SETH'S POND:
PRESENT WATER QUALITY AND PROPOSED MANAGEMENT PLAN

December 2001
Slightly Revised February 2004

Town of West Tisbury Conservation Commission
The Martha's Vineyard Commission

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Executive Summary:

Funding by the DEM and the West Tisbury Conservation Commission allowed a study of Seth's Pond water quality and an assessment of those factors that affect pond quality including the projected development and nutrient loading from the watershed.

FINDINGS & RECOMMENDATIONS:

1. Pond water quality as indicated by chlorophyll content, dissolved oxygen, water column transparency and total nitrogen and phosphorus places the pond in the eutrophic class of pond systems during the course of the study. While this is not necessarily a bad condition, some of the manifestations are perceived as such by the general public. Whether the conditions found during this summer were an extreme condition not likely to repeat or they will occur more frequently or even annually in the future is not yet clear.
2. A good set of baseline parameters have been measured to allow future studies to compare changes in water quality over time.
3. Dissolved oxygen levels in the lower level of the pond became anoxic in late August due to the combined effects of a large algae bloom and a complete die-off of the foliage of the rooted aquatic plant in the deeper water.
4. Water column transparency fell to 0.7 meters that is below the desirable level for swimming (4 feet or 1.3 meters).
5. A small population of fish including pickerel, large mouth bass and pumpkin seeds were observed in September. The pond has a substantial population of bullfrogs in the initial stages of colonization.
6. The pond is about 11.4 acres in area and contains 28.4 million gallons of water. The deepest area was 15.4 feet on June 1. The groundwater input is estimated at 157000 gallons per day. This implies an average residence time of 193 days. Groundwater seepage out of the Pond ranges from 58700 to 162300 gallons per day. The implied residence time is 175 to 484 days. Our best estimate at this time is that the pond volume is exchanged roughly twice per year.
7. The watershed is 87 acres in area. There are 21 existing dwellings and the Focus complex. Growth in the watershed should result in between 28 and 35 primary dwellings with possibly as many as 10 to 23 guest houses in addition to the Focus complex.
8. Present day nitrogen loading from all sources is approximately 203 kilograms and is projected to increase to between 406 and 543 kilograms at buildout.
9. Present day phosphorus loading from the watershed is most likely between 12 and 24 kilograms plus a contribution from the pond sediment of an additional 5 to 10 kilograms. The most likely future loading will be between 21 and 32 kilograms plus the sediment source.
10. Road runoff from Lambert's Cove Road has a potential to adversely impact the pond system despite the presence of an infiltration swale designed to infiltrate the first flush of runoff. A considerable portion of this situation can be corrected by eliminating the discharge of runoff from the 10 driveways that presently drain onto the road. These roadways are clearly impacting the water resource during heavy rainfall.

11. Additional survey work is recommended to more completely grasp the current water quality situation in the pond. This suggested work includes:
    - A survey of fishes, amphibians and invertebrates.
    - Dye testing and inspection of septic systems located within 10 feet elevation of the pond level.
    - Water quality sampling in the July to September period in 2002.
    - Retired Senior Volunteer sampling for dissolved oxygen, transparency and pH annually during late summer.
12. The pond has very low acid buffering capacity and may be impacted in the future by acid rainfall. At this time, the pond itself was moderately acidified (pH 5.5 to 6.2) which is acceptable for the existing biota. This condition should be monitored regularly in the future.
13. Future land clearing and grading activities on the steeper slopes around the east and south shores should be reviewed to assure that an appropriate erosion and sedimentation plan is in place and is followed. This concern applies mainly to parts of 4 vacant lots, 6 built lots and portions of two large lots that might be further developed. This may require an adjustment in the Town's bylaws to refer such developments into a review process.
14. In the future, depending on the results of the surveys recommended in item 11, the use of air diffusers to relieve anoxic conditions, barley straw to limit algae blooms and the addition of limestone to offset acidification may be necessary, low-impact steps to correct the conditions observed this summer.
15. It is suggested that planning for acquisition of an air diffuser and means to power it be initiated prior to next summer. It is also recommended that a trial placement of barley straw be planned for April 2002 as a bioenhancement. A total of 1.5 tons of straw are recommended according to methodology described in Appendix G of this document.
16. It is recommended that discussions begin about the feasibility of controlling the bullfrog population with knowledgeable personnel with expertise in amphibians. Consideration should be given to addressing the problem in nearby vernal pools, kettle holes and Ice House Pond for lasting effect. Talks with school personnel about the advisability of using school children to catch the frogs and the potential of using them in science class are also suggested.
17. Possible sources of funding assistance to correct the runoff problem include the 319 program which provides 60% of the cost of a solution.
18. The Conservation Commission is suggested as the lead agency to coordinate the recommended activities.

