Frequently asked questions about CCNS kettle ponds

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What is the difference between a lake and a pond?

Ponds are shallow and/or clear enough that light is sufficient to support plant growth along the bottom. The deepest sediments of true lakes receive so little light that vegetation cannot survive. Thus, most of the Cape "ponds" are technically lakes.

Why are there trout in Gull Pond?

The Massachusetts Division of Fisheries and Wildlife stocks Gull Pond, along with many other ponds throughout the state, with several species of trout for recreational fishing. There are no native trout in Seashore kettle ponds.

What is pond liming?

Liming is the addition of ground agricultural limestone to reduce the acidity (raise the pH) of the pond water. The intent of liming is to counteract the acid added by industrially polluted rain and snow. On Cape Cod, however, there is strong evidence that our ponds have been acidic for thousands of years and have not been acidified by "acid rain". Naturally acidic conditions are expected given our acid-forming vegetation and the scarcity of alkaline (basic) substances in native soils to buffer acidity. [See discussions of limed Great Pond in Truro, p. 37 and 66.]

Why are boats with gasoline engines prohibited from the kettle ponds?

Internal combustion engines were banned from the ponds by the local towns after a fatal collision with a swimmer many years ago. In general, the public consensus is that noisy, polluting and hazardous high-powered motorboats are not appropriate in these relatively small water bodies. Fishers regularly use electric motors for trolling.

Why study the kettle ponds?

Over the past century many ponds worldwide have been changed for the worse by human disturbance. Seemingly minor disturbances, like residential development along the shoreline, increased swimming, and atmospheric pollution from both distant industry and local automobiles, have turned clear ponds to algae or weed-choked ponds. Although most of the Cape ponds are in excellent shape, all show evidence of the influences of people; some are already showing decreased water clarity since the 1970s. Identifying the causes and monitoring the effects of these disturbances in a scientifically defensible manner requires intensive research and sustained monitoring. Monitoring records changes in those parameters most sensitive to human disturbance; research identifies the *most important water quality problems, and tests and recommends effective solutions. [See Chapter IV. Pond Water Quality, Cultural eutrophication.]*

How many years of monitoring will it take to explain how the ponds are doing?

This depends on how variable pond water quality is from year to year. Pond water quality varies naturally from year to year even without human influences, being affected by annual differences in temperature, winds, precipitation and the surrounding groundwater system. Based on our observations and analysis of this variability so far, it will probably take 10-20 more years of monitoring to discern long-term trends.

Why aren't the more "productive" ponds better?

We commonly think of productivity as a positive attribute; however, in ponds "high productivity" has negative consequences turning naturally clear (unproductive) ponds cloudy. The most common threat to pond water quality worldwide is phosphorus pollution, which actually stimulates plant and algae growth to the detriment of naturally clear-water ponds. Biological and chemical evidence in the pond sediments shows that most of the deep CCNS kettle ponds were naturally clearer, and therefore less productive in terms of algae and aquatic plants and animals, than the more shallow Cape ponds or those polluted by man.

What are the most important changes in the surrounding environment that might affect the ponds? How might the ponds respond? How have people changed the ponds now and in past history?

The water quality of Seashore ponds in large part reflects adjacent vegetation, topography and land use. Even before the arrival of people, we know from sediment analyses that the ponds responded both chemically and biologically to changes in vegetation and fire frequency in adjacent uplands. Even the modest landscape manipulations by native Americans (e.g. presumed ditching to connect adjacent ponds) seem to have affected pond water quality. [See Chapter VII. Herring effects on the trophic dynamics of the Gull Pond chain.] When settlers from Europe began to clear the upland forest, the runoff of nutrients and other substances increased, leading to higher water-column production of organic matter and faster sediment accumulation. With the regrowth of the pine-oak forest over the past 100 years, ponds have somewhat recovered their native clarity, acidity and low sedimentation rates. [See Chapter II. Geologic Origins and Paleoecology: Sediment Cores and Sedimentation Rates.] More recently, especially over the past 30-40 years, human recreational and residential use of the ponds has increased; both forms of use can reduce water clarity by contributing nutrients as septic leachate, through soil erosion, or through the failure of visitors to use restrooms.

How do the ponds record changes in the water column and surrounding landscape?

The "record" is preserved in the pond sediment in the form of chemical changes and plant, animal and microbe remains. Pond sediment is laid down in layers, with oldest remains at the bottom; these layers can be peeled away and examined like the pages of a book describing the environmental history of the pond and its watershed. [See Chapter II: Paleoecology as a Tool for Study of Seashore Kettle Ponds.]

