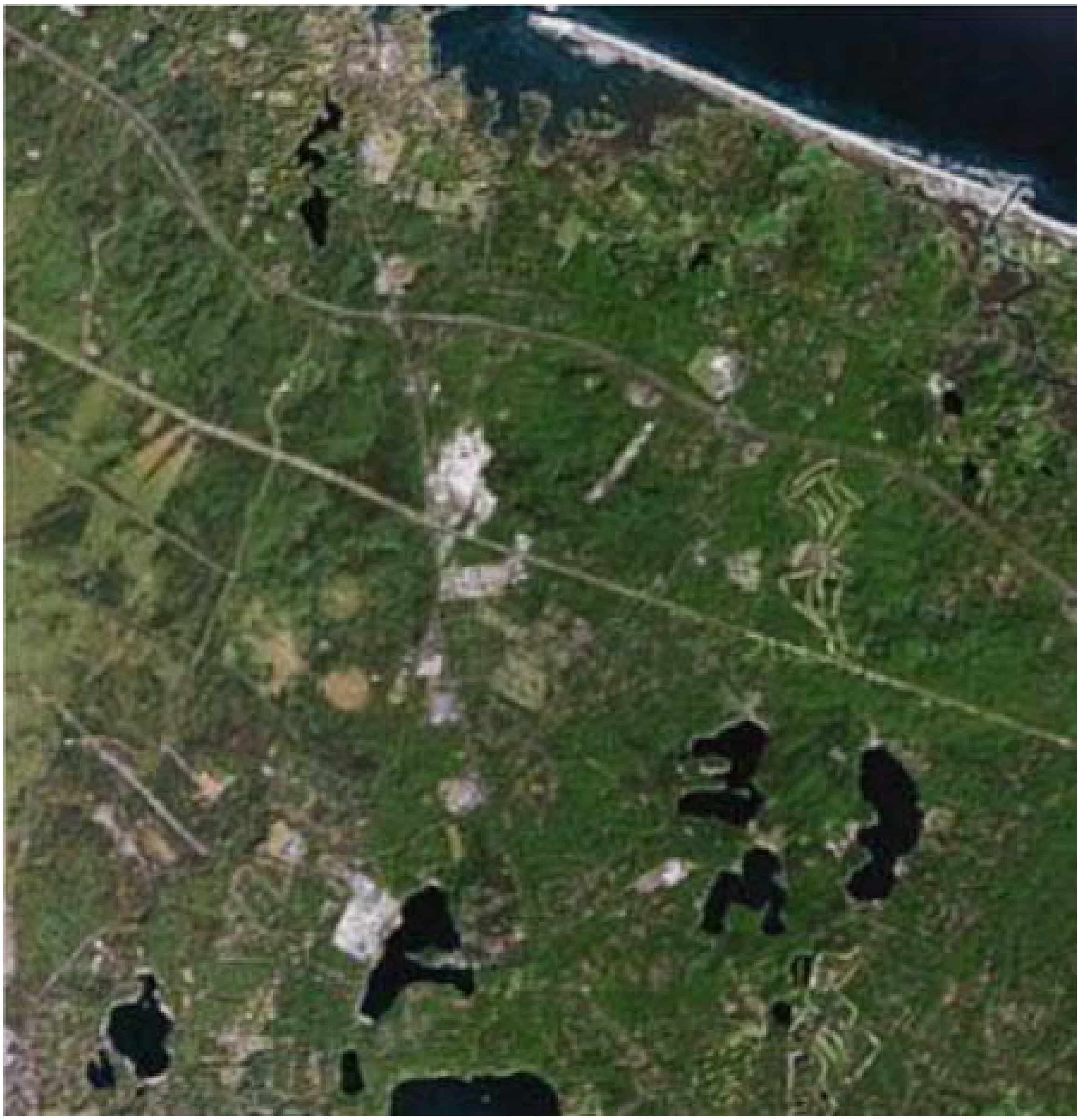
# AN EVALUATION OF SELECTED SANDWICH PONDS



BY WATER RESOURCE SERVICES, INC.

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# Contents

## Introduction

The ponds of Sandwich represent valuable resources by themselves, but they are also an integral part of the overall ecosystem and community fabric of the Town of Sandwich. While much of the cumulative shoreline is under private control, many ponds have public access and some support major public facilities. All have been part of the community for many years. Consideration of their attributes and health is an integral part of any comprehensive water resource management plan. The ponds have not been the subject of any long-term detailed study, but some have been monitored as part of the Pond and Lake Stewards (PALS) program and the Shawme Ponds were the subject of one investigation by a consultant. This assessment is intended to provide a status report as of this time with recommendations for further action.

## Study Approach and Methods

This assessment is based on existing information and a brief field review of conditions. Available information was provided by town sources, and includes monitoring data from past efforts and assimilation projects such as the Local Comprehensive Plan update of 2009. Limited relevant information is available in the Jacobs Engineering report (1999) on the Ashumet ground water pollution plume. A consultant report (ENSR 2001) on the Shawme Ponds provides some useful background on those waterbodies, but there are few other original reports on any ponds in Sandwich. The MA Division of Fisheries and Wildlife provides old (pre-1990) water depth maps for 8 of 12 ponds included in this assessment. Each pond was visited for visual inspection, but no sampling or detailed field work was conducted. An overview of town pond resources is provided, with pond by pond assessments for those waterbodies selected for further evaluation, as allowed by the available data. Considerations for future assessment and management are then offered.

## Overview of Sandwich Ponds

Much background information is contained in the Local Comprehensive Plan for the Town of Sandwich, actually a major update of previous plans that incorporates most efforts conducted through 2008. There are relatively few pond-related reports for Sandwich ponds, Upper and Lower Shawme Lakes have been the subject of several investigations and are listed on the 2010 Integrated Waters List from MA DEP as needing development of a Total Maximum Daily Load (TMDL) for nutrients and eutrophication. Peters and Snake Ponds are also on the 2010 Integrated Waters List as having complete TMDLs for metals. Work on MMR sites has included limited assessments of possible impacts on Sandwich ponds, most notably Peters and Triangle Ponds. Lawrence, Spectacle and Triangle Ponds have been monitored by the Pond And Lake Stewards (PALS) program for several years. Additional information comes from personal experience with other Cape Cod ponds, including assessments and management efforts in Falmouth, Barnstable, Harwich, Brewster, Orleans, Chatham, and Eastham.

## Location of Ponds

The Sandwich Ponds (Figure 1) are surface water features within the Sagamore lens of the sole source aquifer of Cape Cod which tends to be at least 60 feet deep in Sandwich. Pathways of ground water flow affect which lands contribute to which ponds (Figure 2), but there is expected variation in those pathways from season to season and year to year, depending mainly on precipitation.There are 63 ponds in total, but only 5 that are larger than 10 acres. One pair of ponds (the Hog Ponds) in close proximity has a total acreage >10 acres as well. Twelve ponds were selected for further evaluation as part of the overall planning process, based on significant size, public access, natural resource significance, and/or elevated housing density along their shorelines. Key features as relates to this assessment are included in Table 1.

## Origin of Ponds

Ponds in Sandwich are largely of kettlehole origin, formed by stranded blocks of ice in a large, sandy moraine associated with glaciers at the end of the last ice age, about 11,000 years ago. Dams were sometimes constructed to raise the water level, but with the very sandy soil, creation of completely artificial waterbodies is limited in this area. Of the ponds chosen for further examination, only the Shawme Lakes do not appear to be kettleholes. Weeks Pond is very shallow, more so than most true kettleholes, but it appears to be a natural landscape feature. Each of Upper and Lower Shawme has a dam that impounds ground water that used to form a stream (ENSR 2001). There may have been wetlands in the area now occupied by the ponds, but the maximum depth of each is <10 ft, compared to maximum depths of >25 ft in most kettlehole lakes. They may have been named “lakes” for this reason; kettlehole ponds traditionally are called “ponds” on Cape Cod.

Kettlehole ponds rarely have any permanent stream inflows; they depend on precipitation and ground water flow for inputs. Losses include evaporation and ground water outseepage, but many do have overflows. Overflows tend to feed streams that reach the coast and allow anadromous fish such as alewife to enter ponds and spawn, with the fry spending the summer in the pond before heading downstream to the sea. Of the 10 apparent kettlehole ponds being examined here, Hoxie Pond overflows through wetlands into Scorton Creek, but none of the other nine kettlehole ponds appears to have a surface water outlet. Upper Shawme Lake outlets into Lower Shawme Lake, which outlets into Mill Creek, a tidal creek that connects with the bay.

## Uses of Ponds

Historically ponds on Cape Cod were used as local water supplies, sources of ice, fishing resources (including migrating alewife harvest), irrigation supply, and some recreation. Today, uses include mainly recreation, including swimming, boating and fishing, with water supply for cranberry bogs important when bogs are near the ponds. Of the 12 ponds under consideration here, only Hoxie Pond and Upper Shawme Lake appear to ever have had associated cranberry bogs, and only the Hoxie bog is active now. Shoreline residences make use of the ponds for recreation and sometimes landscape irrigation, but where public access exists, town residents or state residents can use the ponds for swimming, boating and/or fishing. There is a 10 hp limit for motorized boats on all but Peters Pond.

**Figure 1. Sandwich Ponds, including all ponds covered in this assessment.**

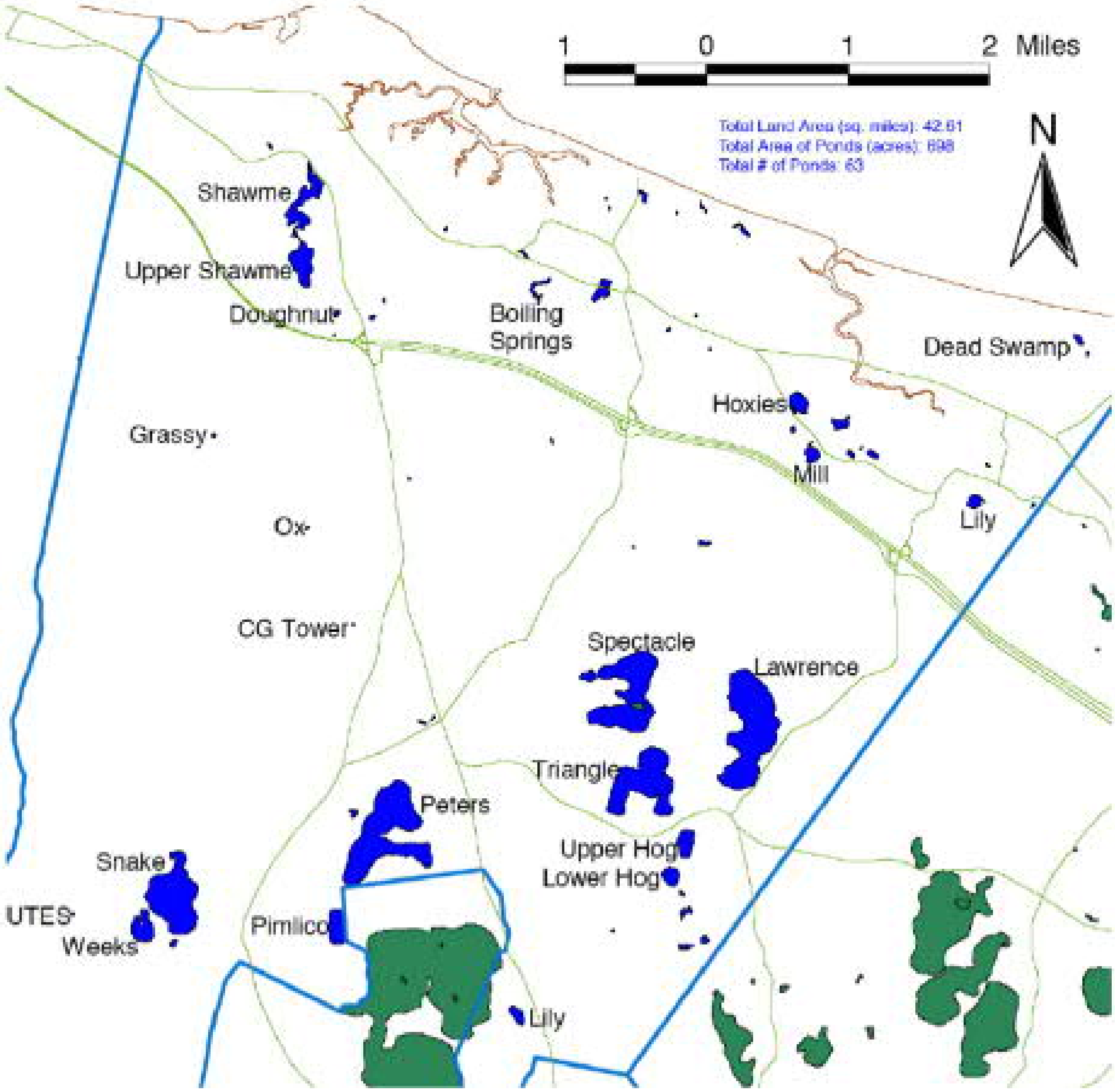


Figure 2. Location of ponds selected for evaluation, with major watershed boundaries.

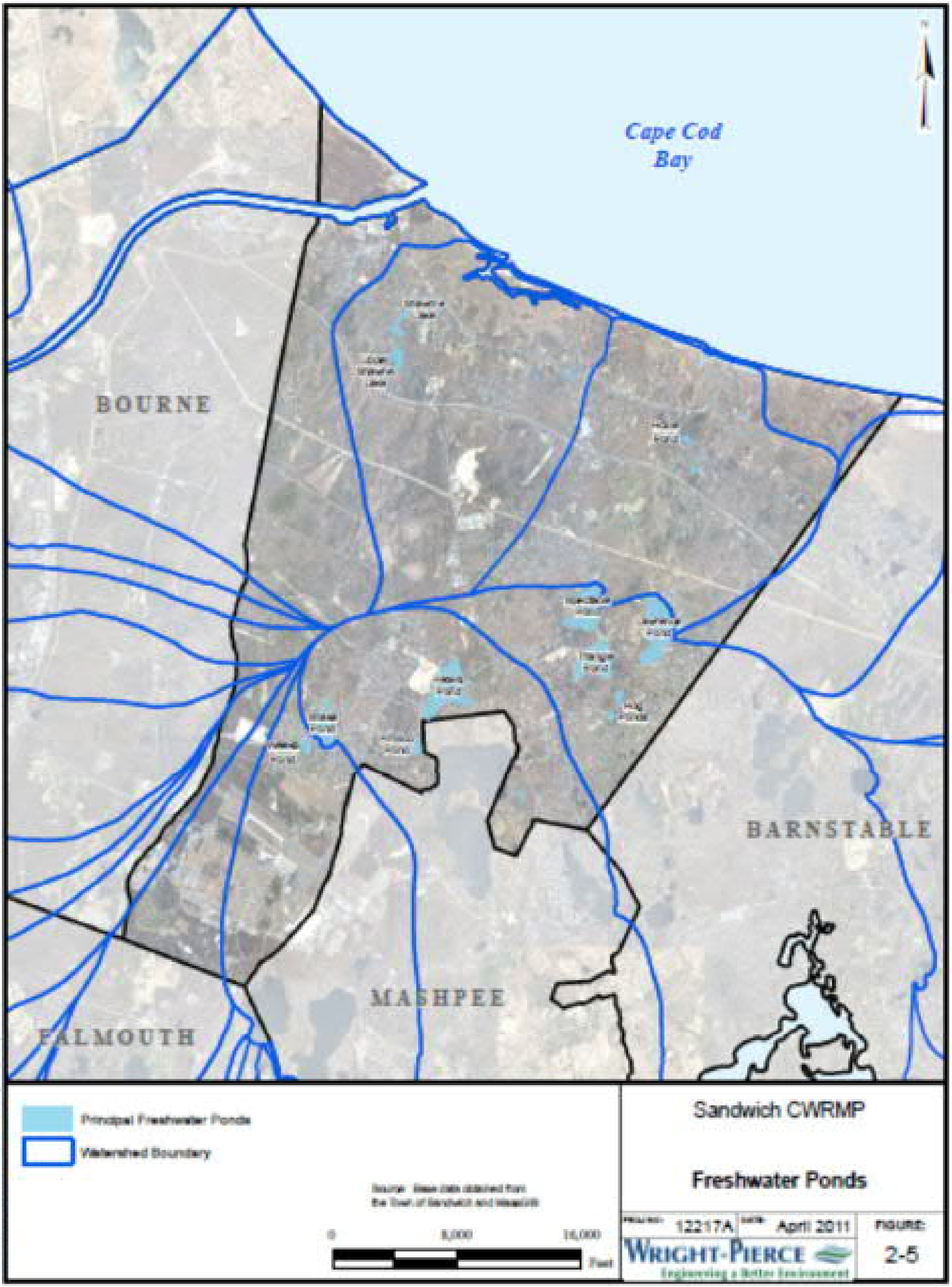


**Table 1. Features of ponds evaluated in this assessment.**

| Pond | Area | Shoreline Length | Max. Depth | Median Depth | Parcels Within 300 Feet | Upgradient Parcels with 300 Feet | | Estimated Waste Water Flow | Reported Algal Blooms |
|---|---|---|---|---|---|---|---|---|---|
| | (acres) | (miles) | (feet) | (feet) | | Total | Developed | (gdp) | |
| Lawrence | 138.0 | 2.30 | 27 | 15.0 | 62 | 7 | 2 | 2570 | N |
| Spectacle | 91.0 | 2.60 | 43 | 25.0 | 25 | 14 | 11 | 2740 | Y |
| Triangle | 84.0 | 2.00 | 30 | 15.0 | 39 | 21 | 17 | 3050 | Y |
| Upper Hog | 11.3 | 0.57 | 20 | 14.0 | 15 | 6 | 2 | 575 | N |
| Lower Hog | 7.8 | 0.50 | 26 | 12.0 | 27 | 5 | 3 | 345 | N |
| Peters | 127.0 | 2.90 | 54 | 22.0 | 58 | 16 | 10 | 1960 | Y |
| Pimlico | 16.4 | 0.57 | 23 | 12.0 | 50 | 32 | 26 | 2680 | N |
| Snake | 83.0 | 1.60 | 33 | 18.0 | 87 | 17 | 15 | 1790 | N |
| Weeks | 15.0 | 0.76 | 15 | 4.0 | 32 | 15 | 12 | 2310 | N |
| Hoxie | 8.5 | 0.42 | 35 | 12.0 | 14 | 6 | 5 | 910 | N |
| Lower Shawme | 24.0 | 1.50 | 5.3 | 4.0 | 65 | 24 | 15 | 2460 | Y |
| Upper Shawme | 21.0 | 0.80 | 11.6 | 7.5 | 32 | 15 | 11 | 1310 | Y |

## Access to Ponds

Of the 12 ponds under consideration here, all except the two Hog Ponds have some form of open public access, but only Peters Pond has well known developed access (town beach and state boat launch). Triangle, Spectacle and Snake Ponds also have boat launch ramps, but with limited facilities and parking, and with a 10 hp limit on the ponds. Six other ponds (Lawrence, Pimlico, Weeks, Hoxie, and Upper and Lower Shawme) provide public access in the form of undeveloped roadside parcels or public lands that support only foot traffic or carry on boats. Several ponds have lake association beaches that afford access to people living on parcels near the ponds, and several more ponds have public campgrounds were access can be gained for a fee. Lawrence, Triangle and Spectacle Ponds each have a YMCA camp on them. So except for the two Hog Ponds, recreational use of the ponds is open to people beyond shoreline property owners.

## Historic Influences

Initial settlement began in the 1600s, when Cape Cod was largely a dense forest of oak and pine on the high ground and a variety of trees in the lower lands, including sassafras, birch, beech, and maple. Evergreen holly and juniper were also common on the Cape at that time. The native Americans had conducted burns to open areas for agriculture, but not on the scale of clearing conducted by white settlers in the 1700s and beyond. By the late 1800s there were few trees in arable areas on the Cape, and most of the topsoil base accumulated over 10,000 years was lost to wind erosion. The sandy nature of the surficial soils as we know them today was the result.

Agriculture was the most influential land use on Cape Cod for several hundred years, at first more subsistence farming but later with a variety of larger vegetable farms and livestock operations, including major duck, goose and turkey farms that were often located near ponds on the Cape. Yet the sandy soils prevented most of the runoff that plagued surface water resources in many other areas of the northeastern USA subject to these agricultural pursuits. Over the last century cranberry farms became abundant, and while the density has declined, cranberry farming is the most active form of agriculture on the Cape today. As bogs are almost always adjacent to a pond and utilize water from the pond for irrigation and flooding for harvest and frost prevention, the potential for impact from this agricultural source through return water is more obvious. Aerial spraying of pesticides and nutrients is another mode of potential impact from cranberry bogs on nearby ponds. Where historic agriculture was adjacent to or actually on ponds (like cranberry bogs at Long Pond in Brewster or duck farming at Hamblin Pond in Marston’s Mills) impacts were sometimes notably severe, but few problems with water quality or pond condition have been reported in anecdotal accounts prior to the last 30 to 40 years.

As agriculture waned and residential development increased, more impervious surface was created and more waste water disposal systems were created, increasing both runoff and ground water impacts by human activity on the Cape. Sandy soils and limited piping systems still limit direct inputs of runoff to most ponds, but inputs to ground water from runoff and waste water have increased dramatically.

Camp Edwards and the Otis Air Force Base, collectively known as the Massachusetts Military Reservation (MMR), represented a source of ground water contamination for many years, and remain an ongoing concern. Nitrogen and to a lesser extent phosphorus that was discharged to soil moved along ground water flow gradients and was known to contaminate some water resources, the most well documented of which was probably Ashumet Pond (Jacobs Engineering 1999), a site of past and recent remediation. Other contaminants of concern from Camp Edwards include various solvents that have floated on top of the ground water and contaminated wells that penetrate only into the upper level of the aquifer. The position of the “crown” of the aquifer is on the MMR, with ground water apparently radiating out in all directions and potentially affecting all the ponds. However, ground water movement may not be consistent or readily predictable in both vertical and horizontal directions, and can vary over time, especially in response to variation in precipitation, so assumptions need to be documented before drawing conclusions about contamination.

## Current Land Use

The primary current developed land uses are residential and commercial, with cranberry farming as the main agricultural activity. Transportation corridors (roads) associated with development constitute a major land use as well. Undeveloped lands include pine and oak forests in uplands and a variety of wetland types in the lowlands.

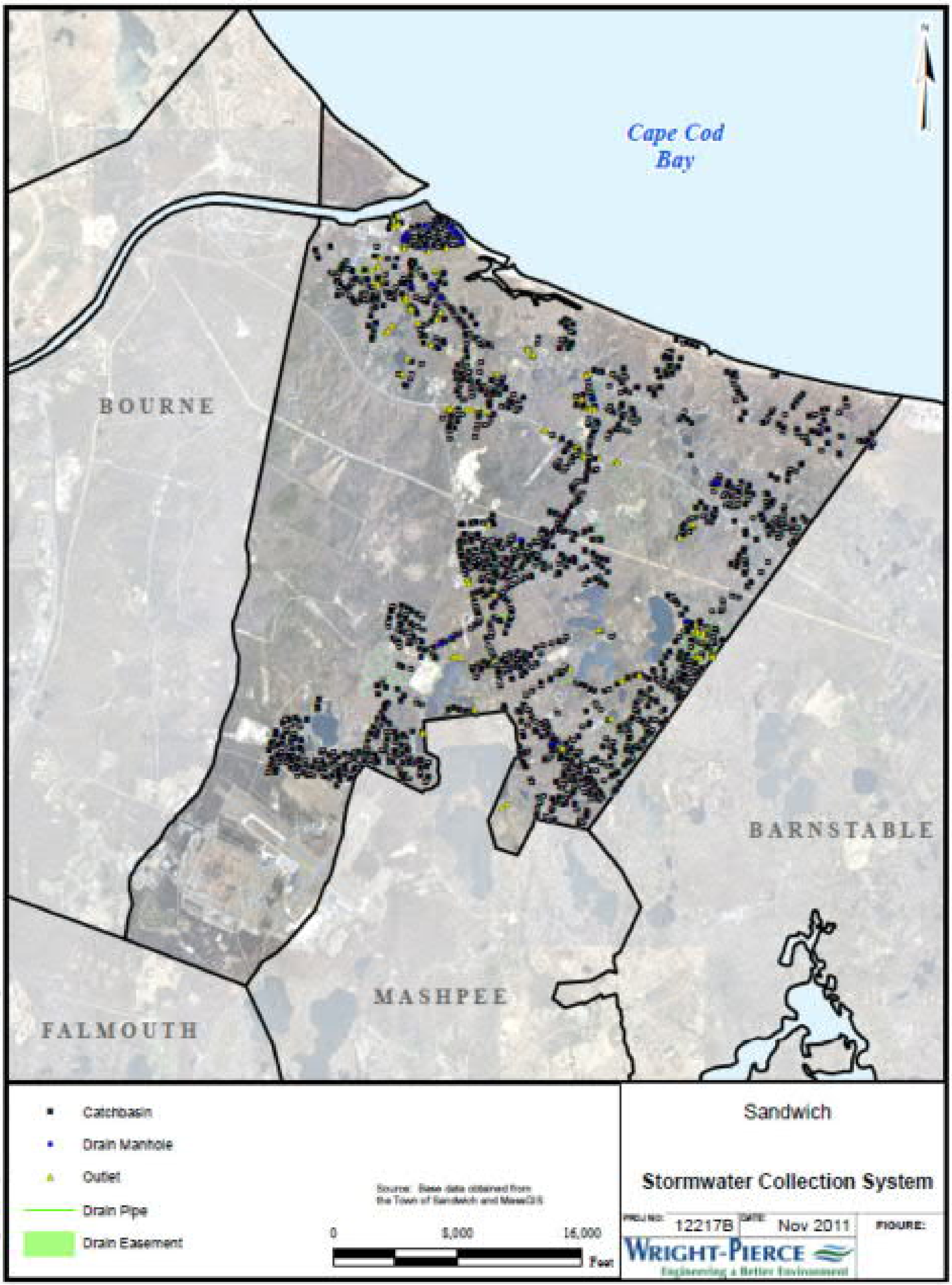
The major pollution threat to ponds is mainly nutrients from developed land and cranberry bogs. Storm water runoff is one form of pollution that may be significant with the level of development now experienced by Sandwich, with nutrients, sediment, bacteria, salt or other deicing chemicals, hydrocarbons and larger trash items all potentially significant. Sandwich has developed a Storm water Management Plan (SMP) that outlines current laws and regulations and specifies best management practices (BMPs) to address storm water impacts. The SMP is intended to meet NPDES Phase II regulations and to provide a framework for protecting water resources. All storm drains in the town have been mapped (Figure 3), but the vast majority are leaching catch basin and do not discharge to any waterbody or stream.

