and Secchi Depth

URIWW collected samples from Yawgoo and Barber ponds for the laboratory determination of chlorophyll-a concentrations. Samples were collected near the deepest portion of the pond at 1 meter below the water surface. Secchi transparency depths were measured at the same location. The chlorophyll-a data are summarized in Table 3.5 and annual Secchi transparency depths are summarized in Table 3.6. The data are represented graphically in Figures 3.6 and 3.7.

The URIWW chlorophyll-a data indicate that Yawgoo Pond generally experienced oligotrophic to mesotrophic states during the mid-1990's. Eutrophic conditions were experienced in 1989 and hypereutrophic conditions (i.e. annual mean level >25 μg/l) were experienced in 1990 and 2001. The Secchi transparency depths appear to confirm these trophic states during the same time periods.

The URIWW chlorophyll-a data indicates that Barber Pond is generally mesotrophic. Eutrophic conditions were experienced in 1995 and hypereutrophic conditions were experienced in 1990 and 2001. The Secchi transparency depths appear to confirm the generally mesotrophic conditions. Eutrophic conditions based on Secchi depth were experienced in 1990, 1998, and 2001.

Dissolved Oxygen

Dissolved Oxygen was measured by titration in the field on a monthly basis by URIWW. The value reported for each date represents an average of typically 2-4 observations. Water samples were collected in Yawgoo and Barber Ponds at 1 m and between 4-5 m below the surface. URIWW data for the three most recent sampling years, 1999 through 2001, were used to characterize the present condition of both ponds. Samples collected during the months of July through September were used to represent the summer season condition of the ponds.

Basic dissolved oxygen and temperature statistics for the 1999-2001 summer period at the 1 m and 4-5 m depths are presented in Table 3.7. Near-surface dissolved oxygen in Yawgoo Pond is generally high during the summer, ranging between 6.0 and 11.4 mg/l with a mean value of 8.4 mg/l. The corresponding near-surface values in Barber Pond are also relatively high, ranging between 5.6 and 9.0 mg/l, with a mean value of 7.4 mg/l over the three summers.

Near-bottom summer season dissolved oxygen levels are significantly lower, with means of 1.0 mg/l or less in Yawgoo Pond and below 3.5 mg/l in Barber Pond. A majority of the summer season near-bottom dissolved oxygen levels in both ponds are less than 1.0 mg/l.

Figure 3.5: Trends in mean Total phosphorus concentration along Chickasheen Brook, 1990-1991 vs. 1998-2002.

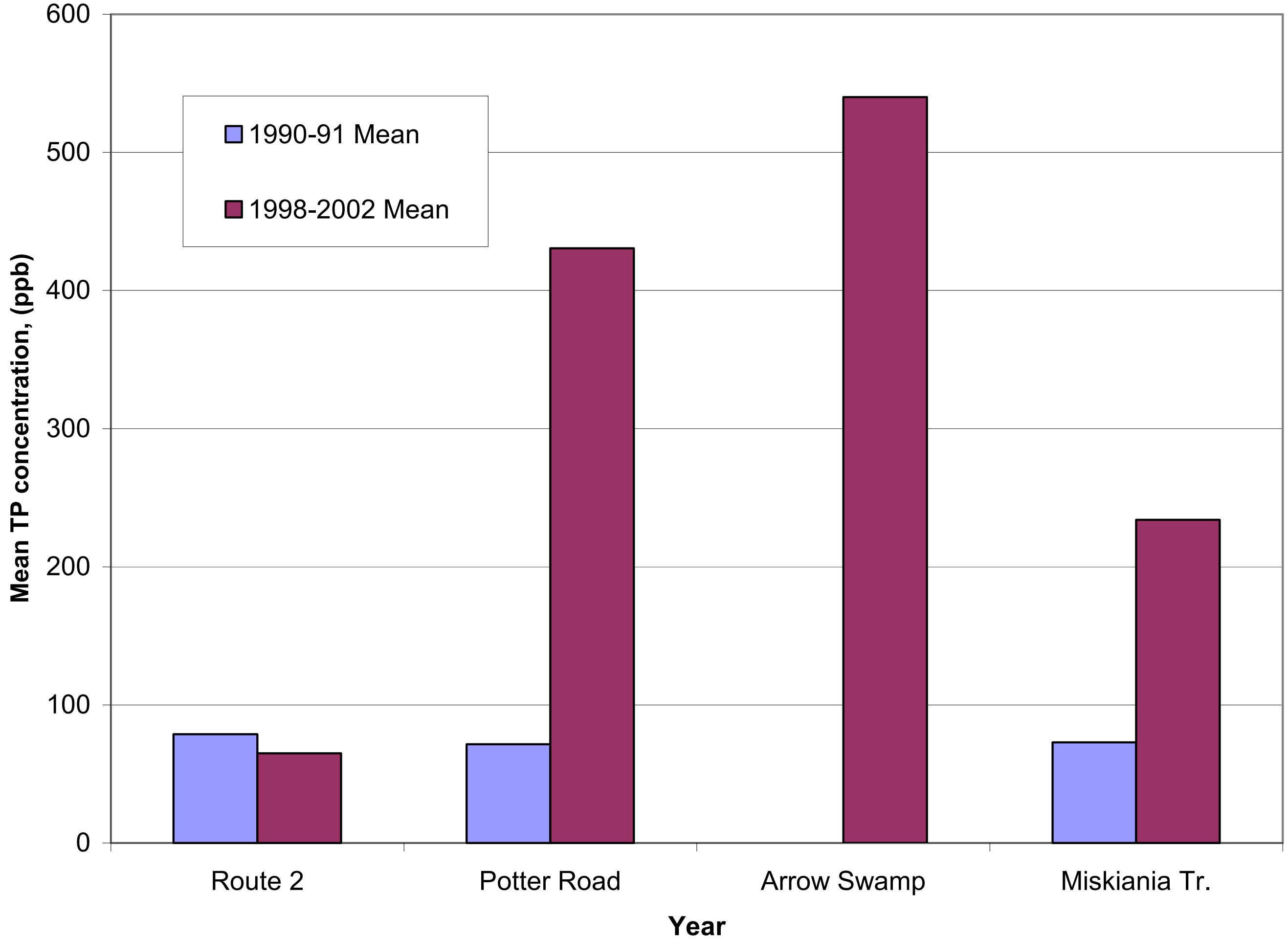


Table 3.5 URIWW Annual chlorophyll-a (μg/l) statistics.

		Year													
Pond	**Statistics**	**1988**	**1989**	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**
Yawgoo Pond	**N**	17	17	16	18	21	11	17	6	14	9	10	10	17	12
	Mean	6.9	**20.3**	**38.3**	6.6	4.3	1.4	2	1.3	4.88	3.48	2.72	3.48	6.16	**34.03**
	Min	1.9	3.7	3.2	0.7	1.4	0.7	0.9	0.07	0.77	1.3	0.88	1.75	2.69	2.51
	Max	**16**	**52.5**	**87.6**	**34**	**14.7**	2.5	4.2	2.66	**16.69**	5.49	5.47	5.61	**16.14**	**78.32**
Barber Pond	**N**	10	18	21	15	4	11	14	9	12	17	17	14	13	10
	Mean	8.7	1.2	**28**	4.9	5.5	4.3	3.3	**12.39**	4.81	2.02	3.62	5.01	6.14	**41.09**
	Min	4.6	0.2	3.8	0.8	2.4	1.1	1.4	1.68	1.65	1.45	1.36	2.63	2.75	1.83
	Max	**15.6**	3.5	**132**	**19.5**	**9.6**	**12.9**	6.5	**90.94**	**11.45**	2.65	**11.01**	8.71	**9.18**	**82.39**

Values shown as **bold** indicate eutrophic conditions and values that are **bold and underlined** indicate hypereutrophic conditions (Nurnberg, 1996).

Table 3.6 URIWW annual Secchi depth (m) statistics.

		Year													
Pond	**Statistics**	**1988**	**1989**	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**
Yawgoo Pond	**N**	19	18	19	19	22	18	19	14	17	14	14	14	17	14
	Mean	2.4	**1.9**	**0.7**	3	3.5	4.32	4.82	4.7	2.99	2.76	2.4	3.09	2.7	**1.6**
	Min	**1.8**	**0.8**	**0.4**	**1.1**	2.5	2.98	3.25	3.65	2.35	**2**	**1.75**	2.2	**1.95**	**0.5**
	Max	3.6	3	2.7	3.3	5	5.27	6.48	6.33	3.7	3.45	3.5	3.98	3.35	3.3
Barber Pond	**N**	21	21	21	24	14	18	17	17	13	17	22	20	18	20
	Mean	2.1	2.5	**1.1**	2.2	2.3	2.4	2.4	2.3	2.2	2.02	1.76	2.08	2.22	**1.47**
	Min	**1.4**	**1.3**	**0.6**	**1.3**	**1.6**	**1.77**	**1.6**	**1.7**	**1.35**	**1.45**	**1.15**	**1.55**	**1.35**	**0.43**
	Max	2.8	3.9	2.4	2.8	2.9	2.23	2.9	3.63	2.73	2.65	3.3	2.73	3.28	3.12

Values shown as **bold** indicate eutrophic conditions and values that are **bold and underlined** indicate hypereutrophic conditions (Nurnberg, 1996).

Figure 3.6: URIWW annual mean chlorophyll concentrations and Secchi transparency depths in Yawgoo Pond.

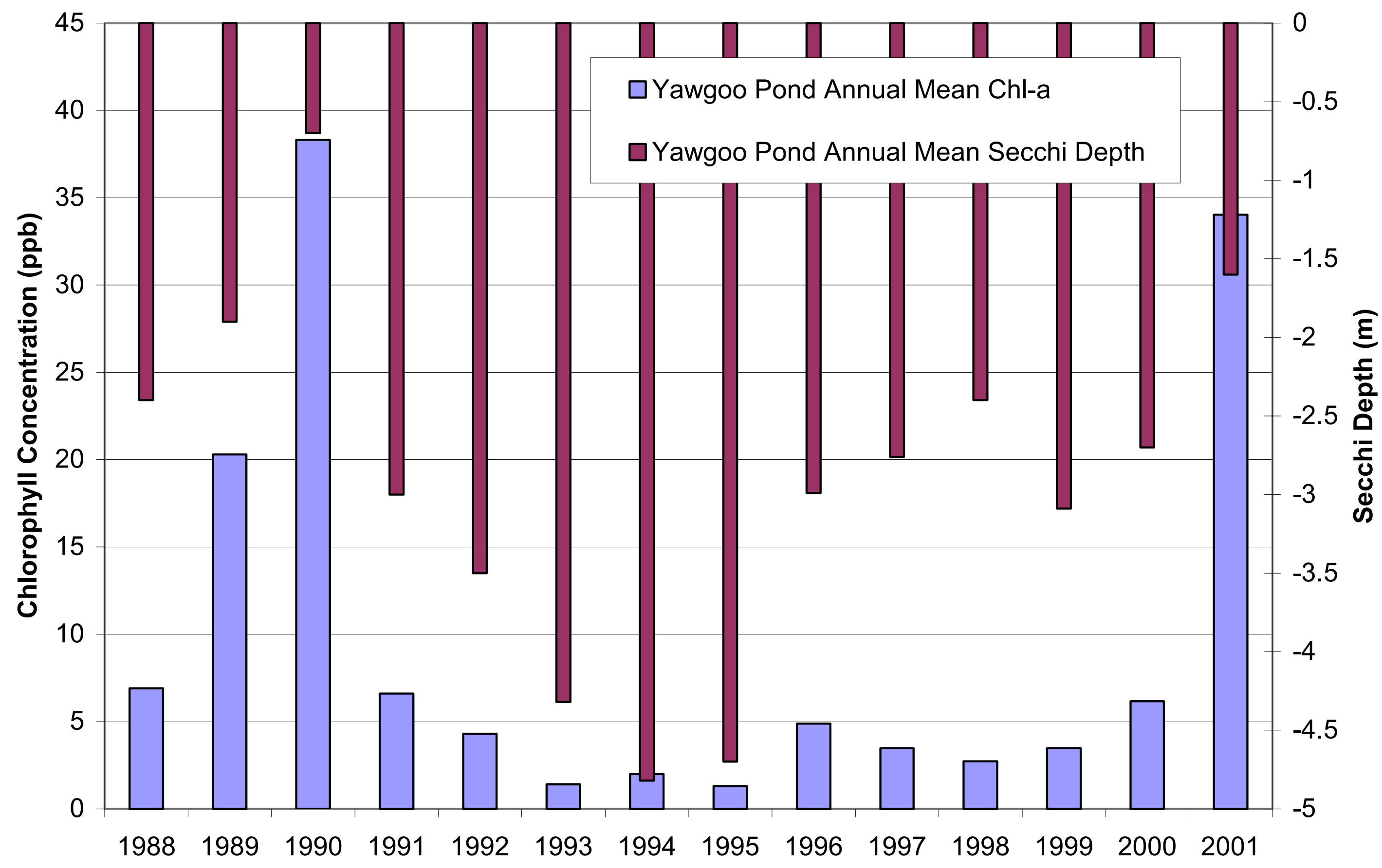


Figure 3.7: URIWW annual mean chlorophyll-a concentrations and Secchi transparency depths in Barber Pond.

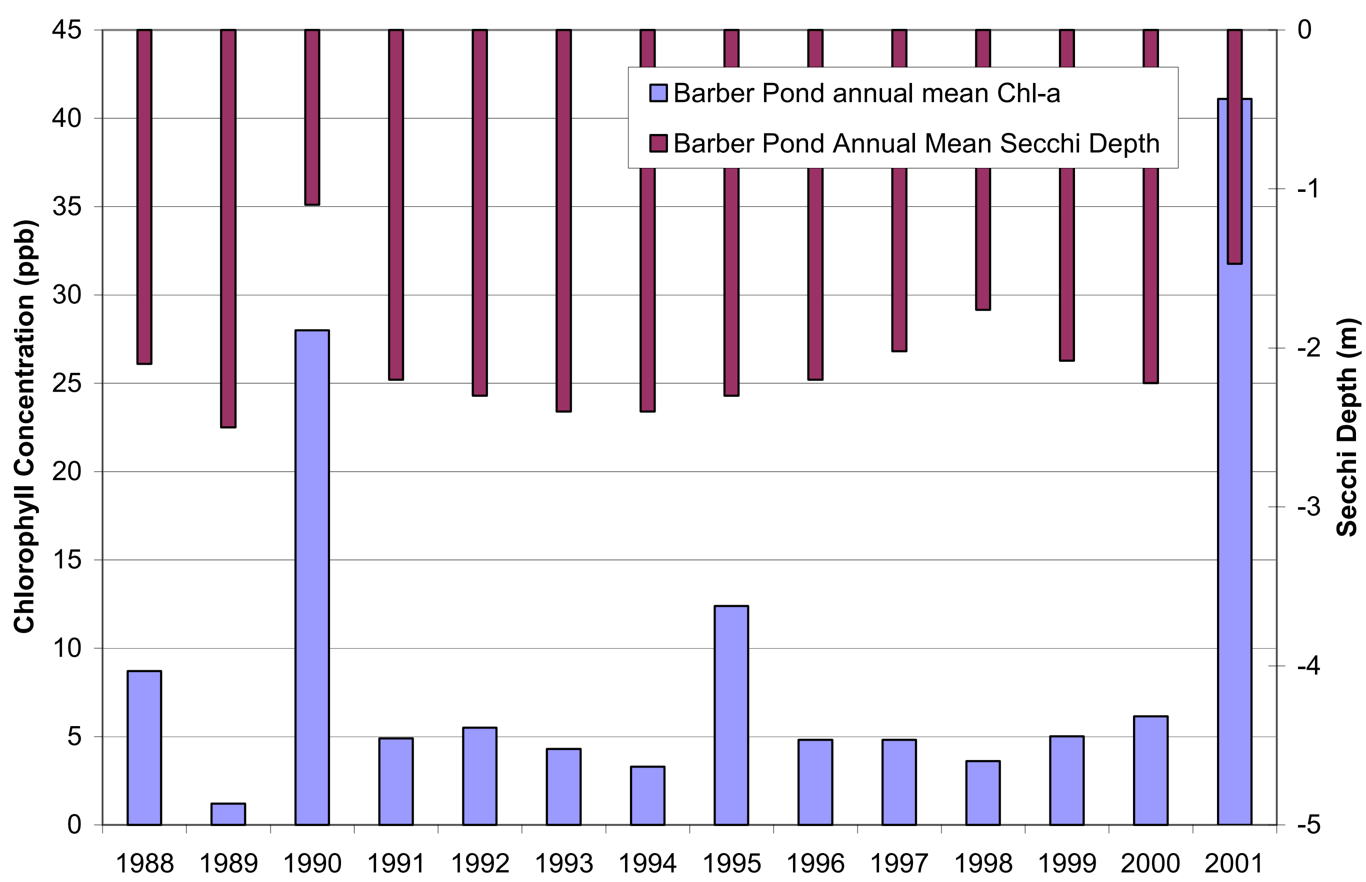


Table 3.7: Dissolved oxygen and temperature statistics for the 1999-2001 summer period in Yawgoo and Barber Ponds.

