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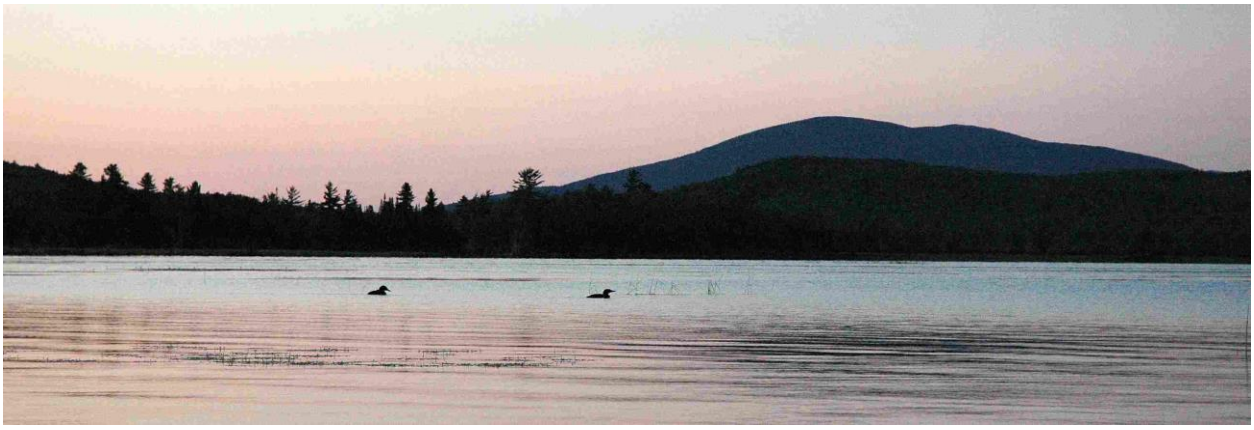
Natural Freshwater Lakes and Ponds in New Hampshire

Draft Classification



A Final Report to
NH Department of Environmental Services

Submitted by
NH Natural Heritage Bureau
December 2015

Completed under EPA Grant CD-96179201-0: Task 2
Advancing Wetland Assessment, Classification, and Permit Review in NH

Overview of the NH Natural Heritage Bureau's Purpose and Policies

The NH Natural Heritage Bureau (NHB) finds, tracks, and facilitates the protection of New Hampshire's rare plants and exemplary natural communities. As a bureau within the NH Department of Resources and Economic Development's Division of Forests & Lands, NHB works with landowners and land managers to help them protect New Hampshire's natural heritage while meeting their land-use needs.

The New Hampshire Native Plant Protection Act (RSA 217A) authorizes NHB to collect and analyze data on state lands about the status, location, and distribution of rare or declining native plant species and exemplary natural communities and maintain that information in a comprehensive database.

The Natural Heritage database contains information about more than 7,000 plant, animal, and natural community occurrences in New Hampshire.

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Cover photo: Umbagog Lake, Errol and Cambridge, NH (Source: NH NHB).

ACKNOWLEDGEMENTS

We thank the following biologists who provided comments on the classification framework for lake and pond systems in NH: Matt Carpenter, Sandy Crystall, Joann Hoy, Sara Steiner, and Barry Wicklow.

This classification is in part the result of adopting and modifying the New York Natural Heritage Program's lacustrine classification (Edinger et al. 2014; Hunt 2003; Hunt 2001).

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INTRODUCTION

Evaluating and protecting aquatic plant and animal diversity in New Hampshire necessitates understanding the diversity, conservation status[1], and condition of lakes and ponds in the state. Representative exemplary[2] examples of each lake and pond type then can be safeguarded in the environmental review and conservation planning process to preserve the full extent of New Hampshire's native aquatic diversity. In Northeast North America, state and regional-scale lake and pond classifications with aquatic bed community descriptions are limited (Edinger et al. 2014; Langdon et al. 1998). A few other classifications focus primarily on attributes important to lake and pond structure, (e.g., water temperature, trophic level, alkalinity, and depth), providing mapped classifications, evaluation of condition and threats, and a framework for biological assemblage descriptions but with limited (Enser and Lundgren 2006; Olivero and Bechtel 2005) or no aquatic bed information (Olivero-Sheldon et al. 2014). The goal of this report is to a) identify and develop a draft lake and pond classification framework directly applicable to waterbodies in New Hampshire, b) provide a framework for aquatic bed communities associated with different waterbody types, c) identify where the largest gaps exist in our understanding of the classification, d) provide ecological context through descriptions, keys (see Appendix 1), and crosswalking New Hampshire's system and natural community types to NatureServe[3] ecological concepts (where possible), and e) propose draft state-level conservation status ranks (see Appendix 2) for each type of lake and pond system[4] to inform environmental reviews and regulatory and conservation planning for naturally occurring waterbodies.

This classification is the result of an extensive literature review, adoption and modification of New York Natural Heritage Program's lacustrine classification (Edinger et al. 2014; Hunt 2003; Hunt 2001), review by aquatic ecologists, and NH Natural Heritage Bureau (NH NHB) surveys. For most of the lake and pond systems, there has been a limited number of NH NHB aquatic bed surveys conducted over the last 25 years, including the sampling of 22 waterbodies during this project (see Appendix 4 for a list of survey sites; see Appendix 5 and 6 for sampling protocols and field form developed and utilized for this project). To a degree, exceptions include coastal plain ponds, oligotrophic ponds, and oligotrophic lakes. This lake and pond system framework necessitates comprehensive statewide sampling to a) test and refine the classification, b) further develop natural community descriptions, and c) better assess state conservation status.

[1] Measure of extirpation risk for each natural community and system type at global and subnational geographic scales (G-Ranks and S-Ranks).
[2] The NH Natural Heritage Bureau tracks "exemplary" natural community and system occurrences. To qualify as exemplary, a natural community or system in a given place must be a rare type (e.g., S1) or a relatively undisturbed occurrence of a common community (e.g., S4 or S5) in good to excellent condition. Exemplary natural communities and systems represent the best remaining examples of New Hampshire's biological diversity.
[3] NatureServe is an international network of natural heritage programs whose mission is to provide the scientific basis for effective conservation action.
[4] Particular associations of natural communities that repeatedly co-occur in the landscape and are linked by a common set of driving forces such as landforms, hydrology, water chemistry, and trophic state.

Aquatic vascular plant species fall into three generalized life-form categories: 1) Submerged aquatics have most or all of their mass below the water surface and typically are rooted to the bottom. Common submerged species in New Hampshire are common waterweed (*Elodea canadensis*), tape-grass (*Vallisneria americana*), and common hornwort (*Ceratophyllum demersum*). 2) Floating-leaved aquatics are rooted plants with leaves floating on the water surface (often with flowers emerging above the water). Examples include water-shield (*Brasenia schreberi*), bullhead pond-lily (*Nuphar variegata*), white water-lily (*Nymphaea odorata*), and little floating-heart (*Nymphoides cordata*). 3) Free-floating aquatics drift freely on the water surface (not rooted to bottom). They are often smaller sized and include northern water-meal (*Wolffia borealis*), common duckweed (*Lemna minor*), and common duck-meal (*Spirodela polyrrhiza*). Emergent species are not strictly aquatics but some classifications consider them a fourth type of aquatic life-form. They are rooted plants with significant portions emergent above the water surface. Examples include pickerelweed (*Pontederia cordata*), American bur-reed (*Sparganium americanum*), and broad-leaved cattail (*Typha latifolia*). The algae growing in our lakes and ponds are non-vascular plants without true roots. Two types are macroalgae attached by rhizoids to the substrate (e.g., *Chara* spp.) and microalgae or phytoplankton floating in the water column.

Natural freshwater lakes and ponds consist of ponded waters that may form wetlands and deepwater habitats in topographic depressions. They are characterized by: areas with native, floating-leaved and submerged aquatic vegetation; the lack of or have limited persistent emergent vegetation; have not been substantially modified by human activities in terms of trophic state, morphometry, and water chemistry; lack dominance by introduced biota; and have ocean-derived salinity less than 0.5 parts per thousand (Cowardin et al. 1979). This classification distinguishes lake and pond types based on trophic state, thermal stratification and circulation cycles, water chemistry, and morphometry (e.g., shoreline complexity, surface area, depth, length, and volume). A lake or pond system type represents the entire body of water, serves as a coarse filter[5] for the system's collective biota, and represents broad scale features that distinguish one type from another.

Aquatic bed communities, characterized by floating-leaved and submersed herbaceous species, occur in intermittently exposed to permanently flooded areas at the transition between emergent marshes and deeper environments of lakes and ponds. Water depths are usually 0.5 m at low-water in most years, and may be as deep as about 3 m, the approximate depth limit for the growth of rooted plants. Pond-lilies, water-shield, water-lilies, bladderworts, pondweeds, floating-heart, duckweeds, duck-meal, quillworts, water-meals, tape grass, and milfoils are all common plants in aquatic beds. Submersed forms of emergent species may also be present, such as golden hedge-hyssop, needle spikesedge, Robbins' spikesedge, and bayonet rush. More than 30 vascular plant species listed in New Hampshire as endangered or threatened are found in aquatic bed communities (see Table 1 below and Appendix 2 & 3 for explanation of state conservation status rank codes and state listing codes). State endangered and threatened species are marked by an asterisk (*) in aquatic bed descriptions.

[5] Coarse filter approach to conserving biodiversity: Conserving examples of each distinct system type, in sufficient abundance and distribution, is an efficient way to protect the majority of biological diversity in New Hampshire.

Table 1. Rare aquatic vascular plant species occurring in New Hampshire's lakes and ponds. In addition to state endangered and threatened species (S1 and S2 conservation status rank), state watch (S3) and indeterminate aquatic vascular plant species are included in the table. See Appendix 2 & 3 for explanation of state conservation status rank and state listing codes.

Scientific Name	Common Name	State Conservation Status Rank	State Listing Code
Bidens beckii	Beck's water-marigold	S2	T
Ceratophyllum echinatum	spineless hornwort	SU	IND
Crassula aquatica	pygmy-weed	SH	E
Elatine minima	small waterwort	SU	IND
Glyceria acutiflora	sharp-flowered mannagrass	S1	E
Glyceria septentrionalis	floating mannagrass	S1	E
Helanthium tenellum	dwarf burhead	S1	E
Heteranthera dubia	grass-leaved mud-plantain	S2	T
Hippuris vulgaris	common mare's-tail	S2	T
Hottonia inflata	American featherfoil	S1	E
Isoetes acadiensis	Acadian quillwort	SH	E
Isoetes engelmannii	Engelmann's quillwort	S1	E
Isoetes lacustris	lake quillwort	SH	E
Isoetes riparia var. *canadensis*	Canada shore quillwort	S1	E
Lemna trisulca	ivy-leaved duckweed	S1	E
Lemna valdiviana	pale duckweed	SH	E
Myriophyllum alterniflorum	alternate-flowered water-milfoil	SU	IND
Myriophyllum farwellii	Farwell's water-milfoil	SU	IND
Myriophyllum humile	low water-milfoil	S3	W
Myriophyllum sibiricum	northern water-milfoil	SU	IND
Myriophyllum verticillatum	whorled water-milfoil	SU	IND
Najas gracillima	slender waternymph	SU	IND
Najas guadalupensis	Guadalupe waternymph	SU	IND
Nuphar microphylla	small-leaved pond-lily	SH	E
Potamogeton alpinus	reddish pondweed	S1	E
Potamogeton confervoides	alga-like pondweed	S3	W
Potamogeton foliosus	leafy pondweed	SH	E
Potamogeton gemmiparus	budding pondweed	SH	E
Potamogeton nodosus	long-leaved pondweed	S2	T
Potamogeton obtusifolius	blunt-leaved pondweed	SH	E
Potamogeton praelongus	white-stemmed pondweed	SH	E
Potamogeton richardsonii	Richardson's pondweed	SH	E
Potamogeton vaseyi	Vasey's pondweed	S1	E
Potamogeton zosteriformis	flat-stem pondweed	S1	E
Proserpinaca pectinata	comb-leaved mermaid-weed	SH	E
Sagittaria cuneata	northern arrowhead	S1	E
Sagittaria rigida	sessile-fruited arrowhead	SH	E
Sagittaria teres	quill-leaved arrowhead	S1	E
Sclerolepis uniflora	sclerolepis	S1	E
Sparganium natans	Arctic bur-reed	S2	T
Stuckenia filiformis	thread-leaved false pondweed	SH	E
Stuckenia pectinata	Sago false pondweed	S1	E
Subularia aquatica ssp. *americana*	American water-awlwort	S1	E
Utricularia minor	lesser bladderwort	S3	W

Scientific Name	Common Name	State Conservation Status Rank	State Listing Code
Utricularia radiata	floating bladderwort	S3	W
Utricularia resupinata	resupinate bladderwort	SH	E

Fish assemblages described for lakes and ponds, largely originating from data collected in nearby states, are not comprehensive nor meant to be used to specifically classify waterbody types. In addition, fish assemblages in most of our region's waterbodies have been altered by introductions of both native and nonnative fish species, creating additional classification challenges (Langdon et al. 1998).

The trophic state of a pond or lake characterizes the waterbody's productivity and is typically determined by measuring chlorophyll-a concentrations, total phosphorous, and/or Secchi transparency, surrogates for algae biomass (Olivero-Sheldon et al. 2014; USEPA 2009). The New Hampshire Department of Environmental Services (NH DES) initiated surveys in 1975 with the intention of determining trophic state of lakes and ponds greater than 10 acres as required by the federal Clean Water Act. By collecting physical, chemical, and biological measurements, 780 lakes and ponds received trophic class ratings and tens of thousands of data points were gathered from 1975–2008. The program was discontinued in 2008. However, to ensure NH DES could continue to make informed decisions concerning changes in trophic status, provide recent water quality information to the public, monitor regional environmental influences, and facilitate water quality stewardship, the lake trophic survey program was modified and reinstated in 2013.

Ponds are usually distinguished from lakes by their smaller size (<8 ha), shallower maximum depth, lack of active wave-formed or bedrock shorelines (Cowardin et al. 1979), and simplified shoreline complexity (they often have a round shape). Maximum depth thresholds for classifying ponds are determined by the ability of light to penetrate to the bottom, which is dependent on water clarity and trophic state. We adopted the following guidelines for pond maximum depth thresholds (Olivero-Sheldon et al. 2014): eutrophic = 3 m; mesotrophic = 6 m; oligotrophic = 9 m. Winter-stratified monomictic lakes (with maximum depths usually <6 m and stratify when ice-covered during the winter) less than 40 ha may be considered "ponds," where the size distinction is believed to be correlated with a lower percent cover of aquatic vegetation in monomictic lakes compared to ponds (Hunt 2003).

Important water chemistry parameters for waterbody classification include alkalinity and pH. Waterbodies with high alkalinity and acid neutralizing capacity are able to buffer against incoming acid deposition and typically have a high pH. In New Hampshire, these waterbodies are largely restricted to watersheds in the southeastern part of the state and near the Connecticut River where they are underlain by bedrock supplying relatively high concentrations of calcium and other base cations. Most of the state is underlain by weather resistant bedrock high in silica and low in base cations, yielding waterbodies with relatively low alkalinity and pH. Factors other than proximate geology influencing pH include the nature of contributions from surface runoff and groundwater, watershed position, and hydrologic connectivity. We adopted the following alkalinity class guidelines (Olivero-Sheldon et al. 2014): low alkalinity <12.5

mg/l $CaCO_3$; medium alkalinity ≥12.5 to <50 mg/l $CaCO_3$; high alkalinity ≥50 mg/l $CaCO_3$ (milligrams per liter calcium carbonate at surface or within 2 m depth).

Vernal pools, shallow intermittently to ephemerally flooded depressions, are treated in this classification. Cultural lakes and ponds (not treated here) include habitat that are either created and maintained by human activities or significantly modified in terms of trophic state, hydrology, morphometry, water chemistry, or biological composition from the character of the waterbody prior to human influence. These waterbodies include reservoirs/artificial impoundments, acidified lakes, cultural eutrophic lakes, farm ponds, quarry ponds, industrial cooling ponds, sewage treatment ponds, and other artificial ponds and pools.

NATURAL FRESHWATER LAKES AND PONDS IN NEW HAMPSHIRE

1. Oligotrophic Lake System

General description: This lake system typically occurs in deep, relatively steep-banked, nutrient-poor basins. Bottom sediments are sand, gravel, and/or rock with an organic layer of variable depth (when present). The lakes are dimictic with two periods of mixing (spring and fall), thermally stratified in the summer, and inversely stratified in the winter after freezing over. Edinger et al. (2014) provide the following description for characteristic features: clear blue or green water with high transparency (Secchi disk depths of 4–8 m); water low in plant nutrients (especially nitrogen and calcium); low primary productivity (inorganic carbon fixed = 7–25 g/m^2/yr); lake sediments low in organic matter; relatively small epilimnion volume compared with hypolimnion; oxygen abundant all year in all strata; and low alkalinity (<12.5 mg/l calcium carbonate).

Vegetation: Aquatic plant cover and species diversity are low and characterized by rosette-leaved aquatics and acidic tolerant species assemblages. Coves and other sheltered areas may support both floating-leaved and submerged aquatic species; more exposed littoral areas may lack aquatic beds or just support submerged species. One of these lakes supports New Hampshire's only population of sclerolepis (*Sclerolepis uniflora*)*. Other rare plant species in oligotrophic lakes in the state include Acadian quillwort (*Isoetes acadiensis*)*, Engelmann's quillwort (*I. engelmannii*)*, lake quillwort (*I. lacustris*)*, Canada shore quillwort (*I. riparia* var. *canadensis*)*, comb-leaved mermaid-weed (*Proserpinaca pectinata*)*, quill-leaved arrowhead (*Sagittaria teres*)*, sessile-fruited arrowhead (*S. rigida*)*, American water-awlwort (*Subularia aquatica* ssp. *americana*)*, and resupinate bladderwort (*Utricularia resupinata*)*. Small waterwort (*Elatine minima*), listed as state indeterminate in New Hampshire, occurs in similar soft water lakes elsewhere (Curtis 1959).

Phytoplankton in oligotrophic lakes in the region is diverse and includes desmids (*Staurastrum* spp.), chrysophytes (*Dinobryum* spp.), and diatoms (*Cyclotella* spp. and *Tabellaria* spp.) (Hunt 2003).

Three aquatic bed community types may be distinguished in New Hampshire:

Oligotrophic pondweed cove (G-, S2; NatureServe crosswalk = unknown): This community occurs in protected coves and is characterized primarily by floating-leaved aquatics including ribbon-leaved pondweed (*Potamogeton epihydrus*), floating pondweed (*P. natans*), little floating-heart (*Nymphoides cordata*), white water-lily (*Nymphaea odorata*), and water-shield (*Brasenia schreberi*; Hunt (2003) notes this species may be more common in mesotrophic to oligotrophic lakes compared to eutrophic lakes). Other pondweeds may include Robbins' pondweed (*P. robbinsii*), grassy pondweed (*P. gramineus*), and clasping-leaved pondweed (*P. perfoliatus*) (Edinger et al. 2014). Seven-angled pipewort (*Eriocaulon aquaticum*), water lobelia (*Lobelia dortmanna*), and quillworts (*Isoetes* spp.) may occur but in lower cover than found in the **water lobelia aquatic sandy pond shore**. The oligotrophic pondweed cove also has a much higher percent cover of vegetation, particularly of floating-leaved aquatics more sensitive to wave disturbance along exposed shores, and possibly edaphically with a deeper organic layer when present compared to the **water lobelia aquatic sandy pond shore**. Emergent plant species can occur in

low cover in shallower water including pickerelweed (*Pontederia cordata*) and American bur-reed (*Sparganium americanum*).