How old are the ponds?

The deep kettle ponds are generally between 10,000 and 13,000 years old, as determined by radio-carbon dating of the remains of the earliest lake organisms in the deepest layers of sediment..

How did the ponds form? How have they changed physically over time? What will happen to them in the future as the Cape erodes and changes?

Huge ice blocks left after glacial retreat were partially buried in outwash sands and gravels transported by glacial meltwater that flowed from the retreating glacier. When the ice melted, the ice-block "kettle" holes remained. Some of the kettle ponds were formed in clay-rich outwash and these basins held freshwater and began sediment accumulation immediately after ice-block melt. However, other of the Wellfleet and Truro kettle ponds did not form until rising sea level pushed the outer Cape's freshwater lens upward until it intersected the previously dry kettle holes. All of these basins were probably as irregularly shaped as the ice blocks when they first began to flood; however, centuries of circular shoreline currents have re-countoured the shorelines leaving the rounded kettles of today. With rising sea level (the present rate of sea level rise is two millimeters per year), the kettle ponds, along with the entire Cape land mass, will be eroded away primarily from the east a process that will likely take many thousands of years unless sea-level rise accelerates due to global warming. One originally freshwater kettle pond, Salt Pond in Eastham, has already been breached by the rising sea; analysis of Salt Pond sediment indicates that it changed from a freshwater pond to a saltwater lagoon about 1200 years ago.

Where else in the world are kettle ponds found?

Kettle ponds occur all across once-glaciated northern Europe and North America, wherever ice-block depressions in glacial outwash have filled with water. Outwash sands and gravels are generally poor in nutrients, accounting for characteristically high clarity of kettle pond waters.

Are all the ponds below sea level?

Pond surface water levels are controlled by, and approximate, local groundwater levels, which around the Seashore ponds range from six to nine feet above average sea level. The bottoms of all the kettle ponds are below sea level.

What is the range of depth of the ponds?

Two to twenty meters, or about 6 to 65 feet.

Why are some ponds (like Herring Pond) full of plants and others clear and sandy? Is Herring Pond dirtier?

It depends on your definition of "dirty". Ponds like Herring are certainly mucky, but naturally so and not because of pollution. Shallower ponds like Herring tend to be more "productive", to produce more organic matter, precisely because of their depth. Nutrients that sediment to the pond bottom are easily mixed by summer winds back into the shallow and therefore well-lit water column (photic zone)) where they can fuel additional plant and phytoplankton growth. Thus, nutrient recycling between water column and sediment is very efficient, supporting high rates of production. In contrast, a large portion of the nutrients that enter deeper ponds ends up in bottom sediment far *removed from the well-lit pond surface. Shoreline (littoral) currents in the larger ponds also help to keep the sands clean-looking by moving organic debris to deeper waters. Herring Pond is also at the downstream end of the Gull Pond chain and thereby receives nutrient-rich runoff from Gull, Higgins and Herring Ponds.*

How do landlocked ponds get rid of waste that might naturally fall in them? Dead animals, runoff, litter, etc?

First, due to the presence of abundant bacteria and fungi, all of these forms of organic matter decompose to some extent within the pond basin, thereafter escaping as gases (e.g. carbon dioxide, dinitrogen, methane). These gases are taken up by microbes, plants and animals, flow out of the pond basin into the groundwater system, or are released into the atmosphere. A very small fraction of these "wastes" is removed by animals like fish-eating waterbirds. The organic debris which remains and resists decomposition ends up in the sediments, accumulating very slowly, usually less than one millimeter per year.

How does the groundwater stay fresh while surrounded by the ocean? Will the ponds ever get salty?

Rain and snowmelt percolate through the ground and accumulate as a freshwater aquifer, in the shape of a lens, atop salty groundwater. The freshwater is lighter (less dense) than the saline groundwater and, therefore, the two mix only within a thin interface. Because the groundwater is restricted to the small pore spaces between soil particles, flow is very slow (e.g. one foot per day) and the resistance to flow causes the fresh ground water to mound up above mean sea level. Because the groundwater level is always higher than mean sea level, groundwater almost always flows seaward (i.e. down hill), preventing salt water intrusion of the fresh aquifer.

The ponds will only become salty thousands of years from now when rising sea level reaches the pond basins.

Does rinsing off in the ponds after swimming in the ocean make the ponds more salty?