	Yawgoo Pond							Barber Pond						
July - September data		Temperature (deg C) at 1m	Dissolved Oxygen (mg/L) at 1 m	Depth of Deep sample (m)	Temperature of deep sample (deg C)	Dissolved Oxygen of deep sample (mg/L)			Temperature (deg C) at 1m	Dissolved Oxygen (mg/L) at 1 m	Depth of Deep sample (m)	Temperature of deep sample (deg C)	Dissolved Oxygen of deep sample (mg/L)
1999	Minimum	20.2	7.1	6.0	12.7	0.1	Minimum	22.0	7.6	4.2	19.0	2.1
	Mean	23.9	7.6	6.8	16.3	1.0	Mean	25.5	7.6	4.3	20.0	3.5
	Maximum	27.8	7.9	8.0	19.1	4.8	Maximum	29.0	7.6	4.5	22.0	5.9
	Count	5	5	5	5	5	Count	4	1	4	4	4
2000	Minimum	21.3	7.6	4.5	18.3	0.2	Minimum	17.0	7.5	4.1	17.0	0.0
	Mean	23.3	8.7	5.6	19.4	0.6	Mean	21.7	7.6	4.2	17.5	1.9
	Maximum	26.0	11.1	7.0	20.9	1.4	Maximum	25.0	7.8	4.5	19.0	6.6
	Count	8	8	7	6	7	Count	7	3	5	7	7
2001	Minimum	23.3	7.9	5.0	12.5	0.1	Minimum	23.0	5.6	4.3	16.0	0.0
	Mean	25.5	8.7	6.3	18.2	0.1	Mean	24.7	7.3	4.5	17.7	0.3
	Maximum	28.0	9.2	8.0	24.3	0.2	Maximum	27.0	9.0	4.8	19.0	1.1
	Count	6	3	6	6	3	Count	7	5	6	7	7
1999-2001	Minimum	13.2	6.0	4.0	11.5	0.1	Minimum	13.0	5.6	4.0	13.0	0.0
	Mean	22.3	8.4	6.3	16.7	0.7	Mean	21.3	7.4	4.4	17.0	1.6
	Maximum	29.5	11.4	8.0	24.3	4.8	Maximum	29.0	9.0	5.1	22.0	6.6
	Count	37	35	36	35	15	Count	42	9	36	42	18

The average sample depths at which these levels were observed range from 4.5 – 6.8 m in Yawgoo Pond and from 4.2 - 4.5 m in Barber Pond. This hypoxia or anoxia is attributed to the thermal stratification of the ponds. Mean summer season temperature differences between the surface and bottom sampling depths range from 4.0 deg C to 7.6 deg C in Yawgoo Pond and by a similar amount in Barber Pond. The resulting density difference impedes the vertical mixing of oxygen from the surface. Thermal stratification has been linked to seasonal hypoxia (DO values down to 2 mg/l) in relatively pristine freshwater ponds in Rhode Island (Tetra-Tech, 2002). The hypolimnetic waters of Yawgoo and Barber Pond would be better characterized as generally anoxic during the summer, in which DO is characteristically less than 1 mg/L.

Yawgoo and Barber Ponds were included in a fisheries assessment of 101 Rhode Island lakes and ponds reported in Guthrie and Stolgitis (1977). Vertical profiles of total alkalinity, dissolved oxygen by Winkler titration, temperature, and pH were measured in the two ponds in mid-August, 1955. In Yawgoo Pond, temperature and dissolved oxygen were relatively constant, at 26° C and 7 to 8 mg/l, to a depth of around 3 m. Both properties then dropped significantly below the thermocline. Temperature declined steadily to nearly 12° C at 9 m. Dissolved oxygen dropped to 2.5 mg/l below 5 m, then to approximately 0.5 - 1.0 mg/l at 9 m. For Yawgoo Pond, Guthrie and Stolgitis concluded that "*the pond is thermally stratified, but does not contain enough oxygen in the hypolimnion to support trout. The extent of deep water constitutes a significant proportion of the total water mass….. The existing fish population appears to be in a healthy condition and under present conditions no management attempts seem warranted.*"

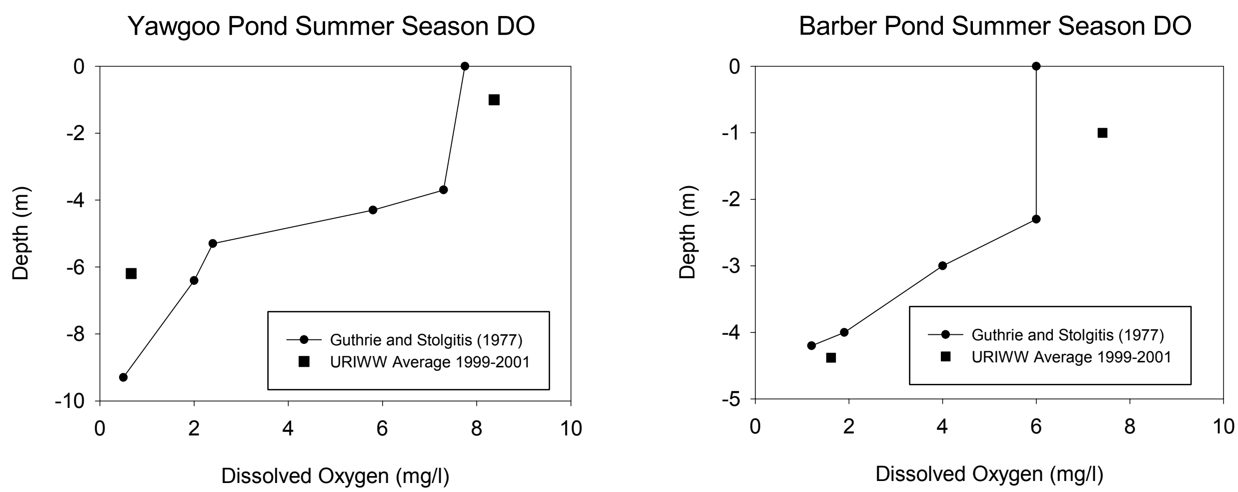
Guthrie and Stolgitis reported that the behavior of temperature and dissolved oxygen was similar in Barber Pond, where surface values were again 26° C and 7 to 8 mg/l, respectively. Temperature appeared to drop more continuously with depth to a low value of 14° C at 4.5 m. Dissolved oxygen remained relatively constant to a depth of 2.5 m, then dropped to 1 mg/l or less at 4.5 m. Guthrie and Stolgitis concluded *"Although the pond is small and shallow, some evidence of thermal stratification was found during summer conditions. Dissolved oxygen tends to be reduced in the cooler water which indicates that this is not trout waters. In spite of the relatively adverse summer conditions for trout, a successful 'put and take' fishery is achieved annually through state stocking*."

The hypolimnia of both lakes were hypoxic and nearly anoxic nearly 50 years ago. Observed dissolved oxygen was less than or equal to 1 mg/l near the bottom (9 m) in Yawgoo Pond and Barber Pond (at 4.5 m) at that time (1955). Aerial photographs of the area taken in 1951 show that the watershed of upper Chickasheen Brook was principally forested open land with minor development along Route 2 during that period. The 1955 near-bottom dissolved oxygen values are equivalent to those listed in Table 3.7 for years1999-2001. It is clear from this information that summer season hypoxia in the hypolimnia of both ponds results from the presence of the thermocline.

The duration and severity of hypoxia in both ponds is exacerbated by current phosphorus loads, however. In the pond hypolimnia, oxygen depletion is largely a function of phytoplankton respiration and sediment oxygen demand (SOD). SOD is in turn dependent on phytoplankton death rate, which increases as the phytoplankton population increases. On a seasonal basis, the result of increased phosphorus loading can be shown to be a shorter time to the onset of hypoxia in the hypolimnion of a pond, and more severe hypoxia at any time during the summer season (Thomann and Mueller, 1987).

Given the historic data available for Barber Pond and the similarity of stratification in the two ponds, it is clear that dissolved oxygen in both ponds would not meet the state water quality standard under any achievable future condition. With the influence of the excessive phosphorus loads eliminated, violations of the numeric dissolved oxygen criteria in the hypolimnia of both ponds would be considered to result from the natural hydraulic condition of the pond. Under that state, hypoxia in the hypolimnia would not considered as violations of the water quality standards.

Figure 3.8: URIWW growing season mean surface and bottom dissolved oxygen compared with pre-development (1955) values in Yawgoo and Barber Ponds.



3.1.2 Current Phosphorus Loads

Existing and allowable load estimates were derived from the URIWW total phosphorus data and estimated stream flows using estimated annual mean discharges obtained by regressing the annual mean flows of nearby gauged rivers against their drainage areas. The upper Chickasheen Brook watershed was divided into three areas consisting of (1) the area contributing to Yawgoo Pond, (2) the area discharging to Chickasheen Brook between Yawgoo and Barber Ponds, including the Mud Brook drainage area, and (3) the area draining directly to Barber Pond (Figure 3.9). Sub-area 1 was further broken down into three sub-areas, 1A, 1B, and 1C for the characterization of sources in Section 3.2. Flow data from six long-term, continuous-record stream flow gauging stations in the Pawcatuck and Potowomut watersheds were used for the estimate. Basic information on the reference gauging stations is presented in Table 3.8.

Annual mean flows were regressed against drainage area for the period of record at each station in Table 3.8. A summary of the runoff factor calculations and the calculations of existing loads are presented in Appendix A. The exercise yielded an estimated annual mean discharge from the watershed upstream of Miskiania Trail (subwatersheds 1A and 1B in Figure 3.9) of 2.83 cfs. The mean discharge of Chickasheen Brook leaving Barber Pond was estimated at 4.3 cfs.

Table 3.8 Gauging stations used in regression analysis.

USGS Waterbody ID	Waterbody Name	Basin	Period of Record	Drainage Area (mi^2)	Mean Annual Discharge (cfs)	POR Runoff Factor (cfs/mi^2)
01117468	Beaver River near Usquepaug, RI	Pawcatuck River	1974 – 2000	8.87	46.9	2.05
01117350	Chipuxet River at West Kingston, RI	Pawcatuck River	1958 – 2000	9.99	21.5	2.15
01117000	Hunt River near East Greenwich, RI	Potowomut River	1940 – 2000	22.9	77.5	2.15
01117420	Usquepaug River near Usquepaug, RI	Pawcatuck River	1958 – 2000	36.1	21.5	2.42
01118000	Wood River at Hope Valley, RI	Pawcatuck River	1941 – 2000	72.4	196	1.96
01117500	Pawcatuck River at Wood River Junction, RI	Pawcatuck River	1940 – 2000	100	156	2.15

Monthly mean flows for the period of record for each of the six rivers in Table 3.8 were next regressed against their drainage areas to produce mean monthly discharge estimates for selected reaches of Chickasheen Brook. Table 3.9 shows the averaged monthly runoff coefficients (cfs/mi^2) for the reference rivers and the estimated flows for Chickasheen Brook at Miskiania Trail and Mud Brook including the drainage area of Barber Pond.

Estimated current total phosphorus loads to Yawgoo and Barber Ponds and the Chickasheen Brook are summarized in Table 3.10. The existing annual total phosphorus load to each water body was taken as the product of the estimated annual mean flow for the period of record and the mean observed Total phosphorus concentration for the period 1998 to 2002. The contribution of atmospheric deposition was assumed to be negligibly small. The load to Yawgoo Pond from Miskiania Trail was calculated for the period of 1998 – 2002 by taking the product of each measured total phosphorus concentration in the stream and the corresponding mean monthly discharge of the brook at that point (from Table 3.9), and converting the result to monthly total flux units (i.e. kg/month). The 1998 – 2002 values were then averaged by month. Because the URIWW were only collected between May and December (in general) during that period, estimates had to be derived for the months of January through April, for the winter season. The winter month concentration was taken as the average of the May and December averages. The monthly loading was then calculated as the product of the winter season concentration and the monthly mean segment flow from Table 3.9. Because relatively little sampling was conducted during November, the November monthly loads were calculated by scaling up the October values by the ratio of monthly flows. The monthly mean loads were summed to produce an estimate of the annual mean total load for the period 1998 – 2002. Using this approach, the annual load in Chickasheen Brook at Miskiania Trail was estimated at 425 kg/yr. The contribution of basin 1C (21 kg/yr) was calculated using the product of the annual mean runoff factor and the mean concentration for Mud Brook. The total load to Yawgoo Pond was therefore 446 kg/yr.

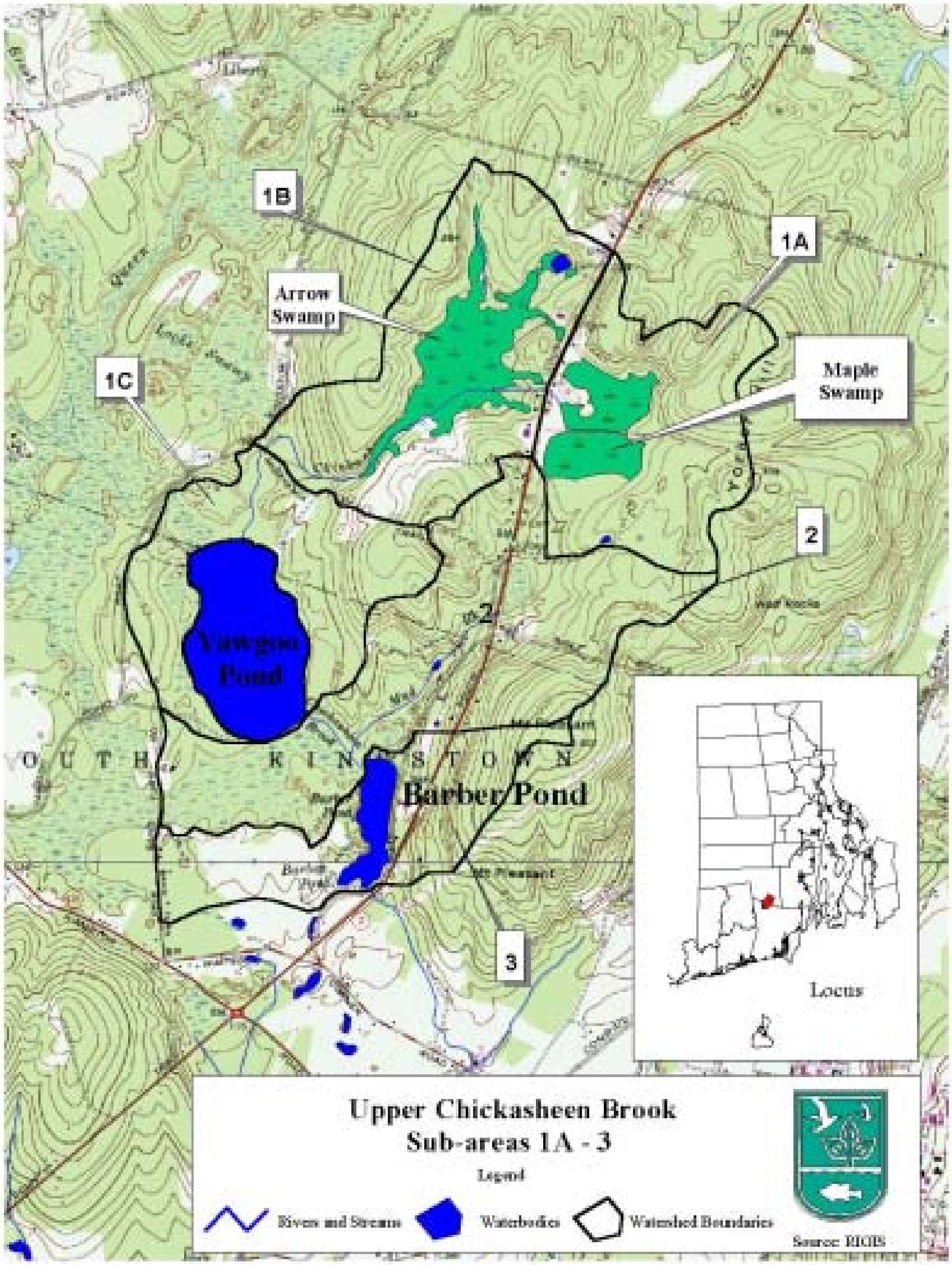
Table 3.9 Averaged monthly runoff coefficients (cfs/mi^2) for the reference rivers and estimated flows for Chickasheen Brook at Miskiania Trail and Mud Brook and the drainage area of Barber Pond.