Acknowledgments:
This project was made possible by a grant from the Department of Environmental Management Lakes and Ponds Grant Program and a match by the West Tisbury Conservation Commission, Judy Crawford, Chair. The recommendations were reviewed and comment provided by the Conservation Commission. John Powers, Board of Health Agent, provided information on the Focus complex and recent septic system upgrades in the watershed. Field work was aided by Robert Ford of the Senior Environment Corps. William Walker of the SEC used the sample analyses as an opportunity for the lab to run duplicates to check for accuracy on nitrate, ammonium and total phosphorus concentration. The water level gauge used to measure the rate of rise of the pond was funded by the Farm Neck Foundation. The meter used to collect in situ data was funded by a grant from the Edey Foundation. Kent Healy provided information on the runoff infiltration swale. Lisa Bowen and Lenora Wilcox assisted in field work and graphics.

This study was planned and carried out by William Wilcox of the Martha’s Vineyard Commission.

Purpose of this Study:
This project was undertaken to gain a better understanding of the water quality of Seth’s Pond, the sources of nutrient input and the level of concern that should be associated with future loading from the watershed.

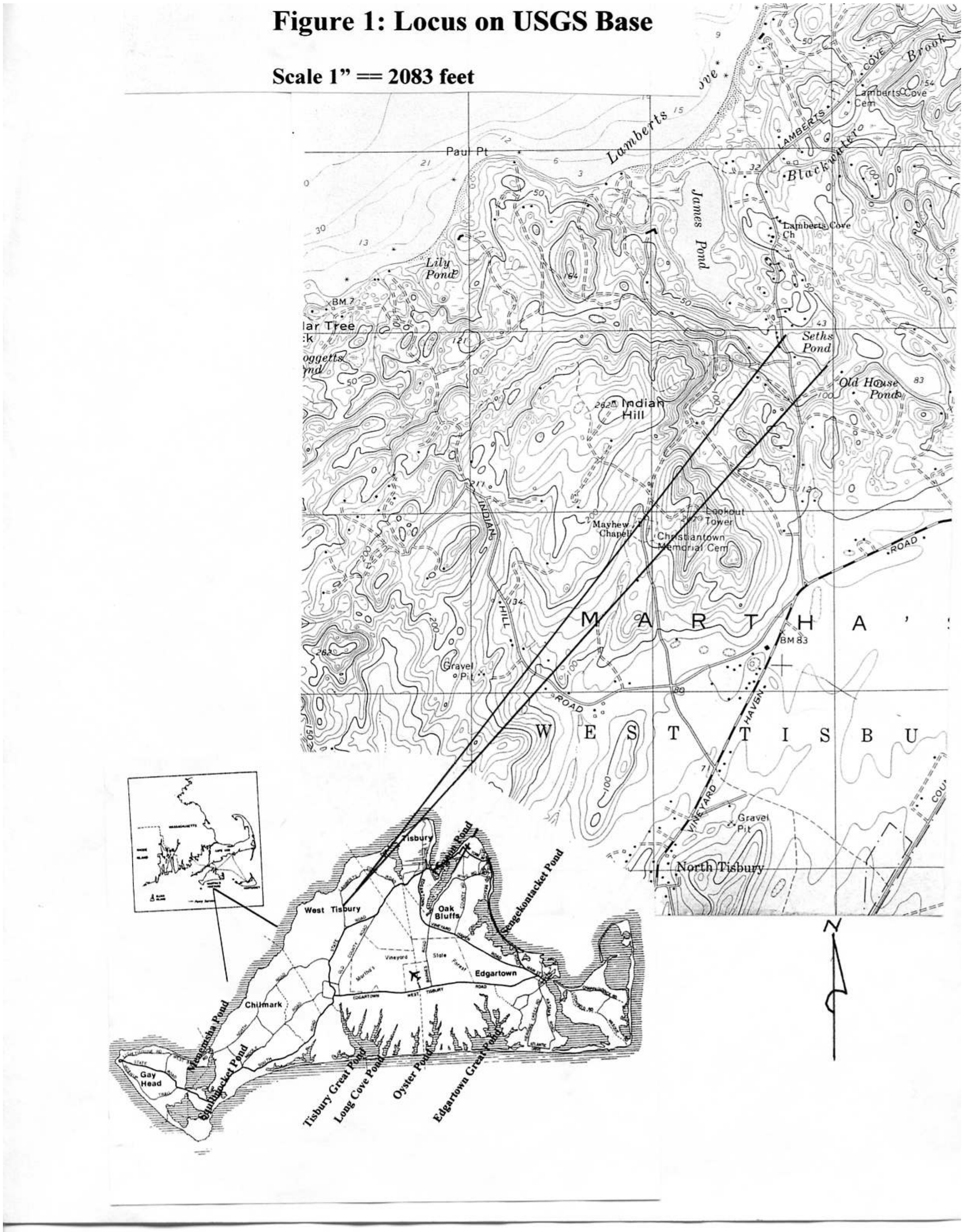
Seth’s Pond: Physical Setting
Seth’s Pond is 11.4 acres in area (4.6 hectares or 494840 square feet) and lies in a topographic depression that is similar to a “kettle hole”. This is a topographic depression formed at the site of a former buried block of glacial ice. The pond is situated at an elevation of 43 feet (NGVD) and is in a broad depression that trends toward James Pond to the northwest. To the west, east and south it is backed by steeply rising ground that quickly attains an elevation of over 100 feet. A locus map is provided in Figure 1.

