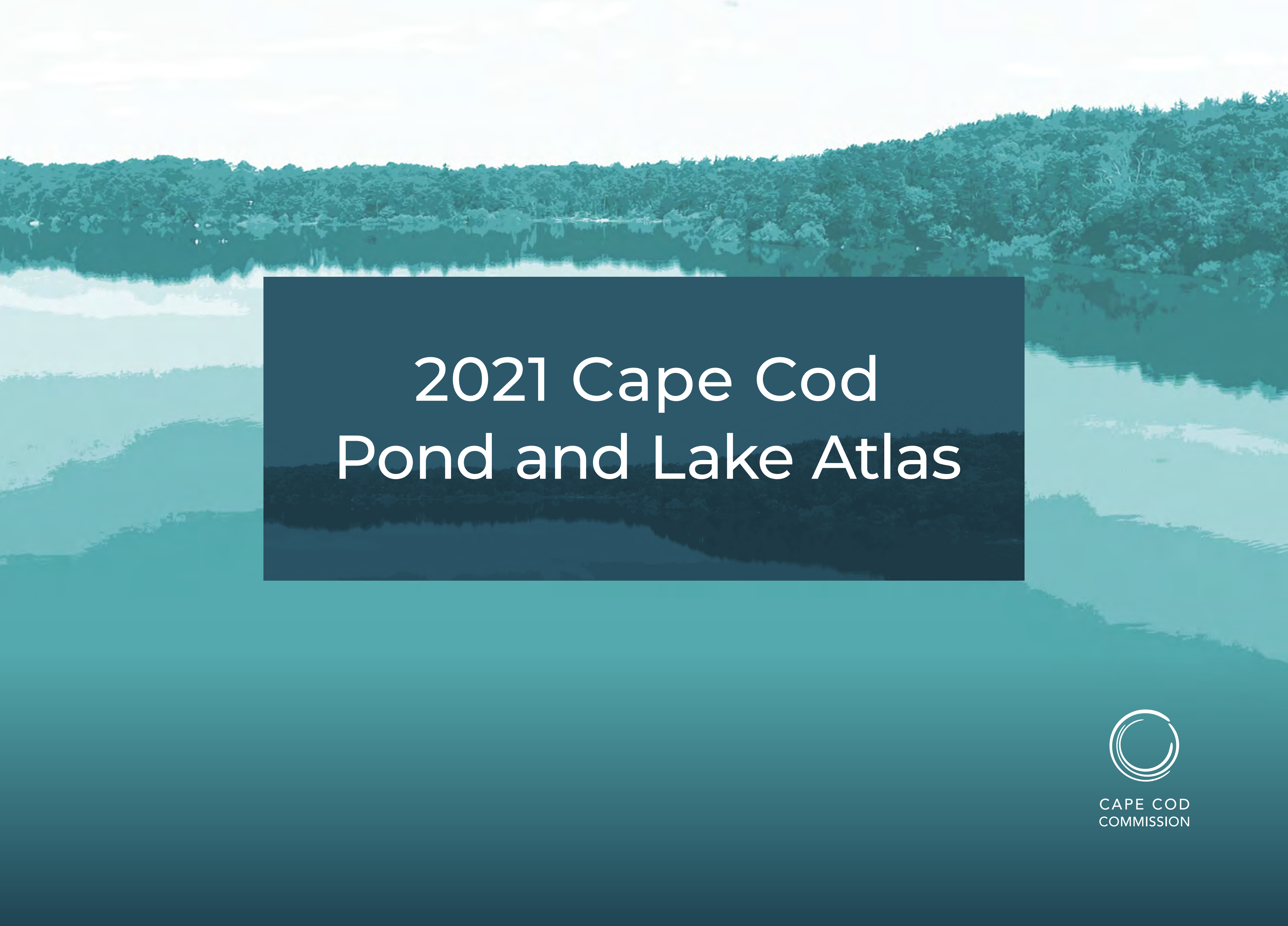

2021 Cape Cod Pond and Lake Atlas

CAPE COD COMMISSION

CAPE COD POND AND LAKE ATLAS
DECEMBER 2021

Prepared by Cape Cod Commission Staff

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CAPE COD COMMISSION

P.O. Box 226, 3225 Main Street
Barnstable, Massachusetts 02630
Phone: 508-362-3828
Email: frontdesk@capecodcommission.org
www.capecodcommission.org

COUNTY OF BARNSTABLE ★ MASSACHUSETTS ★

Table of Contents

Lower Mill Pond, Brewster

Executive Summary

The Cape Cod Commission's (Commission) 2018 Regional Policy Plan identified the health of Cape Cod freshwater ponds and lakes (collectively referred to as "ponds") as a key challenge facing the region, calling for an updated and expanded understanding of freshwater resources data. The recommended planning action includes updating the 2003 Cape Cod Pond and Lake Atlas. The regional need for an update to the Atlas is compounded by increasingly obvious declines in water quality in ponds across the region and an increase in public concern and interest.

Cape Cod's landscape is a product of glacial movement. Generally, the Cape's ponds are depressions left in the land surface that filled with groundwater after glaciers retreated. These resources sit within the Cape's watersheds and are connected to groundwater because their depression in the land surface extends below the water table. The sand and gravel deposited throughout the region during glacial retreat make up the majority of the subsurface. The high permeability of these materials created an aquifer system, the Cape Cod Aquifer, that is both productive and vulnerable to pollutants.

Freshwater ponds are valued natural resources across Cape Cod. The Section 208 Area Wide Water Quality Management Plan, updated in 2015, highlights the importance of ponds in the region's water quality management planning because of their nitrogen filtering capacity and connections to groundwater, the aquifer, and coastal embayments. Ponds are important parts of the Cape Cod ecosystem, providing habitat for a diversity of aquatic flora and fauna. Some Cape Cod ponds support fish species, like herring, or agricultural activities, like cranberry harvesting, that impart cultural values.

CAPE COD POND ATLAS VIEWER

The distribution and characteristics of the Cape's ponds can be explored in the Cape Cod Commission's accompanying Pond Viewer.

cccom.link/pond-atlas

Ponds are also cherished recreational resources, whether it be for swimming, fishing, or boating.

Ponds across the region still provide the recreational, aesthetic, and cultural experiences residents and visitors expect and value, but pond health is showing signs of deterioration. Cape Cod's ponds are fragile. The Commission's 2003 Atlas, as well as town-wide and pond specific assessments completed in the early 2000's identified that most Cape ponds were impaired and did not meet state regulatory standards for surface water. The more recent State of the Waters Report from the Association to Preserve Cape Cod concluded that while data are limited, ponds remain impacted with over one-third of ponds graded as having "unacceptable" water quality in 2019, 2020, and 2021.

Good water quality is vital for the aquatic life a balanced pond ecosystem supports, and the many environmental services a pond provides. However, pond health and water quality have been negatively impacted and continue to be threatened. While ponds undergo natural changes in nutrient cycling, plant productivity, and water levels over time, the historical increase in population on Cape Cod and intensification of human activities in and around ponds have expanded and accelerated threats to pond health. Human activities such as development along pond shorelines and within pond watersheds may increase impervious surfaces, subsequently increasing stormwater runoff, erosion, and addition of nutrients, pollutants, and sediment to ponds. Septic system discharge is another major threat to ponds. Phosphorus and nitrogen in septic discharge have the potential to pass through the Cape's sandy soils, entering and flowing with groundwater into ponds. Pesticide and/or fertilizer runoff may similarly enter ponds. Excess nutrients, especially phosphorus, can shift the natural balance of a pond ecosystem, fueling increased primary productivity through growth of algae and other aquatic vegetation. Excess algal growth may create unsightly and potentially harmful algal blooms while also leading to degraded pond water quality. Climate change exacerbates all these threats. Increasing storm intensity drives greater flow of nutrients and pollutants off the land into ponds. Warmer temperatures enhance growth and abundance of primary producers resulting in algal blooms. Climate change can compound impacts to ponds.

Recognizing the value of the Cape's ponds and the threats these ponds face, numerous groups have formed to monitor pond water quality. For example, through a collaboration of local, county, and state university programming, a network of town-based volunteers established the Pond and Lake Stewardship Program and began annual snapshot water quality monitoring in 2001. The program generated a total of more than 1,800 water samples, collected from 232 ponds in all 15 Cape Cod towns over the last 20 years. Initially, monitoring established baselines to evaluate pond water quality and ecosystem health. Over time the focus of monitoring has shifted to track changes in water quality, measure the effectiveness of restoration projects, and complement larger watershed management programs.

Water quality is also a public health concern. Cape Cod ponds with public swimming beaches are regularly monitored for the presence of fecal bacteria and increasing numbers of ponds are being monitored for algal blooms. Increasing public concern for pond health, compounding threats, and desires to implement pond improvement solutions make consistent pond monitoring a regional need.

Solutions are needed to protect, manage, and improve pond water quality and overall pond health. The threats to pond water quality extend from within the pond to the entire pond's watershed, allowing multiple scales of solutions and strategies. Technical in-pond solutions have been implemented for decades, providing important information and lessons from their application. Numerous other solutions at in-pond or watershed scales are still being researched or identified. Potential solutions to address pond water quality on Cape Cod must work for the Cape's distinct landscape atop sandy soils, and should be combined with wastewater, stormwater, and groundwater management as practicable. Strategies may include both innovative and traditional technologies, regulatory and voluntary options, and consideration for integrated approaches. While phosphorus is a particular concern and focus of strategies for Cape ponds, additional threats to water quality like contaminants of emerging concern, toxic pollutants, invasive species, and sediment are also important considerations.

Consistent management of freshwater ponds that results in improvement is needed. To ensure resources are available for future action to address Cape Cod pond health, in 2022 the Commission is launching the Freshwater Initiative, a comprehensive planning process that engages stakeholders to define a path forward for improving pond water quality across the region. Through its Freshwater Initiative, the Commission will develop pond resources and planning tools for the entire region, making them available and accessible to the public and decision makers. The Commission will develop a comprehensive analysis of pond monitoring data and overall health of Cape Cod's freshwater pond network. Data will be archived and made publicly available in an online interface, accessible for use in management decisions. The Commission will collaborate to establish a long-term volunteer pond monitoring program that provides regionally consistent and quality assured data.

Combined with past and future pond monitoring information and analysis, the Commission's upcoming database of pond improvement strategies will detail available and viable solutions. An economic analysis of ponds, their threats, and the impacts of action or inaction will aid in pond or solution prioritization across the region. With the help of citizens, partners, and local regulators, a stakeholder engagement process will guide Cape Cod pond management.

This updated Pond and Lake Atlas provides a current assessment of the importance of ponds on Cape Cod, the threats they face, and what is needed to improve and properly manage these valued and unique resources. As such, this updated Atlas will serve as a catalyst for renewed and expanded efforts in pond management within the region. Pond water quality is a regional challenge that will require regional collaboration, coordination, and conversations.

List of Figures

List of Tables

Introduction

Cape Cod is a geographic cape, or high point of land, in southeastern Massachusetts extending into the Atlantic Ocean. Cape Cod's land is made up of glacial deposits of mostly sand and gravel. Nearly 900 ponds and lakes cover close to 11,000 acres across the Cape landscape.

The Cape's numerous and diverse ponds and lakes range in size from less than an acre to 735 acres, with the 21 largest ponds making up nearly half of the total Cape-wide pond acreage. Approximately 40% (356) of the ponds are less than an acre whereas about 18% (163) are 10 acres or more.

This Cape Cod Pond and Lake Atlas Update examines the Cape's freshwater bodies from the regional perspective, covering a review of pond ecology, water quality, threats, and strategies to restore pond health. A companion resource to this Pond Atlas Update is the Pond Atlas Viewer (cccom.link/pond-atlas), an online map-based tool that allows the user to view available data on all the ponds and lakes on Cape Cod. Through an easy-to-use online interface, the user can zoom into the map, view map resource layers, select ponds, and access geographic information about a pond of interest. New information will be added to the viewer as it becomes available. Geared toward the typical resident or visitor to Cape Cod, the map viewer may also serve as a planning resource as communities consider management actions to address pond health.

Ponds and lakes are important parts of the Cape Cod ecosystem. They provide habitat for fish, wildlife, aquatic vegetation, and other organisms, including many rare species. They support complex food webs and rare natural communities. They are connected to estuarine and marine ecosystems via ground- and surface water. They attract tourists and make Cape Cod a desirable place to live for year-round and seasonal residents. Residents and visitors use ponds and lakes for recreational activities such as swimming, boating, and fishing. Ponds and lakes provide ecological, economic, and aesthetic benefits.

Cape Cod's ponds and lakes are fragile. According to census data, over the last fifty years, the Cape has seen a significant increase in its year-round population, from approximately 100,000 people in 1970 to almost 230,000 people in 2020, and in population density, from approximately 220 people per square mile in 1970 to almost 590 people per square mile in 2020. The population of the region doubles during the warmer months with seasonal residents and visitors.[1] These increases have led to direct and indirect adverse impacts to these sensitive water bodies. Threats to ponds and lakes from increased human uses and activities on and surrounding them include inputs of chemical contaminants such as herbicides and pesticides, excessive inputs of nutrients such as nitrogen and phosphorus, and introduction of biological contaminants such as invasive plants and animals.

Recognizing the importance of the Cape's ponds and lakes, the Commission and partners developed a Pond and Lake Stewardship (PALS) program in 2000 with the goal of better understanding the status of Cape Cod ponds. In the summer of 2001, PALS participants collected a snapshot of water quality data from 195 ponds. In 2003, the Commission published the Cape Cod Pond and Lake Atlas (2003 Atlas) as a status report on the PALS program. Since publication of the 2003 Atlas, PALS program volunteers and others have continued to monitor the Cape's ponds, and knowledge and data surrounding ponds have evolved.

Coupled with the Pond Viewer, this document serves as the updated Atlas and provides an updated assessment of the Cape's unique freshwater resources, challenges and threats they face, and strategies to protect them.

As with all reports, information presented represents a snapshot in time. Periodic updates are important to revisit the content and recommendations to ensure the information is still accurate, representative of current conditions, and useful to decision-makers. This updated Atlas provides an account of implementation of 2003 Atlas recommendations, progress made, and gaps identified. It also summarizes information on current pond science, monitoring, and management. In addition, this updated Atlas identifies next steps for moving pond monitoring, remediation, and conservation forward on Cape Cod.

POND AND LAKE TERMINOLOGY

As recognized in the 2003 Atlas, there are a wide variety of ponds and lakes on the Cape: small or large, shallow, or deep, with streams or without, surrounded by development or with a largely unaltered shoreline, close to the coast or farther inland. There are also numerous definitions of "pond" and "lake" in dictionaries, textbooks, and other freshwater resources. However, there is no definitive definition of "pond" or distinction between "pond" and "lake." Nevertheless, in the 2003 Atlas, and again in this updated Atlas, Commission staff have attempted to document those bodies of surface water that meet certain criteria to be categorized as ponds and lakes in a Cape Cod context.

The 2003 Atlas utilized Spring 1994 aerial photographs to create a digital map layer of all surface waters on the Cape. Static surface water bodies, such as ponds and lakes, were distinguished from flowing surface waters such as streams and rivers. This work was supplemented through reference to the Massachusetts Department of Environmental Protection's (MassDEP) wetlands dataset. Adjustments to surface water shoreline delineations were performed as warranted. Each water body was assigned a unique number and its surface area determined. The numbering system consists of a two-

1 Cape Cod Commission. 2019 Cape Cod Comprehensive Economic Development Strategy. Available at https://www.capecodcommission.org/our-work/ceds/.

Ashumet Pond, Falmouth

letter town code and a unique number for each pond or lake. This information was then combined in a database with available depth information from various sources, including depths determined during the 2001 PALS water quality monitoring snapshot.

Development of this information allowed Commission staff at that time to review and report on the areas of all and depths of some Cape Cod static fresh surface waters in the 2003 Atlas. Based on this information, 994 static surface waters were identified on Cape Cod with a total area of 10,453 acres. Almost half of the surface waters identified were small, less than one acre in area. Few of the small surface waters were sampled during the 2001 PALS snapshot, and those sampled were shallow (0.2 – 2 meters). The 2003 Atlas noted many of these small, shallow surface waters might not meet the definition of a permanent pond as some likely dry up during low water conditions or even every summer. Data, such as multiple years and seasons of aerial photographs during various water table conditions that could help reveal the ephemerality or seasonality of many of these small, shallow ponds, were not available to make that determination.

For this updated Atlas, Commission staff revisited existing pond and lake definitions and databases with more recent information to reassess which of the Cape's fresh surface water bodies to include in an updated Cape Cod pond and lake database. Information explored to refine the database included Massachusetts Wetlands Protection Act (WPA) definitions.[2] According to the WPA, a lake is any open body of fresh water with a surface area of ten acres or more. An "inland" pond is any open body of fresh water with a surface area observed or recorded within the last ten years of at least 10,000 square feet (0.23 acres), either naturally occurring or human-made by impoundment, excavation, or otherwise, and that contain standing water except for periods of extended drought. The WPA also defines "coastal" or "salt" ponds as shallow enclosed or semi-enclosed bodies of saline water that may be partially or totally restricted by barrier beach formation and

2 Massachusetts Department of Environmental Protection 310 CMR 10.00: The Wetlands Protection Act

that may receive freshwater from small streams emptying into their upper reaches and/or springs in the salt pond itself. For the purposes of this updated Atlas, lakes and inland ponds are included whereas salt ponds are excluded.

In addition to the WPA definitions, staff also explored coarse-resolution information from the United States Fish and Wildlife Service National Wetlands Inventory (NWI) that identifies freshwater ponds and lakes and MassDEP's Wetlands dataset that identifies fresh open bodies of water.[3] Staff also conducted a review of finer-resolution spring 2009, 2014, and 2020 aerial photographs, 2014 planimetrics (points, lines, and polygons representing features on the ground, derived through 3D interpretation of aerial photography), and site visits. When combined, review of these information sources resulted in a more accurate and improved database of fresh, static, permanent surface waterbodies, or ponds and lakes, on Cape Cod and thereby became

3 U.S. Fish and Wildlife Service. National Wetlands Inventory Program Overview. Available at https://www.fws.gov/wetlands/nwi/Overview.html. MassGIS (2017). MassGIS Data: MassDEP Wetlands (2005). Available at https://www.mass.gov/info-details/massgis-data-massdep-wetlands-2005.

DEFINING PONDS AND LAKES FOR THE 2021 ATLAS

There are a wide variety of water bodies on Cape Cod, many of which are referred to simply as "ponds." However, for the purposes of this updated Atlas, only lakes and inland ponds are included, whereas salt ponds are excluded.

FRESHWATER PONDS

For the purposes of this updated Atlas, all fresh, static, and permanent surface water bodies greater than 10,000 square feet (0.23 acres) are considered a pond or lake.

SALTWATER PONDS

"Coastal" or "salt" ponds are shallow enclosed or semi-enclosed bodies of saline water that may be partially or totally restricted by barrier beach formation and that may receive freshwater from small streams emptying into their upper reaches and/or springs in the salt pond itself.

the criteria used for inclusion of a pond or lake in this assessment.

Based on this updated review and criteria, over 200 ponds and lakes identified in the 2003 Atlas were eliminated from the database due to their small size, having tidal or saltwater influences, or lacking consistently open water over the three years of more recent photographs. Concurrently, almost 200 ponds and lakes were added to the database due to being classified as such in 2014 planimetrics. For this updated Atlas, 890 ponds and lakes have been identified. Of these, 549 met the aerial photograph, MassDEP, and NWI criteria for classification as a pond or lake, including having open water over successive years and being identified as “Open Water” and “Freshwater Pond or Lake” in MassDEP and NWI datasets, respectively. The remaining 341 water bodies identified as ponds or lakes are generally smaller but have persisted over time. This snapshot in time of Cape Cod ponds and lakes provides a benchmark for 2021. As new information becomes available, water bodies that meet established criteria may be added or removed from the database. It is anticipated that the number and condition of ponds and lakes will change over time, allowing for the evolution of the database.

Regardless of size or other characteristics, the vast majority (99%) of Cape Cod’s ponds and lakes have been and continue to be considered “ponds” by both residents and visitors alike with the exception of a few waterbodies that retain the “lake” label, including Shawme and Upper Shawme Lakes in Sandwich, Cedar Lake in Falmouth, Mystic and Wequaquet Lakes in Barnstable, Scargo Lake in Dennis, Lovers Lake in Chatham, and Crystal and Pilgrim Lakes in Orleans. Therefore, this updated Atlas will primarily refer to all fresh, static, permanent water bodies as “ponds” but may use the term “lake” interchangeably. Regardless of label, all these water bodies share the public’s ongoing interest in them and their condition, characteristics, and conservation.

Long Pond, Harwich

UPDATED POND CLASSIFICATION

The updated Atlas reviews pond monitoring efforts, data analysis, actions, and impacts that have changed in the nearly 20 years since the original Atlas was released. The update began with a comprehensive review of pond and lake characteristics. While the 2003 Atlas identified 994 ponds, newer data and revised definitions led to identification of 890 ponds and lakes that span the region today. Ponds are defined as fresh, static, and permanent water bodies greater than 10,000 square feet. Utilizing the best available data and analysis has resulted in a more accurate and improved database of freshwater ponds and lakes.

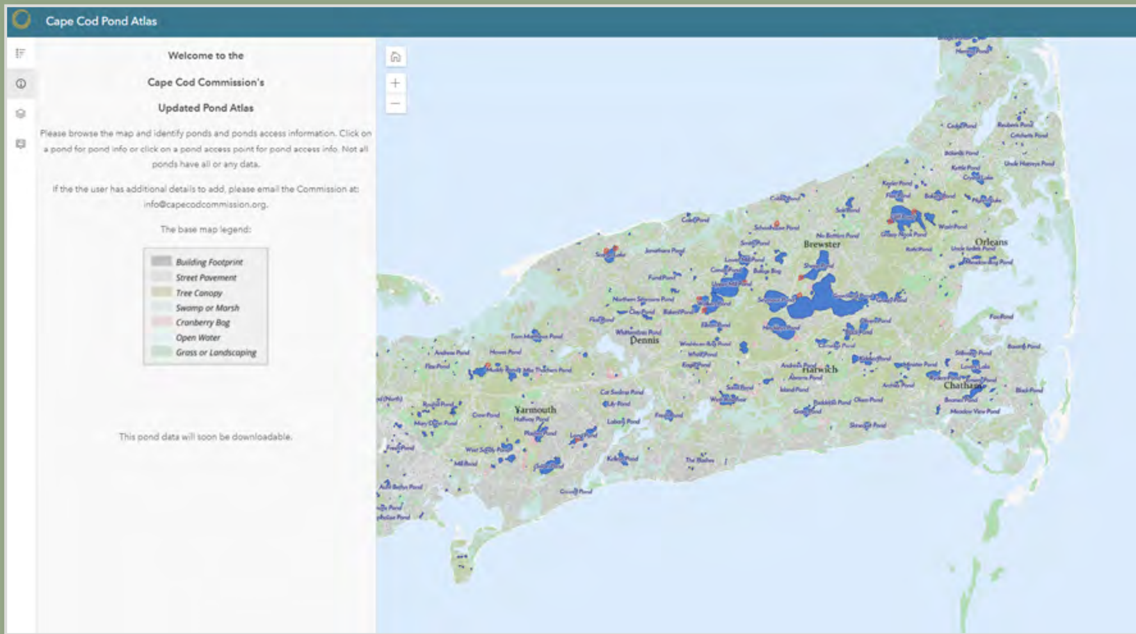
Ponds included in the 2003 Atlas that are not classified as ponds today include ephemeral (or seasonal) pools, salt ponds, waterbodies under 10,000 sq ft, and water resources that are classified as wetlands. Information on specific Cape Cod ponds is now available in the Cape Cod Ponds Atlas Viewer.

PONDS INCLUDED IN THE 2003 ATLAS THAT ARE NOT CLASSIFIED AS PONDS IN THE ATLAS UPDATE INCLUDE:

- SALT PONDS
- WATERBODIES UNDER 10,000 SQ FT
- SEASONAL POOLS
- WETLANDS

An area in Truro, classified in the 2003 Atlas as a pond, has changed over time (shown at left). Aerial images in 2009, 2014 and 2020 consistently show little water in the area. The area is now classified as wetland. This classification is also in alignment with updated federal and state designations in 2015 and 2020.

DATA SOURCES: Commission staff utilized the Massachusetts Wetlands Protection Act definitions, US Fish and Wildlife Service National Wetlands Inventory, MA Department of Environmental Protection Wetlands dataset, multiple recent years of finer resolution aerial photographs, planimetrics (derived from 3D interpretation of aerial photography), and site visits to identify ponds and lakes.



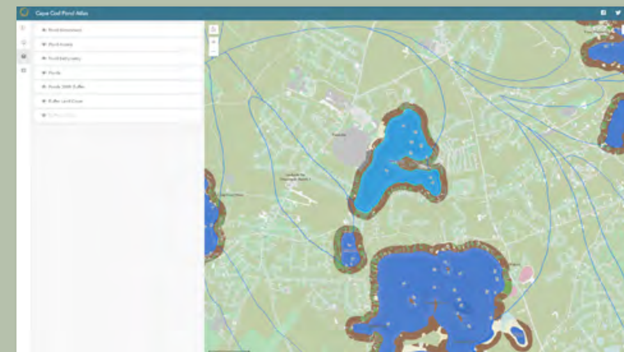
Cape Cod Pond Viewer

AN ATLAS COMPANION

The Pond Viewer serves as a companion to the Atlas and can be used to explore Cape Cod's ponds, ecology, and the challenges they face.

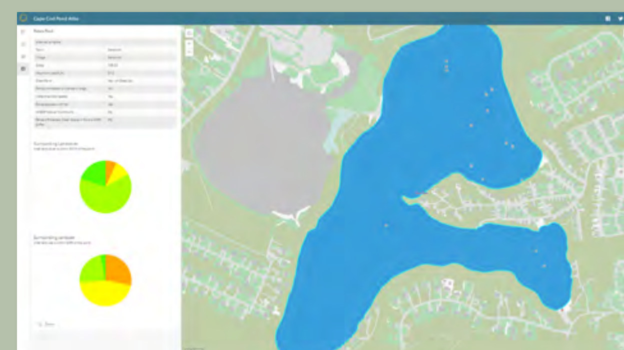
Users can identify ponds and pond access information using the map interface. Click on a pond to view pond characteristics or click on a pond access point for pond access details. Not all ponds have available data.

EXPLORE: cccom.link/pond-atlas



MAP LAYERS

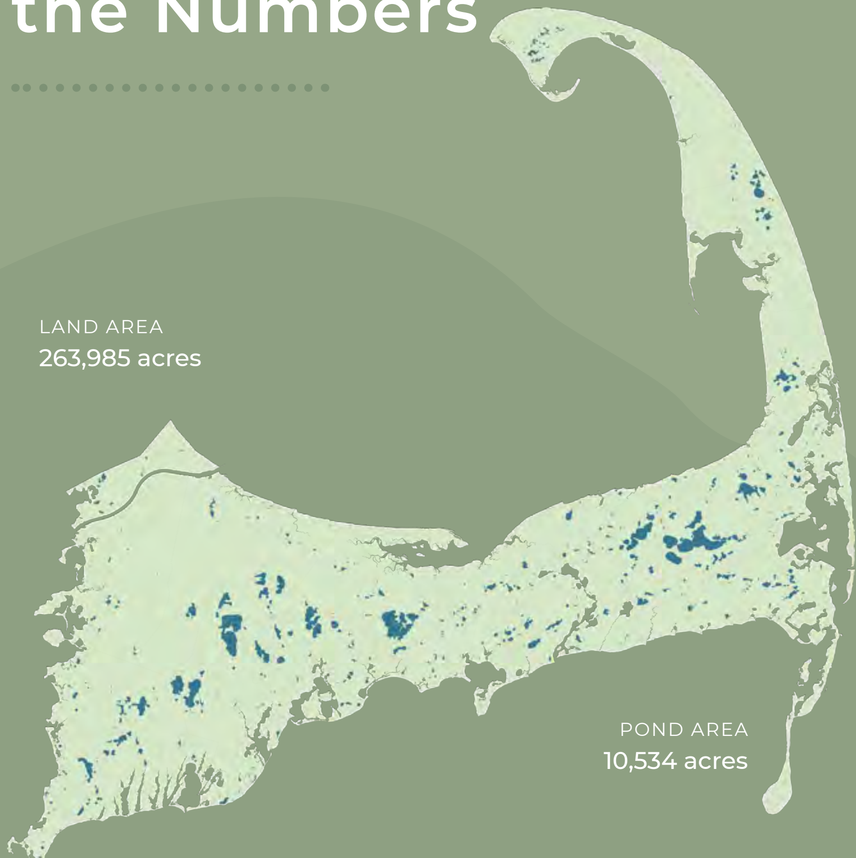
Available map layers include access points, pond watershed delineations, bathymetry data, 300 ft. pond buffer area, and other pond and surrounding land use characteristics.



POND CHARACTERISTICS

Select a pond and open the Info Panel to view related characteristics including acreage, depth, and more. Users can also explore surrounding land cover and land use summaries within a 300 ft. pond buffer area.

Cape Cod Ponds by the Numbers



890 PONDS

171 10+ Acre Ponds

395 Named Ponds

LARGEST PONDS *by area*

1. Long Pond
   Brewster and Harwich
2. Mashpee-Wakeby Pond
   Mashpee and Sandwich
3. Wequaquet Lake
   Barnstable

DEEPEST PONDS *with data available*

1. Cliff Pond
   Brewster
2. Hamblin Pond
   Barnstable
3. White Pond
   Chatham

27 Fish Stocked Ponds

107 Ponds Adjacent to Cranberry Bogs

22 Ponds that Cross Town Boundaries

96 Ponds with Public Access*

30% Protected Open Space
within pond 300ft buffer

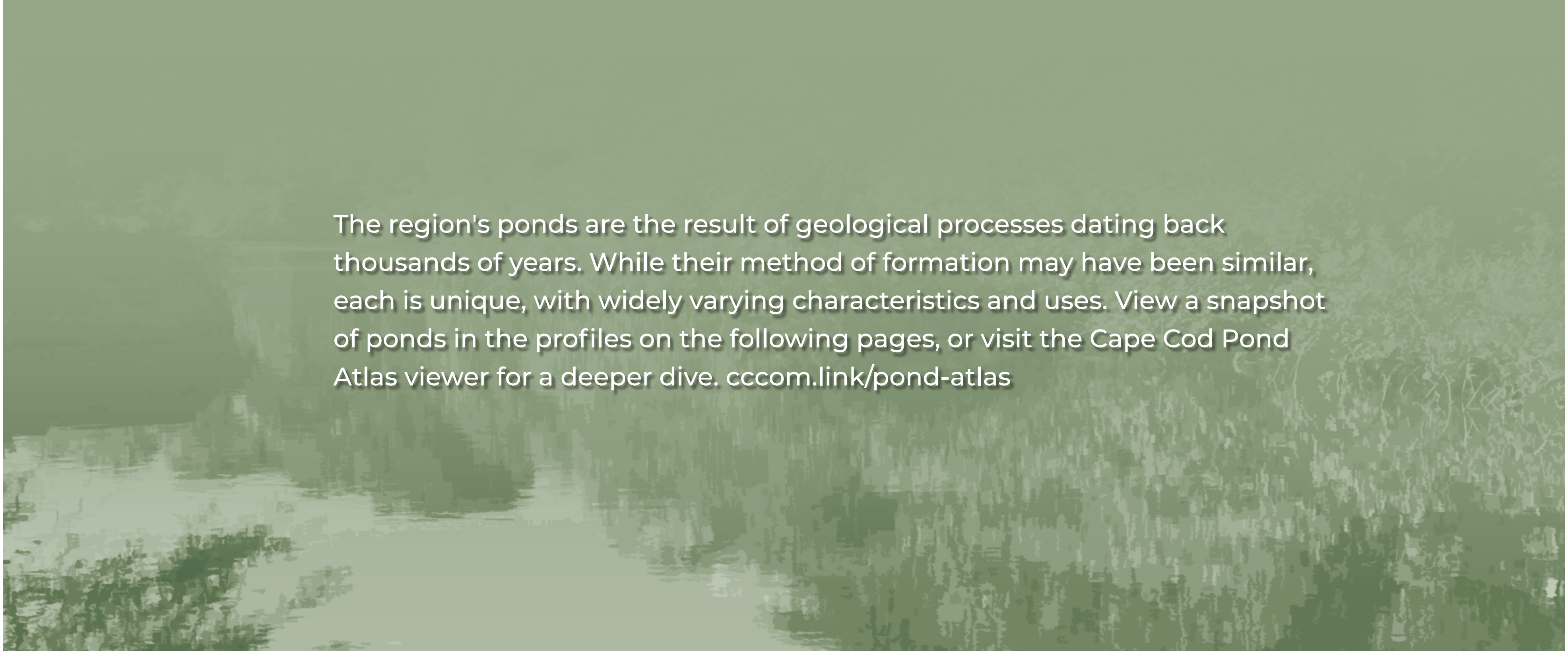
14% Impervious Surfaces
within pond 300ft buffer

**Includes public beaches, boat ramps, and launches*

CAPE COD PONDS AND LAKES

As defined in this Atlas, there are 890 ponds and lakes across the region.