Month of year	Monthly mean runoff factor for six reference rivers by month of year for the period of record (cfs/mi^2)	Estimated mean monthly discharge based on monthly runoff factor, (cfs)	
		Chickasheen Brook at Miskiania Trail (1.32 mi^2)	Mud Brook and the Chickasheen watershed below Yawgoo Pond (0.87 mi^2)
January	2.86	3.77	2.49
February	3.04	4.01	2.65
March	3.77	4.98	3.29
April	3.69	4.87	3.22
May	2.73	3.61	2.38
June	1.95	2.57	1.70
July	1.03	1.36	0.90
August	0.86	1.14	0.75
September	0.78	1.03	0.68
October	0.96	1.27	0.84
November	1.64	2.17	1.43
December	2.38	3.14	2.07

The Barber Pond annual influent total phosphorus load was calculated as the sum of the loads from sub-basin 1 (i.e. 1A, 1B, and 1C) and 2 in Figure 3.9. The sub-basin 1 load was calculated as the product of Yawgoo Pond mean epilimnion total phosphorus concentration and the annual mean outflow of Yawgoo Pond. The Mud Brook and basin 2 contribution to Barber Pond was estimated at 38 kg/yr using the approach described for basins 1A and 1B above. The estimated phosphorus load to Barber Pond was estimated at 134 kg/yr.

In Figure 3.10, mean phosphorus concentrations in various parts of the upper Chickasheen watershed for 1998 to 2002 are compared to their values during 1990 to 1991 when the shellfish facilities had been operating, and from 1994 to 1997 when

Figure 3.9: Sub-watershed areas contributing to Yawgoo and Barber Ponds



Yawgoo and Barber ponds exhibited mesotrophic to oligotrophic conditions. Using the concentration at Miskiania Trail as the key, it appears that loadings to the ponds were elevated before 1992, decreased until 1997, then increased to a significantly higher level beginning in 1998. Given the information presently available for the area, it is apparent that the loading increase to the Chickasheen Brook and ponds originates downstream of Route 2, probably from Arrow Swamp. The data and site visits by URIWW point to the inundation of Arrow Swamp resulting from beaver activity as a cause of the increased

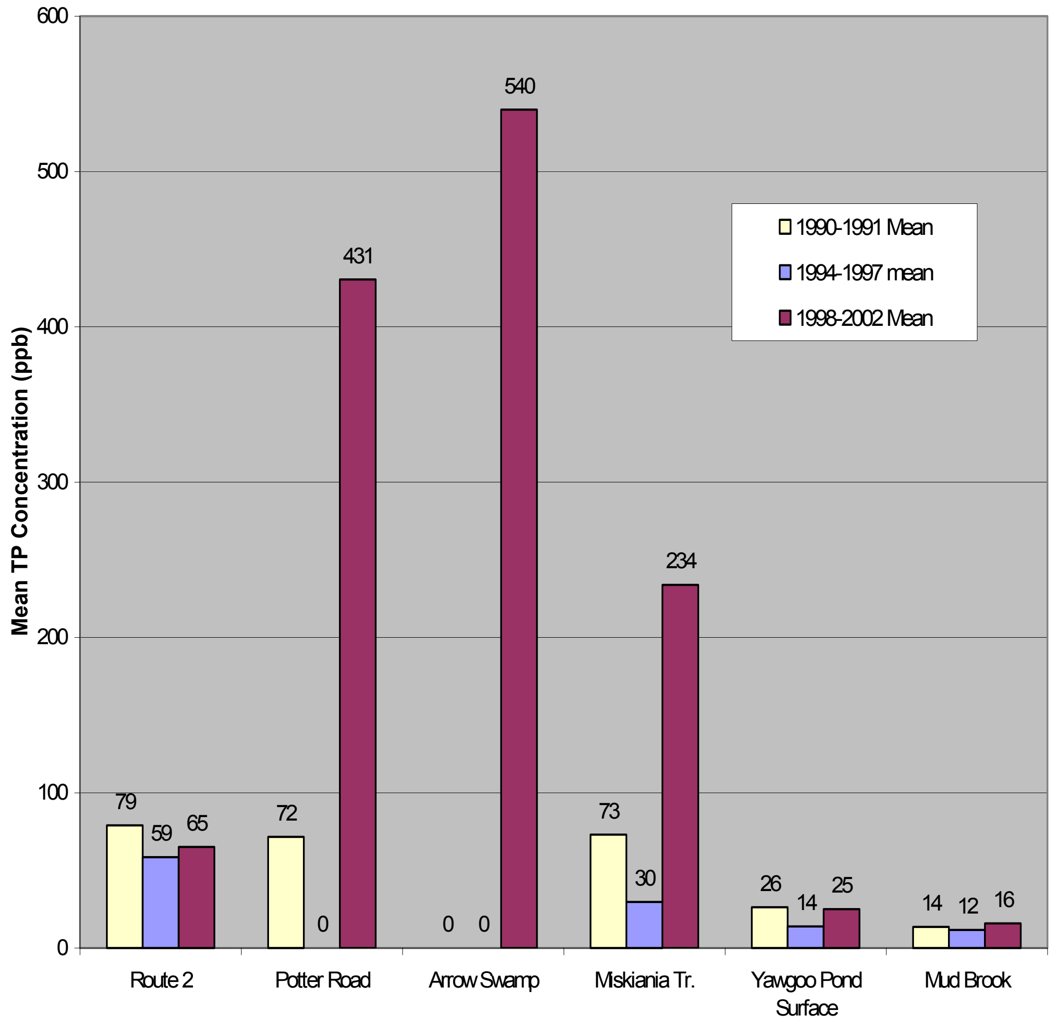
Table 3.10: Summary of estimated present total phosphorus loads and mean flows in the study area

Water body	Drainage area (sq. mi.)	Estimated mean annual discharge (cfs)	Mean annual (1998-2002) TP concentration from measurements (ppb)	Annual TP loading (kg/yr)
Chickasheen Brook at Miskiania Trail point of entry to Yawgoo Pond	1.32	2.83	233.90	425
Total Phosphorus load entering Yawgoo Pond (kg/yr):				446
Discharge leaving Yawgoo Pond and Chickasheen Brook at point of entry to Barber Pond	2.00	4.30	25.04	96
Total Phosphorus load entering Barber Pond (kg/yr):				147*
Discharge leaving Barber Pond	3.30	7.08		

* Load calculated from monthly values

release of phosphorus from the enriched soils of the swamp. Available information indicates that the concentration increase resulted from the release of phosphorus by the sediments. The release may have been triggered by the inundation of the swamp, which changed its physical and chemical properties. The phosphorus burden in the sediments apparently originated from the waste lagoons at the former Harbor Shellfish facility.

Figure 3.10: Comparison of annual phosphorus concentrations along the upper Chickasheen Brook watershed.



Available information suggests that the sludge deposits may still be present in one or more of the back-filled lagoons.

The increase at the Route 2 east station may result from increased development within the headwaters area, or may be an artifact of the measurement process. A comparison of aerial photos of the area in 1995 and 1999 shows eight additional houses on Azalea Drive and Kimberly Hope Drive in Exeter. This additional development would produce a slight load increase due to ISDSs and fertilizer applications to lawns.

The following equation was used to estimate the mean in-pond phosphorus concentration as a function of loading and other variables (Walker, 2001):

$$P = L / (Q + UA)$$

where:
P = lake phosphorus concentration (annual average value);
L = average external phosphorus load (Kg/yr);
Q = average annual lake outflow (million cubic meters/yr);
A = lake surface area (m^2); and
U = phosphorus settling velocity (m/yr).

Walker (2001) provides the following empirically-based means of estimating U:

$U = (zQ/A)^{0.5}$

Where z is the mean depth of the lake and Q and A are as defined above.

Estimates of the existing annual mean TP in the ponds based on the relationships given above using available information on lake outflow and geometry are presented in Appendix B. Using the estimated annual load (446 kg) to Yawgoo Pond, the annual mean concentration in the pond is estimated at 65.5 μg/l. This value is significantly higher than the depth-weighted value of 44.9 μg/l (RPD = 31.5%). The difference between the estimated total phosphorus concentration and the depth-weighted observed value may occur because the actual load from Chickasheen Brook is lower than the estimate or because the internal phosphorus settling velocity is faster than the rate of 5.13 m/yr calculated from the equation given above. For example, the use of the standard reference settling rate of 10 m/yr yields a mean total phosphorus concentration of 47.2 ug/l (RPD = 4.9%). The residence time used in the calculation is also estimated and may vary somewhat from the actual value.

Based on the estimate of annual load to Barber Pond, the annual mean concentration in the pond is expected to be 18.8 μg/l. This value compares well to the observed depth-weighted value of 19.2 μg/l (RPD = 2.4%). This in-pond estimate is closer to the actual value and may reflect that a better loading estimate or that concentrations in the pond have come closer to equilibrium following the load increase because the turnover time is shorter.

In conclusion, the calculations in Appendix B were in reasonable agreement with the historical data and stream discharge estimates. The exercise points out that the Walker equation may be used to set the allowable load to Yawgoo and Barber Ponds in Section 4 below.

3.2 Pollution Sources

Available information indicates that sources include the former Harbor Shellfish, Inc. (HSI) and Hillside Shellfish, Inc., phosphorus releases from sediments of Arrow Swamp, septic systems, former land practices (goat herd, alleged illegal septage dumping/ spreading), and other typical watershed sources (fertilizer applications to lawns, natural decomposition of organic matter, and wildlife). Identified sources vary by location. To simplify the water quality characterization, the upper Chickasheen Brook watershed was divided into segments.

Segment 1A comprises a portion of the Yawgoo Pond subwatershed east of Route 2. This area consists of Maple Swamp, several residences with ISDSs, the former Hillside Shellfish facility, a farm that formerly had a herd of goats, and a property that reportedly has allowed the historic and unlicensed spreading of sewage sludge.

Segment 1B comprises the Yawgoo Pond sub watershed, located between Route 2 and Miskiania Trail. Possible sources include the phosphorus-enriched soils of Arrow Swamp, a phosphorus burden remaining from historic uses at the former Harbor Shellfish facility, and wildlife.

Segment 1C encompasses the remainder of the Yawgoo Pond subwatershed. This area is located south of Miskiania Trail to the outflow of Yawgoo Pond. Possible sources include residential septic systems, atmospheric deposition, internal cycling of phosphorus, and contributions from wildlife (particularly geese).

Segment 2 includes the Mud Brook subwatershed, located between the Yawgoo Pond outflow and the Barber Pond inflow. There are no identified sources within this subwatershed.

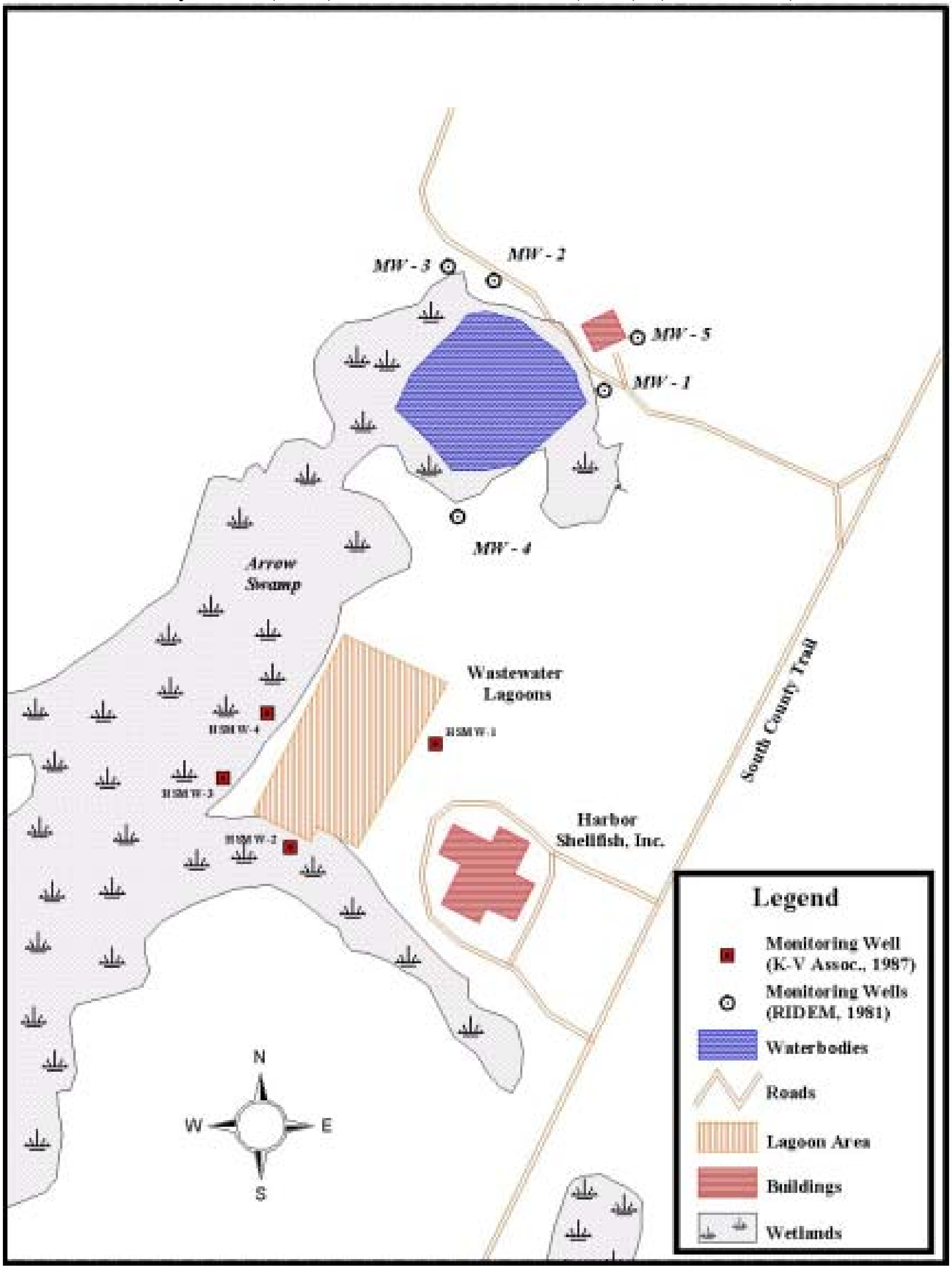
Segment 3 consists of the Barber Pond subwatershed. Other than the Yawgoo Pond discharge, other possible sources include the Allens Health Center on-site waste disposal system, atmospheric deposition, internal cycling of phosphorus, a stormwater discharge adjacent to the and residential septic systems in the watershed.