Water lobelia aquatic sandy pond shore (GNR, S2; NatureServe crosswalk = pipewort sandy pondshore and spikerush sandy pondshore): This aquatic shoreline community has a permanently inundated to intermittently exposed flood regime and is subjected to regular wave and ice disturbance. The bottom is sand to gravelly sand; if an organic layer is present at the substrate surface, it is usually thin peaty muck. Most examples are characterized by a low percent cover of aquatic, rosette-forming, stress-tolerant species (including "Isoetids"). Typical species include seven-angled pipewort (*Eriocaulon aquaticum*; sparse to abundant), water lobelia (*Lobelia dortmanna*), quillworts (*Isoetes tuckermanii*, *I. lacustris**, *I. echinospora* ssp. *muricata*, and others), three-square bulrush (*Schoenoplectus pungens*), creeping bladderwort (*Utricularia gibba*), and submersed aquatic forms of grass-leaved arrowhead (*Sagittaria graminea*), golden hedge-hyssop (*Gratiola aurea*), brown-fruited rush (*Juncus pelocarpus*), needle spikesedge (*Eleocharis acicularis*), and American bur-reed (*Sparganium americanum*). Floating-leaved and submersed species are absent or low in cover. This community is similar floristically to the **bayonet rush emergent marsh/aquatic bed**, primarily differing structurally by being dominated by vegetation of low height, possibly edaphically with a thinner organic layer when present, and hydrologically with intermittently to permanently flooded conditions.

Bayonet rush emergent marsh/aquatic bed (GNR, S2; NatureServe crosswalk = bayonet rush pondshore): This shallow water shoreline community is transitional between aquatic bed and emergent marsh. The sandy bottom often has an organic peaty muck layer at the substrate surface. Bayonet rush (*Juncus militaris*) is dominant; three-square bulrush (*Schoenoplectus pungens*) is a common associate (subdominant in some examples). Other common species include pickerelweed (*Pontederia cordata*), little floating-heart (*Nymphoides cordata*), water lobelia (*Lobelia dortmanna*), water-shield (*Brasenia schreberi*), bladderworts (such as *Utricularia purpurea* and *U. resupinata*), water-milfoils (such as *Myriophyllum tenellum* and *M. alterniflorum*), bur-reeds (*Sparganium* spp.), and northern mannagrass (*Glyceria borealis*). Species nearest the shoreline where the water may draw down later in the summer include golden hedge-hyssop (*Gratiola aurea*), swamp yellow-loosestrife (*Lysimachia terrestris*), false water-pepper smartweed (*Persicaria hydropiperoides*), Virginia marsh-St. John's-wort (*Triadenum virginicum*), seven-angled pipewort (*Eriocaulon aquaticum*), three-way sedge (*Dulichium arundinaceum*), spikesedges (*Eleocharis* spp.), brown-fruited rush (*Juncus pelocarpus*), and redtop-panicgrass (*Coleataenia longifolia*). This community is similar floristically to the **water lobelia aquatic sandy pond shore**, primarily differing structurally by being dominated by a tall graminoid, possibly edaphically with a deeper organic layer when present, and hydrologically with semipermanently to intermittently flooded conditions.

Wildlife: Fish assemblages are usually well-developed and diverse but the abundance of each species is low (Edinger et al. 2014). Warmwater species in shallow areas may include rock bass (*Ambloplites rupestris*), redbreast sunfish (*Lepomis auritus*), pumpkinseed (*L. gibbosus*), smallmouth bass (*Micropterus dolomieui*), yellow perch (*Perca flavescens*), and banded killifish (*Fundulus diaphanus*); coldwater species in deeper water can include lake whitefish (*Coregonus clupeaformis*), cusk (*Lota lota*),

rainbow smelt (*Osmerus mordax*), lake trout (*S. namaycush*), with brook trout (*Salvelinus fontinalis*), rainbow trout (*Salmo gairdneri*), brown trout (*S. trutta*), and landlocked Atlantic salmon (*S. salar*) commonly introduced (Edinger et al. 2014; Langdon et al. 1998; New Hampshire Fish & Game 2014b; M. Carpenter, pers. comm.).

Other characteristic animal species in oligotrophic lakes in the region include eastern lampmussel (*Lampsilis radiata*), eastern elliptio (*Elliptio complanata*), eastern floater (*Pyganodon cataracta*), ramshorn snail (*Heliosoma trivolvis*), physid snail (*Physa heterostropha*), amnicolas (*Amnicola* spp.), mystery snail (*Campeloma decisum*), crayfish (Order Decapoda), caddisflies (Order Trichoptera), alderflies (*Sialis* spp.), midges (*Procladious* spp., *Heterotrissocladius* spp., *Phaenopsectra* spp., *Tanytarsus* spp., and *Tribelos* spp.), mayflies (*Stenonoma* spp.), acid-tolerant odonates (*Aeshna* spp., *Ischnura* spp., *Cordulia shurtleffii*, and *Leccorrhinia* spp.), beetles (Order Coleoptera), water strider (*Gerris* spp.), true water bugs (Family Corixidae), opossum shrimp (*Mysis diluviana*), oligochaete worms (Order Oligochaeta), rotifers (*Asplanchna* spp., *Conochilus* spp., *Keratella* spp., *Kellicotia* spp., and *Polyarthra* spp.), copepods (Class Copepoda), and water fleas (*Daphnia* spp., *Holopedium* spp., *Leptodora* spp., and *Polyphemus* spp.) (NYNHP 2013c; Hunt 2003; Langdon et al. 1998; B. Wicklow, pers. comm.).

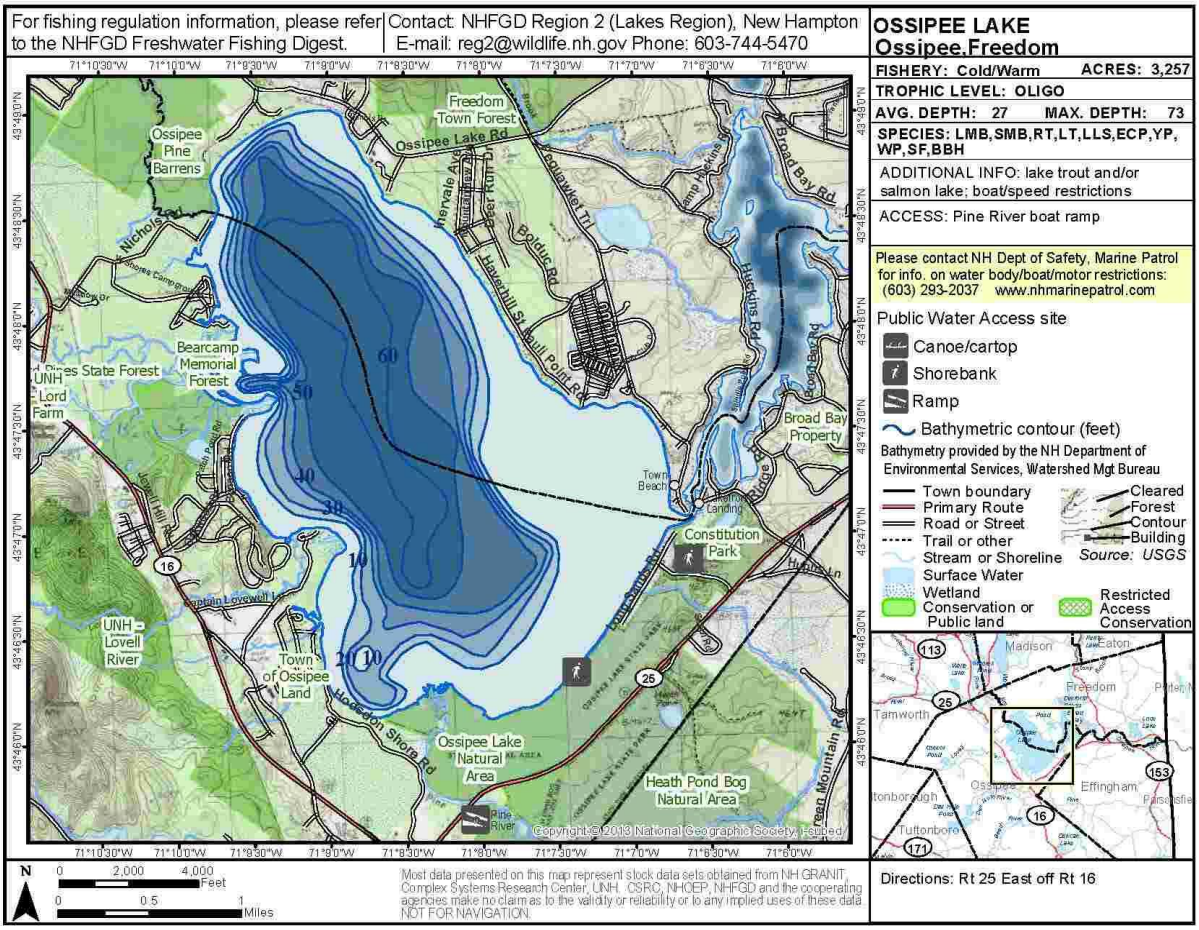
State distribution: This system occurs throughout the state.

NatureServe Ecological System Crosswalk: Unknown.

System Rank: G4, S3 (draft S-Rank).

Sources: Sperduto and Nichols 2011; Sperduto 1994; Sperduto 2000; Sperduto 2011; NH NHB field surveys; Edinger et al. 2014; Hunt 1999; Hunt 2003; Langdon et al. 1998; NatureServe 2015; New Hampshire Fish & Game 2014b; B. Wicklow, pers. comm.

Examples: An example of an oligotrophic lake system is Ossipee Lake in Ossipee and Freedom.



Ossipee Lake in Ossipee and Freedom, NH (Source: New Hampshire Fish & Game 2014a).

2. Mesotrophic Lake System

General description: This lake system is dimictic with two periods of mixing (spring and fall), thermally stratified in the summer, and inversely stratified in the winter after freezing over. Edinger et al. (2014) describe the following characteristic features as moderate and intermediate between oligotrophic and eutrophic lakes: water clarity and transparency (Secchi disk depths of 2–4 m); plant nutrients and primary productivity (inorganic carbon fixed = 25–75 g/m^2/yr); organic matter in lake sediments; water oxygen levels; and alkalinity (slightly greater than 12.5 mg/l calcium carbonate).

Vegetation: Aquatic plant diversity in mesotrophic lakes elsewhere in our region (Edinger et al. 2014) is relatively high (generally higher than in eutrophic lakes) and characterized by several species of pondweeds (*Potamogeton* spp. including *P. perfoliatus* [Mackie 2004]), bladderworts (*Utricularia* spp.), tape-grass (*Vallisneria americana*), and water-shield (*Brasenia schreberi*; Hunt (2003) notes this species may be more common in mesotrophic to oligotrophic lakes compared to eutrophic lakes). Coves and other

sheltered areas may support both floating-leaved and submerged aquatic species; more exposed littoral areas may lack aquatic beds or just support submerged species.

Characteristic phytoplankton includes green algae, cyanobacteria, and diatoms (Hunt 2003).

Rare plant species that occur in mesotrophic lakes in New Hampshire include flat-stem pondweed (*Potamogeton zosteriformis*)*, American water-awlwort (*Subularia aquatica* ssp. *americana*)*, and resupinate bladderwort (*Utricularia resupinata*)*.

No formal aquatic bed community types have been classified yet in New Hampshire:

Unclassified floating-leaved aquatic bed (G4G5, S4; NatureServe crosswalk = water-lily aquatic wetland):

Unclassified aquatic bed cove (G-, S4; NatureServe crosswalk = pondweed - hornwort - waterweed aquatic vegetation):

Unclassified submerged aquatic bed (G-, S4; NatureServe crosswalk = water-milfoil aquatic bed):

Wildlife: Fish diversity is abundant and characterized by warm- to coolwater species including rock bass (*Ambloplites rupestris*), brown bullhead (*Ameiurus nebulosus*), yellow bullhead (*A. natalis*), white sucker (*Catostomus commersoni*), northern pike (*Esox lucius*), chain pickerel (*E. niger*), pumpkinseed (*Lepomis gibbosus*), bluegill (*L. macrochirus*), large and smallmouth bass (*Micropterus salmoides* and *M. dolomieui*), white perch (*Morone americana*), golden shiner (*Notemigonus crysoleucas*), and yellow perch (*Perca flavescens*) (Edinger et al. 2014; Hunt 2003; Langdon et al. 1998; New Hampshire Fish & Game 2014b; M. Carpenter, pers. comm.).

Other characteristic animal species in mesotrophic lakes in the region include zooplankton such as water flea (*Daphnia dubia*) and various crustacean larvae and macroinvertebrates such as sowbugs (Order Isopoda), amphipods (Order Amphipoda), bivalves (pea clams [*Pisidium* spp.], eastern elliptio [*Elliptio complanata*], and eastern floater [*Pyganodon cataracta*]), ramshorn snail (Family Planorbidae), snails (*Amnicola limosa* and Family Physidae), dragonflies (Suborder Anisoptera), beetles (Order Coleoptera), true bugs (Order Hemiptera), dobsonflies (Order Megaloptera), caddisflies (Order Trichoptera), acid-intolerant odonates (*Gomphus* spp., *Basiaeschna* spp., *Aeshna* spp., and *Ischnura* spp.), mayflies (*Stenonema* spp. and *Hexagenia* spp.), and freshwater sponge (Phylum Porifera) (Edinger et al. 2014; Hunt 2003; Langdon et al. 1998; B. Wicklow, pers. comm.).

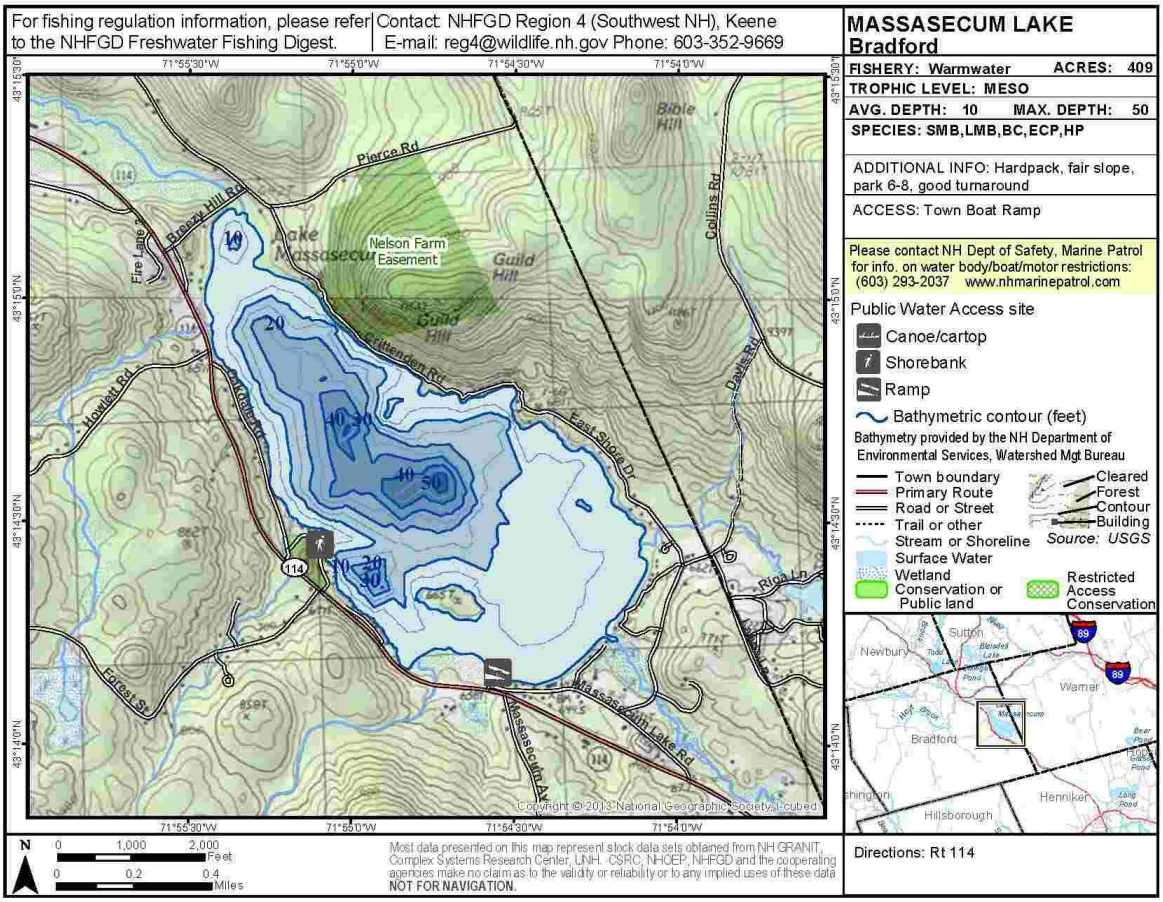
State distribution: This system occurs throughout the state.

NatureServe Ecological System Crosswalk: Unknown.

System Rank: G4, S3S4 (draft S-Rank).

Sources: Sperduto and Nichols 2011; NH NHB field surveys; Edinger et al. 2014; Hunt 1999; Hunt 2003; Langdon et al. 1998; Hellquist 1980; New Hampshire Fish & Game 2014b; B. Wicklow, pers. comm.

Examples: An example of a mesotrophic lake system is Massasecum Lake in Bradford.



Massasecum Lake in Bradford, NH (Source: New Hampshire Fish & Game 2014a; NH NHB).

3. Eutrophic Lake System

General description: This lake system typically occurs in broad, shallow, nutrient-rich basins. The lakes are dimictic with two periods of mixing (spring and fall), thermally stratified in the summer, and inversely stratified in the winter after freezing over. Edinger et al. (2014) provide the following description for characteristic features: murky yellow, green, or brownish-green water with low transparency (Secchi disk depths typically <2.5 m, but up to 4 m in some cases); water rich in plant nutrients (especially high in phosphorus, nitrogen, and calcium); high primary productivity (inorganic carbon fixed = 75–250 g/m^2/yr); lake sediments rich in organic matter (usually consisting of a fine organic silt); well-oxygenated water above the summer thermocline, but oxygen-depleted below the summer thermocline or under ice; weedy shoreline; and alkalinity typically high (>12.5 mg/l calcium carbonate).