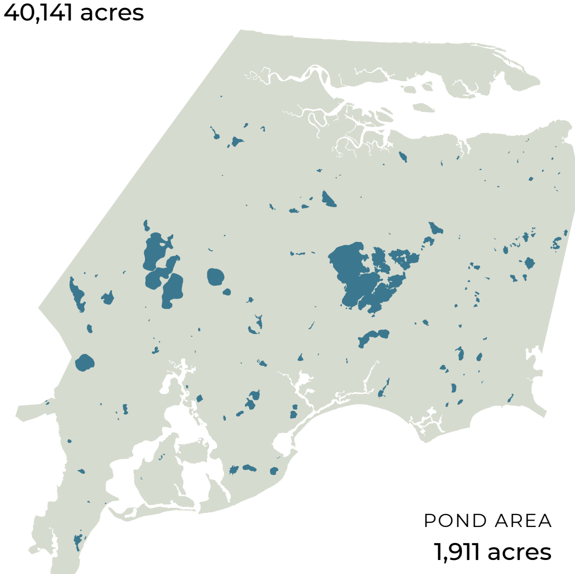
Explore more data at: cccom.link/pond-atlas



The region's ponds are the result of geological processes dating back thousands of years. While their method of formation may have been similar, each is unique, with widely varying characteristics and uses. View a snapshot of ponds in the profiles on the following pages, or visit the Cape Cod Pond Atlas viewer for a deeper dive. cccom.link/pond-atlas

Barnstable

40,141 acres



POND AREA
1,911 acres

163 PONDS

27 10 Acre+ Ponds

62 Named Ponds

Wequaquet Lake (673 acres)
LARGEST POND *by area*

Hamblin Pond (62 feet deep)
DEEPEST POND *with data available*

4 Fish Stocked Ponds

18 Ponds Adjacent to Cranberry Bogs

1 Ponds that Cross Town Boundaries

11 Ponds with Public Access*

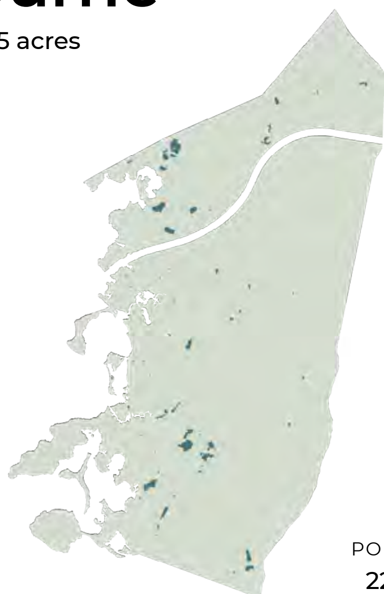
19% Protected Open Space within pond 300ft buffer

16% Impervious Surfaces within pond 300ft buffer

**Includes public beaches, boat ramps, and launches*

Bourne

26,465 acres



POND AREA
228 acres

64 PONDS

6 10 Acre+ Ponds

31 Named Ponds

Flax Pond (23 acres)
LARGEST POND *by area*

Queen Sewell Pond (28 feet deep)
DEEPEST POND *with data available*

0 Fish Stocked Ponds

11 Ponds Adjacent to Cranberry Bogs

0 Ponds that Cross Town Boundaries

4 Ponds with Public Access*

27% Protected Open Space within pond 300ft buffer

13% Impervious Surfaces within pond 300ft buffer

Brewster

16,261 acres

POND AREA
1,785 acres

82 PONDS

27 10 Acre+ Ponds

51 Named Ponds

Long Pond (743 acres)
LARGEST POND *by area*

Cliff Pond (88 feet deep)
DEEPEST POND *with data available*

6 Fish Stocked Ponds

10 Ponds Adjacent to Cranberry Bogs

13 Ponds that Cross Town Boundaries

11 Ponds with Public Access*

37% Protected Open Space within pond 300ft buffer

8% Impervious Surfaces within pond 300ft buffer

**Includes public beaches, boat ramps, and launches*

Chatham

10,913 acres

POND AREA
280 acres

37 PONDS

7 10 Acre+ Ponds

24 Named Ponds

White Pond (43 acres)
LARGEST POND *by area*

White Pond (59 feet deep)
DEEPEST POND *with data available*

2 Fish Stocked Ponds

7 Ponds Adjacent to Cranberry Bogs

1 Ponds that Cross Town Boundaries

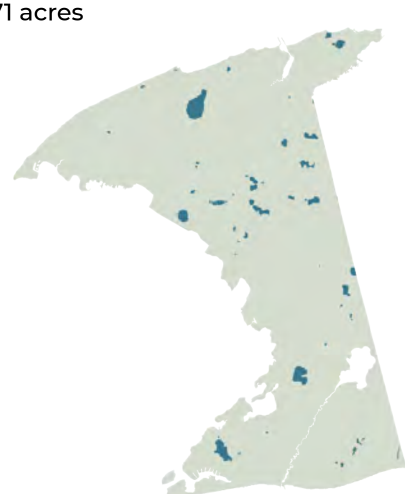
12 Ponds with Public Access*

24% Protected Open Space
within pond 300ft buffer

13% Impervious Surfaces
within pond 300ft buffer

Dennis

13,671 acres



POND AREA
269 acres

52 PONDS

11 10 Acre+ Ponds

24 Named Ponds

Scargo Lake (61 acres)
LARGEST POND *by area*

Scargo Lake (45 feet deep)
DEEPEST POND *with data available*

1 Fish Stocked Ponds

2 Ponds Adjacent to Cranberry Bogs

3 Ponds that Cross Town Boundaries

10 Ponds with Public Access*

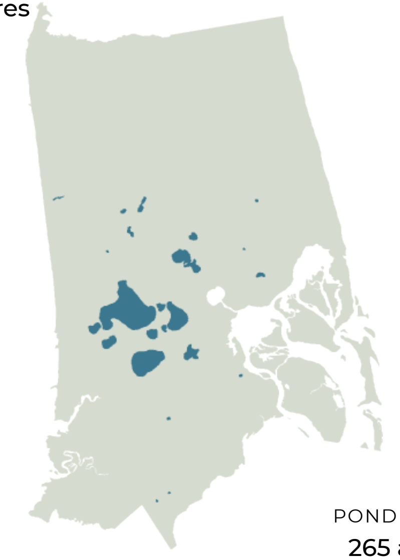
38% Protected Open Space
within pond 300ft buffer

13% Impervious Surfaces
within pond 300ft buffer

**Includes public beaches, boat ramps, and launches*

Eastham

9,181 acres



POND AREA
265 acres

23 PONDS

5 10 Acre+ Ponds

16 Named Ponds

Great Pond (113 acres)
LARGEST POND *by area*

Great Pond (36 feet deep)
DEEPEST POND *with data available*

1 Fish Stocked Ponds

0 Ponds Adjacent to Cranberry Bogs

0 Ponds that Cross Town Boundaries

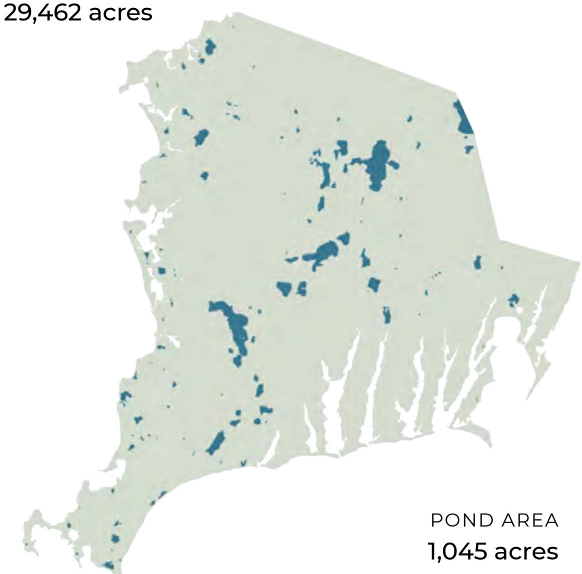
9 Ponds with Public Access*

23% Protected Open Space
within pond 300ft buffer

12% Impervious Surfaces
within pond 300ft buffer

Falmouth

29,462 acres



POND AREA
1,045 acres

123 PONDS

24 10 Acre+ Ponds

48 Named Ponds

Ashumet Pond (220 acres)
LARGEST POND *by area*

Ashumet Pond (84 feet deep)
DEEPEST POND *with data available*

4 Fish Stocked Ponds

14 Ponds Adjacent to Cranberry Bogs

3 Ponds that Cross Town Boundaries

6 Ponds with Public Access*

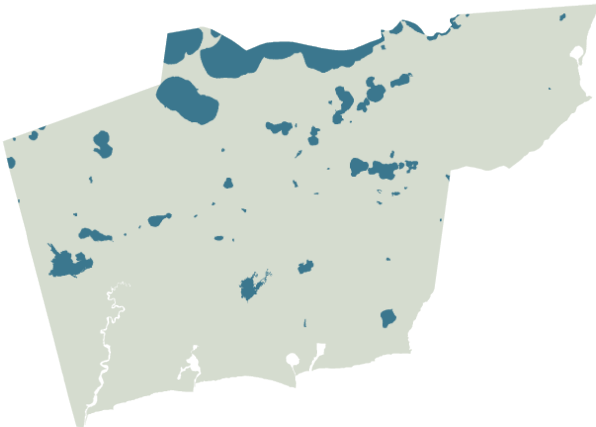
30% Protected Open Space
within pond 300ft buffer

17% Impervious Surfaces
within pond 300ft buffer

**Includes public beaches, boat ramps, and launches*

Harwich

14,442 acres



POND AREA
1,103 acres

62 PONDS

27 10 Acre+ Ponds

36 Named Ponds

Long Pond (743 acres)
LARGEST POND *by area*

Long Pond (70 feet deep)
DEEPEST POND *with data available*

0 Fish Stocked Ponds

13 Ponds Adjacent to Cranberry Bogs

12 Ponds that Cross Town Boundaries

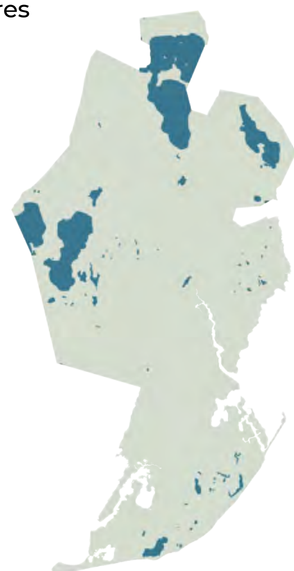
7 Ponds with Public Access*

26% Protected Open Space
within pond 300ft buffer

13% Impervious Surfaces
within pond 300ft buffer

Mashpee

16,584 acres



POND AREA
1,566 acres

69 PONDS

12 10 Acre+ Ponds

21 Named Ponds

Mashpee-Wakeby Pond (736 acres)
LARGEST POND *by area*

Ashumet Pond (84 feet deep)
DEEPEST POND *with data available*

5 Fish Stocked Ponds

10 Ponds Adjacent to Cranberry Bogs

7 Ponds that Cross Town Boundaries

4 Ponds with Public Access*

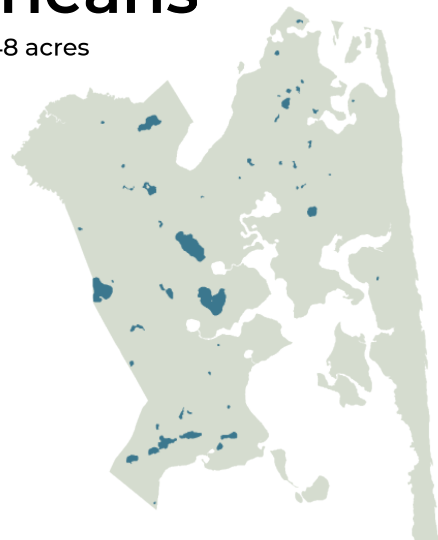
19% Protected Open Space
within pond 300ft buffer

14% Impervious Surfaces
within pond 300ft buffer

**Includes public beaches, boat ramps, and launches*

Orleans

9,248 acres



POND AREA
222 acres

49 PONDS

5 10 Acre+ Ponds

20 Named Ponds

Pilgrim Lake (44 acres)
LARGEST POND *by area*

Bakers Pond (54 feet deep)
DEEPEST POND *with data available*

2 Fish Stocked Ponds

3 Ponds Adjacent to Cranberry Bogs

1 Ponds that Cross Town Boundaries

4 Ponds with Public Access*

21% Protected Open Space within pond 300ft buffer

14% Impervious Surfaces within pond 300ft buffer

Provincetown

6,443 acres

POND AREA
159 acres

36 PONDS

4 10 Acre+ Ponds

10 Named Ponds

Clapps Pond (43 acres)
LARGEST POND *by area*

Bennett Pond (6 feet deep)
DEEPEST POND *with data available*

0 Fish Stocked Ponds

0 Ponds Adjacent to Cranberry Bogs

0 Ponds that Cross Town Boundaries

5 Ponds with Public Access*

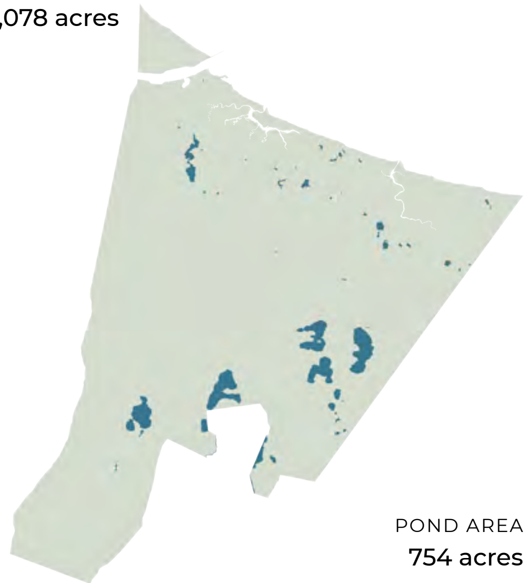
90% Protected Open Space within pond 300ft buffer

5% Impervious Surfaces within pond 300ft buffer

**Includes public beaches, boat ramps, and launches*

Sandwich

28,078 acres



POND AREA
754 acres

55 PONDS

11 10 Acre+ Ponds

18 Named Ponds

Mashpee-Wakeby Pond (736 acres)
LARGEST POND *by area*

Peters Pond (57 feet deep)
DEEPEST POND *with data available*

4 Fish Stocked Ponds

17 Ponds Adjacent to Cranberry Bogs

3 Ponds that Cross Town Boundaries

7 Ponds with Public Access*

23% Protected Open Space within pond 300ft buffer

13% Impervious Surfaces within pond 300ft buffer

Truro

13,864 acres

POND AREA
225 acres

15 PONDS

4 10 Acre+ Ponds

9 Named Ponds

Slough Pond (31 acres)
LARGEST POND *by area*

Great Pond (35 feet deep)
DEEPEST POND *with data available*

1 Fish Stocked Ponds

0 Ponds Adjacent to Cranberry Bogs

0 Ponds that Cross Town Boundaries

1 Ponds with Public Access*

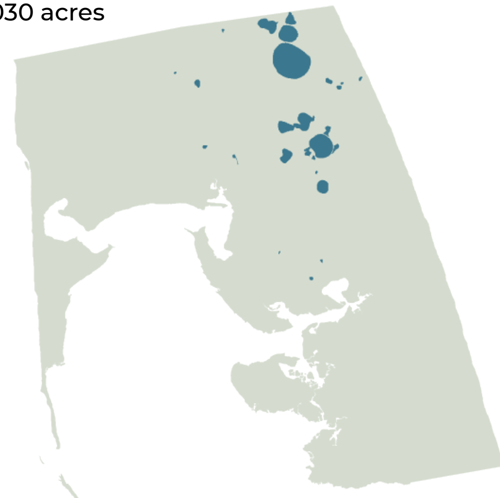
41% Protected Open Space within pond 300ft buffer

13% Impervious Surfaces within pond 300ft buffer

**Includes public beaches, boat ramps, and launches*

Wellfleet

13,030 acres



POND AREA
294 acres

25 PONDS

7 10 Acre+ Ponds

18 Named Ponds

Gull Pond (108 acres)
LARGEST POND *by area*

Gull Pond (64 feet deep)
DEEPEST POND *with data available*

1 Fish Stocked Ponds

0 Ponds Adjacent to Cranberry Bogs

0 Ponds that Cross Town Boundaries

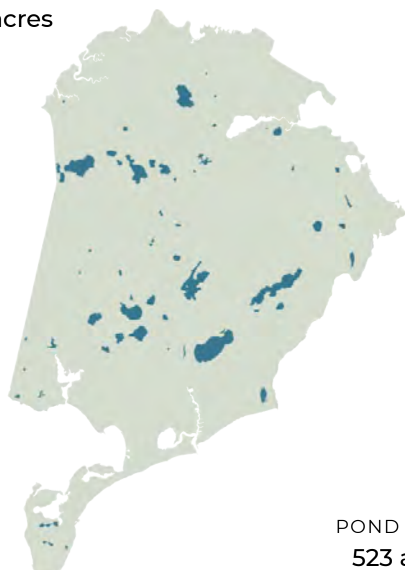
8 Ponds with Public Access*

49% Protected Open Space within pond 300ft buffer

7% Impervious Surfaces within pond 300ft buffer

Yarmouth

16,202 acres



POND AREA
523 acres

60 PONDS

11 10 Acre+ Ponds

28 Named Ponds

Swan Pond (89 acres)
LARGEST POND *by area*

Long Pond (30 feet deep)
DEEPEST POND *with data available*

1 Fish Stocked Ponds

8 Ponds Adjacent to Cranberry Bogs

0 Ponds that Cross Town Boundaries

4 Ponds with Public Access*

28% Protected Open Space within pond 300ft buffer

14% Impervious Surfaces within pond 300ft buffer

**Includes public beaches, boat ramps, and launches*

Pond Function and Management

Pond ecology is influenced by geography, the presence of stream inlets and outlets, surrounding land cover and use, as well as seasonal changes and the changing climate. Variations in these characteristics help define how a pond functions, its role within the greater ecosystem, and how people use these resources. As pond health changes through human activity, pond management will also depend on awareness and interest in pond protection.

HOW PONDS FUNCTION

A pond, when seen from a distance, appears to be a uniform mass of water fixed on the landscape, when in fact it is heterogeneous and dynamic. Its physical, chemical, and biological properties are extremely variable. A pond varies physically in terms of light penetration, temperature, and water circulation; chemically in terms of alkalinity, pH, and dissolved oxygen; and biologically in terms of aquatic species, diversity, and abundance. These properties interact to produce the diversity of ponds present on the Cape.

POND FORMATION AND HYDROLOGY

The ponds that Cape Cod residents and visitors are familiar with today are the result of geological processes dating back thousands of years. The current Cape Cod landscape is a product of glacial movement that most recently concluded about 12,000 years ago leaving deposits that formed moraines and outwash plains as the glaciers retreated to the north. Generally, the Cape's

Higgins Pond, Brewster

ponds are depressions left in the land surface after the glaciers retreated (**Figure 1**). The glaciers left large chunks of ice that were surrounded and covered by sand and gravel carried by glacial meltwater. As these chunks of ice melted, the landscape above them collapsed forming depressions or "kettles." As precipitation fell and the Cape's aquifer system developed, the water table eventually rose to fill these kettles and create many of the hundreds of ponds that exist on Cape Cod today.

The same glacial processes that led to the formation of kettle ponds throughout Cape Cod's landscape are also largely responsible for the appearance and composition of the entire landmass. The sand and gravel deposited throughout the region during glacial retreat makes up the majority of the subsurface. The high permeability of the deposited subsurface materials created an aquifer system, the Cape Cod Aquifer, that is both highly productive and extremely vulnerable to excess nutrient inputs, and biological and chemical contamination.

The Cape Cod Aquifer provides 100% of the Cape's drinking water, and for this reason has been designated a Sole Source Aquifer under the Safe Drinking Water Act by the United States Environmental Protection Agency (EPA). Within the aquifer there are six separate areas of groundwater called lenses. They are named by their location: Sagamore, Monomoy, Nauset, Chequessett, Pamet, and Pilgrim. Lenses of the Cape Cod Aquifer are not confined by impermeable layers (e.g., silt, clay, or bedrock), instead they are separated by tidal rivers which are

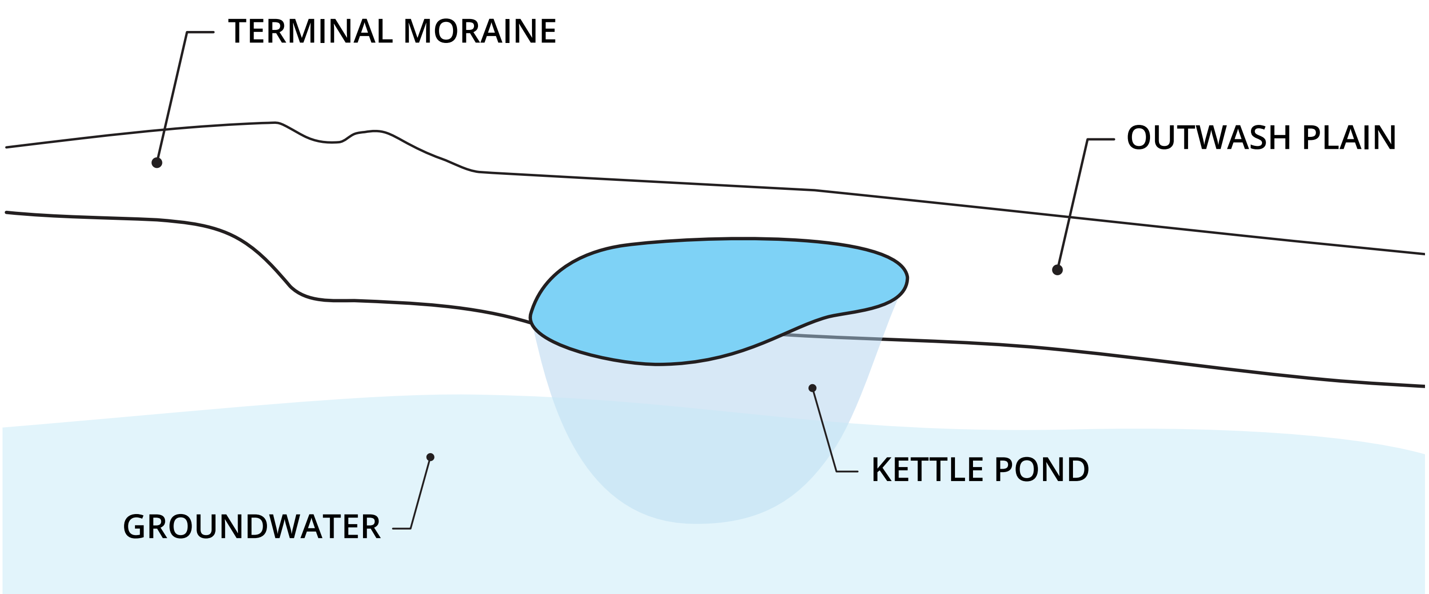


Figure 1. Illustration of glacial retreat depositing sediments and ice chunks to form the Cape Cod landscape including kettle ponds.

UNIQUE PROVINCETOWN POND FORMATION

While all Cape Cod ponds are unique, Provincetown's ponds are notable due to their distinct formation and characteristics. When the glaciers retreated, Provincetown did not exist. As waves eroded the Cape's Atlantic-facing coastal bluffs and longshore drift and currents transported and redeposited sediments to the north, the Provincetown sand dunes appeared.[1] Sand spits continued to grow northward and westward, and wind blew sand inland to form a wide expanse of undulating dunes.[2] As the landscape matured, the dunes stabilized, and forests grew. In the swales between dune ridges, where depressions were low enough to intersect with groundwater, freshwater wetlands, including ponds, emerged.

These interdunal swales are recognized by the Massachusetts Natural Heritage and Endangered Species Program as a natural community of biodiversity conservation interest.[3] Interdunal swales support distinct grass- and shrub-dominated plant communities. Swales can function as vernal pool habitat and provide important amphibian breeding habitat, particularly for toads such as the American toad, Fowler's toad, and eastern spadefoot. Swales can also be an important source of freshwater in the generally very dry and exposed sand dunes.

As noted in the Atlas, due to their unique formation, Provincetown's ponds are much younger than most of Cape Cod's ponds and are generally shallow, very acidic, and contain moderate to high concentrations of nutrients. Nutrient concentrations in Provincetown ponds are likely reflective of natural conditions of these ponds rather than the result of human impacts. Because Provincetown's ponds are so different, their monitoring and management is also different and results from pond monitoring in Provincetown may not be comparable to results from other ponds.

Clapps Pond (top) and an aerial view (below) both provide examples of Provincetown ponds.

Footnotes:

1. Oldale, Robert N. 1976. Geologic history of Cape Cod, Massachusetts. Available at https://pubs.usgs.gov/gip/capecod/ or https://pubs.usgs.gov/gip/7000013/report.pdf

2. Giese, Graham S. et al. 2015. Coastal landforms and processes at the Cape Cod National Seashore, Massachusetts. Available at https://pubs.usgs.gov/circ/1417/circ1417.pdf

3. Natural Heritage & Endangered Species Program. Classification of Natural Communities of Massachusetts – Interdunal Marsh/Swale. 2016. Available at https://www.mass.gov/files/documents/2016/08/ro/interdunal-marsh-swale-fs.pdf

areas of low groundwater elevation where discharge occurs (Bass River, Rock Harbor Creek, Blackfish Creek, Pamet River, Pilgrim Lake). Within each lens the ponds and lakes, groundwater, rivers and streams, and coastal and marine waters are all connected as part of the same hydrologic cycle (**Figure 2**).[4]

Kettle ponds are connected to groundwater because they formed where depressions in the land surface extend below the water table. They generally lack surface waters flowing into or out of them. Precipitation infiltrates through the soil and replenishes groundwater, runs along the land surface to areas of low elevation, or falls into the pond directly. The water level of these ponds is maintained because their sandy sides allow a steady inflow and outflow of groundwater to and from the adjacent aquifer. As groundwater flows into the pond on the upgradient side (area of higher groundwater elevation) and out of the pond on the downgradient side (area of lower groundwater elevation), the pond surfaces fluctuate up and down in response to the rise and fall of the water table. For this

Figure 2. The six distinct groundwater lenses on Cape Cod and the low-lying bodies of water that separate them.

4 Leblanc, D.R., J.H. Guswa, M.H. Frimpter, and C.J. Londquist. (1986) Ground-water Resources of Cape Cod Massachusetts. Hydrologic Atlas 692. https://doi.org/10.3133/ha692.

reason, scientists often refer to Cape Cod's freshwater ponds as "windows into the aquifer." Through this connection, ponds are directly linked to the region's drinking water supplies, coastal estuaries, as well as any sources of contamination that have entered the regional aquifer system.

While many of the Cape's ponds lack surface water inlets or outlets, others connect to coastal and marine waters surrounding Cape Cod via rivers, streams, or creeks. Examples of kettle ponds lacking surface water connections include the ponds in Nickerson State Park in Brewster and those in the Hyannis Ponds Wildlife Management Area in Barnstable. Examples of ponds with surface water connections to the coast include Herring Pond in Eastham and Santuit Pond in Mashpee. Ponds connected to the coast may support fish and wildlife species that depend on these connections, including important fish species such as American eel and river herring (alewife and blueback herring). These species are diadromous, migrating between salt and fresh waters to live out different life stages.

Diadromous species can be further classified as anadromous, migrating up rivers from the sea to spawn in fresh waters, or catadromous, migrating down rivers to the sea to spawn in salt waters. River herring are anadromous and American eel are catadromous.

POND ECOSYSTEMS

Each pond is an ecosystem, a system of interconnected biological organisms and their physical-chemical environment. Physical features include the surface shape of the pond, bathymetry, surrounding topography, and watershed size. Outside physical factors such as strength and direction of wind, air temperature, and groundwater and surface water inflows and outflows also play important roles in how a given pond ecosystem functions. Chemical features include alkalinity, pH, and dissolved oxygen. Biological features include the pond flora and fauna, both permanent and transient. A pond is a complex web of interactions among numerous biological species, chemical compounds, hydrological processes, and human actions, all in constant change.[5]

The terrestrial land beyond the perimeter of the pond influences the system as well. The land area from which water flows to a particular pond is called a watershed and watershed characteristics influence the pond ecosystem. In many regions, watersheds are determined by the topography of the land surface, but due to Cape Cod's geology, the watersheds are determined by the contours of the groundwater table. Therefore, a useful definition of a pond ecosystem is the pond and its watershed. Most impacts on ponds can be related to characteristics of the watershed, although atmospheric (e.g., aerial deposition of wide-spread pollutants, rain) and climate change (e.g., warming air temperatures, altered seasons) impacts demonstrate ponds are susceptible to influences from beyond their watersheds.

Biological communities within ponds can be organized into freshwater aquatic food or energy chains to help understand pond ecosystem functions and interactions (**Figure 3**). At the base of the food chain, primary

5 Wagner, K.J. (2004). The Practical Guide to Lake Management in Massachusetts. Department of Environmental Protection and Department of Conservation and Recreation. Available at https://www.mass.gov/doc/the-practical-guide-to-lake-management-in-massachusetts/download.

producers such as phytoplankton and macrophytes convert sunlight and nutrients into usable forms of energy for other aquatic organisms and are essential to supporting a healthy pond. These primary producers support a complex pond food web of primary consumers such as zooplankton, secondary consumers such as macroinvertebrates and forage fish, and tertiary consumers (predators) such as bass, birds, and humans.

Aquatic food chains depend on two essential biological processes: photosynthesis and respiration. Through photosynthesis, primary producers use the sun's energy to convert carbon dioxide dissolved in water into sugars that can be utilized and converted into other organic molecules by consumers. Oxygen produced during photosynthesis or diffused into the water body from the atmosphere is also needed and used by consumers. Consumers use both sugar and oxygen to fuel their activities via respiration, which generates water and carbon dioxide needed for photosynthesis.

While relative levels of photosynthesis and respiration influence dissolved oxygen concentrations, temperature is the key determinant of the amount of oxygen that

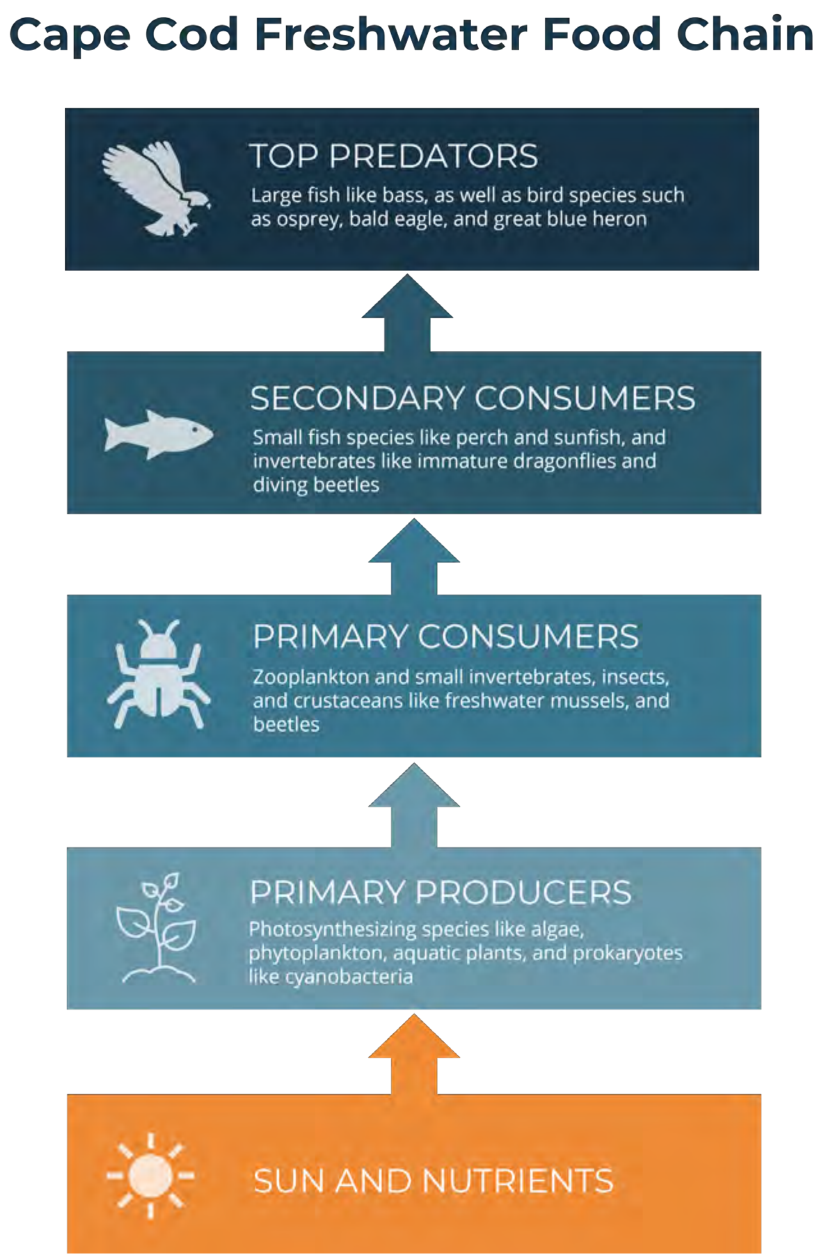


Figure 3. Cape Cod freshwater system food chain. The food chain is fueled by sunlight and nutrients that are used by photosynthesizing primary producers. Example species commonly found on the Cape are included for succeeding levels of the food chain.

can be dissolved in pond water. Colder water holds more oxygen than warmer water. Because water temperature is so critically connected to dissolved oxygen, it plays an important role in determining the suitability of a pond for certain species. Although deeper, cooler waters can support high levels of dissolved oxygen, influxes of organic material (e.g., dead algae or other plant material) from the surface can catalyze low oxygen conditions as bacteria consume oxygen and produce carbon dioxide while breaking down the organic material. When oversupply of organic materials in the pond reaches a certain point, its decomposition will consume enough oxygen to create hypoxic (low oxygen) or anoxic (no oxygen) conditions. These conditions will cause mobile aquatic species, such as fish, to seek colder bottom waters where oxygen may be more plentiful. If unavailable or if hypoxic conditions occur rapidly, fish in a pond or a portion of a pond can die. Less mobile or immobile species, such as mussels, cannot move to waters with more oxygen and are often killed during these events. Anoxic or hypoxic conditions can occur in any pond, regardless of depth.