The first DEM investigations of Chickasheen Brook were initiated by complaints regarding two shellfish processing facilities located proximate to the headwaters. The former Harbor Shellfish, Inc. (HSI) facility was located on the west side of Route 2 and east of Arrow Swamp in Exeter, Rhode Island and is identified on Exeter Tax Assessor's Map 71, Block 4, Lot 3. Hillside Seafood was located approximately opposite HSI, on the east side of Route 2 and is identified on Exeter's Tax Assessor's Plat Map 72, Lot 9.

3.2.1 Harbor Shellfish, Inc.

A review of the DEM files for the former HSI facility was conducted to gather data regarding the facility. According to a DEM report entitled, *State of Rhode Island Surface Impoundment Assessment*, dated November 1980-October 1981, a complaint was received from a northerly abutter to HSI that his private water supply well was contaminated. Specifically, the complaint consisted of a strong hydrogen sulfide odor and a rusty color to the water. HSI was a processor of raw shellfish, and according to the report, the processing involved removal of the meat from the shellfish, washing of the meat and cleaning the shells with a caustic solution. Waste treatment of the effluent was accomplished by a series of 10 lagoons consisting of two lagoons reportedly lined and equipped with an aerator and 8 seepage lagoons. According to the report, the seepage lagoons were used on an alternating basis with 3 or 4 lagoons in use at any given time. The lagoons were reportedly constructed beginning in 1971 over a former wetland that was filled with sand and gravel to a depth of approximately 10 feet.

Figure 3.11: Locations of monitoring wells established in the vicinity of Harbor Shellfish, Inc. by DEM (1981) and K-V Associates (1987). (not to scale)



DEM placed four wells (MW-1 through MW-4 in Figure 3.11) in the vicinity of the abutter. MW-4 was located near the southern boundary of the property, approximately 75 feet from the nearest HSI lagoon. The other three wells were located approximately 400 feet to the north in a “fan pattern”. Samples were collected from the wells on two occasions, however, phosphate as P was only analyzed on the second sampling on July 8, 1981. The results are summarized in Table 3.11.

Table 3.11: Monitor well samples collected by DEM at HSI site on July 8, 1981.

Analyte (ug/l)	MW-1	MW-2	MW-3	MW-4
Phosphate as P	7,500	1,300	900	3,200
Ammonia as N	170	410	120	380
Nitrite as N	40	<20	<20	50
Nitrate as N	<100	<100	200	200
Chloride	6,000	11,000	6,000	92,000
Sulfate	13,000	10,000	7,000	16,000
Sodium	4,000	2,000	5,000	54,000
pH*	5.2	3.4	5.4	5.8

pH is reported in standard units (SU).

According to the report, the analytical results for chloride and sodium from the MW-4 sample “clearly indicate that the groundwater in the immediate vicinity of the impoundments is being contaminated by the wastewater in the lagoons.” However, in regard to the concentrations of chloride and sodium in the other wells, the report concluded that “*The results for these parameters at the other wells are low enough to be caused solely by natural means and contamination by material from the waste lagoons is not conclusively indicated*.” Additionally, despite the elevated concentrations of the other analytes, it was reported that “*The results of the analyses for the other parameters do not reveal any patterns that could demonstrate infiltration of pollutants from the impoundments into the groundwater…It appears that the poor physical quality of the water is being caused by some other localized source of groundwater degradation and/or flaws in the location and construction of the well itself*.”

Reports from nearby residents of odors and breaching of the lagoon berms prompted an inspection by DEM in 1986. On July 3, DEM notified HSI that there was an unpermitted wastewater discharge from the lagoons into Arrow Swamp and Chickasheen Brook, and HSI was ordered to stop all discharges into the swamp and brook and that the lagoon breaches be repaired. On September 8, 1986, DEM issued a Notice of Violation and Order (NOV) to HSI for violations regarding the discharge of pollutants to State waters. On January 5, 1987, DEM and HSI entered into a consent agreement which in part, resulted in a report prepared by K-V Associates, Inc. (K-V) of Falmouth, MA entitled, *An Evaluation of the Hydrogeology, Groundwater Quality, and Structural Integrity Harbor Shellfish Waste Water Treatment System, Exeter, R.I* dated April 1987.

On March 23, 1987, K-V advanced four boreholes using a 3.5-inch hand auger and completed them as monitor wells. These monitor wells are identified as HSMW-1 through HSMW-4, and their approximate locations are depicted in Figure 3.11. These wells ranged between 5.8 to 7.2 feet below surface grade. Analysis of the water table elevations in the wells indicated a southwesterly groundwater flow direction, towards Arrow Swamp. Monitor wells HSMW-1, HSMW3, and HSMW-4 were sampled. The laboratory analytical results from these samples are summarized in Table 3.12. The high levels of nutrients in the up-gradient well (HSMW-1) were attributed to the proximity of the monitor well to discarded shell material and fish and shellfish waste. Apparently the well was located in a low-lying area where the material was dumped. According to

Table 3.12: K-V analytical results, Harbor Shellfish, Inc., March 23, 1987.

Analyte (ug/l)	HSMW-1	HSMW-3	HMSW-4
Nitrate-N	1,240	20,900	3,590
Ammonia-N	7,800	5,000	360
TKN	7,910	5,900	1,770
Total phosphorus	112	120	359
Dissolved Phosphorus	112	120	359
Chloride	78,800	1,130,000	17,700
pH*	6.7	6.2	5.7
BOD	80,000	<3,000	20,000
Fecal Coliform**	<10	20	45
Total Coliform**	2,400	330	130
Sodium	53,500	3,770	21,400

*pH is reported as standard units (SU).
**Fecal and total coliform are reported as coliforms/100ml.

the report, the lowest elevations in the dump area intercepted the water table. Although the analytical results of the groundwater in the downgradient wells indicated impacts from the lagoons, K-V concluded that the "*processes of denitrification, sorption, dilution and degradation in the vast wetland area downgradient of the leaching ponds, however, should act to diminish any impact to Yawgoo Pond or distant water supplies*." K-V also recommended that the 1.1 to 1.5-foot thick layer of sludge in leaching pond 1 be sampled, analyzed and taken off-site for proper disposal. They also recommended that due to the contaminant levels in the up-gradient well, the drinking water well of the northerly abutter and that of HSI be sampled for nitrate-N and total coliform.

In response to the K-V report, DEM issued an evaluation letter to HSI on July 5, 1987. From the information presented in the report, DEM found two issues to be apparent:

- the groundwater proximate to HSMW-1 was impacted far beyond background levels for total coliform and beyond levels required for non-community water systems from the past and current disposal practices and,

- the groundwater quality to the southwest of leaching ponds 2 and 3 were degraded by fecal coliform, chlorides, and nitrates.

DEM also found it unacceptable to allow a freshwater wetland to act as a reducing agent for pollutants moving offsite. DEM required that, among other things, the contaminated effluent in the lagoons be pumped, removed, and disposed of at an approved facility and that quarterly monitoring of the onsite groundwater monitor wells be conducted for a year. Although not incorporated into the comment letter, a summary of comments and questions regarding the K-V report were in the materials reviewed in the DEM file. One of the comments stated that the wetland was not treating the effluent, as was implied in the K-V report, but only storing nutrients for eventual release with storms to Yawgoo and Barber Ponds. The letter noted that algal blooms were worse during wet weather. Another comment noted that both total phosphorus and dissolved phosphorus were high for all wells, enough to cause eutrophication conditions in receiving water bodies.

In response to a letter from the South Kingstown Town Clerk, DEM summarized the response actions of HSI in a letter dated January 27, 1988. According to the letter, HSI repaired the breaches in the lagoons during August and September 1987. HSI did not comply with the other terms of the consent agreement and DEM filed a Complaint and Request for Injunctive Relief in November 1987 with the Rhode Island Superior Court System. On November 25, 1987 a preliminary letter of agreement was drafted and executed on January 21, 1988. In December 1987, HSI replaced a monitor well that was destroyed and removed solid waste debris near the lagoons. All solid waste was reportedly being removed from the site or contained under impermeable material pending ultimate disposal. It appears that removal of the sludge deposits identified in the K-V report was not included as part of the consent agreement, and there is no documentation indicating whether the sludge deposits within the lagoons were ever excavated and disposed of properly.

Environmental Resource Associates (ERA) of Warwick, Rhode Island was hired by HSI to conduct quarterly sampling of the onsite monitor wells. Sampling was conducted on four dates between April and December 1988. The results of the monitoring are summarized in Table 3.13.

Additional assessment work occurred at the former HSI site during 1999 and 2002 that was spurred by the redevelopment of the site into an office park and with the development of the phosphorus TMDL. The site redevelopment also included removal of the liner for the aeration pond and removal of sludge. The sludge was then applied as a fertilizer or topsoil to the surface of the area to be seeded for grass along Route 2 (Robert Ferrari, personal communication). In 1999 RP Engineering was retained by Fieldstone Properties to sample the wells initially established in 1987. Monitoring well HSMW-2 was sampled in February 12. Wells HSMW-1 and HSMW-3 were sampled on March 1, 1999. Results of the 1999 sampling are listed in Table 3.14. Additional sampling of an unused 50’ deep water supply well near the southwest corner of the HSI site was conducted on July 24 and August 1 by DEM and Ferrari Engineering. DEM also collected four surface water samples in Chickasheen Brook on August 1: from the outflow of Arrow Swamp near the recently breached beaver dam, at Miskiania Trail, at the discharge of Chickasheen Brook into Yawgoo Pond, and Chickasheen Brook at the

Table 3.13: HSI quarterly groundwater monitoring, 1988

Station		pH	BOD5 (ug/L)	Ammonia (ug/l)	Total Kjeldahl Nitrogen (ug/L)	Nitrate (ug/L)	Total Phosphate (ug/L)	Chloride (ug/L)	Sodium (ug/L)	Total Coliform (col/100ml)	Fecal Coliform (col/100ml)
HSMW-1	Minimum	6.7	1,500	7,800	7,910	70	112	78,800	53,500	9	1
	Mean	6.9	26,300	78,360	93,782	12,538	940	166,560	131,500	2,206	3
	Maximum	7.0	80,000	126,000	134,000	44,000	2,300	200,000	265,000	7,500	5
	Count	5	5	5	5	5	5	5	5	5	5
HSMW-2	Minimum	6.4	1,500	3,150	4,200	1,380	360	295,000	111,000	23	1
	Mean	6.6	6,000	12,438	11,575	8,645	1,203	613,333	427,250	1,229	30
	Maximum	6.7	13,000	20,000	16,800	15,000	2,800	790,000	749,000	2,400	93
	Count	4	4	4	4	4	4	3	4	4	4
HSMW-3	Minimum	5.5	1,500	3,050	3,400	9,500	120	215,000	3,770	4	1
	Mean	5.8	1,500	5,010	6,910	14,580	411	640,000	192,554	79	5
	Maximum	6.2	1,500	10,000	15,300	20,900	920	1,130,000	351,000	330	20
	Count	5	5	5	5	5	5	5	5	5	5
HSMW-4	Minimum	5.3	1,500	5	1,700	3,590	100	17,700	21,400	1	1
	Mean	5.7	5,200	1,171	2,564	8,370	552	212,540	99,440	28	10
	Maximum	5.9	20,000	3,150	3,400	11,400	1,080	390,000	149,000	130	45
	Count	5	5	5	5	5	5	5	5	5	5

outlet of Barber Pond. The samples were analyzed for chloride and total phosphorus. Results are listed in Table 3.15. The analysis results in Chickasheen Brook are consistent with the URIWW data for the brook during 2002. Total phosphorus levels increased with distance downstream to a maximum value of 420 ug/l at the point where the brook discharges to Yawgoo Pond. Phosphorus and chloride levels in the well sample were 90 ug/l and 50 mg/l, respectively.

On August 1, 2002, the 50' well at the southwest corner of the former HSI property was again sampled, along with the service well located adjacent to Route 2 on the property by

Table 3.14: Sampling results for HSMW-1, HSMW-2, and HSMW-3 during 1999.

	HSMW-1 (ug/l)		HSMW-2 (ug/l)		HSMW-3 (ug/l)	
Date	2/12	3/1	2/12	3/1	2/12	3/1
pH		7.7	6.4			7.4
Nitrate		470	3100			19,700
TKN		<500	3600			12,300
Ammonia		200	3200			9400
Phosphate		500	150			220
Sodium		6510	57500			24200

Table 3.15: DEM sampling results for former HSI site and Chickasheen Brook, August 1, 2002.

Sample Site	50' well	Arrow Swamp	Miskiania Trail	Chickasheen outlet to Yawgoo Pond	Barber Pond Outlet
Chloride (mg/l)	50	20	22	18	16
Total Phosphorus (ug/l)	90	190	340	420	50

Table 3.16: Ferrari Engineering sampling results for former HSI site, July 24 and August 1, 2002.

Sample Site	**50' well** (ug/l)	**500' Service well** (ug/l)
Total Phosphorus	<50	N/A
Total Phosphorus	50	N/A
Nitrite	<10	<10
Nitrate	950	170
Calcium	9400	24500
Chloride	50000	49000
Sodium	N/S	22000

an engineer from Ferrari Engineering, a consultant for the site developer. The water samples were analyzed for total phosphorus, chloride, and calcium. The service well sample was also analyzed for sodium. The results of the August 1 sampling are listed in Table 3.16.

Tables 3.12 through 3.16 show a trend of decreasing phosphorus concentration in groundwater below the former HSI facility between 1988 – 2002. The means of all values for the three sampling periods are 760 ug/l (1988), 290 (1999), and 70 ug/l (for 2002). Phosphorus levels seen in the wells, even during 2002, remain significantly higher than those reported by USGS in other well samples in Washington County. A 1990 letter from the USGS Providence office to Lorraine Joubert of the URI Department of Natural Resources lists groundwater phosphorus data apparently collected during 1989 (not all the data have corresponding dates). The mean of the groundwater data (N=62) is 33 ug/l; the maximum value is 610 ug/l (Burns, 1990). The mean is biased by four values exceeding 100 ug/l; with the four values excluded, the mean groundwater concentration is 15 ug/l. From this information, it is apparent that groundwater phosphorus levels at the former HSI site continue to be elevated. By association, the cause is deduced to be that the historic use of the property has left a phosphorus burden that is dissipating with time.

The available information does not support the hypothesis that the increased migration of phosphorus to Chickasheen Brook is related to the disturbance of soils at the site. This may be discounted by comparing the timing of the start of construction activities at the HSI site in the summer of 2000 (Robert Ferrari, personal communication) with the timing of the total phosphorus concentration increase in Miskiania Brook in Figure 3.4. The fact that the effect precedes the presumed cause by two years is sufficient to show that soil disturbances at the site were not the cause of the increase.

The phosphorus concentrations in groundwater are significantly lower, however, than levels seen in the surface waters of the swamp and stream. In addition, the historic groundwater concentrations (Table 3.11) were lower than those currently seen in the surface: the mean of the of the 2002 data for the 50’ well is 70 ug/l, while the 2002 mean for Chickasheen Brook at Miskiania Trail is 252 ug/l. This comparison indicates that another source exists in the swamp between the edge of the facility and Miskiania Trail. The potential mechanism for this source is discussed in section 3.2.4 below.