No. Compared to atmospheric deposition of salt, amounting to over 5000 pounds of sodium chloride per year for Gull Pond for example, the amount contributed by salty human bathers is insignificant.

If the ponds receive thousands of pounds of salt per year from the atmosphere, how do they stay so fresh?

If you dissolve the annual salt input into 108-acre Gull Pond, it represents a very small increase in the pond's salt concentration, only about one percent. These relatively small salt additions <u>would</u> be significant over the long term of course, except that ponds are flushed out by inflowing and ouflowing groundwater with a turnover rate of 10-15 years for gull Pond. This exchange is enough to prevent the salts from accumulating.

What kinds of life do the ponds support? How did fish and other animals get in there?

Most common fish are banded killifish, yellow perch, pumpkinseed sunfish, brown bullhead (aka horned pout), herring, largemouth bass, smallmouth bass, American eel, chain pickerel, white perch and golden shiner. Common frogs include bullfrogs, green frogs and Fowler's toads during spawning. Turtles: painted, snapping and musk turtles. There are a multitude of invertebrate species both in the water and sediment, and then *hundreds of small and microscopic plankton, algae and animals attached to plants and sediment. At least 50 aquatic vascular plants have been identified along pond shorelines.*

Animals that have terrestrial life stages, can fly at some point in their life cycle, or have eggs that survive desiccation have apparently made it to the ponds on their own. It's likely that most of the fish have been introduced by people. No one knows how the native fishes, including pumpkinseed, yellow perch and pickerel, originally arrived at the outer Cape ponds. Herring, eels and white perch swim up the Herring River into the Gull Pond chain of lakes.

How has acid rain affected the ponds? Mercury? Global warming? Sea-level rise?

Although all of the ponds are acidic (pH less than 7.0) and many have pH less than 5.5, studies of the remains of pH-sensitive organisms in the pond sediment show that in general the ponds were often as acidic before the "acid rain" era as they are today. [See Chapter II, Table 2-1.]

Mercury pollution is transported with polluted air from distant industrial sources to the kettle ponds. Much of it accumulates in the sediment, but some is mobilized by bacteria and concentrated by bottom-dwelling invertebrate animals. Fish that consume these invertebrates can accumulate mercury in their tissues. A preliminary survey of mercury in sediment and pond fish found moderate levels in some of the land-locked and most acidic ponds.

Sea-level rise since deglaciation has actually produced some the kettle ponds by forcing fresh groundwater upward into previously dry ice-block depressions. Global warming and consequently accelerated sea-level rise could cause major changes to kettle pond ecology by altering their hydrology, water chemistry and affecting species ranges. Cape Cod is at the boundary between boreal and more temperate biogeographic regions. For this region, climatic warming will likely produce marked changes in the kinds of animals and plants that can survive here. Aquatic species, like land-locked fish, that cannot shift their ranges as fast as climate warms may disappear.

Do the ponds have microorganisms that are unhealthy for people? Can I get sick from swimming in the ponds?

Toxic algae blooms are extremely rare at the kettle ponds, primarily because the ponds are so clear; toxic cyanobacteria (previously called "blue-green algae") are stimulated by phosphorus pollution and eutrophication. Human pathogenic (disease-causing) microbes are shed into pond water by people but their survival in the pond environment is limited. Of course, just being amongst a large concentration of people may increase your chances of contacting these pathogens. Importantly, human pathogens do not breed in the ponds.

Do you test the water in the ponds?

Seashore staff monitor the kettle ponds for signs of eutrophication and acidification, ecological processes that can affect the whole pond ecosystem including people. The Town of Wellfleet tests bathing waters for bacterial contamination.

Who owns the ponds?

Pond jurisdiction is complicated. The waters and submerged lands of ponds over 10 acres are the property of the Commonwealth of Massachusetts in Wellfleet, but are the property of the U.S. (NPS) within the seashore in Truro (due to a conveyance by the commonwealth). Public access is granted by state law to all ponds over 10 acres (great ponds). Smaller ponds are owned by shoreline property owners, who may include private citizens, a town or the Seashore. All federally-owned portions of the pond shorelines, regardless of pond size, are open to the public (unless they are restricted for resource or public protection purposes).

Why didn't the historical farming, wood cutting and fires destroy the ponds? Or did it?

Forest clearing, farming and frequent fires led to shoreline erosion and increased both pond productivity and sedimentation rate; these effects are evident in the pond sediment record. However, with forest regrowth over the past 100 years, the ponds have largely recovered their clarity and low sedimentation rate.