The ecosystems of Cape Cod ponds change throughout seasons of a year and from year to year depending on the factors above, but temperature changes are a key factor for every pond, especially seasonal thermal stratification in deeper ponds. Warmer, less dense water floats at the surface and colder, denser water sinks. The difference in density between surface and bottom waters creates a thermocline (temperature gradient in a body of water) that is resistant to mixing (**Figure 4**). In summer, the less dense water near the surface warms, strengthening the thermocline and creating layers of different water temperature within the water column, stratifying the pond. In autumn, less solar radiation reaches the water and greater heat losses occur at night, reducing the difference in temperature between the layers. Convection and wind mixing continue to weaken the thermocline. Surface water increases in density as it decreases in

Lake Wequaquet, Barnstable pictured here in both summer and winter.

temperature, and downward movement of cooler surface water allows for mixing to occur, known as the fall overturn. As winter approaches, cooling continues making dense water sink to the bottom. As surface water freezes and floats, it is less dense, allowing stratification to occur again. Spring conditions warm surface temperatures and wind mixes the water causing the spring overturn. Deep lakes undergo these seasonal cycles. Small, shallow ponds exposed to wind may stratify and de-stratify daily as ponds cool in the evening and are circulated by winds, whereas large, deep ponds will remain stratified unless a storm occurs. Stable thermal stratification determines distribution of dissolved nutrients and gases and has implications for water quality and species life cycles.[6]

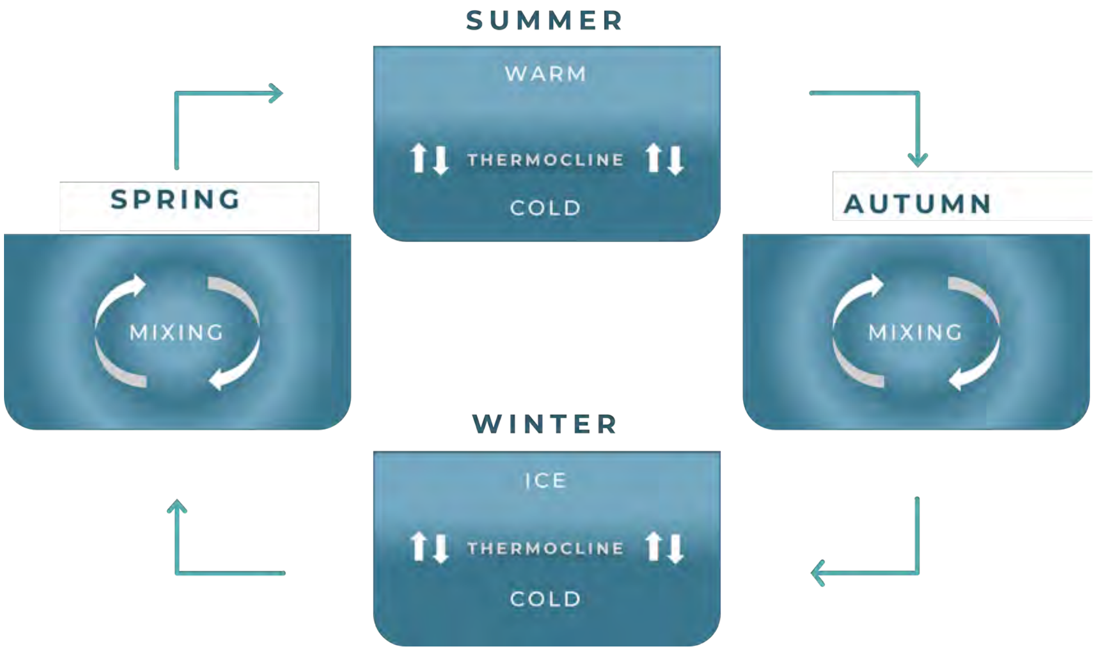


Figure 4. Seasonal climate changes affect pond water temperature and density, resulting in stratification (layering) during summer and winter, and mixing of the layers during the spring and fall "overturn.".

6 Horne, A.J., D.R. Goldman (1994). Limnology, 2nd edition. McGraw-Hill, Inc.

POND PRIMARY PRODUCTION

Plant, algae, and bacteria growth is generally limited by available nutrients. As these photosynthetic organisms form the base of pond ecosystems, the amount and types of dominant photosynthetic organisms generally determines the quantity and composition of other organisms present in a pond.

The total weight or mass of all organisms (biomass) in a pond can be used to characterize the pond's trophic status (**Figure 5**). Trophic status can be related to the amount of available phosphorus, algal and plant species present, season, mixing depth, and other factors.[7]

Scientists have established relationships between several water quality monitoring parameters (algal biomass as measured by chlorophyll a, total phosphorus, and Secchi disk measurements) and the corresponding ranges for the different trophic categories.

While the Cape's ponds took many years to form and may appear as permanent and fixed features on the landscape, they continue to change through natural and anthropogenic processes.[8] All ponds undergo natural succession. Aging ponds fill with sediment and organic matter, becoming smaller and shallower, and undergo changes in plant species composition transitioning from open water with limited vegetation, to more vegetated ponds, and eventually to vegetated wetlands. Water quality and animal life also change in response to physical and

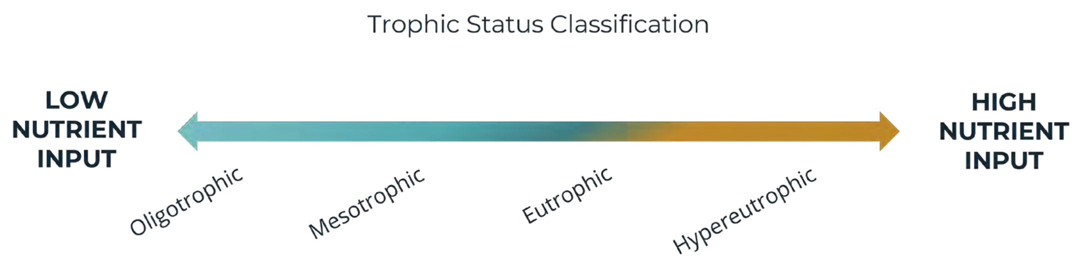


Figure 5. Trophic Status in ponds is defined by the amount of biomass within the water body.

ABOUT POND TROPHIC STATUS

Oligotrophic ponds	have low nutrient inputs and consequently have relatively little primary production.
Mesotrophic ponds	are more productive than oligotrophic ponds but less productive than eutrophic ponds.
Eutrophic ponds	have higher nutrient inputs and significantly more primary production.
Hypereutrophic ponds	have such excessive nutrients that an overabundance of plant and algal growth results and as these die off, bacteria may use up the available oxygen in the water leading to fish die offs.

7 Carlson, R.E. and J. Simpson. 1996. A Coordinator's Guide to Volunteer Lake Monitoring Methods. North American Lake Management Society. 96 pp. Available at https://www.nalms.org/product/a-coordinators-guide-to-volunteer-monitoring/ (as referenced by https://www.nalms.org/secchidipin/monitoring-methods/trophic-state-equations/).

8 Hutchinson., G. E. (1957). A Treatise on Limnology. Volume I: Geography, Physics and Chemistry. John Wiley and Sons NY.

floristic changes. Ultimately, a pond becomes a meadow and is no longer a pond at all. This aging process is often accelerated by human impacts such as land clearing and development that increase erosion and sedimentation rates as well as plant, algae, and bacteria growth in and around ponds.[9] However, human actions may delay natural pond succession through active management such as dredging. While natural succession is not always visible and may take thousands of years to occur, ponds are constantly changing chemically, biologically, and physically.

Nutrients entering and accumulating in ponds can gradually and naturally occur, leading to natural eutrophication and succession over long periods of time. Nutrient loading can also be accelerated and a product of human activities, leading to cultural eutrophication. Human impacts tend to add excess nutrients over relatively short periods of time, causing pond trophic conditions to shift rapidly.

Trophic status alone does not necessarily indicate water quality, but the eutrophic or hypereutrophic status of a pond due to cultural eutrophication may indicate that a pond's water quality is degraded. Slight increases in nutrients can increase production, supporting more and bigger fish which may be desirable; however, excessive eutrophication can be problematic.

Sources of excess nutrients on Cape Cod often are a product of land use in the watershed. These sources include stormwater runoff from impervious surfaces (e.g., roads, parking lots) and fertilized lawns that lack buffers of filtering vegetation, as well as contributions from septic systems to and through the aquifer. In particular, the contribution of phosphorus to ponds from these sources will cause nutrient loading and the subsequent impacts mentioned.

In addition to external sources, phosphorus may already be present within the pond's sediment. Pond sediment is largely a product of pond formation during glacial activities, but sediment is also contributed from the surrounding land surface through runoff, and in certain ponds from stream inputs. Sediments can act as a phosphorus sink, forming chemical complexes with phosphorus that are generally inaccessible for primary production. Storage in sediment however is not permanent. As water quality changes from the combined effects of nutrient loading and climate change, geochemical conditions within the pond water and sediments may allow historic phosphorus to unbind from the sediment and remobilize in the water for use.[10]

While pond ecosystems on Cape Cod are similar to those in other parts of the country, there are characteristics within Cape pond ecosystems that are somewhat unique. These conditions include naturally low pH (acidic) water and a water table fluctuation zone along the pond shores due to kettle pond formation and relationship with groundwater.[11] While ponds on Cape

9 Robinson, M. (2004). The Massachusetts Lake and Pond Guide, Massachusetts Department of Conservation and Recreation, Lakes and Ponds Program. Available at https://www.uwsp.edu/cnr-ap/UWEXLakes/Documents/ecology/shoreland/background/mass_lake_and_pond_guide.pdf.

10 Li, R., L. Gao, Q. Wu, Z.L., Lei Hou, Z. Yang, J. Chen, T. Jiang, A. Zhu, and M. Li. (2021). Release characteristics and mechanisms of sediment phosphorus in contaminated and uncontaminated rivers: A case study in South China. Environmental Pollution, Volume 268, Part A. Available at https://doi.org/10.1016/j.envpol.2020.115749.

11 University of Massachusetts Dartmouth School for Marine Science and Technology and Cape Cod Commission. (2009). Brewster Freshwater Ponds: Water Quality Status and Recommendations for Future Actions. Available at https://www.mass.gov/doc/brewster-freshwater-ponds-water-quality-status-and-recommendations-for-future-activities/download.

Cod may be unique when compared to ponds across the state or New England, Cape ponds will also differ from one to another. Understanding individual pond characteristics (i.e., understanding the pond ecosystem) is a fundamental part of determining appropriate management strategies.

VALUE AND PROTECTION OF PONDS

Cape Cod ponds have been called ecological, aesthetic, and recreational treasures.[12] Most individuals appreciate ponds they can see and experience as serene environments and places to recreate. Pond value extends below the water's surface and beyond the pond's shoreline as they provide extensive ecosystem services. These contributions to the greater regional environment and community's well-being provide motivation for their protection and restoration.

ECOLOGICAL

The Cape's ponds, pond shores, and other freshwater wetland resource areas support many of the plant and wildlife species that make the Cape environmentally rich, unique, and treasured. Pond waters and shores support a diverse native biota of microscopic life, aquatic and riparian plants and invertebrates, filter feeders, freshwater fish, amphibians, reptiles, mammals, and birds including migrating and wintering waterfowl. All these species depend on naturally functioning pond ecosystems and clean pond water for their subsistence. In addition, pond and pond shorelines play a vital role in regulating the environment by absorbing and filtering storm and flood waters, providing natural removal of nutrients, recharging the aquifer, storing carbon in sediments and vegetation, and moderating the climate of surrounding areas. From their connection to coastal and marine waters, freshwater ponds play a significantly beneficial role in coastal watershed nutrient budgets.

The Cape's ponds are part of the Atlantic Coastal Pine Barrens ecoregion (**Figure 6**). Pine Barrens are globally rare and are comprised of unique assemblages of plants and animals that thrive on the nutrient-poor soils and variable climate found on Cape Cod. Within the Pine Barrens ecoregion, there are many habitat types, including freshwater ponds and lakes, shrub and forested swamps, pitch pine-oak woodlands, transitional hardwood-pine forests, vernal pools, streams and rivers, estuaries, salt marshes, dunes, beaches, grasslands, and others. This rich mosaic of interconnected habitat types supports numerous state-listed rare plant and animal species as well as common species that depend on these areas year-round or seasonally when migrating or for breeding.[13]

Healthy, naturally vegetated shorelines, also referred to as riparian zones, provide important habitats as well as assist in the management of pollutants, trapping or arresting nutrients and sediment before they can flow into ponds and impair them. Most terrestrial and aquatic species use

12 National Park Service. (2018). Lakes and Ponds, Cape cod National Seashore, Massachusetts. Available at https://www.nps.gov/caco/learn/nature/lakes-and-ponds.htm.

13 Coastal Pine Barrens Endangered Species. Available at https://pinebarrensendangeredspecies.org/. The Nature Conservancy (2009). The Pine Barrens of Southeast Massachusetts. Available at https://www.mass.gov/doc/nature-conservancy-pine-barrens-of-se-mass-brochure/download.

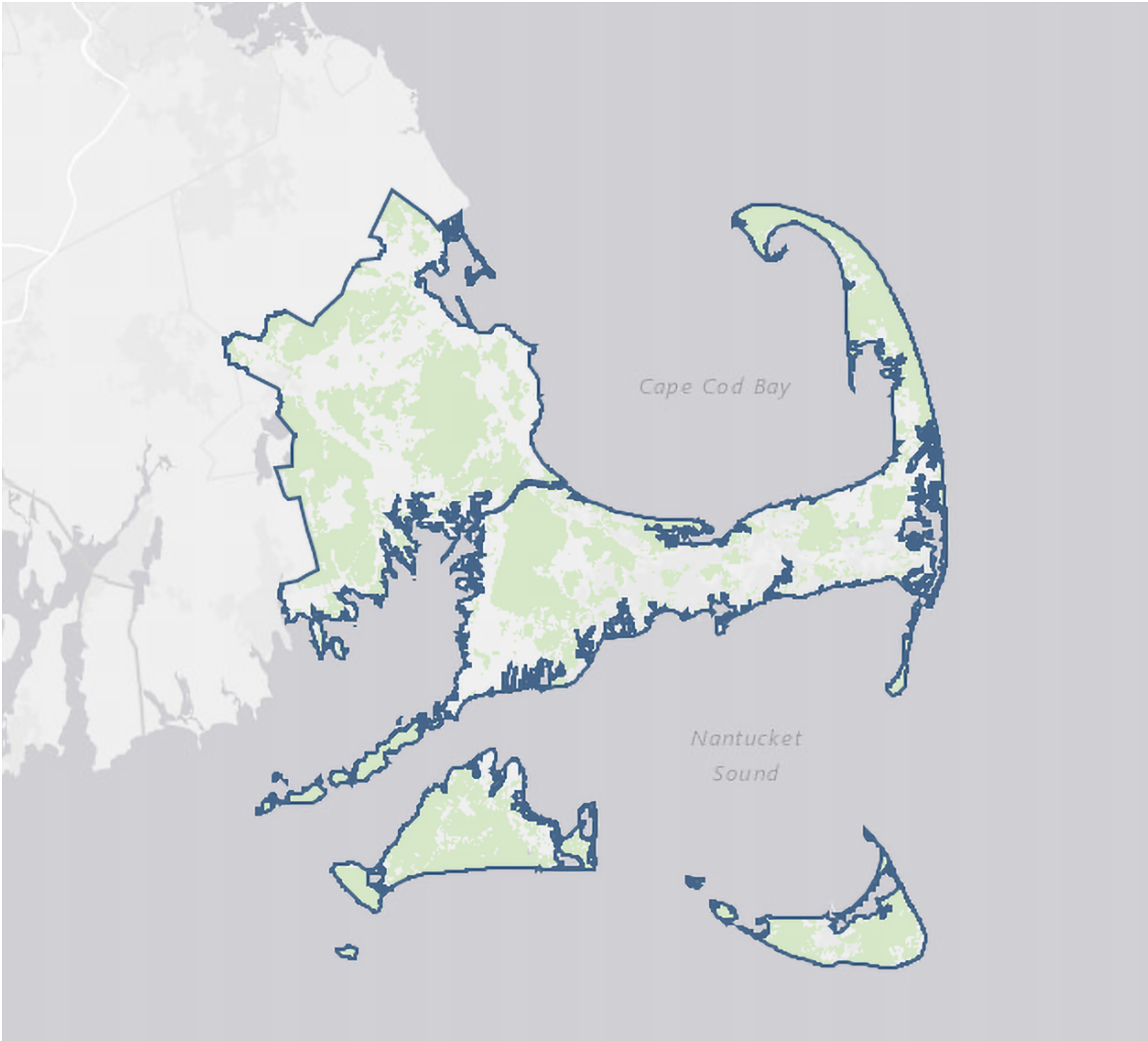


Figure 6. Ecoregions are areas where ecosystems are generally similar. Cape Cod, the Islands, and portions of the southeastern Massachusetts mainland are in the Atlantic Coastal Pine Barrens Ecoregion, Shown here in the blue outline. Shown also (in light green) is the BioMap2 Core Habitat and Critical Natural Landscape Areas.

Atlantic Coastal Pine Barrens Ecoregion

BioMap2 Core Habitat and Critical Natural Landscape Areas

Reference: Massachusetts Coastal Pine Barrens Partnership. Available at: pinebarrenspartnership.org/.

riparian zones at some point of their life, be it for breeding, feeding, migrating, or shelter. Vegetated buffers preserved from development help to prevent erosion, stabilize shorelines, and temper stormwaters. When vegetation is removed from the pond shore and its watershed, the pond water becomes susceptible to sedimentation, pollution, increased water fluctuations, and habitat and species loss. A healthy, diverse native plant community in and around a pond indicates a healthy pond providing valuable habitat.

Many of the Cape's kettle ponds are part of a unique, ecologically distinct, and globally rare Priority Natural Community, the Coastal Plain Pondshore Community. The Massachusetts Natural Heritage and Endangered Species Program (NHESP) identifies Natural Communities as groups of plants and associated animals classified and described by their dominant biological and physical features. The Coastal Plain Pondshore Community is characterized by a distinct plant community associated with shallow, acidic, low nutrient kettle ponds, with gentle slopes and no inlet or outlet.[14] Water in these ponds rises and falls with changes in the groundwater table, typically leaving an exposed shoreline in late summer. Annual and inter-annual water level fluctuations maintain this community. In ponds where the water level has been low for a period of years, scrub pine and scrub oak trees will invade the area of historic fluctuations, but when the water level rises again, inundation kills the invaders and specialized Coastal Plain Pondshore Community species reappear. While NHESP has documented the best examples of these communities on Cape Cod, not all have been recorded.[15]

14 Sorrie, Bruce A. (1994). Coastal plain ponds in New England. Biological Conservation. Volume 68, Issue 3. Available at https://www.sciencedirect.com/science/article/abs/pii/0006320794904103. Massachusetts Division of Fisheries & Wildlife. (2016). Coastal Plain Pondshore Community, Classification of Natural Communities of Massachusetts. Available at https://www.mass.gov/files/documents/2016/08/wi/coastal-plain-pondshore-community-fs.pdf

15 MassGIS (2016). MassGIS Data: NHESP Natural Communities. Available at https://www.mass.gov/info-details/massgis-data-nhesp-natural-communities. MassWildlife NHESP staff (2021), personal communication.

COASTAL PLAIN PONDSHORE COMMUNITIES PROVIDE HABITAT

Coastal Plain Pondshore Communities provide habitat for many state-listed rare animal and plant species. For example, the globally rare Plymouth gentian is a plant that lives within the area of the fluctuating water levels.[16] Named for its native range in coastal Massachusetts, it grows along coastal plain pond shores on Cape Cod as well as several other disjunct locations up and down the east coast.[17]

16 Andres, K. (2020). Ecologically Unique and Globally Rare Habitat— The Cape's Coastal Plain Ponds. The Cape Cod Chronicle. Available at https://capecodwaters.org/wp-content/uploads/2021/02/Coastal-Plain-Ponds.pdf.

17 MassWildlife. (2020). Species Spotlight: Plymouth gentian. Available at https://www.mass.gov/news/species-spotlight-plymouth-gentian.

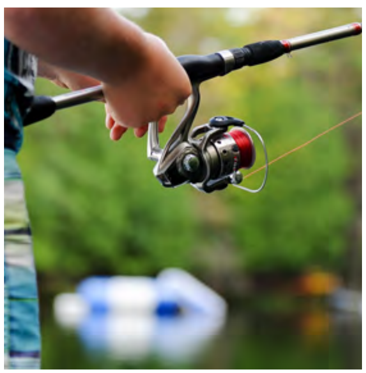
RECREATION

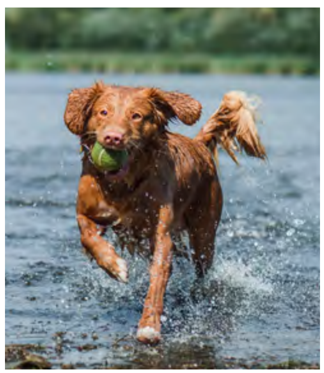
In addition to their ecological value, Cape Cod ponds are hotspots for recreation, and a freshwater alternative to the Cape's popular saltwater beaches. The sandy freshwater ponds are integral to the character of Cape Cod, appealing to both residents and visitors.

In warmer months, ponds support swimming, sun-bathing, picnicking, hiking, fishing, and boating. Motorized watercraft such as motorboats and jet skis for fishing, waterskiing, wakeboarding, and tubing are allowed on some ponds. Only non-motorized watercraft such as canoes, kayaks, stand-up paddleboards, and sailboats are allowed on other ponds. To promote recreational use of freshwater ponds and meet user demands, the provision of seasonal storage racks for unmotorized watercraft has become more common at pond access points. Ponds are also relied upon to host numerous private, and town sponsored recreational activities, including summer camps, as well as swimming and sailing lessons.

In winter, the Cape's ponds may support ice fishing, ice skating, snow shoeing, and cross-country skiing. However, with warming air and water temperatures, the formation and duration of winter ice and snow cover is in decline and these activities may no longer be safe or possible.[18]

Pond use can be limited by the availability of town-owned public access amenities including public parking, landings, and boat ramps. Most towns with public ponds charge for parking during the summer season. More remote ponds may only be accessible by foot or bike trails. Private ponds may only be accessible to the pond's surrounding property owners.





Cape Cod ponds are hotspots for recreation, and a freshwater alternative to saltwater beaches.

FISHERIES

Cape Cod pond fishery resources have been one of their most well documented and long-term uses. The limited fish fauna on Cape Cod includes over 30 species of native, introduced, and diadromous fishes (**Table 1**).[19] Fish runs of river herring are an important resource. Indigenous Wampanoags continue to exercise their aboriginal rights to harvest fish and teach the next generation about traditional ways.

18 Filazzola, A, K. Blagrave, M. Ashrad Imrit, and S. Sharma. (2020). Climate Change Drives Increases in Extreme Events for Lake Ice in the Northern Hemisphere. Geophysical Research Letters 47(18). Available at https://doi.org/10.1029/2020GL089608.

19 Cape Cod fisheries resources information, including table, provided by Steve Hurley, MassWildlife (2021)

Table 1. Fish that occur in Cape Cod ponds or occurred historically. Not all fish occur in all ponds; more common and widespread fish are highlighted in bold. Fish that occurred in Cape Cod ponds historically are italicized. Table adapted from a list of freshwater fish of Cape Cod ponds provided by Steve Hurley, Southeast District Fisheries Manager, MassWildlife (2021).

FISH FAMILY	COMMON NAME	NOTES
Freshwater eels	**American eel**	Catadromous
Herrings	Blueback Herring	Anadromous
	Alewife	Anadromous
Trouts	Rainbow Trout	Stocked
	Brown Trout	Stocked
	Brook Trout	Stocked
	Tiger Trout	Stocked
	Coho Salmon	Stocked
	Kokanee Salmon	Stocked
	Atlantic Salmon	Introduced
Smelts	*Rainbow Smelt*	Anadromous and Stocked
Pikes	Northern Pike	Stocked (Wequaquet Lake)
	Chain Pickerel	Native
Carps and Minnows	**Golden Shiner**	Native
	Bridle Shiner	Native
	Koi	Introduced (Johns Pond)
	Goldfish	Introduced
	Common Carp	Introduced

FISH FAMILY	COMMON NAME	NOTES
Suckers	White Sucker	Native
Bullhead Catfishes	White Catfish	Introduced (Mashpee-Wakeby)
	Yellow Bullhead	Introduced (Coonamessett)
	Brown Bullhead	Native
Killifish	**Banded Killifish**	Native
	Mummichog	Coastal Ponds
Temperate Basses	White Perch	Anadromous (Coastal Ponds)
	Striped Bass	Anadromous (Coastal Ponds)
Sunfishes	Banded Sunfish	Native
	Green sunfish	Introduced
	Pumpkinseed	Native
	Bluegill	Introduced
	Smallmouth Bass	Introduced
	Largemouth Bass	Introduced
	Black Crappie	Introduced
Perches	Tesselated Darter	Native
	Yellow Perch	Native
	Walleye	Stocked

Building of grist mills during the colonial period, while limited on Cape Cod compared to the rest of Massachusetts, led to an increase in formation of small ponds and decline in herring runs and brook trout on Cape Cod. Examples on Cape Cod include the Stony Brook grist mill in Brewster and Dexter grist mill in Sandwich – herring runs at both have since been restored. Town control of herring runs led to the sale of fishing rights in particular streams. This led to the building of herring ditches in the 1700s and 1800s, connecting to headwater ponds to increase herring runs and returns on private parties' investments for the rights to a specific run. These ditches were often later expanded to provide flood water for downstream cranberry bogs.

In the late 1700s and early 1800s, Cape Cod rivers attracted the attention of the first sport anglers fishing for native sea run brook trout, locally known as salters. The 1850s introduction of black bass (smallmouth and largemouth) to Massachusetts started the change in Cape Cod's pond fish fauna.

Establishment of state and federal fisheries agencies led to a long period of fish introductions and fisheries management in Cape Cod ponds. Several species were introduced in the late nineteenth and early twentieth century, including Chinook salmon and rainbow trout from the Pacific coast, Atlantic salmon from Maine, and brown trout from Europe. Native brook trout and white perch were also introduced during this time to enhance their numbers and range.

Starting in 1950, a natural fish poison called rotenone was introduced into many Cape Cod ponds to remove existing fish populations and restock with more desirable recreational species (primarily trout fingerlings). Toxaphene, an insecticide, was briefly used for the same purpose in the 1960s. Data collected during these fish removal and restocking efforts indicated the low fertility of Cape Cod ponds (about 50-100 pounds of fish per acre) and the relatively low proportion (about 5-10 percent) of game fish in a pond's fish population.

Concerns about acid rain and its impacts on fish populations led to the addition of ground limestone in many stocked trout ponds in the 1980s. Liming neutralizes acid waters and can be an effective stopgap measure to maintain fish on a small scale in otherwise acidic lakes and ponds; however, liming has the potential to cause harm to other aquatic organisms, limiting its appropriateness and effectiveness.[20] The passage of clean air legislation has led to a notable reduction in acid rain impacts to Cape Cod ponds and reduced the need for liming.[21]

Massachusetts was colonized and industrialized well before adverse health effects of consuming fish contaminated with harmful industrial chemicals was recognized. Mercury and polychlorinated biphenyls (PCBs) are the primary chemicals of concern.[22] Mercury is a naturally

20 Gould R. (1985) Strategies for Reducing Acid Rain. Going-Sour: 81-85. Available at https://doi.org/10.1007/978-1-4899-6683-4_6. Helfrich, L.A., R.J. Neves, and J. Parkhurst. (2009). Liming Acidified Lakes and Ponds. VCE Publications 420(420-254). Available at https://ext.vt.edu/content/pubs_ext_vt_edu/en/420/420-254/420-254.html.

21 WBUR. (2017). Cape Cod's kettle ponds are showing signs of climate change. Available at https://www.wbur.org/news/2017/08/02/cape-cod-kettle-ponds. Fox, Sophia E. (2021). Pond resource management: Applying science to understand pond condition, ecology, and responses to atmospheric changes and human uses. Presentation at OneCape Summit 2021. Available at https://onecape.capecodcommission.org/2021-freshwater/.

22 Bureau of Environmental Health. Eating fish safely in Massachusetts. Available at https://www.mass.gov/info-details/eating-fish-safely-in-massachusetts.

occurring metal found in the environment. However, mercury is also released by coal burning power plants. Once released into the air, it can travel long distances and be deposited on soil and in water bodies. PCBs are man-made chemicals that were banned in the 1970s. However, due to their widespread use, PCBs can still be found in our environment and get into our food. Historically, mercury has been the most common contaminant of concern in fish in Cape Cod ponds, however more recent advisories have been issued due to the presence of a group of man-made chemicals (per- and polyfluoroalkyl substances [PFAS]) in fish.[23]

Native and stocked fish may uptake contaminants that are then stored (bioaccumulation) and concentrated (bioconcentration) in their tissues. Stocked fish are generally considered safe to eat because they are stocked and fished regularly; however, any freshwater fish may be contaminated, and anglers should check fish consumption advisories posted by the Bureau of Environmental Health prior to consuming fish caught in Cape Cod ponds.[24] Unsafe fish consumption advisories can serve as an indicator of poor water quality. In many ponds, fish species may be a food source for residents, highlighting the necessity for pond fisheries monitoring and management. Fishes in ponds should be tested for contaminants and found "clean" before consumption is encouraged.

Angling is a common pond use, with anglers targeting both native and introduced fish species (**Table 2**). MassWildlife stocks select Cape Cod ponds with catchable sized trout on an annual basis from March to May with a smaller number of ponds also stocked in the fall (from late September to early October). This seasonal stocking is a put-and-take management practice – large fish are released when water conditions can support them, and most are harvested before conditions (hot summer temperatures) become unacceptable. Stocking is controlled to maintain historic recreational fishing opportunities and as part of overall lake

Table 2. Cape Cod Trout Stocked Waters 2021. All listed waters are stocked in spring. Bold waters are stocked in spring and fall. Daily stocking updates can be viewed at Mass.gov/Trout.