3.2.2 Hillside Seafood

Hillside Seafood (Hillside) was located across the street from HSI, on the east side of Route 2. A DEM Underground Injection Control (UIC) Application, dated November 10, 1989 was reviewed from the UIC Program files. Laboratory analytical data, dated February 15, 1990, was also in the file, presumably in support of the UIC application and characterized the wastewater effluent. This data is presented in Table 3.17. In May 1990, a complaint was filed with DEM regarding the possible “dumping” of pollutants into Chickasheen Brook. A preliminary inspection by DEM revealed apparent seafood process effluent in the catch basins along the east side of Route 2 that eventually discharged to Chickasheen Brook. The inspector followed staining in a stormwater swale that led to the Hillside operation.

Table 3.17: Wastewater characterization for Hillside Seafood, February 6, 1990.

Analyte	Concentration (ug/l)
pH*	6.6
Chloride	100,000
Ammonia as N	135,000
Nitrate as N	750
Sulfate	195,000
Phosphate as P	36,000

*pH reported as Standard Units (SU).

On May 18, 1990, representatives of the DEM UIC Program, Water Resources, and Solid Waste conducted a joint inspection of Hillside. The purpose of the inspection was to determine if there were any violations of DEM laws and regulations. The processing facility had a floor drain running the length of the seafood cleaning and packaging room. The owners of the operation indicated that there was a "state-approved" individual septic disposal system (ISDS) for the disposal of the effluent. A large stockpile (40' x 50' x 8') of shells and shellfish meat residue were noted on the northeast portion of the property with associated vector (fly) and odor problems. In a letter issued by DEM on May 30, 1990, to avoid the issuance of a Notice of Violation and Administrative Penalty to Hillside, a plan of remediation was requested. The plan was to address the storage of shells on site and an odor and vector control program was to be established. Hillside was informed that the on-site landfilling of shells was prohibited.

Complaints against the Hillside operation prompted several sampling events that were conducted by DEM. The laboratory analytical results from these surveys are summarized in Table 3.18.

A complaint regarding a blue-green algal bloom on Yawgoo Pond was received by DEM on May 19, 1990. In response, DEM conducted sampling of Chickasheen Brook from the headwater swamp outflow, located below the Hillside operation, to the inflow of Yawgoo Pond on June 21, 1990. On October 24 and 26, 1990, additional inspections of Hillside and Chickasheen Brook were conducted during a wet weather event. The rain gauge at the DEM office in Providence recorded 1.18 inches of rain on October 23 and 24, 1990.

A DEM inter-office memo, dated October 30, 1990, summarized the October 24th inspection. A "seepage area" was adjacent to a 4-inch PVC groundwater observation pipe and a sample was collected from the depression. Presumably, the seepage area collected the drainage from a stockpiled area of discarded shells and clam bellies. The memo indicated that a Notice of Violation would be issued with an administrative penalty.

On May 1, 1991, a NOV was issued by DEM to Hillside. On June 12, 1991, Hillside responded with a denial of the alleged violations and filed a notice of claim for appeal and requested an adjudicatory hearing.

Table 3.18: Laboratory analytical results for total phosphorus from DEM sampling at Hillside Seafood (ug/l).

Sampling Station	6/21/90	10/24/90	10/26/90	12/4/90	1/17/91
Onsite seepage pit	NS	167,500	NS	NS	NS
Headwaters, Rte. 2 west	200	700	<100	330	40
Entrance to Arrow Swamp	180	NS	<100	250	70
Exit to Arrow Swamp	230	NS	<100	140	110
Entrance to Yawgoo Pond	180	NS	<100	NS	NS

NS= Not Sampled

On March 11, 1992, DEM sent a proposed Consent Agreement to resolve the NOV that was issued to Hillside. After several correspondences between DEM and Hillside's legal representative, a revised consent agreement was fully executed on December 21, 1993. In regards to water quality issues, the consent agreement stipulated that all commercial operations at the property would permanently cease, that a licensed septage hauler would pump out all sewage waste contained in the septic tank/holding tank, and that the septic tank/holding tank would be removed. On January 6, 1994, DEM issued a letter to Hillside that all the stipulations in the consent agreement had been met and that the Department considered the matter resolved.

3.2.3 University of Rhode Island, Graduate School of Oceanography Report

The DEM Office of Compliance and Inspection (OCI) file contained a short report by two researchers from the URI Graduate School of Oceanography (GSO) (Rahn and Cullen, 1991). According to the report, the researchers collected samples throughout the Yawgoo Pond watershed and analyzed the samples for a variety of major and minor indicator elements and compared the results to "signatures" of various types of pollution that were developed by the GSO. Rahn and Cullen (1991) compared the pollution signatures from Arrow Swamp and from Maple Swamp. They described Maple Swamp as being U-shaped and opened to the northwest. This wetland drained to Arrow swamp via the Chickasheen Brook (south lobe) and an unnamed brook (north lobe). The southern portion of Maple Swamp extends beyond Yawgoo Valley Road via two culverts under the road. According to Rahn and Cullen (1991), water flows clockwise around most of the swamp to Chickasheen Brook. The northern unnamed brook appeared to drain only the small part of the swamp nearest to it.

Rahn and Cullen (1991) presented the elemental signature data as weighted concentrations to produce approximately flat plots for typical South County streams so that deviations from the norm would appear as peaks or valleys on the plots. The weighting factors consisted of Na, Cl, and Ca x 1, Mg and K x 10, Br and PO_4 x 100, and I x 1,000.

The pollution signal from Maple Swamp contained much more phosphorus and less salt. To Rahn and Cullen (1991), this indicated pollution from fresh instead of marine sources. The elemental signature of the water within Maple Swamp was also unusually enriched in potassium, and, according to Rahn and Cullen indicated a strong correlation toward human (septic effluent) and/or animal waste (attributed to a goat population of approximately 100 or more animals from the mid-1970s to 1990 that grazed on land within the swamp) as the phosphorus source.

According to Rahn and Cullen, the chemical signal from Arrow Swamp contained much salt but little phosphorus, the kind of signal expected from shellfish processing if waste parts decayed slowly. The salt also chemically appeared to be sea salt rather than road salt. For these reasons, they believed that Arrow Swamp's signal was most likely from old effluent from HSI.

In the report, Rahn and Cullen compared the elemental signature of the headwaters region (sample station east of Rt. 2) to signatures of possible sources. Sources enriched in K and Mg include sewage sludge (the best overall match), angiosperms, manure and possibly modified septic effluent. The signature for clams appeared to be similar, but reportedly was based only on the living matter, and according to the authors, if 10 to 15 ml of seawater liquor per clam is also considered, did not match the signature of the headwaters region.

The report concluded that although there was a strong link between pollution sources from the seafood operations and water quality impairments to Yawgoo Pond, other sources needed to be investigated.

3.2.4 Arrow Swamp

Arrow Swamp has been identified as the major source of phosphorus to Chickasheen Brook, Yawgoo Pond, and Barber Pond. The sediments of the swamp have an apparently phosphorus enrichment that originated with historic loadings from the Harbor and Hillside facilities. The construction of beaver dams at the outlet has inundated the swamp. This inundation has apparently been of sufficient depth to produce anoxia at the sediment/water interface, resulting in the release of phosphorus to the water column.

Based on triangulation of the water table elevations in the monitor wells installed around the HSI lagoons, a southwesterly flow direction of groundwater towards Arrow Swamp was indicated by K-V Associates. The phosphorus concentrations in wells sampling by K-V and ERA indicate elevated groundwater phosphorus loading to the swamp, at least during the period when HSI was in operation. While the swamp was dewatered and the soil oxidized, the low concentrations in surface water flowing from Arrow Swamp indicated that the phosphorus was bound to the soil in Arrow Swamp. However, the later inundation caused by beaver activity and the subsequent increase in concentration of surface water exiting the swamp indicated that the phosphorus was released from the soil to the ground/surface water. The release and retention of phosphorus in soil is briefly explained below.

Phosphorus occurs in nature almost exclusively as phosphate. A large fraction of the phosphate in soil is typically sorbed to soil particles or incorporated into soil organic matter (Holtan et al, 1988).

According to Holtan et al, sorption-desorption reactions are responsible for determining the level of phosphate in the solution at equilibrium in soils and sediments with large amounts of iron hydrous oxides. The charge of the iron hydrous oxides is pH-dependent. At low pH, the iron oxides have a positive surface charge. The soils within Arrow Swamp consists of Adrian mucks, which are strongly to slightly acidic in the surface horizon (Rector, 1981). Sorption-desorption is expected to be the primary mechanism affecting retention and release of phosphorus in the swamp, based on the acidity of the mucks and the concomitant surface charge of the iron hydrous oxides. In environments enriched by elevated phosphorus concentrations, phosphorus may precipitate directly on soil surfaces. In these systems, precipitation may dominate as the process retaining phosphorus.

Under oxidized conditions, phosphate is adsorbed and co-precipitated with amorphous ferric oxyhydroxides, and the swamp would adsorb phosphate loadings. This condition would exist when the beaver dam and inundation are present. Under reduced (flooded) conditions, the reduction of iron occurs when microorganisms use ferric iron as an electron acceptor during respiration after oxygen and nitrate are depleted. The reduction of ferric (Fe^{3+}) iron to ferrous (Fe^{2+}) iron causes the dissolution of the ferric-oxyhydroxide-phosphate complexes, resulting in a release of ferrous iron and phosphate to the water column. Holtan et al also indicates that "soils earlier exposed to reducing conditions have shown a great capacity to sorb phosphate by formation of new amorphous iron compounds." This indicates that a return to oxidized conditions in Arrow Swamp by eliminating the inundation of the swamp may enable the continued retention of phosphorus by the soil to reduce loadings to the surface water bodies. The oxic conditions are also anticipated to promote re-vegetation of the swamp and additional phosphorus retention within the plants.

3.2.5 Direct storm runoff via point sources

The upper Chickasheen Brook watershed is principally undeveloped, so most storm-related runoff to its surface waters is nonpoint (diffuse) in nature. Runoff from roadways in the area, however, combines in discrete conveyances and is discharged to area surface waters as point rather than as nonpoint discharges. Road runoff directly entering the area's surface waters is therefore considered to represent a group of point sources of pollution that would be included in the stormwater (SW) component of the waste load allocation (WLA). An estimate of the current point source loading from roadways was made by combining the area of roadway contributing runoff with annual rainfall data and empirical data on phosphorus concentrations in storm runoff.

DEM staff identified areas of Route 2 and Yawgoo Valley Road that would drain directly to upper Chickasheen Brook in March 2003. Measurements of both roads indicated that an area of approximately 0.83 ha, 6280 m^2 from Route 2, and 2040 m^2 from Yawgoo Valley Road, discharges to the brook. Similarly, an area of 0.43 ha drains directly to

Barber Pond, with 3870 m^2 from Route 2 and 360 m^2 from Barber Pond Road. A concentration of 0.26 mg/l was chosen as representative of stormwater from roads (Smullen and Cave, 1998). Annual rainfall was taken as the mean for the period of record at Green Airport, 1.07 m/yr. The combination of these three factors, assuming no infiltration or other loss from the roadway surfaces, yielded estimated point source stormwater loadings to upper Chickasheen Brook and Barber Pond of 2.4 kg and 1.2 kg, respectively. The point stormwater loads are therefore quite small when compared to the total loads entering the stream and ponds.

3.3 Summary of current point and nonpoint loads

The estimates of point source loadings in Section 3.2.5 allow the total loadings to upper Chickasheen Brook, Yawgoo Pond and Barber to be broken down into their point and nonpoint components in Table 3.19 below. Stormwater inputs to Chickasheen Brook are assumed to represent the point source component of the total phosphorus load to Chickasheen Brook and Yawgoo Pond. The estimated point source load entering Barber Pond is the sum of loads directly entering the pond near the fishing access and those entering upstream reaches. This assumption yields a high estimate of the point loading to Barber Pond because it is apparent, based on the available data, that only a fraction of the nonpoint phosphorus load entering Yawgoo Pond exits via Chickasheen Brook to enter Barber Pond, perhaps because a majority of the phosphorus load entering Yawgoo Pond is trapped in its sediments. The point source component of the Barber Pond load listed in the table is probably at the high end of the likely range.

Table 3.19: Point and nonpoint total phosphorus loads summary

Water body	Total annual TP loading (kg/yr)	Point source TP loading (kg/yr)	Nonpoint source TP loading (kg/yr)
Chickasheen Brook at Miskiania Trail point of entry to Yawgoo Pond	425	2.4	422.6
Total phosphorus load entering Yawgoo Pond	446	2.4	443.6
Leaving Yawgoo Pond and Chickasheen Brook at point of entry to Barber Pond	96	2.4	93.6
Total phosphorus load entering Barber Pond	147	3.6	143.4

3.4 Natural Background Conditions

Natural background concentrations are those that would exist in the area in the absence of human-induced sources. Observed total phosphorus concentrations in remote areas of the Mud Brook subwatershed for the period of 1998-2002 ranged from non-detectable (<4 ug/l) to 66 ug/l with a mean value of 15.9 ug/l. These levels are considered to be representative of the natural background condition. The historical data for both ponds summarized in Section 3 indicates that the natural background growing season condition of the hypolimnia of both ponds was at least periodically hypoxic because instantaneous dissolved oxygen concentrations were less than 5.0 mg/l. It is also likely, given the thermal stratification of the ponds, that the other parts of the oxygen criteria were also violated. These conditions are considered as representative of natural oxygen levels in the ponds.

3.5 Water Quality Impairments

Based on data gathered during this TMDL study, segment 1B of Chickasheen Brook, which includes the reach between the headwaters of the brook east of Route 2 to the discharge point to Yawgoo Pond, exceeds the State's total phosphorus criterion of 0.025 mg/l. Yawgoo Pond (in segment 1C) consistently does not meet Class B criteria for dissolved oxygen (instantaneous minimum dissolved oxygen content not less than 5.0 mg/l), total phosphorus (0.025 mg/l), and excess algal growth. Barber Pond (segment 3) also does not meet the numeric dissolved oxygen criteria. The dissolved oxygen conditions of the hypolimnia of both ponds are considered to be attributable to natural causes, however the duration and severity of the hypoxia are considered to be aggravated by current levels of phosphorus loadings that are attributable to historic human activity.

4.0 TOTAL MAXIMUM DAILY LOAD ANALYSIS

As described in EPA guidelines, a TMDL identifies the pollutant loading that a waterbody can assimilate per unit of time without violating water quality standards (40 C.F.R. 130.2). The TMDL is often defined as the sum of loads allocated to point sources (i.e. waste load allocation, WLA), loads allotted to nonpoint sources, including natural background sources (i.e. load allocation, LA), and a margin of safety (MOS). The loadings are required to be expressed as mass per time, toxicity, or other appropriate measures (40 C.F.R. 130.2[I]).

4.1 Establishing a numeric water quality target

Margin of Safety (MOS)

The MOS may be incorporated into the TMDL in two ways. One can implicitly incorporate the MOS using conservative assumptions to develop the allocations or explicitly allocate a portion of the TMDL as the MOS. This TMDL includes an explicit MOS of 10% of the design load from Chickasheen Brook at Miskiania Trail. Implicit MOS are included in the phosphorus loading targets for the two ponds by setting targets that are significantly below the state phosphorus standard for lakes (54% and 58% for Yawgoo and Barber Ponds, respectively). The targets are based on the expected load to the ponds in the absence of human influence, to ensure that impairments for dissolved oxygen and aquatic vegetation are eliminated.