Yet waste water disposal is generally recognized as the biggest pollution threat, and includes nutrients and various household products that can negatively impact ponds receiving significant ground water flow. This pollution source is addressed separately in the next section.

## Waste Water Disposal in Sandwich

While there are a few small waste water treatment facilities in Sandwich, Wright-Pierce (unpublished data) reports that approximately 97% of waste water is disposed by on-site subsurface treatment systems with release into soil, particularly near the ponds assessed here. Some larger communal systems exist, but most properties are served by individual systems. Nitrogen is minimally removed by conventional on-site (septic) systems and concentrations can be predicted from housing density, related disposal features and precipitation/recharge features. Concentrations high enough to impact coastal resources have been documented as part of the Massachusetts Estuaries Program, and it is conceivable that ponds are being impacted as well, although impacts have been less studied. Phosphorus is adsorbed to soil particles and travels less freely, but adsorption capacity is lower for sand than many other soils and breakthrough to water resources can occur over time as adsorption capacity is

Figure 3. Storm water drains in Sandwich, Massachusetts.



exhausted. Hydrocarbons tend to “float” on the ground water and create elongate plumes. Various solvents and personal care products mix with ground water and should be diluted to a large extent, but some compounds (e.g., endocrine disruptors, hormone mimics) may cause impacts at very low concentrations. Viruses are known to move through soils and could contaminate ponds.

The MMR has impacted ground water in multiple towns from waste disposal operations over many years. Impacts on pond water quality and biological components, including fish, are still under study, but some cases of documented impact (Ashumet Pond, Mashpee Lake 27) exist. Remediation programs are underway, but the extent of contamination from past spread is an ongoing concern for water resources, including some Sandwich Ponds.

In recognition of the role that ground water plays in surface water quality, Sandwich has also adopted a ground water protection statute under its zoning process that regulates development within 300 feet of any pond or wetland. It is not certain that a 300 foot buffer is sufficient to protect associated surface water resources, but this is a generally recognized setback for limitation of phosphorus impacts and is thought to provide enough adsorption and dilution capacity to address many other contaminants.

In 2000 the Cape Cod Commission designated the Three Ponds Area of south Sandwich as a District of Critical Planning Concern to help protect these water resources. Such a district allows establishment of special regulations to protect resources in the designated area, which in this case includes 692 acres of land associated with Lawrence, Spectacle and Triangle Ponds. One focus of the district is protection of endangered species, and there are multiple listed plant species associated with some of the ponds in Sandwich. However, the District includes only the three ponds mentioned above, leaving other ponds with less protection.

## Internal Recycling Influences

The accumulation of nutrients in ponds on Cape Cod has become a significant issue for eutrophication (overfertilization) over the last couple of decades. There is a lot that is not thoroughly understood about this accumulation, such as whether there is a clear threshold for impact or how much organically bound phosphorus may contribute, but it is clear that phosphorus bound to iron can be released when oxygen is lacking and that iron-bound phosphorus is a major component of accumulated surficial sediment phosphorus in many Cape Cod ponds. It appears to take a fairly long time (many years) for enough phosphorus to build up to allow significant internal recycling, so the sources may not be consistent or obvious over time. Yet once internal recycling becomes a significant influence, it tends to accelerate and become a dominant influence in a few years. At that point, watershed inputs from surface or ground water become less important to pond condition, which is typically poor as a consequence of algal blooms.

Internal recycling of phosphorus in deeper (>25 ft) ponds is facilitated by low oxygen at the bottom of those ponds and typically results in high bottom water phosphorus levels, but there is not enough light in deep water to support algal blooms. How much of that phosphorus gets into better lit upper waters where it can support algal blooms is a function of wind-induced mixing, upward diffusion, and iron sulfide formation, which limits the amount of iron available to re-bind the phosphorus when it reaches the upper waters. When sediment release of phosphorus results in concentrations >20 ug/L in upper waters, algal blooms tend to develop. As there is not nearly as much nitrogen being recycled with the phosphorus, the N:P ratio is relatively low and cyanobacteria (blue-green algae) are favored. Cyanobacterial blooms are also favored by warm summer temperatures, can float to form surface scums, and some forms can cause taste and odor and even toxicity. Such blooms are therefore a serious concern in Cape Cod ponds and have been increasing in frequency and severity over the last two decades.

## Other Threats to Use Support

Climate change is an issue for Cape Cod ponds, leading to greater extremes in weather. Higher precipitation in storms leads to more runoff, and warmer summer temperatures promote algal blooms and favor cyanobacteria. Rooted plant growths may also be favored. Variability will increase, and that may be more of a problem than any shift in average conditions. Lack of predictability requires greater management effort to maintain desirable conditions.

Invasive species represent another threat to use support, including both plant and animal species that can invade a pond and alter its utility for various uses. Cape Cod ponds are not particularly susceptible to zebra mussels or Asian clams, but a number of invasive aquatic plants can thrive in the low alkalinity, acidic aquatic habitats of the Cape. Variable leaf water milfoil (*Myriophyllum heterophyllum*) and fanwort (*Cabomba caroliniana*) are two species of concern that have invaded Cape ponds already.

# Pond by Pond Assessment

## Lawrence Pond

### Pond Features

Lawrence Pond is one element of the “Three Pond District” that also includes Spectacle and Triangle Ponds. Lawrence Pond has an area of 138 acres, about 2.3 miles of shoreline, a median depth of 15 ft and a maximum depth of 27 ft (Table 1). Bathymetry (Figure 4) is slightly irregular but not unusual for kettlehole ponds. Lawrence Pond has a largely sandy to rocky shoreline and sand and gravel in the shallow areas. There are no surface inlets or outlets at this pond. Access for the public is informal, off Great Hill Road on the southeast side of the pond, with no developed boat ramp or facilities. Lawrence Pond has a typical warm water fishery for Cape Cod, with largemouth and smallmouth bass, chain pickerel, yellow perch, pumpkinseed sunfish, brown bullheads and killifish.

### Watershed Features

The exact area of the watershed has not been delineated, and would depend largely on ground water flow paths. Surface water runoff to Lawrence Pond appears minor; runoff from Great Hill Road and many adjacent lots along the eastern shore (Figure 5) has been captured and routed to leaching catch basins as part of the towns storm water mitigation plan. There are many leaching catch basins on the east side of the pond (Figure 3), but it is generally believed that ground water influence from this side of the pond is low. There is a YMCA camp adjacent to Lawrence Pond on the west side and a campground

Figure 4. Bathymetry of Lawrence Pond from pre-1990 MA DFW records.

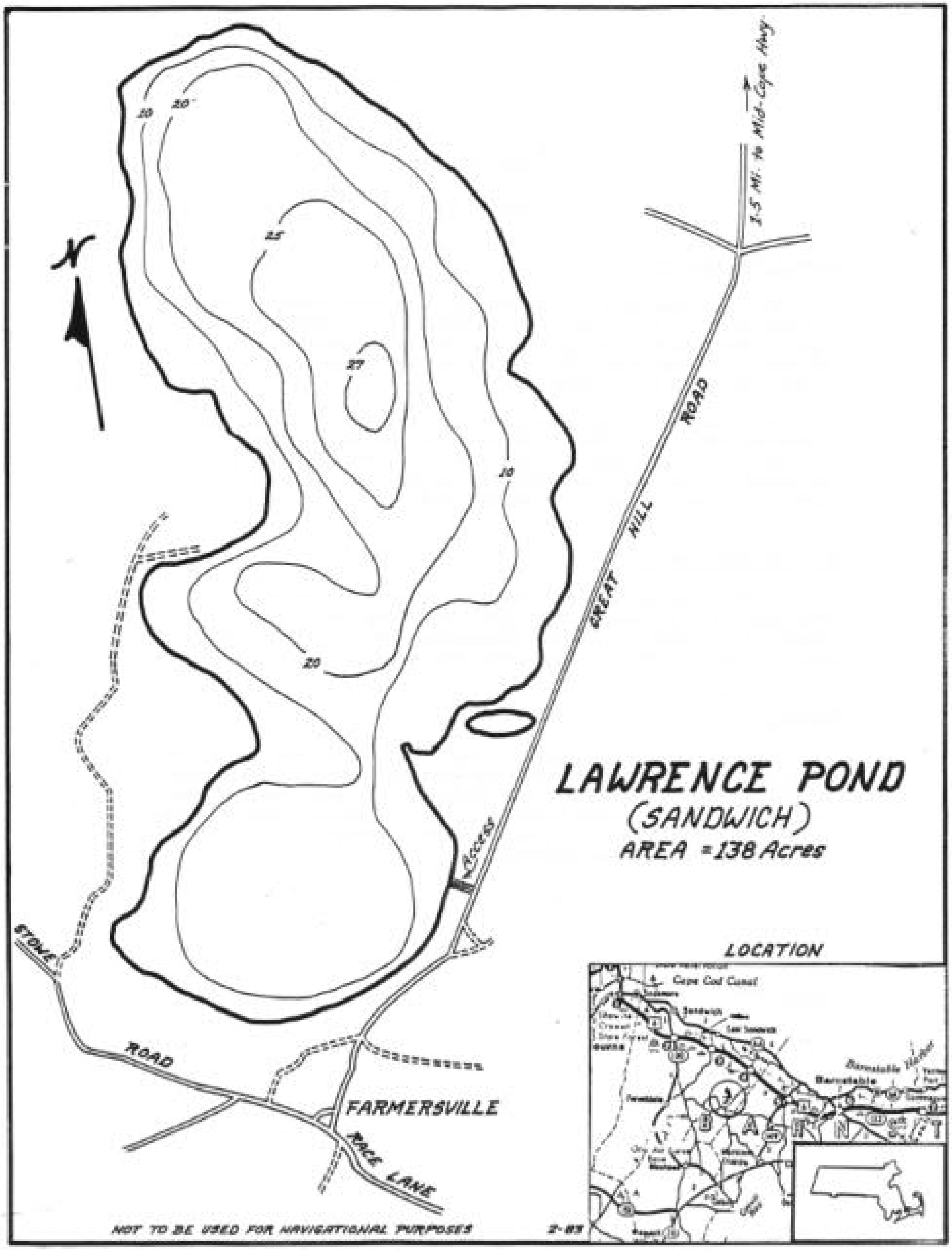
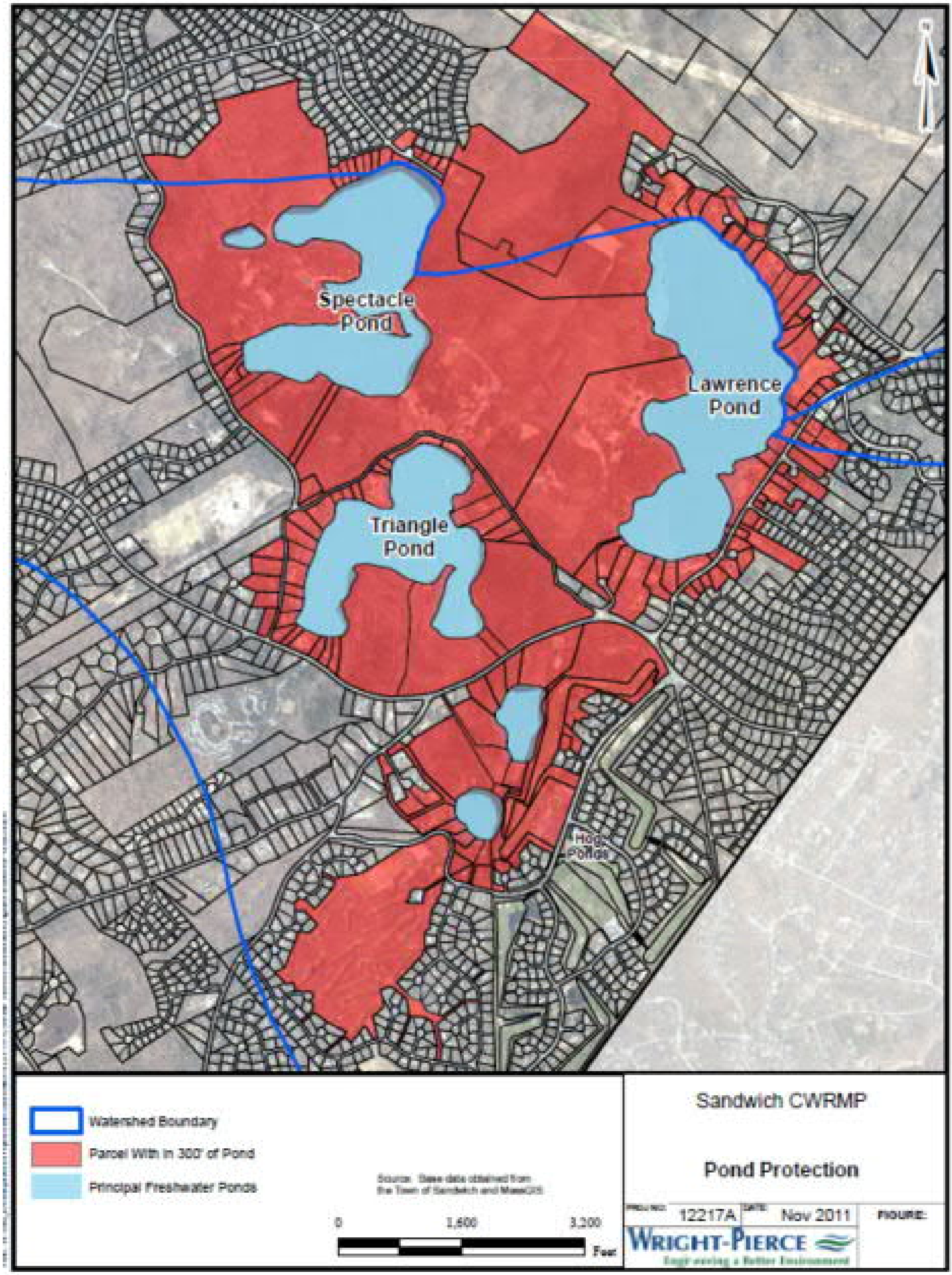
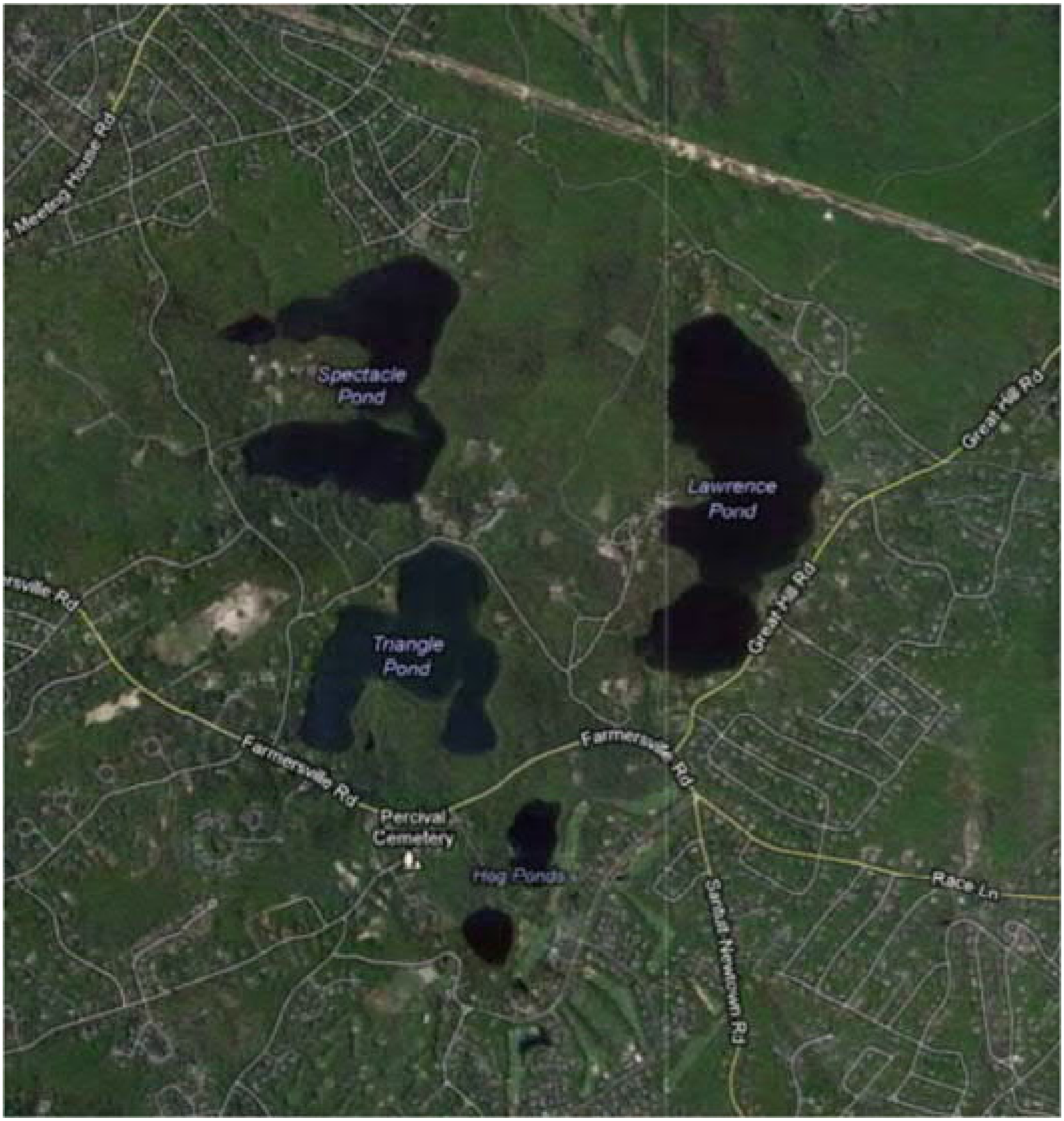


**Figure 5. Pond and parcel layout for Lawrence, Spectacle, Triangle and the Hog Ponds.**



Source: Base data obtained from the Town of Sandwich and MassGIS

**Figure 6. Aerial view of immediate area of Lawrence, Spectacle, Triangle and the Hog Ponds.**



on the southeast side. There are two community associations, each with lake access points. There is a lot of undeveloped land in large parcels along the western shore (Figures 5 and 6), much of under conservation easement and extending all the way to Spectacle Pond. While there are many itemized parcels within 300 ft of the shore (Figure 4), there are only 6 parcels in the immediate upgradient direction of ground water flow and only 2 of these are developed. Impact from other parcels is certainly possible, including from developed land farther from the lake to the west, and there is concern by town officials regarding intense development to the northwest.

### Pond Condition

Water quality data and some biological observations are available through the PALS program, supported by the School for Marine Science and Technology at UMASS Dartmouth (Table 2). Water clarity ranged from 4 to 7.7 m in three samplings in 2008-2010, with depleted oxygen only right at the sediment water interface. The pond is too shallow to stratify strongly, so oxygen problems should not be severe. The pH is acidic, alkalinity is very low, as are phytopigments and nutrients. Phosphorus is <10 ug/L in all samples, while nitrogen is close to or less than 300 ug/L. Water color varies but appears to be a function of natural color more than algae, rooted plants are reported as sparse, but no detailed survey has been conducted. In 2010, peripheral algal mats were noted, but no surface blooms have been reported. Lawrence Pond supports a warmwater fishery, with at least largemouth bass, chain pickerel and yellow perch stocked historically by the former MA Division of Fisheries and Game. However, no recent survey data for fish are available.

### Designated Use Support

Lawrence Pond is used mainly for swimming, boating and fishing, and supports those uses.

### Risk from Future Development

Most land around the pond is privately held, and additional development would represent a substantial threat to pond condition. The undeveloped lands to the west represent a very valuable buffer, and should be protected. There is concern over inputs via ground water from the intensely developed area beyond Spectacle Pond to the northwest. The Three Ponds (or South Sandwich Ponds) District of Critical Planning Concern was established to further that protection, with a focus on rare plant species, but some emphasis on water quality as well.

### Assessment Needs

Knowledge of specific ground water flow paths and the quality of that water would be valuable to have. Detailed monitoring of inputs to Lawrence Pond has not been conducted. A full plant survey would be useful, as would analysis of the available fraction of sediment phosphorus in the surficial pond sediments. If Lawrence Pond experiences algae problems, it will almost undoubtedly be related to internal recycling of long-term inputs.

### Management Needs

There are no obvious remediation needs at this time. Lawrence Pond is in relatively good condition, and most actions would be preventive. Land protection and assessment of inputs are the primary needs.

# Table 2. Lawrence Pond water quality and related observations from the PALS program, 2008-2010.

| Date | Depth (M) | Number of Samples | Total Depth (M) | Secchi Depth (M) | % Secchi | Temp ( C ) | DO (mg/L) | pH (SU) | Alk (mg $CaCO_3$/L) | Chla (ug/L) | Phaeo (ug/L) | TP (ug/L) | TN (ug/L) | Water Color | Plants | Notes |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 8/20/2008 | 0.5 | 2 | 8.2 | 4.5 | 54.4% | 24.6 | 5.91 | 6.02 | 1.80 | 2.05 | 0.46 | 8.8 | 239.1 | brown/green | <1% | |
| 8/20/2008 | 1 | | | | | 24.7 | 6.18 | | | | | | | brown/green | | |
| 8/20/2008 | 2 | | | | | 24.8 | 6.22 | | | | | | | brown/green | | |
| 8/20/2008 | 3 | | | | | 24.8 | 6.07 | | | | | | | brown/green | | |
| 8/20/2008 | 4 | | | | | 24.9 | 6.11 | | | | | | | brown/green | | |
| 8/20/2008 | 5 | | | | | 24.9 | 6.13 | | | | | | | brown/green | | |
| 8/20/2008 | 6 | | | | | 24.8 | 6.08 | | | | | | | brown/green | | |
| 8/20/2008 | 7 | | | | | 24.8 | 5.95 | 6.17 | 1.90 | 2.68 | 0.48 | 8.1 | 242.4 | brown/green | | |
| 8/20/2008 | 8 | | | | | 24.8 | 6.08 | | | | | | | brown/green | | |
| 9/8/2009 | 0.5 | | 8.1 | 7.7 | 95.1% | 22.8 | 8.7 | 5.32 | 2.10 | 1.07 | 1.11 | 4.5 | 233.1 | blue | Emergent grasses/sedges: 1%, other: 1%, no waterlilies or floating algal mats | |
| 9/8/2009 | 1 | | | | | 22.9 | 8.5 | | | | | | | blue | | |
| 9/8/2009 | 2 | | | | | 22.9 | 8.5 | | | | | | | blue | | |
| 9/8/2009 | 3 | | | | | 22.9 | 8.4 | | | | | | | blue | | |
| 9/8/2009 | 4 | | | | | 22.9 | 8.4 | | | | | | | blue | | |
| 9/8/2009 | 5 | | | | | 22.9 | 8.3 | | | | | | | blue | | |
| 9/8/2009 | 6 | | | | | 22.9 | 8.3 | | | | | | | blue | | |
| 9/8/2009 | 7 | | | | | 22.8 | 8.3 | 5.36 | 2.10 | 1.04 | 0.95 | 6.2 | 252.3 | blue | | |
| 9/8/2009 | 8 | | | | | 22.8 | 8.2 | | | | | | | blue | | |
| 8/26/2010 | 0.5 | 2 | 8.7 | 4 | 46.0% | 22.9 | 6.50 | 6.93 | 27.5 | 2.91 | 1.38 | 7.6 | 314.3 | brown | <1% | Higher than normal accumulation of green algae around the shore. Also highest water level in at least 15 years |
| 8/26/2010 | 1 | | | | | 24.4 | 6.20 | | | | | | | brown | | |
| 8/26/2010 | 2 | | | | | 24.5 | 5.90 | | | | | | | brown | | |
| 8/26/2010 | 3 | | | | | 24.5 | 5.90 | | | | | | | brown | | |
| 8/26/2010 | 4 | | | | | 24.5 | 5.80 | | | | | | | brown | | |
| 8/26/2010 | 5 | | | | | 24.5 | 5.70 | | | | | | | brown | | |
| 8/26/2010 | 6 | | | | | 24.4 | 5.50 | | | | | | | brown | | |
| 8/26/2010 | 7 | | | | | 24.4 | 5.50 | | | | | | | brown | | |
| 8/26/2010 | 8 | | | | | 19.9 | 1.90 | 6.40 | 4.6 | 1.91 | 0.84 | 8.4 | 306.9 | brown | | |
| 8/26/2010 | 9 | | | | | 18.0 | 0.20 | | | | | | | brown | | |

## Spectacle Pond

### *Pond Features*

Spectacle Pond covers 91 acres in south Sandwich, part of the Three Pond District with Lawrence and Triangle Ponds. It has 2.6 miles of shoreline with an average depth of 26 ft and a maximum depth of 43 ft (Table 1). It is a “double kettlehole”, with two basins separated by a shallower sandy zone and an island (Figure 7). There are no surface inlets or outlets at this pond. Access is available at the southwest corner of the lake, including a boat ramp, but public recreational facilities are very limited. Nearshore areas are mostly sand and gravel. Plant cover is very limited in sandy, shallow areas.