Town	Trout Stocked Waters
Barnstable	**Hamblin Pond**, Hathaway Pond, Lovells Pond, **Shubael Pond**
Brewster	**Cliff Pond**, **Flax Pond**, Higgins Pond, **Little Cliff Pond**, **Sheep Pond**
Chatham	Goose Pond, Schoolhouse Pond
Dennis	**Scargo Lake**
Eastham	**Herring Pond**
Falmouth	**Ashumet Pond**, Deep Pond, **Grews Pond**, Mares Pond
Mashpee	**Ashumet Pond, Johns Pond, Mashpee/Wakeby Ponds**
Orleans	**Baker Pond, Crystal Lake**
Sandwich	**Peters Pond**, Pimlico Pond, Scorton Creek, **Spectacle Pond**
Truro	Great Pond
Wellfleet	Gull Pond
Yarmouth	Long Pond

23 Department of Public Health Press Release. 11/02/2021. Department of Public Health issues fish consumption advisories for five Cape Cod waterbodies. Available at https://www.mass.gov/news/department-of-public-health-issues-fish-consumption-advisories-for-five-cape-cod-waterbodies.

24 Bureau of Environmental Health. Fish consumption advisories. Commonwealth of Massachusetts. Available at https://www.mass.gov/lists/fish-consumption-advisories.

management in the Commonwealth. Regular stocking of deep ponds sustains trout fisheries. Ponds with increased nutrients generally favor bass fishing.

Recent fisheries management on Cape Cod by MassWildlife is focused on trout stocking primarily from the Sandwich State Fish Hatchery, trout pond temperature and dissolved oxygen profiles, periodic pond fish surveys, permitting of bass tournaments on ponds with Office of Fishing and Boating access ramps, fish kill investigations, technical assistance, and improvement in pond bathymetry maps. MassWildlife also manages fishing licenses and provides fishing resources including fish stocking reports.[25]

Massachusetts DMF deals with marine fishes and focuses on the protection of migratory routes of diadromous fish species, such as river herring, through restoration, improvement, or maintenance of fish runs. River herring connect the freshwater and coastal food webs and serve as an important indicator to the health of the waterways.[26] Diadromous fish return to the same freshwater source each year, however, if water quality is poor and habitat availability is lacking or the waterbodies are not well connected, less or no fish return. Therefore, DMF also counts fish passage for annual population assessments, often with the help of local herring wardens and volunteers. Restoration work and improvement to water quality are important to ensure healthy populations of river herring and other diadromous fish species.

COMMERCIAL CRANBERRY FARMING

Ponds are also associated with production of cranberries across the Cape landscape.[27] Cranberry growers frequently use nearby pond waters for irrigation and for wet harvesting. Many apply fertilizers and pesticides to their crops, which can later mix with the irrigation or harvest water. Therefore, water discharged from bogs can potentially carry excess nutrients and other contaminants into ponds. The impact of cranberry production to surrounding ponds and downstream watersheds is uncertain, but impacts are likely linked to fall wet harvesting and to periodic flushing of the bogs. While biological processes in ponds may remove and sequester added nutrients from bogs without major impact, discharge of nutrients like phosphorus in large volumes can have a negative impact to pond health.

Cranberry harvests across Cape Cod faced market disequilibrium in the late 1990s, leaving many cranberry growers with no choice but to stop farming and harvesting their bogs.[28] Cranberry cultivation on Cape Cod has become less profitable because of factors including, but not limited to, oversupply, low cranberry prices, and less efficient bogs as compared to those in the Upper Midwest and Canada; consequently, cranberry growers are looking for possible

25 MassWildlife. (2021). Trout Stocking Program. Available at https://www.mass.gov/masswildlife-trout-stocking-program.
26 Massachusetts Division of Marine Fisheries. (2017). A Guide to Viewing River Herring in Coastal Massachusetts. Available at https://www.mass.gov/files/2017-07/river-herring-viewing-guide.pdf.
27 Wagner, K.J. (2004). The Practical Guide to Lake Management in Massachusetts. Department of Environmental Protection and Department of Conservation and Recreation. Available at https://www.mass.gov/doc/the-practical-guide-to-lake-management-in-massachusetts/download.
28 Jesse, E.V. and R.T. Rogers. (2006). The Cranberry Industry and Ocean Spray Cooperative: Lessons in Cooperative Governance. Food System Research Group Monograph Series 19. Available at https://www.researchgate.net/publication/237672003_The_Cranberry_Industry_and_Ocean_Spray_Cooperative_Lessons_in_Cooperative_Governance.

exit strategies.[29] Some bogs have the potential to be returned to a more natural state.

In 2018, in response to the state of the cranberry industry and the potential for the ecological restoration of retired cranberry farms, the Massachusetts Division of Ecological Restoration (DER) created a new program focused solely on wetland restoration in retired cranberry farms in southeastern Massachusetts, including Cape Cod.[30] The program focuses on options to restore cranberry bogs to natural wetland habitats to improve water quality throughout the region, help mitigate flooding, and benefit cranberry growers.[31] Bog conversions to more functional natural wetlands will benefit water quality throughout the watershed, including ponds, as water flows through the old cranberry bogs and into other water bodies.

REGULATIONS

Federal, state, and local laws protect the Cape's ponds through regulating water quality and activities in ponds and their watersheds. The most significant of these are described below.

Clean Water Act

The federal Clean Water Act (CWA) establishes the basic structure for regulating discharges of pollutants into waters of the United States and regulating quality standards for surface waters.[32] The EPA provides for water quality management planning programs in accordance with Sections 208 and 303(e) of the CWA. In 1978, the Cape Cod Planning and Economic Development Commission (the predecessor to today's Commission), completed a Water Quality Management Plan for the region. In 2015, the Commission completed an update to the 1978 Plan, the Section 208 Area Wide Water Quality Management Plan (208 Plan Update), to address the degradation of Cape Cod's water resources from excessive nutrients.[33] The 208 Plan Update recognizes ponds as an important component in the region's water quality management planning.

The CWA requires states to submit reports on the status of their water bodies every 2 years. These reports are called Integrated Lists of Waters (Integrated Reports). After a public comment period, MassDEP submits these reports to EPA in fulfillment of CWA's reporting requirements. MassDEP uses these reports to develop Total Maximum Daily Loads (TMDL). A TMDL is the calculation of the maximum amount of a pollutant allowed to enter a waterbody so that the waterbody will meet and continue to meet water quality standards for that pollutant. The MassDEP established Surface Water Quality Standards (314 CMR 4.00), that are the basis for listed freshwaters under CWA Section 303(d) Integrated List of Waters, for impaired

29 Hoekstra, B.R., C. Neill, and C.D. Kennedy. (2019) Trends in the Massachusetts cranberry industry create opportunities for the restoration of cultivated riparian wetlands. Restoration Ecology 28(1):185-195. Available at https://doi.org/10.1111/rec.13037.

30 Division of Ecological Restoration. DER's New Cranberry Bog Program. Available at https://www.mass.gov/news/ders-new-cranberry-bog-program.

31 Houghton, S. (2020) Returning Cranberry Bogs to Nature: The Green Exit Strategy. CAI News. Available at https://www.capeandislands.org/in-this-place/2020-11-25/returning-cranberry-bogs-to-nature-the-green-exit-strategy. Moran, B. (2019). The State Wants to Turn Cranberry Bogs into Wetlands, It's Gritty Work. WBUR News. Available at https://www.wbur.org/news/2019/11/26/transforming-cranberry-farmers-wetlands-cape-cod. Massachusetts Division of Ecological Restoration. Cranberry Bog Program. Available at https://www.mass.gov/cranberry-bog-program.

32 United States Environmental Protection Agency. Summary of the Clean Water Act. Available at https://www.epa.gov/laws-regulations/summary-clean-water-act.

33 Cape Cod Commission. (2015). 208 Plan, Cape Cod Area Wide Water Quality Management Plan Update. Available at https://www.capecodcommission.org/our-work/208/.

waters.[34] Under CWA 303(d), 40 CFR 130.7, states are required to evaluate all available water quality-related data to develop lists of waters that do not meet water quality standards. Each assessed waterbody is listed in one of five categories with Category 5 meaning the waterbody is impaired or threatened by pollutant(s) for one or more designated uses and requires a TMDL. Impairments identified for the water bodies are categories defined and established by MassDEP. Water bodies remain in Category 5 until a TMDL is developed for all pollutants causing impairment.

Great Ponds

A Great Pond is any pond or lake having a surface water area of 10 acres or more in its natural (historic) state. Ponds that once measured 10 or more acres in their natural state, that are now smaller, are still considered Great Ponds. One of the most important laws governing the management of Cape Cod's Great Ponds was their recognition as a public resource

Cliff Pond (top), Mystic Lake (above), and Shubael Pond (left) in Barnstable are examples of great ponds on Cape Cod, having more than 10 acres of surface water area.

34 Massachusetts Department of Environmental Protection 314 CMR 4.00: The Massachusetts Surface Water Quality Standards.

by the Colonial Ordinances of 1641-1647.[35] According to the Colonial Ordinances, private rights of land ownership extend to the low water mark of Great Ponds in the Commonwealth. The title to land below the low water mark is held by the Commonwealth in trust for the public. The Colonial Ordinances and subsequent legislation protect the public's rights to fish, fowl, and navigate on Great Ponds. Public access to Great Ponds is not guaranteed however, and where there is none, citizens may petition for such access.[36] Great Ponds over 20 acres are public for the purpose of hunting or boating and open to all inhabitants of the Commonwealth for fishing.[37]

Great Pond designation is important for establishing and protecting public rights. MassDEP maintains a list of ponds designated Great Ponds in the Commonwealth.[38] MassDEP presumes that any pond presently larger than ten acres is a Great Pond, unless presented with topographic, historic, or other information demonstrating that the original size of the pond was less than ten acres, prior to any alteration by damming or other human activity. MassDEP lists 132 Great Ponds on Cape Cod, whereas the 2003 Atlas and more recent analysis by the Commission indicate there are over 160 ponds that were designated historically or may qualify as Great Ponds.

Chapter 91

Adopted in 1866, Massachusetts General Law Chapter 91 protects the public's interest in waterways of the Commonwealth.[39] MassDEP administers the regulatory provisions of Chapter 91.[40] The program issues licenses for projects in waterways and ensures that projects meet public-access requirements. It ensures public rights to fish, fowl and navigate are not unreasonably restricted and that unsafe or hazardous structures are repaired or removed. Chapter 91 also protects a waterfront property owner's ability to approach their land from the water. Chapter 91 authorization through MassDEP is required for all activities in, on, over, or under the entire area of any Great Pond.

Wetlands Protection Act

Massachusetts adopted the nation's first wetlands protection laws in the early 1960s. The Massachusetts WPA, through its implementing regulations (310 CMR 10.00), protects all Commonwealth wetlands, including ponds, lakes, and any land under those waters, as well as other wetland resource areas that may be associated with ponds including bordering vegetated wetlands, beaches, floodplains, rivers, and fish runs.[41] The WPA protects wetlands and the public interests they serve, including flood control, prevention of pollution and

35 Massachusetts Court System Library. Colonial Ordinances of 1641-1647. Available at https://www.mass.gov/doc/colonial-ordinances-of-1641-1647.

36 Massachusetts General Law Part 1 Title XIV Chapter 91 Section18A: Public access to greats ponds; petition.

37 Massachusetts General Law Part 1 Title XIX Chapter 131 Section 1: Definitions; rules of construction. Massachusetts General Law Part 1 Title XIX Section 45: Great ponds; public use; rules and regulations.

38 Massachusetts Great Ponds List. Available at https://www.mass.gov/doc/massachusetts-great-ponds-list/download

39 Massachusetts General Law Chapter 91: The Massachusetts Public Waterfront Act.

40 Massachusetts Department of Environmental Protection. Waterways Program (Chapter 91). Available at https://www.mass.gov/waterways-program-chapter-91.

41 Massachusetts General Law Part 1 Title XIX Chapter 131 Section 40: Removal, fill, dredging or altering of land bordering waters. Massachusetts Department of Environmental Protection 310 CMR 10.00: Wetlands Protection Act Regulations.

storm damage, and protection of public and private water supplies, groundwater supply, fisheries, land containing shellfish, and wildlife habitat. These public interests are protected by requiring a careful review of proposed work that may alter wetlands. Alterations include impacts from development, as well as pond restoration and management projects.

At the local level, a community's Conservation Commission administers the WPA, and, at the state level, MassDEP oversees administration of the law and hears appeals of decisions made by the local Conservation Commissions. NHESP also reviews proposed alterations to wetland habitats of rare wildlife protected under the WPA and creates maps of habitats of rare wildlife as a screening tool.[42] Local communities may also adopt local wetlands protection bylaws and regulations that provide extra protections to wetland resources within their borders.

As public resources, substantial activities on, in, or near ponds, including adopting local bylaws and developing pond or watershed management plans, generally require some sort of public notice and discussion between a government agency, like a local Conservation Commission or MassDEP, and stakeholders. This need for public participation in the review of changes to pond characteristics or uses generally ensures that decisions regarding ponds are subject to public discussion.

MANAGEMENT

Where there is an interest or need to develop a pond management plan, who develops such a plan will depend on who is responsible for the management of that pond. Municipalities are generally responsible for the management of larger, town-owned ponds and public accesses. Small ponds may be privately owned with restricted access. If there is no public access or town control of a smaller pond, pond front landowners may be responsible for managing the pond. However, collaboration between a town and landowners to develop a pond management plan, even for smaller, private ponds, may be beneficial. Development of cooperative pond management plans by multiple towns in a watershed is also desirable.

Groundwater flows through both private and public ponds, meaning that each pond is impacted by upstream activities and contributes to downstream water quality within its watershed. Groundwater connections necessitate proper and coordinated management of all ponds within a watershed. Public and private entities may join interests to ensure healthier ponds and better water quality throughout the region. Partnerships may also benefit private pond owners because many state funding opportunities are only available for publicly owned resources or to municipal agencies.

SUPPORT

To implement pond assessment and restoration management projects that improve water quality the state offers two main grant programs. The Section 319 Nonpoint Source Pollution Competitive Grants Program, administered by MassDEP, and authorized under Section 319 of the

42 Natural Heritage and Endangered Species Program. Rare species and the Wetlands Protection Act (WPA). Available at https://www.mass.gov/service-details/rare-species-and-the-wetlands-protection-act-wpa.

CWA, is available to any Massachusetts public or private organization.[43] Most of the annual 319 program funds are distributed to applicants proposing "a watershed-based strategy to implement a combination of structural and non-structural Best Management Practices (BMPs) addressing all impairments and leading to restoration of impaired waters."[44] The 604(b) grant program for Water Quality Management Planning, also administered by MassDEP and authorized by the CWA Section 604(b), is available to regional planning agencies, councils of governments, counties, conservation districts, and cities and towns.[45] Fiscal year 2021 604(b) grant round focused on development of Watershed-based Plans (WBPs) for local watershed planning and providing support to implement future 319 projects.[46]


Princess Beach, Dennis

Other potential sources of funding for pond monitoring, assessment, protection, and/or remediation include the EPA's Southeast New England Program (SNEP), MassDEP's Water Quality Monitoring Grant Program, the Massachusetts Environmental Trust, and local financial institutions, foundations, and trusts such as the Cape Cod Five Cents Savings Bank, Cooperative Bank of Cape Cod, and the Cape Cod Foundation.[47]

43 MassDEP. Grants & Financial Assistance: Watersheds & Water Quality. Available at https://www.mass.gov/info-details/grants-financial-assistance-watersheds-water-quality#604b-grant-program:-water-quality-management-planning-.

44 Department of Environmental Protection, Commonwealth of Massachusetts. Notice of Upcoming Grant Opportunity. Available at https://www.mass.gov/doc/notice-of-availability-request-for-responses-ffy-2022-s-319-nonpoint-source-pollution-grant-program-fall-grant-round/download.

45 Department of Environmental Protection, Commonwealth of Massachusetts. Notice of Upcoming Grant Opportunity. Available at https://www.mass.gov/doc/notice-of-availability-request-for-responses-ffy-2022-s-319-nonpoint-source-pollution-grant-program-fall-grant-round/download.

46 Massachusetts Department of Environmental Protection. (2021). Request For Response Federal Fiscal Year 2021 Section 604(b) Water Quality Management Planning Grant Program. Available at https://www.mass.gov/doc/ffy2021-request-for-responses-s604b-water-quality-management-planning-0/download.

47 United States Environmental Protection Agency. Southeast New England Program. Available at https://www.epa.gov/snep. Grants & Financial Assistance: Watersheds & Water Quality. Massachusetts Department of Environmental Protection. Available at https://www.mass.gov/info-details/grants-financial-assistance-watersheds-water-quality. Commonwealth of Massachusetts. Massachusetts Environmental Trust (MET). Available at https://www.mass.gov/orgs/massachusetts-environmental-trust. Cape Cod Five Cents Savings Pond. Community Support Applications. Available at https://www.capecodfive.com/community-support-applications. The Cape Cod Foundation. Available at https://www.capecodfoundation.org/.

IMPLEMENTATION

The value of ponds goes beyond the pond perimeter, extending into the watershed and region. State and regional agencies, towns, citizen pond groups, and homeowners all have parts to play in pond management. Solutions that have been proposed and implemented to address pond water quality have historically been in-pond solutions, but as the 208 Plan Update recognizes, ponds are part of larger watershed and water quality concerns across the Cape. The Cape's unique landscape and aquifer system lends itself to solutions that address both wastewater management and pond water quality management. Stakeholders must be engaged in developing solutions, which may include an array of strategies at a variety of scales.

PROGRESS SINCE THE 2003 ATLAS

The 2003 Atlas generated nine recommendations to reinforce and encourage the nascent network of PALS on Cape Cod. Generally, future steps identified were to continue annual pond monitoring, add more ponds into the pond monitoring program, provide adequate funding and technical assistance to oversee pond monitoring activities, and consider pond water quality in town comprehensive wastewater assessments.

In general, and as will be discussed in more detail in subsequent sections, recommendations have been fulfilled as many pond groups and towns continue to monitor pond water quality annually and freshwater ponds have been considered in local and regional water management programs (see ***Pond Water Quality*** section). However, funding for pond monitoring and technical assistance is still lacking.

RECOMMENDED FUTURE STEPS IDENTIFIED IN THE 2003 CAPE COD POND AND LAKE ATLAS

1. *Continue the PALS Snapshots of pond water quality*
2. *Recruit volunteer coordinators, volunteers, and other PALS in each town*
3. *Encourage towns to acquire necessary sampling equipment*
4. *Encourage towns to initiate summer pond sampling programs*
5. *Provide sufficient personnel to retain volunteer monitors develop monitoring locations, provide regular feedback to volunteers to ensure protocols are followed during sampling season*
6. *Provide qualified personnel to review and analyze sampling data*
7. *Provide adequate funding to have annual or semi-annual PALS gatherings for outreach, education, and technical transfer*
8. *Provide adequate long-term funding to remediate impairments*
9. *Ensure that pond water quality is thoroughly considered in town comprehensive wastewater assessments*

In 2020, with the assistance of an AmeriCorps Cape Cod Service Member, the Commission started to compile information from the 30+ pond groups active on Cape Cod through internet searches, phone interviews, and an online survey. The purpose of the survey was to collect information about ponds that are monitored, data collected at ponds, and identified needs. The survey was sent to 20 pond monitoring groups and 12 responses were received from groups in the towns of Barnstable, Brewster, Falmouth, and Wellfleet.

Of the over 100 ponds monitored by 30 known groups, over 70 are monitored by the 12 groups that responded to the survey. Most pond monitoring programs collect similar data using similar protocols for similar reasons; however, there are inconsistencies in parameters being measured and measurement methods. Survey results of parameters measured by pond monitoring groups illustrate these inconsistences (**Figure 7**). Attempting to compare data among ponds may prove challenging, underscoring the need for standardized methodologies, information-sharing, and coordination among pond monitoring programs.

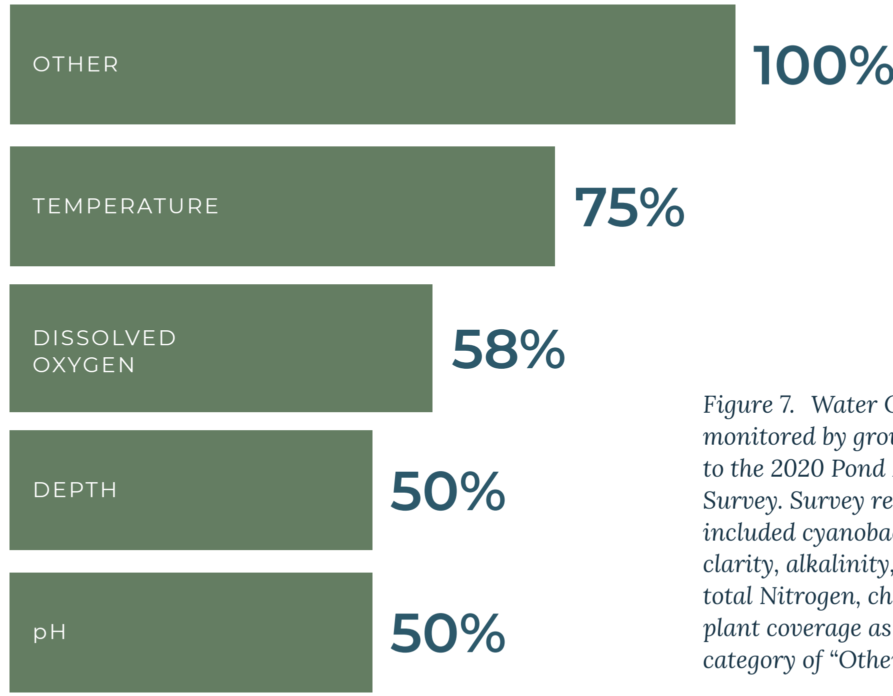


Figure 7. Water Quality parameters monitored by groups who responded to the 2020 Pond Monitoring Survey. Survey respondents included cyanobacteria, water clarity, alkalinity, total Phosphorus, total Nitrogen, chlorophyll a, and plant coverage as write-ins for the category of "Other."

Survey results indicate that these mostly volunteer-run programs continue to struggle with lack of funding, equipment, and volunteers, as well as lack of access to technical assistance (**Figure 8**). Limitations in sampling due to pandemic restrictions associated with the COVID-19 pandemic were also mentioned. Most programs depend on member dues and private donations of money, time, and supplies to support their efforts. Grants and town sponsorships also help maintain these programs. As public concern for pond water quality rises with increased awareness and desire to mitigate worsening conditions and extensive summer algal blooms, the demand for resources by monitoring groups is expected to increase.

Preservation and enhancement of pond resources is becoming a higher priority across Cape Cod. Current and reliable data are essential to inform effective solutions and decisions. As the Commission compiles available pond data, it is apparent that differences in pond monitoring programs make it challenging to compare information and trends among ponds and regionally. This highlights the need for a science-based, expanded, consistent, and sustainable Cape Cod pond monitoring program to help inform pond management decisions moving forward.

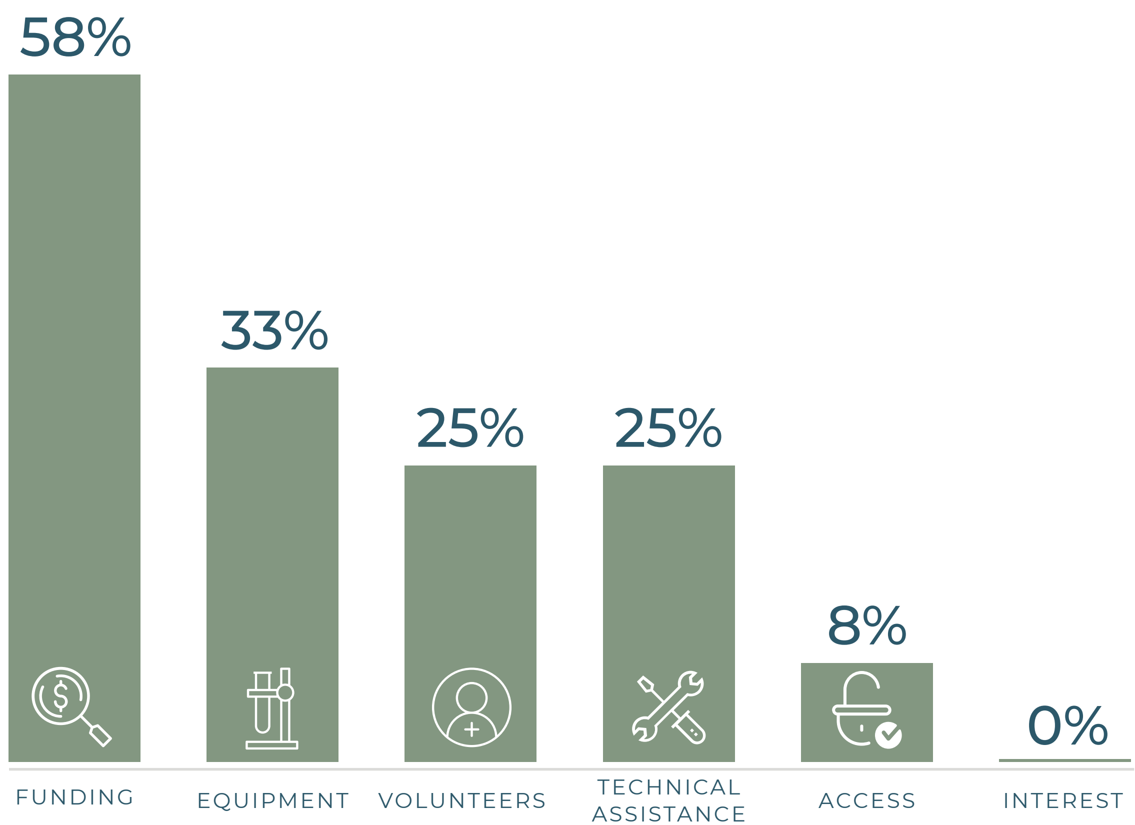


Figure 8. Needs identified by pond monitoring groups who responded to the 2020 Pond Monitoring Survey.

Pond Monitoring on Cape Cod

Several regional plans recognize the importance of Cape Cod's pond resources and the need for comprehensive monitoring and reporting on their health. The direct connection between groundwater and surface water in most ponds on Cape Cod means that pond water quality measurements taken throughout the region and over time can provide insight about the general condition of the surrounding aquifer, in addition to the ponds themselves.

WHY MONITOR PONDS

In its most basic sense, monitoring is conducted to quantify selected physical, chemical, and biological characteristics of ponds. Monitoring can generate data and determine whether pond conditions are suitable for specific uses (e.g., swimming or fish consumption), assess current pond health, and to infer whether and how pond health is changing over time. Various monitoring programs have actively collected data from Cape Cod's ponds since publication of the 2003 Atlas, with different objectives, methodologies, and information. These data have been used to prepare assessment reports that evaluate the health of Massachusetts' surface waters and provide specific recommendations for solutions in accordance with the federal CWA. Data gathered helps inform water quality management, restoration or pond improvement projects, and to establish TMDLs.

Historical surface water monitoring is important as it established baselines to evaluate pond water quality and ecosystem health. Monitoring also provided quantitative evidence to accompany anecdotal observations relating to water quality degradation. Historical monitoring generally focused on standard chemical and physical water quality parameters (e.g., nitrogen and phosphorus, water clarity, water temperature, pH, alkalinity, specific conductivity, chlorophyll a, and dissolved oxygen), and has been traditionally conducted by the PALS program or similar local programs. Local pond monitoring, whether performed by volunteers or by town staff, has also been conducted in response to public concerns about pond health. Over time the focus of monitoring programs has shifted to track changes in water quality, measure effectiveness of restoration projects, and complement larger watershed management programs. Most recently, water quality monitoring has become proactive with pond monitoring programs measuring pond water quality parameters more regularly to generate real-time information and facilitate preemptive responses to identified problems.

The direct connection between groundwater and surface water in most ponds on Cape Cod means that pond water quality measurements taken throughout the region and over time can provide insight about the general condition of the surrounding aquifer, in addition to the ponds themselves. Since groundwater sampling is limited throughout the region, and ponds are relatively accessible indicators of water quality on Cape Cod, groundwater condition and presence of pollutants in the aquifer can be inferred through pond water quality testing.

Water quality monitoring is also important from a public health standpoint. Pursuant to the Massachusetts Department of Public Health's Minimum Standards for Bathing Beaches (105 CMR 445.000), freshwater ponds with public and semi-public bathing beaches must be monitored weekly during the bathing season for fecal bacteria to ensure that water remains safe for swimming.[48] Barnstable County's Department of Health and Environment (BCDHE) has conducted monitoring at bathing beaches across the Cape for over 30 years. At freshwater beaches BCDHE staff test water for the presence of the fecal bacteria *E. coli*. *E. coli* is an indicator species, whose presence may serve as an indicator of other organisms, viruses, and conditions that have the potential to cause illness. These harmful organisms are present in stormwater runoff, as well as animal and human waste.

More recently, pond monitoring has expanded to include sampling for cyanobacteria and surveillance for harmful algal blooms. Until recently, there was no concerted effort to coordinate all the various pond bacteria monitoring activities on Cape Cod. In 2021, the Association to Preserve Cape Cod (APCC) and BCDHE partnered to expand the County's bacteria sampling to include cyanobacteria monitoring because of their potential to degrade water quality and produce toxins.

The need for monitoring programs to adapt to new concerns and priorities over time is evidenced by the Commonwealth's publication of a revised water quality monitoring strategy in 2018, entitled, *A Strategy for Monitoring and Assessing the Quality of Massachusetts' Waters to Support Multiple Water Resources Management Objectives (2016 - 2025)*.[49] This report identifies the continuing need for credible scientific water quality monitoring data, but also highlights how shifting priorities in response to new and emerging water management issues and technologies necessitate periodic examination and adjustment of water monitoring programs to ensure they provide the most current and reliable data and information.

Several regional plans recognize the importance of Cape Cod's pond resources and the need for comprehensive monitoring and reporting on their health. As noted above, the 2003 Atlas listed several recommendations for pond monitoring and management. The 208 Plan Update identified that "despite data gathered by citizen monitoring groups and assessments

48 Massachusetts Department of Public Health 105 CMR 445.00: State Sanitary code chapter VII: Minimum standards for bathing beaches. Available at https://www.mass.gov/regulations/105-CMR-44500-state-sanitary-code-chapter-vii-minimum-standards-for-bathing-beaches.

49 Massachusetts Division of Watershed Management Planning Program. (2018) A Strategy for Monitoring and Assessing the Quality of Massachusetts Waters to Support Multiple Water Resource Management Objectives. Commonwealth of Massachusetts. Available at https://www.mass.gov/doc/water-quality-monitoring-strategy-2016-2025/download.

that document water quality impairment, the state has placed only a few freshwater ponds on the 303(d) list for impaired waters for nutrients under the CWA. Additional dialogue is needed between the towns, state, and county to evaluate the best use of information collected and how it should be incorporated into the Commonwealth's clean water program."[50] The 2018 Cape Cod Regional Policy Plan (RPP) made recommendations to "compile available freshwater resources water quality data into a regional database," and to "seek funding to update the Cape Cod Ponds and Lakes Atlas to reflect current water quality data collected by the Ponds and Lakes Stewardship Program."[51] In 2019, APCC published its first annual State of the Waters: Cape Cod report in which pond water quality was graded based on PALS data collected over the years. APCC's State of the Waters: Cape Cod report is a web and map-based project that displays water quality status determined by collected data and existing analytical methods. The map shows color-coded pond grades to indicate water quality status as "unacceptable" (requires immediate restoration) or "acceptable" (requires ongoing protection).[52]

According to the State of the Waters report, only 15% of Cape Cod's ponds had water quality data available for grading in 2019, using data from 2003 to 2017. APCC's 2020 and 2021 updates to the State of the Waters report used more stringent criteria to grade ponds. To be included, ponds needed at least three years of data from 2015 or 2016 on, respectively. Only about 10% of the Cape's ponds meet the new criteria. In each of the three years of reporting, more than one-third of graded ponds suffered from "unacceptable" water quality due to excess nutrients. The State of the Waters reports demonstrate the severe shortage in recent Cape-wide pond water quality monitoring data needed to inform pond management and protection measures.

Continued collection of nutrient, bacteria, and algal bloom information at ponds will help:

- Inform where additional monitoring at higher spatial or temporal resolution is needed;
- Inform how changes within pond watersheds influence pond water quality;
- Develop policies, standards, and identify emerging issues;
- Develop, implement, and evaluate pollution control strategies;
- Track pond ecosystem recovery and overall pond restoration project impacts at sufficient scale to track progress and inform adaptive management;
- Identify what drivers lead to harmful algal blooms in Cape Cod ponds and whether early responses can be initiated before harmful algal bloom formation; and
- Inform town water withdrawals for public drinking water supplies.

50 Cape Cod Commission. (2015). Cape Cod Area Wide Water Quality Management Plan Update. Available at https://www.capecodcommission.org/resource-library/file/?url=/dept/commission/team/208/208%20Final/Cape_Cod_Area_Wide_Water_Quality_Management_Plan_Update_June_15_2015.pdf.

51 Cape Cod Commission. (2018). Cape Cod Regional Policy Plan. Available at https://www.capecodcommission.org/resource-library/file/?url=/dept/commission/team/Website_Resources/RPP/2018_Cape_Cod_Regional_Policy_Plan_for_web.pdf.