Where did all these private houses inside the Seashore come from?

When the Seashore was established ca. 1960, people with homes built prior to September 1959 were allowed to keep their dwellings indefinitely provided they comply with guidelines intended to preserve adjacent natural resources.

Who studies the ponds, what are their qualifications? Is there any work for volunteers?

The ponds are monitored by a team of professional ecologists, chemists, students and volunteers. Specific research projects are conducted by Seashore scientific staff, academic cooperators and scientists from the US Geological Survey with advanced degrees and experience in limnology, aquatic ecology and biogeochemistry.

Volunteers have helped with monitoring and will continue to do so.

What do you mean by C3 and C4 plants?

The two groups of plants use different biochemical pathways for the assimilation of carbon in photosynthesis. A consistent difference in the efficiency of the two pathways results in a distinct difference in the relative proportions of the stable isotopes of carbon in resulting organic matter. These distinct "isotopic signatures" can be used to trace the source of carbon at different points within the pond food web. For example, the isotopic signature of a fish that eats invertebrates that eat C3 oak leaves will differ detectably from the isotopic signature of a fish that eats invertebrtates that eat C4 grasses.

How old are pond bottom sediments and how quickly are they deposited over time? How accurately can you date the ponds and their changes?

See Figure 2-2. The oldest pond sediments are more than 13,000 years old; most pond sediments are deposited at the rate of about one millimeter per year. Radio-carbon-14 dates are typically accurate to within 150 years. The lead-210 isotope, with a much shorter half-life than carbon-14, provides a time-line for the last 150 years.

What do the different colors of pond mud and sand indicate?

The color of pond sediment can depend on organic content, element composition, particle size of inorganic matter (sand versus clay) and the amount of oxygen present. Sandy sediments of low organic content are nearly white; sediments with lots of organic debris *are brown or, if low in oxygen, black. Red sands are produced where iron-rich water or sediments are exposed to oxygen; they often indicate a shoreline where iron-rich groundwater is discharging into the pond basin.*

If the bottom sediments of our kettle ponds range from 3-7 meters thick, how deep are sediments in non-glacial ponds elsewhere? What does that say about their age?

Non-glacial ponds/lakes can contain from a few centimeters to thousands of meters of sediment. In most lakes age increases with sediment depth. Some non-glacial lakes, like Lake Biwa in Japan and Lake Baikal in central Asia, are millions of years old. More than 1400 meters of lake sediment have been obtained from a coring operation at Lake Biwa. Other non-glacial lakes formed in volcanoes (maar lakes), in abandoned river meanders, in sink holes, and in deflation basins caused by wind.

Ponds like Great-Wellfleet and Snow that have bog origins – does that mean that they are not kettle ponds with glacial origins?

No, both ponds began life as dry kettle holes left by ice blocks. The reason for bog development here but not in other ponds is unknown, but may be due to local hydrology.

Do the ponds provide breeding areas for mosquitos? If so what kind?

Mosquitoes cannot successfully breed in the kettle ponds, primarily because of the presence of predatory fish and frogs which eat mosquito larvae..

If ponds become degraded by septic leaking or misuse, can they ever be cleaned up? What would the NPS do to cure them?

As indicated in the sediment record, the ponds are capable of considerable self-regulation, buffering the effects of acid rain and nutrients through in-lake chemical and biological processes. For example, the sediments have the capacity to bind up a large reserve of the nutrient phosphorus, especially if iron is abundant. With increasing human use there is concern that nutrient loading (e.g. from septic leachate) may increase beyond a pond's capacity to assimilate the added nutrients. If this were to happen, there may be no real "cure"; therefore, our goal is to minimize nutrient additions.

What kind of effect does shoreline erosion have on the ponds (for example, trails on steep banks leading down to the water)?

Soils can contain a substantial amount of phosphorus, the nutrient limiting aquatic growth in Cape kettle ponds; erosion washes soil and its contained nutrients into the water column. Shoreline erosion also involves the loss of vegetative cover, which leads to more erosion; it's important to realize that the forest vegetation captures phosphorus, nitrogen and other substances that would otherwise leach into the pond system.

What are the most important gaps in our knowledge of the ponds and how they work?

See Chapter VII. Recommended Research and Monitoring. Probably the two most important needs are for hydrogeologic studies and phosphorus budgets, the former to identify where each pond's water comes from and the latter to rate the different sources of phosphorus pollution for intervention.

How long does it take a pond to completely flush itself? Which ponds flush slowly and which ones quickly?