### *Watershed Features*

The watershed has not been delineated, but surface runoff is possible only from the immediate shoreline, most of which is undeveloped. The area to the north, which is densely residential (Figures 5 and 6), presents a runoff threat; this Lakewood Hills area has numerous leaching catch basins, installed around 2000 to minimize direct storm water outlet to the lake. There is also a direct entry storm drain at the southeast corner of the pond, draining part of the YMCA camp, and further evaluation of this drainage system is warranted. Ground water flow paths will be more important to pond inputs, and the dominant pathway for ground water flow is from the densely developed land to the northwest. Spectacle Pond has a YMCA Camp (Camp Haywood) adjacent to it, and considerable undeveloped forest to the east and west.

### *Pond Condition*

Water quality data and some biological observations are available through the PALS program, supported by the School for Marine Science and Technology at UMASS Dartmouth (Table 3). Water clarity ranged from 3 to 5 m in three samplings in 2008-2010. There is thermal stratification at about 30 ft (9 m), with oxygen depression observed below that depth. Oxygen depletion occurs only in the last few feet above the bottom in the deepest area, however. The pH is acidic and alkalinity is very low, as are phytopigments, although algal blooms have been reported for this lake in recent years. Phosphorus levels ranged from 5.4 to 16.1 ug/L, while nitrogen ranged from 211 to 561 ug/L, both in the low to moderate range. Water color varies but may be affected by algae at times. Rooted plants are reported as sparse, but no detailed survey has been conducted. The pond has been stocked with trout and smallmouth bass in the past, but fishery management effort appears very limited and no recent surveys have been conducted.

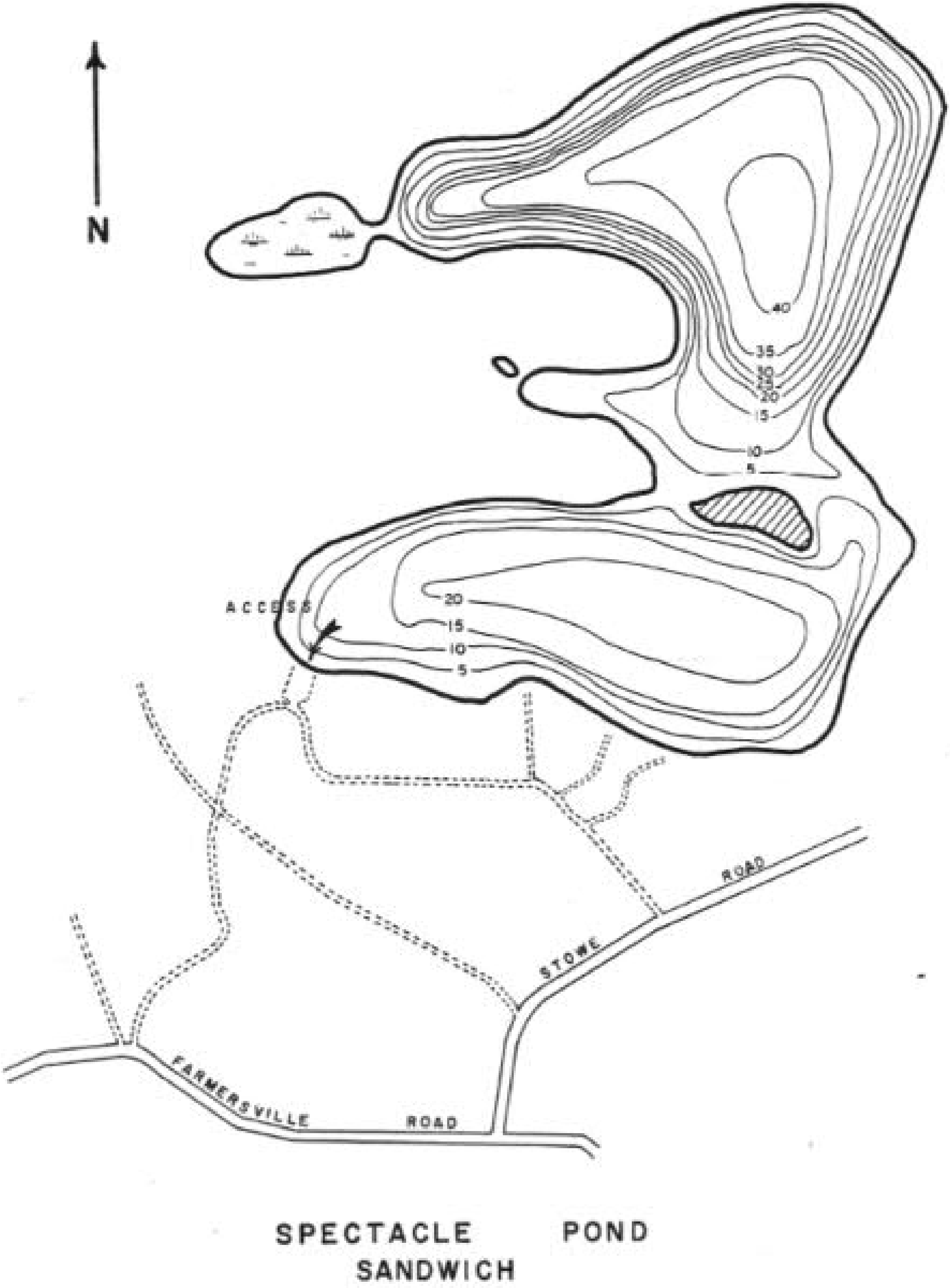
### *Designated Use Support*

Spectacle Pond is used mainly for swimming, boating and fishing, and appears to support those uses, although there is a perception of increasing algal abundance that is consistent with the nutrient data.

### *Risk from Future Development*

There is considerable land near the pond that, if developed, would constitute a substantial threat to its quality. The Three Ponds (or South Sandwich Ponds) District of Critical Planning Concern was established to further that protection, with a focus on rare plant species, but some emphasis on water quality as well.

**Figure 7. Bathymetry of Spectacle Pond from pre-1990 MA DFW records.**



## Table 3. Spectacle Pond water quality and related observations from the PALS program, 2008-2010.

| Pond | Date | Depth (M) | Number of Samples | Total Depth (M) | Secchi Depth (M) | % Secchi | Temp ( C ) | DO (mg/L) | pH (SU) | Alk (mg $CaCO_3$/L) | Chla (ug/L) | Phaeo (ug/L) | TP (ug/L) | TN (ug/L) | Water Color | Plants | Notes |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Spectacle | 8/26/2008 | 0.5 | 4 | 12.2 | 4.1 | 33.7% |  | 6.78 | 6.32 | 3.40 | 2.07 | 0.55 | 5.7 | 247.4 | blue | 10% submerged algae |  |
| Spectacle | 8/26/2008 | 1 |  |  |  |  | 24.9 | 6.80 |  |  |  |  |  |  | blue |  |  |
| Spectacle | 8/26/2008 | 2 |  |  |  |  | 24.9 | 6.75 |  |  |  |  |  |  | blue |  |  |
| Spectacle | 8/26/2008 | 3 |  |  |  |  | 24.8 | 6.73 | 6.62 | 3.50 | 1.71 | 0.27 | 6.0 | 218.4 | blue |  |  |
| Spectacle | 8/26/2008 | 4 |  |  |  |  | 24.8 | 6.71 |  |  |  |  |  |  | blue |  |  |
| Spectacle | 8/26/2008 | 5 |  |  |  |  | 24.8 | 6.71 |  |  |  |  |  |  | blue |  |  |
| Spectacle | 8/26/2008 | 6 |  |  |  |  | 24.8 | 6.67 |  |  |  |  |  |  | blue |  |  |
| Spectacle | 8/26/2008 | 7 |  |  |  |  | 24.6 | 6.56 |  |  |  |  |  |  | blue |  |  |
| Spectacle | 8/26/2008 | 8 |  |  |  |  | 22.7 | 7.13 |  |  |  |  |  |  | blue |  |  |
| Spectacle | 8/26/2008 | 9 |  |  |  |  | 18.5 | 9.08 |  |  | 2.03 | 0.91 | 5.4 | 217.2 | blue |  |  |
| Spectacle | 8/26/2008 | 10 |  |  |  |  | 16.5 | 8.26 |  |  |  |  |  |  | blue |  |  |
| Spectacle | 8/26/2008 | 11 |  |  |  |  | 14.7 | 3.65 | 6.37 | 3.40 | 2.34 | 1.28 | 6.9 | 211.0 | blue |  |  |
| Spectacle | 8/26/2008 | 12 |  |  |  |  | 13.8 | 0.17 |  |  |  |  |  |  | blue |  |  |
| Spectacle | 9/8/2009 | 0.5 |  | 11.3 | 5 | 44.2% | 23.3 | 6.7 | 5.69 | 3.40 | 1.81 | 0.95 | 16.1 | 272.0 | ND | Waterlilies: <1%, floating algae: <1%, emergent grasses/sedges: up to 10% |  |
| Spectacle | 9/8/2009 | 1 |  |  |  |  | 23.2 | 6.1 |  |  |  |  |  |  | ND |  |  |
| Spectacle | 9/8/2009 | 2 |  |  |  |  | ND | ND |  |  |  |  |  |  | ND |  |  |
| Spectacle | 9/8/2009 | 3 |  |  |  |  | 23.1 | 6.7 | 5.54 | 3.20 | 2.16 | 0.72 | 7.9 | 281.8 | ND |  |  |
| Spectacle | 9/8/2009 | 4 |  |  |  |  | 23.1 | 6.5 |  |  |  |  |  |  | ND |  |  |
| Spectacle | 9/8/2009 | 5 |  |  |  |  | 23.0 | 6.3 |  |  |  |  |  |  | ND |  |  |
| Spectacle | 9/8/2009 | 6 |  |  |  |  | 23.1 | 6.2 |  |  |  |  |  |  | ND |  |  |
| Spectacle | 9/8/2009 | 7 |  |  |  |  | 22.9 | 6.0 |  |  |  |  |  |  | ND |  |  |
| Spectacle | 9/8/2009 | 8 |  |  |  |  | 22.9 | 5.8 |  |  |  |  |  |  | ND |  |  |
| Spectacle | 9/8/2009 | 9 |  |  |  |  | 21.5 | 4.1 | 5.32 | 4.30 | 4.29 | 2.89 | 9.1 | 372.9 | ND |  |  |
| Spectacle | 9/8/2009 | 10 |  |  |  |  | 18.6 | 3.2 |  |  |  |  |  |  | ND |  |  |
| Spectacle | 9/8/2009 | 11 |  |  |  |  | 17.2 | 1.0 | 5.77 | 4.50 | 3.17 | 2.73 | 8.9 | 375.0 | ND |  |  |
| Spectacle | 9/8/2009 | 12 |  |  |  |  | 16.8 | <0.1 |  |  |  |  |  |  | ND |  |  |
| Spectacle | 8/31/2010 | 0.5 | 3 | 7.2 | 3 | 41.7% | 24.0 | 7.43 | 6.45 | 4.1 | 0.89 | <0.05 | 14.1 | 561.0 | blue/green | <1% | Samplers could not find deepest area |
| Spectacle | 8/31/2010 | 1 |  |  |  |  | 23.9 | 7.33 |  |  |  |  |  |  | blue/green |  |  |
| Spectacle | 8/31/2010 | 2 |  |  |  |  | 23.6 | 7.18 |  |  |  |  |  |  | blue/green |  |  |
| Spectacle | 8/31/2010 | 3 |  |  |  |  | 23.3 | 7.26 | 6.48 | 4.2 | 2.39 | 1.44 | 9.7 | 320.0 | blue/green |  |  |
| Spectacle | 8/31/2010 | 4 |  |  |  |  | 23.0 | 6.92 |  |  |  |  |  |  | blue/green |  |  |
| Spectacle | 8/31/2010 | 5 |  |  |  |  | 22.8 | 6.88 |  |  |  |  |  |  | blue/green |  |  |
| Spectacle | 8/31/2010 | 6 |  |  |  |  | 22.3 | 6.29 |  |  |  |  |  |  | blue/green |  |  |
| Spectacle | 8/31/2010 | 7 |  |  |  |  | 21.4 | 2.96 | 6.72 | 4.0 | 0.85 | 0.84 | 10.5 | 380.4 | blue/green |  |  |

### *Assessment Needs*

Knowledge of specific ground water flow paths and the quality of that water would be valuable to have. There is some monitoring of Town wells to the west, but detailed monitoring of inputs to Lawrence Pond has not been conducted. Monitoring of ground water inputs near the north end of the lake would be advisable now. The direct entry storm water drainage system at the southeast end of the pond should be further evaluated and possibly mitigated. A full plant survey would be useful, as would analysis of the available fraction of sediment phosphorus in the surficial pond sediments.

### *Management Needs*

It is difficult to define management needs with a lack of basic background information, but the densely developed area to the north and northwest of the pond represents a big enough threat to pond quality to suggest as the key target of management at this time. The first step in sound management would be an evaluation of inputs from this area, focusing mainly on ground water contamination. Education of residents about their role in maintaining water quality would be desirable.

## Triangle Pond

### *Pond Features*

Triangle Pond covers 84 acres in south Sandwich and is part of the Three Pond District with Lawrence and Spectacle Ponds. It has 2 miles of shoreline with an average depth of 15 ft and a maximum depth of 30 ft (Table 1). No bathymetric map is available for this pond, and there is controversy over the maximum depth; some parties claim a depth in excess of 60 ft, but data from past sampling effort suggests that the depth is no more than 32 ft. There are no surface inlets or outlets at this pond. Access is available from a little known state boat launching area on the west side of the pond. Nearshore areas are mostly sand and gravel. Plant cover is very limited in sandy, shallow areas.

### *Watershed Features*

The watershed of Triangle Pond has not been carefully delineated, but only land in close proximity presents any threat of overland flow, and development is light around this pond (Figures 5 and 6). Most of the nearby land is wooded. A YMCA camp is adjacent to Triangle Pond at the north end. Ground water flow from the MMR and the residential area to the north and west represent threats, but these have not been studied in any appreciable detail for this pond.

### *Pond Condition*

Water quality data and some biological observations are available through the PALS program, supported by the School for Marine Science and Technology at UMASS Dartmouth (Table 4). Water clarity ranged from 3.4 to 3.9 m in three samplings in 2008-2010. The pond appears to be just deep enough to undergo thermal stratification, with just a small deep water layer below 27 ft (8 m); oxygen depression is observed below that depth, with oxygen depletion only right at the sediment-water interface in the deepest area. The pH is acidic and alkalinity is very low, as are phytopigments, although algal blooms have been reported for this lake with increasing frequency over the last 6 years. Phosphorus levels ranged from 5 to 142 ug/L in surface water, a striking range, and reached 467 ug/L at the sediment-

## Table 4. Triangle Pond water quality and related observations from the PALS program, 2008-2010.

| Pond | Date | Depth (M) | Number of Samples | Total Depth (M) | Secchi Depth (M) | % Secchi | Temp ( C ) | DO (mg/L) | pH (SU) | Alk (mg $CaCO_3$/L) | Chla (ug/L) | Phaeo (ug/L) | TP (ug/L) | TN (ug/L) | Water Color | Plants | Notes |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Triangle | 8/26/2008 | 0.5 | 3 | 9.2 | 3.9 | 42.1% | 25.2 | 6.73 | 6.45 | 3.20 | 1.32 | 0.43 | 141.7 | 199.4 | blue green | 10% bottom algae | pond receding |
| Triangle | 8/26/2008 | 1 | | | | | 25.0 | 6.67 | | | | | | | blue green | | |
| Triangle | 8/26/2008 | 2 | | | | | 24.8 | 6.66 | | | | | | | blue green | | |
| Triangle | 8/26/2008 | 3 | | | | | 24.8 | 6.67 | 6.45 | 3.10 | 1.29 | 0.32 | 31.4 | 179.9 | blue green | | |
| Triangle | 8/26/2008 | 4 | | | | | 24.7 | 6.60 | | | | | | | blue green | | |
| Triangle | 8/26/2008 | 5 | | | | | 24.6 | 6.50 | | | | | | | blue green | | |
| Triangle | 8/26/2008 | 6 | | | | | 24.5 | 6.47 | | | | | | | blue green | | |
| Triangle | 8/26/2008 | 7 | | | | | 24.4 | 6.42 | | | | | | | blue green | | |
| Triangle | 8/26/2008 | 8 | | | | | 21.7 | 2.39 | | | | | | | blue green | | |
| Triangle | 8/26/2008 | 9 | | | | | 19.1 | 0.07 | 6.11 | 9.40 | 1.17 | 15.06 | 42.4 | 302.5 | blue green | | |
| Triangle | 8/26/2008 | 10 | | | | | 18.3 | 0.04 | | | | | | | blue green | | |
| Triangle | 9/8/2009 | 0.5 | | 8.8 | 3.6 | 40.9% | 22.8 | 8.3 | 5.88 | 3.30 | 2.25 | 0.92 | 4.5 | 262.1 | ND | Waterlilies:<1% to none, floating algae: <1% to none, emergent grasses/sedges: <2% | |
| Triangle | 9/8/2009 | 1 | | | | | 22.9 | 8.7 | | | | | | | ND | | |
| Triangle | 9/8/2009 | 2 | | | | | 22.8 | 8.6 | | | | | | | ND | | |
| Triangle | 9/8/2009 | 3 | | | | | 22.8 | 8.5 | 5.60 | 3.20 | 1.56 | 1.01 | 11.9 | 256.6 | ND | | |
| Triangle | 9/8/2009 | 4 | | | | | 22.8 | 8.5 | | | | | | | ND | | |
| Triangle | 9/8/2009 | 5 | | | | | 22.8 | 8.4 | | | | | | | ND | | |
| Triangle | 9/8/2009 | 6 | | | | | 22.8 | 8.3 | | | | | | | ND | | |
| Triangle | 9/8/2009 | 7 | | | | | 22.8 | 8.2 | | | | | | | ND | | |
| Triangle | 9/8/2009 | 8 | | | | | 22.5 | 7.2 | 5.77 | 4.50 | 15.99 | 107.32 | 467.9 | 3962.0 | ND | | |
| Triangle | 9/1/2010 | 0.5 | 3 | 9.7 | 3.4 | 35.1% | 24.5 | 7.66 | 6.69 | 4.1 | 0.17 | 0.56 | 10.5 | 365.2 | blue/green | <1% | Water level highest in many years- least amount of algae in years! Very nice swimming |
| Triangle | 9/1/2010 | 1 | | | | | 24.3 | 7.51 | | | | | | | blue/green | | |
| Triangle | 9/1/2010 | 2 | | | | | 24.0 | 7.46 | | | | | | | blue/green | | |
| Triangle | 9/1/2010 | 3 | | | | | 23.6 | 7.44 | 6.60 | 3.6 | 0.56 | 0.11 | 9.9 | 284.3 | blue/green | | |
| Triangle | 9/1/2010 | 4 | | | | | 23.2 | 7.42 | | | | | | | blue/green | | |
| Triangle | 9/1/2010 | 5 | | | | | 22.8 | 7.47 | | | | | | | blue/green | | |
| Triangle | 9/1/2010 | 6 | | | | | 22.4 | 7.32 | | | | | | | blue/green | | |
| Triangle | 9/1/2010 | 7 | | | | | 21.8 | 6.86 | | | | | | | blue/green | | |
| Triangle | 9/1/2010 | 8 | | | | | 20.2 | 5.35 | | | | | | | blue/green | | |
| Triangle | 9/1/2010 | 9 | | | | | 16.0 | 0.42 | 6.28 | 7.0 | 3.35 | 2.47 | 18.9 | 307.3 | blue/green | | |

water interface in one sampling (2009). Nitrogen ranged from <200 to almost 4000 ug/L. The wide variation in nutrients, coupled with what we know of the immediate watershed and pond depth, suggests internal recycling as a dominant process. Water color varies but may be affected by algae at times. Rooted plants are reported as sparse, but no detailed survey has been conducted. A warmwater fishery is present, with smallmouth bass added historically, but no indication of any trout fishery.

### *Designated Use Support*

Triangle Pond is used mainly for swimming, boating and fishing. It appears to support those uses, and has not been placed on the state list of waters not attaining use designations, but concern over the last few years for increasing algae suggests that there is a threat to uses. Nutrient levels are high enough to be a concern in that regard.

### *Risk from Future Development*

Much of the immediate watershed is not densely developed, and further development would constitute a threat to pond condition. The Three Ponds (or South Sandwich Ponds) District of Critical Planning Concern was established to further that protection, with a focus on rare plant species, but some emphasis on water quality as well.

### *Assessment Needs*

Triangle Pond represents one of the more troubling combinations of limited data and perceived problems of any assessed pond in Sandwich. We have no bathymetric map or fishery data, no plant survey has been conducted, no algae samples have been analyzed, the watershed has not been delineated, and sediments have not been surveyed, yet there are clear signals that this pond is suffering from seasonal and erratic elevated nutrient levels and possible algal blooms. Given its inclusion in the Three Ponds District of Critical Planning Concern, further studies on every aspect of this pond are warranted. Assessment of ground water inputs and in-lake physical, chemical and biological features are needed to characterize current conditions and evaluate threats.

### *Management Needs*

Assuming that anecdotal evidence of algal blooms and declining quality is valid, and considering the available nutrient data, there is a need for nutrient management in Triangle Pond. It is too early to provide a definitive program, but either a mixing system that would prevent anoxia and phosphorus release or a phosphorus inactivation program to permanently bind phosphorus in deep sediments might be considered. There does not appear to be any localized watershed management need, but an evaluation of incoming ground water quality may reveal a need for remediation of associated inputs. It is most likely that current problems stem from internal loading from sediment phosphorus reserves accumulated over many years; inactivation of that phosphorus is a practical approach.

## Upper Hog Pond

### *Pond Features*

Upper Hog Pond covers about 11.3 acres in south Sandwich, with about 0.6 miles of shoreline, an average depth of about 14 ft and a maximum depth of about 20 ft (Table 1). Relatively little is known about this pond; the shoreline is privately held, so there is no public access. However, the area of the pond qualifies it as a Great Pond under Commonwealth of Massachusetts statute, making the pond itself a public resource, and access could be made across private property within reason. No bathymetric map appears available, and there is no annual or other sampling to assess pond condition. There are no reports of algal blooms or other problems.

### *Watershed Features*

Upper Hog Pond sits in a sandy bowl, a small but classic kettlehole formation. There are just a few residences around the pond, most seasonal, many derived from old hunting camps. An old, historic home was apparently relocated to the south end of this pond, and represents the largest and most well-kept property in the area. The immediate watershed is largely forested, but there are more densely residential areas to the west that may influence the pond via ground water flow (Figures 5 and 6). There are two golf courses to the east and south (Holly Ridge and Ridge Club), but it is generally believed that ground water in that area flows away from the Hog Ponds.

### *Pond Condition*

Little is known of the condition of Upper Hog Pond. There are no reports of problems, the water appears clear, and it is known as a local bird sanctuary. The area adjacent to the pond is believed to support multiple protected plant species.

### *Designated Use Support*

Upper Hog Pond is not used extensively, but would appear to support swimming, fishing, small boating, aesthetics, and other passive uses such as bird watching.

### *Risk from Future Development*

The area around the pond could be developed, as it is not part of the District of Critical Planning Concern associated with the ponds just to the north. Transformation of the small seasonal homes into much larger dwellings with potentially greater lawn area and larger waste disposal needs does represent a threat to this small pond.

### *Assessment Needs*

As almost nothing is known of the physical, chemical and biological features of Upper Hog Pond, a baseline survey would be in order. This is not likely to have a high priority, given the lack of known problems and private nature of the shoreline, but no management program can be contemplated without such baseline information.

### *Management Needs*

No management needs are recognized at this time.

## Lower Hog Pond

### *Pond Features*

Lower Hog Pond covers about 7.8 acres in south Sandwich, with about 0.5 miles of shoreline, an average depth of about 12 ft and a maximum depth of about 26 ft (Table 1). As with nearby Upper Hog Pond, relatively little is known about this pond. The shoreline is privately held, so there is no public access, and Lower Hog Pond is not large enough to be a Great Pond under Massachusetts law. No bathymetric map appears available, and there is no annual or other sampling to assess pond condition. There are no reports of algal blooms or other problems.

### *Watershed Features*

Lower Hog Pond sits in a sandy bowl, a small but classic kettlehole formation. There are just a few residences around the pond, seemingly all seasonal, many derived from old hunting camps. The immediate watershed is largely forested, but there are more densely residential areas to the west that may influence the pond via ground water flow (Figures 5 and 6). There are two golf courses to the east and south (Holly Ridge and Ridge Club), but it is generally believed that ground water in that area flows away from the Hog Ponds, and a small buffer strip was maintained when the courses were built to minimize the chance of surface water impact.