Vegetation: Aquatic plant species diversity and cover is relatively high, although species diversity is believed to be in general lower than in mesotrophic lakes. Coves and other sheltered areas may support both floating-leaved and submerged aquatic species; more exposed littoral areas may lack aquatic beds or just support submerged species. Rosette-leaved aquatics are absent or in low abundance. Rare plant species that occur in eutrophic lakes in New Hampshire include pale duckweed (*Lemna valdiviana*)* and flat-stem pondweed (*Potamogeton zosteriformis*)*. These lake systems are especially prone to invasive species such as variable-leaved water-milfoil (*Myriophyllum heterophyllum*), Eurasian water-milfoil (*M. spicatum*), brittle waternymph (*Najas minor*), curly pondweed (*Potamogeton crispus*), and water-chestnut (*Trapa natans*).

Phytoplankton in eutrophic lakes in the region is abundant but low in species diversity and characterized by diatoms (*Asterionella* spp.), cyanobacteria (*Ceolosphaerium* spp., *Anabaena* spp., and *Microcystis* spp.), and golden algae (*Dinobryon* spp.) (Hunt 2003; B. Wicklow, pers. comm.).

Three aquatic bed community types may be distinguished in New Hampshire:

Water-lily aquatic bed (G4G5, S4; NatureServe crosswalk = water-lily aquatic wetland): This shallow water community is dominated by rooted, floating-leaved aquatic vegetation with moderate to high cover and diversity (although species diversity was found to by highest in mesotrophic lakes in New York; Edinger et al. 2014). Emergent species are absent or relatively low in cover (see **pickerelweed - arrow-arum - arrowhead emergent marsh** description). Free-floating and submerged plant species are typically present. The **water-lily aquatic bed** (or closely related types) occurs in eutrophic lakes and ponds, oxbow ponds, backwater sloughs, and fluvial ponds. Dominant species include white water-lily (*Nymphaea odorata*) and/or bullhead pond-lily (*Nuphar variegata*). Common associates are water-shield (*Brasenia schreberi*; Hunt (2003) notes this species may be more common in mesotrophic to oligotrophic lakes compared to eutrophic lakes), pondweeds (*Potamogeton* spp.), tape-grass (*Vallisneria americana*), duckweeds (*Lemna* spp.), common duck-meal (*Spirodela polyrrhiza*), water-meals (*Wolffia* spp.), common hornwort (*Ceratophyllum demersum*), common waterweed (*Elodea canadensis*), bladderworts (*Utricularia* spp.), grass-leaved mud-plantain (*Heteranthera dubia*)*, wavy waternymphs (*Najas* spp.), and bur-reeds (*Sparganium* spp.).

Pondweed - hornwort - waterweed cove (G-, S4; NatureServe crosswalk = pondweed - hornwort - waterweed aquatic vegetation): Occurring in shallow coves and other sheltered areas, this aquatic bed community is most well developed in eutrophic settings in water less than 2 m deep. Submerged aquatic cover is usually ≥25%; emergent species and/or floating-leaved aquatic cover is usually <25%. This community may be characterized by a mix of species or dominated by just a few including the following (NatureServe 2015; Hunt 2003): pondweeds (e.g., *Potamogeton epihydrus*, *P. bicupulatus*, *P. natans*, *P. zosteriformis**, *P. amplifolius*, and *P. richardsonii**), common hornwort (*Ceratophyllum demersum*), waterweeds (*Elodea* spp.), and greater bladderwort (*Utricularia vulgaris* ssp. *macrorhiza*). Other associated species are bullhead pond-lily (*Nuphar variegata*), duckweeds (*Lemna* spp.), common duck-meal (*Spirodela polyrrhiza*), tape-grass (*Vallisneria americana*), and wavy waternymph (*Najas flexilis*). Rosette-leaved aquatics are absent or in low abundance.

Water-milfoil submerged aquatic bed (G-, S4; NatureServe crosswalk = water-milfoil aquatic bed): This permanently flooded aquatic community is characterized by submerged native species including alternate-flowered water-milfoil (*Myriophyllum alterniflorum*), Farwell's water-milfoil (*M. farwellii*), low water-milfoil (*M. humile*), northern water-milfoil (*M. sibiricum*), slender water-milfoil (*M. tenellum*), whorled water-milfoil (*M. verticillatum*), submerged pondweeds (*Potamogeton* spp.), and tape-grass (*Vallisneria americana*). Submerged vegetation cover ranges from sparse to dense. Floating-leaved species are occasional to uncommon. This submerged aquatic bed community usually occurs in water between 1–3 m deep where wave action is limited (NatureServe 2015).

Associated with the aquatic bed vegetation in shallower water immediately adjacent to the shoreline is the **pickerelweed - arrow-arum - arrowhead emergent marsh** (G5, S5; NatureServe crosswalk = northeastern leafy forb marsh). This community usually occurs on muck soils and is dominated by broad-leaved, aerenchymatous plants such as pickerelweed (*Pontederia cordata*), green arrow-arum (*Peltandra virginica*), and common arrowhead (*Sagittaria latifolia*). Other emergent species include bur-reeds (*Sparganium* spp.), broad-leaved cattail (*Typha latifolia*), common spikesedge (*Eleocharis palustris*), rushes (*Juncus* spp.), soft-stemmed bulrush (*Schoenoplectus tabernaemontani*), water bulrush (*S. subterminalis*), and three-way sedge (*Dulichium arundinaceum*). Floating-leaved aquatics that may be present include white water-lily (*Nymphaea odorata*), bullhead pond-lily (*Nuphar variegata*), pondweeds (*Potamogeton* spp.), and bladderworts (*Utricularia* spp.). The combination of species at a given location depends on factors such as water depth and amplitude of water level fluctuations.

Wildlife: In eutrophic lakes in the region, fish diversity is abundant and characterized by warm- to coolwater species (Edinger et al. 2014; Hunt 2003; Langdon et al. 1998; New Hampshire Fish & Game 2014b; M. Carpenter, pers. comm.). These species include rock bass (*Ambloplites rupestris*), yellow bullhead (*Ameiurus natalis*), brown bullhead (*A. nebulosus*), white sucker (*Catostomus commersoni*), northern pike (*Esox lucius*), chain pickerel (*E. niger*), pumpkinseed (*Lepomis gibbosus*), bluegill (*L. macrochirus*), large and smallmouth bass (*Micropterus salmoides* and *M. dolomieui*), white perch (*Morone americana*), golden shiner (*Notemigonus crysoleucas*), and yellow perch (*Perca flavescens*).

Other characteristic animal species in eutrophic lakes in the region include zooplankton (*Keratella cf. cochlearis*, *Diaptomus* spp., *Bosmina* spp., and *Daphnia dubia*); profundal benthos invertebrate species tolerant of low oxygen such as oligochaetes (Order Oligochaeta), larvae of midges (*Chironomus* spp.), and phantom midges (*Chaoborus* spp.); and other macroinvertebrates such as amphipods (Order Amphipoda), bivalves (*Pisidium* spp.), ramshorn snail (Family Planorbidae), other snails (*Amnicola limosa* and Family Physidae), mayflies (*Stenonema* spp. and *Hexagenia* spp.), sowbugs (Order Isopoda), and acid-intolerant odonates (*Gomphus* spp., *Basiaeschna* spp., *Aeshna* spp., and *Ischnura* spp.) (Edinger et al. 2014; Hunt 2003; Langdon et al. 1998).

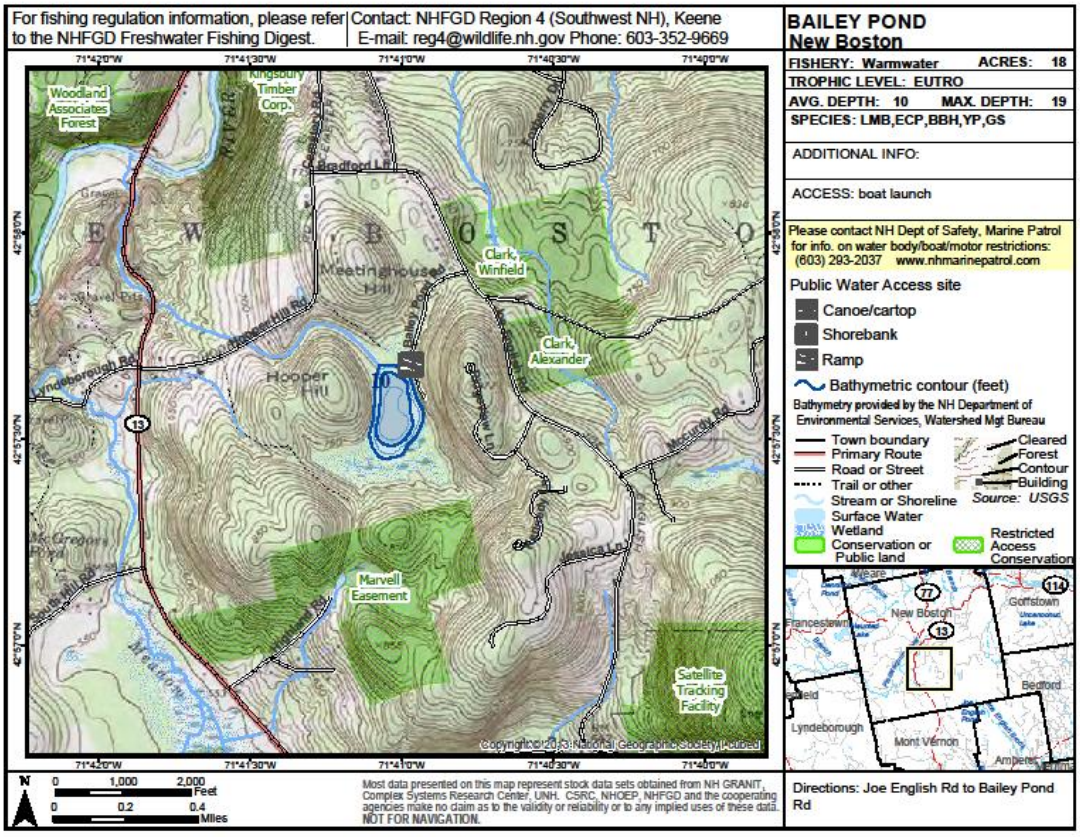
State distribution: This system occurs throughout the state at low elevations.

NatureServe Ecological System Crosswalk: Unknown.

System Rank: G4, S3S4 (draft S-Rank).

Sources: Sperduto and Nichols 2011; NH NHB field surveys; Edinger et al. 2014; Hunt 1999; Hunt 2003; Langdon et al. 1998; NatureServe 2015; New Hampshire Fish & Game 2014b; B. Wicklow, pers. comm.

Examples: A small-sized example may be Bailey Pond in New Boston (NH DES 2007).



Bailey Pond in New Boston, NH (Source: New Hampshire Fish & Game 2014a).

4. Monomictic Lake System

General description: This typically mesotrophic to eutrophic system occurs in shallow, large lakes (usually at least 40 ha) such that the ratio between depth, width, and surface area allows the wind to keep the water column well mixed during the summer months (preventing summer stratification), as a result of wind exposure (Hunt 2003). This creates a relatively uniform temperature and oxygen concentrations throughout the water column. Although maximum lake depths are usually less than 6 m, for some larger broader exposed lakes, depths can reach up to 10 m and still remain relatively well mixed from top to bottom during the summer. There is only one period of mixing each year and lakes are only stratified when ice-covered during the winter (winter stratified monomictic). These lakes usually support high habitat diversity and pelagic species assemblages are moderately-well developed (Edinger et al. 2014).

Monomictic lakes less than 40 ha can be considered "ponds" where the size distinction is believed to be correlated with a lower percent cover of aquatic vegetation in monomictic lakes compared to ponds (Hunt 2003). If the width and surface area are not large enough to allow wind-influenced mixing throughout the water column, a shallow waterbody could be considered a pond. Waterbodies too deep relative to their width and surface area, preventing stratification disruption at least at some point during the summer of an average year, could be considered a dimictic lake (Hunt 2003).

Vegetation: Vascular aquatic plants are usually diverse in monomictic lakes in the region (Edinger et al. 2014). Species include grass-leaved mud-plantain (*Heteranthera dubia*), common hornwort (*Ceratophyllum demersum*), waterweeds (*Elodea* spp.), waternymphs (*Najas* spp.), tape-grass (*Vallisneria americana*), and pondweeds (*Potamogeton perfoliatus, P. pusillus, P. richardsonii, P. nodosus, P. zosteriformis*, and *Stuckenia pectinata*). Coves and other sheltered areas may support both floating-leaved and submerged aquatic species; more exposed littoral areas may lack aquatic beds or just support submerged species.

Characteristic phytoplankton includes golden algae (*Dinobryon* spp.) and dinoflagellates (*Ceratium* spp.) with lesser amounts of the diatoms *Asterionella* spp. and *Melosira* spp. (Hunt 2003).

No formal aquatic bed community types have been classified yet in New Hampshire:

Unclassified floating-leaved aquatic bed (G4G5, S4; NatureServe crosswalk = water-lily aquatic wetland):

Unclassified aquatic bed cove (G-, S4; NatureServe crosswalk = pondweed - hornwort - waterweed aquatic vegetation):

Unclassified submerged aquatic bed (G-, S4; NatureServe crosswalk = water-milfoil aquatic bed):

Wildlife: Littoral and epilimnion fish species assemblages dominate including bullheads (*Ameiurus* spp.), white sucker (*Catostomus commersoni*), pumpkinseed (*Lepomis gibbosus*), largemouth bass (*Micropterus salmoides*), and yellow perch (*Perca flavescens*) (Edinger et al. 2014; M. Carpenter, pers. comm.).

Other characteristic animal species in these lakes in the region include macroinvertebrates such as isopods (Order Isopoda), amphipods (Order Amphipoda), bivalves including eastern elliptio (*Elliptio complanata*) and eastern floater (*Pyganodon cataracta*), ramshorn snails (Family Planorbidae), other snails (*Amnicola limosa* and Family Physidae), mayflies (*Stenonema* spp.), and acid-intolerant odonates (*Gomphus* spp., *Basiaeschna* spp., *Aeshna* spp., and *Ischnura* spp.) (Edinger et al. 2014; Hunt 2003; Langdon et al. 1998; B. Wicklow, pers. comm.).

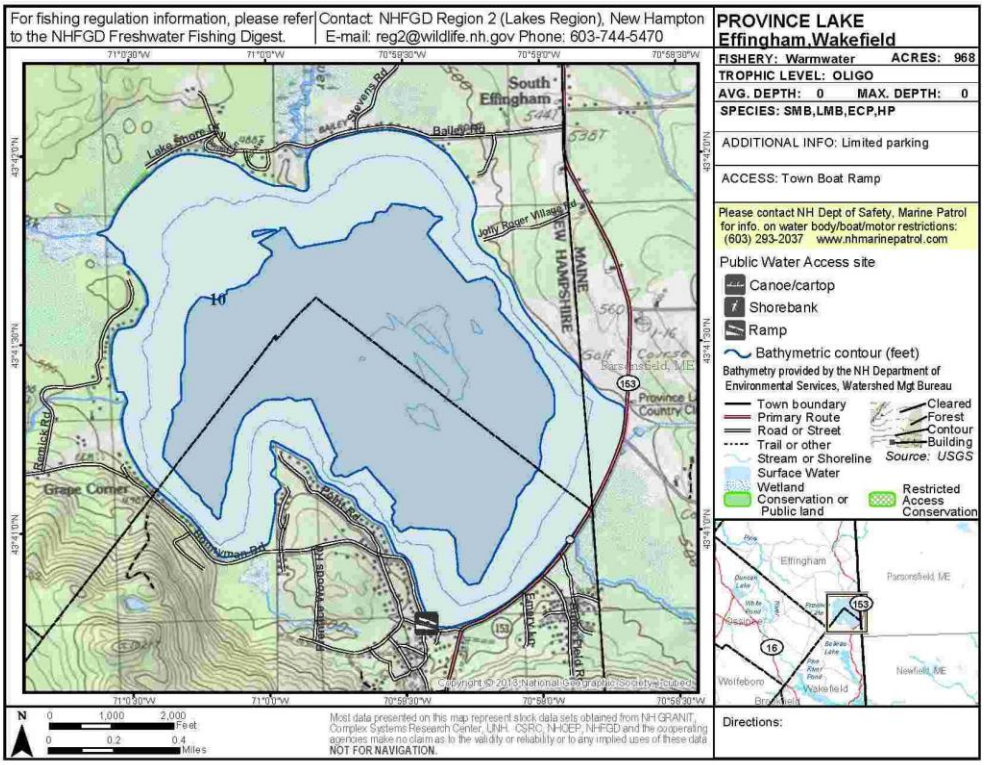
State distribution: Unknown.

NatureServe Ecological System Crosswalk: Unknown.

System Rank: G3G4, S2 (draft S-Rank).

Sources: Edinger et al. 2014; Hunt 1999; Hunt 2003; Langdon et al. 1998; B. Wicklow, pers. comm.

Examples: Province Lake in Effingham/Wakefield possibly fits a monomictic lake system (more research needed).



Province Lake in Effingham and Wakefield, NH (Source: New Hampshire Fish & Game 2014a).

5. Meromictic Lake System

General description: These lakes are relatively deep, with small surface areas, and lack complete mixing from their sheltered surroundings (usually with only partial mixing in the upper water column). They are thermally stratified during the winter when they freeze over and transition through periods of isothermy without circulating during the spring and fall. Meromictic lakes typically remain chemically stratified throughout the year; chemical gradients may be present for hydrogen sulfide, ammonia, phosphorus, or iron (Edinger et al. 2014). The stagnant, deeper, lower layers are characterized by high concentrations of dissolved salts and anoxic conditions. These lakes usually have low flushing rates.

Vegetation: Aquatic vegetation documented in meromictic lakes in the region include stoneworts (*Chara* spp.), waterweeds (*Elodea* spp.), and pondweeds (*Potamogeton* spp.) (Edinger et al. 2014). Coves and other sheltered areas may support both floating-leaved and submerged aquatic species; more exposed littoral areas may lack aquatic beds or just support submerged species.

Phytoplankton includes cyanobacteria, diatoms (*Asterionella* spp.), dinoflagellates (*Ceratium hirundinella* and *Peridinium* spp.), and heterokont algae (*Synura* spp.) (Hunt 2003).

No formal aquatic bed community types have been classified yet in New Hampshire:

Unclassified floating-leaved aquatic bed (G4G5, S4; NatureServe crosswalk = water-lily aquatic wetland):

Unclassified aquatic bed cove (G-, S4; NatureServe crosswalk = pondweed - hornwort - waterweed aquatic vegetation):

Unclassified submerged aquatic bed (G-, S4; NatureServe crosswalk = water-milfoil aquatic bed):

Wildlife: Species diversity is low due to the inability of all but a few organisms to tolerate the harsh chemical conditions in deeper water near lake bottoms (Edinger et al. 2014; Hunt 2003). Fish when present are restricted to the epilimnion and may include warm- and coolwater species such as brown bullhead (*Ameiurus nebulosus*), white sucker (*Catostomus commersoni*), and yellow perch (*Perca flavescens*) (Edinger et al. 2014).