52 Association to Preserve Cape Cod. State of the Waters: Cape Cod 2021. Available at https://capecodwaters.org/.

How freshwater is used, managed, and treated affects all aspects of living and working on Cape Cod. Pond water quality, ecological health, and aesthetics play significant roles in the region's "nature-based economy" – supporting commercial and recreational activities, property ownership, quality of life, and tourism. Monitoring ponds for baseline and trend assessments are important to include in town local comprehensive plans, open space and recreation plans, and water management plans. Careful thought should be given to how monitoring efforts can be modified, or developed and implemented, to best address specific management and restoration objectives.

DEVELOPMENT IMPACTS | *Natural vegetation acts as a sponge, intercepting rainfall and allowing it to gently fall to the ground to percolate into the soil or slowly evaporate. Development disrupts this natural function. Impervious surfaces, such as turf, roofs, roads, and parking areas, cause accelerated rates of stormwater runoff. Stormwater collects pollutants such as litter, debris, sediment, pathogens, petrochemicals, fertilizers, pesticides, and other substances as it moves. Stormwater, and the particles it collects, also scour the ground, causing erosion. These adverse impacts become even more acute along developed pond shorelines where runoff quickly and directly enters the water. Buffers of natural shoreline vegetation around ponds provide the opportunity to intercept stormwater and prevent it, and the pollutants it carries, from entering and degrading ponds.*

HISTORY OF POND MONITORING ON CAPE COD

Freshwater ponds are important surface water resources that local, regional, and state management agencies should include as part of any comprehensive analysis of local water quality or water management plan. This section provides an overview of local and regional efforts to assess and manage surface water resources, specifically ponds and lakes, on Cape Cod since the publication of the 2003 Atlas.

Concern over algal growth was at a high in 1999 when news broke of two dogs dying after swimming in toxic algae-filled Cliff Pond in Nickerson State Park.[53] This incident led to other conversations regarding threats impacting Cape Cod ponds, and the need for more information about the status of ponds. Concerned citizens united with county and town partners to launch the PALS pond water quality monitoring program in 2001. The PALS program initiated monitoring of water quality parameters in ponds across the Cape.

With the 2001 PALS snapshot data, the Commission published a status report on Cape Cod ponds and the PALS program in 2003. Utilizing water quality data collected

53 Cape Cod Times Staff. (Feb. 2, 1999). The latest round of testing at Cliff Pond found none of the deadly toxin from algae that killed two dogs and sickened two others. Cape Cod Times. *Since original access by Commission staff, updates to the Cape Cod Times archives made this article inaccessible.

at 62 ponds in 2001, along with Secchi disk measurements of water clarity at additional ponds, the 2003 Atlas concluded that about half the Cape's ponds were impaired. The 2003 Atlas also compared 2001 dissolved oxygen concentrations collected from PALS with concentrations measured in 1948 and concluded many Cape Cod pond ecosystems were seriously impaired. Based on information in the 2003 Atlas, between 74% and 93% of the Cape's ponds were impacted by surrounding development or uses. Based largely on the dissolved oxygen information, approximately 45% of all ponds and 89% of the deepest ponds were impaired. The findings suggest that the low dissolved oxygen concentrations observed in the ponds were not "natural" conditions but the reflection of 50 years' worth of impacts from surrounding development and land use.

The annual PALS snapshot monitoring program has continued every year since 2001 through the collaboration of local, county, state, and university programming. Monitoring efforts generated a database of over 1,800 water samples from 232 ponds in all 15 Cape Cod towns.[54] Over the past 20 years (2001- 2021) these data have been collected through a network of town-based volunteers who conduct field monitoring with laboratory analyses of collected water samples provided by the University of Massachusetts Dartmouth's School for Marine Science and Technology (SMAST). In addition, the Center for Costal Studies (CCS) and the North Atlantic Coastal Laboratory (NACL) at the Cape Cod National Seashore (CCNS) also provide analysis of some pond water samples. Increased quality and frequency of data collection has supported more detailed assessments of pond water quality, provided better baseline information, and garnered insight into long-term trends. Many towns not only took advantage of the opportunities presented by the annual PALS snapshots, they also expanded their own municipal monitoring programs. These local efforts and supplemental funding from the Barnstable County Growth Management Initiative enabled completion of additional lake and pond assessments in the past decade.[55]

Since 2001, approximately thirty town-wide or pond-specific assessments were completed. Cape Cod towns used a combination of data including data collected by the PALS program, independent town monitoring, or supplemental monitoring to generate the pond assessments. Pond assessment reports summarized background information on the pond(s), status of water quality data, and recommendations for improvement to pond monitoring or pond health. Most of the published pond assessments determined that many ponds across the Cape face water quality concerns, were impaired as measured by state surface water standards, and/or require a TMDL plan. Many were impaired during stratification which prevents mixing and impairs water quality in deeper waters due to low oxygen concentrations, excessive phosphorus, and high primary production, which compounds the low dissolved oxygen concentrations. While assessments indicated many ponds still provided recreational uses, some did not, and others were becoming eutrophic, which can potentially diminish their recreational value. The pond assessment reports highlighted concern about internal loading, or the remobilization of phosphorus from the sediment and its subsequent increased

54 These data are currently managed by UMass Dartmouth, SMAST, and are only available upon request. The CCC is compiling data which will soon be publicly available on a web interface.
55 Additional information on the lake and pond assessments are available in later sections of this report.

availability in the water (which leads to eutrophication).

In response to pond assessment conclusions, many reports recommended additional analyses be conducted that include nutrient and watershed budgets, sediment sampling, and more frequent water quality monitoring than the current one day per year sampling. Reports recognized that ponds across the Cape differ from one another, and, ultimately, each pond may require individual analysis to identify appropriate protection and restoration strategies. Early reports focused on assessments of pond conditions at a town scale, with subsequent reports to assess individual ponds. Ponds crossing jurisdictional boundaries have been the subject of collaborative, multi-town repots, while other analyses were performed by a single town, often with recommendations to collaborate with neighboring towns. These reports and their recommendations provide a guide for pond-specific solutions.

Recommendations made in the reports to improve pond water quality included in-lake management to address existing phosphorus loads, as well as watershed approaches to minimize current and future nutrient inputs. Reports frequently recommended educational elements and review of town regulations to help reduce additional future nutrient inputs and to initiate remediation as appropriate. In many reports, numerous in-lake management solutions were evaluated as viable pond improvement strategies, but phosphorus inactivation treatment (typically using alum) and aeration methods were frequently chosen as the most cost-efficient options.

The body of pond assessment reports across the region over the last 20+ years has contributed a basic understanding of pond water quality threats. The reports have called for more extensive monitoring, using best practices for assessments, and identifying strategies for restoration. Increasingly, towns have responded by taking an integrated approach to natural resources management, by incorporating pond water quality considerations into wastewater treatment, management of open space, and other activities at the town level. As towns seek to implement solutions, many of the recommendations in pond assessment reports remain valid and can aid pond management planning.

While the reports provided some assessment of pond health and recommendations, data for most ponds was limited, not readily accessible, and often insufficient to draw conclusions or make management recommendations. Ponds were monitored infrequently in a limited time span (August-September), and data were collected using different protocols. Collected data are often difficult to translate into easily integrated and understandable results. More importantly, most of the Cape's ponds lack any data at all.

There are clear opportunities to build upon and improve the current monitoring efforts across the region. To optimize monitoring and management efforts, it is important to define the specific questions these efforts are intended to answer, to design the monitoring and management efforts with those specific questions in mind, to proceed within the constraints of available resources, and to periodically reassess both the questions being addressed and approaches employed to obtain valid data for long-term monitoring and management of water quality.

STANDARD WATER QUALITY PARAMETERS

To track water quality in ponds, a suite of standard and critical physical, chemical, and biological parameters are analyzed. Each parameter influences other parameters. Collectively, variations in parameters influence the health of the water body. Sampling the parameters at multiple depths and times determines potential variations that can occur within the water column and across seasons, providing a temporally sensitive, three-dimensional picture of the water quality of the pond.

Temperature - Influences on pond temperature include solar radiation; shading from shoreside vegetation; river, stream, and/or groundwater inputs; and the local climate and weather. Temperature influences biological and chemical processes within the ecosystem. For example, temperature can affect the solubility of chemicals, the amount of dissolved oxygen available, and reproductive timing of species. Additionally, most species have optimal temperatures and thresholds for survival. In some ponds, stratification, the separation of water into layers, may occur, and mobile organisms will relocate to their optimal temperature.

A Secchi disk is used to measure transparency depth. Photo sourced from United States Geological Survey.

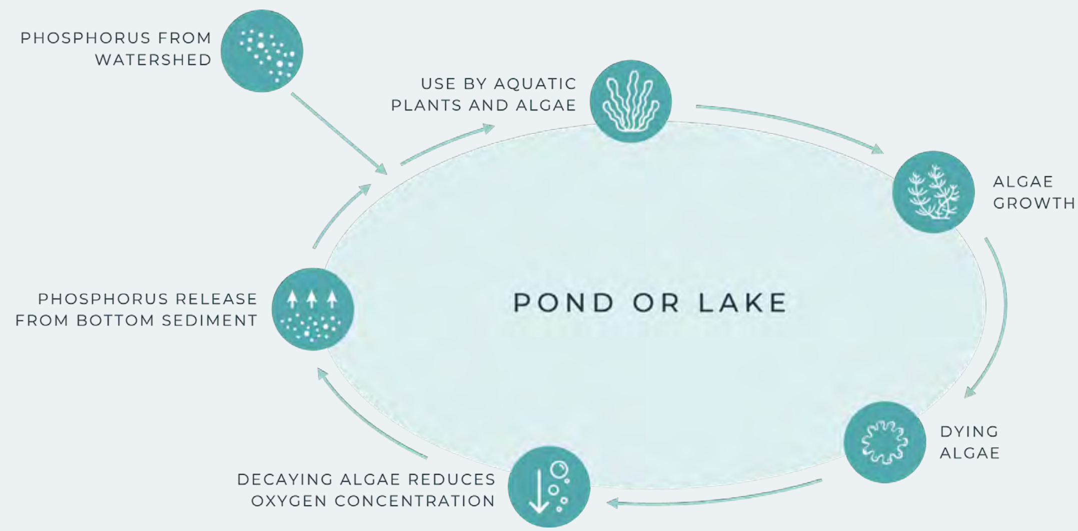
Secchi Depth - A Secchi disk is a weighted, round, black and white tool used to measure the depth of visibility, termed the Secchi depth. It serves as a proxy for the depth of the photic zone, the depth in the pond that receives sufficient sunlight for productivity.[56] Instead of describing how clear the water is, Secchi depth provides a non-subjective indicator. A small Secchi depth indicates limited penetration of light and could be an indicator of pollution. Since the Secchi disks rely on penetration of light from the sun into the water body, Secchi measurements will differ depending on the time of day, angle of the sun, and environmental conditions (i.e., cloud cover, precipitation).

Total Depth - Measuring the total depth of the pond helps track changes in pond volume and water level. It is also important to compare the Secchi depth to total depth to understand vertical stratification in a pond's water column.

Dissolved Oxygen - Oxygen is pivotal to life in an aquatic ecosystem. Oxygen in water is in a gaseous and dissolved state and is referred to as dissolved oxygen (DO).

56 Garrison, P. (2007). Numbers and Limnological Variables. Lakeline 27(1): 21-24.

Its abundance is expressed as milligram of DO per liter of water (mg/L). Oxygen enters the pond through photosynthesis and by diffusion from the atmosphere. DO is consumed by chemical (e.g., nitrification, oxidation) and biological (e.g., decomposition of organic material, aerobic respiration) processes. Concentration of DO in a water body is influenced by temperature. As temperature rises, solubility of oxygen in water decreases. Low levels of DO can stress and kill species, most notably fish. DO levels also influence the availability of phosphorus. Water with low DO concentrations cause phosphorus that was bound to iron in the soil to be released into the water column and become biologically available.[57]



THE PHOSPHORUS CYCLE

Figure 9. Excessively high levels of phosphorus can cause high plant algae and cyanobacteria productivity that lead to reduced dissolved oxygen levels available for aquatic life.

pH – pH is a measure of how acidic or basic the water is, which is dictated by the amount of hydrogen and hydroxyl ions present. It is measured on a logarithmic scale of 1 to 14 with 7 being neutral, 1 being very acidic (like vinegar and stomach acid), and 14 being very basic. A change of 1 pH unit represents a 10-fold change in acidity. pH is affected by other chemicals in the water that remove or add hydrogen ions, as well as photosynthesis and respiration, which can cause pH levels to fluctuate through the course of a day. The solubility of chemicals and uptake of nutrients (and contaminants) by species is also affected by pH. Most ponds have a pH of 6-9.

Phosphorus - Phosphorus in ponds can occur naturally at low concentrations and be recycled within the water body. The internal loading or phosphorus cycling within the pond system is exacerbated by external sources that enter from the watershed (**Figure 9**). This input may come from natural sources such as leaf litter or from man-made sources such as agricultural runoff or other land use practices. Phosphorus is a limiting factor for primary productivity in freshwater. When it is abundant, primary

57 Garrison, P. (2007). Numbers and Limnological Variables. Lakeline 27(1): 21-24.

productivity is high.[58] Excessively high levels of phosphorus, and therefore high plant, algae, and cyanobacteria productivity, can cause eutrophic or hypereutrophic conditions that lead to reduced dissolved oxygen available for aquatic life. Phosphorus measurements will help indicate if the nutrient is static, decreasing, increasing, or in excess, potentially leading to algal blooms.

Nitrogen - Nitrogen is essential for life and a balanced aquatic ecosystem. Like phosphorus, nitrogen causes similar concerns when it is in excess within a water body. Excess nitrogen increases primary productivity causing plants, algal, and cyanobacteria blooms, which decreases dissolved oxygen, and blocks light from passing through the water column. When nitrogen, which is already more abundant than phosphorus, is in excess, it causes an unbalanced system and poor water quality for aquatic life and drinking water use. Like phosphorus, nitrogen measurements will quantify the amount and type of nitrogen present and indicate if levels are static or changing and causing concerns for water quality.

Nitrogen can be present in various forms, which are utilized differently in an ecosystem. Each form can convert to another as part of the nitrogen cycle. Nitrogen exists in a molecular (gaseous) form (N_2) and as ions (NO_2^-, NO_3^-, NH_4^+). Most plants, including algae, use nitrogen in its nitrate form (NO_3^-). Some plants, including cyanobacteria, are nitrogen fixers and can convert nitrogen gas (N_2) to ammonia (NH_3) for their use. Since nitrogen gas is readily available in the atmosphere, this provides nitrogen fixers a competitive advantage when the concentration of nitrates is low, resulting in undesirable and potentially toxic blooms.

N:P - Although not a parameter per se, the nitrogen to phosphorus ratio is a good measure of the relationship of nutrients and overall pond conditions. The atomic ratio of nitrogen to phosphorus (N:P), for many phytoplankton species, or the Redfield ratio, is 16. This ratio indicates which of the two nutrients is more likely limiting growth of algae or plants in a given system. Waterbodies with a N:P ratio greater than 17 are indicative of phosphorus limitations. When the N:P ratio falls below 16, nitrogen becomes the limiting factor for primary productivity. Many species of cyanobacteria can fix atmospheric nitrogen to more useable forms (NO_2^-, NO_3^-), and subsequently their growth is not limited by the availability of nitrate nitrogen in the water.

Chlorophyll a - Chlorophyll a is the primary photosynthetic pigment in algae and plants. Chlorophyll a can occur in higher amounts when excess nutrients are available. Measuring chlorophyll a indicates how much algae or plants are present in the water body. Periodic monitoring of chlorophyll a provides a relatively easy way to assess the health of photosynthetic organisms and whether populations are stable, increasing or decreasing.

Phaeopigment - Phaeopigment is a product of the degradation of chlorophyll, the primary pigment in algae.[59] When algae decompose,

58 Robinson, M. (2004). The Massachusetts Lake and Pond Guide, Massachusetts Department of Conservation and Recreation, Lakes and Ponds Program. Available at https://www.mass.gov/doc/lakes-ponds-guide-0/download.

59 Fuch E., R.C. Zimmerman, J.S. Jaffe. (2002). The effect of elevated levels of phaeophytin in natural water on variable fluorescence measured from phytoplankton. Journal of Plankton Research24(11): 1221-1229. Available at https://doi.org/10.1093/plankt/24.11.1221.

phaeopigment is released and can become abundant. Measuring this pigment indicates the level of productivity in the water and status of recent algal growth and if it is stable, increasing, or decreasing.

Alkalinity - The buffering capacity of water is expressed as alkalinity and indicates the level of basic compounds available in the water body to buffer hydrogen ions and other acids released in the water. If alkalinity is low, small additions of acids can change the pH of the water, but if alkalinity is adequate, the pond has the capacity to resist changes in pH. Measuring alkalinity is important to assess how a pond will respond to acidic pollutant discharge or even acidic rain.

Specific Conductance - This indirectly measures the concentration of dissolved ions in water. If inorganic dissolved solids that carry a negative charge like nitrate, sulfate, phosphate, and chloride are present in the water, conductivity will be high. Sodium, potassium, calcium, and magnesium hold a positive charge, their presence therefore lowers the waters conductivity. General conductivity is affected by water temperature, therefore specific conductance corrects for temperature and reports what the value would be at 25 degrees Celsius. "The term, 'specific conductance,' is correctly defined as the electrical conductance of 1 cm^3 of a solution at 25°C."[60] High specific conductivity may indicate inputs from septic systems, stormwater, or saltwater intrusion, but it can also result from natural mineral weathering processes.

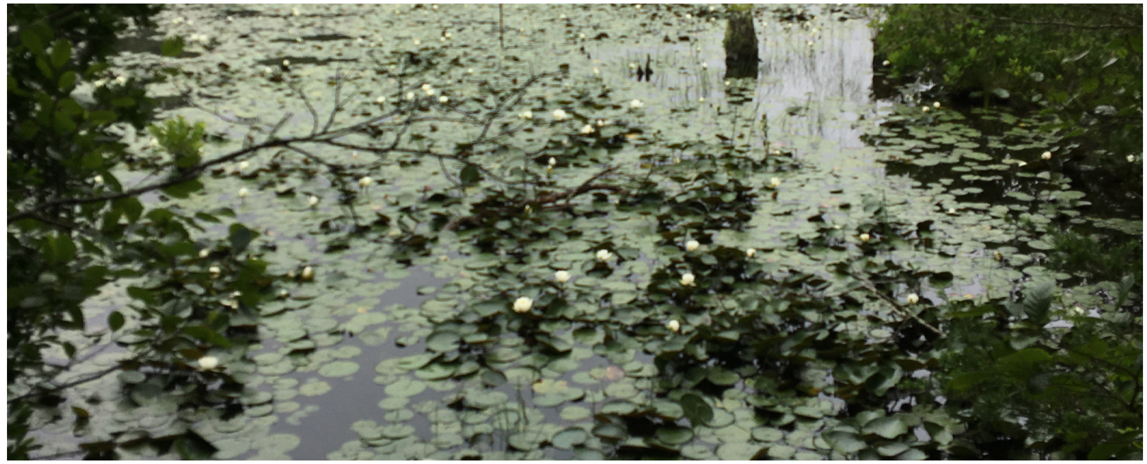
Cyanobacteria - Cyanobacteria, also called blue-green algae (although it is not an algae), naturally occur in aquatic systems. However, overgrowth of cyanobacteria can lead to blooms that degrade water quality, harming habitat and aquatic organisms. Additionally, some cyanobacteria species can produce toxins harmful to humans, animals, and aquatic ecosystems. The presence and relative abundance of cyanobacteria are measurements of particular concern from a public health standpoint. Toxins within cyanobacteria can be measured, however, the correlation between blue-green algae abundance and toxins present in the environment is not always uniform. Cyanobacteria blooms are produced as a result of several factors, and while warm temperatures and excess nutrients are two common factors, they are not the only ones.[61]

In addition to the above listed parameters, site observations at ponds are also important to note when water sampling. These include the presence of plants (including invasive plants and/or algal growth) presence of animals (including nuisance waterfowl), pond perimeter shoreline observations, water color, wind direction, and weather conditions like cloud cover, recent precipitation, time of day, and air temperature. These observations can help tell the story of a pond's water quality status. For example, noting a precipitation event may help identify reasons for high values of other quantitative parameters such as nitrogen, phosphorus, and temperature. Precipitation could temporarily increase input of stormwater that carries sediments and nutrients from around the watershed, and water with a different temperature or different pH.

60 U.S. Geological Survey. (2019). Specific Conductance: U.S. Geological Survey Techniques and Methods, Book 9, Chap. A6.3. Available at https://pubs.usgs.gov/tm/09/a6.3/tm9-a6_3.pdf.
61 Graham, J. (2021). Cyanotoxin Occurrence in the US: A 20-Year Retrospective. Lakeline 41(2):8-11.

TARGETED CAPE COD POND MONITORING

In addition to pond monitoring for the standard suite of water quality parameters listed above, several pond monitoring programs have taken a more targeted approach to documenting specific pond characteristics, challenges, or geography.



Macrophytes, or aquatic plants, cover the surface of West Pond in Osterville. This overgrowth is likely caused by excessive nutrients in the pond water.

CYANOBACTERIA MONITORING PROGRAM

The incidence of cyanobacterial blooms in freshwater systems has been rising over the past several decades as conditions that favor their growth become more prevalent. Some algal and cyanobacterial blooms can negatively impact ecosystems and produce toxins that are harmful to human health or ecosystems. These are referred to as harmful algal blooms, or HABs.

APCC has partnered with town health departments and the BCDHE to monitor cyanobacteria.[62] The program currently monitors certain ponds in all 15 Cape Cod towns on a weekly or biweekly basis. Monitoring parameters include turbidity, water color, odor, water temperature, and presence/absence of scum. Water samples are also taken for laboratory analysis of cell count of cyanobacteria concentrations, and cyanobacteria species identification.

FISH TOXICS

Fish in Cape Cod ponds may be exposed to toxic chemical pollutants that can impact their health and survival. Toxic chemicals also pose a threat to humans who consume contaminated fish. Mercury contamination of fish is the primary reason for issuing fish consumption advisories.[63]

Mercury is a naturally occurring element that is often released into the atmosphere by burning fossil fuels and trash. In ponds, mercury can be transformed by natural processes into a more toxic form called methylmercury, which enters the food chain when small organisms absorb it. Mercury is a pollutant and neurotoxin that can

62 Association to Preserve Cape Cod. Cyanobacteria. Available at https://apcc.org/our-work/science/community-science/cyanobacteria/.
63 United States Geological Survey. 1995. Mercury Contamination of Aquatic Ecosystems. Available at https://pubs.usgs.gov/fs/1995/fs216-95/.

accumulate and concentrate in fish to levels that are a health concern for humans that eat them. Once in the environment, mercury persists for a long time and never degrades into a harmless substance.

Studies of lake pH levels and concentrations of mercury in fish have shown that low pH/acidic conditions generally favor high mercury concentrations.[64] Given the generally low pH of most Cape Cod ponds, this relationship raises concerns about the safety of freshwater fish consumption.

Studies conducted by the Commission, MassDEP, and CCNS in the early 2000's on eighteen ponds found that fish sampled from half of these ponds contained mercury concentrations above health thresholds. Because mercury persists for so long, it takes many years for mercury levels in fish to drop significantly. Massachusetts Department of Public Health (DPH) maintains a Freshwater Fish Consumption Advisory List of ponds and lakes in the Commonwealth with various forms of fish consumption advisories, mostly related to mercury impacts.[65] As of 2021, twenty-nine ponds within Barnstable County are on the list. Fish testing may also be requested by contacting MassDEP.[66]

While mercury remains a concern, there have been significant local and regional reductions in mercury emissions in the Northeast over the last two decades and corresponding decreases in mercury concentrations in largemouth bass and yellow perch in Massachusetts lakes.[67] To continue the trend of reduced mercury levels in fish in Massachusetts requires regional, national, and global reduction in mercury emissions to decrease below fish consumption advisory levels.

More recently MassDEP, DPH, and Department of Fisheries, Wildlife, and Environmental Law Enforcement (DFWELE) initiated a cooperative effort, called the Fish Toxics Monitoring Program, to assess the

As of 2021, there are 29 ponds within Barnstable County listed with advisories regarding fish consumption by the Massachusetts Department of Public Health. Pictured here is Great Pond in Wellfleet.

64 Greenfield, B.K., T.R. Hrabik, C.J. Harvey, and S.R Carpenter. (2001). Predicting mercury levels in yellow perch: use of water chemistry, trophic ecology, and spatial traits. Canadian Journal ofF-isheries and Aquatic Sciences 58(7): 1419-1429. Available at DOI:10.1139/f01-088. Massachusetts Department of Environmental Protection. (1997). Fish Mercury Distribution in Massachusetts Lakes. Office of Research and Standards and Office of Watershed Management. Available at https://www.mass.gov/doc/final-report-fish-mercury-distribution-in-massachusetts-lakes-may-1997/download.

65 Massachusetts Department of Public Health. (2021). Freshwater Fish Consumption Advisory List. Available at https://www.mass.gov/doc/public-health-freshwater-fish-consumption-advisories-2021/download?_ga=2.245612804.1627199449.1633535981-980125762.1623689512.

66 Massachusetts Department of Environmental Protection. Form for Requesting Fish Testing. Available at https://www.mass.gov/doc/fish-testing-request-form/download.

67 Hutcheson, M.S., C.M. Smith, J. Rose, C. Batdorf, O. Pancorbo, C.R. West, J. Strube and C. Francis. (2014). Temporal and Spatial Trends in Freshwater Fish Tissue Mercury Concentrations Associated with Mercury Emissions Reductions. Environmental Science & Technology 48(4): 2193-2202. Available at https://doi.org/10.1021/es404302m.

risk to human consumers associated with consuming freshwater fish.[68] At the request of the public, edible fillets from fish collected can be analyzed for the presence of mercury, arsenic, cadmium, and selenium. Cape Cod communities and pond organizations should consider incorporating such fish toxics testing into their pond monitoring programs. In addition to the toxics listed, testing for PFAS in fish should also be considered.

POND WATER LEVELS

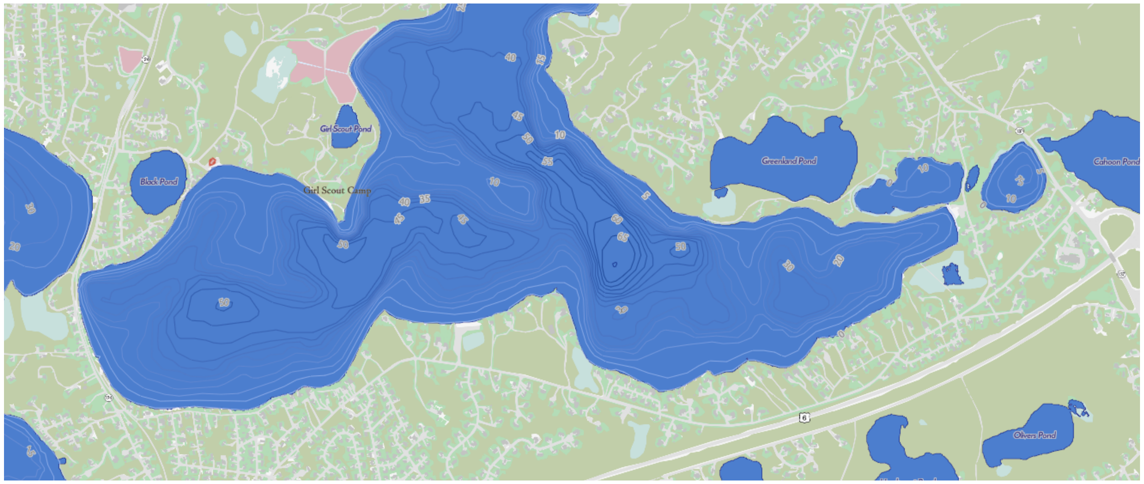
Pond water levels on Cape Cod generally fluctuate with groundwater levels. The Commission has been monitoring groundwater levels from a regional network of 60 to 65 wells since the early 1970's. This monitoring supports United States Geological Survey (USGS) programs and provides data necessary for groundwater separation calculations required in the state septic system regulations (310 CMR 15: Title 5) and the state stormwater management regulations (310 CMR 10.00; 314 CMR 9.00). The historic database of groundwater levels is an important resource for management of water resources on Cape Cod.

Monitoring surface water levels of lakes and ponds across Cape Cod is important to assess the impacts of climatic changes and other sources of drawdown on surface waters. Most ponds on Cape Cod are directly connected to the groundwater as kettle ponds. Generally, surface water fluctuations coincide with groundwater response to varying precipitation amounts. Groundwater levels tend to be the highest in the early summer, following the winter and spring recharge periods. Levels are lowest in the early winter, following many months where precipitation is intercepted by vegetation or directly evaporated. In the summer, higher air temperatures increase evaporation rates, lowering source water levels more rapidly than groundwater. Besides these seasonal patterns, other factors affect water levels as well. Large precipitation events will cause surface water to rise more rapidly than groundwater levels. Precipitation is a direct input to surface waters, while it takes longer for precipitation to travel though soil before recharging the groundwater. Patterns of surface level and groundwater fluctuation impact ecosystem response and management techniques. Fluctuation data may inform the distribution of rare and endangered plants, herring run maintenance, dock and shoreline maintenance, storm water management, septic system design and other home construction issues.

In 1986, MassDEP instituted registration and permitting of water withdrawal under the Water Management Act (WMA). As part of the permitting requirement public water suppliers may be required to monitor nearby pond water levels to ensure drinking water withdrawal does not negatively impact pond water levels. In 2003, 14 ponds were monitored by various public drinking water suppliers as a condition of water withdrawal permits. In 2021, three ponds are required to be monitored per a WMA permit. MassDEP oversees public water supply withdrawal and if a supplier's annual average withdrawal volume reaches or exceeds the amount for which they are permitted, monitoring of nearby surface water bodies must recommence to reevaluate the withdrawal impacts. This is particularly important for withdrawal wells located near coastal plain pond shores as water levels impact pond shore ecosystems. Existing WMA permits and decisions can be found on MassDEP's WMA

68 Massachusetts Department of Environmental Protection. Water Quality Monitoring: Bioaccumulation Assessment. Available at https://www.mass.gov/guides/water-quality-monitoring.

Permit website or on the individual water supplier's website.[69]



The Cape Cod Pond Atlas Viewer presents available bathymetric data for Cape Cod ponds as a map layer. Explore at: cccom.link/pond-atlas

POND BATHYMETRY

Bathymetry describes the topographic features of a pond's basin and is important for understanding water quality information and for informing pond monitoring activities. Bathymetric maps are useful in understanding potential impacts of recreational activities on bottom sediments such as in ponds where motorized watercraft are allowed. Fishermen rely on bathymetric maps to locate the deepest part of the lake and to target different depths and habitats within a pond.

According to the 2003 Atlas, only 89 Cape Cod ponds had bathymetric data at that time. Over the intervening years and as part of PALS and other pond monitoring programs, the Commission, MassDEP, and others have added or updated bathymetric information, for a total of 96 ponds with bathymetric maps. As towns and others study individual ponds, including a bathymetric survey will provide valuable pond attribute data. A future regional aerial flyover could collect bathymetry for targeted ponds using LiDAR, allowing for new and updated images of pond geomorphology.

Select ponds have bathymetric maps available from MassWildlife.[70] MassWildlife pond maps provide bathymetry, average and maximum pond depth, shore and boat access, and the types of fish found in the pond. All ponds on the MassWildlife list allow public access. MassWildlife continues to add new bathymetric maps each season. Bathymetry maps and information for ponds not on the MassWildlife list may be available in PALS or other pond monitoring reports.

INVASIVE SPECIES

Invasive species are those that are not native to an ecosystem and whose introduction causes economic and or environmental harm by disrupting native ecosystems. In aquatic systems both plant and animal invasive species are of concern. Once invasive species are introduced, managing and controlling them is a significant challenge.

69 MassDEP Water Management Act Permits and Decisions. Available at https://www.mass.gov/guides/water-management-act-permits-and-decisions.

70 Massachusetts Division of Fisheries and Wildlife. Massachusetts pond maps. Available at https://www.mass.gov/info-details/massachusetts-pond-maps.

The Massachusetts Invasive Plant Advisory Group (MIPAG) was established in 1995 and charged by the Massachusetts Executive Office of Energy and Environmental Affairs (EEA) to provide recommendations regarding invasive species management through avoidance of introduction and management once established. MIPAG established biologically based criteria to identify plants that could become or are documented as invasive. Using these criteria, plant species are categorized into one of four groups: invasive, likely invasive, potentially invasive, and not currently meeting the criteria.[71] Following categorization, recommendations are made to prevent introductions or for appropriate management actions.