The largest and deepest ponds flush most slowly, e.g. 10-15 years for 108-acre Gull Pond. Smaller ponds like Duck completely flush over a 1-2 year period.

What are Group I and Group II ponds?

The first group are ponds that began to fill with water about 13,000 years ago and steadily accumulated pond sediment to the present. Group II pond sedimentation was interrupted by layers of gravel and appear to have become flooded only 2000-5000 years ago. The source of the gravel layers is as yet unknown.

What accounts for year to year fluctuations in the acidity of the ponds?

We don't know but are testing some ideas. Increased nutrient loading should cause pond acidity to decrease, a process that seems to be occurring in Long Pond (see p. 64). Rainfall (or lack of it) may also play a role, for example at Ryder Pond where recent trends in acidity appear related to the amount of precipitation (see pp. 42 & 71). Seasonal changes are more easily explained as the result of temperature-dependent biological processes, i.e. acid ion uptake in summer, and release in winter.

Which ponds are oligotrophic and which are mesotrophic? Will the oligotrophic ponds eventually become mesotrophic or eutrophic over time?

See Table 4-4 and p. 51. If phosphorus pollution continues or increases, oligotrophic ponds will become mesotrophic or, over time, even eutrophic.

Why are some pond shorelines full of plants and others bare sand?

A recent NPS-supported study has shown that aquatic plant abundance around pond shorelines is directly related to water quality, with more nutrient-enriched ponds having most plants. This is expected for two reasons: 1) the growth of aquatic plants is dependent on nutrient supply; and 2) plants grow best in shallow ponds (because they can root in the nutrient-rich sediment and still reach the well-lit water's surface) and these shallow ponds tend to have high water-column nutrients.

What makes Snow Pond different from the other ponds?

Like all of the ponds, Snow has a unique post-glacial history. Although its kettle hole first began to fill with water 6000 years ago, a bog, rather than an open-water pond, first developed and persisted for about 2500 years. Thereafter, Snow Pond sediments show the development of more typical open-water habitats. No one has fully explained why the bog developed her and not in similarly deep kettle holes.

Will rising sea levels create new ponds in formerly dry kettle holes? How long might that process take?

It all depends on the elevation (altitude) of the hole relative to sea level and on the rate of sea-level rise, presently about two millimeters per year on Cape Cod. If sea level continues to rise at the current rate, and we assume that groundwater rises along with sea level, holes presently perched a meter above sea level will become ponds in 500 years. *This is a gross simplification because it ignores other factors, e.g. sea-level rise erodes and shrinks the Cape Cod peninsula, thereby reducing the width and height of the groundwater lens and retarding groundwater inundation of the land surface, including the kettle holes.*

You say that Duck Pond has mosses growing at a depth of 40 feet. How is this possible? Is this some kind of record? Are they unique moss species adapted to conditions at these depths? I thought mosses were terrestrial plants…

Submerged aquatic mosses are common, but not at these depths. For plants to survive 40 feet below the water's surface, there must be sufficient light for plants to "make a living". [The plant's photosynthetic production of organic matter must exceed its respiratory loss of organic matter.] For this condition to exist at 40 feet the water must be extremely clear. In addition, the mosses probably grow slowly and are adapted to low light. Mosses have been collected from similar depths in kettle ponds elsewhere in the U.S. Some of the mosses are the same as species growing in much shallower water; others are different. If ponds become more cloudy, these mosses may decline or disappear.

What causes pond waters to become stratified? Is this a bad or unnatural condition?

Waters stratify as they warm in the spring. Water molecules vibrate faster as they warm and move further apart, become less dense, i.e. lighter. As the density difference between cold bottom waters and warm surface waters increases, it takes more and more energy to mix them. [Consider how a half full bottle of pop is more stable than a full one.] Relatively light spring and summer winds don't provide enough force, so the ponds stratify.

The process is natural but can be a problem for aquatic life because the bottom water, isolated from the oxygen-rich atmosphere and receiving lots of settling organic matter, can become depleted of oxygen. The situation is worsened by nutrient loading which increases organic loading to bottom waters. If conditions worsen to the point of total oxygen depletion, phosphorus is chemically released from the sediment to fuel even more organic production when the pond re-mixes in the fall.

When do the pond waters turn over and why does this occur?

In the fall (usually October or November) cold nights cause surface waters to cool and to approach the density of deeper water. As densities become more equal, it takes less wind energy to turn the water mass over (remember the pop bottle). Fall mixing is also helped by stronger northerly winds during that season.