Other characteristic animal species in these lakes in the region include zooplankton (*Diaphanasoma brachyurium*, *Ceriodaphnia* spp., *Holopedium* spp., and *Bosmina* spp.), freshwater sponges (Phylum Porifera), dragonflies (Suborder Anisoptera), beetles (Order Coleoptera), true bugs (Order Hemiptera), dobsonflies (Order Megaloptera), and caddisflies (Order Trichoptera) (Edinger et al. 2014; Hunt 2003; Langdon et al. 1998).

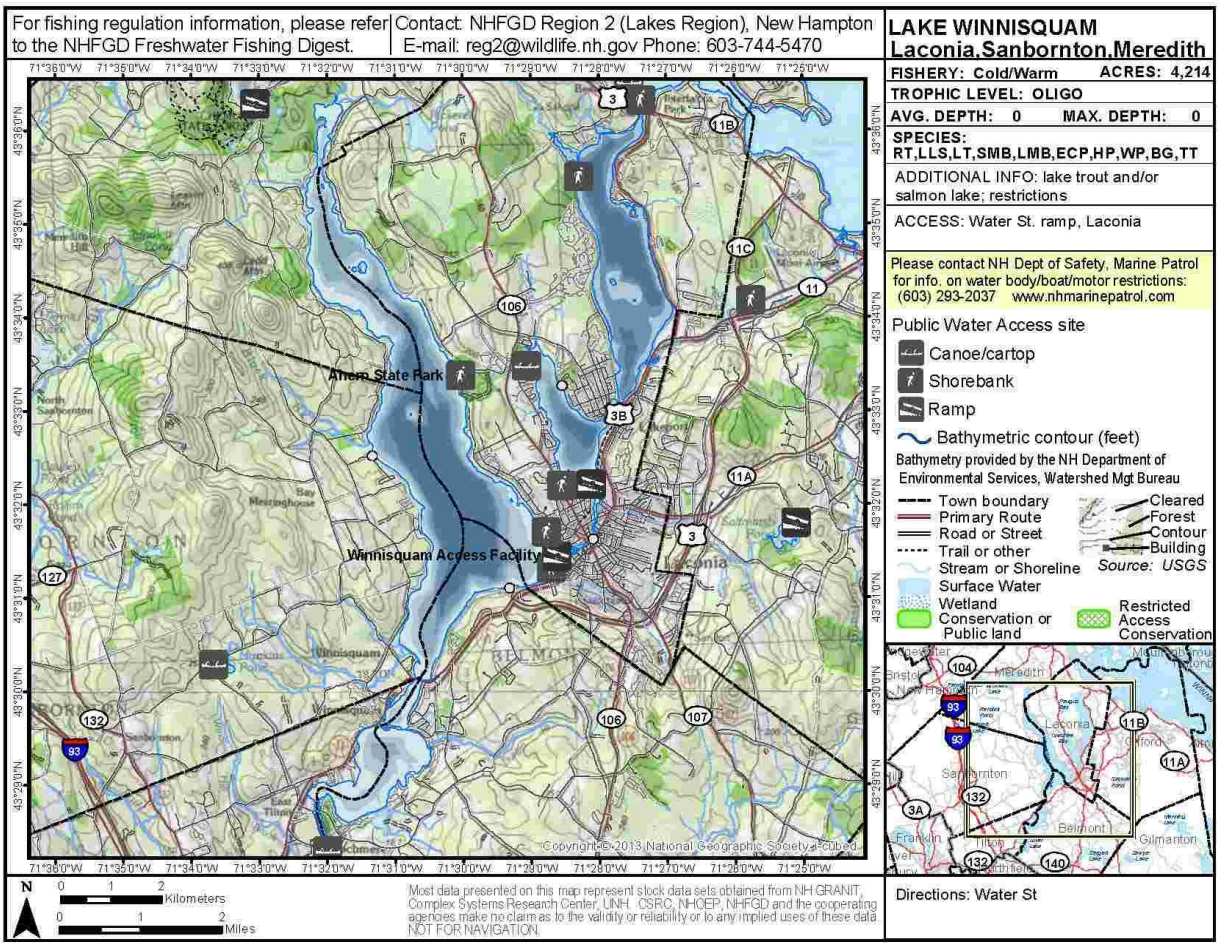
State distribution: The distribution of this system in the state is poorly known. Two possible occurrences are located in the Lakes Region and Coastal Plain.

NatureServe Ecological System Crosswalk: Unknown.

System Rank: G3G4, S1S2 (draft S-Rank).

Sources: Anderson et al. 1985; Edinger et al. 2014; Hunt 2003.

Examples: Based on Anderson et al. (1985), examples of meromictic lake systems include Lake Winninsquam in Laconia, Sanbornton, and Meredith and Barbadoes Pond in Madbury. A small-sized example (2 ha) is Black Pond in Lincoln (S. Bailey, pers. comm.).



Lake Winninsquam in Laconia, Sanbornton, and Meredith, NH (Source: NH Fish & Game 2014a).

6. Coastal Plain Pond System

General description: This is an oligotrophic, topogenous/groundwater influenced system with significant seasonal and annual vertical water level fluctuations. This shallow water aquatic system occurs in closed basins (without inlets or outlets) in sand plain settings characterized by outwash, ice-contact, or other glacio-fluvial deposits. Soils are deep muck over sand or gravelly sand (Sperduto 2011). Examples of bog pond systems in closed basins are without widely fluctuating seasonal and annual water levels.

Sand plain basins in New Hampshire are generally less than 6 ha and occur singly or as two or more separate basins in close proximity that may be hydrologically connected, either by groundwater or intermittent surface flow. See Sperduto (2011) and Sperduto and Nichols (2011) for a description of the adjacent sand plain basin marsh system and related marsh and shrub dominated natural communities. Aquatic species are restricted to semipermanently flooded to intermittently exposed zones lacking wave and ice action in shallow sand plain basins. When the water table drops below the surface during dry years or late in the growing season, exposed sediments usually remain saturated. More surveys are needed to determine if some basins support permanently flooded ponded areas. In examples elsewhere in the Northeast, water is typically acidic, darkly stained, and with low transparency.

Vegetation: Rare plant species that occur in coastal plain ponds in New Hampshire include sharp-flowered mannagrass (*Glyceria acutiflora*)* and ovoid spikesedge (*Eleocharis ovata*)*.

One aquatic bed community type is described in New Hampshire:

Spikesedge - floating-leaved aquatic mudflat marsh (G3G5, S1; NatureServe crosswalk = spikerush sandy pondshore): Floating-leaved aquatic vegetation may be moderate to dense and includes bullhead pond-lily (*Nuphar variegata*), snail-seed pondweed (*Potamogeton bicupulatus*), and Oakes' pondweed (*P. oakesianus*). Other aquatics include low water-milfoil (*Myriophyllum humile*) and floating bladderwort (*Utricularia radiata*). When shallow water areas draw down, short rhizomatous species and mudflat annuals emerge along with aerenchymatous species and “stranded” floating-leaved and submerged aquatics. Perennial, short rhizomatous species include yellow spikesedge (*Eleocharis flavescens* var. *olivacea*), common spikesedge (*E. palustris*), needle spikesedge (*E. acicularis*), brown-fruited rush (*Juncus pelocarpus*), Torrey's bulrush (*Schoenoplectus torreyi*), northern St. John's-wort (*Hypericum boreale*), golden hedge-hyssop (*Gratiola aurea*), and false water-pepper smartweed (*Persicaria hydropiperoides*). The floating-stemmed graminoid northern mannagrass (*Glyceria borealis*) is occasional. Characteristic and frequent mudflat annuals include blunt spikesedge (*Eleocharis obtusa*) and Smith's bulrush (*Schoenoplectus smithii* var. *setosus*). Tuckermann's panicgrass (*Panicum tuckermannii*), purple-stemmed beggar-ticks (*Bidens connata*), small beggar-ticks (*B. discoidea*), seven-angled pipewort (*Eriocaulon aquaticum*), American bur-reed (*Sparganium americanum*), and American burnweed (*Erechtites hieraciifolius*) are occasional.

Wildlife: Characteristic fish in larger examples in the region include banded sunfish (*Enneacanthus obesus*), swamp darter (*Etheostoma fusiforme*), chain pickerel (*Esox niger*), and redfin pickerel (*E. americanus americanus*) (Edinger et al. 2014; M. Carpenter, pers. comm.).

State distribution: This system has only been documented in the lower Merrimack River Valley region.

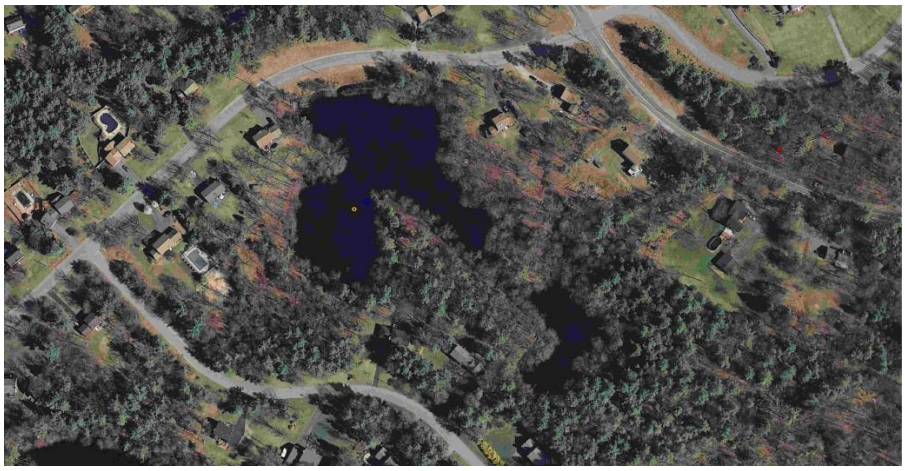
NatureServe Ecological System Crosswalk: Northern Atlantic Coastal Plain Pond. This pond system generally occurs from the Delmarva Peninsula to Cape Cod, with scattered occurrences to southern New Hampshire and Maine; disjunct occurrences in Nova Scotia, Lake Michigan, and Vermont (NatureServe 2015).

System Rank: G3G4, S1 (draft S-Rank). Most examples of this rare system type have been impacted by development, altered hydrology and water quality, and recreational use.

Sources: Sperduto 2011; Sperduto and Nichols 2011; NH NHB field surveys; Edinger et al. 2014; NatureServe 2015.

Examples: Examples are Rocky Hill Pond, Litchfield and Hollis Depot Basins, Hollis.

Coastal plain pond system at Rocky Hill Pond, Litchfield, NH (Source: NH NHB).



Rocky Hill Pond, Litchfield, NH (Source: New Hampshire GRANIT 2010).

7. Bog Pond System

General description: This system occurs in shallow, typically wind-protected and stagnant basins with mucky peat bottom sediments and closely associated bog or poor fen vegetation fringing the pond margin. False bottoms, composed of suspended organic particles appearing as an actual bottom at a depth between 0.3–0.9 m, are common features in these ponds (Edinger et al. 2014; Hunt 1999). Bog ponds are dystrophic and characterized by low conductivity and brown, murky, naturally acidic water (pH <5.4) from high concentrations of humus material (Edinger et al. 2014). Plant nutrients are low, especially calcium, limiting bacterial decomposition of organic matter and increasing peat and muck accumulation; alkalinity is usually <15 mg/l calcium carbonate (Langdon et al. 1998). Bog ponds are typically unstratified during the summer months, often occur in kettle holes or other isolated to poorly drained basins, underlain by non-calcareous bedrock or glacial till, and usually fringed by a floating mat.

Vegetation: Species diversity is low for phytoplankton and macrophytes (Edinger et al. 2014; Hunt 1999).

One aquatic bed community type may be described in New Hampshire:

Bog pond aquatic bed (G-, S3 [draft S-Rank]; NatureServe crosswalk = unknown): Aquatic plant species diversity is low and includes water-shield (*Brasenia schreberi*), bullhead pond-lily (*Nuphar variegata*), white water-lily (*Nymphaea odorata*), pondweeds (*Potamogeton* spp.), and bladderworts (*Utricularia vulgaris* ssp. *macrorhiza* and other species). Aquatic peat mosses (*Sphagnum* spp.) are common along the edge of the outer floating peat mat. In dystrophic ponds in nearby states, other aquatic species include northern mannagrass (*Glyceria borealis*), spiny-spored quillwort (*Isoetes echinospora* ssp. *muricata*), snail-seed pondweed (*Potamogeton bicupulatus*), alga-like pondweed (*P. confervoides*), ribbon-leaved pondweed (*P. epihydrus*), Oakes' pondweed (*P. oakesianus*), and mixed bladderwort (*Utricularia geminiscapa*) (Hunt 2003; Langdon et al. 1998).

Wildlife: Species diversity is low for all types of aquatic organisms including zooplankton, zoobenthos, and fish (Edinger et al. 2014; Hunt 1999). Fish when present, often include brown bullhead (*Ameiurus nebulosus*), a species tolerant of extreme environmental conditions and able to survive long term in dystrophic ponds (Langdon et al. 1998). Dystrophic ponds also sometimes support golden shiner (*Notemigonus crysoleucas*) and stocked species such as brown trout (*Salmo trutta*). Bog ponds, typically with shallow water depths, are susceptible to fish winterkill.

Other characteristic animal species in bog ponds in the region include zooplankton such as rotifers (*Keratella* spp. and *Brachionus* spp.), copepods, phantom midges (*Chaoborus* spp.), and other invertebrates such as acid-tolerant odonates (*Cordulia* spp., *Leucorrhinia* spp., *Aeshna* spp., and *Ischnura* spp.), water beetles (Family Dyticidae), midges (*Tribelos* spp., *Phaenopsectra* spp., *Chironomus* spp., and *Zalutschia* spp.), mayflies (Order Ephemeroptera), true bugs (Family Notonectidae), caddisflies (Order Trichoptera), beetles (Order Coleoptera), water strider (*Gerris* spp.), true water bugs (Family Corixidae),

amphipods (e.g., *Hyalella azteca*), crayfish (Order Decapoda), and bivalves (*Musculium* spp.) (Edinger et al. 2014; Hunt 2003; Langdon et al. 1998).

State distribution: Scattered throughout the state but concentrated in the central and southern portions of the state where kettle holes are more abundant.

NatureServe Ecological System Crosswalk: Unknown.

System Rank: G4, S3 (draft S-Rank).

Sources: Sperduto 2011; Sperduto and Nichols 2011; NH NHB field surveys; Edinger et al. 2014; Hunt 1999; Hunt 2003; Langdon et al. 1998.

Examples: An example of a bog pond system is Heath Pond Bog in Ossipee and Effingham.

Heath Pond Bog, Ossipee and Effingham, NH (Source: NH NHB; New Hampshire GRANIT 2010).

8. Oligotrophic Pond System

General description: This system occurs in small, shallow, acidic, nutrient-poor, clear water ponds. Bottom sediments are sand, gravel, and/or rock with an organic layer of variable depth (when present). Shallow pond depths disrupt stratification during the summer months; they stratify when ice-covered during the winter (winter-stratified monomictic). Edinger et al. (2014) provide the following description for characteristic features: clear blue or green water with high transparency (Secchi disk depths of 4–8 m); water low in plant nutrients (especially nitrogen and calcium); low primary productivity (inorganic carbon fixed = 7–25 g/m^2/yr); and low alkalinity (<12.5 mg/l calcium carbonate).

The typical oligotrophic pond system has inlets and/or outlets and does not occur in kettle holes or alpine/subalpine setting. Two variants may be recognized:

i. ***Tarn pond***: This variant includes all high elevation ponds in alpine and subalpine settings (generally above 1000 m elevation) including those more characteristically formed when water fills the base of a cirque (typically three-sided, concave valley head excavated by a glacier) where a barrier, such as bedrock, till, or moraine sediments, form a natural dam at the outlet. Tarn ponds are highly acidic, usually clear watered, relatively cold, and shallow to moderately deep. These ponds remain frozen for extended periods and are prone to fish winterkill.

ii. ***Clear water kettle hole pond***: Oligotrophic ponds in kettle holes or other small isolated basins (lack inlets and outlets) with clear water and without a fringing peatland (compare to dystrophic bog ponds). They receive water through precipitation, groundwater, and limited runoff from small watersheds. Retention times are relatively long due to lack of surface outlets; water is lost from evaporation and groundwater recharge.

Vegetation: Aquatic plant cover and species diversity are low and characterized by rosette-leaved aquatics and acidic tolerant species assemblages. Rare plant species that occur in oligotrophic ponds in New Hampshire include lake quillwort (*Isoetes lacustris*)*, comb-leaved mermaid-weed (*Proserpinaca pectinata*)*, and resupinate bladderwort (*Utricularia resupinata*)*. Small waterwort (*Elatine minima*), listed as state indeterminate in New Hampshire, occurs in similar soft water ponds elsewhere (Curtis 1959).

Phytoplankton in oligotrophic ponds in the region is diverse and includes diatoms (*Asterionella* spp. and *Tabellaria* spp.), dinoflagellates (*Ceratium* spp.), and desmids (Hunt 2003).

Five aquatic bed communities may be distinguished in New Hampshire:

A. Communities associated with the typical expression:

Oligotrophic pondweed cove (G-, S2; NatureServe crosswalk = unknown): This community occurs in protected coves and has a much higher percent cover of vegetation, particularly of floating-leaved aquatics more sensitive to wave disturbance along exposed shores, and possibly edaphically with a deeper

organic layer when present, compared to the **water lobelia aquatic sandy pond shore**. The **oligotrophic pondweed cove** is characterized primarily by floating-leaved aquatics including ribbon-leaved pondweed (*Potamogeton epihydrus*), floating pondweed (*P. natans*), little floating-heart (*Nymphoides cordata*), white water-lily (*Nymphaea odorata*), and water-shield (*Brasenia schreberi*; Hunt (2003) notes this species may be more common in oligotrophic ponds compared to eutrophic ponds). Other pondweeds may include Robbins' pondweed (*P. robbinsii*), grassy pondweed (*P. gramineus*), and clasping-leaved pondweed (*P. perfoliatus*) (Edinger et al. 2014). Seven-angled pipewort (*Eriocaulon aquaticum*), water lobelia (*Lobelia dortmanna*), and quillworts (*Isoetes* spp.) may occur but in lower cover than found in the **water lobelia aquatic sandy pond shore**. Emergent plant species can occur in low cover in shallower water including pickerelweed (*Pontederia cordata*) and American bur-reed (*Sparganium americanum*).