### *Pond Condition*

Little is known of the condition of Lower Hog Pond. There are no reports of problems, the water appears clear, and it is known as a local bird sanctuary. The area adjacent to the pond is believed to support multiple protected plant species.

### *Designated Use Support*

Lower Hog Pond is not used extensively, but would appear to support swimming, fishing, small boating, aesthetics, and other passive uses such as bird watching for the seasonal dwelling around the pond.

### *Risk from Future Development*

The area around the pond could be developed, as it is not part of the District of Critical Planning Concern associated with the ponds just to the north. Transformation of the small seasonal homes into much larger dwellings with potentially greater lawn area and larger waste disposal needs does represent a threat to this small pond.

### *Assessment Needs*

As almost nothing is known of the physical, chemical and biological features of Lower Hog Pond, a baseline survey would be in order. This is not likely to have a high priority, given the lack of known problems and private nature of the shoreline, but no management program can be contemplated without such baseline information.

### *Management Needs*

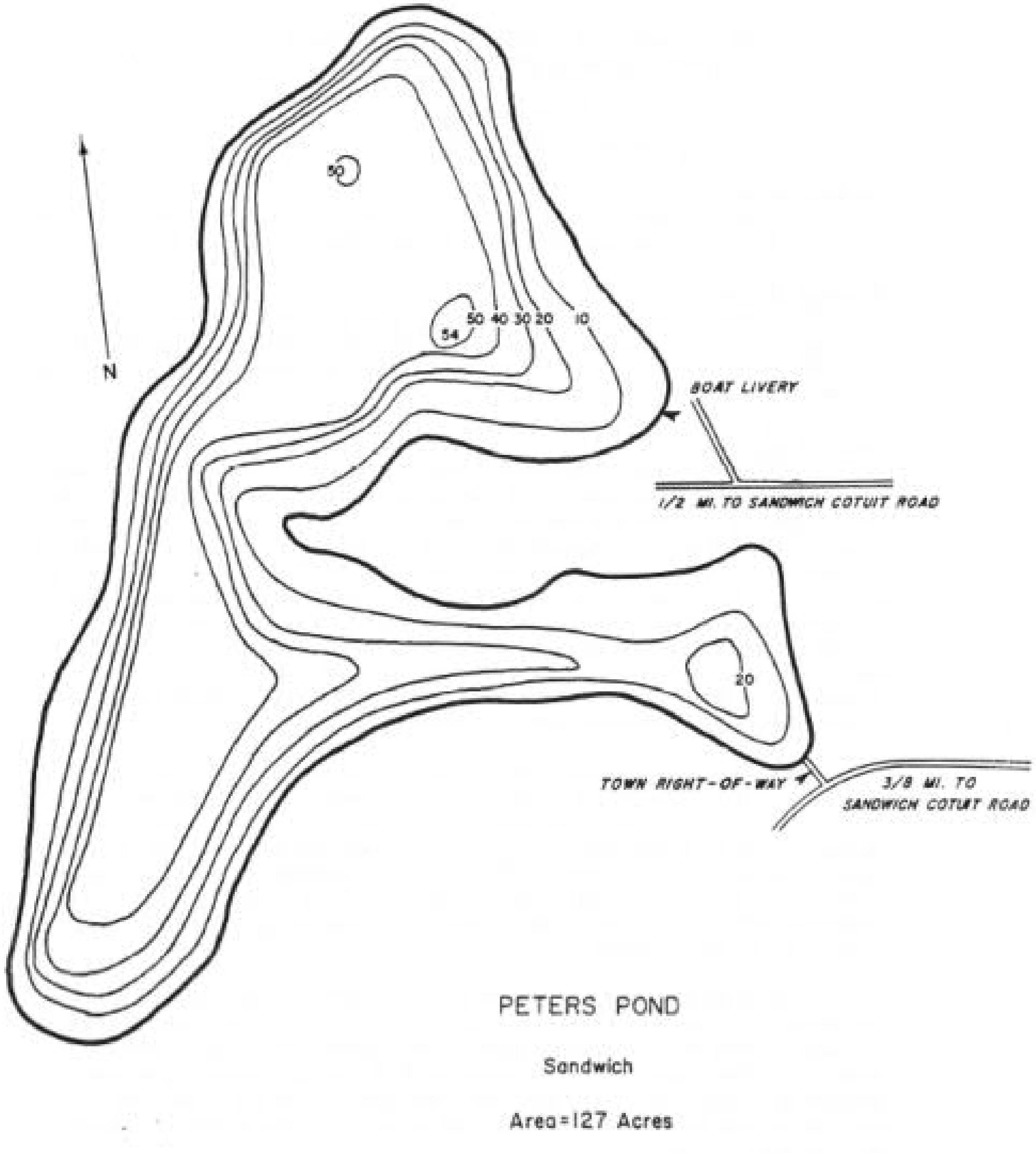
No management needs are recognized at this time.

## Peters Pond

### *Pond Features*

Peters Pond covers about 127 acres, although there is variability in areal estimates, with a range of 123 to 130.6 acres (some water level fluctuation occurs, so this is not unusual). Average depth is 22 ft while maximum depth is 54 ft (Table 1). The bathymetry is somewhat irregular, with an elongate cove to the east and the deepest part far to the north (Figure 8). The pond has no surface water inlets or outlet. There is a paved state boat launch and a town right of way for boat launching across a sandy beach, plus two campgrounds that afford access for a fee. There is a large community association beach as well.

**Figure 8. Bathymetry of Peters Pond from pre-1990 MA DFW records.**



Peters Pond is stocked with brown, brook and rainbow trout annually. Peters Pond is the most publicly used pond in Sandwich, with many large boats launched on it during summer.

### *Watershed Features*

The complete watershed of Peters Pond has not been determined. The immediate watershed of Peters Pond includes several large parcels around the northern half of the pond, including campgrounds, town land, and a gravel pit (Figures 9 and 10). Many smaller parcels, containing mainly seasonal cottages, are present around the southern half of the lake. Residential density is moderate to high moving further from the pond, and there are catch basins in some of those areas (Figure 3), but surface runoff is unlikely to reach the lake from more than the immediate shoreline. Ground water flow is expected mainly from the west and north. The gravel pit reportedly experienced a blow out from a berm that dumped silty water into the lake a few years ago, but overall impact appears low.

### *Pond Condition*

The former Division of Fisheries and Game, now the Division of Fisheries and Wildlife, was actively involved in the management of Peters Pond as early as 1911. A variety of salmonid species have been stocked over the last century, and the pond was reclaimed (all fish killed or salvaged, followed by restocking of salmonids) in 1955. Historically, Peters Pond was habitat for a wide variety of warm water fish species, but was considered to have very poor population structure prior to reclamation. While some warm water species undoubtedly remain, Peters Pond is largely a managed trout fishery. Plant growth appears very limited in the shallow areas of the pond, but no detailed survey is known.

Water quality in 1948 appeared excellent, with stratification at 30 ft but no oxygen depletion in the bottom waters (DO >4 mg/L). Yet in 2001 the oxygen profile exhibited no oxygen below 40 ft, an apparent deterioration of bottom water quality over a 50-year period, a common observation for deeper Cape Cod lakes. Water quality data have not been collected since 2002, however, so there is no documentation of conditions in recent years. Data from the PALS program in 2001 indicate slightly acidic pH, alkalinity of 12 to 15 mg/L, low surface nutrients (phosphorus = 8 ug/L, nitrogen = 290 ug/L) and moderate to slightly elevated bottom nutrients (phosphorus = 28 ug/L, nitrogen = 400 ug/L). Chlorophyll *a* was 5 ug/L at the surface and 20 ug/L in deep water. There have been reports of algal blooms in the eastern cove, with wind-driven blue-green scums in the northern cove as well. The 1960 DFW estimate was that 19% of the pond volume would support trout, but more recent estimates appear unavailable.

Peters Pond is on the Massachusetts 2010 Integrated Waters List as having a completed TMDL for metals. The TMDL relates to mercury and is not lake-specific; Peters Pond and Snake Pond in Sandwich are two of almost 100 Massachusetts ponds included in the Northeast Regional Mercury Total Maximum Daily Load developed by the New England states plus New York and finalized in 2007. This Total Maximum Daily Load (TMDL) document outlines a strategy for reducing mercury concentrations in fish in northeastern freshwater systems. This will require reductions from mercury sources within the Northeast region, U.S. states outside of the region, and global sources. In the Northeast, the majority of mercury pollution is a result of atmospheric deposition, so there is little that Sandwich can do on its own. This TMDL could very well apply to all Sandwich Ponds, but only Peters Pond and Snake Pond were included in the project.

Figure 9. Pond and parcel layout for Peters, Pimlico, Snake and Weeks Ponds.

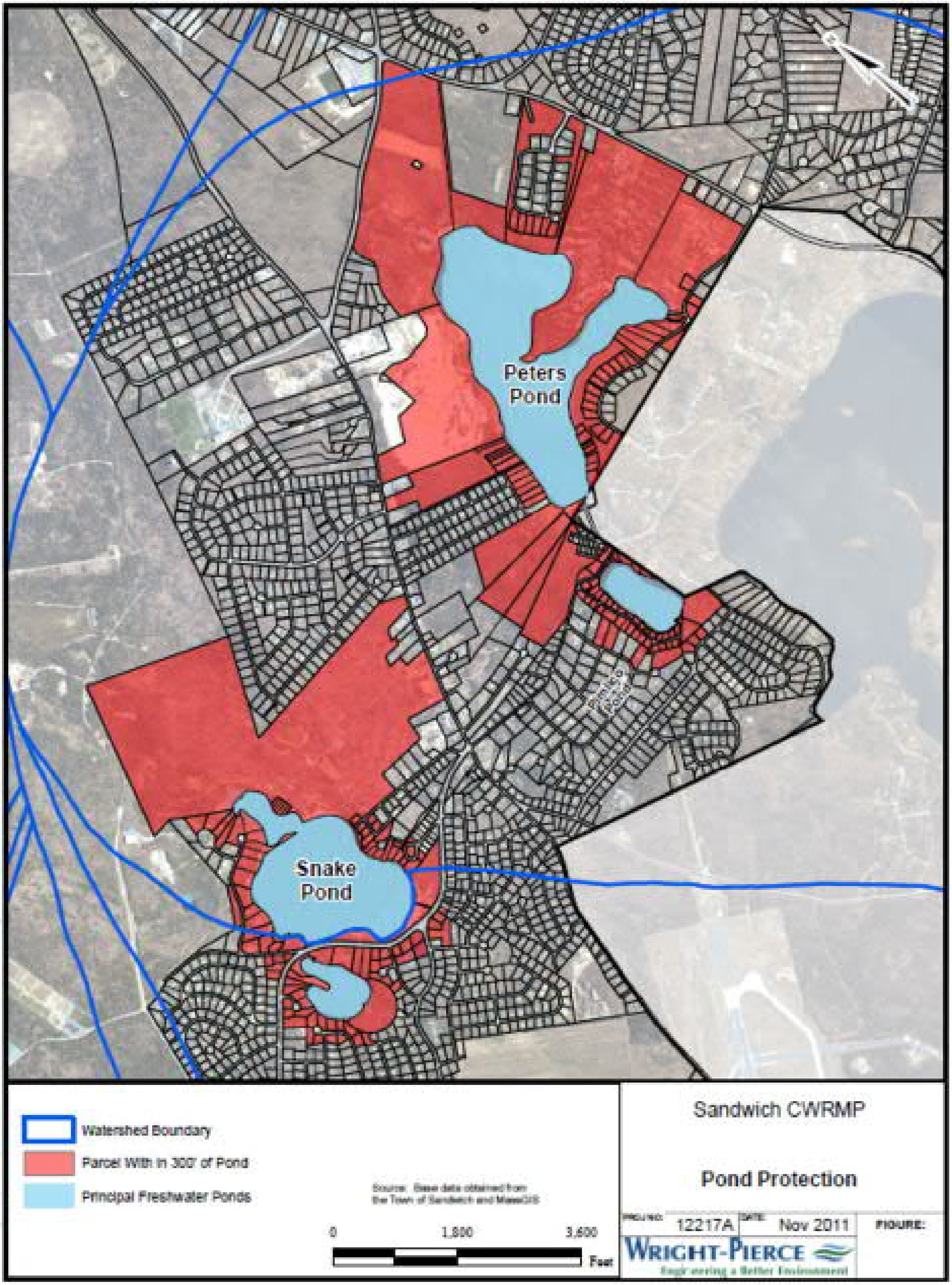
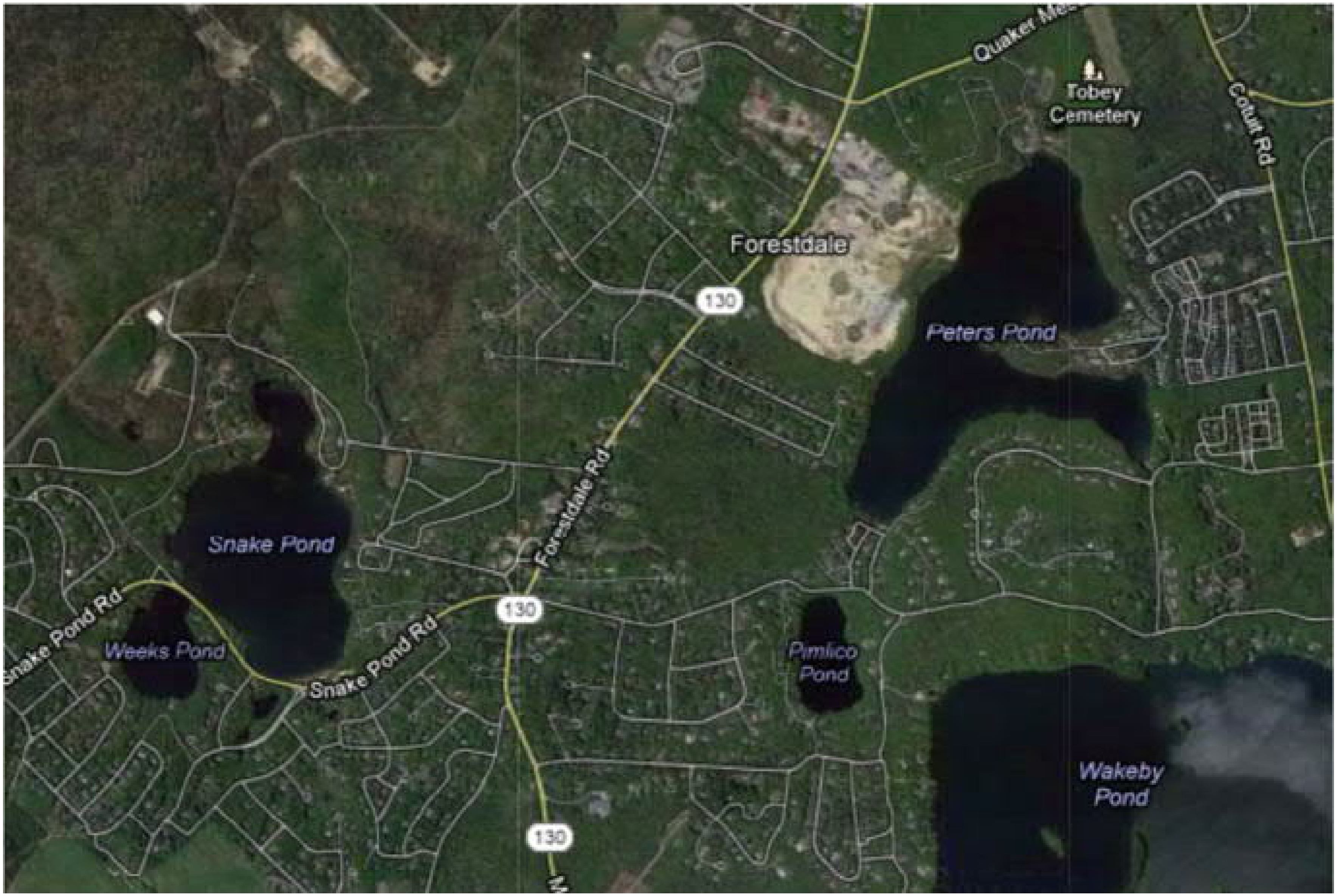


Figure 10. Aerial view of immediate area of Peters, Pimlico, Snake and Weeks Ponds.



### *Designated Use Support*

Peters Pond is very popular for swimming, boating and fishing, and appears to support those uses. Anecdotal evidence suggests that those uses may be threatened, but there are no data to document conditions or evaluate trends. Inclusion in a TMDL for mercury for a pond with an active trout fishery is a concern, but no recent data were found to indicate any contamination of fish.

### *Risk from Future Development*

Although there are some large parcels that are not developed as residential housing in the immediate area of the pond, most are tied up in easements or uses that may not be appreciably more beneficial to the pond.  There are fewer developable parcels with the potential to impact Peters Pond than for many of the other ponds in Sandwich. There does appear to be a risk of continued deterioration from current development, but additional development is viewed as less of a risk.

### *Assessment Needs*

The lack of a routine monitoring program for Peters Pond in recent years, such as that conducted for Lawrence, Spectacle and Triangle Ponds, is a major shortcoming for such a publicly used lake and local economic driver. At a minimum, annual assessment of water clarity, temperature and oxygen profiles, and pH, alkalinity, chlorophyll and nutrients at the top and bottom is needed. Surficial sediment in the deep zone should be tested for available phosphorus; if reports of algal blooms are correct, they are likely linked to internal recycling. Assessment of ground water inputs and any storm water discharges is also highly advisable.

### *Management Needs*

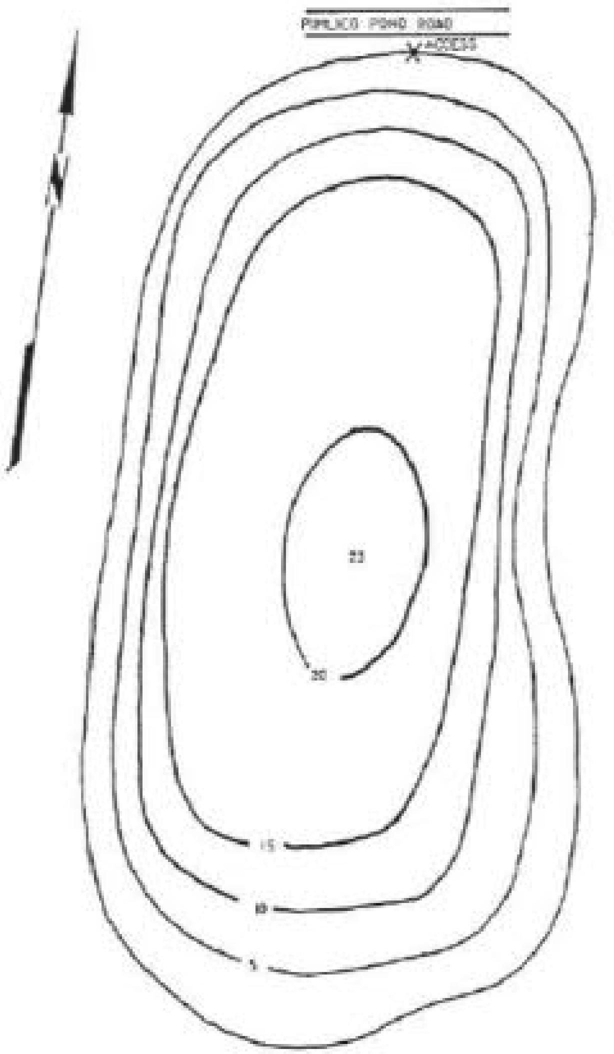
It would appear that there is a need to counter algal blooms, but without further information on what types of algae are involved and the timing and frequency of such blooms, it is difficult to recommend a specific approach. Aeration of bottom waters without breaking stratification would be a positive step, minimizing internal recycling while enhancing habitat for trout. If ground water inputs of nutrients are substantial, sewering in the path of ground water flow may be desirable. Storm water inputs from nearby land may be significant and could be better managed. Action to limit mercury inputs is called for by the regional TMDL, but this relates to widespread atmospheric contamination; there is little that Sandwich can do in this regard.

## Pimlico Pond

### *Pond Features*

Pimlico Pond covers 16.4 acres to an average depth of 12 ft, with a maximum depth of 23 ft (Table 1). It has about 0.6 miles of shoreline. Bathymetry (Figure 11) indicates a simple kettlehole “bowl”, although this pond is slightly shallower than most kettlehole ponds. The pond has no surface water inlets or outlet.  Access to Pimlico Pond is from an undeveloped boat launch along Pimlico Pond Road. Pimlico Pond is stocked with trout each spring, but does not have enough cold water to support a resident population all year. Pimlico Pond is known to have dense subsurface rooted plant growths, but the pond periphery exhibits little obvious plant growth.

**Figure 11. Bathymetry of Pimlico Pond from pre-1990 MA DFW records.**



### *Watershed Features*

The immediate drainage area of Pimlico Pond is a fairly steep hillside much of the way around the pond, with a number of small lots on the zoning map (Figure 9). However, many of these lots are not developed, and housing density around the pond is low (Figure 10). Most homes have substantial buffer zones and there has been relatively little clearing of trees. Ground water flow is mostly from the west, but there could be surface or subsurface drainage from the immediately adjacent land into the pond, given the slope. There is direct drainage off Pimlico Pond Road, with evidence of erosion and possible impacts.

### *Pond Condition*

Pimlico Pond was sampled in 2001 and 2002 as part of the PALS program, and this is the only sampling known to have occurred at this pond. The pond is well mixed from top to bottom, and there is no oxygen depression. The pH was slightly acidic, alkalinity was low, and nutrient levels were also low.

While no algal blooms have been reported, growths of rooted plants are dense. While no detailed survey has been conducted, fragments of low watermilfoil (*Myriophyllum humile*), bladderwort (*Utricularia sp*.) and spikerush (*Eleocharis acicularis*) were observed on the shore at the public access point in fall of 2011.

### *Designated Use Support*

Pimlico Pond supports swimming, fishing and boating. Dense plant growths may not be impeding these uses, but concern over potential impairment has been expressed and the need for more study to support management planning has been noted.

### *Risk from Future Development*

It is not clear that the many small listed land parcels around the lake are actually buildable lots, but construction on many of these would constitute a threat to pond quality. The steep slopes would be prone to erosion and waste water may reach the pond on any side. However, there are relatively few additional parcels on which building could occur further from the lake to the west and north, from which most ground water is expected to come.

### *Assessment Needs*

Resumption of annual monitoring through the PALS program is highly recommended. A thorough survey of the plant community is also advisable. Investigation of ground water movement and quality all the way around this pond is warranted.

### *Management Needs*

Protection of the pond through control of any additional building near the pond is the most obvious management need. Some mitigation of storm water inputs from Pimlico Pond Road appears warranted. There may be a need to control rooted aquatic vegetation, but if that vegetation is not impairing uses, it might be better left in place to act as a nutrient sink and water quality enhancer.

## Snake Pond

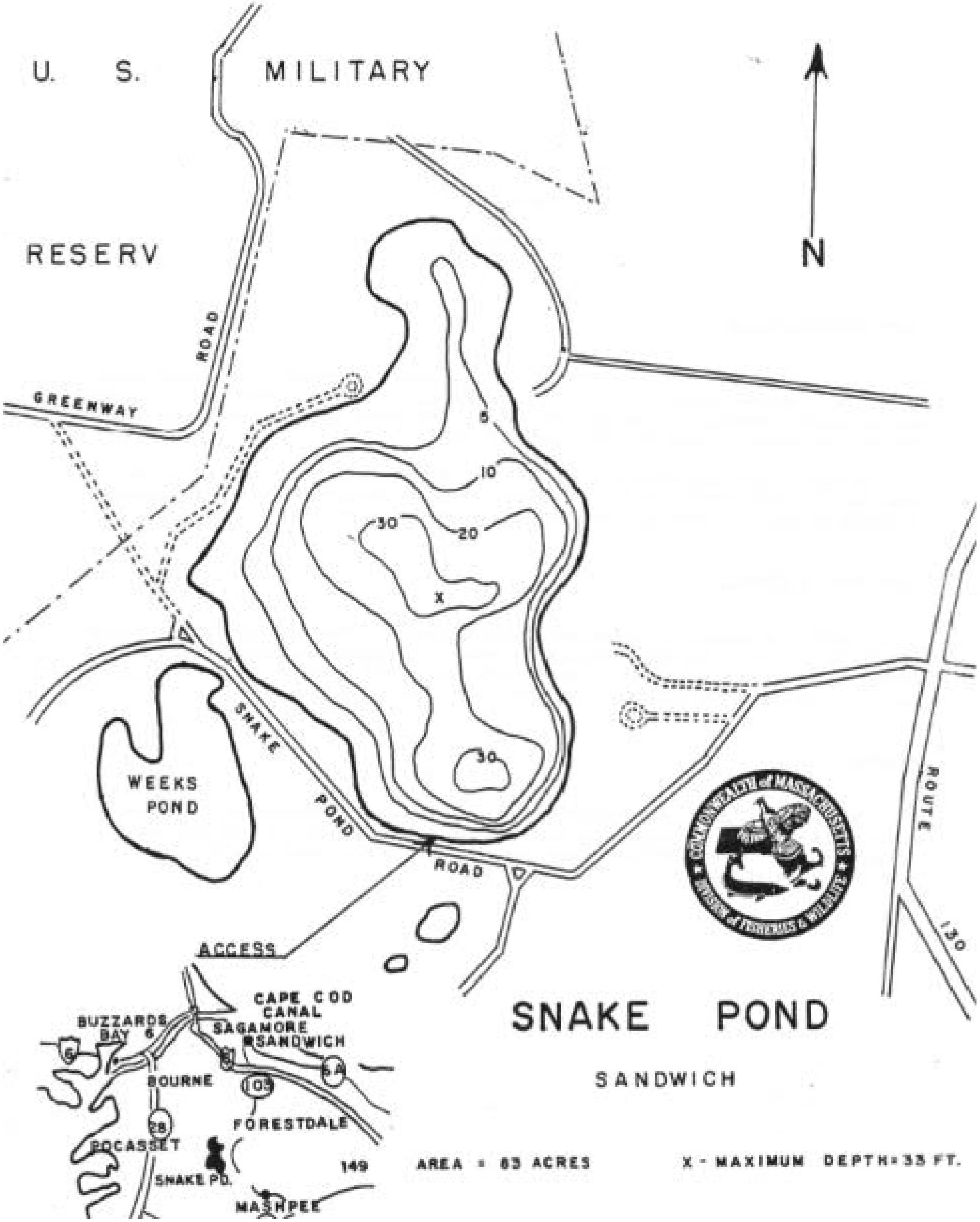
### *Pond Features*

Snake Pond covers 83 acres, offers about 1.6 miles of shoreline, has an average depth of 18 ft and a maximum depth of 33 ft (Table 1), although some accounts suggest a maximum depth of no more than 27 ft. Bathymetry (Figure 12) is bowl-like to 20 ft, with two separate depressions of 30 ft. The pond has no surface water inlets or outlets. Access is off Snake Pond Road, with a small boat ramp and limited parking area. There is also a town beach on the south side. Snake Pond hosts a warm water fishery, with chain pickerel, smallmouth bass, golden shiner, white and yellow perch, pumpkinseed, white sucker and brown bullhead reportedly present.