Seasonal Variation/Critical Conditions

As the term implies, TMDLs are often expressed as maximum daily loads. However, as specified in 40 CFR 130.2(I), TMDLs may also be expressed in other terms as appropriate. For Chickasheen Brook, Yawgoo Pond, and Barber Pond, the TMDL is expressed in terms of allowable annual loadings of total phosphorus. Critical water quality conditions for total phosphorus, dissolved oxygen, and plant growth occur during the summer season. However, the information available on phosphorus loads to Yawgoo and Barber Ponds indicates that summer season phosphorus loads are lower, primarily because inflows decrease. The evaluation of loads and load reductions on an annual basis is therefore considered to be more protective of the water bodies. Given the 215 to 246 day detention time of Yawgoo Pond, consideration of phosphorus loading on an annual basis is appropriate. In addition, the effectiveness of nonpoint source controls is better evaluated on an annual, rather than a daily basis.

Numeric Water Quality Targets

Historic shellfish processing operations in the Chickasheen Brook watershed are believed to be the primary source of phosphorus, causing water quality impairments in both Yawgoo and Barber Ponds. This TMDL sets numeric concentration targets for Chickasheen Brook of 22.5 ppb, which is equivalent to the state's water quality standard of 25 ppb minus a 10% explicit margin of safety.

The resulting numeric concentration targets for Yawgoo and Barber Ponds establish the scale of the reductions necessary to support their designated uses. It may not be necessary, however, to attain the numeric targets specified to achieve the goal of supporting designated uses. This TMDL will be considered implemented when the conditions necessary to support each water body's designated uses, as naturally occurs, are attained. More specifically, these conditions are algal abundance equivalent to a chlorophyll-a level less than 9 ug/l, a shift from blue-green algae as the dominant species, elimination of noxious plant accumulations in Chickasheen Brook, and return of dissolved oxygen conditions in the ponds to those seen in the 1950's.

DEM has set numeric targets for total phosphorus concentration in Chickasheen Brook, Yawgoo Pond, and Barber Pond that vary by water body. A concentration of 22.5 ug/l is the target for Chickasheen Brook upstream of Yawgoo Pond. The point of compliance for Chickasheen Brook is the historic measurement point at Miskiania Trail. The total phosphorus numeric targets for Yawgoo Pond and Barber Pond are concentrations of 11.4 ug/l and 10.6 ug/l, respectively. The compliance points for Yawgoo and Barber Ponds are the historic surface sampling stations.

The URIWW data indicates that the primary problem affecting Yawgoo and Barber ponds is an overabundance of algae caused by elevated levels of phosphorus. The presence of algal blooms diminishes the value of the ponds for virtually all uses and aggravates hypoxic conditions in the bottom waters of the ponds in the summer months. Recreational use is made less appealing, aesthetic enjoyment is impaired, and habitat value is reduced. There are no regulatory standards governing the precise target level of algal abundance and the ideal level will vary depending on the management goal of the water bodies. Yawgoo Pond currently experiences blue-green algal blooms during the summer months. Blue-green algae, also known as cyanobacteria, have the highest biomass:chlorophyll ratio (up to 300:1) (DEM, 1998), and as such, the type of algae present requires attention. Although 9 μg/L of chlorophyll, even if associated with blue-green algae, is likely to cause only limited impairment of use, it would be far more desirable for recreation, aesthetics, and habitat value if the algae were dominated by diatoms and green algae. Diatoms and green algae would yield a lower biomass per unit of chlorophyll and be more easily utilized in the food web. Chickasheen Brook also experiences undesirable accumulations of duckweed (*Lemna* spp.), a small vascular plant that readily takes up phosphorus (See the cover of this document). Consequently, the restoration goals for Yawgoo Pond and Chickasheen Brook should reflect reductions in chlorophyll levels to 9 μg/L, a shift away from blue-green algae as the dominant algal division present during the summer, and the need to eliminate the presence of noxious plant species in the brook.

It is possible to address the algal abundance impairment and the component of the dissolved oxygen impairment related to nutrient loads by reducing the phosphorus load to the ponds. This is principally due to the fact that algal abundance in fresh water bodies is generally limited by the availability of phosphorus. Empirical relationships between chlorophyll a and total phosphorus in lakes, summarized in Thomann and Mueller (1987), are presented below:

1) Bartsch and Gakstatter (1978):

$$\text{Log}_{10}(\text{chl a}) = 0.807 \log_{10}(\text{TP}) - 0.194$$

2) Rast and Lee (1978):

$$\text{Log}_{10}(\text{chl a}) = 0.76 \log_{10}(\text{TP}) - 0.259$$

3) Dillon and Rigler (1974):

$$\text{Log}_{10}(\text{chl a}) = 1.449 \log_{10}(\text{TP}) - 1.136$$

The chlorophyll-a concentrations predicted by the relationships above for the water quality standard concentration of 25 ug/l total phosphorus in the water column are presented in Table 4.1. The three empirical equations project that with total phosphorus at the water quality standard, chlorophyll-a concentrations will be in the range of values expected for a mesotrophic pond. The use of total phosphorus as the numeric target is therefore considered suitable for ensuring that chlorophyll-a concentrations will be in an acceptable range.

Yawgoo and Barber Ponds must also meet the numeric dissolved oxygen criteria discussed in section 1.4: an instantaneous value not less than 5.0 mg/l, not less than a daily averaged saturation value not less than 60%, and a 7-day mean water column concentration not less than 6 mg/l. It is DEM's opinion that oxygen levels in the hypolimnia could improve if phosphorus loadings were reduced, however no widely accepted methodology exists for establishing the degree of improvement in dissolved oxygen levels. Historic data presented in section 3 indicate that the ponds were hypoxic when the watershed was largely open land. It is therefore apparent that the dissolved oxygen criteria would not be met if the ponds were returned to their historic condition, so the current oxygen impairment reflects their natural condition (i.e. thermal stratification). The definition for "Low quality waters" in the Water Quality Regulations states, "*Waters in their natural hydraulic condition may fail to meet their assigned water quality criteria from time to time due to natural causes, without necessitating the modification of assigned water quality standard(s). Such waters will not be considered to be violating their water quality standards if violations of criteria are due solely to naturally occurring conditions unrelated to human activities.*" The clear intent of the definition is to state that a water body not meeting numeric criteria solely due to natural causes is not considered impaired.

Total phosphorus concentrations in Barber Pond are presently below (i.e. levels meet) the state water quality standard. A component of the existing load reaching Barbers Pond is related to upstream sources caused by historic human activities along Chickasheen Brook and from stormwater discharges to the pond. This human-related phosphorus load exacerbates the violation of the dissolved oxygen numeric criteria in the hypolimnion of the pond, and contributes to blooms of blue-green algae in the pond. The reductions in phosphorus loads to the upstream waters of Yawgoo Pond and Chickasheen Brook, combined with the reduction in direct stormwater loads will effectively remove the human-related sources that partially contribute to the failure of Barber Pond to meet the numeric dissolved oxygen criteria. It is DEM's opinion that once phosphorus loadings to Yawgoo Pond are reduced to below the annual target values, Yawgoo and Barber Ponds will be considered to be in their natural state. DEM estimates that this condition will occur when the concentration targets in the stream and ponds are met, however the TMDL will be considered implemented when conditions necessary to support the designated uses of each waterbody, as naturally occurs, are restored.

Table 4.1: Ambient chlorophyll-a concentrations expected to correspond to the water quality standard concentration for total phosphorus predicted by three studies.

Reference	Total phosphorus (ug/l)	Chlorophyll-a (μg/l)
	(Input)	(Output)
Bartsch and Gakstatter (1978)	25	8.6
Rast and Lee (1978)	25	6.4
Dillon and Rigler (1974)	25	7.8

The objective of this TMDL is to restore the ponds to a condition that supports their designated uses and protects them from future degradation. In summary, the goals of this TMDL are to:

- Reduce total phosphorus levels in the ponds and Chickasheen Brook at the points where it discharges into the ponds;
- Reduce algal abundance to below a chlorophyll level of approximately 9 μg/L;
- Shift away from blue-green algae as the dominant algal division in the summer;
- Eliminate noxious plant accumulations in Chickasheen Brook; and
- Improve instantaneous dissolved oxygen levels in the ponds to the maximum extent feasible.

4.2 Establishing the Allowable Loading (TMDL)

The allowable pollutant load, or TMDL for Chickasheen Brook and Yawgoo and Barber Ponds can be expressed as follows (EPA, 2002):

Allowable pollutant load (TMDL) = Waste load allocation (WLA)
+ Load allocation (LA)
+ Margin of safety (MOS)

where WLA = Non-stormwater point source waste load allocation (NSW)
+ Stormwater waste load allocation (SW)

No non-stormwater point discharge inputs have been identified in the study area. Loads from stormwater systems discharging to Chickasheen Brook and Barber Pond are identified in section 3.2.5 above; this term (SW) is considered a component of the WLA. Other stormwater sources are nonpoint in nature and are included in the LA. Ten percent of the allowable pollutant load from Chickasheen Brook at Miskiania Trail is reserved for an explicit MOS. For the other water bodies, the MOS is incorporated implicitly by setting concentration and load targets for phosphorus that are very protective.

Load and concentration targets for Chickasheen Brook upstream of Yawgoo Pond and for Yawgoo pond were established by setting a target concentration for Chickasheen at 10% below the state phosphorus standard at its point of discharge into Yawgoo Pond. The allowable annual load was calculated as the product of the annual mean discharge of the stream at that point and the target mean concentration. The Miskiania Trail station is selected as the point of compliance for discharge to Yawgoo Pond because of the availability of historical data for that point, and because the station is sufficiently close to the pond. Appendix C documents the calculation of an annual loading target of 57 kg/yr at Miskiania Trail. When the load from Chickasheen Brook to Yawgoo Pond drops from its current value of 425 kg to 57 kg, the overall total phosphorus load to Yawgoo Pond will decrease significantly from 446 to 78 kg/yr.

The allowable loading (TMDL) for each reach is divided into its component parts in Table 4.2. The non-stormwater waste load allocation (NSW) is zero for all waterbody reaches. The stormwater waste load allocations (SW) were set as 30% reductions of the existing loads. This reduction level is consistent with the implementation of nonstructural BMPs and/or vegetated filter strips (either grass or woody vegetation) along the roadway areas draining to Chickasheen Brook (Rte. 2 and Yawgoo Valley Road) and Barber Pond (fishing access and Barber Pond Road). The LA is calculated as the difference between the TMDL minus the MOS, and the sum of the other terms.

Table 4.2: Allocation of phosphorus loads for each water body

Water Body	TMDL (kg/yr)	=	WLA (kg/yr)	+	SW (kg/yr)	+	LA (kg/yr)	+	MOS (kg/yr)
Chickasheen Brook (Miskiania Trail)	57	=	0	+	1.7	+	49.2	+	6
Yawgoo Pond	78	=	0	+	1.7	+	76.0	+	0
Chickasheen Brook (entry to Barber Pond)	44	=	0	+	1.7	+	42.1	+	0
Barber Pond	83	=	0	+	2.5	+	80.7	+	0

The projected loadings to Yawgoo and Barber Ponds calculated in Appendix C for the condition where Chickasheen Brook meets its targets are summarized in Table 4.2. These target loadings are 57 kg/yr at Miskiania Trail and 44 kg/yr at the point of entry to Barber Pond. Appendix C projects annual mean TP concentrations of 11.4 and 10.6 ug/l in Yawgoo and Barber Ponds, respectively, when the numeric targets are met in Chickasheen Brook. Appendix C shows that with the reduction target met from the upper Miskiania watershed, phosphorus levels in the two ponds will be significantly lower than the state standard. Total phosphorus in Yawgoo pond will also be lower than the annual mean conditions observed during 1994 to 1997 when the mean TP concentration was 13.9 ug/l at the surface (1 m) and 17.9 ug/l at the deep (~5 m) station. Similarly, the projected mean concentration in Barber Pond will also be lower than the 1994 to 1997 mean values of 13.3 ug/l and 12.2 ug/l at the shallow and deep depths.

4.3 Required reductions (Load Allocation/Waste Load Allocation)

Current loads, target loads (TMDL), and reductions in existing loads are summarized in Table 4.3.

Table 4.3: Required load reductions

Water Body	Current Load (kg/yr)	TMDL (kg/yr)	Load Reduction (kg/yr)	Loading reduction (% present value)
Chickasheen Brook (at entry to Yawgoo Pond)	425	57	368	87%
Yawgoo Pond	446	78	368	83%
Chickasheen Brook (at entry to Barber Pond)	96	44	52	54%
Barber Pond	147	83	64	43%

4.4 Strengths and Weaknesses in the TMDL Process

<u>Strengths:</u>

- The TMDLs set reductions that are expected to return the water bodies to their pre-development condition.
- The TMDL is based on extensive data and knowledge of the watershed provided by URIWW;
- The TMDL incorporates the findings of several studies and utilizes data collected over several years;
- The phased approach allows an emphasis on mitigation strategies rather than on modeling and more complex monitoring issues to keep the focus on removing sources; and
- The TMDL is based on actual data collected in the watershed.

<u>Weaknesses:</u>

- Stream flows were estimated and not measured to produce loading estimates to the ponds.
- It is apparent that both ponds were historically hypoxic or anoxic below the thermocline in the summer months. No well-established method is presently available to estimate the changes in dissolved oxygen levels in the ponds when total phosphorus load reductions are implemented.

4.5 Supporting documentation

Recent water quality studies considered significant to this TMDL are presented in Table 4.4. These references were used to characterize the present water quality conditions or identify water quality trends.

Table 4.4: Supporting documentation.

Primary Organization or Authors	Title	Date of Report	Approximate Date of Study
URIWW	Chickasheen Brook Water Quality Data	2002	1988-2002
DEM	Total Maximum Daily Load for Total phosphorus Loads to Stafford Pond	1998	1997
ENSR	Limnological Investigation of Stafford Pond Tiverton, Rhode Island	1997	1996

5.0 IMPLEMENTATION

The impairments of Chickasheen Brook are caused by excessive phosphorus loadings entering the stream principally in the Arrow Swamp reach, and to a lesser degree, from the area of the watershed east of Route 2. The nature of and mechanisms causing these sources have not been verified. Similarly, the means of reducing these sources require further evaluation, as discussed below. This TMDL relies upon phased implementation to reach water quality goals. The corresponding response in total phosphorus concentrations must be measured as remedial measures are implemented. As appropriate, additional measures will be required if standards are not met after the recommended remedial measures are implemented.

Implementation recommendations are organized into the categories listed below:

- Control of phosphorus being released to the waters of Chickasheen Brook from the sediments of or from emergent groundwater entering Arrow Swamp.
- Control of phosphorus that is currently being conveyed from the former HSI site.
- Monitoring of phosphorus entering Maple Swamp and the headwaters of Chickasheen Brook upstream of Route 2.
- Control of other phosphorus sources along Yawgoo and Barber Ponds.

5.1 Arrow Swamp

The persistent trend of increasing phosphorus concentration with distance along the brook indicates that phosphorus is entering the brook from distributed sources through Arrow Swamp. The source(s) are nonpoint in nature and enter the brook in areas where physical (e.g. dredging) or chemical alterations of the environment are probably not appropriate. DEM recommends that a strategy be developed to control phosphorus and algae blooms in Yawgoo and Barber Ponds by a consultant with expertise and experience in addressing similar situations. Possible actions for consideration in the development of this strategy are described below.

<u>Prevent brook impoundments</u>

Current understanding of the processes affecting phosphorus behavior in the environment point to the release of phosphorus formerly bound to the sediments as a result of the inundation of Arrow Swamp as the primary cause of the load increase. It is anticipated that elimination of the impoundment in the swamp will produce a significant reduction in the total phosphorus loading entering the ponds via Chickasheen Brook. The level of reduction is not known, but conditions could potentially return to those seen during 1994 -1997. Measures to control the inundation of the swamp with water include the ongoing removal of dam materials deposited by the beaver at the outflow to Arrow Swamp. The property owner at the Potter Road sampling site appears committed to maintaining the breach of the upper dam. The landowner at the second dam site, however, may not support this approach. In this case, other potential solutions, such as removal of the beavers may not be viable.