Water lobelia aquatic sandy pond shore (GNR, S2; NatureServe crosswalk = pipewort sandy pondshore and spikerush sandy pondshore): This aquatic shoreline community has a permanently inundated to intermittently exposed flood regime and is subjected to regular wave and ice disturbance. The bottom is sand to gravelly sand; if an organic layer is present at the substrate surface, it is usually thin peaty muck. Most examples are characterized by a low percent cover of aquatic, rosette-forming, stress-tolerant species (including "Isoetids"). Typical species include seven-angled pipewort (*Eriocaulon aquaticum*; sparse to abundant), water lobelia (*Lobelia dortmanna*), quillworts (*Isoetes tuckermanii*, *I. lacustris**, *I. echinospora* ssp. *muricata*, and others), three-square bulrush (*Schoenoplectus pungens*), creeping bladderwort (*Utricularia gibba*), and submersed aquatic forms of grass-leaved arrowhead (*Sagittaria graminea*), golden hedge-hyssop (*Gratiola aurea*), brown-fruited rush (*Juncus pelocarpus*), needle spikesedge (*Eleocharis acicularis*), and American bur-reed (*Sparganium americanum*). Floating-leaved and submersed species are absent or low in cover. This community is similar floristically to the **bayonet rush emergent marsh/aquatic bed**, primarily differing structurally by being dominated by vegetation of low height, possibly edaphically with a thinner organic layer when present, and hydrologically with intermittently to permanently flooded conditions.

In nearby states, acidic oligotrophic pond indicators are mixed bladderwort (*Utricularia geminiscapa*), water bulrush (*Schoenoplectus subterminalis*), alga-like pondweed (*Potamogeton confervoides*), and peat mosses (*Sphagnum* spp.) (Hunt 2003).

Bayonet rush emergent marsh/aquatic bed (GNR, S2; NatureServe crosswalk = bayonet rush pondshore): This shallow water shoreline community is transitional between aquatic bed and emergent marsh. The sandy bottom often has an organic peaty muck layer at the substrate surface. Bayonet rush (*Juncus militaris*) is dominant; three-square bulrush (*Schoenoplectus pungens*) is a common associate (subdominant in some examples). Other common species include pickerelweed (*Pontederia cordata*), little floating-heart (*Nymphoides cordata*), water lobelia (*Lobelia dortmanna*), water-shield (*Brasenia schreberi*), bladderworts (such as *Utricularia purpurea* and *U. resupinata*), water-milfoils (such as *Myriophyllum tenellum* and *M. alterniflorum*), bur-reeds (*Sparganium* spp.), and northern mannagrass (*Glyceria borealis*). Species nearest the shoreline where the water may draw down later in the summer include golden hedge-hyssop (*Gratiola aurea*), swamp yellow-loosestrife (*Lysimachia terrestris*), false water-pepper smartweed (*Persicaria hydropiperoides*), Virginia marsh-St. John's-wort (*Triadenum*

virginicum), seven-angled pipewort (*Eriocaulon aquaticum*), three-way sedge (*Dulichium arundinaceum*), spikesedges (*Eleocharis* spp.), brown-fruited rush (*Juncus pelocarpus*), and redtop-panicgrass (*Coleataenia longifolia*). This community is similar floristically to the **water lobelia aquatic sandy pond shore**, primarily differing structurally by being dominated by a tall graminoid, possibly edaphically with a deeper organic layer when present, and hydrologically with semipermanently to intermittently flooded conditions.

B. Communities associated with tarn ponds:

Tarn pond aquatic bed (G-, S1 [draft S-Rank]; NatureServe crosswalk = unknown): Aquatic vegetation is absent to sparse and can include little floating-heart (*Nymphoides cordata*), bullhead pond-lily (*Nuphar variegata*), slender water-milfoil (*Myriophyllum tenellum*), alga-like pondweed (*Potamogeton confervoides*), and mixed bladderwort (*Utricularia geminiscapa*) (Edinger et al. 2014; Hunt 2003; Langdon et al. 1998).

C. Communities associated with clear water kettle hole ponds:

Acidic water-lily aquatic bed (G-, S3 [draft S-Rank]; NatureServe crosswalk = unknown): Aquatic plant species diversity is low and includes water-shield (*Brasenia schreberi*), bullhead pond-lily (*Nuphar variegata*), white water-lily (*Nymphaea odorata*), pondweeds (*Potamogeton* spp.), and bladderworts (*Utricularia vulgaris* ssp. *macrorhiza* and other species).

Wildlife: Fish diversity is typically low, fish assemblages usually poorly developed, and ponds may support either cold- or warmwater species, depending upon summer temperatures (Edinger et al. 2014). Clear water kettle hole ponds may have even lower fish diversity due to their landlocked settings.

Tarn ponds may support highly tolerant species such as brown bullhead (*Ameiurus nebulosus*) and golden shiner (*Notemigonus crysoleucas*); stocked fish reportedly do not persevere. It is assumed to be difficult to distinguish pre-settlement fish assemblages (with little or no fish) from effects of acid rain, which likely reduced fish diversity and abundance (Hunt 2003). Lake trout (*Salvelinus namaycush*) may be a characteristic fish in some tarn ponds. Many tarn ponds are historically fishless and remain so due to their remoteness and chemical and physical nature; fishless examples may support aquatic organisms that are suppressed or extirpated in ponds with fish communities (New York State Department of Environmental Conservation 1999).

Zooplankton in acidic ponds in the region is believed to be a low diversity assemblage compared to corresponding oligotrophic lake assemblage (Hunt 2003) and includes rotifers (*Keratella* spp.) and various crustacean larvae. Macroinvertebrates include pea clams (*Pisidium* spp.) and other bivalves, crayfish (Order Decapoda), amphipods (Order Amphipoda), diving beetles (Family Dytiscidae), beetles (Order Coleoptera), water boatman (Family Corixidae), mayflies (Order Ephemeroptera), true bugs (Family Notonectidae), caddisflies (Order Trichoptera), water strider (*Gerris* spp.), midges (*Heterotrissocladius* spp., *Phaenopsectra* spp., *Procladious* spp., and *Tribelos* spp.), alderflies (*Sialis* spp.), and acid-tolerant odonates (*Aeshna* spp., *Ischnura* spp., *Cordulia shurtleffii*, and *Leccorrhinia* spp.) (Edinger et al. 2014; Hunt 2003; Langdon et al. 1998).

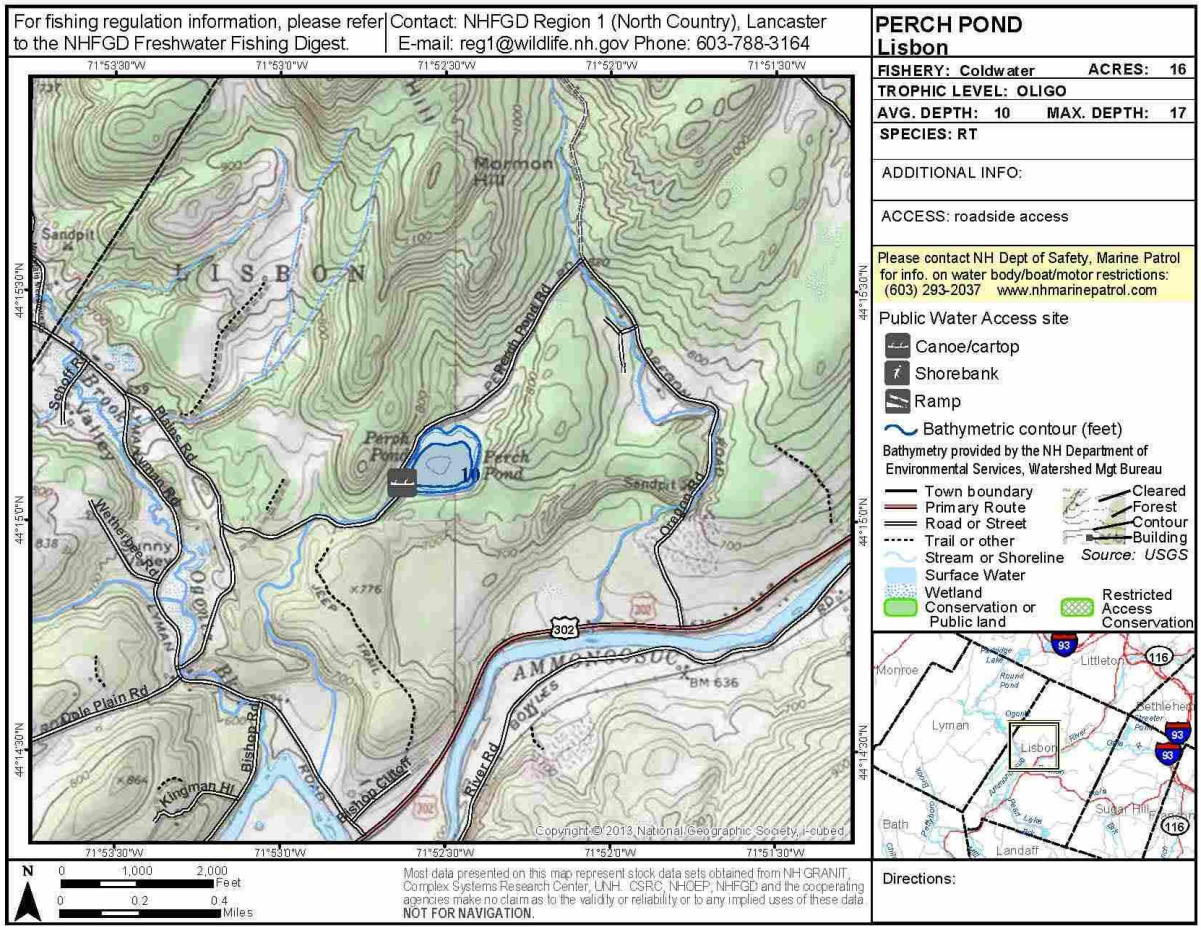
State distribution: The typical expression of the oligotrophic pond system occurs throughout the state, often higher in watersheds and at higher elevations. Tarn ponds occur in alpine and subalpine habitats. Clear water kettle hole ponds are broadly distributed in New Hampshire, but concentrated in the central and southern portions of the state where kettle holes are more abundant.

NatureServe Ecological System Crosswalk: Unknown.

System Rank: G4; S4 for typical oligotrophic pond system; S1 for tarn pond; S2 for clear water kettle hole pond (draft S-Ranks).

Sources: Sperduto and Nichols 2011; Sperduto 1994; Sperduto 2000; Sperduto 2011; NH NHB field surveys; Edinger et al. 2014; Hunt 1999; Hunt 2003; Langdon et al. 1998; New York State Department of Environmental Conservation 1999.

Examples: An example of the typical oligotrophic pond system is Perch Pond in Lisbon (NH DES 2007). Spaulding Lake on Mt. Clay, Star Lake on Mt. Quincy Adams, Lake of the Clouds between Mt. Monroe and Mt. Washington, Hermit Lake in Tuckerman Ravine, and Lonesome Lake on Cannon Mt. may be good examples of tarn ponds. A possible example of the clear water kettle hole pond is Blue Pond in Madison.



Oligotrophic pond at Perch Pond in Lisbon, NH (Source: New Hampshire Fish & Game 2014a).

Tarn pond at Star Lake between Mt. Quincy Adams and Mt. Madison in Thompson & Meserve, NH (Source: NH NHB).

9. Eutrophic Pond System

General description: This system occurs in small, shallow, nutrient-rich ponds with mucky bottom sediments and water usually green with algae. Shallow pond depths disrupt stratification during the summer months; they stratify when ice-covered during the winter (winter-stratified monomictic). Edinger et al. (2014) provide the following description for characteristic features: murky water with low transparency (Secchi disk depths typically <4 m); water rich in plant nutrients (especially high in phosphorus, nitrogen, and calcium); high primary productivity (inorganic carbon fixed = 75–250 g/m^2/yr); weedy shoreline; and alkalinity typically high (>12.5 mg/l calcium carbonate).

Vegetation: Aquatic plant cover and diversity are high. Rosette-leaved aquatics are absent or in low abundance. These pond systems are especially prone to invasive species such as variable-leaved water-milfoil (*Myriophyllum heterophyllum*), Eurasian water-milfoil (*M. spicatum*), brittle waternymph (*Najas minor*), curly pondweed (*Potamogeton crispus*), and water-chestnut (*Trapa natans*). Rare plant species that occur in eutrophic ponds in New Hampshire include ivy-leaved duckweed (*Lemna trisulca*)*, pale duckweed (*L. valdiviana*)*, Richardson's pondweed (*Potamogeton richardsonii*)*, and flat-stem pondweed (*P. zosteriformis*)*.

Characteristic phytoplankton in eutrophic ponds in the region includes golden algae (*Chrysosphaerella longispina*) and dinoflagellates (*Ceratium* spp.) (Hunt 2003).

Three aquatic bed community types may be distinguished in New Hampshire:

Water-lily aquatic bed (G4G5, S4; NatureServe crosswalk = water-lily aquatic wetland): This shallow water community is dominated by rooted, floating-leaved aquatic vegetation with moderate to high cover and diversity (although species diversity was found to by highest in mesotrophic lakes in New York; Edinger et al. 2014). Emergent species are absent or relatively low in cover (see **pickerelweed - arrow-arum - arrowhead emergent marsh** description). Free-floating and submerged plant species are typically present. The **water-lily aquatic bed** (or closely related types) occurs in eutrophic lakes and ponds, oxbow ponds, backwater sloughs, and fluvial ponds. Dominant species include white water-lily (*Nymphaea odorata*) and/or bullhead pond-lily (*Nuphar variegata*). Common associates are water-shield (*Brasenia schreberi*; Hunt (2003) notes this species may be more common in oligotrophic ponds compared to eutrophic ponds), pondweeds (*Potamogeton* spp.), tape-grass (*Vallisneria americana*), duckweeds (*Lemna* spp.), common duck-meal (*Spirodela polyrrhiza*), water-meals (*Wolffia* spp.), common hornwort (*Ceratophyllum demersum*), common waterweed (*Elodea canadensis*), bladderworts (*Utricularia* spp.), grass-leaved mud-plantain (*Heteranthera dubia*)*, wavy waternymphs (*Najas* spp.), and bur-reeds (*Sparganium* spp.).

Pondweed - hornwort - waterweed cove (G-, S4; NatureServe crosswalk = pondweed - hornwort - waterweed aquatic vegetation): Occurring in shallow coves and other sheltered areas, this aquatic bed community is most well developed in eutrophic settings in water less than 2 m deep. Submerged aquatic cover is usually ≥25%; emergent species and/or floating-leaved aquatic cover is usually <25%. This community may be characterized by a mix of species or dominated by just a few including the following

(NatureServe 2015; Hunt 2003): pondweeds (e.g., *Potamogeton epihydrus*, *P. bicupulatus*, *P. natans*, *P. zosteriformis**, *P. amplifolius*, and *P. richardsonii**), common hornwort (*Ceratophyllum demersum*), waterweeds (*Elodea* spp.), and greater bladderwort (*Utricularia vulgaris* ssp. *macrorhiza*). Other associated species are bullhead pond-lily (*Nuphar variegata*), duckweeds (*Lemna* spp.), common duck-meal (*Spirodela polyrrhiza*), tape-grass (*Vallisneria americana*), and wavy waternymph (*Najas flexilis*). Rosette-leaved aquatics are absent or in low abundance.

Duckweed free-floating aquatic bed (G5, S4; NatureServe crosswalk = eastern North America duckweed pond): This community, characterized by free-floating aquatic species, is dominated by common duckweed (*Lemna minor*) and usually occurs in permanently to semipermanently flooded areas of small, eutrophic ponds. Common associates of duckweed include common duck-meal (*Spirodela polyrrhiza*), northern water-meal (*Wolffia borealis*), and Columbian water-meal (*Wolffia columbiana*). The free-floating, small-sized species comprising this community can also be found stranded on the exposed surfaces after drawdown. The highest vegetation cover usually occurs downwind against shorelines where this community can intermingle with rooted floating-leaved and emergent species. Community composition can change over short periods of time as influenced by wind, waves, and currents, although the community's habitat (upper few centimeters of water) is homogenous (NatureServe 2015). More enriched, eutrophic ponds can support a high plant cover.

Associated with the **water-lily aquatic bed** in shallower water immediately adjacent to the shoreline is the **pickerelweed - arrow-arum - arrowhead emergent marsh** (G5, S5; NatureServe crosswalk = northeastern leafy forb marsh). This community usually occurs on muck soils and is dominated by broad-leaved, aerenchymatous plants such as pickerelweed (*Pontederia cordata*), green arrow-arum (*Peltandra virginica*), and common arrowhead (*Sagittaria latifolia*). Other emergent species include bur-reeds (*Sparganium* spp.), broad-leaved cattail (*Typha latifolia*), common spikesedge (*Eleocharis palustris*), rushes (*Juncus* spp.), soft-stemmed bulrush (*Schoenoplectus tabernaemontani*), water bulrush (*S. subterminalis*), and three-way sedge (*Dulichium arundinaceum*). Floating-leaved aquatics that may be present include white water-lily (*Nymphaea odorata*), bullhead pond-lily (*Nuphar variegata*), pondweeds (*Potamogeton* spp.), and bladderworts (*Utricularia* spp.). The combination of species at a given location depends on factors such as water depth and amplitude of water level fluctuations.

Wildlife: Fish assemblages are usually warmwater including brown bullhead (*Ameiurus nebulosus*), northern pike (*Esox. lucius*), chain pickerel (*E. niger*), pumpkinseed (*Lepomis gibbosus*), large and smallmouth bass (*Micropterus salmoides* and *M. dolomieui*), golden shiner (*Notemigonus crysoleucas*), and yellow perch (*Perca flavescens*) (Edinger et al. 2014; New Hampshire Fish & Game 2014b; M. Carpenter, pers. comm.).

Macroinvertebrates in eutrophic ponds in the region include acid-intolerant odonates (*Aeshna* spp., *Ischnura* spp., *Gomphus* spp., and *Basiaeschna* spp.), sowbugs (Order Isopoda), mayflies (*Stenonema* spp.), amphipods (Order Amphipoda), leeches (Subclass Hirudinae), ramshorn snail (Family Planorbidae), and other snails (*Amnicola limosa* and Family Physidae) (Edinger et al. 2014; Hunt 2003;

Langdon et al. 1998). Zooplankton includes various crustacean larvae, cyclopoids, cladocerans, and rotifers (*Keratella* spp.).