The Massachusetts Department of Conservation and Recreation (DCR) Lake and Ponds Program developed a Weed Watchers program. Through the program, citizens volunteers are trained to monitor ponds for the presence of invasive species. Lakes and Ponds Program staff continue to provide hands-on training workshops for live plant identification.

Given the potential rapid spread, extensive impact, and number of pond ecosystems that could be impacted on the Cape, public education and assistance is necessary to prevent entrance and establishment of invasive organisms on Cape Cod.

BATHING BEACH WATER QUALITY

Since Cape Cod ponds are used extensively for swimming, ensuring that waters are safe for swimming is an important pond monitoring and management consideration. In 2001, Massachusetts adopted the Beaches Bill, which requires regular testing of all public and semi-public bathing beaches during the bathing season. On a weekly basis 350 marine and freshwater beaches are sampled, adding up to 4,300 samples per season. The BCDHE conducts most of the laboratory analyses for Cape towns and maintains the results on their website.[72]

71 Lists of plant species are available on the MIPAG website. Available at https://www.massnrc.org/MIPAG/.

72 Barnstable County Department of Health and Environment. Beach Sample Results. Available at https://www.barnstablecountyhealth.org/programs-and-services/bathing-beach-water-quality/beach-sample-results-2.

POND HEALTH IN THE CAPE COD NATIONAL SEASHORE

Staff at CCNS have monitored ponds within the CCNS boundaries since the 1970s with the goal of assessing trends in water quality, trophic status, and vegetation to better understand pond processes in a changing environment.[73] Unlike PALS snapshot monitoring, CCNS monitoring occurs bi-weekly over up to 10 months, from March to fall turnover (September through December) providing a robust dataset that allows for inter- and intra-annual temporal trend analyses.

Beyond monitoring that is performed within the Seashore, CCNS supports Outer Cape towns in their pond management efforts through sampling, restoration, and information sharing. Environmental parameters measured in the field include temperature, dissolved oxygen, pH, Secchi depth, and phytoplankton biomass. Water samples are analyzed at CCNS's NACL for total nitrogen, total phosphorus, nitrate-nitrogen, ortho-phosphorus, and chlorophyll a.

Current and upcoming pond research by CCNS includes an inventory of phytoplankton and zooplankton, a nation-wide harmful algal bloom project, and further research and tracking of cyanobacteria blooms, toxicity, and ecological effects.[74] They also plan to conduct existing condition assessments and define ecological integrity goals.

Gull Pond (left) and Spectacle Pond (right) in Wellfleet are both within the Cape Cod National Seashore

73 McCobb, T.D., and P.K. Weiskel. (2003). Long-Term Hydrologic Monitoring Protocol for Coastal Ecosystems. United States Geological Survey. Available at https://pubs.usgs.gov/of/2002/ofr02497/pdf/ofr02497.pdf. National Park Service. (2018). Status of Kettle Pond Plant Communities of Cape Cod National Seashore, Report on 2016 Surveys and Analyses of Temporal Change Since 1995.U.S. Department of the Interior.

74 Liesman, J. (2020). Scientists Pick Up Effort to Study Ponds. The Provincetown Independent. Available at https://provincetownindependent.org/news/2020/11/12/scientists-pick-up-effort-to-study-ponds/.

Results of Pond Monitoring

Improving the quality of freshwater resources requires a better understanding of the impacts of pollutants and climate change, as well as the connection between Cape Cod surface waters, the aquifer, and coastal embayments.

Monitoring and mitigation of excess nutrients entering waterways from fertilizer use, stormwater runoff, and septic systems have been prioritized in recent years through the 208 Plan Update and related efforts. While nutrients remain a problem in marine waters, public concerns related to harmful algal blooms and emerging knowledge about Contaminants of Emerging Concern (CECs), which include pharmaceuticals and personal care products harmful to aquatic life, and PFAS make clear that a renewed focus on ponds and lakes is necessary. Potential impacts from climate change makes finding management solutions urgent. To improve freshwater resources, managers need to understand the impacts of pollutants and climate change on these resources and the connection between Cape Cod surface waters, the aquifer, and the effects from upstream to coastal embayments. Previous regional efforts to better understand pond water quality, and the health of Cape Cod's ponds more generally have typically been responsive to highly visible and well-publicized negative impacts to pond ecosystems (e.g., fish kills) or recreational

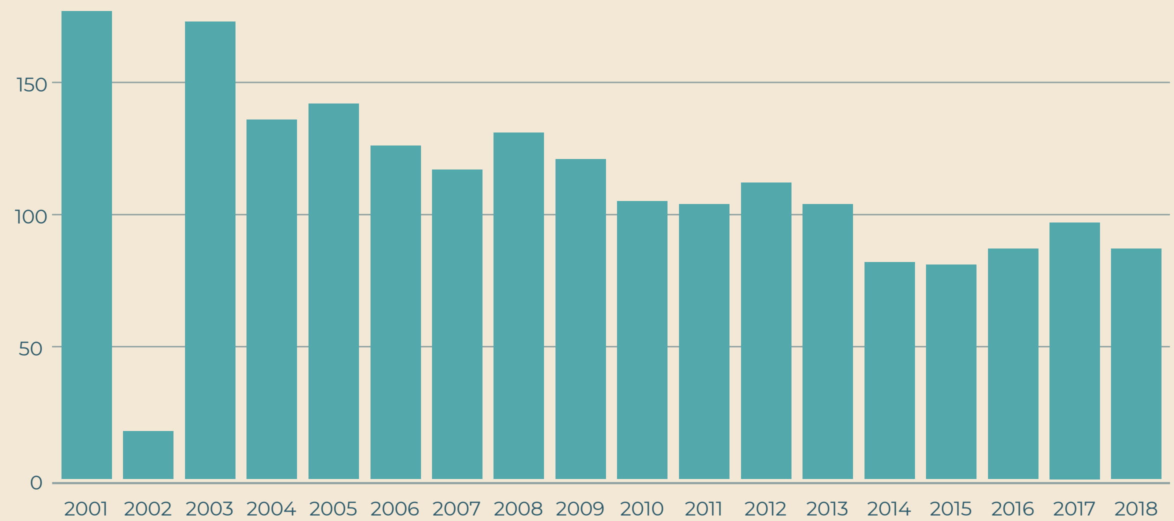


Figure 10. Number of Cape Cod ponds monitored by the PALS program from 2001 through 2018.

uses (e.g., closures to swimming or boating). A proactive approach is necessary moving forward to mitigate current and future impacts to pond health.

Over the last twenty years, access to data generated by ongoing PALS monitoring (**Figure 10**) helped towns and pond associations take proactive measures to assess their ponds and start considering possible pond improvement strategies. While most towns were still assessing the overall health of their ponds in the 2000s, some solutions were being discussed and implemented, such as the mid-2000s alum treatment applied to Long Pond in Brewster and Harwich.[75] However, guidance on effective pond management was needed.

To meet the need, towns, with help from the Commission and SMAST, began pond water quality assessments to document and archive pond health and to generate recommendations for improvement. These data, documented in pond assessment reports that include PALS data, town data, and/or other collected data, confirmed that most Cape ponds were impaired and did not meet the surface water quality standards established by the Commonwealth. For example, five out of the six ponds surveyed in Eastham were identified as impaired, and a pond remediation program was recommended as a next step for the town.[76] Many ponds were impaired by low oxygen concentrations confined to the bottom of the pond due to normal stratification that occurs in the summer months. Most ponds were also found to have high nitrogen to phosphorus ratios, indicating that the ponds are phosphorus limited.

Subsequently, multiple towns developed specific pond management action plans. In 2012, Sandwich generated an Evaluation of Selected Ponds Report and Harwich conducted an Evaluation of Hinckley Pond.[77] In 2011, Mashpee citizens stated "The problem is only getting worse," inspiring allocation of $357,000 of community preservation funds to purchase water circulators to improve water quality and reduce severe algal blooms that adversely impacted Santuit Pond.[78] Whether inspired as an effort to protect their "beloved body of water" from becoming an eyesore, or to ensure safe drinking water for years to come, activity to address the poor status of Cape ponds moved forward.[79]

Town-wide and specific pond reports were generated across the Cape as early as 2000, but most were developed between 2006 and 2009. According to Commission records, no pond reports were published between 2013 and 2017. Pond reports published since 2018 tend to be follow-up monitoring assessments as recommended in initial pond assessment reports, or performance reports

75 Lord, R. (2008). Towns await results of Long Pond cleanup. Cape Cod Times. Available at https://www.capecodtimes.com/article/20080319/NEWS/803190332.

76 Coastal Systems Group, School of Marine Science and Technology, University of Massachusetts Dartmouth, and Cape Cod Commission. (2009). Eastham Freshwater Ponds: Water Quality Status and Recommendation for Future Activities, Final Report. Town of Eastham and Barnstable County.

77 Water Resources Services, Inc. (2012). An Evaluation of Selected Sandwich Ponds. WRS, Wilbraham, MA. Water Resources Services, Inc. and CDM Smith. (2012). Evaluation of Hinckleys Pond, Harwich, Massachusetts. Available at https://www.harwich-ma.gov/sites/g/files/vyhlif7091/f/file/file/harwich_-_final_evaluation_of_hinckleys_pond_reduced.pdf.

78 Wysocki, H. (2011). Mashpee residents OK Santuit Pond cleanup. Cape Cod Times. Available at https://www.capecodtimes.com/article/20111018/NEWS/110180313.

79 Wysocki, H. (2011). Santuit 'Friends' make plea for help. Cape Cod Times. Gouveia, A. (2011). Falmouth voters approve water study. Cape Cod Times.

on specific remediation methods.[80] Release of the 208 Plan Update in 2015 prompted towns towards development of integrated water management plans or targeted watershed management plans, which as the 208 Plan highlighted, will benefit both coastal and freshwater resources.

As towns advance toward creation and implementation of water management plans, solutions will benefit freshwater pond and coastal water quality. Illustrative is the Comprehensive Water Resource Management Plan (CWRMP) from the town of Sandwich that seeks "to guide the improvement of water quality in groundwater, freshwater ponds and coastal estuaries," directly acknowledging the ability of the solutions to improve water resources broadly.[81] However, there have been no assessments performed to indicate any positive impacts on freshwater systems from CWRMPs farther along in the implementation process; and for other CWRMPs, it is too early for assessment. Progress of wastewater management plan implementation varies widely throughout Cape Cod. Many towns are still moving forward to determine funding strategies and gain town approval for CWRMPs. For example, as of October 2021, the town of Mashpee is pushing to promote water quality in freshwater ponds through their sewer expansion plan.[82]

POND REPORTS

Town commissioned pond reports and assessments can be accessed, as available, on the Commission website: capecodcommission.org/our-work/ponds-and-lakes

While towns shift their focus from pond-specific assessments to watershed nutrient management plans, pond reporting that makes news headlines still primarily centers around consequences of diminished water quality such as beach closures, algal blooms, and limited pond management solutions, mostly alum treatment and aeration/agitation.[83] However, conversations about ponds emphasized the need for additional monitoring information to inform best methods for protection, restoration, and a collaborative, regional, watershed approach. Support and advancement of the APCC State of the Waters reports have confirmed the public's continued concern and interest in freshwater ponds. Findings from State of the Waters analyses conclude that while data are limited, ponds remain impacted, with over one-third of ponds graded as having "unacceptable" water quality in 2019, 2020, and 2021.[84] While APCC's State of the Waters report relies on the Carlson Trophic Index and cyanobacteria monitoring of Cape Cod water bodies, analyses of other data sources, such as Integrated Lists of Waters and PALS

80 Water Resource Services, INC. (2019). Investigation of Twelve Sandwich Ponds. Available at https://storage.googleapis.com/wzukusers/user-18152207/documents/483a2b39506744b-b9a444698a3259871/Sandwich%20Ponds%202018%20032919.pdf. Schlezinger, D.R., B.L. Howes, and S.S. Horvet. (2017). Pond Water Quality Assessment of 23 Ponds in the Town of Barnstable using Pond and Lake Stewardship (PALS) Protocols. University of Massachusetts Dartmouth, The School for Marine Science and Technology (SMAST).

81 Wright-Pierce. (2017). Town of Sandwich Comprehensive Water Resources Management Plan. Town of Sandwich. Available at https://www.sandwichmass.org/DocumentCenter/View/4195/12217A-Report-F-Vol01-SandwichCWRMP-2017-Dec.

82 Jung, A. (2021). 'The worst water quality on Cape Cod': Mashpee adds ponds, lakes to clean-water push. Cape Cod Times. Available at https://www.capecodtimes.com/story/news/2021/10/08/mashpee-add-ponds-and-lakes-escalated-clean-water-push-estuaries-nitrogen-cyanobacteria-pollution/6018387001/.

83 Meyers, K.C. (2012). Orleans warns of bacteria spike in Uncle Harvey's Pond. Cape Cod Times. Available at https://www.capecodtimes.com/article/20120926/NEWS11/120929837.

84 Association to Preserve Cape Cod. State of the Waters: Cape Cod 2021. Available at https://capecodwaters.org/.

data analyses, also confirm degradation of freshwater resources across the Cape.

In the most recent Integrated List of Waters published by MassDEP in 2016, twenty freshwater ponds on Cape Cod were listed under Category 5, impaired and requiring one or more TMDL (**Table 3**). Causes of impairment to the 20 Cape Cod ponds listed in the 2016 303(d) list include harmful algal blooms, high chlorophyll a, low dissolved oxygen, nutrient or eutrophication biological indicators, turbidity, transparency, and total phosphorus levels. Most ponds had multiple causes of impairment documented.

The 2004 Integrated List of Waters, published a year after the 2003 Atlas, included 13 freshwater ponds in Category 5. Reasons for needing a TMDL for these ponds included low dissolved oxygen, excessive nutrients, organic enrichment, presence of metals, noxious aquatic species, and high turbidity. Eight ponds listed in the 2004 303(d) list were also listed in the 2016 list. These include Long Pond (Brewster/Harwich), Lower Mill Pond (Brewster), Red Lily Pond (Barnstable), Ryder Pond (Truro), Santuit Pond (Mashpee), and Walkers Pond (Brewster). These ponds have been listed in each impaired water list since 2004 and are currently listed on the 2018/2020 proposed list, which is still in draft format.

However, some ponds have been listed and removed in subsequent years. Water bodies removed from Category 5 have been documented as meeting the state water quality standards. It is important to note that this list may not fully encapsulate the number of Cape Cod ponds that are impaired or may need a TMDL. When creating a list, states must evaluate whether a water body meets water quality standards, which is done by evaluation of all possible data and information on a water body.[85] However, as identified previously, not all Cape Cod ponds have extensive information and monitoring data. This lack of information may contribute to an underestimation of ponds that should be listed under Category 5 of the CWA 303(d) Integrated List of Waters.

Changes to trophic status may also indicate changes in water quality. In 2003, 172 ponds were sampled, with 23% (40) considered oligotrophic, 28% (49) mesotrophic, 39% (67) eutrophic, and 9% (16) hypereutrophic using the Carlson Trophic Index based on chlorophyll a measurements from PALS monitoring (**Table 4**). In 2016, only 87 ponds were sampled, nearly all of which were also sampled in 2003. While the overall count was much lower, the trophic status distribution was quite similar, with 21% (18) considered oligotrophic, 30% (26) mesotrophic, 39% (34) eutrophic, and 10% (9) as hypereutrophic (**Table 4**). It is not clear whether these results indicate some mitigation of development impacts since the 2003 Atlas was published, or whether the ponds were already degraded in 2003 and have not changed dramatically since.

Although water quality data collected over the past two decades indicate ecological impacts, most ponds still support most activities residents and visitors enjoy. For example, bacterial testing of ponds has generally indicated conditions suitable for swimming. Review of 2020 and 2021 testing results shows that *E. coli* exceedances at freshwater pond beaches has not increased

85 United States Environmental Protection Agency. Overview of Listing Impaired Waters under CWA Section 303(d). Available at https://www.epa.gov/tmdl/overview-listing-impaired-waters-under-cwa-section-303d.

POND NAME	TOWN	2004	2006	2008	2010	2012	2014	2016	2018/2020
Ashumet Pond	Mashpee/Falmouth		X			X	X	X	
Bournes Pond	Falmouth		X	X					
Cedar Pond	Orleans							X	X
Cliff Pond	Brewster							X	X
Crystal Lake	Orleans	X	X	X	X	X	X	X	X
Flax Pond	Brewster								X
Great Pond	Eastham	X	X	X	X	X	X	X	X
Hamblin Pond	Barnstable		X			X	X	X	X
Johns Pond	Mashpee		X						
Long Pond	Brewster/Harwich	X	X	X	X	X	X	X	X
Lovells Pond	Barnstable					X	X	X	X
Lovers Lake	Chatham					X	X	X	X
Lower Mill Pond	Brewster	X	X	X	X	X	X	X	X
Mashpee Pond	Mashpee/Sandwich		X						
Middle Pond	Barnstable					X	X	X	X
Mill Pond	Chatham	X							
Moll Pond	Eastham							X	
Mystic Lake	Barnstable					X	X	X	X
Oyster Pond	Falmouth	X	X	X					
Peters Pond	Sandwich	X							
Peters Pond	Sandwich		X						
Red Lily Pond	Barnstable	X	X	X	X	X	X	X	X
Ryder Pond	Truro	X		X	X	X	X	X	X
Santuit Pond	Mashpee	X	X	X	X	X	X	X	X
Shawme Lake Lower	Sandwich				X	X	X		X
Sheep Pond	Brewster	X	X	X	X				
Snake Pond	Sandwich		X						
Spectacle Pond	Sandwich								X
Stillwater Pond	Chatham					X	X	X	X
Uncle Harvey Pond	Orleans							X	X
Upper Mill Pond	Brewster	X	X	X	X				
Upper Shawme Lake	Sandwich				X	X	X	X	X
Wakeby Pond	Mashpee/Sandwich		X						
Walkers Pond	Brewster	X	X	X	X	X	X	X	X
Wequaquet Lake	Barnstable		X						

*Table 3. Cape Cod Ponds listed as Category 5, impaired waters requiring a TMDL, in MassDEP's Integrated List of Water Reports published from 2004 to 2020. *Note the 2018/2020 report is a combined report that has not yet been finalized, it is a draft awaiting public comment and finalization by EPA.*[1]

1 United States Environmental Protection Agency. Impaired Waters and TMDLs, Region 1 Impaired Waters and 303(d) Lists by State. Available at https://www.epa.gov/tmdl/region-1-impaired-waters-and-303d-lists-state#iw-ma.

dramatically since 2001 (**Table 5**). According to the US EPA guidelines for recreational waters, the maximum *E. coli* allowed is 235 colony-forming units per 100 milliliters (cfu/100mL).

Actions to develop or update pond assessments and correct identified ecological impairments varies with community and state priorities. Active discussion of pond conditions and ecological management strategies may lead to refinement of pond users' expectations relative to habitat, recreation, and future TMDLs for ponds.

Additional and improved dialogue is needed between the towns, state, and county to evaluate how individual towns, ponds, and watersheds should be monitored or managed, the best use of information collected, and how information should be incorporated into the Commonwealth's clean water program.

Study	Ponds Assessed	Oligotrophic	Mesotrophic	Eutrophic	Hypereutrophic
2003	172	40 (23%)	49 (28%)	67 (39%)	16 (9%)
2016	87	18 (21%)	26 (30%)	34 (39%)	9 (10%)

Table 4. Categorization of Cape Cod ponds eutrophication status based on the Carlson Trophic Index reported in 2003 and 2016.

Study	Number of Samples	Number of Pond Beaches	Number of Samples Failed
2001	1,112	83	15 (1.5%)
2002	928	74	10 (1.1%)
2020	1,406	104	23 (1.6%)
2021	1,364	105	25 (1.8%)

Table 5. E.coli sampling results taken at public and semi-public freshwater pond beaches and compared from 2001 and 2002 to 2020 and 2021.

Threats to Pond Water Quality

Cape Cod ponds are fragile and vulnerable to perturbations that challenge the ecosystem's ability to maintain a healthy balance of water quality and aquatic life. Land use, wastewater discharges, contaminant inputs, invasive species, as well as the local effects of climate change impact watersheds and ponds.

A watershed is the area of land that drains all flowing water and precipitation to a common, low-lying area such as a pond, mouth of a bay, or any point along a stream. Watersheds consist of surface water (streams, ponds) and the underlying groundwater. As water on Cape Cod flows from inland sources through streams, groundwater, and into the coastal embayments it also has the potential to flow through a pond (**Figure 11** *and* **Figure 12**).

In the same way that watershed characteristics influence the health of an embayment, threats to the ecosystem health of a pond extend beyond its direct borders. Cape Cod kettle ponds offer a low point in elevation where surface waters collect and connect to the aquifer via groundwater inflows and outflows.[86] The entire upstream portion of the watershed to the pond shoreline can influence pond water quality. Land use, wastewater discharges, contaminant inputs, invasive species, as well as the local effects of climate change impact watersheds and ponds (**Figure 11** *and* **Figure 12**). Cape Cod ponds are fragile and vulnerable to perturbations that challenge the ecosystem's ability to maintain a healthy balance of water quality and aquatic life.[87]

Pond water quality is impacted by surface water that enters the pond as runoff, groundwater that seeps in below the surface, the temperature, and mixing of water. The health of a pond is directly related to the land use within, and condition of, its watershed. Threats to pond water quality stem from shoreside and upstream watershed land use.

86 Cape Cod Commission. Ponds and Lakes. Available at https://www.capecodcommission.org/our-work/ponds-and-lakes/.

87 Massachusetts Division of Fisheries and Wildlife, Department of Fish & Game, Executive Office of Energy & Environment. (2015). Massachusetts State Wildlife Action Plan, Chapter 4: 4 Habitats of Species of Greatest Conservation Need. Coastal Plain Ponds: 299-307. Available at https://www.mass.gov/files/documents/2016/12/wh/ma-swap-public-draft-26june2015-chapter4.pdf.

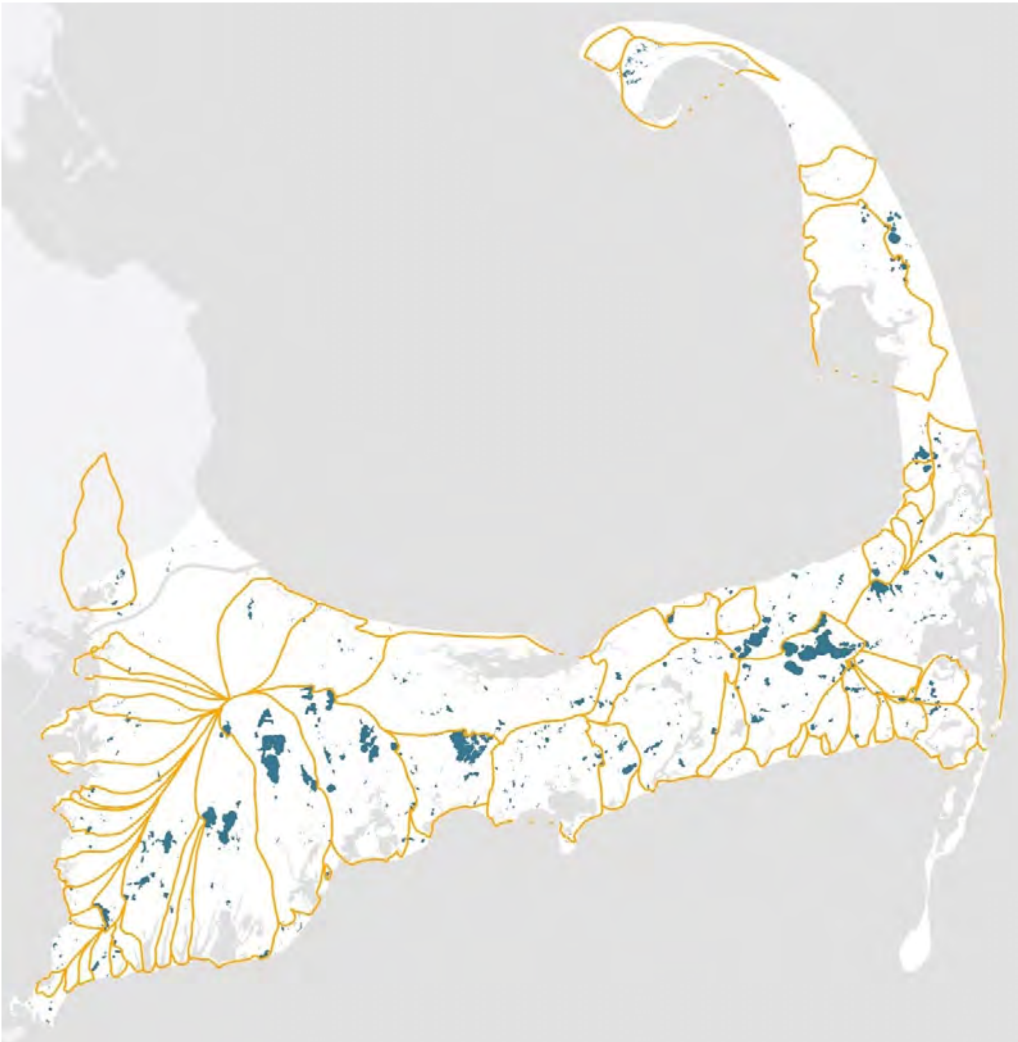


Figure 11. Ponds, colored in blue, are impacted by threats throughout their watersheds. These impacts follow the extent of the watershed, outlined in yellow, which flow to marine embayments. Kettle ponds, stream influenced ponds, and coastal ponds exhibit different interactions with the watershed in terms of inflow and outflow or discharge.

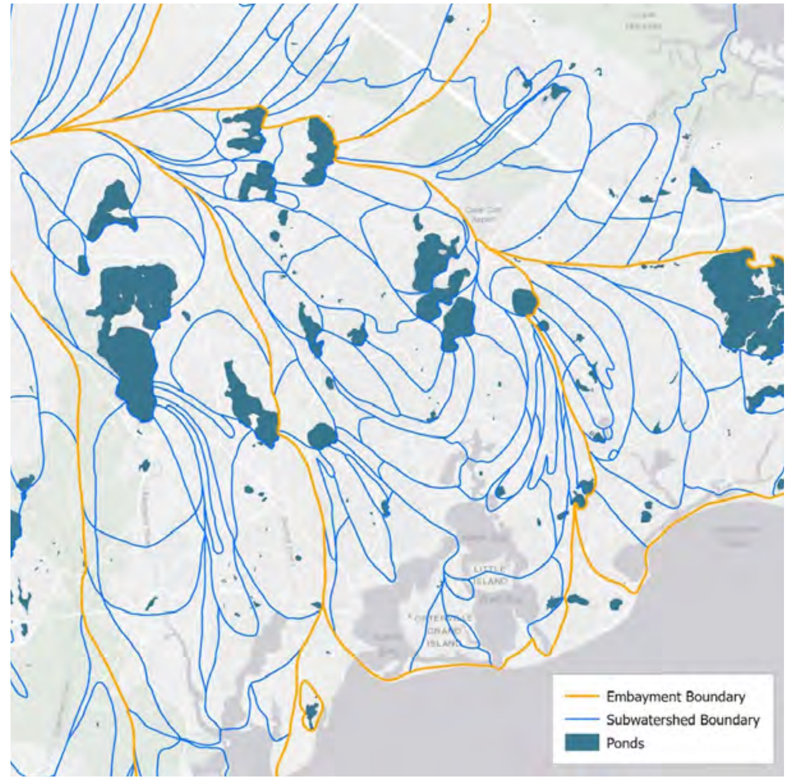


Figure 12. A subset image of the previous figure showing portions of Mashpee, Sandwich, and Barnstable with embayment boundaries (yellow), subwatersheds (blue), and ponds (blue polygons). Each embayment consists of multiple subwatersheds.

TITLE 5 SEPTIC SYSTEMS

A major concern across Cape Cod centers on wastewater and the use of traditional Title 5 septic systems. In 1978, Title 5 septic systems were deemed adequate wastewater treatment for purposes of drinking water protection. Title 5 systems remove pathogens to a sufficient degree to protect public health but provide only modest nutrient removal. As of 2019, 125,000 septic systems were in use on Cape Cod, comprising 20% of septic systems in the state of Massachusetts.[88] Relatively low septic system removal efficiencies for nitrogen and phosphorus combined with highly permeable sandy soils results in the discharge of wastewater with high nutrient concentrations, which can move through the soil to reach groundwater (**Figure 13**).[89] Water quality monitoring across the Cape has shown that population growth and the region's sandy soils have resulted in excess nutrients reaching and threatening Cape Cod's fresh and marine water bodies.[90]

The sandy soils on Cape Cod provide very little attenuation of nitrogen, and thus once in the subsurface nitrogen tends to follow groundwater flow to coastal waters. Phosphorus, on the other hand, is readily taken up and held by naturally occurring metal oxides and other minerals in the soil, and to a point is much less mobile than nitrogen. With sustained phosphorus loading soils can become saturated at which point phosphorus can be readily transported with groundwater and into surface waters. Phosphorus is typically the primary driver of algal growth in ponds across Cape Cod, though in some cases with significant phosphorus inputs, nitrogen can become limiting.

As many towns move forward with plans to address excess nutrients in Cape Cod water, solutions to reduce nutrient inputs to groundwater will also benefit pond health. Until those solutions are implemented, continued nutrient inputs from septic systems and the environment generally (e.g., runoff from pavement, treatment of lawns using pesticides or fertilizers) into ponds and their upstream watersheds will remain a threat to pond water quality. Even after solutions have been put in place to reduce or eliminate nutrient contributions from septic systems, historic nutrients added to the watershed from septic systems and other sources can remain in the soil, groundwater, or pond sediments. Phosphorus from these reservoirs, or nutrient sinks, will continue to be released and fuel primary production in ponds. The various sources and reservoirs for nutrients that can exist throughout a pond and its watershed emphasize the need for integrated solutions that can address nutrients at different scales and locations.

STORMWATER

Surface water flow in the form of stormwater runoff poses threats to pond water quality.

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88 Cape Cod Commission. (2015). Cape Cod Area Wide Water Quality Management Plan Update. Available at https://www.capecodcommission.org/resource-library/file/?url=/dept/commission/team/208/208%20Final/Cape_Cod_Area_Wide_Water_Quality_Management_Plan_Update_June_15_2015.pdf.

89 United States Environmental Protection Agency. Septic Systems and Surface Water. Available at https://www.epa.gov/septic/septic-systems-and-surface-water.

90 Cape Cod Commission. (2019). Cape Cod and Islands Water Protection Fund FAQ. Available at https://www.capecodcommission.org/resource-library/file?url=%2Fdept%2Fcommission%2Fteam%2FWebsite_Resources%2Fcciwpf%2FCCIWPF_FAQs.pdf.