### *Watershed Features*

Camp Good News occupies a large parcel at the north end of the pond, and the MMR boundary is not far from the pond to the northwest. The remainder of the shoreline is broken into smaller lots (Figure 9). However, there is substantial wetland around this pond, and housing density is not as high as parcel listing might make it seem (Figure 10). There is a town beach and boat launch on the south side, but

Figure 12. Bathymetry of Snake Pond from pre-1990 MA DFW records.



most shoreline land is privately held. Storm water drainage systems are limited near this pond, and the town diverted storm water from Snake Pond Road east of the pond into vegetated areas to limit impact to the pond. Storm water from the west side of the pond remains a concern and addressing it is part of the town storm water mitigation plan. Weeks Pond is directly across the road to the southwest. Ground water flows mainly from the northwest, the direction of least development in this case, but the MMR lies in that direction and there are monitoring wells used to evaluate possible contaminant movement from that military site.

### *Pond Condition*

A water clarity reading from at least two decades ago was 22 ft (6.7 m) and oxygen profiles in 1948, 1997, 2001 and 2002 indicate no anoxia near the bottom. Given its bathymetry, it is unlikely that Snake Pond would experience any widespread oxygen depletion. In 2001, the pH was slightly acidic, alkalinity was very low, chlorophyll was low (1-2 ug/L), phosphorus was low (12 ug/L) and nitrogen was low (40 to 160 ug/L). It has been speculated that Snake Pond is in a relatively unimpacted condition and has been stable for over 50 years, but data from the last decade are lacking.

The pond supports a warm water fishery and is considered to offer good ice fishing opportunity. The former Division of Fisheries and Game stocked the pond with various warmwater species decades ago, but no recent management appears to have occurred and this is not a trout pond. No algae blooms have been reported. Plant growth is minimal in shallow water in the associated sand and gravel, but is reportedly denser in deeper offshore areas; no survey has been conducted. Ground water inputs relating to the MMR are monitored in wells at Snake Pond, but no data appear to be available.

Snake Pond is on the Massachusetts 2010 Integrated Waters List as having a completed TMDL for metals. The TMDL relates to mercury and is not lake-specific; Peters Pond and Snake Pond in Sandwich are two of almost 100 Massachusetts ponds included in the Northeast Regional Mercury Total Maximum Daily Load developed by the New England states plus New York and finalized in 2007. This Total Maximum Daily Load (TMDL) document outlines a strategy for reducing mercury concentrations in fish in northeastern freshwater systems. This will require reductions from mercury sources within the Northeast region, U.S. states outside of the region, and global sources. In the Northeast, the majority of mercury pollution is a result of atmospheric deposition, so there is little that Sandwich can do on its own. This TMDL could very well apply to all Sandwich Ponds, but only Peters Pond and Snake Pond were included in the project.

### *Designated Use Support*

Snake Pond supports swimming, fishing and boating. No impairment of these uses has been reported, but very little monitoring occurs at this pond. The existence of a TMDL for mercury is a concern, but no recent data were found to indicate any contamination of fish.

### *Risk from Future Development*

Additional development near the pond could be detrimental, but it is not clear that such development could occur under current regulations. Current inputs from the MMR via ground water are an apparent concern, and any future development of MMR property represents a concern for this pond.

### Assessment Needs

An assessment of pond conditions, including water quality, algae and plants, is needed. Annual water quality monitoring is advised, through the PALS program.

### Management Needs

There may be a need to address ground water contamination, based on the presence of monitoring wells associated with the MMR remediation program, but no data are available to support such a supposition. Action to limit mercury inputs is called for by the regional TMDL, but this relates to widespread atmospheric contamination; there is little that Sandwich can do in this regard. Mitigation of storm water from west of the pond is part of the town storm water mitigation plan. No other problems are currently known for this pond that would require remedial action.

## Weeks Pond

### Pond Features

Weeks Pond covers 15 acres adjacent to Snake Pond, with just the road separating them. It is likely that they were connected at some point in history. There are 0.76 miles of shoreline. The average depth is listed as 4 ft, with a maximum depth of 15 ft (Table 1), but vegetation protrudes from the pond far from the edges; it is likely that this pond is shallower than listed, but there is no bathymetric map available. Access is along Snake Pond Road, but it is undeveloped and impeded by a guardrail. There is no surface water inlet or outlet. Emergent vegetation, some of it woody, sticks out of the nearshore waters and in some areas quite far from shore. The visible bottom is largely sandy. There is no known significant recreational use of Weeks Pond.

### Watershed Features

There are numerous small land parcels around the lake, with 15 within 300 feet and upgradient in terms of expected ground water flow. Twelve of those lots are developed, and a few buildings are very close to the pond, but most of the shoreline is wooded. There are many storm water collection basins near the pond, but no known direct discharges to it; catch basins appear to be leaching basins. Storm drainage improvements along Snake Pond Road to protect Snake Pond are done in a way to also prevent impact to Weeks Pond. Beyond the 300 foot limit in all directions but to the northeast (where Snake Pond is situated) there are many small lots, most developed. There is a nearby town well. As with Snake Pond, there is concern that ground water from the MMR may impact the pond and/or town well.

### Pond Condition

No monitoring data were found for Weeks Pond. It is shallow enough that oxygen depletion should not occur, but the nutrient status is unknown. No algal blooms have been reported, but depth and vegetation features of this pond may restrict uses. Aside from emergent brush, multiple species of pondweed (*Potamogeton* spp.) and spikerush (*Eleocharis acicularis*) were observed washed up on shore, and remnant stalks of what appeared to be bulrush (*Schoenoplectus validus*) were common in shallow water. Other emergent plants, such as pickerelweed (*Pontederia cordata*) are also likely to be dense during summer. Water level fluctuations are reportedly frequent and substantial at Weeks Pond.

### *Designated Use Support*

Weeks Pond might support some fishing and non-motorized boating, and swimming may be possible from some shoreline locations. However, little recreational use is apparent and specific conditions that would support or impair such use have not been documented.

### *Risk from Future Development*

Most of the land area within half a mile of Weeks Pond is already developed, at least to a moderate density. While any additional development within the ground water contribution zone may present additional threats, it does not appear that further development is as big a risk for Weeks Pond as it is for many of the other ponds assessed. Shallow depth may limit ground water impacts, as much of the flow may pass under the pond with no interaction.

### *Assessment Needs*

There are few data of any kind for Weeks Pond. A simple but complete diagnostic assessment, with water depth, sediment features, water quality and biological components would be advisable. Ground water inputs and interaction with the nearby town well should also be assessed.

### *Management Needs*

It is not clear that there are any management needs for Weeks Pond at this time. No specific problems are known, but there are some threats to potential uses that bear scrutiny in an assessment project.

## Hoxie Pond

### *Pond Features*

Hoxie Pond covers 8.5 acres slightly south of Rt 6A and just north of Old County Road, although some estimates suggest an area of as little as 7.7 acres. Average depth is believed to be about 12 feet (Table 1), while maximum depth is shown as 35 ft on the pond bathymetric map (Figure 13). Hoxie Pond has a typical kettlehole bowl shape and has 0.42 miles of shoreline. There are no natural inlets, but the pond is connected to a cranberry bog to the west, so there is inflow at times. Ground water inflow is expected to be mainly from the south. Hoxie Pond outlets through a wetland area into Scorton Creek, which discharges to the bay. There is no formal access, but Hoxie Pond can be accessed off the railroad bed off Old County Road to the south of the pond. The railroad bed appears to have cut off a small part of the pond many years ago. Fishing from carry in boats is popular, and the pond is stocked with trout annually. Warmwater species are also present, but no surveys have recently been conducted.

### *Watershed Features*

The watershed of Hoxie Pond (Figures 14 and 15) includes relatively few parcels near the pond, with one very large one extending downstream to Scorton Creek and including the former state game farm with considerable wetland. Of the six parcels in the upgradient direction of expected ground water flow, five are developed, but not densely. Most prominent is the cranberry bog, which does withdraw water for irrigation and flooding from Hoxie Pond and returns most of that water to the pond. Further north there are more residential areas with small to moderate sized lots, while further west there are larger parcels that are largely undeveloped. A state fish hatchery produces trout downstream of the pond off Scorton Creek, reportedly the oldest hatchery in the USA.

Figure 13. Bathymetry of Hoxie Pond from pre-1990 MA DFW records.

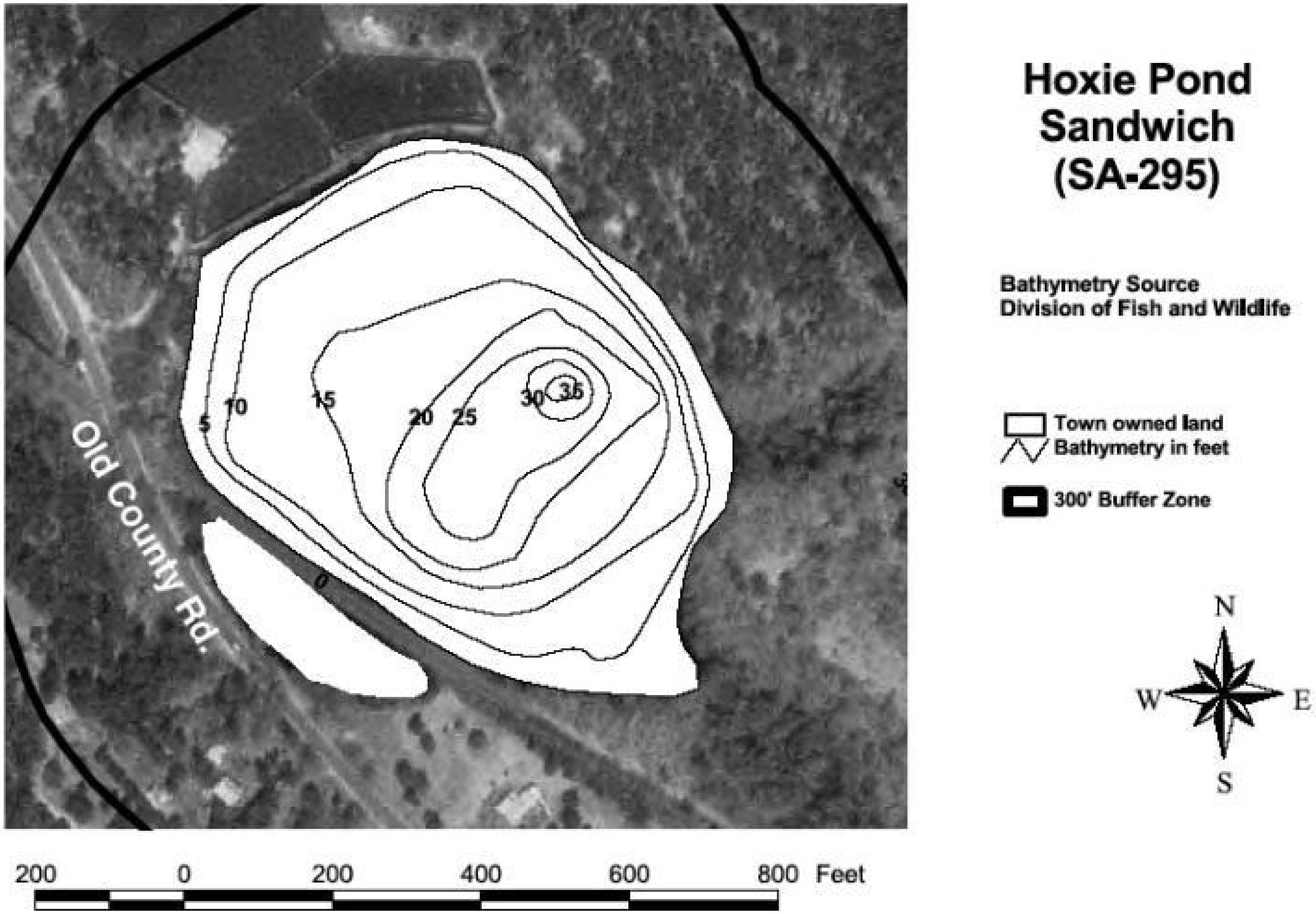
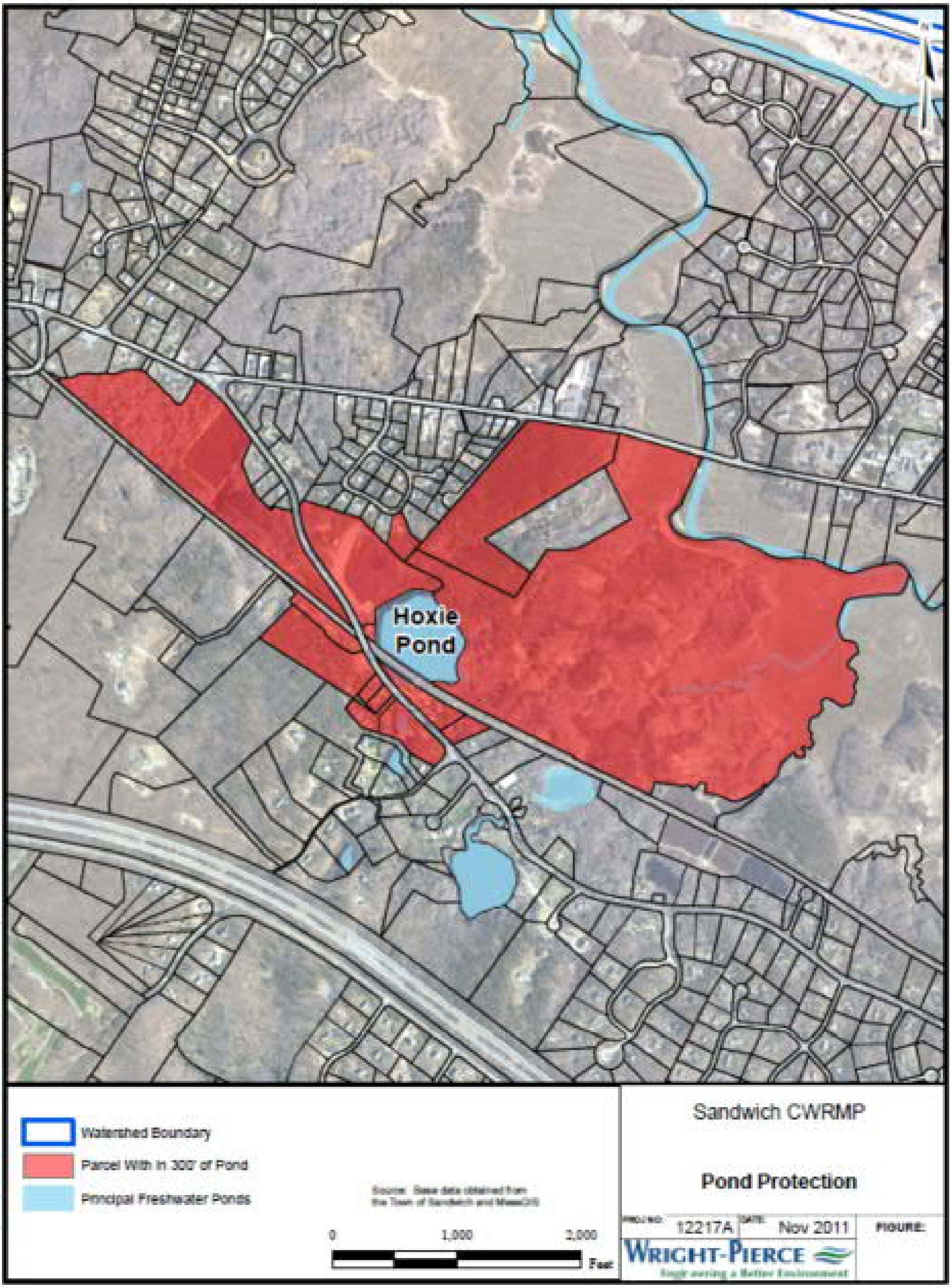
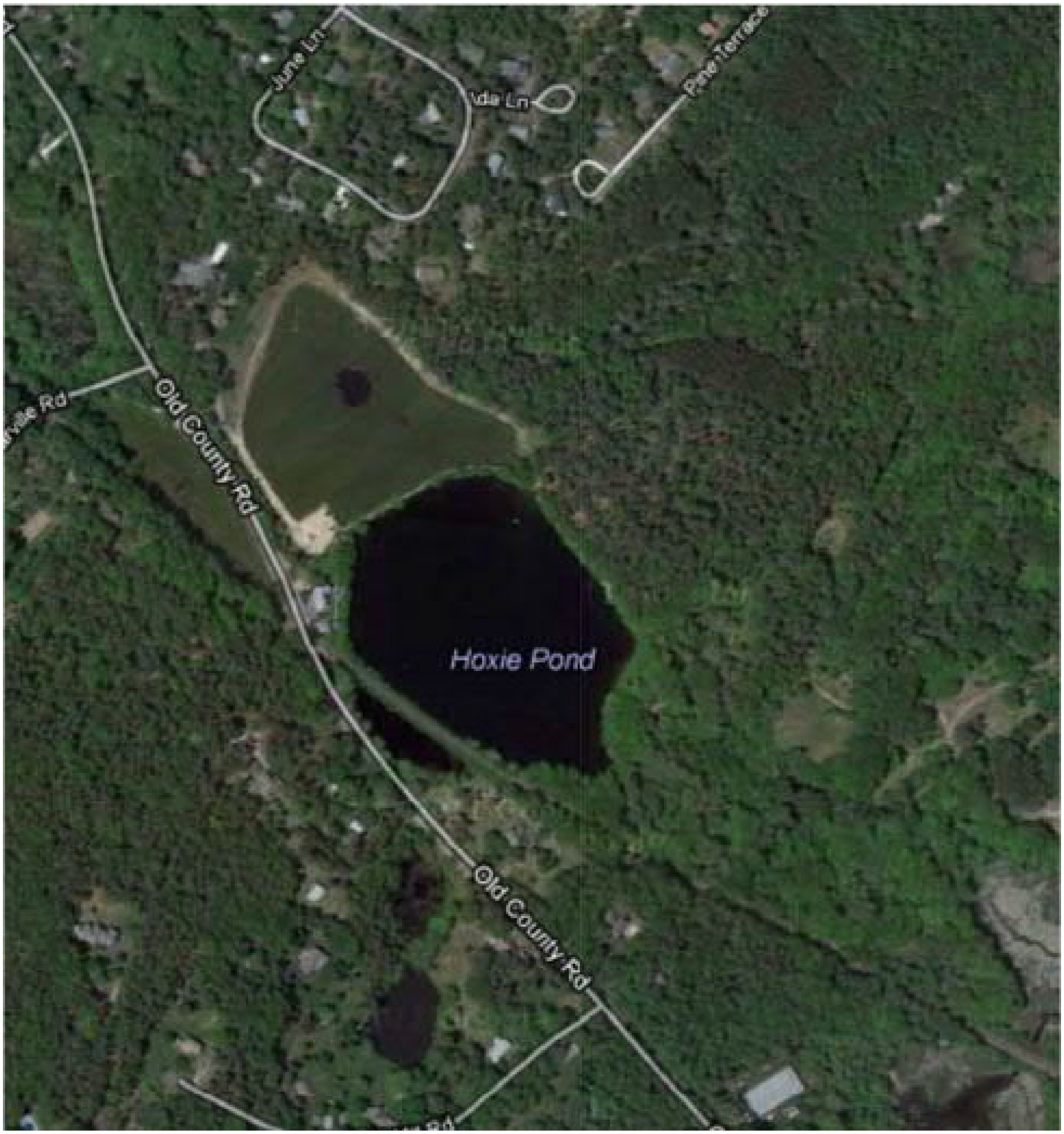


**Figure 14. Pond and parcel layout for Hoxie Pond.**



Source: Base data obtained from the Town of Sandwich and MassGIS

Figure 15. Aerial view of immediate area of Hoxie Pond.



### *Pond Condition*

There are few known water quality data for Hoxie Pond. Water clarity ranged from 1.5 to 3.6 m, and oxygen was low below 18 ft of water depth, based on a MA DFW listing last updated in 2007. Some water lily growth is evident near shore, but vegetation is reportedly limited to shallow peripheral areas. No algal blooms have been reported, and Hoxie Pond is touted as a good swimming pond, but water clarity is marginal at times and the primary use appears to be fishing. This pond was reclaimed for trout management in August 1956, and was reclaimed again seven times prior to 1969. Brook, rainbow and brown trout are stocked each spring on a put and take basis; some tiger trout may also be stocked. During the most recent survey the pond contained yellow perch, largemouth bass, brown trout, sunfish and banded killifish. Chain pickerel have also been caught in the pond. Abundant American eels are expected, based on the connection to the bay, but there is no mention of any alewife use of the pond. The potentially large influence of the cranberry bog is a concern, and may explain the lower water clarity, but no major impacts have been described. Bottom sediments are sandy around the periphery, but are expected to be mainly muck in deeper water.

### *Designated Use Support*

The primary use is fishing, with small boat use and swimming also supported, although the value of the pond as a water source to the cranberry bogs would also seem very important. The cranberry bog represents a threat to some designated uses, but Hoxie Pond is listed on the 2010 Integrated List as a category 3 waterbody, indicating that no uses have been assessed. Low deep water oxygen limits trout habitat, and it is suspected that trout congregate near springs in the southern portion of the pond during summer, but no mortality has been reported.

### *Risk from Future Development*

Increased development on parcels around Hoxie Pond would constitute a threat to water quality, but parcels would have to be subdivided to facilitate additional development in most cases.

### *Assessment Needs*

With relatively little data available and Hoxie Pond representing an apparently valued fishing resource, a survey of physical, chemical and biological characteristics would seem in order. The magnitude of inputs from the cranberry bog and internal recycling within the pond would be important parts of a meaningful assessment of Hoxie Pond.

### *Management Needs*

Water clarity seems marginal at times for swimming, and oxygen in deep water is not suitable for trout, limiting holdover capacity, but there are no data to indicate serious problems and a need for specific management actions. Application of best management practices to the cranberry bog operation would certainly be appropriate. Mixing of the pond to eliminate low oxygen would be desirable, but may increase thermal stress on trout.

## Upper Shawme Lake

### *Pond Features*

Upper Shawme Lake is the upstream part of a two pond complex, and covers about 21 acres to an average depth of 7.5 ft with a maximum depth of 11.6 ft (Table 1, Figure 16). However, there are multiple estimates of area and depth from various sources; most area estimates are similar, but some depth estimates are much deeper. However, given the history of the pond as a dammed stream and the presence of considerable accumulated muck sediment (ENSR 2001), greater depth is unlikely. There are about 0.8 acres of shoreline, most of it wooded. There is no surface water inlet, but water outlets through a recently reconstructed dam with a fish ladder, with an average flow of about 7 cfs. Detention time in the lake is about 11 days on average. Access through large public parcels (Cook Trust, Heritage Museum and Gardens) is possible, but there is no formal boat launch or other access facility. Ground water enters mainly from the south, but with steep slopes, some undoubtedly enters from the east and west as well. There are distinct springs in Upper Shawme Lake, with classic “sand boils” where ground water inflow is major. A variety of warmwater fish are present and alewife have been stocked in an apparent effort to establish a sea-run population, as the Shawme Lakes are connected to the bay by Mill Creek. What was known of Upper Shawme Pond and its watershed was summarized by ENSR in a 2001 letter report, and that information is considerable, but there are few data since that time.

### *Watershed Features*

Upper Shawme Lake has a delineated surface watershed of approximately 440 acres. Approximately 55% of the total watershed of Upper and Lower Shawme Lakes is forested, with about 24% in residential uses and another 8% in other developed uses. The rest is wetland or lake, including an inactive cranberry bog on the east side not far upstream of the outlet. Highview Condominiums sit at the top of the drainage area, off to the southwest, with moderate density housing situated on the slope to the lake from the south (Figures 17 and 18). The Cook Trust lands extend along the east side, while the Heritage Museum and Gardens run along the west side.