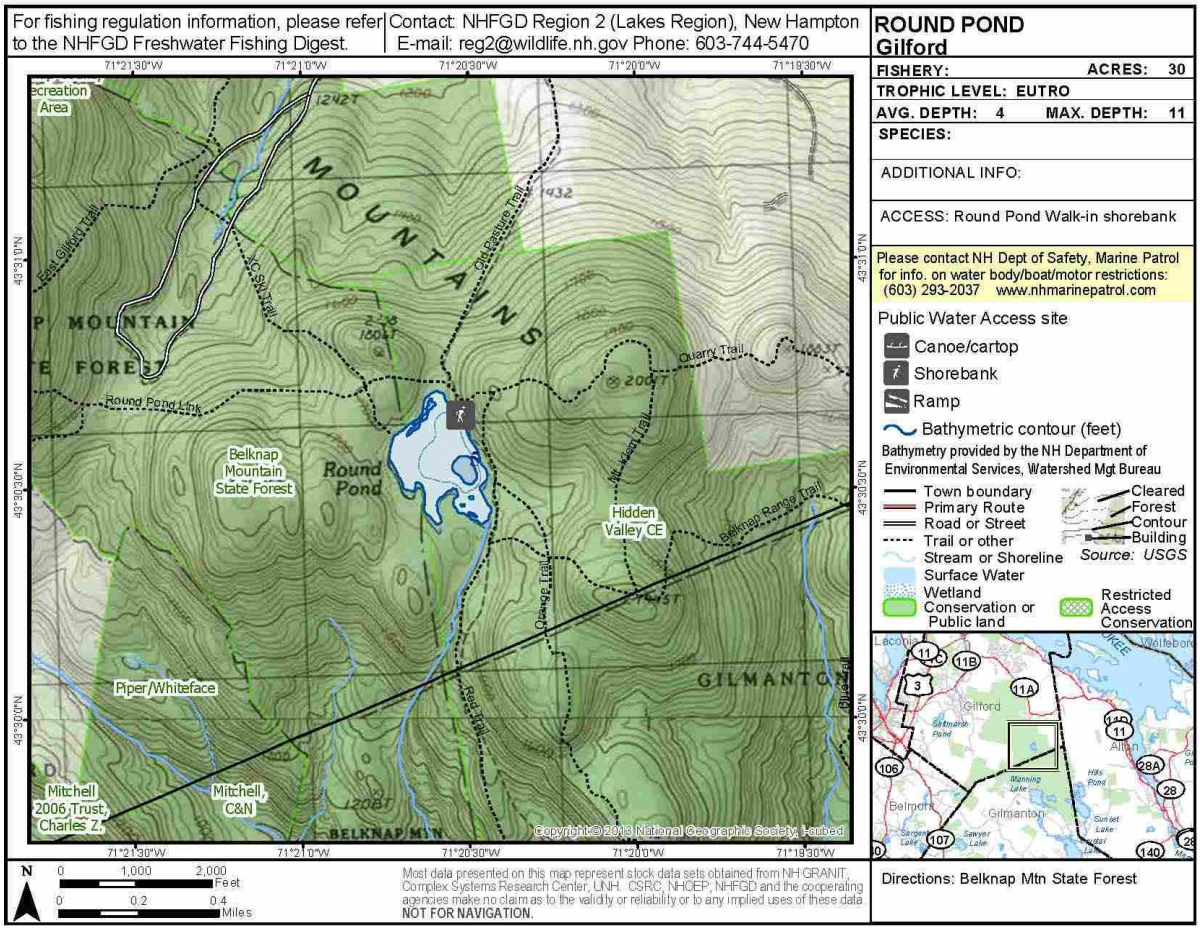
State distribution: This system occurs throughout the state, more common at low elevations.

NatureServe Ecological System Crosswalk: Unknown.

System Rank: G4, S4 (draft S-Rank).

Sources: Sperduto and Nichols 2011; NH NHB field surveys; Edinger et al. 2014; Hunt 1999; Hunt 2003; Langdon et al. 1998; NatureServe 2015.

Examples: A good example of a eutrophic pond system may be Round Pond in Gilford (NH DES 2007).



Round Pond in Gilford, NH (Source: New Hampshire Fish & Game 2014a).

10. Circumneutral Pond (Lake) System

General description: This broadly described meso- to eutrophic system supports a diversity of aquatic plant species including those restricted to relatively high pH and alkalinity (although lower than what is found in oligotrophic marl ponds). In circumneutral waterbodies in Maine, conductivity readings usually exceed 50 umho/cm.

Vegetation: Several rare or uncommon aquatic plant species may be found in this lake system type (see aquatic bed community description below). Species notably absent are water lobelia (*Lobelia dortmanna*), seven-angled pipewort (*Eriocaulon aquaticum*), water-shield (*Brasenia schreberi*), and pickerelweed (*Pontederia cordata*); white water-lily (*Nymphaea odorata*) and bullhead pond-lily (*Nuphar variegata*), when present, are low in cover (Maine Natural Areas Program 2013; NatureServe 2015). These lake systems are prone to invasive species such as Eurasian water-milfoil (*Myriophyllum spicatum*), variable-leaved water-milfoil (*M. heterophyllum*), and curly pondweed (*Potamogeton crispus*).

One aquatic bed community type may be described in New Hampshire:

Circumneutral aquatic bed (GNR, S1S2; NatureServe crosswalk = Canadian waterweed - pondweed species eastern herbaceous vegetation): Typically occurs in quiet shallow water 0.5–2 m deep. Indicator species for waterbodies with relatively high pH and alkalinity include reddish pondweed (*Potamogeton alpinus*)*, alga-like pondweed (*P. confervoides*), leafy pondweed (*P. foliosus*)*, budding pondweed (*P. gemmiparus*)*, long-leaved pondweed (*P. nodosus*)*, blunt-leaved pondweed (*P. obtusifolius*)*, white-stemmed pondweed (*P. praelongus*)*, Richardson's pondweed (*P. richardsonii*)*, Vasey's pondweed (*P. vaseyi*)*, flat-stem pondweed (*P. zosteriformis*)*, thread-leaved false pondweed (*Stuckenia filiformis*)*, Sago false pondweed (*S. pectinata*)*, grass-leaved mud-plantain (*Heteranthera dubia*)*, small-leaved pond-lily (*Nuphar microphylla*)*, northern arrowhead (*Sagittaria cuneata*)*, sessile-fruited arrowhead (*S. rigida*)*, Arctic bur-reed (*Sparganium natans*)*, Farwell's water-milfoil (*Myriophyllum farwellii*), northern water-milfoil (*M. sibiricum*), and whorled water-milfoil (*M. verticillatum*). Other species are common waterweed (*Elodea canadensis*), Beck's water-marigold (*Bidens beckii*)*, and tape-grass (*Vallisneria americana*), with white water-lily (*Nymphaea odorata*) and bullhead pond-lily (*Nuphar variegata*) low in cover (Maine Natural Areas Program 2013; NatureServe 2015).

Wildlife: Characteristic wildlife may be many of the same species found in more acidic waterbodies (Maine Natural Areas Program 2013).

State distribution: This rare system may be largely restricted to the southeastern part of the state, Connecticut River valley, and North Country in watersheds underlain by bedrock supplying relatively high concentrations of calcium and other base cations.

NatureServe Ecological System Crosswalk: Unknown.

System Rank: G-, S1S2 (draft S-Rank).

Sources: Sperduto and Nichols 2011; NH NHB field surveys; Hellquist 1980; Maine Natural Areas Program 2013; NatureServe 2015.

Examples: None currently formally identified.

11. Marl Pond System

General description: These spring-fed ponds have high concentrations of dissolved calcium, resulting in calcium carbonate precipitation at certain water temperatures and pH and leading to the formation over time of white marl bottom sediments (calcium carbonate mixed with clay). Non-vascular aquatic plant species may also play an important role in lacustrine $CaCO_3$ sedimentation (Pelechaty et al. 2013). Marl ponds are usually oligotrophic, with clear water and white bottoms. The high pH in the pond makes phosphorous and other nutrients unavailable to plant or microbial life. As a result, aquatic vegetation is sparse or absent. They usually occur in areas underlain by carbonate-rich bedrock.

The marl at the bottom of Lime Pond in Columbia, currently the only known occurrence of this system type in the state, was up to 4.5 meters thick in places (Hitchcock 1878) before much of the lime was mined by the early 20th century. Lime Pond is underlain by non-calcareous phyllite and schist of the Frontenac Formation, however, a calcareous member of the Frontenac Formation underlies part of the watershed east of the pond (S. Bailey, pers. comm.; Lyons et al. 1997). Bailey notes "The chemical conditions of Lime Pond are either due to unmapped/unexposed calcareous rocks under the pond, or, more likely, due to stream and groundwater inputs from portions of the watershed underlain by calcareous rocks" and that marl remains on the bottom and likely continues to form.

Measures of water chemistry taken from Lime Pond in 1972 include a pH of 7.9 and alkalinity of 52.5 mg/l (B. Hellquist, pers. comm.). Water depth reaches over 4 meters; historically, water levels were lowered in the pond to extract marl for making lime. Nearby, Fish Pond is directly underlain by the calcareous member of the Frontenac Formation and past studies at Lombard Pond recorded an alkalinity measure of 67.0 mg/l (B. Hellquist, pers. comm.) but there is no mention of these ponds having marl in geology documents or local histories (S. Bailey, pers. comm.).

Vegetation: Marl ponds have very low primary productivity and sparse growth of aquatic macrophytes. Rare plant species occurring in the only known marl pond in New Hampshire are noted with an asterisk (*) in the description below.

One aquatic bed community type may be described in New Hampshire:

Marl pond aquatic bed (G-, S1 [draft S-Rank]; NatureServe crosswalk = unknown): Aquatic vegetation documented from Lime Pond is characterized by species largely restricted to circumneutral and basic water including northern arrowhead (*Sagittaria cuneata*)*, blunt-leaved pondweed (*Potamogeton obtusifolius*)*, and peat moss (*Sphagnum contortum*)*.

In marl lakes and ponds in the region (Edinger et al. 2014), other aquatic species are thread-leaved false pondweed (*Stuckenia filiformis*), Sago false pondweed (*S. pectinata*), white water crowfoot (*Ranunculus aquatilis* var. *diffusus*), muskgrass (*Chara* spp.), and other macroalgae (Edinger et al. 2014; Hunt 2003). Certain diatoms can be abundant in marl lakes; characteristic plankton include calciphilic desmids, the cladoceran *Holopedium*, and calciphilic species of the rotifer *Brachionus* (Edinger et al. 2014).

Wildlife: The marl bottom of Lime Pond was once described as being covered by snail shells (*Planorbis* spp.) and other mollusk (Jackson 1844).

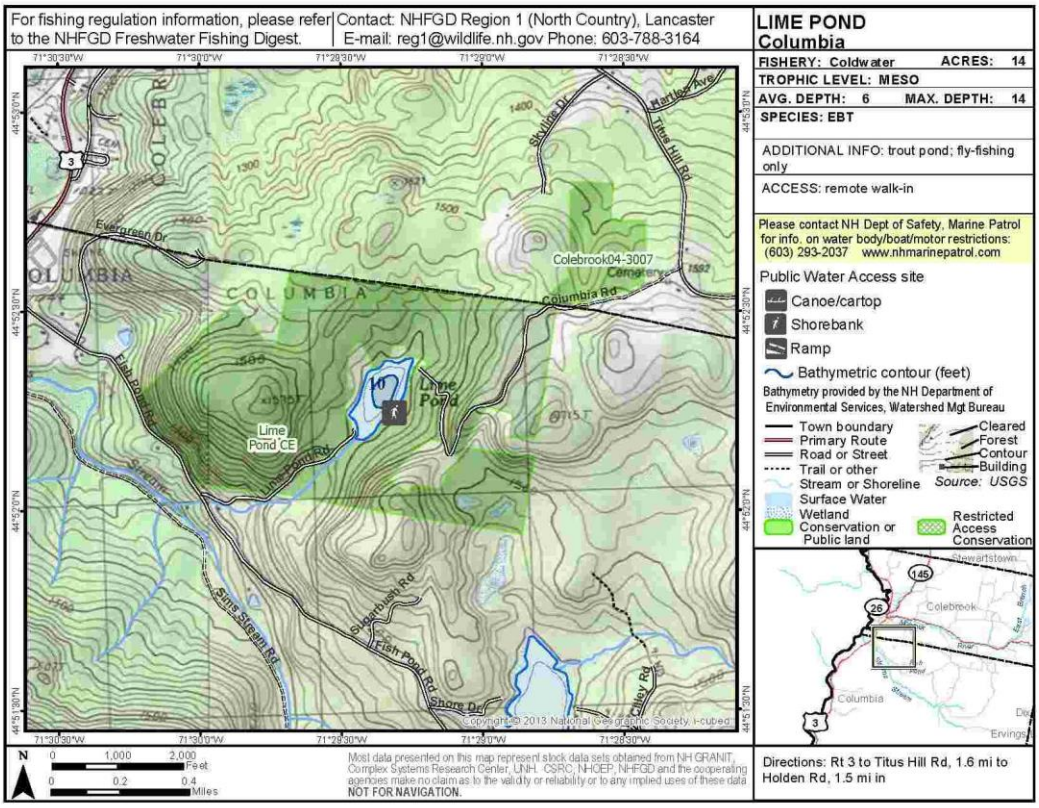
State distribution: Restricted to areas in the North Country near the Connecticut River underlain by or proximate to carbonate-bearing bedrock.

NatureServe Ecological System Crosswalk: Unknown.

System Rank: G3G4, S1 (draft S-Rank).

Sources: NH NHB field surveys; Edinger et al. 2014; Fogg 1874; Jackson 1844; Parker 2005; Pelechaty et al. 2013.

Examples: This system is currently only known from Lime Pond in Columbia.



Marl Pond System at Lime Pond, Columbia, NH (Source: New Hampshire Fish & Game 2014a).

12. Oxbow Pond System

General description: This system occurs in oxbows – small, shallow, typically eutrophic river meanders isolated from the river's main stem by levees. Oxbows are most often associated with third order streams or higher (floodplains of larger streams and rivers). Backwater sloughs, shallow, quiet to stagnant riverine embayments and old meanders isolated from main stem by an upstream levee, could also be treated here due to their physical, hydrological, and biological resemblance to oxbow ponds. For oxbows, periodic river floods over the levee banks replenish river water and biota to this lacustrine system. Overall, oxbow ponds have relatively low flushing rates and are fairly stagnant. Many oxbow ponds are relatively short-lived, shifting into either backwater sloughs or part of the river's main stem when levees are breached. Soils in these quite water settings are silts and mucks.

Geographic variants in the region are known based on differences in vascular plants, fishes, mollusks, and insects (NYNHP 2013a). New York also recognizes three morphological types: "1) classical oxbow lakes formed from old river channels, 2) small levee lakes formed as pools from levee overwash, and 3) floodplain lakes formed and replenished during high annual water of the associated river." Presence and character of these variants should be evaluated in New Hampshire for future consideration in this classification.

Vegetation: Rare plant species that occur in oxbow ponds in New Hampshire include grass-leaved mud-plantain (*Heteranthera dubia*)* and pygmy-weed (*Crassula aquatica*)*.

One aquatic bed community type may be described in New Hampshire:

Oxbow pond aquatic bed (G-, S2S3 [draft S-Rank]; NatureServe crosswalk = unknown):
This shallow water community is characterized by aquatic vegetation and emergent species. The **water-lily aquatic bed** (or closely related types) occurs in eutrophic lakes and ponds, oxbow ponds, backwater sloughs, and fluvial ponds. Species include white water-lily (*Nymphaea odorata*), bullhead pond-lily (*Nuphar variegata*), water-shield (*Brasenia schreberi*), pondweeds (*Potamogeton* spp.), duckweeds (*Lemna* spp.), common duck-meal (*Spirodela polyrrhiza*), water-meals (*Wolffia* spp.), common hornwort (*Ceratophyllum demersum*), common waterweed (*Elodea canadensis*), bladderworts (*Utricularia* spp.), and water-milfoils (*Myriophyllum* spp.). Because other biota in this system are usually characterized by riverine species (Edinger et al. 2014), this aquatic bed community is considered separately from the floristically similar **water-lily aquatic bed**.

Wildlife: In examples elsewhere in our region, characteristic biota vary from riverine to mixed riverine-lacustrine species assemblages, depending on frequency of levee flooding events (Edinger et al. 2014; Hunt 2003).

For backwater sloughs nearby in the region, a habitat with a similar physical, hydrological, and biological resemblance to oxbow ponds, characteristic fish are brown bullhead (*Ameiurus nebulosus*), chain pickerel

(*Esox niger*), pumpkinseed (*Lepomis gibbosus*), and golden shiner (*Notemigonus crysoleucas*) (NYNHP 2013b). Characteristic macroinvertebrates in these backwater sloughs are odonates (Order Odonata), stoneflies (*Plecoptera*), water beetles (Family Dytiscidae), mosquitoes (Family Culicidae), true flies (*Tipula* spp., *Atherix* spp., and *Simulum* spp.), midges (Family Chironomidae), mayflies (*Stenonema* spp.), crustaceans (*Hyalella* spp.), and clams (*Pisdium* spp.).

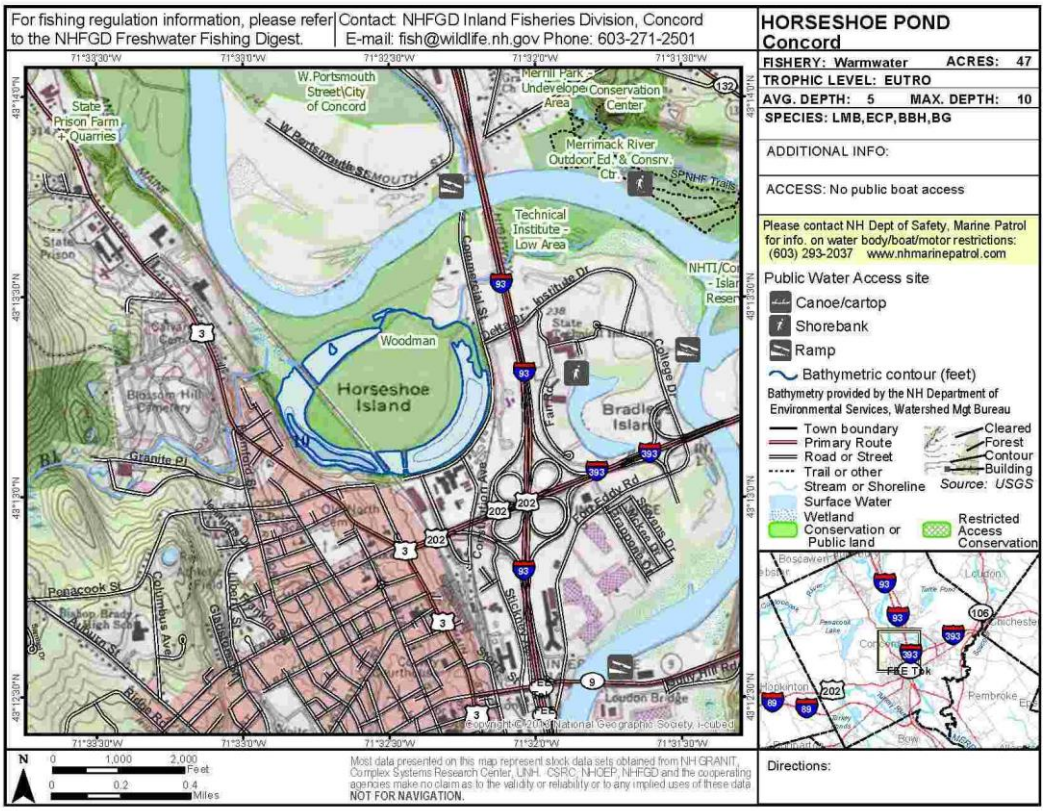
State distribution: The oxbow pond system is scattered throughout much of the state, most often at low elevations.

NatureServe Ecological System Crosswalk: Unknown.