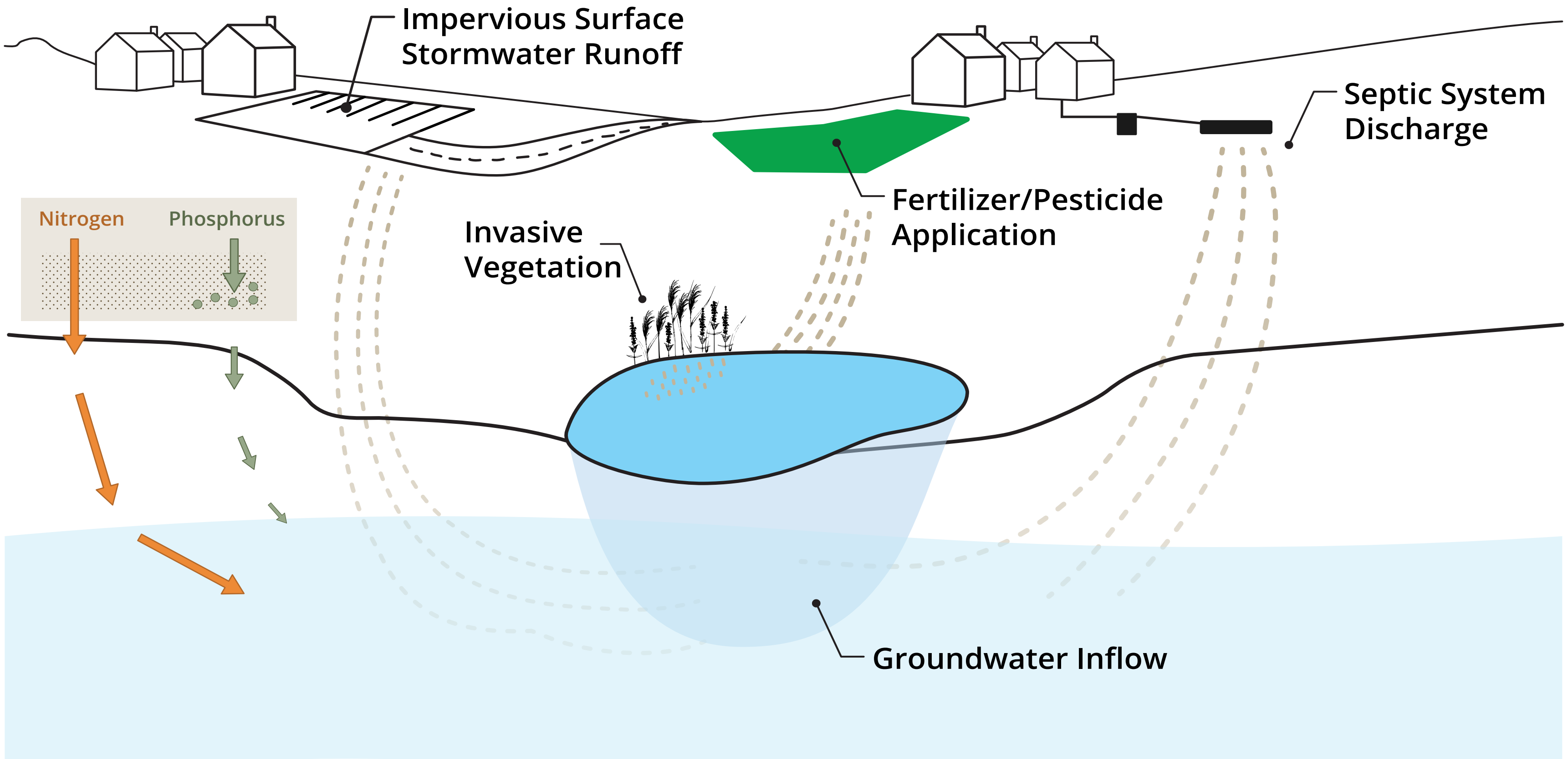


Figure 13. Threats to pond quality including presence of aquatic invasive species, contribution of nutrients from septic system discharge and fertilizer/ pesticide application, and contribution of nutrients or increased erosion and flow from impervious surfaces. Phosphorus and nitrogen are nutrients of concern and have the potential to come from any or all these sources. Nitrogen easily flows through the soil and into groundwater, while phosphorus may be bound in the soil or pass through depending on soil type and condition.

Average annual rain and snowfall amounts are calculated to be 43.3 inches in Hyannis and 47 inches in Chatham.[91] In a natural, undeveloped landscape stormwater absorbs or infiltrates into the ground. In developed areas the stormwater cannot infiltrate into the ground, instead it flows over the land or collects at topographical low spots. Stormwater will flow over impervious surfaces such as roofs, roads, and parking lots, potentially with more volume and higher velocity, eventually reaching an area that is pervious or a surface water body. As stormwater flows over impervious surfaces it can accumulate pollutants such as oil, grease, nutrients, and sediment. These pollutants are delivered to bodies of water through several different pathways: infiltration into the ground, run off from impervious surfaces, or flow over saturated soils. Eventually, stormwater will enter the groundwater or a pond, potentially altering its chemical, biological, or physical characteristics.

Stormwater runoff can also damage a pond shoreline or increase sedimentation. Increased stormwater flow erodes the shoreline, damaging plant life in the buffer zone. The extent of damage depends on the volume and rate of precipitation and the slope of the shoreline. More water during a shorter period traversing steep slopes that lack vegetation increase stormwater flow rates. Additional impervious shoreside infrastructure such as parking lots and boat ramps can contribute to increased stormwater runoff velocity and channelization. These impervious surfaces increase erosion risks and often provide a direct input of untreated stormwater runoff into surface waters. Insufficiently treated stormwater is of particular concern to pond health as a source of excessive nutrients, pollutants, and bacteria that can cause beach closures and contribute to eutrophication. Extreme rainfall events exacerbate challenges of stormwater management and negative impacts to ponds.

As water flows over the land surface or through the subsurface, it might also pick up fertilizer or pesticides applied in residential yards, agricultural fields, managed commercial landscapes, and golf courses, which can be a threat to pond health.[92] Therefore, use of these chemicals across the watershed should be considered for their impact to pond water quality. Many towns already enacted control measures for the use of these substances to reduce nutrient loading to Cape Cod water bodies. In 2013, to address nutrient enrichment, the Commission established a Fertilizer District of Critical Planning Concern (DCPC) for Cape-wide fertilizer management (Ordinance 13-07).[93] The designation of the Fertilizer DCPC allowed municipalities to voluntarily adopt enforceable regulations governing the application of turf fertilizer within their own towns. This option is no longer available to towns as adoption needed to occur within a specific timeframe. The towns of Barnstable, Brewster, Chatham, Eastham, Mashpee, and Provincetown adopted local nitrogen-

91 Current Results. Average Annual Precipitation for Massachusetts. Available at https://www.currentresults.com/Weather/Massachusetts/average-yearly-precipitation.php. Data Source: Arguez, A., I. Durre, S. Applequist, M. Squires, R. Vose, X. Yin, and R.y Bilotta (2010). *NOAA's U.S. Climate Normals (1981-2010)*. NOAA National Centers for Environmental Information. DOI:10.7289/V5PN93JP.

92 Massachusetts Division of Fisheries and Wildlife, Department of Fish & Game, Executive Office of Energy & Environment. (2015). Massachusetts State Wildlife Action Plan, Chapter 4: 4 Habitats of Species of Greatest Conservation Need. Coastal Plain Ponds: 299-307. Available at https://www.mass.gov/files/documents/2016/12/wh/ma-swap-public-draft-26june2015-chapter4.pdf.

93 Barnstable County. (2013). *Ordinances 13-07*. Available at https://www.capecodcommission.org/resource-library/file/?url=/dept/commission/team/Website_Resources/dcpc/ordinances/Ord13-07Cape-wideFertilizerMgtdcpc.pdf.

oriented fertilizer regulations. The towns of Falmouth and Orleans had grandfathered nitrogen bylaws. Orleans added phosphorus to its nitrogen bylaw through the DCPC.

Although commercial-scale agriculture on Cape Cod is limited, there are potential impacts from the agricultural practices that are present, as well as lingering impacts from earlier practices. Non-point source nutrient pollution and pesticide inputs from cranberry bogs or animal farms could potentially impact pond water quality.

Threats from runoff and erosion are greatest when land covers such as lawns and impervious surfaces are near ponds. Nutrients traveling with runoff from these sources are more likely to become bound in the soil and not enter the water when distance to a pond is substantial. Proximity to ponds reduces travel time and increases the chance of nutrients and pollutants entering the pond.

INVASIVE SPECIES

Presence of invasive species on Cape Cod poses a threat to pond health and the overall balance of the ecosystem.[94] Invasive plant species can outcompete native plant species for light, water, and nutrients, dominating the water body and reducing plant biodiversity. Invasive animal species can also outcompete native animal species and reduce biodiversity. Changes in species composition affect proportions of other species and habitat, ultimately altering the entire food chain, food web, or ecosystem, and causing the ecosystem to change.[95] In addition, invasive species can impact recreational activities by impeding boat navigation, damaging docks, and extirpating desirable species.

Invasive species can be transported among water bodies by boats and trailers, scuba divers' and fishermen's gear, waterfowl, and aquatic organisms, among others. Fish bait buckets containing invasive species can introduce foreign and invasive fish, plants, and plankton into a pond. Waders and boots can move mud with invasive animals or parasites. Invasive species are also often introduced when an individual empties a home aquarium into a pond or stream.

In Cape Cod ponds, aquatic plants are usually the primary invasive species of concern (**Figure 14**). Given that the pond ecosystems on Cape Cod are relatively rare in the United States, there are several native species that are correspondingly rare and likely to be threatened by invasive species.

The aquatic invasive plant hydrilla is of tropical Asian origin but has a high level of adaptability. Hydrilla was first identified in Massachusetts in 2001 within the waters of Long Pond in Centerville. DCR and the Town of Barnstable responded rapidly to address the potential threat by appropriating funding and completing herbicide application.[96] Nevertheless, it was detected again in Long Pond and other ponds in Barnstable in subsequent years due to the persistence of its reproductive tubers that can remain dormant for over five

94 Robinson, M. (2004). The Massachusetts Lake and Pond Guide. Massachusetts Department of Conservation and Recreation, Lakes and Ponds Program. Available at https://www.uwsp.edu/cnr-ap/UWEXLakes/Documents/ecology/shoreland/background/mass_lake_and_pond_guide.pdf.

95 Massachusetts Division of Fisheries and Wildlife, Department of Fish & Game, Executive Office of Energy & Environment. (2015). Massachusetts State Wildlife Action Plan, Chapter 4: 4 Habitats of Species of Greatest Conservation Need. Coastal Plain Ponds: 299-307. Available at https://www.mass.gov/files/documents/2016/12/wh/ma-swap-public-draft-26june2015-chapter4.pdf.

96 USGS. Nonindigenous Aquatic Species: Hydrilla verticillata. Available at https://nas.er.usgs.gov/queries/CollectionInfo.aspx?SpeciesID=6&State=MA.

AQUATIC INVASIVE PLANT SPECIES

Figure 14. Invasive species are those that are not native to an ecosystem and whose introduction causes economic and/or environmental harm. In aquatic systems, both plant and animal invasive species are of concern; however, most of the invasive species documented in Cape Cod ponds have been plants. Prevention is paramount because once invasive species are introduced, managing and controlling them is a significant challenge.

FANWORT

HYDRILLA

COMMON REED

VARIABLE MILFOIL

EURASIAN MILFOIL

PURPLE LOOSESTRIFE

years before sprouting. Infested ponds were closed to boat launching temporarily to stop hydrilla from spreading to other ponds while additional funding was appropriated for further herbicide applications. This example highlights the need for early and ongoing detection and repeated control of invasive species to prevent their spread throughout the region.

Other invasive aquatic plants include water chestnut, fanwort (documented in Wequaquet Lake, Barnstable), variable milfoil (documented in Johns Pond, Mashpee) and Eurasian watermilfoil. Invasive plants that are found alongside ponds and in wetlands include common reed and purple loosestrife.

In addition to invasive aquatic plants, invasive mollusks are also a concern. The DCR Lake and Ponds Program maintains a list of current and potential aquatic invasive species that includes Asian clam and zebra mussel.[97] Zebra mussels can be transported between water bodies on boats, trailers, and

97 Massachusetts Department of Conservation and Recreation, DCR Division of Water Supply Protection. List of Current and Potential Aquatic Invasive Species. Available at https://www.mass.gov/service-details/list-of-current-and-potential-aquatic-invasive-species.

equipment, and larvae can be found inside ornamental moss balls sold in pet stores for aquariums. Zebra mussels grow with such vigor they can alter nutrient dynamics in lake ecosystems and clog municipal drinking water intakes. Zebra mussels have been found in several lakes in western Massachusetts.[98] However, the coastal plain ponds associated with Cape Cod are not likely to support zebra mussels due to their low pH and low calcium concentrations.[99] The Asian clam has been documented in a few Cape Cod ponds.[100] This clam is native to southeast Asia and is a prolific and highly competitive species capable of rapid growth and spread. It forms dense clusters that can alter entire pond ecosystems.

The threat of invasives may become more pervasive with climate change as seasonal temperature patterns shift, causing changes in species composition and geographic ranges, leaving pond ecosystems vulnerable to colonization and dominance by invasive species.

EMERGING CONTAMINANTS

Contaminants of Emerging Concern include PFAS, pesticides, and pharmaceuticals and personal care products (PPCPs). These contaminants can cause ecological and human health impacts and can have a detrimental impact on fish and other aquatic pond species. They are increasingly being detected in ponds and are often unregulated or have no action level. Studies by the Silent Spring Institute (SSI) conclude that most CECs on Cape Cod come from wastewater. Septic systems alone were attributed to 75% detection of CECs with PFOS (Perfluorooctane sulfonate), belonging to the chemical group of PFAS, and antibiotics as the highest detected substances.[101] A study conducted by USGS and the Barnstable County Health Department detected PPCPs and organic wastewater contaminants in wastewater, private wells, and public drinking water.[102] There is increasing knowledge of PFAS in drinking water sources and ponds on Cape Cod with some concentrations above state limits. CECs are a concern for pond water quality as well as drinking water quality, but these concerns are accentuated as ponds are interconnected through the hydrologic flow of groundwater on Cape Cod.

CLIMATE CHANGE

Climate change is an unprecedented challenge that is transforming Cape Cod. The Commission's Climate Action Plan outlines strategies for regional climate actions. Climate change will have many impacts across Cape Cod with some affecting pond ecosystem health. Changes in climate bring more frequent and higher intensity storms and precipitation events. These will negatively affect ponds through increased

98 USGS. Nonindigenous Aquatic Species. Available at https://nas.er.usgs.gov/.

99 Smith, D.G. (1993). The potential for spread of the exotic zebra mussel (Dreissena polymorpha) in Massachusetts. Massachusetts Department of Environmental Protection Report MS-Q-11. Available at https://www.mass.gov/doc/zebra-mussel-report-potential-for-spread-in-massachusetts/download.

100 USGS. Nonindigenous Aquatic Species: Corbicula fluminea. Available at https://nas.er.usgs.gov/queries/CollectionInfo.aspx?SpeciesID=92&State=MA.

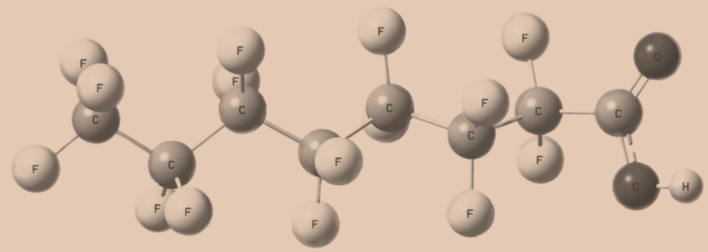
101 Schaider, L., K. Rodgers, and R. Ruthann. (2013) Contaminants of Emerging Concern and Septic Systems: A Synthesis of Scientific Literature and Application to Groundwater Quality on Cape Cod. Silent Spring Institute. United States Environmental Protection Agency. United States Environmental Protection Agency. PFAS Explained. Available at https://www.epa.gov/pfas/pfas-explained.

102 Cape Cod Groundwater Guardians. Emerging Contaminants in Our Water. Cape Cod Groundwater Guardians, County of Barnstable, Massachusetts. Available at https://www.capecodgroundwater.org/learn-more/emerging-compounds-in-drinking-water/.

influx of stormwater runoff into ponds, higher frequency of flood events and higher volume of flood waters that persist longer, which can increase shoreline erosion.

Climate change also causes extreme weather events, such as prolonged drought, and disrupts seasonal patterns. More precipitation and drought events will cause uncertainty or fluctuation in groundwater levels. Growing seasons are lengthening with increased average temperatures and diminished duration and intensity of winter seasons. These changes will alter species compositions regionally as well as increase the potential for algal blooms and establishment of invasive species. Too high temperatures and too low oxygen levels can cause substantial harm to pond species. Additionally, higher temperatures and longer periods of drought will threaten freshwater resources and the species that depend on cool and clean water. The warmer summer seasons and shortened winters may also change the use of Cape Cod ponds by residents and visitors.

WHAT ARE PFAS AND WHY ARE THEY A PROBLEM?



Per- and polyfluoroalkyl substances (PFAS) are a large group of chemicals manufactured to produce stain-resistant, water-resistant, and non-stick products. They are commonly used in everyday products like carpets, clothing, and cookware. Their slow breakdown and persistence in the environment are why PFAS are termed “forever chemicals,” and are of major concern.

PFAS are water soluble and can easily move into and through soil to groundwater, surface water, and drinking water. PFAS have been found in water, air, fish, soil, and human blood and tissue at locations across the world. When ingested PFAS can build up in the body. Research is currently ongoing to better understand the health risks, but studies indicate exposure to elevated levels of PFAS may affect the thyroid, liver, kidney, and development in fetuses and infants.

In October 2020, MassDEP established a maximum contamination level (MCL) of 20 nanograms per liter (ng/L), or 0.2 parts per billion, for six specific PFAS, individually or as a summed combination of concentrations. These substances include perfluorooctane sulfonic acid (PFOS), perfluorooctanoic acid (PFOA), perfluorohexane sulfonic acid (PFHxS), perfluorononanoic acid (PFNA), perfluoroheptanoic acid (PFHpA) and perfluorodecanoic acid (PFDA). This set of six are abbreviated as PFAS6.

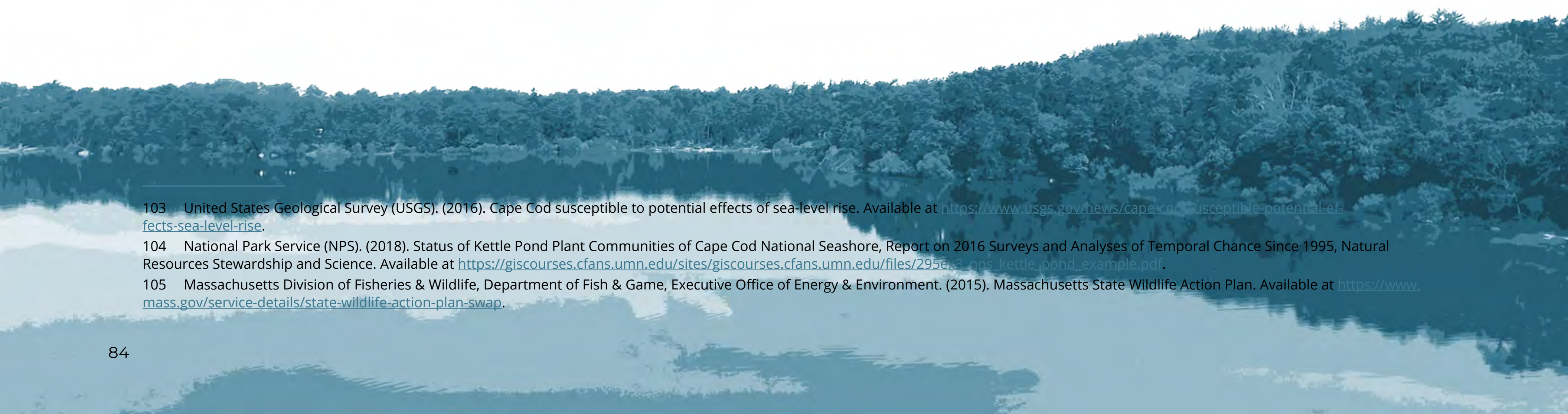
Information is still being determined about the impacts and methods to monitor and remove PFAS from water. As more information, regulations, and monitoring requirements are produced, the impacts and management of PFAS in Cape Cod water resources will need to be revisited.

Climate change is also causing sea level to rise which may result in rising water tables and, in some areas, groundwater inundation.[103] Groundwater inundation may result in saltwater intrusion into the aquifer and septic system failures that may impact ponds. The water table on Cape Cod could rise by about two feet, on average, in response to a six-foot sea-level rise; the level some models predict will occur by 2100. The potential rise in the water table is less than the potential rise in sea level because the Cape's streams and wetlands are expected to dampen the water-table response, which likely would mitigate some of the effects of sea level rise in inland areas.

Impacts from climate change are already being documented on Cape Cod as indicated by changes in pond water levels. CCNS records water levels annually in April (the start of the growing season) in ponds within its boundaries and has documented an increase from 2000 to 2016, mostly due to higher groundwater levels.[104] Changes in water depth influence plant species and their ability to survive. These same ponds have shown decreases in species composition, richness, and general plant cover since 1995. Changes will likely continue to occur as sea levels rise and/or more frequent and intense rainstorms raise the groundwater level and subsequently the pond water level in these low lying, shallow depth to water, areas.

Pond water levels can also be influenced by surface and groundwater withdrawals for public drinking water supplies and agricultural purposes. These withdrawals may remove water directly from, or intercept water contributing to ponds, resulting in reduced water levels. Severe withdrawals can dewater the nearshore littoral habitat, which is used for foraging, reproduction, and refuge by numerous species.[105] Impacts of drought conditions of longer duration and intensity related to climate change may permanently lower pond water levels.

While surface water levels of ponds fluctuate naturally, climate change impacts of more intense storms, sea level rise and drought will alter these fluctuation trends further. Ultimately, climate change can exacerbate all existing threats and cause excess stress on pond ecosystems.



103 United States Geological Survey (USGS). (2016). Cape Cod susceptible to potential effects of sea-level rise. Available at https://www.usgs.gov/news/cape-cod-susceptible-potential-effects-sea-level-rise.

104 National Park Service (NPS). (2018). Status of Kettle Pond Plant Communities of Cape Cod National Seashore, Report on 2016 Surveys and Analyses of Temporal Chance Since 1995, Natural Resources Stewardship and Science. Available at https://giscourses.cfans.umn.edu/sites/giscourses.cfans.umn.edu/files/295ex3_nps_kettle_pond_example.pdf.

105 Massachusetts Division of Fisheries & Wildlife, Department of Fish & Game, Executive Office of Energy & Environment. (2015). Massachusetts State Wildlife Action Plan. Available at https://www.mass.gov/service-details/state-wildlife-action-plan-swap.

Strategies and Solutions

Possible solutions to address pond water quality are extensive, and the Commission is developing a database of strategies to specifically address the health of ponds across the region. While some approaches have been implemented for decades, providing lessons from their application, other strategies are new and still being researched by scientists across the country.

Possible solutions to address pond water quality are extensive, and the Commission is in the process of building an organized database of solutions to specifically address the health of ponds across the region. Threats to pond water quality extend from within a pond to the entire watershed, necessitating multiple approaches and scales of solutions. While some solutions have been implemented for decades, providing lessons from their application, other solutions are new and still being researched by scientists across the country. Overall, the database of solutions selected to address pond water quality vary in performance confidence, scale of approach, site suitability, and effectiveness for achieving desired outcomes.

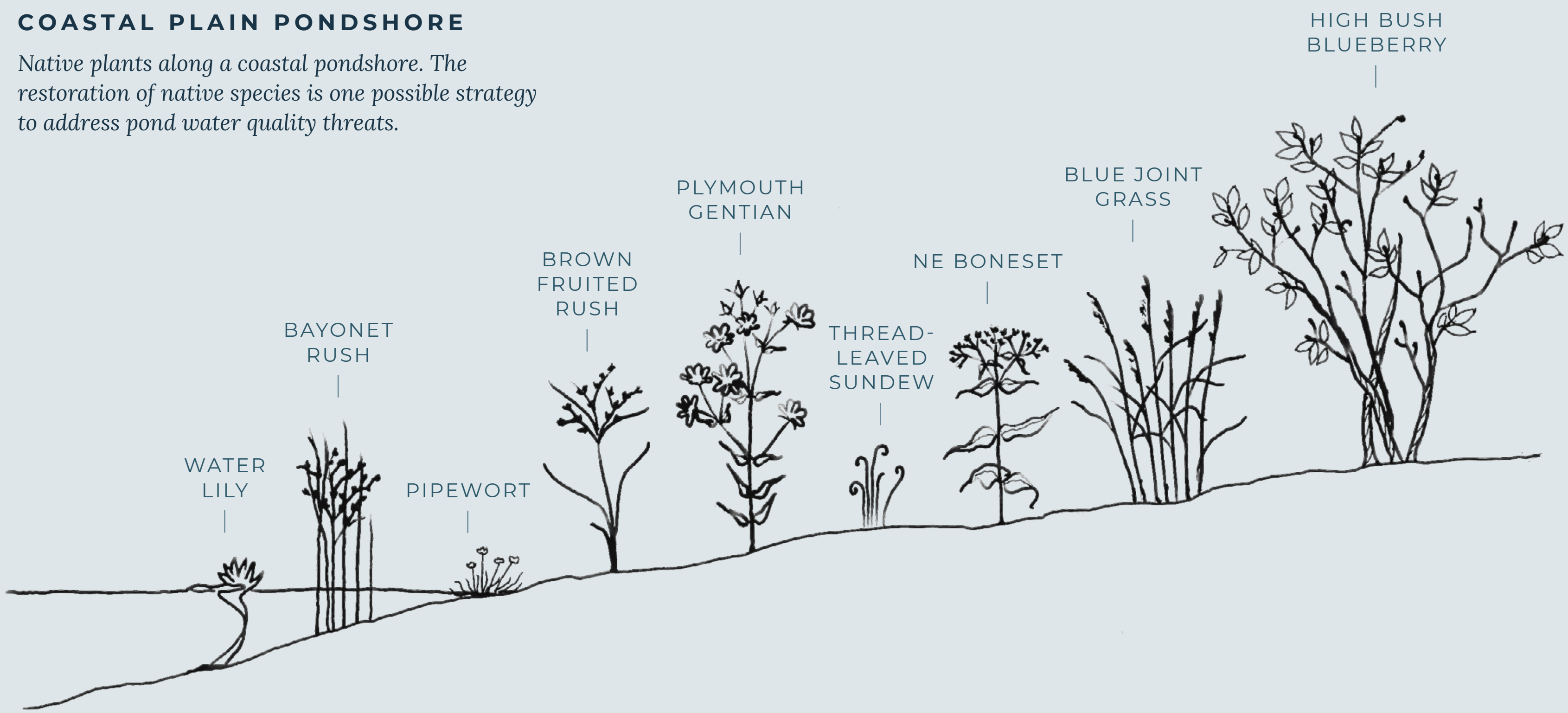
"The overall health of an inland lake depends on both the implementation of within-basin improvement methods along with immediate watershed best management practices (BMPs)."[106] Addressing pond water quality threats at a watershed scale is one approach. Solutions may also exist at the interface of the pond and the land where nutrients and invasive species can present immediate threats. Solutions at the pond shore and land interface can similarly address impacts from wastewater, land use, and stormwater, but at a more targeted and proximate scale. Solutions within the pond itself may also be viable. These solutions are generally the most popular because of their ability to show on-site remedial results quickly. However, they fail to address the sources of many negative impacts to pond health. In essence, in-pond management characteristically addresses the symptoms and not the cause of the problem.

Management options are limited and no one approach is universally applicable. Every pond has different characteristics, whether historical use and treatment, hydrologic factors, size, or exposure to weather elements. Understanding pond characteristics and the current health of

106 Jermalowicz-Jones, J.L. (2018). Immediate Watershed & Within-Basin Management for Inland Lakes. NALMS Lakeline 38(3):12-15.

COASTAL PLAIN PONDSHORE

Native plants along a coastal pondshore. The restoration of native species is one possible strategy to address pond water quality threats.



a pond are important when choosing the most effective pond improvement strategy. Even after a solution has been implemented, monitoring and follow-up pond assessments are necessary. Management strategies may need to be adapted based on a solution's performance and as conditions change.

Lessons can be derived from in-pond solutions that have already been implemented at multiple ponds across the Cape. Information on the solutions and ponds where they were applied can be viewed in the Commission's Cape Cod Freshwater Ponds Restoration Projects viewer.[107] Management strategies identified to lessen impacts from development include in-pond restoration using aluminum sulfate (alum) treatment or oxygen infusion and aeration devices; establishing minimum setbacks for septic systems, roads, and lawns; providing vegetated buffer strips between lawns and ponds; treatment of direct and near shore stormwater runoff; and public education.

In-pond treatments often target phosphorus. Phosphorus in a pond can be bound in the sediment, particularly at the sediment water interface. In the presence of oxygen, iron forms rust-colored particles (iron-hydroxide) in the sediment, to which phosphorus binds. When oxygen levels are low or depleted, these bonds break releasing phosphorus into the water. Alum treatment binds phosphorus in the sediment to prevent its release into the water column when oxygen levels are low. Alternatively, pumping oxygen to the sediment water interface will prevent release of phosphorus from the sediments. Aerators or hypolimnetic aeration can provide an effective treatment when bottom water is lacking oxygen.

These solutions are not a one-size-fits-all-ponds approach. The Commonwealth's Generic Environmental Impact (GEI) Report is part of a watershed approach to assess water quality and resource management challenges, and to assess potential solutions.[108] The GEI report reviews numerous alternative pond water quality restoration and plant control strategies to address non-point source pollution, point source control, hydrologic controls, phosphorus inactivation/precipitation, aeration, dredging, drawdown, harvesting, hydrosoaking, and biological controls. The case studies and performance assessment for each technique listed in the GEI report, as well as lessons from previously implemented pond solutions on Cape Cod can help inform future pond management. Similar solutions will be listed in the Commission's pond strategies database.

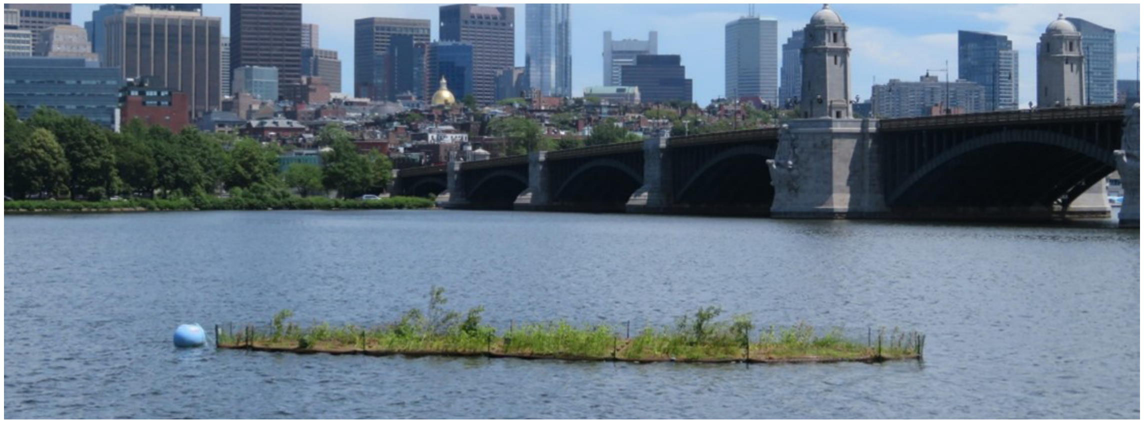
Other solutions that are applicable at a watershed scale are outlined in the 208 Plan Update and included in the 2020 Technology Matrix Update (Technologies Matrix).[109] Solutions listed in the Technologies Matrix include advanced wastewater treatment systems to replace Title 5 septic systems, constructed wetlands to treat groundwater and stormwater, stormwater management, and compact and open space development. Additional solutions will be derived from ongoing and new innovative research, such as floating wetlands currently being tested in the Charles River by the Charles River Conservancy and Northeastern University researchers where water quality threats from urban landscapes and runoff promote algal blooms and diminish zooplankton populations.[110] Floating wetlands are

107 Cape Cod Commission. Cape Cod Freshwater Ponds Restoration Projects. Available at https://cccommission.maps.arcgis.com/apps/MapTour/index.html?appid=7839e9ffe8f94d1794a22e-c1c1c53420.

108 Mattson, M.D., P.J. Godfrey, R.A. Barletta and A. Aiello. (2004). Eutrophication and Aquatic Plant Management in Massachusetts. Final Generic Environmental Impact Report. Edited by Kenneth J. Wagner. Department of Environmental Protection and Department of Conservation and Recreation, Executive Office of Environmental Affairs, Commonwealth of Massachusetts. Available at https://www.mass.gov/files/documents/2016/08/sd/eutrophication-and-aquatic-plant-management-in-massachusetts-final-generic-environmental-impact-report-mattson.pdf.

109 Cape Cod Commission. Technologies Matrix. Available at https://capecodcommission.org/our-work/technologies-matrix/.

110 Charles River Conservancy, M. Rome, and P.T. Studio. (2019). Charles River Floating Wetlands. The Charles River Conservancy. Available at http://thecharles.org/wp-content/uploads/2019/05/Charles-River-Conservancy-Floating-Wetland-Sasaki-Storyboard.pdf.



Floating wetland in the Charles River, Boston, MA. Photo from The Charles River Conservancy.