What were some of the detectable changes in conditions of the various ponds when the Europeans arrived in the 1600s and after 1950 when summer tourism began to take off? How are these events evident in the pond bottom sediments ?

The pond sediments show increased rates of sedimentation and nutrient loading, and lower acidity, after European settlement and land clearing. This is because resulting soil erosion contributed sediment mass, the nutrient phosphorus, and acid-buffering substances into the pond basins. After 1950 changes became more obvious. Changes in species and their abundances accompanying these changes are clearly reflected in the sediments.

Ryder pond seems to have a unique sediment record. How could flooding or drought affect one pond and not all the others?

This is the important, and as yet unanswered, question. The reason may be due to differences in the early origins of Ryder Pond that make it especially sensitive to drought (see p. 71). Another possible explanation is that water levels fluctuate more radically at Ryder, because of its position within the local aquifer. Ponds nearer the top of the groundwater lens would fluctuate more as a result of changing recharge than ponds nearer the ocean or bay. An ongoing hydrological study (Masterson & Barlow 2000) will refine the local water table map around Ryder and will provide critical information for addressing this possibility. Major changes in water level can affect whether sulfur is stored by or released from shoreline sediments: low water levels cause the release of sulfur as sulfate which increases the acidity of Ryder Pond; high water levels induce sulfur storage and low pondwater sulfate and acidity.

What are the effects of drought on the ponds? Aren't these fluctuations natural? When might these effects cause concern to pond users and managers?

Low precipitation causes the level of both the groundwater and ponds to drop, exposing shoreline that during wetter years may have been completely covered. This is a natural process that, in fact, allows certain shoreline plants like carnivorous sundews to flower and produce seed. These species could not reproduce sexually without occasional dry years. Low water levels can be of concern if they are produced artificially, e.g. from excessive groundwater pumping. Unlike drought, the artificial drawdown of the pond by pumping may be <u>sustained</u>, leading to the elimination of habitat for shoreline plants adapted to periodic flooding and dewatering.

What might lead to fish kills in the ponds?

Fish kills in ponds are often caused by oxygen depletions, especially during the period of ice cover in winter when atmospheric oxygen cannot diffuse into the pond water. However, the period of ice cover on Cape ponds is infrequent and brief, so that fish kills are rare.

How do alewives contribute to the alkaline and saline conditions in Gull Pond? (P43)

Alewives and blueback herring carry in their bodies the marine salts assimilated during their development in the ocean; however, this source of salt is likely insignificant compared to atmospheric deposition (see above).

Is there evidence that Native Americans first opened the Gull Pond complex to herring for fishing?

Yes, there is evidence in the sediment, i.e in stable carbon isotopes and in the remains of diatoms and fish prey organisms (crustacean zooplankton), that Native Americans opened sluiceways between the ponds as early as 2000 years ago. It seems reasonable to speculate that their intent was to extend the fish run.

How important have birds been as a nutrient source for the ponds now and historically?

Birds that feed on the ponds, like fish-eating cormorants and ospreys, probably remove as much nitrogen and phosphorus as they excrete into the ponds. Birds that rest on the ponds but feed elsewhere, like gulls, can be a major source of phosphorus especially where they concentrate, for example on Gull Pond, Wellfleet. The situation was much worse when garbage was available to gulls at local landfills; gulls by the thousands *transported nutrients obtained at landfills, as well as coastal feeding areas, to the ponds. Since landfills closed in the late 1980s, gull numbers on the kettle ponds have decreased greatly.*

What are the relative contributions of nutrients from direct runoff, septic leaching, marine salt spray and from the atmosphere?

Complete nutrient budgets, including inputs, storage and exports, have not been worked out as yet for the kettle ponds. However, work at Gull Pond showed that atmospheric inputs, from precipitation and salt spray, are small. Runoff has not been studied. Research is ongoing by USGS and NPS to determine whether shoreline septic systems contribute nutrients, especially phosphorus, to the ponds.

Can the deformed diatoms in Long Pond be linked with heavy metals?

The cause of deformities is unknown.

Can you detect a decrease in lead levels in sediments in the years since lead was removed from gasoline?

Yes, the Snow Pond sediment core clearly shows that reductions in lead in gasoline have resulted in reduced lead deposition in the ponds.

Seashore Ponds are described as approximating dilute seawater. What is the source of all that sodium and chloride and what are the implications?