System Rank: G4, S2S3 (draft S-Rank). The number of occurrences of this pond system and the condition of many of the remaining extant examples has declined in the state as a result of hydrologic alterations and floodplain conversion to agricultural lands and other land uses.

Sources: Sperduto 2011; Sperduto and Nichols 2011; NH NHB field surveys; Edinger et al. 2014; Hunt 1999.

Examples: Good examples occur along the Blackwater River in Webster and Lamprey River (at Camp Hedding) in Epping. A degraded example is Horseshoe Pond in Concord.



Horseshoe Pond in Concord, NH (Source: New Hampshire Fish & Game 2014a).

Horseshoe Pond in Concord, NH (Source: NH NHB).

13. Fluvial Pond System

General description: This system occurs in impoundments behind beaver dams along low order streams (mainly first to third order). They have a relatively high flushing rate. Formation of ponds by beaver dam construction significantly alters environmental conditions from those associated with streams. Some of these changes include increased channel width and depth; reduced current velocity and increased sediment trapping; a shift from running-water biota to pond species; increased nutrient availability, plankton productivity, and cover and diversity of aquatic bed vegetation; and increased aerobic respiration (Gurnell 1998; Hammerson 1994). Beavers may inhabit a pond for 10–20 years but once abandoned, a pond can persist for decades (Wessels 1997).

Vegetation: The aquatic bed community in fluvial ponds in New Hampshire is similar to the **water-lily aquatic bed** found in eutrophic ponds and lakes in the state. Common mare's-tail (*Hippuris vulgaris*)*, a rare aquatic species preferring non-acidic waters, occurs in northern New Hampshire in shallow drawn-down ponds behind abandoned beaver dams. In the southeast corner of the state, the rare American featherfoil (*Hottonia inflata*)* occurs at a few locations in fluvial ponds.

One aquatic bed community type may be described in New Hampshire:

Water-lily aquatic bed (G4G5, S4; NatureServe crosswalk = water-lily aquatic wetland):
This shallow water community is dominated by rooted, floating-leaved aquatic vegetation with moderate to high cover and diversity (although species diversity was found to by highest in mesotrophic lakes in New York; Edinger et al. 2014). Emergent species are absent or relatively low in cover (see **pickerelweed - arrow-arum - arrowhead emergent marsh** description). Free-floating and submerged plant species are typically present. The **water-lily aquatic bed** (or closely related types) occurs in eutrophic lakes and ponds, oxbow ponds, backwater sloughs, and fluvial ponds. Dominant species include white water-lily (*Nymphaea odorata*) and/or bullhead pond-lily (*Nuphar variegata*). Common associates are water-shield (*Brasenia schreberi*), pondweeds (*Potamogeton* spp.), tape-grass (*Vallisneria americana*), duckweeds (*Lemna* spp.), common duck-meal (*Spirodela polyrrhiza*), water-meals (*Wolffia* spp.), common hornwort (*Ceratophyllum demersum*), common waterweed (*Elodea canadensis*), bladderworts (*Utricularia* spp.), grass-leaved mud-plantain (*Heteranthera dubia*)*, wavy waternymphs (*Najas* spp.), and bur-reeds (*Sparganium* spp.).

Associated with the **water-lily aquatic bed** in shallower water immediately adjacent to the shoreline is the **pickerelweed - arrow-arum - arrowhead emergent marsh** (G5, S5; NatureServe crosswalk = northeastern leafy forb marsh). This community usually occurs on muck soils and is dominated by broad-leaved, aerenchymatous plants such as pickerelweed (*Pontederia cordata*), green arrow-arum (*Peltandra virginica*), and common arrowhead (*Sagittaria latifolia*). Other emergent species include bur-reeds (*Sparganium* spp.), broad-leaved cattail (*Typha latifolia*), common spikesedge (*Eleocharis palustris*), rushes (*Juncus* spp.), soft-stemmed bulrush (*Schoenoplectus tabernaemontani*), water bulrush (*S. subterminalis*), and three-way sedge (*Dulichium arundinaceum*). Floating-leaved aquatics that may be

present include white water-lily (*Nymphaea odorata*), bullhead pond-lily (*Nuphar variegata*), pondweeds (*Potamogeton* spp.), and bladderworts (*Utricularia* spp.). The combination of species at a given location depends on factors such as water depth and amplitude of water level fluctuations.

Wildlife: Characteristic biota is likely a variable and mixed riverine-lacustrine species assemblage. Redbelly dace (*Phoxinus eos*) is found in a few northern ponds, but more common in cold stream habitat with beaver activity (M. Carpenter, pers. comm.).

State distribution: The fluvial pond system is found throughout the state in beaver impoundments along low order streams.

NatureServe Ecological System Crosswalk: Unknown.

System Rank: G-, S4 (draft S-Rank).

Sources: Sperduto 2011; Sperduto and Nichols 2011; NH NHB field surveys; Edinger et al. 2014.

Examples: An example is an unnamed fluvial pond at Corey Wildlife Management Area in Deerfield.

Unnamed fluvial pond at Corey Wildlife Management Area in Deerfield, NH (Source: NH NHB).

14. Vernal Pool System

General description: Vernal pools are isolated wetlands that fill from runoff, groundwater, and precipitation, holding water through the spring and drying out most years during the summer. Typically small (usually <2,000 m^2), vernal pools vary in size from 0.3 m^2 to more than 20,000 m^2 and in depth to over 3 m deep (Colburn 2004). They lack perennial inlets or outlets, and typically occur as patches within other habitats. Vernal pools are usually surrounded by upland or wetland forests (such as floodplain forests or swamps) with overhanging tree canopy branches frequent, at least 10% cover but ideally 40% or more (Hunt 1999). When the canopy is more open, the pool may grade into other wetland types (e.g., coastal plain pond).

Periodic natural drawdown, hydrologic isolation, and low oxygen levels preclude permanent fish populations. With fish predators excluded, vernal pools serve as important feeding and breeding grounds for reptiles, amphibians, and invertebrates, several of which are adapted to, and completely dependent on, the cyclic and ephemeral nature of these wetland basins. Vernal pool indicator species include wood frog, marbled salamander, spotted salamander, blue-spotted salamander, Jefferson salamander, and fairy shrimp (Marchand 2014; Kenney and Burne 2000).

Vegetation: Rare plant species that occur in vernal pools in New Hampshire include sharp-flowered mannagrass (*Glyceria acutiflora*)* and floating mannagrass (*G. septentrionalis*)*.

No formal aquatic bed community types have been classified yet in New Hampshire:

Unclassified aquatic bed: Plant species richness and cover are highly variable and depend on the extent of water fluctuations, light, geographic location, variation in seed dispersal, and other factors. Aquatic plant species may be frequent in some examples and include mannagrasses (*Glyceria* spp.), duckweeds (*Lemna* spp.), waternymphs (*Najas* spp.), common water-primrose (*Ludwigia palustris*), needle spikesedge (*Eleocharis acicularis*), and others.

Shrubland and marsh communities peripheral to vernal pools include **highbush blueberry - winterberry shrub thicket**, **buttonbush shrubland**, and **meadowsweet - robust graminoid sand plain marsh**. When present, these and other communities are typically restricted to elevated mounds or areas near the pool margins. Trees that occur on higher ground in areas transitioning to swamp or forested habitat may include red maple (*Acer rubrum*), hemlock (*Tsuga canadensis*), yellow birch (*Betula alleghaniensis*), black gum (*Nyssa sylvatica*), swamp white oak (*Quercus bicolor*), balsam fir (*Abies balsamea*), spruce (*Picea* spp.), and others.

Wildlife: Vernal pools can support a diverse group of amphibians, reptiles, crustaceans, mollusks, annelids, and insects. Primary vernal pool indicators (named in NH DES wetlands rules) include wood frogs (*Lithobates sylvaticus*) and spotted (*Ambystoma maculatum*), blue-spotted (*A. laterale*), and Jefferson (*A. jeffersonianum*) salamanders. Amphibians migrate to vernal pools from their upland habitats

on the first warm rainy night of spring (about 5° C, usually in early April) to court, mate, and lay eggs in the pools, and then return to the forest. After hatching, successful growth and metamorphosis from larvae to adult must happen before water in the pools disappears. Also characteristic are fairy shrimps (*Eubranchipus* spp.) that lay desiccation-resistant eggs in leaf litter on the bottom of pools. In early spring, the eggs hatch and colorful orange, yellow, and turquoise crustaceans appear, swimming on their backs.

Secondary vernal pool indicators, those families or groups also named in NH DES wetlands rules, include caddisfly larvae or cases (Family Limnephilidae, Phryganeidae, and Polycentropodidae), clam shrimp or shells (Suborder Laevicaudata and Spinicaudata), fingernail clams or shells (Family Sphaeriidae), aquatic beetle larvae (Family Dytiscidae, Gyrinidae, Haliplidae, and Hydrophilidae), dragonfly larvae or exuviae (Family Aeshnidae and Libellulidae), damselfly larvae or exuviae (Family Coenagrionidae and Lestidae), true fly larvae or pupae (Family Culicidae, Chaoboridae, and Chironomidae), spire-shaped snails or shells (Family Physidae and Lymnaeidae), and flat-spire snails or shells (Family Planorbidae).

Additional widespread species include American toad (*Bufo americanus*), spring peeper (*Pseudacris crucifer*), grey tree frog (*Hyla versicolor*), and the common garter snake (*Thamnophis sirtalis*). Many insects, including mosquitoes, have eggs or larvae that can withstand the seasonal drawdown by remaining in the moist leaf litter.

State distribution: The vernal pool system is known throughout the state.

NatureServe Ecological System Crosswalk: Unknown.

System Rank: G4, S3S4 (draft S-Rank).

Sources: Sperduto and Nichols 2011; NH NHB field surveys; Edinger et al. 2014; Hunt 1999; Colburn 2004.

Examples: Good examples occur at Pawtuckaway State Park, Nottingham.

Vernal pool at Pawtuckaway State Park, Nottingham, NH (Source: NH NHB).

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APPENDIX 1. KEY TO NATURAL FRESHWATER LAKE AND POND SYSTEMS IN NEW HAMPSHIRE

1a. Surface water draws down below surface of bottom substrate most years, usually ponded in spring and dry late summer; significantly influenced by fluctuating groundwater levels; usually fishless or if present, scarce and not permanent populations.

2a. Support one or more vernal pool indicator species (e.g., wood frog, marbled salamander, spotted salamander, blue-spotted salamander, Jefferson salamander, and fairy shrimp); usually occurs in a forested settings with overhanging tree canopies; maximum water depth and seasonal vertical groundwater fluctuation usually less than that found in coastal plain ponds; usually with leaf littered flats over loamy soils in drawn-down zones and poorly developed emergent and aquatic vegetation zones ..... **Vernal Pool System**

2b. Lack vernal pool indicator species; occurs in non-forested, sand plain setting; significant seasonal vertical groundwater fluctuations (up to 2 m); coarse underlying sediments usually with shrub and/or meadow marsh vegetation in drawn-down zones and moderately developed emergent and aquatic vegetation zones ..... **Coastal Plain Pond System**

1b. Surface water perennial, remaining above surface of bottom substrate most years; not significantly influenced by fluctuating groundwater levels; fish usually present.

3a. Ponds directly associated with current or former river channels; hydrology strongly associated with the river either directly or from periodic river floods over the levee banks approximately every 2-4 years; water depths are relatively shallow (usually less than 6 m); usually bordered by marsh or floodplain communities; characteristic biota vary from riverine to mixed riverine-lacustrine species assemblages.

4a. Occurring in river meanders isolated from the river's main stem by levees; periodic river floods over the levee banks replenish river water and biota; water with relatively low flushing rates and fairly stagnant; most often associated with 3rd order streams or higher …..**Oxbow Pond System**

4b. Occurring in impoundments behind beaver dams along low order streams (mainly 1st to 3rd order); with relatively high flushing rate ..... **Fluvial Pond System**

3b. Ponds and lakes not directly associated with river channels; waterbodies more significantly influenced by groundwater and less strongly associated with a river; water depths range from shallow to deep; usually not bordered by marsh or floodplain communities; characteristic biota primarily lacustrine species assemblages.

5a. Relatively deep lakes with small surface areas; lack complete mixing from their sheltered surroundings, usually with only partial mixing in the upper water column (mixolimnion); the monimolimnion below the chemocline lack mixing and characterized by high concentrations of dissolved salts, anoxic conditions, and "chemically tolerant" species …….. **Meromictic Lake System**

5b. Holomictic waterbodies characterized by complete mixing one or more times each year; lack permanent chemical stratification and "chemically tolerant" species.

6a. Waterbodies acidic with low alkalinity (typically <12.5 mg/l calcium carbonate) and acidic neutralizing capacity; trophic state typically oligotrophic; characterized by "acid tolerant" species and low vascular plant species diversity.

7a. Dystrophic (with low conductivity and brown, murky, acidic water from high concentrations of humic matter), shallow, stagnant ponds closely associated with bogs or poor fens; organic substrate of peat or muck; "dystrophic tolerant" species present ..... **Bog Pond System**

7b. Clear, acidic to highly acidic, oligotrophic waterbodies; depth variable; typically not closely associated with bogs or poor fens; substrate coarse mineral sediments low in

organic matter; vascular plant cover relatively low and characterized by rosette-forming, stress-tolerant species (including "Isoetids"); dominated by oxygen-requiring, coldwater fish species; "dystrophic tolerant" species sparse.

8a. Relatively shallow waterbody depths (maximum to approximately 6 m or less); habitat diversity typically low; profundal obligate species sparse to absent; pelagic assemblages poorly developed (oligotrophic ponds).

9a. Acidic ponds at elevations below alpine/subalpine zones; usually with fish species; aquatic vegetation sparse.

10a. Ponds with inlets and/or outlets ..... **Oligotrophic Pond System (typical expression)**

10b. Ponds lacking inlets and outlets, occurring in kettle holes or other small isolated basins ……..... ***Clear Water Kettle Hole Pond***

9b. Highly acidic ponds in alpine and subalpine settings (generally above 1000 m elevation) including those more characteristically formed when water fills the base of a cirque; relatively cold-watered and remain frozen for extended periods; many may be historically fishless due to their remoteness and chemical and physical nature; aquatic vegetation very sparse ……..... ***Tarn Pond***

8b. Moderate to deep lakes (maximum depth >6 m, ideally >9 m); habitat diversity typically high; profundal obligate species common; pelagic assemblages well developed with coldwater fish species usually abundant ..... **Oligotrophic Lake System**

6b. Waterbodies with moderate to high alkalinity (typically greater than 12.5 mg/l calcium carbonate) and acidic neutralizing capacity; trophic state usually either eutrophic or mesotrophic (oligotrophic in marl pond system); usually characterized by high vascular plant species diversity and relative cover of floating-leaved aquatic plants and low abundance of "acid tolerant" species (plant diversity and cover low in marl pond system).

11a. Alkaline, monomictic lakes and ponds; depths relatively shallow (mostly with a maximum depth to 6 m); profundal obligate species sparse to absent; pelagic species assemblages poorly to moderately-well developed.

12a. Large, shallow lakes (usually at least 40 ha) such that the ratio between depth and width/surface area allows the wind to keep the water column well mixed during the summer months (preventing summer stratification); maximum depths usually <6 m (for some larger broader exposed lakes, depths can reach up to 10 m and still remain relatively well mixed from top to bottom during the summer); usually support high habitat diversity and pelagic species assemblages moderately-well developed ..... **Monomictic Lake System**

12b. Shallow ponds (usually <8 ha and <6 m deep).

13a. Ponds with moderate to high alkalinity (calcium carbonate concentrations usually between 12.5–50 mg/l); vascular plant cover and diversity high.

14a. Calcium carbonate concentrations likely on the lower half of the 12.5–50 mg/l range ..... **Eutrophic Pond System**

14b. Calcium carbonate concentrations likely on the upper half of the 12.5–50 mg/l range ..... **Circumneutral Pond (Lake) System**

13b. Ponds with very high alkalinity (calcium carbonate concentrations usually exceed 50 mg/l); calcium carbonate precipitation forms marl bottom sediments; vascular plant diversity low and characterized by calciphiles (e.g., *Potamogeton obtusifolius**, *Stuckenia filiformis**, *Sagittaria cuneata**, *Sphagnum contortum**, and/or *Chara* spp.) ..... **Marl Pond System**

11b. Alkaline, dimictic lakes; depths moderate to deep (maximum depth typically >6 m); habitat diversity typically high; profundal obligate species common; pelagic assemblages well developed.

15a. Mesotrophic lakes intermediate in terms of productivity and nutrient status between oligotrophic and eutrophic lakes; moderately clear water with medium transparency (Secchi disk depths of 2–4 m); water with moderate amounts of plants nutrients; moderate primary productivity (inorganic carbon fixed = 25–75 g/m^2/yr); sediments with moderate amounts of organic matter; moderately-well oxygenated water; and alkalinity is typically moderate (slightly greater than 12.5 mg/l calcium carbonate) ..... **Mesotrophic Lake System**

15b. Eutrophic lakes, occurring in broad, shallow, nutrient-rich basins; murky water with low transparency (Secchi disk depths typically <2.5 m, but up to 4 m in some cases); water rich in plant nutrients (especially high in phosphorus, nitrogen, and calcium); high primary productivity (inorganic carbon fixed = 75–250 g/m^2/yr); sediments rich in organic matter (usually consisting of a fine organic silt); well-oxygenated water above the summer thermocline, but oxygen-depleted below the summer thermocline or under ice; weedy shoreline; and alkalinity is typically high (greater than 12.5 mg/l calcium carbonate) ..... **Eutrophic Lake System**

APPENDIX 2. EXPLANATION OF GLOBAL AND STATE CONSERVATION STATUS RANK CODES

These rank codes describe the degree of vulnerability of an element of biodiversity (species, natural community, or natural community system) to extirpation, either throughout its range (global or "G" rank) or within a subnational unit such as a state (subnational or "S" rank). For species, the vulnerability of a subspecies or variety is indicated with a taxon ("T") rank. For example, a G5T1 rank for a subspecies indicates that the subspecies is critically imperiled (T1) while the species is secure (G5).

Code	Examples		Description
1	G1	S1	Critically imperiled because of extreme rarity (e.g., one to five occurrences), very restricted range, very steep recent declines, or other factors making it extremely vulnerable to extirpation.
2	G2	S2	Imperiled due to very few occurrences (e.g., six to 20), restricted range, steep recent declines, or other factors making it very vulnerable to extirpation.
3	G3	S3	Vulnerable due to relatively few occurrences (e.g., 21 to 80), relatively restricted range, recent declines, or other factors making it vulnerable to extirpation.
4	G4	S4	Apparently secure due to having more than a few occurrences (e.g., >80) and/or an extensive range, but possible cause for long-term concern due to local recent declines or other factors.
5	G5	S5	Secure; widespread and abundant.
U	GU	SU	Status uncertain. More information needed.
H	GH	SH	Known only from historical records (e.g., a species not reported as present within the last 20 years or a community or system that has not been reported within 40 years).
X	GX	SX	Believed to be extinct. May be rediscovered, but habitat alteration or other factors indicate rediscovery is unlikely.