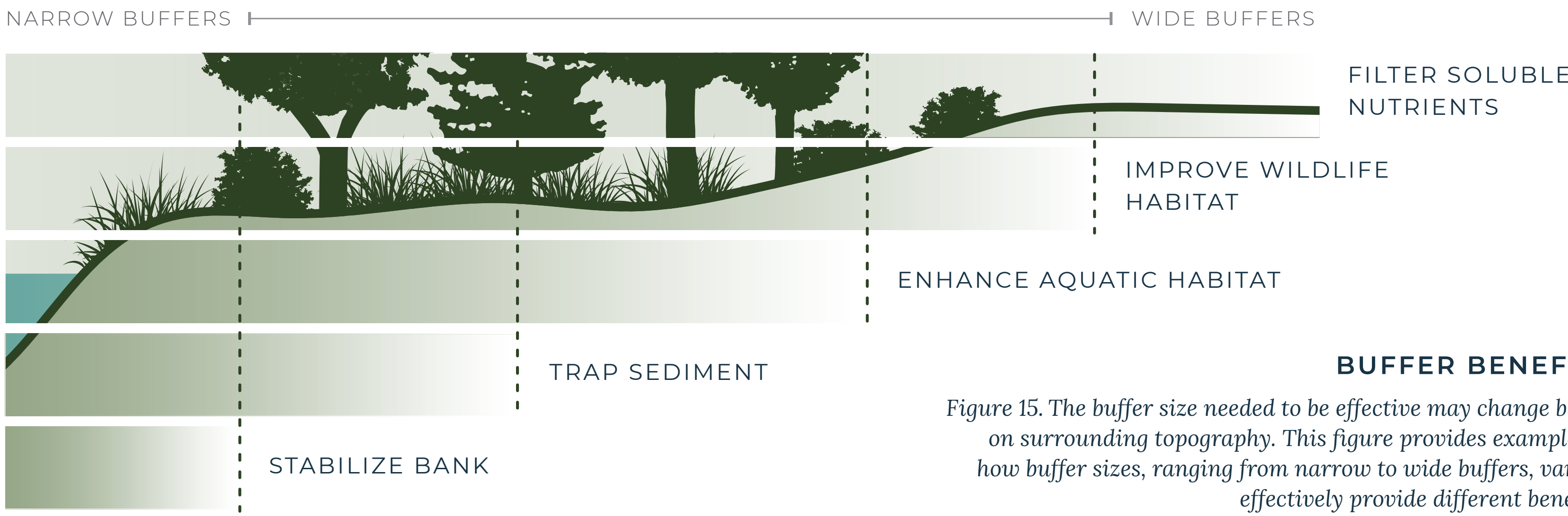
designed to provide zooplankton habitat and enhance populations of these algal consumers. Additional ecosystem benefits include the floating wetland's ability to filter water, sequester nutrients, and provide habitat for diverse vegetation. Also, innovative alternative (I/A) septic systems are being researched for their ability to improve the status of Cape Cod's freshwater systems. I/A systems are onsite denitrifying systems that are standard septic systems with components augmented to remove nutrients.[111] I/A systems were implemented in Barnstable in 2021 as part of a pilot research project designed to prevent excess nutrients from entering estuaries and ponds.[112] By referencing these approaches, as well as following new innovative research on novel approaches, a database of solutions can be generated that can address pond water quality at multiple scales, with assessment of their performance.

Threats to ponds may also be addressed through regulations and BMPs. As noted above, the Fertilizer DCPC has enabled half the towns on Cape Cod to adopt local nitrogen-focused fertilizer regulations and Orleans added phosphorus to its nitrogen bylaw. In addition to the WPA, towns on Cape Cod can adopt their own stricter wetlands bylaws and regulations that can provide more protections to ponds than does the state law. Setback requirements for development, septic systems and leachfields, and soil absorption systems exist within state regulations, and in some towns, local bylaws provide additional setbacks to protect ponds from adverse impacts. Through Title 5, MassDEP mandates a 25-foot setback from pond or surface waters for septic tanks, and a 50-foot setback for a leachfield.[113] Some towns adopt a larger setback for leachfields; for example, the Town of Brewster established a 300-foot setback distance from a lake or pond if the lot is upgradient of a lake or pond, and the Town of Bourne has a 150-

111 Cape Cod Commission. Technologies Matrix. Available at http://www.cch2o.org/Matrix/detail.php?treatment=38.

112 United States Environmental Protection Agency. Cape Cod Pilot Project Research and Updates: Innovative/Alternative Septic Systems Research Pilot and Demonstrations. United States Environmental Protection Agency, Water Research. Available at https://www.epa.gov/water-research/cape-cod-pilot-project-research-and-updates.

113 Massachusetts Department of Environmental Protection 310 CMR 15.000: The State Environmental Code, Title 5: Standard Requirements for the Sitting, Construction, Inspection, Upgrade and Expansion of On-Site Sewage.



BUFFER BENEFITS

Figure 15. The buffer size needed to be effective may change based on surrounding topography. This figure provides examples of how buffer sizes, ranging from narrow to wide buffers, vary to effectively provide different benefits.

foot setback, while most Cape towns have at least 100-foot setback requirements.[114] Other adopted bylaws may include setback distances from ponds to buildings, landscaping, docks, impervious surfaces, or staircases. Setback requirements are typically designed to prevent pollutants and phosphorus from entering the waters. They may not prevent more mobile compounds like PPCPs or nitrate from reaching surface waters. Setback requirements exist to protect the health of the natural ecosystem from development and nutrient impacts, but if minimum requirements are not enforced, ponds will face negative impacts.

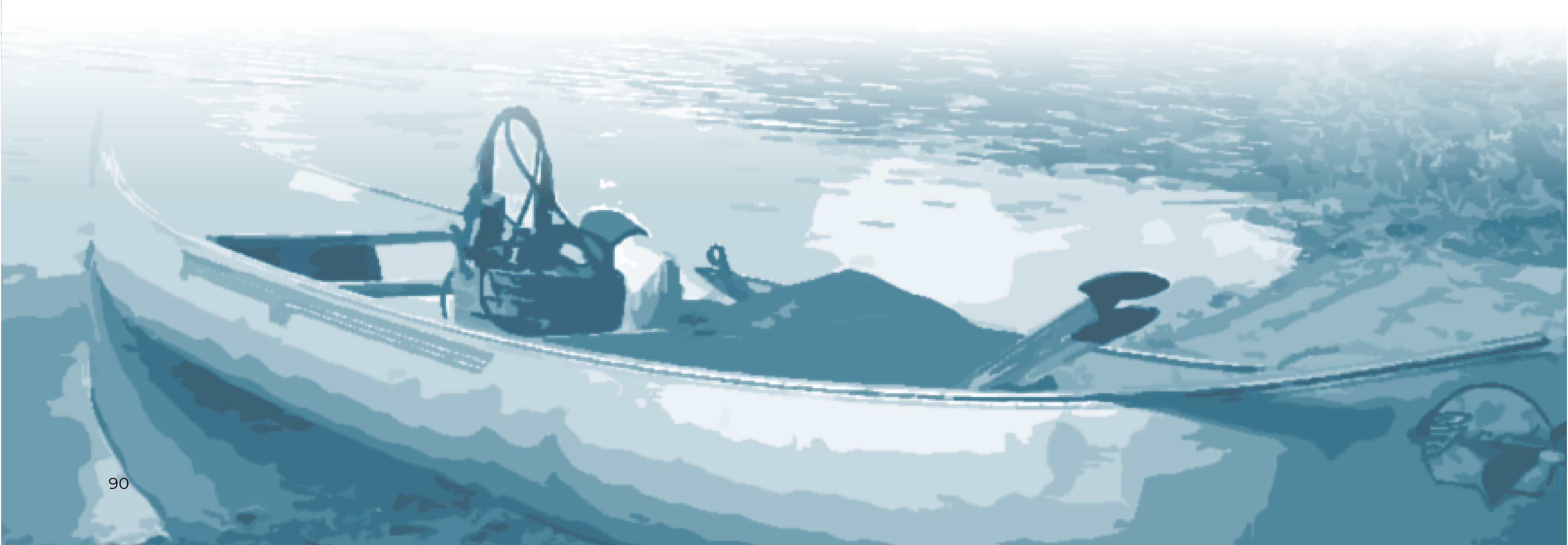
Whether required through regulation or implemented voluntarily through pond shore BMPs, maintaining zones of vegetation between certain land uses provides ponds with buffers from pollutant and nutrient runoff (**Figure 15**). Buffer zones of vegetation and adequate distances are important to protect ponds from these runoff threats. The vegetation in buffer zones and pond shores may impact the performance of uptake and flow of the nutrients and pollutants. Barnstable County Cooperative Extension created guidelines and a list of native plants for use within a

114 Town of Brewster Health Department. Leaching Facility Set Back. Available at http://records.brewster-ma.gov/weblink/0/doc/75966/Page1.aspx. Town of Bourne, Board of Health. 150 Foot Setback Regulation. Available at https://www.townofbourne.com/sites/g/files/vyhlif7346/f/pages/150_setback_regulation.pdf. Brewster Board of Health. (2016). Regulation of Sewage Disposal Systems to Protect Surface Waters and Pond Water Quality. Brewster Ponds Coalition. Available at http://www.brewsterponds.org/uploads/1/8/9/6/18965133/proposed_septic_reg_revised_7-20-16.pdf.

100-foot buffer of wetland resource areas.[115] In agricultural settings, BMPs to manage and improve water quality of agricultural runoff, such as vegetated buffers, cover crops, nutrient management plans and continuous no-till, should be advocated and employed to reduce downstream impacts.

Extensive options for restoration of pond water quality exist and can be accessed and assessed for specific ponds to determine beneficial actions as pond management plans are drafted. An extensive database of potential pond solutions will serve as a resource to guide strategies and solutions. Each strategy and solution can be assessed and validated through comparison of approach scales, long- versus short-term effectiveness, level of research confidence, permitting needs, and most effective solutions based on pond characteristics. The resultant regional understanding of applicable solutions will then guide development of partnerships amongst stakeholders based on preferred strategies and scale of approach.

115 Cape Cod Cooperative Extension. Guidelines for planting within the 100 Ft. Buffer. Available at https://www.harwich-ma.gov/sites/g/files/vyhlif7091/f/file/file/guidelinesbufferzone.pdf.



Next Steps

The updated Pond and Lake Atlas provides a current assessment of the importance of ponds on Cape Cod, the threats they face, and what is needed to improve and properly manage these valued and unique resources. As such, this updated Atlas will serve as a catalyst for renewed and expanded efforts in pond management within the region. Pond water quality is a regional challenge that will require regional collaboration, coordination, and conversations.

PONDS IN THE REGIONAL CONTEXT

Since 2015, much of the water quality work on Cape Cod has been focused on nitrogen and its impact to coastal waters through the framework established in the 208 Plan. As ponds are inextricably linked to coastal waters, groundwater, and the sole source aquifer, and provide natural attenuation of nitrogen in groundwater, acting as "nitrogen filters", ponds are given some consideration in the 208 Plan Update but are not that plan's primary focus. Assessment and management of fresh surface waters is more commonly regulated through various other sections of the CWA, including Section 303(d) which deals with impaired waters and establishment of TMDLs, Section 305(b) which requires states to periodically report on the health of water resources throughout the state, Section 319 which governs non-point source pollution, or Section 604(b) which provides grants for water quality assessment and management planning.[116]

The 2003 Atlas identified development as the primary stressor to pond water quality on Cape Cod, through its modification of the landscape, direct addition of nutrients from septic system effluent and fertilizer inputs, and indirect inputs from stormwater runoff. The 208 Plan Update identified many of the same stressors to coastal waters, including population growth and changes to land use. Similar changes are continuing to impact coastal and freshwater resources, such as:

- The region's population, which increased approximately 3% from 2000 to 2020.
- Increased use of second or seasonal homes during the pandemic compared to the past 5 years and increases in intended future conversion to primary residency.[117]
- Changes to land use (both development and loss of vegetation within pond watersheds, as well as direct shoreline development and pond's edge impacts). Residential and commercial land use within 300 feet of ponds have both increased from 2003 to 2020.

116 33 U.S.C §§ 1251 et seq.: The Clean Water Act (CWA).
117 Cape Cod Commission and UMass Donahue Institute. Cape Cod Second Homeowners Survey – 2021 Report.

Unlike marine watersheds which frequently span multiple towns, most freshwater ponds are contained within a single town, and regulation of land use and shorefront activities is largely handled at the local level. Towns regulate development around ponds through their local zoning regulations, by enforcing state and local wetlands regulations, and by adopting regulations that require additional protections such as septic system setbacks or septic systems with enhanced treatment on the upgradient side of ponds. These regulations are generally handled by town Health and Conservation Departments.

Individual ponds benefit from protection through these local regulations. Likewise, monitoring and management of ponds tends to happen at the local (village or town) or hyperlocal (pond associations focused on a single pond or group of ponds) level, and is often driven by the interest and enthusiasm of pond shore residents and pond users. With monitoring and regulation of the areas surrounding ponds occurring primarily at the local level, our understanding of the ponds themselves, the regulations designed to protect them, and the effectiveness of management actions to restore them varies widely. Without a regional program to coordinate pond monitoring and data analysis, Cape Cod has lacked the means to effectively gather and examine the monitoring data collected at a regional level since completion of the 2003 Atlas. A holistic assessment of pond remediation strategies with consideration for their implementation and effectiveness is additionally still needed. In addition to new water quality data that has been collected since 2003, the resources available to estimate watershed contributions to ponds have evolved substantially. GIS analysis can determine how the land areas that contribute to ponds through surface runoff and groundwater inflow have changed over time, incorporate new data to estimate wastewater loads within pond watersheds, and assess whether those changes are reflected in water quality measurements.


Eagle Pond, Barnstable


Peter's Pond, Sandwich


Schoolhouse Pond, Chatham

As strategies to improve pond health are implemented, these same analyses can be used to track their efficacy and progress towards restoration goals.

PUBLIC-PRIVATE PARTNERSHIPS

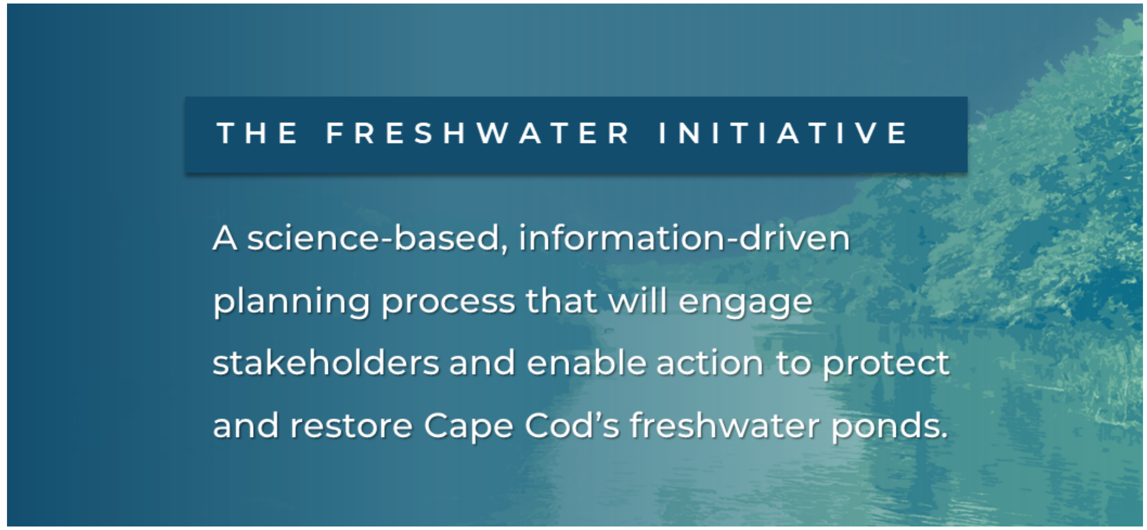
Since the publication of the 2003 Atlas, private pond associations and municipalities have worked semi-autonomously to address water quality issues and develop pond management and improvement plans. Working together through public-private partnerships and taking a regional approach to pond and watershed management can lead to farther-reaching benefits. Watersheds and the water bodies within them are fundamentally regional, not limited by municipal boundaries. Therefore, it is critical for pond stakeholders to become watershed stakeholders and to understand the nutrients and pollutants entering ponds from the surrounding watershed when addressing in-lake issues.

Public and private pond stakeholders should work together to develop comprehensive watershed assessments and create watershed improvement plans based on those assessments. Watershed improvement plans should recommend and prioritize key watershed management measures that would have widespread impacts on water quality in individual ponds and throughout the watershed. Watershed assessments may entail several analyses including but not limited to watershed modeling, hydrologic and pollutant loading, watershed-based and in-lake water quality assessments, and trophic state assessments. Assessments should aim to:

1. Identify, quantify, and prioritize the watershed-based factors which may cause pond impairment;
2. Identify the watershed management measures needed to address general causes of water quality impairments;
3. Identify the relative cost of the recommended general watershed management measures; and
4. Generate a general schedule, based on priority, for the implementation of the recommended watershed management measures.

To facilitate collaboration, coordinate efforts, and provide access to management decision tools, a central location and template for pond improvement updates is needed. The Commission has initiated the development of a user interface to access the freshwater quality data in the Regional Water Quality Database and plans to develop an online hub where local and regional initiatives, along with developments at the state level and throughout New England can be tracked and shared. Towns, pond associations, resource managers and advocates can learn from implemented approaches, benefit from updates about local actions, identify potential partners or collaborators, and find access to funding opportunities. The success of a regional effort to improve freshwater quality and support a thriving natural and economic environment on Cape Cod depends on open information and data sharing, utilizing existing partnerships and building new collaborations, and engaging the community through multiple avenues to celebrate and restore the region’s freshwater resources.

FRESHWATER INITIATIVE



The Cape Cod Freshwater Initiative provides a strategic approach to restoring the health of the region's abundant local freshwater resources.

Despite significant and ongoing ecological impacts indicated by the pond reports and water quality data collected since the 2003 Atlas, most ponds still provide the majority of uses Cape Cod residents and visitors desire. Ponds are regularly used for numerous recreational activities such as fishing and boating; bacterial testing of ponds has generally indicated healthy conditions for swimming; and recent property values and sales show that demand for pond front properties is increasing.[118] According to the Commission's second homeowner survey conducted in 2021, 45% of second homeowners indicated that access to freshwater ponds was extremely or very important in their decision to keep their Cape Cod second homes.[119] Protection of ponds will ensure their health, long time use and enjoyment by residents and visitors, along with continuing indirect beneficial impacts to the regional economy.[120] To protect the Cape's ponds however, additional steps must be taken. This updated Atlas serves as a baseline to inform the next steps outlined below and a resource for those seeking implementation funding.

To facilitate a strategic approach to restoring the health of Cape Cod's abundant freshwater resources and address previous limitations with data collection and information-sharing, the Commission has launched a Freshwater Initiative. The Freshwater Initiative is a comprehensive planning process that will incorporate new data and analysis, engage stakeholders through meetings, workshops, and media, and leverage the public's attention and energy to better understand and address

118 Cape Cod Commission. (2015). Cape Cod Area Wide Water Quality Management Plan Update. Available at https://www.capecodcommission.org/resource-library/file/?url=/dept/commission/team/208/208%20Final/Cape_Cod_Area_Wide_Water_Quality_Management_Plan_Update_June_15_2015.pdf.

119 Cape Cod Commission and UMass Donahue Institute. Cape Cod Second Homeowners Survey – 2021 Report.

120 A deeper look at the economic benefits of ponds to the regional economy will be the subject of a future task in 2022.

threats to Cape Cod pond ecosystems. The Initiative will define a path forward for improving pond water quality across the region. Elements of the Freshwater Initiative include:

Data Management and Analysis

The Commission has incorporated available pond and lake water quality monitoring data into its Regional Water Quality Database. The database is currently linked to the Cape Cod Water Quality Data Portal, a map-based viewer that allows users to explore marine water quality data aggregated from regional partners to depict high level temporal trends. The Regional Water Quality Database includes field collected data, lab data, and historical data, allows for trend analysis, and is updated regularly. The Freshwater Initiative will facilitate similar data access, exploration, and analysis capability for pond and lake data through the Water Quality Data Portal or similar user interface.

Physical Characteristics

The Commission has developed the Online Pond Viewer (cccom.link/pond-atlas), an online mapping application where users

PROPOSED FRESHWATER INITIATIVE ELEMENTS

Components of the Freshwater Initiative include an online pond viewer, online pond water quality data portal, water quality data analysis, geospatial analyses, remote sensing data collection, regional water quality monitoring program, pond improvement strategies database, economic and regulatory analysis, stakeholder engagement process, and broad communications.

can open and explore a map of Cape Cod, pan and zoom in on a pond of interest, and click on a pond to access pond spatial characteristics such as pond location, size, and depth, and other factual information such as the pond's name and GIS ID. The viewer will also provide information on pond access points and amenities available such as parking, boat ramps, and hiking trails. To populate the viewer, Commission staff are building a geodatabase of linked tables that will connect all of the different types of pond-related information being collected through the Freshwater Initiative.

Assessing, through the use of GIS and other data sources, characteristics that may contribute to changes in water quality, and determining potential internal and external drivers of water quality will be necessary to inform action.

The Commission will compile future pond water quality data collected in the field and through remote sensing, plus any new historical data that becomes available, into the Regional Water Quality Database to support informed, science-based decisions about pond management. This approach will allow the Commission to provide up-to-date and easily accessible information on pond water quality to towns, residents, visitors, and researchers. It will also allow users to track pond water quality trends, target and conduct monitoring of ponds to address data gaps, develop model action plans for impaired ponds, and develop a response plan to prioritize restoration.

The Commission will conduct a comprehensive analysis of regional pond monitoring data for nutrients and other water quality parameters to assess the overall condition of Cape Cod's freshwater pond network and identify larger regional trends in pond water quality. Updated data and information on pond characteristics, remediation activities, and surrounding land uses will be compiled and coupled with trend analysis results.

Volunteer pond monitoring to-date has focused on ponds where there is a local or municipal interest or established pond association. Ponds monitored have been selected due to factors such as ease of access, level of interest, usage, popularity, or available funding. To help prioritize which ponds to monitor in the future in a more scientific manner, the Commission will conduct a GIS analysis of Cape Cod ponds based on factors that may contribute to changes in water quality, such as surrounding land covers and uses, sewered areas, stormwater systems, and impervious coverage, as well as an assessment of potential internal and external drivers of pollution.

Remote Sensing

As has been shown through past pond monitoring efforts, the logistics of field sampling can be time consuming and expensive, even with volunteers. Current and proposed field monitoring only represents a small percentage of Cape Cod ponds. Given the unique characteristics and surroundings for each pond, measurements from a small percentage of ponds may not be representative or transferrable to other ponds or the region.

To help address these gaps, analysis of satellite-derived data may allow us to quantify changes in certain pond characteristics over time without requiring field visits and help focus expanded volunteer monitoring in the future. Satellite imagery is currently being used to measure water clarity at ponds throughout Cape Cod as a general indicator of pond health, providing measurements for several hundred ponds on Cape Cod as often as every 8-16 days. Other parameters such as chlorophyll a (which can be an indicator of increased nutrients or a direct measure of potential harmful algal blooms), temperature, cyanobacteria cell counts, and dissolved organic matter may also be quantified using satellite data. The Commission will continue to explore opportunities to use remote sensing data to investigate pond water quality and identify ponds showing signs of change that can be targeted for further investigation or field sampling efforts. The use of both remote sensing data and field sampling will provide a more complete picture of overall Cape Cod pond health.

Regional Pond Water Quality Monitoring Program

As water quality in most ponds is not being monitored at all and degraded water quality is typically detected after it becomes a problem, better monitoring and more tools to track pond health are needed. Therefore, a goal of the Freshwater Initiative is to develop a science-based, expanded, consistent, and sustainable Cape Cod pond monitoring program that allows for earlier detection of harmful algal blooms and other threats to pond water quality, and facilitates targeted intervention before public health and ecosystem impacts occur.

The Commission will work with partners and collaborators to establish a stable, long-term volunteer pond monitoring program. Through coordinated training and annual meetings, the program will create a model for a sustained volunteer workforce. This monitoring program will be consistent with current data collection, interpretation, and reporting needs and capabilities. A robust pond monitoring program will also function as a window into the overall condition of the Cape Cod Aquifer. Conditions observed via pond monitoring may help identify sources of nutrients, cyanobacteria, or pollution to groundwater and surrounding coastal waters.

Specific goals of the Regional Pond Water Quality Monitoring Program are to integrate remote sensing of ponds into the sampling design for volunteer pond monitoring; visit more ponds on Cape Cod than have been visited in the past to collect water quality data; collect samples more frequently than the once-a-year snapshot that is typically provided by the PALS program; and coordinate monitoring of pond water quality and harmful algal blooms so that pond water quality data can be used to help predict where serious blooms may occur. In addition, this program will reassess the types of monitoring and analysis to-date, identify gaps, and incorporate additional parameters, contaminants, and sampling methodologies as needed to address identified concerns.

The Quality Assurance Project Plan (QAPP) for the Regional Pond Monitoring Program has already been developed and approved by EPA, and details the program's structure, function, and protocols under which the regional program will operate.[121] By monitoring ponds in accordance with a comprehensive and EPA-approved QAPP, pond water quality data collection will be strengthened and the ability to share and integrate pond data across private and academic institutions as well as state and

121 Cape Cod Commission (2021). Quality Assurance Project Plan for Cape Cod Ponds Monitoring Program.

federal agencies will be enhanced. Benefits to Cape Cod include assured quality of data collection, comparability of data across the region, acceptance of monitoring data and results by state and federal agencies for regulatory listing purposes, better access to programs that require QAPPs to fund and support local water quality monitoring, and enhanced confidence in using water quality data to inform the public and decision makers regarding the need for pond protection and restoration.

Pond Improvement Strategies Database

The Commission and partners have previously developed several tools that compile information and explore a variety of strategies to address a particular environmental concern on Cape Cod - including the marine water quality decision support tools WatershedMVP and Technologies Matrix, and the sea-level rise focused Coastal Planner Tool. Examples of water quality management strategies for both freshwater and marine environments are also described in the Commission's Cape Cod Freshwater Ponds Restoration Project Viewer, and Cape Cod Water Quality Improvement Projects Viewer. While these various tools and viewers provide information on individual strategies that may be applicable to ponds, a single compilation that specifically addresses the full spectrum of pond water quality problems and evaluates current strategies to improve Cape Cod's freshwater ponds has not yet been created. A system to categorize ponds and identify appropriate improvement strategies based on physical characteristics, nutrient loading source(s) and magnitude, and other details will increase the applicability of the Pond Improvement Strategies Database.

Building on the strategies identified in this updated Atlas and resources listed above, the Commission and partners will develop a detailed pond-specific strategies database, including a full range of technologies, regulatory and voluntary options, and management approaches for protecting, managing, and restoring pond water quality. The database will include information on performance, cost, permitting and implementation complexity, operations and maintenance requirements, and will explore integrated solutions that combine wastewater, stormwater, and groundwater approaches.

Economic and Regulatory Analyses

People who are fortunate to live near a pond recognize its importance, but the entire region benefits from the numerous freshwater bodies that embroider the Cape due to economic and ecosystem services ponds provide to residents and visitors alike. The Commission will complete an economic impact study to assess the value of ponds to the regional economy. In addition, the Commission will complete a legal and jurisdictional analysis including a comprehensive review of federal and state laws relative to public and private interests in and around freshwater ponds and identify opportunities for local and regional action to improve or strengthen pond protection.

Engagement and Outreach

All the above Freshwater Initiative elements will be informed and guided by a robust stakeholder engagement process. A diverse group of pond stakeholders will be engaged to develop the framework to identify ponds and/or watersheds requiring significant management efforts and to define a path forward for improving freshwater quality across the region. The broad-based target audience will seek to include all people or groups of people impacted by pond management with consideration of environmental justice and equity in relation to pond management. Specific stakeholders will include appointed and elected local officials, town staff, state agencies, pond associations, the business community, non-governmental organizations, residents, tribes, visitors, and others. Stakeholder feedback will be incorporated into analysis approaches, and results from the Initiative will be shared with stakeholders via meetings, websites, reports, and other outreach strategies. Stakeholders will have the opportunity to share feedback and provide additional perspectives, which will help to develop a regional framework for freshwater planning and management actions. Including outreach and engagement in the Freshwater Initiative will tailor the development of other project resources to build local and regional capacity, tools, and knowledge, strengthen sustainable partnerships, and better connect environmental monitoring to ecosystem management.

RECOMMENDATIONS AND FUTURE ACTIONS

The 2003 Atlas concluded with a list of nine recommendations, largely targeted at building upon the early momentum of the PALS program to expand its reach, technical capacity, and connection to town planning activities. Continuing visits by PALS volunteers nearly twenty years later demonstrate that there has been great success in accomplishing the recommendation to continue the PALS snapshots of pond water quality. Recent town- or watershed-wide wastewater management plans have increasingly included freshwater ponds as a priority resource alongside coastal waters and drinking water supplies. Success in achieving other recommendations, like recruiting volunteers and PALS groups in each town, obtaining sampling equipment, providing personnel to train volunteers and review sampling data, has varied from town to town. At the regional level, there has been limited success identifying sources of funding to support annual or semi-annual PALS sampling events, and for planning studies or implementation plans to remediate pond impairments.

Since the publication of the 2003 Atlas, the landscape surrounding Cape Cod's ponds has changed both literally and figuratively. Many of the same threats to pond water quality still exist today (shoreline development, impervious cover, phosphorus inputs from septic systems), while new threats have emerged (PFAS, cyanobacteria and HABs, temperature and precipitation pattern changes). The 208 Plan update provided a blueprint for the type of framework that can galvanize towns, non-profits, and pond groups throughout the region together around common interests and concerns, and to equip them with better information and resources for decision making. New avenues that did not exist twenty years ago may be available to fund pond-related work, including EPA's Southeast New England Program, the Cape and Islands Water Protection Fund, and various programs related to the Clean Water Act (e.g., Section 319 and 604b grants).

The Freshwater Initiative aims to respond to the successes and progress made since

2003, while also addressing new challenges and opportunities for understanding and improving pond water quality across Cape Cod. Through a structured and re-invigorated regional pond monitoring program, the Freshwater Initiative can provide a forum for volunteer engagement and additional resources to obtain and share equipment, data, and funding opportunities. Online tools will enhance the accessibility of monitoring data, information about ponds and the water quality improvement strategies that best apply to them. Analysis of the economic role that ponds play and the regulatory framework surrounding their protection and management will help further illustrate the benefits of pond preservation and restoration while examining opportunities to maintain and strengthen pond protections.

Hoxie Pond, Sandwich

A VISION FOR CAPE COD'S PONDS

Throughout the years following the 2003 Atlas publication, and throughout various regional planning efforts that overlap with freshwater ponds, proponents have been vocal about the need to dedicate more attention and resources to protecting Cape Cod's freshwater ponds. The efforts of past and current volunteers to continue sampling ponds each summer have built a foundation on which to expand our understanding of how ponds are changing throughout Cape Cod, and where there are opportunities to preserve and improve them. The future work outlined in this updated Atlas hopes to create a regional network of resources whereby ponds are strategically monitored, in the field and remotely; where monitoring data are readily accessible and can be used to identify future problems and design solutions before critical thresholds are reached; and where the passionate and focused pond volunteers can see tangible results from their work at the local level and as part of a larger regional movement for Cape ponds and the aquifer that connects them.

List of Abbreviations

208 Plan Update: Section 208 Area Wide Water Quality Management Plan

APCC: Association to Preserve Cape Cod

2003 Atlas: 2003 Cape Cod Pond and Lake Atlas

BCDHE: Barnstable County Department of Health and Environment

BMPs: Best Management Practices

CCNS: Cape Cod National Seashore

CCS: Center for Coastal Studies

CECs: Contaminants of Emerging Concern

Commission: Cape Cod Commission

CWA: Clean Water Act

CWRMP: Comprehensive Water Resource Management Plan

DCPC: District of Critical Planning Concern

DCR: Massachusetts Department of Conservation and Recreation

DER: Massachusetts Division of Ecological Restoration

DFG: Massachusetts Department of Fish and Game

DMF: Massachusetts Division of Marine Fisheries

DO: Dissolved Oxygen

EEA: Massachusetts Executive Office of Energy and Environmental Affairs

EPA: United States Environmental Protection Agency

GEI: Final Generic Environmental Impact Report

MassDEP: Massachusetts Department of Environmental Protection

MassWildlife: Massachusetts Division of Fisheries and Wildlife

MIPAG: Massachusetts Invasive Plant Advisory Group

NACL: Cape Cod National Seashore's North Atlantic Coastal Laboratory

NWI: National Wetlands Inventory

NHESP: Natural Heritage and Endangered Species Program

PALS: Pond and Lake Stewardship Program

PCBs: Polychlorinated Biphenyls

PFAS: Per- and Polyfluoroalkyl Substances

PPCPs: Pharmaceuticals and Personal Care Products

QAPP: Quality Assurance Project Plan

Updated Atlas: 2021 Cape Cod Pond and Lake Atlas

SMAST: University of Massachusetts Dartmouth School for Marine Science and Technology

SNEP: Southeast New England Program

TMDL: Total Maximum Daily Load

USGS: United States Geological Survey

WBP: Watershed-based Plan

WPA: Wetlands Protection Act

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CAPE COD POND AND LAKE ATLAS
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CAPE COD
COMMISSION

P.O. BOX 226, 3225 MAIN STREET
BARNSTABLE, MASSACHUSETTS 02630
PHONE: 508-362-3828
EMAIL: FRONTDESK@CAPECODCOMMISSION.ORG
WWW.CAPECODCOMMISSION.ORG

COUNTY OF BARNSTABLE ★ MASSACHUSETTS ★