The sea salts found in kettle pond water originate from local soil weathering, from atmospheric deposition and from salt spray from the nearby ocean. They are present in approximate seawater proportions, but seawater is <u>600 times</u> more concentrated. Native plants, animals and microbes are adapted to the salt composition and concentration of the kettle ponds.

How does low dissolved oxygen contribute to the release of nutrients from bottom sediments and where will this lead?

The nutrient phosphorus is removed from water by adsorption onto oxidized iron minerals. A layer of oxidized iron normally coats pond bottom sediment and captures phosphorus leaching from the sediment before it reaches the water column. If oxygen is depleted in pond bottom waters, the iron minerals dissolve and thereby release phosphate into the pond water. With eutrophication and the increase of organic loading, oxygen depletions become more frequent and prolonged, in this way increasing phosphorus release from the sediment and exacerbating eutrophication.

Is "hypolimnetic anoxia" a normal condition? Under what circumstances?

Periods of deep-water oxygen depletion (anoxia) may be natural for the deepest ponds that stratify early and remain stratified for most of the summer. This is especially true of the small, but deep, kettle ponds like Duck and Dyer. Once the ponds start to become thermally stratified, summer winds are too weak to completely mix them. Once stratified, bottom waters are largely cut off from atmospheric oxygen, while organic matter, with a high oxygen demand, continues to rain down into the "hypolimnion". Eutrophication prolongs and intensifies anoxia by increasing organic loading and by stimulating algal *blooms which, in turn, cut off light for photosynthetic oxygen production within the deep portions of the water column.*

Are swimmers contributing significant contaminants to ponds?

It's possible if people are urinating in the ponds instead of using the woods or restrooms. People excrete a substantial amount of phosphorus in urine each day (2-3 grams per person).

Has anyone ever mapped all the septic systems around the ponds? What is a decent recommended buffer distance for siting septic systems on pond shore properties?

Septic systems and older waste treatment systems (e.g. cesspools) have not been mapped. Many shoreline owners have moved their treatment systems back from the shoreline to reduce phosphorus contamination of the ponds. The recommended buffer distance is under study by USGS at Gull Pond.

How many years of continuous scientific monitoring is necessary for you scientists to be willing to stick your necks out and tell us what is going on?

Scientists assess trends and make predictions based on available data. The reliability of those assessments and predictions depends on how variable past observations have been. It is essentially an exercise in seeing the signal behind the noise. Based on the data in hand and its seasonal and annual variability, it appears that 10-20 more years of annual water quality monitoring will be required to identify trends. Meanwhile, scientists are conducting focused research on specific aspects of "what is going on". For example, there is work under way to determine the importance of shoreline wastewater disposal on water quality. Other scientists are studying the outer Cape aquifer to figure out what areas, and potential pollution sources, contribute water to each pond. Still others are monitoring aquatic plants and fish as indicators of water quality.

What is the relative importance of nitrogen and phosphorus in nutrient loading to Cape Cod ponds? Are these considered pollutants? What are the sources that need to be controlled? Are there health risks to humans from these nutrients?

Phosphorus is the nutrient in shortest supply for algal and plant growth in freshwater ponds; nitrogen, the other major plant nutrient, is generally abundant in fresh water ecosystems. Because phosphorus is naturally scarce in the ponds, any added by soil erosion, septic leachate, or swimmers is a pollutant giving rise to algal blooms and/or stimulating the growth of aquatic plants. There are rarely direct health risks associated with nutrient loading except when they cause blooms of toxic cyanobacteria (previously called blue-green algae) or perhaps when the water becomes so turbid that survival of pathogens shed by human bathers is prolonged. High nitrogen (nitrates) in drinking water is a severe health problem but is usually found only in areas where fertilizer is heavily used. Fertilization of lawns and gardens should be minimized on Cape Cod because the shallow and sandy aquifer is especially sensitive to nitrate pollution.

What is meant by a groundwater lens?

This is the thin veneer of fresh groundwater that floats atop salty groundwater underlying the outer Cape. Its thickness is at a maximum of 200 feet in the approximate middle of the land mass surrounding the Wellfleet-Truro kettle ponds.

How does the concept of a watershed apply to a place like Cape Cod where there is so little surface water flow?
Not too well. The sandy Cape Cod soils are too porous to "shed" all but the heaviest rainfalls. Instead of running across the land as streams, fallen precipitation percolates downward through the soil. Water not evaporated or taken up by plants collects within the fresh groundwater lens.