Modifiers are used as follows:

Code	Examples		Description
Q	G5Q	GHQ	Questions or problems may exist with the element's taxonomy or classification, so more information is needed.
?	G3?	3?	The rank is uncertain due to insufficient information at the global level, so more inventories are needed. When no rank has been proposed the global rank may be "G?" or "G5T?".

When ranks are somewhat uncertain or the element's status appears to fall between two ranks, the ranks may be combined. For example:

G4G5	The element rank is either 4 or 5, or its rank is near the border between the two.
G5T2T3	For a plant or animal, the species is globally secure (G5), but the subspecies is vulnerable or imperiled (T2T3).
G5?Q	The element seems to be secure globally (G5), but more information is needed to confirm this (?). Further, there are questions or problems with the element's taxonomy or classification (Q).
G3G4Q S1S2	The element is globally vulnerable or apparently secure (G3G4), and there are questions about its taxonomy or classification (Q). In the subnation, the element is imperiled or critically imperiled (S1S2).

APPENDIX 3. EXPLANATION OF STATE LISTING CODES

In 1987, the New Hampshire state legislature passed the Native Plant Protection Act (RSA 217-A) and formally recognized that "for human needs and enjoyment, the interests of science, and the economy of the state, native plants throughout this state should be protected and conserved; and . . . their numbers should be maintained and enhanced to insure their perpetuation as viable components of their ecosystems for the benefit of the people of New Hampshire." To compile a list of the species requiring protection, the NH Natural Heritage Bureau collaborated with knowledgeable botanists and identified the most imperiled taxa as "endangered" and those likely to become endangered as "threatened." The most recent revision to the list was completed in 2010.

In addition to endangered and threatened, state watch and indeterminate categories exist for taxa appearing vulnerable to extirpation where current information does not justify designating them endangered or threatened.

Endangered (E): Native plant taxa vulnerable to extirpation based on having five or fewer natural occurrences in the state observed within the last 20 years, or taxa with more than five occurrences that are, in the judgment of experts, vulnerable to extirpation due to other important rarity and endangerment factors (population size and trends, area of occupancy, overall viability, geographic distribution, habitat rarity and integrity, and/or degree of protection). A rare native plant taxon that has not been observed in over 20 years is considered endangered unless there is credible evidence that all previously known occurrences of the taxon in the state have been extirpated.

Threatened (T): Native plant taxa vulnerable to becoming endangered based on having 6–20 natural occurrences in the state observed within the last 20 years, or taxa that are, in the judgment of experts, vulnerable to becoming endangered due to other important rarity and endangerment factors (population size and trends, area of occupancy, overall viability, geographic distribution, habitat rarity and integrity, and/or degree of protection).

Watch (W): Native plant taxa vulnerable to becoming threatened based on having 21–80 natural occurrences in the state observed within the last 20 years, or taxa that are, in the judgment of experts, vulnerable to becoming threatened due to other important rarity and endangerment factors (population size and trends, area of occupancy, overall viability, geographic distribution, habitat rarity and integrity, and/or degree of protection).

Indeterminate (Ind): Plant taxa under review for listing as endangered, threatened, or watch, but their rarity, nativity, taxonomy, and/or nomenclature are not clearly understood.

APPENDIX 4. LIST OF 22 SITES SURVEYED IN 2015

Date	Site	Town
8/19/2015	Barbadoes Pond	Madbury
8/20/2015	Round Pond	Gilford
8/26/2015	Mack Pond	Madison
8/26/2015	Cranberry Bog	Madison
8/26/2015	Blue Pond	Madison
8/26/2015	Drew Pond	Madison
8/27/2015	Blackwater River - Fluvial Pond #1	Salisbury
8/27/2015	Blackwater River - Fluvial Pond #2	Salisbury
9/2/2015	Lake Solitude	Newbury
9/3/2015	Bear Brook - Fluvial Pond #1	Deerfield
9/3/2015	Bear Brook - Fluvial Pond #2	Deerfield
9/8/2015	Greenough Pond	Salisbury
9/9/2015	Ice Pond	Lincoln
9/9/2015	Black Pond	Lincoln
9/9/2015	North of Black Pond	Lincoln
9/15/2015	Pond of Safety - Fluvial Pond	Randolph
9/15/2015	Pond of Safety	Randolph
9/15/2015	Stag Hollow Brook Tributary - Fluvial Pond	Randolph
9/16/2015	Lime Pond	Columbia
9/16/2015	Fish Pond	Columbia
9/17/2015	Cherry Pond	Jefferson
9/17/2015	Little Cherry Pond	Jefferson

APPENDIX 5. AQUATIC PLANT SAMPLING PROTOCOLS

These protocols pertain to both lake and river surveys, the latter applied to one river segment at a time. Plant species composition is influenced by several factors including water quality and clarity, water flow, substrate composition and gradient, nutrients, temperature, wave exposure, slope, and depth. Lakes and rivers supporting more diverse habitats typically require more sample plots compared to relatively homogenous examples. Surveyors should be familiar with regional aquatic macrophyte species and the use of plant identification keys (e.g., Haines 2011). Surveyors should also know how to prepare and preserve aquatic plants for office identification or submission to a qualified plant taxonomist. Specific study designs may also require retention of reference collections.

AQUATIC PLANT LIFE-FORMS

This method is intended for sampling in open-water habitats, where plants fall into four generalized life-form categories:

Submergents: Entire plants submerged, most rooted to the bottom. Examples of submergent species in New Hampshire include *Ceratophyllum demersum* (common hornwort) and *Utricularia vulgaris* ssp. *macrorhiza* (greater bladderwort).

Floating-leaved: Rooted plants with leaves floating on water surface (often with flowers emerging above the water). Examples include *Brasenia schreberi* (water-shield), *Nymphaea odorata* (white water-lily), and *Potamogeton epihydrus* (ribbon-leaved pondweed).

Free Floating: Plants that float on the surface freely (not rooted to bottom). Plants are often smaller sized and include *Wolffia borealis* (northern water-meal), *Lemna minor* (common duckweed), and *Spirodela polyrrhiza* (common duck-meal).

Emergents: Rooted plants with significant portions emergent above the water surface. Examples include *Typha angustifolia* (narrow-leaved cattail), *Lythrum salicaria* (purple loosestrife), and *Juncus militaris* (bayonet rush).

TIMING OF SURVEY

Timing of survey may depend on study objectives and design, but in most cases is best completed from mid-July through August when most of New Hampshire's macrophyte species are in full growth and flowering/fruiting (increasing ability to correctly identify challenging species). Surface and reconnaissance surveys can be conducted outside of peak growing season, provided plant growth has advanced enough to determine bed extent and species identification. However, it is difficult to identify many aquatic plants prior to flower/fruit development. Submerged plants are most visible and best surveyed when light penetration is greatest during the day (e.g., between 10 AM and 2 PM).

SELECTING SURVEY LOCATIONS

Ideally, survey locations in a lake or river should be selected at sufficient intervals to construct a map of plant coverage throughout the littoral zone. If logistically possible, a preliminary assessment should be performed where the surveyor views as much as the lake perimeter as possible, marking locations of aquatic macrophyte beds on a map.

If available, a bathymetric map should be used. New Hampshire Department of Environmental Services and New Hampshire Fish & Game have made available bathymetric maps for over 650 lakes and ponds in PDF format at the following links:

- http://www.wildlife.state.nh.us/Fishing/bathy_maps.htm
- http://des.nh.gov/organization/divisions/water/wmb/vlap/annual_reports/bathymetric.htm

Aerial photographs and USGS topographic maps should also be printed and used during surveys to delineate plant beds. A survey location may consist of a 1) transect with plots; 2) releve plot; or 3) whole bed plot. The size and number of plots should reasonably capture the diversity of aquatic bed habitats in the lake or river segment. If all major plant beds cannot be sampled, target data collection in beds that are most likely to best inform the goals of the survey (e.g., assessing biomass, composition, diversity, and condition; rare plant and invasive species monitoring, and habitat classification).

STEP-BY-STEP AQUATIC PLANT SURVEY INSTRUCTIONS

Step 1: Reviewing checklist.

a) Review the checklist before leaving for site.
- Clip board and pencils.
- GPS unit (accuracy 3 m or better), camera, and light meter or turbidity meter.
- Aquatic plant survey forms (on water resistant paper) and protocols; water resistant notebook.
- Lake map (bathymetric and topographic) and aerial photograph.
- Transect line.
- Weighted measuring tape, sounding line, depth sounder, or depth gun.
- Secchi disk and thermometer.
- View scope or goggles (underwater viewer); polarized sunglasses.
- Weighted rake (double-headed if available) with long handle or throw rope.
- Hand rake with 10 m throw rope.
- Ekman dredge, or similar grab sampler.
- Sealable plastic bags (medium & large size) and permanent ink pen.
- Boat anchor and personal floatation device (PFD).

b) If sampling shore side, several of items listed above will not be needed (e.g., anchor and PFD).

Step 2: Locate first survey site and record general site information on Aquatic Plant Survey Form.

a) At first survey site, record the following general site information.

- Write in Date, Surveyor(s), Town, Water Body Name, and unique Site Code (e.g., A, B, etc.). Record Present Water Level compared to average year (if estimate-able).

Step 3: Record plot information.

a) General: Collect GPS data at the point along the shore where the transect, releve plot, or whole bed plot runs out perpendicular to the shore. Note GPS waypoint number (WP#) on form; also use tracking feature to provide record of survey pattern. Take a photograph from this onshore GPS location capturing the sample area offshore. Also take a photograph from the deep end of the transect, plot, or bed back toward shore (if boat survey).

b) **Transect with plots (from boat):** Move perpendicular to the shoreline out to deepest plot (~3 meters) at offshore end of transect (or out to single representative plot); and anchor the boat.

- Record GPS Plot WP# and Plot Size.
- Record Water Depth using a weighted measuring tape and estimate Distance from Shore.
- Determine Substrate Type using view scope or goggles over all sides of boat. If bottom not visible because of plants or debris, use rake to clear bottom (also record type and cover of debris). Typical bottom compositions:
  - Mud: silt, clay, and fine sand.
  - Sand: mineral particles between 0.0625–2 mm.
  - Gravel: particles between 2–64 mm.
  - Rock: particles larger than gravel.
  - Muck: well decomposed organic matter, often with some sand, silt, or clay (may appear like mud).
  - Other: describe.
- List each plant species and document cover in the following categories: emergent (Em), water surface (WSur), water column (WCol), and bottom (Bot). Treat macroalgae the same way (e.g., *Chara* sp. and *Nitella* sp. which are similar to vascular aquatic macrophytes in size, form, and function).
  - Pitch weighted rake shoreward about 2 meters from boat. Allow rake to settle to bottom then slowly pull the line so rake teeth drag along bottom. Bring rake in boat and remove vegetation, examine the piles, and use relative cover to inform estimate of absolute cover. Place unidentified specimens in a labeled plastic bag. Repeat rake grab three more times, away from shore and parallel to shore to the right and left. Place all plants from same plot into the same plastic bag and store out of sunlight.
  - Viewing the water column and bottom using a view scope or goggles may increase estimate accuracy.
- Move toward shore in a straight line perpendicular to the shoreline, repeating the steps above for the second and third plots. The other two plots are spaced equidistant to the shore along the transect from the deep plot (e.g., if first plot is ~75' from shore, the second and third plot would be ~50' and ~25' from shore).
- In "Comments (on plot)" field, record locations of all key features using a GPS unit and describe feature on survey form. These features include rare plant species, invasive species, plant bed boundaries, and transitions from one plant community type to another.

- Depending on study design, temperature profiles, Secchi depth, turbidity, water velocity (where applicable), and bottom light level can be recorded at all key feature GPS points.

c) **Releve plot (from boat):** Surveyor selects an area within the aquatic bed community that is representative of the overall community composition to place a sampling plot (recommended default plot size 100 m^2 [10 x 10 m or 5 x 20 m]).
   - Record GPS Plot WP#, Plot Size, Water Depth, Distance from Shore, and Substrate Type.
   - Estimate percent cover for each plant species in plot (using view scope or goggles and rake where needed; see description above).
   - In "Comments (on plot)" field, record locations of all key features using a GPS unit and describe feature on survey form. These features include rare plant species, invasive species, plant bed boundaries, and transitions from one plant community type to another.
   - Depending on study design, temperature profiles, Secchi depth, turbidity, water velocity (where applicable), and bottom light level can be recorded at all key feature GPS points.

d) **Releve plot adjacent to shore (without a boat):** Surveyor selects an area within the aquatic bed community that is representative of the overall community composition to place a sampling plot (recommended default plot size 100 m^2 [10 x 10 m or 5 x 20 m]).
   - Record GPS Plot WP#, Plot Size, Water Depth, Distance from Shore, and Substrate Type.
   - Estimate percent cover of emergent and floating species in plot (make initial cover estimate of submerged species if practical).
   - Refine submerged species cover estimates by sampling from shore following Bourdaghs (2012):
     - Throw hand rake 5 m out into the water (allowing it to settle to bottom) and retrieve three times: once perpendicular from the shore and both at (+/-) 45°.
     - Examine the vegetation, and use relative cover for each species to inform estimate of absolute cover.
     - Also, use view scope or goggles and weighted rake where needed.
   - In "Comments (on plot)" field, record locations of all key features using a GPS unit and describe feature on survey form. These features include rare plant species, invasive species, plant bed boundaries, and transitions from one plant community type to another.
   - Depending on study design, temperature profiles, Secchi depth, turbidity, water velocity (where applicable), and bottom light level can be recorded at all key feature GPS points.

e) **Whole bed plot (from boat):** Aquatic plant beds in lake or river littoral regions are surveyed by boat in a zig-zag pattern from shallow nearshore waters out to the extent of plant beds, where the plant bed is the plot. The distance between passes depends on visibility, but should allow complete coverage for visual assessment. Shallow water bodies with aquatic plant growth throughout can be surveyed in a grid pattern. Grid density would be dependent on study design, area to be surveyed, or time constraints. GPS tracking feature should be used to provide a record of survey pattern and area traversed.
   - Record GPS Plot WP#, Plot Size, Water Depth, Distance from Shore, and Substrate Type.
   - Within the bed, identify plant species and cover. In shallow water with adequate visibility, plants may be identified by observation from the boat. In deeper or murkier water, or where a canopy of plants obscures plants at lower levels, an underwater viewer can be useful. At intervals within each plant bed, plant samples should be collected with the weighted rake for closer examination.

Additional information from shallow nearshore waters may be obtained from shore or by wading. Samples to be archived or included in reference collections should be properly preserved in a plant press.

- In "Comments (on plot)" field, record locations of all key features using a GPS unit and describe feature on survey form. These features include rare plant species, invasive species, plant bed boundaries, and transitions from one plant community type to another.
- Depending on study design, temperature profiles, Secchi depth, turbidity, water velocity (where applicable), and bottom light level can be recorded at all key feature GPS points.

Step 4: Map the location of aquatic plants at or near the surface.

a) Draw on map areas where aquatic vegetation is on or near the surface.

Step 5: Completing the "Site Summary" section.

a) Record the following information in the Site Summary section on Aquatic Plant Survey Form:

- Wetland System:
  - Name the wetland system type being evaluated.
- Interesting Features Associated with System:
  - List each vegetation zone (natural community) that was documented in the system on separate lines (e.g., aquatic bed, emergent marsh, etc.).
  - Also list other interesting features on separate lines when present:
    - Upland vegetation zones (natural communities) in the surrounding landscape, as needed.
    - Rare, uncommon, and/or invasive species.
    - Photo locations (record only if specific location of photo point is important).
    - Anthropogenic features (onshore or nearshore).
- Status:
  - Use the following codes for rare, uncommon, and/or invasive species (see NH Natural Heritage Bureau rare plant tracking list):
    - SE: state endangered.
    - ST: state threatened.
    - SW: state watch.
    - Ind: indeterminate.
    - Inv: invasive.
  - Use the following code for anthropogenic features:
    - Anthro: anthropogenic.
- % in sys:
  - Estimate the percent cover of each vegetation zone within the system (total cover of zones within a system = 100%).
- WP:
  - Note the GPS waypoint number for each vegetation zone; rare, uncommon, and/or invasive species; anthropogenic feature; etc.
- Comment (as needed for site):

- For example, note any natural and manmade features occurring onshore that may be influencing the distribution of aquatic plants.

- Diagram (as needed):
  - Draw a site diagram as needed

Step 6: Completing the aquatic plant survey.

a) The number of plots, site selection and specific parameters measured depends on the particular study being done and should be discussed with the project manager prior to sampling.

REFERENCES FOR AQUATIC PLANT SAMPLING PROTOCOLS

Alberta Environment. 2006. Aquatic Ecosystems Field Sampling Protocols. Environmental Monitoring and Evaluation Branch Environmental Assurance Division, Edmonton, Alberta. Website (http://environment.gov.ab.ca/info/posting.asp?assetid=7805&categoryid).

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Environmental Protection Agency. 2002. Volunteer Lake Monitoring: A Methods Manual. EPA Office of Water, EPA440-4-91-002. Website (http://water.epa.gov/type/watersheds/monitoring/lakevm.cfm).

Haines, A. 2011. Flora Novae Angliae: A Manual for the Identification of Native and Naturalized Higher Vascular Plants of New England. Yale University Press, New Haven, CT.

New York Department of Environmental Conservation. 2011. Aquatic Plant Sampling Protocol. Website (http://nysfola.mylaketown.com/uploads/tinymce/nysfola/2011%20CSLAP%20Plant%20Sampling%20Protocol.pdf).

University of Rhode Island Cooperative Extension. 2014. University of Rhode Island Watershed Watch: Aquatic Plant Survey Manual. Website (http://www.uri.edu/ce/wq/ww/Manuals.htm).

APPENDIX 6. AQUATIC BED SURVEY FORM

NH NATURAL HERITAGE - Aquatic Bed Survey Form			Date:	NC or Veg Zone:						Plot WP#:	
Surveyor(s): *Bill Nichols*			Town:	Species		Em	WSur	WCol	Bot	Plot Size (m):	
Water Body Name:			Site Code:							Water Depth (m):	
Present Water Level (circle one): HIGH AVE LOW UNK			F15_____NHUS							Dist. from Shore (m):	
Status	SITE SUMMARY									Substrate Type	
	Wetland System:									Mud:	
	Interesting Features Associated with System	% in sys	WP							Sand:	
										Gravel:	
										Rock:	
										Muck:	
										Other:	
										Comments (on plot):	
				Totals:							
				NC or Veg Zone:						Plot WP#:	
				Species		Em	WSur	WCol	Bot	Plot Size (m):	
										Water Depth (m):	
										Dist. from Shore (m):	
										Substrate Type	
										Mud:	
										Sand:	
										Gravel:	
										Rock:	
										Muck:	
										Other:	
Comments (as needed for site):										Comments (on plot):	
Diagram (as needed):											
				Totals:							

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