Identification of spring sources, culverts, drains and property parcels has been completed by both the Shawme Ponds Watershed Association and Lycott in separate efforts in the late 1990s, as summarized by ENSR (2001). Areas surrounding the Shawme Lakes are very permeable sandy loams, generating little runoff and suggesting that ground water inputs will be dominant. Groundwater seepage rates into Upper Pond from 2000 (ESS 2000 as summarized by ENSR 2001) ranged from 18 to 344 $L/m^2/day$. Values in excess of 40 $L/m^2/day$ are considered high, but are not unusual on Cape Cod. Average monthly discharge out of the ponds has ranged from just over 1 cfs to 12 cfs, with an average of about 7 cfs. Assuming direct precipitation of 46 inches per year (about 0.3 cfs) and no appreciable overland runoff, groundwater seepage would have to average 6.7 cfs to achieve the estimated observed average flow. For just the upper lake, the seepage rate would have to be 178 $L/m^2/day$ to provide the observed flow, consistent with observed seepage rates. However, there are two active storm drains from developed areas that do deliver storm water to Upper Shawme Lake (Figure 3), so runoff is not an insignificant factor.

Figure 16. Bathymetry of Upper and Lower Shawme Lakes from pre-1990 MA DFW records.

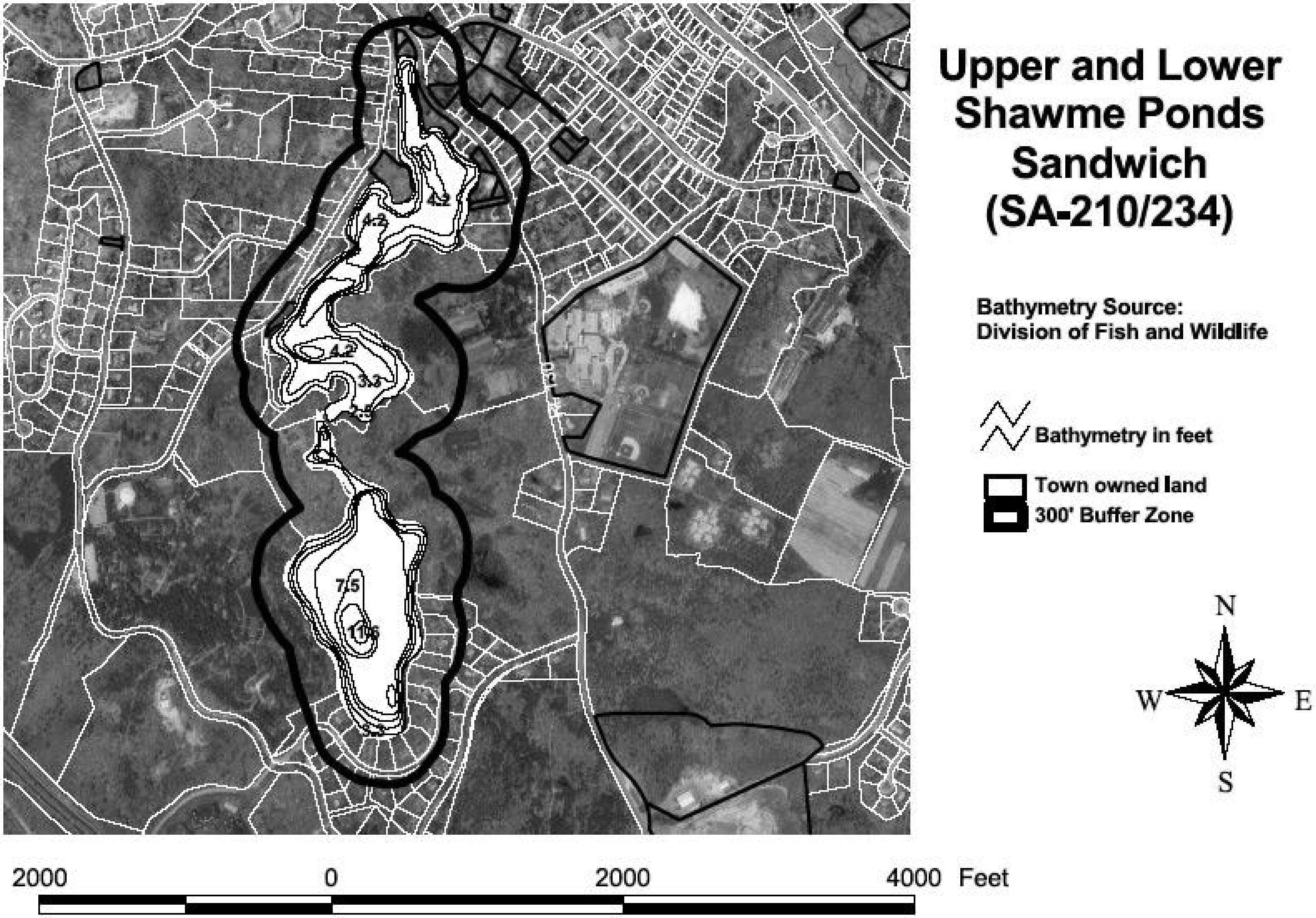


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Figure 17. Pond and parcel layout for Upper and Lower Shawme Lakes.

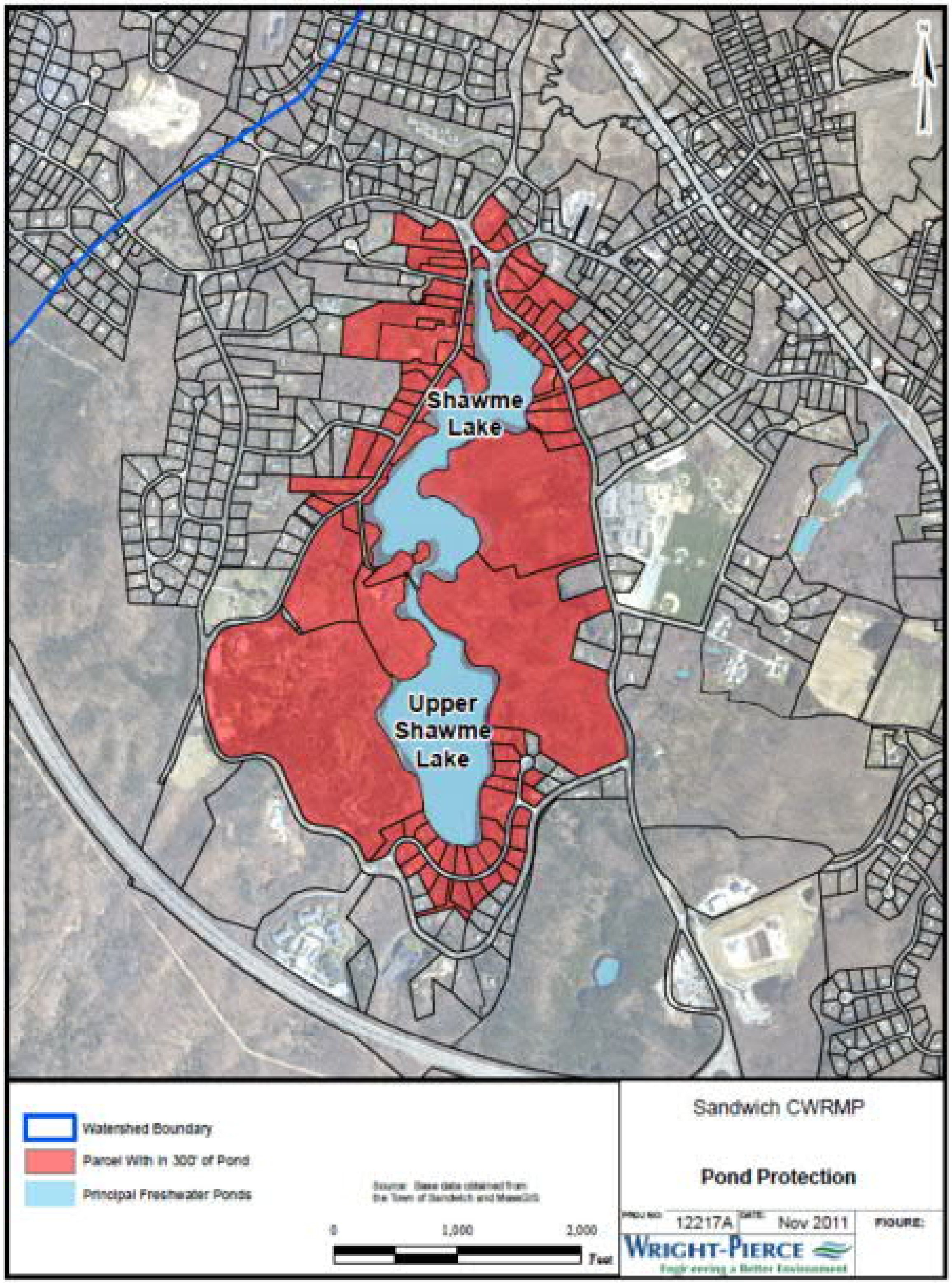
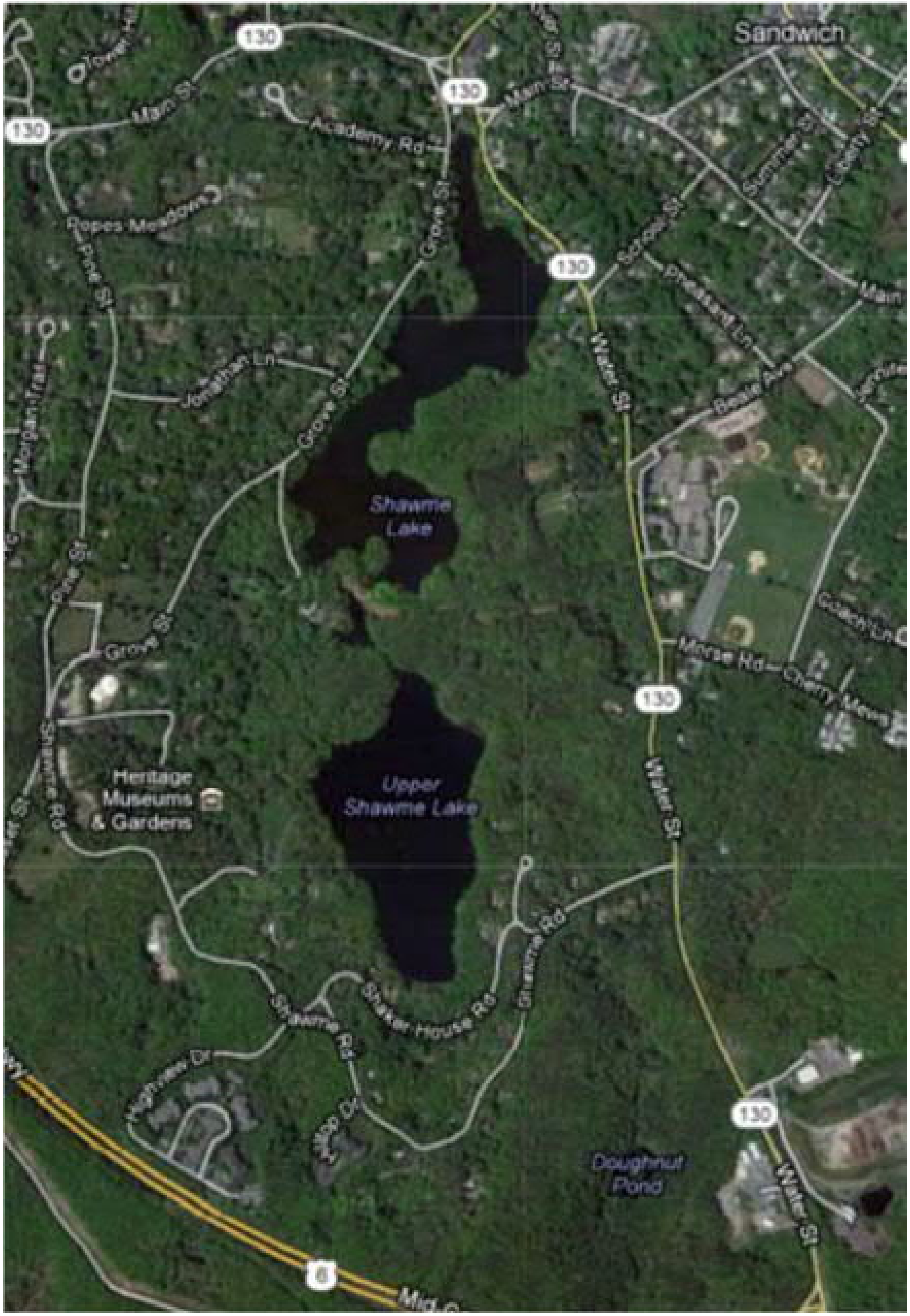


Figure 18. Aerial view of immediate area of Upper and Lower Shawme Lakes.



### *Pond Condition*

Upper Shawme Lake is on the Massachusetts 2010 Integrated List of Waters as a category 5 waterbody, requiring a TMDL for nutrients and eutrophication as evidenced by biological indicators. Total phosphorus values from Upper Shawme Lake and surface inputs are reported as 11-339 ug/L, a rather wide range, with all of the values collected in the fall and winter. The highest value was obtained from a culvert off Water Street during a rain storm. Other high values tended to coincide with heavy precipitation as well. Nitrogen values are generally low for nitrate and higher for ammonium. All nitrogen values were low from a lake management perspective and suggest low N:P ratios that would favor cyanobacterial dominance of the algae.

Levels of total phosphorus in seepage have ranged from 19 to 280 ug/L over a period of about 20 years from 1980 to 2000. While there have been methodological issues that cloud interpretation, it does appear that phosphorus is sometimes elevated. Levels of iron in ground water are relatively low, indicating that the associated phosphorus will not be completely inactivated by the iron. Nitrogen data from seepage samples indicates that nitrate is greater than ammonium, with nitrate values from 0.05 to 0.24 mg/L as N and ammonium levels ranging from <0.01 to 0.04 mg/L, but overall inorganic nitrogen levels are fairly low in those samples. Oxygen appears plentiful in Upper Shawme Lake and the incoming groundwater, given the higher nitrate and lower ammonium values.

Soft sediment has accumulated, and much may have been present in wetlands that were flooded when the lake was created. Average soft sediment depth was about 8 ft in 2000, with a maximum depth of about 12 ft. Sediments are muck material, high in organic content and overlying mostly sand. Nutrient levels are likely high in the sediment, but no testing has been completed to determine if phosphorus release might be affecting measured levels in the pond or seepage.

Blooms of algae were not often reported prior to 2001, but cyanobacterial blooms have been noted over the last decade and are probably the reason that Upper Shawme Lake was placed on the Integrated Waters List. Rooted plants have been abundant for many years, and included mainly Robbin's pondweed (*Potamogeton robbinsii*) and waterweed (*Elodea canadensis*) and aquatic mosses in the 1980s. Waterweed and coontail (*Ceratophyllum demersum*) were observed in fall of 2011, but no recent detailed survey has been conducted. Pickerel is the main gamefish in the lake, but there is an active alewife run, so past stocking was apparently successful in establishing a migratory population.

### *Designated Use Support*

Designated uses for Upper Shawme Lake include swimming, boating and fishing, along with aesthetic and passive uses. As a breeding area of sea-run alewife, the lake is also important for fish and wildlife propagation. Upper Shawme Lake is on the 2010 Integrated Waters List for not supporting designated uses as a consequence of excess nutrients and eutrophication as indicated by system biology, and is supposed to be the subject of a TMDL (category 5).

### *Risk from Future Development*

Future development would constitute an increased threat, but the lake is already listed for failing to properly support designated uses, and the key undeveloped lands on the east and west sides of the lake are publicly held.

### *Assessment Needs*

While there has probably been more study of the Shawme Lake system than any other in Sandwich, the specific cause of the biological impairment in Upper Shawme Lake (algal blooms and rooted plant growth) is not completely clear. The thick accumulated muck supports the rooted plants, but the species are not invasive forms and it is not known if the fertility was there when the ponds were formed or was substantially increased by human inputs over time. Cyanobacterial blooms appear linked to high phosphorus with low nitrate, a situation that strongly favors those algae. However, if on-site waste water disposal was the main source, the nitrogen levels should be much higher than they are. Further, phosphorus is adsorbed to soil, even sand, and it would take a very large input to that soil over a very long time to exhaust the removal capacity. That could be the case, but the presence of storm drains with very high phosphorus levels suggests an alternative explanation for algal blooms, one that seems more likely than waste water from review of the available data. Possible release of phosphorus from sediment is yet another potential phosphorus source that would add appreciably less nitrogen and could be a factor in the observed blooms. An investigative study is needed to determine the causative agents and best means of control. A thorough plant survey is also needed.

### *Management Needs*

Upper Shawme Lake needs reduced algae growth, which translates into reduced available phosphorus inputs. It may also need rooted plant control, but in the absence of any recent plant survey, this need is uncertain.

## Lower Shawme Lake

### *Pond Features*

Lower Shawme Lake is the downstream part of a two pond complex, and covers about 24 acres to an average depth of 4 ft with a maximum depth of 5.3 ft (Table 1, Figure 16). However, as with Upper Shawme Lake, there are multiple estimates of area and depth from various sources. Area estimates are similar, but some depth estimates are much deeper. However, given the history of the pond as a dammed stream and the presence of considerable accumulated muck sediment (ENSR 2001), much greater depth is unlikely. There are about 1.5 acres of shoreline, some of it wooded, but much in residential backyards. There is a surface water inlet from Upper Shawme Lake, and the outlet is the start of Mill Creek, which runs to the bay with an average flow in excess of 7 cfs. Detention time in Lower Shawme Lake is about 7 days. There is some access through a large public parcel on the southwest side and near the outlet in town, but there are no developed boat launch or beach facilities. Ground water enters from the east and west, but most flow is surface water inflow. A variety of warmwater fish are present and alewife run from the bay into and through Lower Shawme Lake. What was known of Lower Shawme Pond and its watershed was summarized by ENSR in a 2001 letter report, and that information is considerable, but there are few data since that time.

### *Watershed Features*

The watershed of Lower Shawme Lake includes all the drainage area for Upper Shawme Lake plus an additional watershed area of approximately 162 acres. Approximately 55% of the total watershed is forested according to ESS (2001), with about 24% in residential uses and another 8% in other developed uses. The rest is wetland and lake. There is more developed land immediately adjacent to Lower Shawme Lake (Figures 17 and 18), and there are at least four active storm drains discharging to the lake (Figure 3), although two are near the outlet. Soils surrounding the Shawme Lakes are very permeable sandy loams, but with storm water drainage systems associated with developed areas, storm water runoff can be significant.

### *Pond Condition*

Ground water was shown to be the dominant inflow source to Upper Shawme Lake, but seepage into Lower Shawme Lake is much lower, at -5 to 21 L/m$^2$/day. Lower Shawme Lake therefore also experiences outseepage, and most of its inflow comes from Upper Shawme Lake. This is consistent with land slopes near the pond, which are far less steep than for Upper Shawme Lake. However, there are active storm drains discharging runoff from nearby developed lands and roadways, and these may be significant sources of contaminants if not actual flow.

Water quality is similar to that of Upper Shawme Lake, consistent with that upper lake as the main source of water to the lower lake. Phosphorus remains elevated. One difference is higher ammonium in the lower lake, probably a function of sediment and rooted plant influence on nitrogen forms, but possibly also related to on-site waste water inputs from nearby developed land. Nitrate nitrogen was elevated in the town spring near the outlet, not to an extent that would represent a human health hazard, but to a degree that suggests a different water source than what supplies the lower lake. No oxygen problems have been noted, but with such a shallow pond this is to be expected.

Since at least the late 1980s, the plant community of Lower Shawme Lake has been dense and dominated by water weed (*Elodea canadensis*), with profuse growths of Robbin's pondweed (*Potamogeton robbinsii*), wild celery (*Vallisneria americana*) and bushy pondweed (*Najas flexilis*). Swamp loosestrife (*Decodon verticillatus*), purple loosestrife (*Lythrum salicaria*) and reed grass (*Phragmites sp.*) were observed along the shoreline, the latter two being invasive plant species. No recent study has been conducted, but plant cover is known to still be dense. The fish community of the lower lake is similar to that of the upper lake, with warmwater species and sea-run alewife.

### *Designated Use Support*

Designated uses for Lower Shawme Lake include swimming, boating and fishing, along with aesthetic and passive uses. As a breeding area of sea-run alewife, the lake is also important for fish and wildlife propagation. Lower Shawme Lake is on the 2010 Integrated Waters List for not supporting designated uses as a consequence of excess nutrients and eutrophication as indicated by system biology, and is supposed to be the subject of a TMDL (category 5).

### *Risk from Future Development*

Future development would constitute an increased threat, but the lake is already listed for failing to properly support designated uses, and most developable land near the lake is already developed.

### *Assessment Needs*

While there has probably been more study of the Shawme Lake system than any other in Sandwich, the specific cause of the biological impairment in Lower Shawme Lake (algal blooms and rooted plant growth) is not completely clear. The thick accumulated muck supports the rooted plants, but the species are not invasive forms and it is not known if the fertility was there when the ponds were formed of was substantially increased by human inputs over time. Cyanobacterial blooms appear linked to high phosphorus with low nitrate, a situation that strongly favors those algae. However, if on-site waste water disposal was the main source, the nitrogen levels should be much higher than they are. Further, phosphorus is adsorbed to soil, even sand, and it would take a very large input to that soil over a very long time to exhaust the removal capacity. That could be the case, but the presence of storm drains with very high phosphorus levels suggests an alternative explanation. Possible release from sediment is yet another potential phosphorus source that would add appreciably less nitrogen. An investigative study is needed to determine the causative agents and best means of control. A thorough plant survey is also needed.

### *Management Needs*

Lower Shawme Lake needs reduced algae growth, which translates into reduced available phosphorus inputs. It may also need rooted plant control, but in the absence of any recent plant survey, this need is uncertain.

## Waste Water Disposal Impact Assessment

Waste water is an ongoing threat to many Cape Cod ponds, as much waste water is disposed of in on-site systems that discharge to ground water, and ground water constitutes a major input to many ponds. Transport of nitrogen, with dilution as the primary means of concentration reduction, is relatively well understood, but movement of phosphorus is less well understood. Phosphorus levels tend to be very high in waste water, and while removal through adsorption to soil particles is an effective removal mechanism, removal efficiencies are lowest in sand and adsorption capacity can be depleted over time with constant inputs, as with on-site waste water disposal.

The conventional wisdom is that phosphorus will be removed to very low levels within 300 ft of the discharge point when moving through oxygenated soil, but this is a largely untested assumption in many situations. Further, not all pathways from discharge to pond include oxygenated soil, and there have been cases where phosphorus break out has been documented (e.g., Ashumet Pond in Falmouth, and that involved inputs from the MMR that could be a factor in some Sandwich Ponds as well). It is clearly best to directly evaluate ground water loading to ponds to the extent possible. Effective inputs are largely controlled by available iron and oxygen in Cape Cod ponds; if iron is high and oxygen is present, most ground water phosphorus will precipitate and not support algal blooms. But if iron is limiting or oxygen is depleted, the phosphorus will be available and can support algal growth.

With limited data from which to derive a direct analysis of waste water impacts on the assessed Sandwich Ponds, we can still look at qualitative and calculated aspects of waste water loading to get a reasonable impression of the threat of impact posed by waste water to each pond. Generation of waste

**Table 5. Ratings of potential impact from specified factors for each assessed pond.**

| Pond | Waste Water | Storm Water | Internal Recycling | Rooted Plants | Algal Blooms | Preliminary Trophic State Assessment |
|---|---|---|---|---|---|---|
| Lawrence | M | L | M | L | L | Oligo-Meso |
| Spectacle | H | M | H | L | M | Meso |
| Triangle | M | L | M | L | H | Meso-Eut |
| Upper Hog | L | L | L | L | L | Oligo |
| Lower Hog | L | L | L | L | L | Oligo |
| Peters | M | M | H | L | M | Meso-Eut |
| Pimlico | M | M | L | M | L | Meso-Eut |
| Snake | M | M | M | L | L | Oligo-Meso |
| Weeks | L | M | L | M | L | Meso |
| Hoxie | M | L | H | L | M | Meso-Eut |
| Lower Shawme | M | H | L | H | H | Eut |
| Upper Shawme | M | H | L | H | H | Eut |

H = high, M = moderate, L = low

Oligo = Oligotrophic, Meso = Mesotrophic, Eut = Eutrophic

water within 300 ft of each pond in what is understood to be the likely path of ground water flow (Table 1) suggests waste water inputs of 345 to 3050 gallons per day (gpd) which, at roughly 23 mg/gallon, translates into loads of roughly 8 to 70 g/d to the ground water moving toward the lake. For an entire year, this equates to between 2.9 and 25.6 kg/yr. At removal rates that are typically at least 90%, this would result in loads to ponds of 0.3 to 2.6 kg/yr. While pond size will affect concentration, such inputs are not likely to be sufficient by themselves to significantly increase measured phosphorus concentration. However, most of that phosphorus will wind up in the pond sediment, and the build-up over time could fuel substantial internal recycling and related algal blooms.