Alternate approaches to dam removal may also warrant consideration. These could included periodic controlled breaching of the dam(s) on a temporary basis to facilitate the removal of phosphorus from the upper Chickasheen watershed and through the two ponds. The breaching would be timed to occur when increased influxes of phosphorus will not trigger algae blooms, and when the lowered pond levels will not expose beaver to harsh winter conditions. Care should also be taken to avoid scouring and erosion of downstream reaches of the brook and exposing entrances to beaver lodges.

Harvesting of duckweed (*Lemna spp*.) is occasionally used to remove phosphorus and nitrogen in the treatment of industrial or domestic wastewater (USEPA, 1988; Körner and Vermaat, 1998). The removal of duckweed by siphoning water from the impoundment surface and filtering off duckweed for upland composting may provide a reasonable solution to partially removing phosphorus from the brook.

<u>Use of alum to remove phosphorus</u>

Another option involves alum (aluminum sulfate) treatment of Yawgoo Pond. On contact with water, alum forms an aluminum hydroxide precipitate or floc. Aluminum hydroxide reacts with phosphorus in water to form an insoluble aluminum phosphate compound that makes the phosphorus unavailable as food for algae under most conditions. As the floc settles it removes some dissolved and particulate phosphorus from the water column. The floc forms a layer on the bottom of the lake that acts as a phosphorus barrier by combining with phosphorus as it is released from the sediments. A second option is the treatment of the waters of Chickasheen Brook prior to their entry to Yawgoo Pond. This would involve the installation of an alum dosing system above the point of entry to the pond. The application of alum to the impoundment should also be evaluated as a means of slowing the release of phosphorus from the upper watershed.

Alum is widely used to control eutrophication in lakes, particularly in the mid-west, but also in New England. Locally, alum has been used on Cape Cod to control the impacts of a historic subsurface wastewater treatment plant plume from Otis Air Force Base that is discharging phosphorus to Ashumet Pond. The treatment is being applied to 28 acres of the 203-acre pond. Application has been made in a batch mode, as with Ashumet Pond, and in a continuous mode to treat stormwater discharges.

If not carried out properly, alum treatment may cause fish kills. In those instances, poor project oversight and management appear to have been key causes. Any scheme involving the use of alum should involve retaining an experienced consultant to propose the dose and method of application, and to obtain the appropriate permits.

<u>Aeration of impounded areas</u>

As section 4 discusses, the phosphorus release is related to the development of an anoxic zone at the bottom of the area impounded by the beaver dam. Aeration of the hypolimnion can be accomplished by pumping air through a system of diffusers lying on the bottom of the impoundment. This option could be employed at relatively low cost where dam removal is not desired.

5.2 Source control at the former HSI site

The recent data from groundwater wells at the former HSI site show that elevated levels of phosphorus still remain in the area. The elevation results from the historic use of the property, and it appears that remedial actions previously taken have caused the elevations to dissipate with time. DEM encourages the initiative taken by the owner of this facility to further evaluate whether any phosphorus-rich materials remain on the site that may continue to contribute elevated phosphorus loads to the brook and two ponds. DEM recommends that the owner continue to monitor groundwater at HSMW-1 through HSMW-3 and the 50' shallow well to verify the continuing abatement of levels on site. Analyses of the samples should include Total Phosphorus, Nitrate, Ammonia, Total Kjeldahl Nitrogen, pH, Calcium, Sodium, and Chlorides.

In the future, on-site structural BMPs approved by the DEM Wetlands Program will control phosphorus loadings entering Arrow Swamp with stormwater runoff from the former HSI facility. The BMP design includes the construction of detention ponds on the site to trap and infiltrate runoff on site. The largest detention pond will be placed in the location of the former settling ponds along the western edge of the site. The plan calls for a loam cover and grass plantings to take up nutrients introduced to the pond. During recent site work, material contained in the lined aeration pond area was excavated and moved upland for use as topsoil and fertilizer. The information available on the former settling ponds does not definitively indicate that material at the bottom of those ponds was removed when the site was previously cleaned up. Preliminary indications are that the pond bottom may be underlain by fine sand, however. To reduce any further off-site transport of phosphorus currently present in the subsoils of the site, DEM recommends that the current owner have the soils beneath the proposed detention ponds profiled and evaluated for their nutrient content, and removed if the phosphorus burden is found to affect nearby water bodies.

5.3 Sources upstream of Route 2

The headwaters of Chickasheen Brook in Maple Swamp contribute phosphorus to the lower brook and ponds. Although significantly lower than those downstream and west of Route 2, total phosphorus concentrations in Chickasheen Brook at Route 2 continue to remain elevated. No information exists on historic or current land use practices in the area that could warrant an investigation by the DEM Office of Compliance and Inspection. Information that emerges on problems such as failing septic systems or domesticated animals in the wetlands should be referred to Compliance and Inspection for enforcement action. In addition, the Phase II stormwater program shall be implemented for the Urbanized Areas in the watershed as outlined below.

5.4 Stormwater and the RIPDES Phase II program

Effective February 25, 2003, DEM amended the existing Rhode Island Pollutant Discharge Elimination System (RIPDES) regulations to include Phase II Storm Water regulations. On December 19, 2003, the DEM RIPDES Program issued the General Permit for Storm Water Discharge from Small Municipal Separate Storm Sewer Systems (MS4s) and from Industrial Activity at Eligible Facilities Operated by Regulated Small MS4s (DEM, 2003). This General Permit gave MS4 operators within regulated areas (i.e.

designated municipalities) until March 18, 2004 to submit the Notice of Intent (NOI) and the Storm Water Management Program Plan (SWMPP). MS4s in the watershed that discharge to Chickasheen Brook and Barber Pond are owned and operated by the Towns of Exeter and South Kingstown, and the Rhode Island Department of Transportation (DOT). The MS4s contribute to water quality impairments of both water bodies that are related to their phosphorus loadings. The Phase II Program requires operators of municipal separate storm sewer systems (MS4s) in urbanized areas (UAs) to develop storm water management program plans (SWMPPs) and obtain a permit for those MS4s. The Director of DEM (Director) will additionally require permits for MS4s in areas outside the UAs that contribute to a violation of a water quality standard, are significant contributors of pollutants to waters of the State or that require storm water controls based on waste load allocations (WLAs) determined through a TMDL.

The SWMPP for each MS4 must describe the Best Management Practices (BMPs) for each of the following minimum control measures:

- Public education and outreach program to inform the public about the impacts of storm water on surface water bodies.
- Public involvement/participation program.
- Illicit discharge detection and elimination program.
- Construction site storm water runoff control program for sites disturbing one or more acres.
- Post construction storm water runoff control program for new development and redevelopment sites disturbing one or more acres.
- Municipal pollution prevention/good housekeeping operation and maintenance program.

The six minimum measures above offer a number of opportunities to reduce phosphorus loads from home, commercial properties, and roadways in the watershed. These include:

Public Education/Public Involvement

The public education program should focus on both water quality and water quantity concerns within the watershed. Public education material should target the particular audience being addressed. For example, the residential community should be educated about the water quality impacts from residential use and activities and the measures they can take to minimize and prevent these impacts. Examples include storing and disposing of waste from pets and domestic animals properly, discouraging large waterfowl populations by eliminating human feeding of waterfowl, eliminating waterfowl access from water bodies to adjacent open land to congregate and feed, and informing residents about disposing yard wastes improperly (i.e. not disposing into storm drains or wetlands). Public involvement programs should actively involve the community in addressing these concerns. Involvement activities may include posting signs informing the public not to feed waterfowl, and stenciling storm drains with *Do Not Dump* labels. The residential community should be informed about measures to reduce runoff, such as the infiltration of roof runoff where feasible and landscaping choices that minimize runoff. Some examples of landscaping measures are grading the site to minimize runoff and promote storm water attenuation and infiltration, reducing paved areas such as driveways, and use of porous driveways such as crushed shells or stone. Uptake of phosphorus in runoff can also be promoted by vegetated buffer strips and. These examples can also be targeted to residential land developers, commercial property owners, and landscapers. BMPs that minimize runoff and promote infiltration should be encouraged when redeveloping or repaving a site. Examples include porous pavement, infiltrating catch basins, breaking up large tracts/areas of impervious surfaces, sloping surfaces towards vegetated areas, and incorporating buffer strips and swales where possible.

Illicit Discharge Detection and Elimination
The town and DOT may propose to address potential illicit discharges, such as in Chickasheen Brook upstream of Route 2 through inspection dry weather flow sampling in the area.

Construction/Post Construction
Storm water volume reduction requirements for development and redevelopment of commercial and industrial properties should be considered in the development of ordinances to comply with the construction and post construction minimum measures (see General Permit Part IV.B.4.a.1 and Part IV.B.5.a.2 respectively). As mentioned previously, examples of acceptable reduction measures include reducing impervious surfaces, sloping impervious surfaces to drain towards vegetated areas, using porous pavement, and installing infiltration catch basins where feasible. Other reduction measures to consider are the establishment of buffer zones, vegetated drainage ways, cluster zoning or low impact development, transfer of development rights, and overlay districts for sensitive areas.

Good Housekeeping/Pollution Prevention
The Storm Water General Permit (see Part IV.B.6.a.2 and Part IV.B.6.b.1) extends storm water volume reduction requirements to operator-owned facilities and infrastructure (RIDEM, 2003a). Similarly, municipal and state facilities could incorporate measures such as reducing impervious surfaces, sloping impervious surfaces to drain towards vegetated areas, incorporating buffer strips and swales, using porous pavement and infiltration catch basins where feasible. In addition, any new municipal construction project or retrofit should incorporate BMPs that reduce storm water and promote infiltration such as the before-mentioned measures: buffer strips, swales, vegetated drainage ways, infiltrating catch basins, porous roads etc.

The SWMPP must include the measurable goals for each control measure (narrative or numeric) that will be used to gauge the success of the program. It must also contain an implementation schedule that includes interim milestones, frequency of activities and reporting of results. In addition, the Director can require additional permit requirements based on the recommendations of a TMDL.

Areas adjacent to Chickasheen Brook and Barber Pond are in a UA that contains MS4s operated by Rhode Island Department of Transportation (DOT), and the Towns of Exeter and South Kingstown. Under the Phase II Rule, MS4s would include drainage systems, catch basins, ditches, man-made channels, or storm used for collecting or conveying storm water. The headwaters of Chickasheen Brook, including Maple Swamp in Exeter is inside a UA bounded by Liberty Road, Yawgoo Valley Road, Yawgoo Mill Pond, and Route 2. MS4s operated by DOT along Route 2 and by the Town of Exeter along Yawgoo Valley Road discharge to upper Chickasheen Brook in this UA. The headwaters of Chickasheen Brook have been identified as contributing to the phosphorus impairment of the brook. Controls for MS4s in that area must be included in SWMPPs submitted by the Town of Exeter and DOT. MS4s along Route 2 and Barber Pond Road that discharge to Barber Pond are operated by DOT and the Town of South Kingstown, and must be included in SWMPPs submitted by the Town of South Kingstown and DOT. The Director will require that the SWMPPs for the areas outlined above contain provisions that address the systems identified above and any other MS4s in the regulated area through the six minimum measures followed by monitoring to determine the need for additional measures.

A separate nonpoint stormwater issue is that of sedimentation at the DEM Fish and Wildlife public boat launch adjacent to Route 2 near the Barber Pond outlet caused by erosion of the ramp. Catch basins, vegetated filter strips or buffers, or other suitable BMPs should be installed at this site to infiltrate runoff, stabilize soils in the area of the boat ramp, prevent the conveyance of phosphorus to Barber Pond in sheet flow, and to prevent further sedimentation along this area of the pond shoreline.

RIDEM will work with the agencies to identify funding sources and to evaluate locations and designs for storm water control BMPs throughout the watershed. In accordance with the requirements of this phased TMDL, monitoring of the Chickasheen Brook watershed should continue so that the effectiveness of ongoing remedial activities can be gauged.

6.0 PUBLIC PARTICIPATION

A public meeting was held on August 6, 2003 to obtain public response and input following the initial EPA review of the draft Yawgoo and Barber Pond, and Chickasheen Brook TMDL. The public was then afforded a 30-day period in which to submit comments on the study and its findings. Comments received have been incorporated into Appendix D of this document.

7.0 FOLLOW UP MONITORING

This is a phased TMDL and, as such, additional monitoring is required to ensure that water quality objectives are met as remedial actions are accomplished. Monitoring by URIWW will be the principle method of obtaining the data necessary to track water quality conditions in the watershed.

Periodic monitoring should continue at a minimum of three stations to ensure that progress is being made toward the water quality targets for Chickasheen Brook. The URIWW stations at Route 2 and Miskiania Trail should be sampled to verify that loadings from the upper watershed are decreasing, and that the allowable loading targets for Chickasheen Brook and Yawgoo Pond are being met. The URIWW surface and deep stations in Yawgoo and Barber Ponds should be sampled to track trends in the condition of the ponds and to verify attainment of the target phosphorus condition of the ponds.

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Appendix A: Calculation of existing loads to Yawgoo and Barber Ponds

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Watershed area	Drainage Area (sq. mi.)	Estimated Mean Annual Discharge (cfs)	Mean annual (1998-2002) TP concentration from measurements (ppb)	Annual TP Loading (kg/yr) (see next page)
Basin 1A	0.57	1.22		
Basin 1B	0.75	1.61		
Sum for Basins 1A and 1B: Influx to Yawgoo Pond at Miskiania Trail	1.32	2.83	233.90	425
Basin 1C: Area draining directly to Yawgoo Pond *	0.68	1.46	15.85	21
Total Phosphorus load entering Yawgoo Pond (kg/yr):				**446**
Sum for Basin 1: Outflow from Yawgoo to Barber Pond	2.00	4.30	25.04	96
Basin 2: Estimated additional discharge from Mud Brook and the Chickasheen watershed below Yawgoo Pond	0.87	1.87	15.85	38
Basin 3 *	0.43	0.91	15.85	13
Total Phosphorus load entering Barber Pond (kg/yr):				**147**
Sum for Basins 1 - 3: Outflow from Barber Pond	3.30	7.08		

* Estimate uses Mud Creek TP concentration

Station Name	Drainage Area (mi2)	Mean Annual Discharge (cfs)	Runoff Factor (cfs/mi2)
Hunt River near East Greenwich, RI	22.9	46.9	2.05
Chipuxet River at West Kingston, RI	9.99	21.5	2.15
Usquepaug River near Usquepaug, RI	36.1	77.5	2.15
Beaver River near Usquepaug, RI	8.87	21.5	2.42
Pawcatuck River at Wood River Junction, RI	100	196	1.96
Wood River at Hope Valley, RI	72.4	156	2.15

Mean Runoff factor:	2.15	(cfs/mi2)

Estimated Monthly average total phosphorus flux (kg P/month) at sampling stations based on Monthly mean flows and observed total P concentration data, for months of May - December 1998 - 2002. January- April fluxes are estimated from the product of monthly mean flow and average of May and December concentration.