Why is the sulfate-to-chloride ratio important in Duck and other ponds?
A low sulfate-to-chloride ratio, below that of unpolluted seawater, suggests that sulfate is being removed by bacteria that inhabit highly organic, oxygen-free environments. These bacteria are sulfate reducers, using sulfate instead of oxygen to break down organic matter for energy for growth. Thus, increased loading of the ponds with organic matter should depress the ratio of sulfate to conservative (non-reactive) chloride.

Do measured levels of nitrogen and phosphorus in pond water correspond to the number of private houses built along the pond shorelines?
No. At present a much more important factor affecting nutrient concentrations is pond depth, with shallowest ponds having highest nutrient concentrations. If dwelling units and residency increase, effects of house density may become apparent.

What is the role of sulfate in acidifying the ponds? Where does it come from and where does it go?
Sulfate, essentially sulfuric acid in typically dilute Cape Cod fresh water, enters the ponds with precipitation, from pond sediments, salt spray and even from groundwater. The sulfur in sulfate <u>cycles</u> between organisms, water and sediment; the latter represents a large reserve of sulfur locked up in mineral matter with iron.

How does water flow through land-locked kettle ponds? Is groundwater always moving?
Groundwater is always flowing towards the ocean (or bay) in response to gravity. Ponds along the lateral flow path of groundwater receive water on their upgradient sides and discharge water back into the groundwater system on their downgradient sides.

Pond sediments sound as if they are time bombs waiting to release destabilizing inputs to the ponds as soon as they are disturbed? What accounts for this unstable situation?

Phosphorus, the nutrient that controls algal and plant growth in the ponds, and many metallic pollutants are stored in pond sediments. Although the deep kettle pond sediments are protected from most mechanical disturbance, pollutants can be re-dissolved into the water column by changes in bottom water quality. In particular, changes in pH and dissolved oxygen are important in pollutant storage and mobilization. For example, oxygen depletion at the sediment surface can release a large mass of phosphorus into the pond water.

Over the long term (past century), why has pond acidity remained relatively unchanged while global environmental conditions (atmospheric acid sources from industrialization) have changed so dramatically?
Sulfuric and nitric acid, the two principal acids in acid deposition, can be removed by in-pond processes. Both can be assimilated by microbes and plants. Both can be converted by bacteria to non-acidic chemical species of sulfur and nitrogen. In particular, bacterial sulfate reduction is believed to be very important in buffering the effects of acid precipitation on Cape ponds; the resulting iron-sulfide minerals are buried innocuously in the sediment.

How can study of the kettle ponds enlighten us about the geologic formation of the Cape and its barrier beaches, shorelines and marshes?
The aging and analysis of kettle pond sediments can help reconstruct prehistoric sea levels (since pond levels have always been at least partly dependent on sea level), describe ancient climates including storm frequency (also affecting coastal processes), and detail past vegetation of both the upland landscape and adjacent coastal marshlands.

What are the possible explanations of the interruptions of pond sediments by sand and gravel deposits in the early to mid-Holocene?

The specific event/s that brought gravels to some ponds and not to others nearby is not known, although severe storms or drought effects on ponds without perched aquifers are possibilities. Ephemeral barrier beaches may have formed and eroded since deglaciation in such a way that they protected some kettles and not others, We know that the outline of this dynamic land has changed dramatically over time. Hurricanes or earthquakes may have affected a small area and missed adjacent land.

What are the implications of potential changes in pond water quality and environmental conditions (why should we care if our health and aesthetic preferences are not at risk)?
But aesthetics <u>are</u> at risk if natural pond water clarity is compromised by algal blooms caused by increased nutrient loading. Also, toxic cyanobacterial blooms and prolonged pathogen survival are possible health implications of reduced clarity.

Seems like you can track most changes by just looking at Secchi depth observations. Why the need for more complex studies? What is the long term "bang for the buck" for the various types of monitoring?
Secchi depth is a wonderfully useful and repeatable measurement, meaning that future pond researchers can easily "repeat" the same methods for comparable results; however, it does not address the causes for observed changes in water clarity. Detailed studies are required to identify and mitigate most important sources of disturbance to the naturally clear-water ponds.

Aren't pH and alkalinity two sides of the same coin? Why measure both?

pH measures the <u>intensity</u> of acidity. Alkalinity is actually a measure of <u>the acid-neutralizing capacity</u> of water, determined by adding a known amount of acid and *recording the pH change. So pH tells us current conditions of acid-base balance, while alkalinity tells us how resistant a pond water is to added acids.*