For waste water to represent a more immediate threat (e.g., within the year of input), the load must be much higher or the removal rate of soil must be much lower. Such conditions can exist where years of loading have exhausted the adsorption capacity of the associated soils and waste water disposal is large (many individual systems or fewer large communal systems). This will most likely require a substantial development within a mile of the pond, probably closer, although larger inputs further away for a longer period of time could be involved. With water movement measured in feet per day, it is less that rate of movement than the adsorption capacity of the soil that will determine phosphorus delivery. Both the actual adsorption capacity (mg P/g soil, which is around 100 mg P/g sand) and the path of the ground water plume containing the waste water (focused vs. diffuse, well mixed vs. segregated) will be important, and site specific conditions must be examined to gain insights in that regard.

For the Sandwich ponds assessed, the potential for waste water impacts is categorized as high (H), moderate (M) or low (L). Key factors include development density (and by extension waste water disposal volume) in the upgradient direction and depth of the pond (deeper ponds can intercept more ground water). Spectacle Pond has the only high rating, although one could make a case for Peters Pond receiving a high rating as well; it would have the highest priority for attention after Spectacle Pond. All the other ponds except Weeks and Upper and Lower Hog Ponds have moderate ratings (Table 5). Over time, even a moderate rating represents a threat of phosphorus accumulation in the pond and a potential internal recycling threat. Consequently, 9 out of 12 ponds warrant additional waste water investigations and consideration of waste water management options.

## Storm Water Impact Assessment

The potential for storm water to impact the Sandwich ponds is largely a function of nearby development and routing of water to the ponds by storm water drainage systems. The vast majority of storm water drainage systems in Sandwich are leaching systems, and improvements in some of the direct drainage systems have been made under the town storm water mitigation plan, so storm water is not as big a threat as in many developed areas off the Cape. Upper and Lower Shawme Lakes have multiple direct entry storm drains serving developed areas that have tested high for nutrient levels, making the potential for storm water impact on these ponds high (Table 5). Spectacle, Peters, Pimlico, Snake and Weeks Ponds received moderate ratings, with some storm water issues to be addressed, but these are relatively minor. The remaining ponds have low potential for storm water impacts, although the discharge from the cranberry bog may be a substantial influence on Hoxie Pond, but this is not characterized as a storm water input.

## Internal Nutrient Recycling Impact Assessment

Internal loading in Cape Cod ponds is a function of accumulated iron-bound phosphorus and oxygen depletion that leads to the release of that phosphorus. The original sources of that phosphorus are not critical to this assessment, although they may be important to long-term pond management activities. Phosphorus bound to organic matter may also be important in the long-term, as decomposition will release some of that phosphorus, but it is iron-bound phosphorus that is released relatively rapidly under anoxic conditions and fuels algal blooms through that increase in available phosphorus.

We have no data for available sediment phosphorus in any of the assessed ponds, but based on depth and oxygen features, ponds can be sorted into categories of high, moderate or low potential for internal recycling (Table 5). Spectacle, Peters and Hoxie Ponds have high potential for internal recycling, while Lawrence, Triangle and Snake Ponds have more moderate potential. The others have lower potential for internal recycling, but some recycling is still possible. Addition of sample analysis for iron-bound phosphorus would allow considerable refinement of this assessment.

## Rooted Plant Issues Assessment

There are not recent surveys of rooted plants in the assessed ponds, but from the available background data and a cursory viewing in fall of 2011, there are few rooted plant issues (Table 5). The Shawme Lakes have dense assemblages that may need some management, but as far as is known, plant populations include only native species. Pimlico and Weeks Ponds have enough vegetation to warrant a high priority for assessment, but only a moderate rating for potential problems. Vegetation in Pimlico Pond may actually be protecting the pond from other influences. Other ponds appear to have a low potential for rooted plant impacts.

## Algal Issues Assessment

Increased fertility leads to greater algal production, which can be desirable if the biological structure processes that production and generates desirable features such as abundant gamefish stocks. However, overfertilization often leads to excessive algal production and build-up of algal biomass that may be perceived as a "bloom". Note that there is no official level of algae that constitutes a bloom, but high levels of any algae can cause discoloration of pond water that qualifies as a bloom. Blue-green algae (cyanobacteria) are particularly troublesome, as many have gas vacuoles that allow them to form surface scums. Cyanobacteria often cause taste and odor and can create toxicity in water at high enough densities. Cyanobacteria are also favored by warm temperatures and low N:P ratios common in Cape ponds during summer.

Based on the combination of past reports, water quality, and pond features, potential for algal blooms is projected for the assessed ponds (Table 5). The two Shawme Lakes and Triangle Pond have high potential, while Spectacle, Peters and Hoxie Ponds have moderate potential. The remaining six ponds have low potential, but this could change and some additional data for actual algal communities and more recent nutrient levels would help refine this analysis.

## Additional Threats to Pond Condition

In the course of evaluating the Sandwich ponds, no invasive species were encountered. These ponds are not likely to be susceptible to zebra mussels, but there are other mollusks (e.g., Asian clams) and some fish that could invade Cape ponds; none are known from these ponds. Invasive plant species are far more likely, with variable milfoil, fanwort and even hydrilla known from multiple Cape ponds. No invasive plant species are known from the assessed ponds, but a lack of detailed surveys hinders meaningful assessment. It would be worthwhile to perform at least a short survey of each pond to characterize plant communities and detect any major infestations.

Sedimentation is not often a major problem for Cape ponds, as water flow is limited and usually diffuse. Exceptions occur where there are major inlets or where storm drains outlet with no energy dissipation. No serious problems were noted in this pond assessment, but there are indications of erosion and sedimentation at Peters Pond, Pimlico Pond, and the Shawme Ponds in association with storm water inputs. There may be other localized impacts that were not detected at Spectacle, Snake and Weeks Ponds. Mitigation would be desirable.

## Management Needs Summary

The greatest management need is really additional information for the ponds of Sandwich. A comprehensive pond sampling program is needed. The Pond And Lake Steward (PALS) program, conducted by volunteers with testing and analysis by the School for Marine Science and Technology at UMASS Dartmouth is an excellent program, and the Town has taken advantage of this where volunteers have been available (most notably in the Three Ponds District over the last four years). Getting and maintaining volunteers has been a challenge, but effort needs to be made to interest residents in the valuable resources represented by the ponds.

The typical PALS approach involves a single sampling at multiple depths (usually surface and bottom, with a mid-depth sample if the pond stratifies) at the deepest location in the pond, usually in August, with testing for temperature, oxygen, pH, alkalinity, phosphorus, nitrogen, chlorophyll and water clarity. For those ponds where algal blooms have developed, samples should also be collected for algal analysis, and water quality sampling should include spring (early to mid-May) and July events as well, to fill in potentially important gaps in data for the growing season. For ponds with more than one basin, as defined by the bathymetric maps, sampling should be extended to each basin.

A plant survey is needed at each pond. This should be conducted by someone with expertise in plant identification and possible management approaches, but volunteers could learn from the process and expand or extend it later. The survey would yield a map of plant distribution and density, with frequency for each species and a description of the plant community, any invasive species, and threats by plants to designated uses.

Samples of surficial bottom sediment should be collected from the ponds and tested for available sediment phosphorus, a key feature that allows assessment of potential internal recycling of phosphorus. All of the ponds would benefit from this assessment, but those that have experienced algal blooms or for which there is documented high phosphorus levels would be especially important to assess. Testing is done by a qualified lab, and samples are normally collected with an Ekman dredge by qualified personnel, although the process is not difficult to learn if volunteers wish to be involved.

No harm would be done by better and more storm water and waste water management, but these tend to be expensive activities best applied with adequate planning that requires more data than are currently available. Proper assessment is an important element of management planning and implementation. While more investigation is needed before management plans can be crafted, the most likely needs for each pond can be summarized as follows:

Lawrence – Protection of undeveloped land.

Spectacle – Management of ground water quality to the northwest.

Triangle – In-pond nutrient control, most likely by mixing or phosphorus inactivation.

Upper Hog – Protection of undeveloped land.

Lower Hog – Protection of undeveloped land.

Peters – In-pond nutrient control, most likely by mixing or phosphorus inactivation.

Pimlico – Storm water mitigation, undeveloped land protection.

Snake – Storm water mitigation, ground water management to the north and west.

Weeks – Storm water mitigation, ground water management to the west.

Hoxie – Cranberry bog best management practices, possible mixing in pond.

Upper Shawme – Storm water and ground water management, possible in-pond nutrient control, possible in-pond rooted plant control.

Lower Shawme – Storm water and ground water management, possible in-pond nutrient control, possible in-pond rooted plant control.

## Management Options

Key aspects of pond management are covered in Mattson et al. 2004, and those interested in the management of waterbodies are strongly urged to acquaint themselves with that publication, which can be obtained for free online on the DCR Ponds and Lakes program web page. Based on the information available, it is definitely premature to specify management methods to be applied to the assessed ponds and/or their watersheds. Protection of undeveloped land is a matter of purchase, easement, or regulatory controls. Waste water management consists mainly of diversion or treatment measures, of which there are a variety. Storm water management typically involves detention and/or infiltration, with the details highly dependent on site specific features. In-pond mixing could be accomplished by addition of air or mechanical force, and the choice is largely a matter of economics and pond configuration. Phosphorus inactivation has been performed on Cape Cod previously and has involved addition of aluminum compounds in each case so far. Rooted plant control can involve physical, chemical or biological approaches, but most often will involve herbicides on a localized to lakewide scale or localized mechanical techniques such as bottom barriers (mats laid on top of plants to prevent growth) or forms of harvesting (ranging from simple hand pulling to highly mechanized cut and collection systems). A tabular summary of control options for algae and rooted aquatic plants is provided as an appendix.

## References

Division of Fisheries and Wildlife. 1990. Cape Cod Pond Maps. Publication #16.235-77-250-3-90-C.R. MA DFW, Westborough, MA.

ENSR, 2001. Shawme Pond Data Review. ENSR International, Willington, CT.

Ground Water Guardians. Web site of Sandwich Ponds information. http://www.capecodgroundwater.org/ponds/Sandwichponds/sandwich.html

Jacobs Engineering Group, Inc. 1999. Final ecological quarterly data report for the Ashumet Valle groundwater plume: fall 1998. Massachusetts Military Reservation. Document No.: AFC-J23-35Q85005-M22-0004.

Mattson, M., Godfrey, P.J., Barletta, R.A. and A. Aiello. (edited by K. Wagner). 2004. Generic Environmental Impact Report for Eutrophication and Aquatic Plant Management in Massachusetts. MADCR/MADEP, Boston, MA

NEIWPCC. 2007. Northeast Regional Mercury Total Maximum Daily Load. New England Interstate Water Pollution Control Commission.

Sandwich Local Planning Committee. 2009. Sandwich Local Comprehensive Plan. Section 2.0 Natural Resources p. 2-4 to 2-9.

# Appendix: Algae management options template

| OPTION | MODE OF ACTION | ADVANTAGES | DISADVANTAGES | APPLICABILITY TO SANDWICH PONDS |
|---|---|---|---|---|
| **WATERSHED CONTROLS** | | | | |
| 1)Management for nutrient input reduction | ♦ Includes wide range of watershed and lake edge activities intended to eliminate nutrient sources or reduce delivery to lake<br>♦ Essential component of algal control strategy where internal recycling is not the dominant nutrient source, and desired even where internal recycling is important | ♦ Acts against the original source of algal nutrition<br>♦ Creates sustainable limitation on algal growth<br>♦ May control delivery of other unwanted pollutants to lake<br>♦ Facilitates ecosystem management approach which considers more than just algal control | ♦ May involve considerable lag time before improvement observed<br>♦ May not be sufficient to achieve goals without some form of in-lake management<br>♦ Reduction of overall system fertility may impact fisheries<br>♦ May cause shift in nutrient ratios which favor less desirable algae | ♦ |
| 1a) Point source controls | ♦ More stringent discharge requirements<br>♦ May involve diversion<br>♦ May involve technological or operational adjustments<br>♦ May involve pollution prevention plans | ♦ Often provides major input reduction<br>♦ Highly efficient approach in most cases<br>♦ Success easily monitored | ♦ May be very expensive in terms of capital and operational costs<br>♦ May transfer problems to another watershed<br>♦ Variability in results may be high in some cases | ♦ |

| OPTION | MODE OF ACTION | ADVANTAGES | DISADVANTAGES | APPLICABILITY TO SANDWICH PONDS |
|---|---|---|---|---|
| 1b) Non-point source controls | ♦ Reduction of sources of nutrients<br>♦ May involve elimination of land uses or activities that release nutrients<br>♦ May involve alternative product use, as with no phosphate fertilizer | ♦ Removes source<br>♦ Limited ongoing costs | ♦ May require purchase of land or activity<br>♦ May be viewed as limitation of "quality of life"<br>♦ Usually requires education and gradual implementation | ♦ |
| 1c) Non-point source pollutant trapping | ♦ Capture of pollutants between source and lake<br>♦ May involve drainage system alteration<br>♦ Often involves wetland treatments (det./infiltration)<br>♦ May involve storm water collection and treatment as with point sources | ♦ Minimizes interference with land uses and activities<br>♦ Allows diffuse and phased implementation throughout watershed<br>♦ Highly flexible approach<br>♦ Tends to address wide range of pollutant loads | ♦ Does not address actual sources<br>♦ May be expensive on necessary scale<br>♦ May require substantial maintenance | ♦ |
| **IN-LAKE PHYSICAL CONTROLS** | | | | |
| 2) Circulation and destratification | ♦ Use of water or air to keep water in motion<br>♦ Intended to prevent or break stratification<br>♦ Generally driven by mechanical or pneumatic force | ♦ Reduces surface build-up of algal scums<br>♦ May disrupt growth of blue-green algae<br>♦ Counteraction of anoxia improves habitat for fish/invertebrates<br>♦ Can eliminate localized problems without obvious impact on whole lake | ♦ May spread localized impacts<br>♦ May lower oxygen levels in shallow water<br>♦ May promote downstream impacts | ♦ |

| OPTION | MODE OF ACTION | ADVANTAGES | DISADVANTAGES | APPLICABILITY TO SANDWICH PONDS |
|---|---|---|---|---|
| 3) Dilution and flushing | ♦ Addition of water of better quality can dilute nutrients<br>♦ Addition of water of similar or poorer quality flushes system to minimize algal build-up<br>♦ May have continuous or periodic additions | ♦ Dilution reduces nutrient concentrations without altering load<br>♦ Flushing minimizes detention; response to pollutants may be reduced | ♦ Diverts water from other uses<br>♦ Flushing may wash desirable zooplankton from lake<br>♦ Use of poorer quality water increases loads<br>♦ Possible downstream impacts | ♦ |
| 4) Drawdown | ♦ Lowering of water over autumn period allows oxidation, desiccation and compaction of sediments<br>♦ Duration of exposure and degree of dewatering of exposed areas are important<br>♦ Algae are affected mainly by reduction in available nutrients. | ♦ May reduce available nutrients or nutrient ratios, affecting algal biomass and composition<br>♦ Opportunity for shoreline clean-up/structure repair<br>♦ Flood control utility<br>♦ May provide rooted plant control as well | ♦ Possible impacts on non-target resources<br>♦ Possible impairment of water supply<br>♦ Alteration of downstream flows and winter water level<br>♦ May result in greater nutrient availability if flushing inadequate | ♦ |

| OPTION | MODE OF ACTION | ADVANTAGES | DISADVANTAGES | APPLICABILITY TO SANDWICH PONDS |
|---|---|---|---|---|
| 5) Dredging | ♦ Sediment is physically removed by wet or dry excavation, with deposition in a containment area for dewatering<br>♦ Dredging can be applied on a limited basis, but is most often a major restructuring of a severely impacted system<br>♦ Nutrient reserves are removed and algal growth can be limited by nutrient availability | ♦ Can control algae if internal recycling is main nutrient source<br>♦ Increases water depth<br>♦ Can reduce pollutant reserves<br>♦ Can reduce sediment oxygen demand<br>♦ Can improve spawning habitat for many fish species<br>♦ Allows complete renovation of aquatic ecosystem | ♦ Temporarily removes benthic invertebrates<br>♦ May create turbidity<br>♦ May eliminate fish community (complete dry dredging only)<br>♦ Possible impacts from containment area discharge<br>♦ Possible impacts from dredged material disposal<br>♦ Interference with recreation or other uses during dredging | ♦ |
| 5a) “Dry” excavation | ♦ Lake drained or lowered to maximum extent practical<br>♦ Target material dried to maximum extent possible<br>♦ Conventional excavation equipment used to remove sediments | ♦ Tends to facilitate a very thorough effort<br>♦ May allow drying of sediments prior to removal<br>♦ Allows use of less specialized equipment | ♦ Eliminates most aquatic biota unless a portion left undrained<br>♦ Eliminates lake use during dredging | ♦ |
| 5b) “Wet” excavation | ♦ Lake level may be lowered, but sediments not substantially exposed<br>♦ Draglines, bucket dredges, or long-reach backhoes used to remove sediment | ♦ Requires least preparation time or effort, tends to be least cost dredging approach<br>♦ May allow use of easily acquired equipment<br>♦ May preserve aquatic biota | ♦ Usually creates extreme turbidity<br>♦ Normally requires intermediate containment area to dry sediments prior to hauling<br>♦ May disrupt ecological function<br>♦ Use disruption | ♦ |

| OPTION | MODE OF ACTION | ADVANTAGES | DISADVANTAGES | APPLICABILITY TO SANDWICH PONDS |
|---|---|---|---|---|
| 5c) Hydraulic removal | ◆ Lake level not reduced<br>◆ Suction or cutterhead dredges create slurry which is hydraulically pumped to containment area<br>◆ Slurry is dewatered; sediment retained, water discharged | ◆ Creates minimal turbidity and impact on biota<br>◆ Can allow some lake uses during dredging<br>◆ Allows removal with limited access or shoreline disturbance | ◆ Often leaves some sediment behind<br>◆ Cannot handle coarse or debris-laden materials<br>◆ Requires sophisticated and more expensive containment area | ◆ |
| 6) Light-limiting dyes and surface covers | ◆ Creates light limitation | ◆ Creates light limit on algal growth without high turbidity or great depth<br>◆ May achieve some control of rooted plants as well | ◆ May cause thermal stratification in shallow ponds<br>◆ May facilitate anoxia at sediment interface with water | ◆ |
| 6.a) Dyes | ◆ Water-soluble dye is mixed with lake water, thereby limiting light penetration and inhibiting algal growth<br>◆ Dyes remain in solution until washed out of system. | ◆ Produces appealing color<br>◆ Creates illusion of greater depth | ◆ May not control surface bloom-forming species<br>◆ May not control growth of shallow water algal mats<br>◆ Altered thermal regime | ◆ |
| 6.b) Surface covers | ◆ Opaque sheet material applied to water surface | ◆ Minimizes atmospheric and wildlife pollutant inputs | ◆ Minimizes atmospheric gas exchange<br>◆ Limits recreation | ◆ |

| OPTION | MODE OF ACTION | ADVANTAGES | DISADVANTAGES | APPLICABILITY TO SANDWICH PONDS |
|---|---|---|---|---|
| 7) Mechanical removal | ◆ Filtering of pumped water for water supply purposes<br>◆ Collection of floating scums or mats with booms, nets, or other devices<br>◆ Continuous or multiple applications per year usually needed | ◆ Algae and associated nutrients can be removed from system<br>◆ Surface collection can be applied as needed<br>◆ May remove floating debris<br>◆ Collected algae dry to minimal volume | ◆ Filtration requires high backwash and sludge handling capability<br>◆ Labor and/or capital intensive<br>◆ Variable collection efficiency<br>◆ Possible impacts on non-target organisms | ◆ |
| 8) Selective withdrawal | ◆ Discharge of bottom water which may contain (or be susceptible to) low oxygen and higher nutrient levels<br>◆ May be pumped or utilize passive head differential | ◆ Removes targeted water from lake efficiently<br>◆ May prevent anoxia and phosphorus build up in bottom water<br>◆ May remove initial phase of algal blooms which start in deep water<br>◆ May create coldwater conditions downstream | ◆ Possible downstream impacts of poor water quality<br>◆ May promote mixing of remaining poor quality bottom water with surface waters<br>◆ May cause unintended drawdown if inflows are low | ◆ |
| 9) Sonication | ◆ Sound waves disrupt algal cells | ◆ Supposedly affects only algae (new technique)<br>◆ Applicable in localized areas | ◆ Unknown effects on non-target organisms<br>◆ May release cellular toxins or other undesirable contents into water column | ◆ |
| **IN-LAKE CHEMICAL CONTROLS** | | | | |
| 10) Hypolimnetic aeration or oxygenation | ◆ Addition of air or oxygen provides oxic conditions<br>◆ Maintains stratification<br>◆ Can also withdraw water, oxygenate, then replace | ◆ Oxic conditions reduce P availability<br>◆ Oxygen improves habitat<br>◆ Oxygen reduces build-up of reduced cpds | ◆ May disrupt thermal layers important to fish community<br>◆ Theoretically promotes supersaturation with gases harmful to fish | ◆ |

| OPTION | MODE OF ACTION | ADVANTAGES | DISADVANTAGES | APPLICABILITY TO SANDWICH PONDS |
|---|---|---|---|---|
| 11) Algaecides | ◆ Liquid or pelletized algaecides applied to target area<br>◆ Algae killed by direct toxicity or metabolic interference<br>◆ Typically requires application at least once/yr, often more frequently | ◆ Rapid elimination of algae from water column , normally with increased water clarity<br>◆ May result in net movement of nutrients to bottom of lake | ◆ Possible toxicity to non-target species<br>◆ Restrictions on water use for varying time after treatment<br>◆ Increased oxygen demand and possible toxicity<br>◆ Possible recycling of nutrients | ◆ |
| 11a) Forms of copper | ◆ Cellular toxicant, disruption of membrane transport<br>◆ Applied as wide variety of liquid or granular formulations | ◆ Effective and rapid control of many algae species<br>◆ Approved for use in most water supplies | ◆ Possible toxicity to aquatic fauna<br>◆ Accumulation of copper in system<br>◆ Resistence by certain green and blue-green nuisance species<br>◆ Lysing of cells releases nutrients and toxins | ◆ |
| 11b) Peroxides | ◆ Disrupts most cellular functions, tends to attack membranes<br>◆ Applied as a liquid or solid.<br>◆ Typically requires application at least once/yr, often more frequently | ◆ Rapid action<br>◆ Oxidizes cell contents, may limit oxygen demand and toxicity | ◆ Much more expensive than copper<br>◆ Limited track record<br>◆ Possible recycling of nutrients | ◆ |

| OPTION | MODE OF ACTION | ADVANTAGES | DISADVANTAGES | APPLICABILITY TO SANDWICH PONDS |
|---|---|---|---|---|
| 11c) Synthetic organic algaecides | ◆ Absorbed or membrane-active chemicals which disrupt metabolism<br>◆ Causes structural deterioration | ◆ Used where copper is ineffective<br>◆ Limited toxicity to fish at recommended dosages<br>◆ Rapid action | ◆ Non-selective in treated area<br>◆ Toxic to aquatic fauna (varying degrees by formulation)<br>◆ Time delays on water use | ◆ |
| 12) Phosphorus inactivation | ◆ Typically salts of aluminum, iron or calcium are added to the lake, as liquid or powder<br>◆ Phosphorus in the treated water column is complexed and settled to the bottom of the lake<br>◆ Phosphorus in upper sediment layer is complexed, reducing release from sediment<br>◆ Permanence of binding varies by binder in relation to redox potential and pH | ◆ Can provide rapid, major decrease in phosphorus concentration in water column<br>◆ Can minimize release of phosphorus from sediment<br>◆ May remove other nutrients and contaminants as well as phosphorus<br>◆ Flexible with regard to depth of application and speed of improvement | ◆ Possible toxicity to fish and invertebrates, especially by aluminum at low pH<br>◆ Possible release of phosphorus under anoxia or extreme pH<br>◆ May cause fluctuations in water chemistry, especially pH, during treatment<br>◆ Possible resuspension of floc in shallow areas<br>◆ Adds to bottom sediment, but typically an insignificant amount | ◆ |
| 13) Sediment oxidation | ◆ Addition of oxidants, binders and pH adjustors to oxidize sediment<br>◆ Binding of phosphorus is enhanced<br>◆ Denitrification is stimulated | ◆ Can reduce phosphorus supply to algae<br>◆ Can alter N:P ratios in water column<br>◆ May decrease sediment oxygen demand | ◆ Possible impacts on benthic biota<br>◆ Longevity of effects not well known<br>◆ Possible source of nitrogen for blue-green algae | ◆ |