	Chickasheen Brook at Miskiania Trail, (kg TP/month)	Mud Brook and the Chickasheen watershed below Yawgoo Pond, (kg TP/month)
January	59.74	3.02
February	63.53	3.21
March	78.85	3.98
April	77.17	3.90
May	16.02	3.63
June	24.81	4.84
July	11.54	1.89
August	10.79	1.56
September	11.33	1.48
October	15.47	1.42
November	20.37 *	2.42 *
December	35.58	6.61
Annual Total Loads (kg/yr)	425	38

* November values were calculated from October estimates, adjusted for mean flow

Appendix B: Calculation of existing mean concentrations in Yawgoo and Barber Ponds using the loading - response model

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Calculation of Existing Mean Concentrations in Yawgoo and Barber Ponds

from Walker, 2001:

$$TP = \frac{L}{(Q + UA)}$$

where

TP = Annual mean TP concentration (ppb)
L = external TP loading (kg/yr)
Q = Average annual lake outflow (m3/yr)
A = Lake surface area (m2)
U = TP settling speed (m/yr)

$$U = (z^*Q/A)^{0.5}$$

where

z = mean depth of lake (Volume/surface area)
V = pond volume (m3)

For Yawgoo Pond,

Q =	3.84E+06	m3	4.30 cfs, pond outflow from Appendix A
V =	2.30E+06	m3	(from Linda Green)
A =	5.79E+05	m2	(from Linda Green)
z =	3.97E+00	m	
L =	4.46E+02	kg/yr	
U =	5.13	m/yr	

<u>Given the inputs above, the Walker equation yields a estimated present concentration in Yawgoo Pond of:</u>

TP = 65.5 ppb

				Depth range:	Volume (m3)		Volume-weighted Concentration (ppb)
TP	{1 m} =	25.04	ppb	0.3 - 3.7 m	7.78E+05	1.95E+07	44.9
TP	{5 m} =	55.25	ppb	3.9 - 11 m	1.49E+06	8.23E+07	

Relative % difference (RPD): $= \frac{\text{(Volume weighted observed - Estimated)}}{\text{Volume weighted observed}}$

RPD = 31.5%

For Barber Pond,

Q =	6.32E+06	m3	7.08 cfs, pond outflow from Appendix A
V =	3.58E+05	m3	(from Linda Green)
A =	1.01E+05	m2	(from Linda Green)
z =	3.54E+00	m	
L =	1.47E+02	kg/yr	
U =	14.90	m/yr	

<u>The estimated present concentration in Barber Pond is:</u>

TP = 18.8 ppb

			Depth range:	Volume (m3)		Volume-weighted Concentration (ppb)
TP {1 m} =	18.1	ppb	0.3 - 3.7 m	7.78E+05	1.41E+07	19.2
TP {5 m} =	19.8	ppb	3.9 - 11 m	1.49E+06	2.95E+07	

RPD = 2.4%

Appendix C: Calculation of Allowable Loads to Yawgoo and Barber Ponds and Chickasheen Brook

Appendix C: Calculation of allowable loads to Yawgoo and Barber Ponds and Chickasheen Brook

For Chickasheen Brook at Miskiania Trail, the allowable load is expressed as the numeric target concentration times the annual mean net runoff past that point:

$L = TP * Q$ where TP = Numeric target concentration
Q = Net annual mean discharge

Q = 2.53E+06 m3/yr (2.83 cfs)
TP = 2.50E-05 kg/m3

L =	63	kg/yr

Subtracting 10% of the allowable load for an explicit MOS :

L =	57	kg/yr

The reduced load from Chickasheen is next combined with the existing load from other watershed sources to establish the target condition and expected final concentration in Yawgoo Pond using the Walker (2001) relationship.

from Walker, 2001:

$$TP = \frac{L}{(Q + UA)}$$

or,

$$L = TP*(Q+UA)$$

where
TP = Annual mean TP concentration (ppb)
L = external TP loading (kg/yr)
Q = Average annual lake outflow (m3/yr)
A = Lake surface area (m2)
U = TP settling speed (m/yr)

$$U = (z*Q/A)^{0.5}$$

where
z = mean depth of lake (Volume/surface area)
V = pond volume (m3)

For Yawgoo Pond,
Q = 3.84E+06 m3 — 4.30 cfs, pond outflow from Appendix A
V = 2.30E+06 m3 — (from Linda Green)
A = 5.79E+05 m2 — (from Linda Green)
z = 3.97E+00 m
U = 5.13 m/yr

Watershed area	Drainage Area (sq. mi.)	Estimated Mean Annual Discharge (cfs)	Mean annual (1998-2002) TP (ppb)	Annual TP Loading (kg/yr)
Sum for Basins 1A and 1B: Influx to Yawgoo Pond at Miskiania Trail*	1.32	2.83	22.50	57
Basin 1C: Area draining directly to Yawgoo Pond	0.68	1.46	15.85	21

* For this analysis, road runoff is assumed to be a component of the Basin 1A loading

The target TP load to Yawgoo Pond (kg/yr) is:

L =	78	kg/yr

For comparison, the load that achieves the lake TP WQ standard (25 ppb) in Yawgoo Pond is:

L = 170 kg/yr

When the target load is achieved, the volume-averaged TP concentration in Yawgoo Pond will be:

TP = 11.4 ppb

The allowable load from Chickasheen Brook at the point of entry to Barber Pond:

L = TP * Q where TP = TP target concentration of water leaving Yawgoo Pond
Q = Net annual mean discharge from Yawgoo to Barber Pond

Q = 3.84E+06 m3/yr (4.3 cfs)
TP = 11.4E-5 kg/m3

L = 44 kg/yr

The TP sources to Barber Pond are Chickasheen Brook coming from Yawgoo Pond, stormwater inputs, and inputs from the remainder of its drainage area.

Watershed area	Drainage Area (sq. mi.)	Estimated Mean Annual Discharge (cfs)	Target TP (ppb)	Annual target TP Loading (kg/yr)
Sum for Basin 1: Outflow from Yawgoo to Barber Pond	2.00	4.30	11.41	44
Basin 2: Estimated additional discharge from Mud Brook and the Chickasheen watershed below Yawgoo Pond	0.87	1.87	15.85	27
Basin 3 *	0.43	0.91	15.85	13

* For this analysis, road runoff is assumed to be a component of the Basin 3 loading

The target load for Barber Pond is the sum in the right column above from the three basins:

L = 83 kg/yr

For comparison, the load that achieves the lake TP WQ standard (25 ppb) in Barber Pond is:

L = 196 kg/yr

When the target load is achieved, calculate the volume-averaged TP concentration in Yawgoo Pond:

Again, $TP = \frac{L}{(Q + UA)}$

Barber Pond properties:

Q =	6.32E+06	m3	7.08 cfs, pond outflow from Appendix A
V =	3.58E+05	m3	(from Linda Green)
A =	1.01E+05	m2	(from Linda Green)
z =	3.54E+00	m	
U =	14.90	m/yr	

TP = 10.6 ppb

Appendix D: Response to public comments

August 6, 2003 Public Meeting for the upper Chickasheen Brook, and Yawgoo and Barber Pond TMDLs held at the Coastal Institute Building auditorium in Kingston.

Chris Turner presentation:
1. Agenda:
Introduction: What is a TMDL?
Linda Green (URI): History of water quality problems in the area
Conditions in ponds and brook.
Insight into causes
TMDL findings:
Current loads to ponds and brook.
Necessary load reductions
Summary of potential solutions.

2. Discussion of basic information on the TMDL and the process:
3. Discussion of state water quality standards for dissolved oxygen and phosphorus

Linda Green presentation:
- Linda began with an overview of eutrophication in fresh water lakes and ponds, describing how increased nutrient (P) loadings contribute to increased algae, decreased water clarity, and reduced DO, especially near the bottom.
- Linda then presented an overview of the history of water quality problems in Yawgoo and Barber Ponds:
- In photos, impacts can be seen back to 1984. Monitoring began in 1988.
- Processing of clams at Harbor and Hillside Shellfish led to high phosphorus in groundwater and in Chickasheen Brook.
- After plants were shut down, conditions improved (between 1991 – 1997).
- Beginning in 1998, conditions in stream and ponds again worsened.
- Problem was linked to inundation of Arrow swamp by beaver dam. Pictures showed dense buildup of duckweed above dam.
- Dam was breached in 2001; beavers moved downstream to build another dam.
- Increase in phosphorus levels seen in downstream waters was linked to inundation of swamp. P binds tightly to upland soils, but is released from soil in water, particularly when pH of water is acidic. Presence of anoxia at bottom accelerates release of P to water column. Need only ppb amounts to cause eutrophication.
- Linda thinks that elimination of the dams may alleviate the problem, at least somewhat. Application of alum may be a consideration in seeing full recovery of the area.

Chris Turner continued his presentation:
- A summary of existing TP loadings was done by breaking the area up into five segments and summarizing all known sources by segment.
- In segment 1A, Chris discussed the operation at the former Hillside facility. Started up in 1989, closed after DEM found that clam waste and shells were being disposed of illegally. Faciltiy apparently stopped operation in 1991. By 1994, DEM considered

the problems there to be resolved. The area is no longer considered a source to the Chickasheen. DEM would like to receive any information from the public on other potential sources that could be investigated upstream of Route 2.

- Segment 1B between Route 2 and Miskiania Road is mainly affected by historic uses at Harbor Shellfish (HSI) site and by wild life, as described earlier by Linda.
- HSI operated between around 1970 and 1988.
- Daily effluent was 7,000 gpd, with max values around 20,000 gpd. HSI used two aeration ponds and around 10 leaching ponds.
- Well problems on adjacent property in the fall of 1980. Groundwater sampling hinted at but did not conclusively link HSI to the problem.
- In 1986, DEM received a complaint that HSI was breaching lagoons into Maple Swamp. It is apparent that HSI had been doing this at least as far back as 1985, probably earlier. The breaching probably contributed a large phosphorus burden to the swamp. The breaching stopped by 1987.
- Chris stated that the breaches probably occurred over a period of several years and probably resulted in the discharge of a considerable mass of phosphorus to the swamp. This phosphorus was bound to the sediments of the swamp until the modification of the chemical environment of the swamp by beavers caused the phosphorus to change to a dissolved form and be transported down the stream into the ponds.
- Sampling by HSI's consultant in 1987 showed high levels of phosphorus and other pollutants in groundwater.
- 1988: HSI operation ended.
- 1999-2002- Oak Harbor development began.
- 2002 - Well sampling by developer site shows elevated TP in groundwater that appears to be diminishing over time. The means of all values for the three sampling periods were 760 ug/l (1988), 290 (1999), and 70 ug/l (2002).
- 2003 - DEM Wetlands inspection of Oak Harbor reports that stormwater structures are not constructed as designed and permitted. The outlet structure was not detaining water and was permitting sand to escape the detention pond and go into the wetland.
- Segments 1C, 2, and 3 contain minor sources that include residential and a few large commercial septic systems, wildlife, atmospheric deposition, stormwater runoff, and internal recycling. With the exception of internal recycling, these sources are generally small.
- Target TP loadings and necessary load reductions were presented. Reductions ranged between 10% for Chickasheen entering Barber Pond to 88% for Chickasheen Brook entering Yawgoo Pond.
- Implementation - How to reduce existing loadings
- Reduce sediment/groundwater phosphorus releases.
- Reduce phosphorus conveyed to Arrow Swamp from the Oak Harbor site.
- Monitor phosphorus entering Arrow Swamp from the headwaters.
- Reduce other phosphorus sources along Yawgoo and Barber Ponds.

<u>Comments and Questions on the presentation:</u>

- Dr. John Sieburth stated that the waterfront along his home is clogged with aquatic plants. What can he do to remedy this problem? Chris Turner responded that the Wetlands Regulations do allow property owners to clear floating or submerged plants from areas immediately adjacent to docks and/or swimming areas, if done by hand. Another option would be to obtain a permit to apply a herbicide to remove the vegetation.

- A member of the audience asked about the status of septic systems at Allen's Nursing Home. Chris Turner responded that no problems had been reported there. Dr. Sieburth stated that he had walked by the facility on the Barber Pond side and had smelled sewage. Chris responded that this issue should be brought to Compliance and Inspection (OCI) and stated that he would follow up on this issue with Dr. Sieburth.

- Another member of the audience asked whether large commercial septic systems similar to those at Allen's Nursing Home are inspected. Chris replied that they are not, however, the system could be inspected under South Kingstown's wastewater management program. Mr. Ray Nickerson of the South Kingstown Planning department added that the area was scheduled for ISDS inspections during 2006, year 5 of the program.

- Richard Marcello, owner of the Oak Harbor development, stated that the development was slightly more than a quarter of the way complete, and that the stormwater controls had not yet been completed. Mr. Marcello disputed DEM claims that sand was being transported to Arrow Swamp. He also stated that the loam and planting called for in the stormwater design had been completed, and that the outlet structure would be completed shortly.

- Chris Turner asked whether groundwater monitoring at the site would continue. Mr. Marcello replied that the sampling of the existing wells would continue. Chris also asked whether soil profiling under the detention ponds would be conducted to verify that any sludge remaining from the former Harbor Shellfish operation had been removed. Mr. Marcello replied that the soil profiling would be conducted at the site.

- A member of the audience asked for additional detail on the consultant services recommended for the area in the implementation plan. Chris stated that virtually no work of this type had been performed in Rhode Island, so that it was most prudent to retain the services of a professional with experience in similar studies. The service would include the drafting of a watershed management plan for the area that would include management of the impoundments in the upper watershed and Yawgoo Pond. The plan could serve to document understanding between landowners in the upper watershed over what measures would be taken to control impoundments, and whether other measures such as aeration and duckweed harvesting (or alum application) wold be useful. Should alum application be considered further, the consultant could be tasked with designing and obtaining permits for the application.

- Chris stated that funding for the services could be obtained from at least three sources. The 319 Nonpoint Program provides grants on an annual basis (Contact: Jim Riordan 222-4700, ext. 4421). The DEM Sustainable Watersheds Office will shortly be announcing a program to provide grants up to $10,000 (Contact: Scott Millar, 222-3434, ext. 4419). The Narragansett Bay Program is also administering a grant program, known as BAYWAG for grants of a similar nature (Contact: Richard Ribb, 222-4700, ext. 7271).

- Art Gold of URI mentioned that the use of laundry and dish detergents that are low in phosphorus in homes near the waterfronts will reduce phosphorus loads to the stream and ponds from septic systems in the watershed.

- Angelo Liberti of DEM asked whether anyone in the audience did not agree with DEM's conclusion that the dominant source of phosphorus was the release of phosphorus from the sediments due to the presence of the beaver impoundments along the stream. Chris added that another possible mechanism could be that a groundwater plume originating from the Harbor Shellfish site could be another potential mechanism, however DEM discounted that theory given the coincidence between the appearance of the dams in the watershed and the increase in concentration in the stream. Chris also stated that it was not likely that a plume would be delayed in appearing for some period of time after the end of the HSI operation.

Comments received by mail:

<u>e-mail message from Linda Green, landowner along Yawgoo Pond:</u>
Linda questioned the accuracy of the loading calculation due to the short flushing time of Barber Pond and requested a recalculation of the loading. Linda also asked that DEM lower the target TP concentration set for both Yawgoo and Barber Ponds, picking a value of about 12 ppb, which was the annual mean observed during the mid-1990's when the ponds were at their cleanest. Linda suggested that TP concentration at the 1 m depth be used to evaluate compliance with the water quality goal and expressed her belief that the use of alum should be explored.

Response by DEM:
The numeric target for Chickasheen Brook at Miskiania Trail was set at a mean total phosphorus concentration of 22.5 ppb. Appendix C projects that when this target is met, the mean total phosphorus concentrations in Yawgoo and Barber Ponds will be 11.4 and 10.6 ug/l. These projected conditions are lower than the lowest of the yearly mean concentrations seen during 1994-1997. A discussion of this point has been added to section 4.2 of the TMDL.

<u>Letter received from Perry Jeffries, Yawgoo Pond Road:</u>
Dr. Jeffries attached a September 2002 commentary article describing the effects of the excess TP load on harmful aquatic blooms in Yawgoo Pond and the resulting impacts on freshwater clams in the pond. Dr. Jeffries also requested that a monitoring site be

established at the margin of the Oak Harbor development to characterize the phosphorus, fecal coliform, and dissolved hydrocarbon impacts of the development twice each season.

Response by DEM:
The owner of the Oak Harbor development has indicated that measurements of TP concentrations in groundwater will be made on an ongoing basis. The locations of these samples should be sufficient to adequately characterize the evolution in loads leaving the site. The scope of the TMDL does not cover fecal coliform and dissolved hydrocarbon loads leaving the site. In addition, the migration of fecal coliforms in groundwater is negligible in all but a few limited conditions. DEM does not believe that monitoring for fecal coliforms would be necessary at this site.