| OPTION | MODE OF ACTION | ADVANTAGES | DISADVANTAGES | APPLICABILITY TO SANDWICH PONDS |
|---|---|---|---|---|
| 14) Settling agents | ♦ Closely aligned with phosphorus inactivation, but can be used to reduce algae directly too<br>♦ Lime, alum or polymers applied, usually as a liquid or slurry<br>♦ Creates a floc with algae and other suspended particles<br>♦ Floc settles to bottom of lake<br>♦ Re-application typically necessary at least once/yr | ♦ Removes algae and increases water clarity without lysing most cells<br>♦ Reduces nutrient recycling if floc sufficient<br>♦ Removes non-algal particles as well as algae<br>♦ May reduce dissolved phosphorus levels at the same time | ♦ Possible impacts on aquatic fauna<br>♦ Possible fluctuations in water chemistry during treatment<br>♦ Resuspension of floc possible in shallow, well-mixed waters<br>♦ Promotes increased sediment accumulation | ♦ |
| 15) Selective nutrient addition | ♦ Ratio of nutrients changed by additions of selected nutrients<br>♦ Addition of non-limiting nutrients can change composition of algal community<br>♦ Processes such as settling and grazing can then reduce algal biomass | ♦ Can reduce algal levels where control of limiting nutrient not feasible<br>♦ Can promote non-nuisance forms of algae<br>♦ Can improve productivity of system without increased standing crop of algae | ♦ May result in greater algal abundance through uncertain biological response<br>♦ May require frequent application to maintain desired ratios<br>♦ Possible downstream effects | ♦ |
| **IN-LAKE BIOLOGICAL CONTROLS** | | | | |
| 16) Enhanced grazing | ♦ Manipulation of biological components of system to achieve grazing control over algae<br>♦ Typically involves alteration of fish community to promote growth of grazing zooplankton | ♦ May increase water clarity by changes in algal biomass or cell size without reduction of nutrient levels<br>♦ Can convert unwanted algae into fish<br>♦ Harnesses natural processes | ♦ May involve introduction of exotic species<br>♦ Effects may not be controllable or lasting<br>♦ May foster shifts in algal composition to even less desirable forms | ♦ |

| OPTION | MODE OF ACTION | ADVANTAGES | DISADVANTAGES | APPLICABILITY TO SANDWICH PONDS |
|---|---|---|---|---|
| 16.a) Herbivorous fish | ♦ Stocking of fish that eat algae | ♦ Converts algae directly into potentially harvestable fish<br>♦ Grazing pressure can be adjusted through stocking rate | ♦ Typically requires introduction of non-native species<br>♦ Difficult to control over long term<br>♦ Smaller algal forms may be benefited and bloom | ♦ |
| 16.b) Herbivorous zooplankton | ♦ Reduction in planktivorous fish to promote grazing pressure by zooplankton<br>♦ May involve stocking piscivores or removing planktivores<br>♦ May also involve stocking zooplankton or establishing refugia | ♦ Converts algae indirectly into harvestable fish<br>♦ Zooplankton response to increasing algae can be rapid<br>♦ May be accomplished without introduction of non-native species<br>♦ Generally compatible with most fishery management goals | ♦ Highly variable response expected; temporal and spatial variability may be high<br>♦ Requires careful monitoring and management action on 1-5 yr basis<br>♦ Larger or toxic algal forms may be benefitted and bloom | ♦ |
| 17) Bottom-feeding fish removal | ♦ Removes fish that browse among bottom deposits, releasing nutrients to the water column by physical agitation and excretion | ♦ Reduces turbidity and nutrient additions from this source<br>♦ May restructure fish community in more desirable manner | ♦ Targeted fish species are difficult to control<br>♦ Reduction in fish populations valued by some lake users (human/non-human) | ♦ |
| 18) Microbial competition | ♦ Addition of microbes, often with oxygenation, can tie up nutrients and limit algal growth<br>♦ Tends to control N more than P | ♦ Shifts nutrient use to organisms that do not form scums or impair uses to same extent as algae<br>♦ Harnesses natural processes<br>♦ May decrease sediment | ♦ Minimal scientific evaluation<br>♦ N control may still favor cyanobacteria<br>♦ May need aeration system to get acceptable results | ♦ |

| OPTION | MODE OF ACTION | ADVANTAGES | DISADVANTAGES | APPLICABILITY TO SANDWICH PONDS |
|---|---|---|---|---|
| 19) Pathogens | ♦ Addition of inoculum to initiate attack on algal cells<br>♦ May involve fungi, bacteria or viruses | ♦ May create lakewide “epidemic” and reduction of algal biomass<br>♦ May provide sustained control through cycles<br>♦ Can be highly specific to algal group or genera | ♦ Largely experimental approach at this time<br>♦ May promote resistant nuisance forms<br>♦ May cause high oxygen demand or release of toxins by lysed algal cells<br>♦ Effects on non-target organisms uncertain | ♦ |
| 20) Competition and allelopathy by plants | ♦ Plants may tie up sufficient nutrients to limit algal growth<br>♦ Plants may create a light limitation on algal growth<br>♦ Chemical inhibition of algae may occur through substances released by other organisms | ♦ Harnesses power of natural biological interactions<br>♦ May provide responsive and prolonged control | ♦ Some algal forms appear resistant<br>♦ Use of plants may lead to problems with vascular plants<br>♦ Use of plant material may cause depression of oxygen levels | ♦ |
| 19a) Plantings for nutrient control | ♦ Plant growths of sufficient density may limit algal access to nutrients<br>♦ Plants can exude allelopathic substances which inhibit algal growth<br>♦ Portable plant “pods” , floating islands, or other structures can be installed | ♦ Productivity and associated habitat value can remain high without algal blooms<br>♦ Can be managed to limit interference with recreation and provide habitat<br>♦ Wetland cells in or adjacent to the lake can minimize nutrient inputs | ♦ Vascular plants may achieve nuisance densities<br>♦ Vascular plant senescence may release nutrients and cause algal blooms<br>♦ The switch from algae to vascular plant domination of a lake may cause unexpected or undesirable changes | ♦ |

| OPTION | MODE OF ACTION | ADVANTAGES | DISADVANTAGES | APPLICABILITY TO SANDWICH PONDS |
|---|---|---|---|---|
| 19b) Plantings for light control | ♦ Plant species with floating leaves can shade out many algal growths at elevated densities | ♦ Vascular plants can be more easily harvested than most algae<br>♦ Many floating species provide waterfowl food | ♦ Floating plants can be a recreational nuisance<br>♦ Low surface mixing and atmospheric contact promote anoxia | ♦ |
| 19c) Addition of barley straw | ♦ Input of barley straw can set off a series of chemical reactions which limit algal growth<br>♦ Release of allelopathic chemicals can kill algae<br>♦ Release of humic substances can bind phosphorus | ♦ Materials and application are relatively inexpensive<br>♦ Decline in algal abundance is more gradual than with algaecides, limiting oxygen demand and the release of cell contents | ♦ Success appears linked to uncertain and potentially uncontrollable water chemistry factors<br>♦ Depression of oxygen levels may result<br>♦ Water chemistry may be altered in other ways unsuitable for non-target organisms | ♦ |

# Appendix: Rooted plant management options template

| OPTION | MODE OF ACTION | ADVANTAGES | DISADVANTAGES | APPLICABILITY TO SANDWICH PONDS |
|---|---|---|---|---|
| **Physical Controls** | | | | |
| 1) Benthic barriers | ♦ Mat of variable composition laid on bottom of target area, preventing growth<br>♦ Can cover area for as little as several months or permanently<br>♦ Maintenance improves effectiveness | ♦ Highly flexible control<br>♦ Reduces turbidity from soft bottoms<br>♦ Can cover undesirable substrate<br>♦ Can improve fish habitat by creating edge effects | ♦ May cause anoxia at sediment-water interface<br>♦ May limit benthic invertebrates<br>♦ Non-selective interference with plants in target area<br>♦ May inhibit spawning/feeding by some fish species | ♦ |
| 1.a) Porous or loose-weave synthetic materials | ♦ Laid on bottom and usually anchored by weights or stakes<br>♦ Removed and cleaned or flipped and repositioned at least once per year for maximum effect | ♦ Allows some escape of gases which may build up underneath<br>♦ Panels may be flipped in place or removed for relatively easy cleaning or repositioning | ♦ Allows some growth through pores<br>♦ Gas may still build up underneath in some cases, lifting barrier from bottom | ♦ |
| 1.b) Non-porous or sheet synthetic materials | ♦ Laid on bottom and anchored by many stakes, anchors or weights, or by layer of sand<br>♦ Not typically removed, but may be swept or “blown” clean periodically | ♦ Prevents all plant growth until buried by sediment<br>♦ Minimizes interaction of sediment and water column | ♦ Gas build up may cause barrier to float upwards<br>♦ Strong anchoring makes removal difficult and can hinder maintenance | ♦ |

| OPTION | MODE OF ACTION | ADVANTAGES | DISADVANTAGES | APPLICABILITY TO SANDWICH PONDS |
|---|---|---|---|---|
| 1.c) Sediments of a desirable composition | ◆ Sediments may be added on top of existing sediments or plants.<br>◆ Use of sand or clay can limit plant growths and alter sediment-water interactions.<br>◆ Sediments can be applied from the surface or suction dredged from below muck layer (reverse layering technique) | ◆ Plant biomass and propagules can be buried<br>◆ Sediment can be made less hospitable<br>◆ Nutrient release from sediments may be reduced<br>◆ Surface sediment can be made more appealing to humans<br>◆ Reverse layering requires no addition or removal of sediment | ◆ Lake depth may decline<br>◆ Sediments may mix with underlayment<br>◆ Permitting for added sediment difficult<br>◆ Addition of sediment may cause initial turbidity<br>◆ New sediment may contain nutrients or other contaminants<br>◆ Generally too expensive for large scale application | ◆ |
| 2) Dredging | ◆ Sediment is physically removed by wet or dry excavation, with deposition in a containment area<br>◆ Dredging can be applied on a limited basis, but is most often a major restructuring of a severely impacted system<br>◆ Plants and seed beds are removed and re-growth can be limited by light and/or substrate limitation | ◆ Plant removal with some flexibility<br>◆ Increases water depth<br>◆ Can reduce pollutant reserves<br>◆ Can reduce sediment oxygen demand<br>◆ Can improve spawning habitat for many fish species<br>◆ Allows complete renovation of aquatic ecosystem | ◆ Temporarily removes benthic invertebrates<br>◆ May create turbidity<br>◆ May eliminate fish community (complete dry dredging only)<br>◆ Possible impacts from containment area discharge<br>◆ Possible impacts from dredged material disposal<br>◆ Interference with uses during dredging<br>◆ Usually very expensive | ◆ |

| OPTION | MODE OF ACTION | ADVANTAGES | DISADVANTAGES | APPLICABILITY TO SANDWICH PONDS |
|---|---|---|---|---|
| 2.a) “Dry” excavation | ♦ Lake drained or lowered to maximum extent practical<br>♦ Target material dried to maximum extent possible<br>♦ Conventional excavation equipment used to remove sediments | ♦ Tends to facilitate a very thorough effort<br>♦ May allow drying of sediments prior to removal<br>♦ Allows use of less specialized equipment | ♦ Eliminates most aquatic biota unless a portion left undrained<br>♦ Eliminates lake use during dredging | ♦ |
| 2.b) “Wet” excavation | ♦ Lake level may be lowered, but sediments not substantially dewatered<br>♦ Draglines, bucket dredges, or long-reach backhoes used to remove sediment | ♦ Tends to require less preparation and be less costly than dry dredging<br>♦ May allow use of easily acquired equipment<br>♦ May preserve most aquatic biota | ♦ Usually creates extreme turbidity<br>♦ Sediment deposits in surrounding area<br>♦ Normally requires containment area to dry sediments prior to hauling<br>♦ Severe disruption of ecological function<br>♦ Lake uses impaired during dredging | ♦ |
| 2.c) Hydraulic (or pneumatic) removal | ♦ Lake level not reduced<br>♦ Suction or cutterhead dredges create slurry which is hydraulically pumped to containment area<br>♦ Slurry is dewatered; sediment retained, water discharged | ♦ Creates minimal turbidity and limits impact on biota<br>♦ Can allow some lake uses during dredging<br>♦ Allows removal with limited access or shoreline disturbance | ♦ Often leaves some sediment behind<br>♦ Cannot handle extremely coarse or debris-laden materials<br>♦ Requires advanced and more expensive containment area<br>♦ Requires overflow discharge from containment area | ♦ |

| OPTION | MODE OF ACTION | ADVANTAGES | DISADVANTAGES | APPLICABILITY TO SANDWICH PONDS |
|---|---|---|---|---|
| 3) Dyes and surface covers | ♦ Water-soluble dye is mixed with lake water, thereby limiting light penetration and inhibiting plant growth<br>♦ Dyes remain in solution until washed out of system.<br>♦ Opaque sheet material applied to water surface | ♦ Light limit on plant growth without high turbidity or great depth<br>♦ May achieve some control of algae as well<br>♦ May achieve some selectivity for species tolerant of low light | ♦ May not control peripheral or shallow water rooted plants<br>♦ May cause thermal stratification in shallow ponds<br>♦ May facilitate anoxia at sediment interface with water<br>♦ Covers inhibit gas exchange with atmosphere | ♦ |
| 4) Mechanical removal (“harvesting”) | ♦ Plants reduced by mechanical means, possibly with disturbance of soils<br>♦ Collected plants may be composted otherwise disposed<br>♦ Wide range of techniques employed, from manual to highly mechanized<br>♦ Application once or twice per year usually needed | ♦ Highly flexible control<br>♦ May remove other debris<br>♦ Can balance habitat and recreational needs | ♦ Possible impacts on aquatic fauna<br>♦ Non-selective removal of plants in treated area<br>♦ Possible spread of undesirable species by fragmentation<br>♦ Possible generation of turbidity | ♦ |
| 4.a) Hand pulling | ♦ Plants uprooted by hand (“weeding”) and preferably removed | ♦ Highly selective technique | ♦ Labor intensive<br>♦ Difficult to perform in dense stands | ♦ |

| OPTION | MODE OF ACTION | ADVANTAGES | DISADVANTAGES | APPLICABILITY TO SANDWICH PONDS |
|---|---|---|---|---|
| 4.b) Cutting (without collection) | ♦ Plants cut in place above roots without being harvested | ♦ Generally efficient and less expensive than complete harvesting | ♦ Leaves root systems and part of plant for re-growth<br>♦ Leaves cut vegetation to decay or to re-root<br>♦ Not selective within applied area | ♦ |
| 4.c) Harvesting (with collection) | ♦ Plants cut at depth of 2-10 feet and collected for removal from lake | ♦ Allows plant removal on greater scale | ♦ Limited depth of operation<br>♦ Usually leaves fragments which may re-root and spread infestation<br>♦ May impact lake fauna<br>♦ Not selective within applied area<br>♦ More expensive than cutting | ♦ |
| 4.d) Rototilling | ♦ Plants, root systems, and surrounding sediment disturbed with mechanical blades | ♦ Can thoroughly disrupt entire plant | ♦ Usually leaves fragments which may re-root and spread infestation<br>♦ May impact lake fauna<br>♦ Not selective within applied area<br>♦ Creates substantial turbidity<br>♦ More expensive than harvesting | ♦ |

| OPTION | MODE OF ACTION | ADVANTAGES | DISADVANTAGES | APPLICABILITY TO SANDWICH PONDS |
|---|---|---|---|---|
| 4.e) Hydroraking | ♦ Plants, root systems and surrounding sediment and debris disturbed with mechanical rake, part of material usually collected and removed from lake | ♦ Can thoroughly disrupt entire plant<br>♦ Also allows removal of stumps or other obstructions | ♦ Usually leaves fragments which may re-root and spread infestation<br>♦ May impact fauna<br>♦ Not selective within applied area<br>♦ Creates substantial turbidity<br>♦ More expensive than harvesting | ♦ |
| 5) Water level control | ♦ Lowering or raising the water level to lower suitability for aquatic plants<br>♦ Disrupts plant life cycle by drying/ freezing, or light limitation | ♦ Requires only outlet control to affect large area<br>♦ Provides widespread control in increments of water depth<br>♦ Complements dredging and flushing | ♦ Potential issues with water supply<br>♦ Potential issues with flooding<br>♦ Potential impacts to non-target flora and fauna | ♦ |
| 5.a) Drawdown | ♦ Lowering of water over winter period allows desiccation, freezing, and physical disruption of plants, roots and seed beds<br>♦ Timing and duration of exposure and degree of dewatering are critical aspects<br>♦ Variable species tolerance | ♦ Control with some flexibility<br>♦ Opportunity for shoreline clean-up/structure repair<br>♦ Flood control utility<br>♦ Impacts vegetative propagation species with limited impact to seed producing populations | ♦ Possible impacts on emergent wetlands<br>♦ Possible effects on overwintering vertebrates<br>♦ Reduction in potential supply<br>♦ Alteration of downstream flows<br>♦ Possible overwinter water level variation<br>♦ May result in greater nutrient availability for algae | ♦ |

| OPTION | MODE OF ACTION | ADVANTAGES | DISADVANTAGES | APPLICABILITY TO SANDWICH PONDS |
|---|---|---|---|---|
| 5.b) Flooding | ◆ Higher water level in the spring can inhibit seed germination and plant growth<br>◆ Higher flows which are normally associated with elevated water levels can flush seed and plant fragments from system | ◆ Where water is available, this can be an inexpensive technique<br>◆ Plant growth need not be eliminated, merely retarded or delayed<br>◆ Timing of water level control can selectively favor certain desirable species | ◆ Water for raising the level may not be available<br>◆ Potential peripheral flooding<br>◆ Possible downstream impacts<br>◆ Many species may not be affected, and some may be benefitted<br>◆ Algal nuisances may increase where nutrients are available | ◆ |
| **Chemical controls** | | | | |
| 6) Herbicides | ◆ Liquid or pelletized herbicides applied to target area or to plants directly<br>◆ Contact or systemic poisons kill plants or limit growth<br>◆ Typically requires application every 1-5 yrs | ◆ Wide range of control is possible<br>◆ May be able to selectively eliminate species<br>◆ May achieve some algae control as well | ◆ Possible toxicity to non-target species<br>◆ Possible impacts downstream<br>◆ Restrictions of water use for varying time after treatment<br>◆ Increased oxygen demand from decaying vegetation<br>◆ Possible recycling of nutrients to allow other growths | ◆ |

| OPTION | MODE OF ACTION | ADVANTAGES | DISADVANTAGES | APPLICABILITY TO SANDWICH PONDS |
|---|---|---|---|---|
| 6.a) Forms of copper | ◆ Contact herbicide<br>◆ Cellular toxicant, suspected membrane transport disruption<br>◆ Applied as wide variety of liquid or granular formulations | ◆ Moderately effective control of some submersed plant species<br>◆ More often an algal control agent | ◆ Toxic to aquatic fauna as a function of concentration, formulation, and water chemistry<br>◆ Ineffective at colder temperatures<br>◆ Copper ion persistent; accumulates in sediments | ◆ |
| 6.b) Forms of endothall<br><br>(7-oxabicyclo [2.2.1] heptane-2,3-dicarboxylic acid) | ◆ Contact herbicide with limited translocation potential<br>◆ Membrane-active chemical which inhibits protein synthesis<br>◆ Causes structural deterioration<br>◆ Applied as liquid or granules | ◆ Moderate control of some emersed plant species, moderately to highly effective control of floating and submersed species<br>◆ Limited toxicity to fish at recommended dosages<br>◆ Rapid action | ◆ Non-selective in treated area<br>◆ Toxic to aquatic fauna (varying degrees by formulation)<br>◆ Time delays on use for water supply, agriculture and recreation<br>◆ Safety hazards for applicators | ◆ |
| 6.c) Forms of diquat<br><br>(6,7-dihydropyrido [1,2-2’,1’-c] pyrazinediium dibromide) | ◆ Contact herbicide<br>◆ Absorbed by foliage but not roots<br>◆ Strong oxidant; disrupts most cellular functions<br>◆ Applied as a liquid, sometimes in conjunction with copper | ◆ Moderate control of some emersed plant species, moderately to highly effective control of floating or submersed species<br>◆ Limited toxicity to fish at recommended dosages<br>◆ Rapid action | ◆ Non-selective in treated area<br>◆ Toxic to zooplankton at recommended dosage<br>◆ Inactivated by suspended particles<br>◆ Time delays on use for water supply, agriculture and recreation | ◆ |

| OPTION | MODE OF ACTION | ADVANTAGES | DISADVANTAGES | APPLICABILITY TO SANDWICH PONDS |
|---|---|---|---|---|
| 6.d) Forms of glyphosate<br>(N-[phosphonomethyl glycine) | ◆ Contact herbicide<br>◆ Absorbed through foliage, disrupts enzyme formation and function in uncertain manner<br>◆ Applied as liquid spray | ◆ Moderately to highly effective control of emersed and floating plant species<br>◆ Can be used selectively, based on application to individual plants<br>◆ Rapid action<br>◆ Low toxicity to aquatic fauna at recommended dosages<br>◆ No time delays for use of treated water | ◆ Non-selective in treated area<br>◆ Inactivation by suspended particles; ineffective in muddy waters<br>◆ Not for use within 0.5 miles of potable water intakes<br>◆ Highly corrosive; storage precautions necessary | ◆ |
| 6.e) Forms of 2,4-D<br>(2,4-dichlorophenoxyl acetic acid) | ◆ Systemic herbicide<br>◆ Readily absorbed and translocated throughout plant<br>◆ Inhibits cell division in new tissue, stimulates growth in older tissue, resulting in gradual cell disruption<br>◆ Applied as liquid or granules, frequently as part of more complex formulations, preferably during early growth phase of plants | ◆ Moderately to highly effective control of a variety of emersed, floating and submersed plants<br>◆ Can achieve some selectivity through application timing and concentration<br>◆ Fairly fast action | ◆ Variable toxicity to aquatic fauna, depending upon formulation and ambient water chemistry<br>◆ Time delays for use of treated water for agriculture and recreation<br>◆ Not for use in water supplies | ◆ |

| OPTION | MODE OF ACTION | ADVANTAGES | DISADVANTAGES | APPLICABILITY TO SANDWICH PONDS |
|---|---|---|---|---|
| 6.f) Forms of fluridone<br>(1-methyl-3-phenyl-5-[-3-{trifluoromethyl} phenyl]-4[IH]-pyridinone) | ♦ Systemic herbicide<br>♦ Inhibits carotenoid pigment synthesis and impacts photosynthesis<br>♦ Best applied as liquid or granules during early growth phase of plants | ♦ Can be used selectively, based on concentration<br>♦ Gradual deterioration of affected plants limits impact on oxygen level (BOD)<br>♦ Effective against several difficult-to-control species<br>♦ Low toxicity to fauna | ♦ Impacts on non-target plant species possible at higher doses<br>♦ Extremely soluble and mixable; difficult to perform partial lake treatments<br>♦ Requires extended contact time | ♦ |
| 6.g Amine salt of triclopyr<br>(3,5,6-trichloro-2-pyridinyloxyacetic acid) | ♦ Systemic herbicide<br>♦ Readily absorbed by foliage, translocated throughout plant<br>♦ Disrupts enzyme systems specific to plants<br>♦ Applied as liquid spray or subsurface injected liquid | ♦ Effectively controls many floating and submersed plant species<br>♦ Selectively effective against dicot plant species, including many nuisance species<br>♦ Effective against several difficult-to-control species<br>♦ Low toxicity to fauna<br>♦ Fast action | ♦ Impacts on non-target plant species possible at higher doses<br>♦ Current time delay of 30 days on consumption of fish from treated areas<br>♦ Necessary restrictions on use of treated water for supply or recreation not yet certain | ♦ |

| OPTION | MODE OF ACTION | ADVANTAGES | DISADVANTAGES | APPLICABILITY TO SANDWICH PONDS |
|---|---|---|---|---|
| **Biological Controls** | | | | |
| 7) Biological introductions | ◆ Fish, insects or pathogens which feed on or parasitize plants are added to system to affect control<br>◆ Grass carp most commonly used, but the larvae of several insects have been used and viruses are being tested | ◆ Provides potentially continuing control with one treatment<br>◆ Harnesses biological interactions to produce desired conditions<br>◆ May produce potentially useful fish biomass as an end product | ◆ Typically involves introduction of non-native species<br>◆ Effects may not be controllable<br>◆ Plant selectivity may not match desired target species<br>◆ May adversely affect indigenous species | ◆ |
| 7.a) Herbivorous fish | ◆ Sterile juveniles stocked at density which allows control over multiple years<br>◆ Growth of individuals offsets losses or may increase herbivorous pressure | ◆ May greatly reduce plant biomass in single season<br>◆ May provide multiple years of control from single stocking<br>◆ Sterility intended to prevent population perpetuation and allow later adjustments | ◆ May eliminate all plant biomass, or impact non-target species<br>◆ Funnels energy into algae<br>◆ Alters habitat<br>◆ May escape lake<br>◆ Population control issues | ◆ |

| OPTION | MODE OF ACTION | ADVANTAGES | DISADVANTAGES | APPLICABILITY TO SANDWICH PONDS |
|---|---|---|---|---|
| 7.b) Herbivorous insects | ◆ Larvae or adults stocked at density intended to allow control with limited growth<br>◆ Intended to selectively control target species<br>◆ Milfoil weevil is best known, but still experimental | ◆ Involves species native to region, or even targeted lake<br>◆ Expected to have no negative effect on non-target species<br>◆ May facilitate longer term control with limited management | ◆ Incomplete control likely; oscillating cycle of control and re-growth expected<br>◆ Predation by fish may complicate control<br>◆ Other lake mgmt actions may interfere | ◆ |
| 7.c) Fungal/bacterial/ viral pathogens | ◆ Inoculum used to seed lake or target plant patch<br>◆ Growth of pathogen population expected to achieve control over target species | ◆ May be highly species specific<br>◆ May provide substantial control after minimal inoculation effort | ◆ Effectiveness and longevity of control not well known<br>◆ Infection ecology suggests incomplete control likely | ◆ |
| 7.d) Selective plantings | ◆ Establishment of plant assemblage resistant to undesirable species<br>◆ Plants introduced as seeds, cuttings or whole plants | ◆ Can restore native assemblage<br>◆ Can encourage assemblage most suitable to lake uses<br>◆ Supplements targeted species removal effort | ◆ Largely experimental<br>◆ May not prevent nuisance species from returning<br>◆ Introduced species may become nuisances | ◆ |