The pond is found within the geologic deposit that consists of the Martha’s Vineyard Moraine atop the older Gay Head Moraine (Kaye, USGS). These deposits consist of sandy till overlying what geologists call an imbricated thrust sheet of early glacial till and outwash as well as the Tertiary deposits of clay found in the Gay Head Cliffs. An imbricated thrust sheet forms when an advancing glacial ice front bulldozes up frozen earth deposits and pushes them in large (100’s of feet thick) sections up atop those deposits that are further ahead. The completed formation consists of the same materials stacked almost vertically and repeating the sequence of deposits: sand-till-clay and again sand-till-clay.

The result is that the surface soils are sandy or cobbly sands such as Eastchop loamy sand and, where the clayey deposits are near the surface, poorly drained soils like Ridgebury variant fine sandy loam (USDA, 1986). At greater depth, the geology is uncertain but probably consists of a jumble of widely varying deposits similar to those seen in the Lambert’s Cove cliffs to the northwest which range from sandy till, to sand to gray clay.
Note: Not to scale.

Figure 1: Locus on USGS Base

Scale 1" == 2083 feet



Given the soils and the topography, it is highly likely that Seth's Pond is within the watershed of James Pond and that subsurface seepage from Seth's Pond makes its way through the groundwater to James Pond, some 40 feet lower in elevation. The topographic (Figure 2) watershed as drawn is much larger to the south, west and east, away from James Pond, than it is to the northwest, toward this pond. In reality, there may be very little groundwater contribution to Seth's Pond from the north and northwest because groundwater is moving away from Seth's Pond in that direction but, to be conservative, we include some land in this direction.

<u>Priority Uses of Seth's Pond</u>:
Swimming is an important recreational use of the pond as it is the only accessible fresh water pond suited to swimming. It is the site of Town-sponsored swimming instruction during the summer months. Winter skating is also an important use. The pond is also an important aesthetic resource as it is sited immediately adjacent to a Town roadway. The pond is used for recreational fishing and is habitat for numerous native species. The uses identified have many common requirements including relatively clear waters, moderate plankton populations, cool temperatures and rooted plant cover primarily at depth. Maintenance of these characteristics should be the basis for the development of a management plan for the pond. This plan should emphasize retention of common use requirements and needs that are mutually inclusive. Next, the plan should support retention of requirements that may support one or more uses but that do not adversely impact other uses.

<u>Seth's Pond Bathymetry and Volume:</u>
Bathymetric soundings were made on June 1 using Speedtech Instruments depth sounder and Trimble Geoexplorer 3 GPS to locate the measurement points. The depth sounder has accuracy to 0.1 meter while the corrected GPS locations are expected to be accurate to within 1 meter. The depth data (~ 55 points) were contoured at one meter depth intervals and this is presented in Figure 3. The total area of the Pond at the time of the survey as determined by a GPS perimeter survey, was 11.44 acres. The pond reaches a depth of over 4 meters with the maximum recorded depth (on June 1) at 15.4 feet during the time of the survey. As the pond surface fluctuates from wet to dry years, maximum depth could easily be recorded at over 17 feet in wet years (as indicated by high water marks on shoreline boulders) and less than 13 feet in dry years.

The hypsographic curve is used to assess the area within each contour interval. A curve is included in Appendix A. The curve indicates that the mean depth is at about 2.4 meters. Depth is important as it controls the amount of lake bottom where adequate sunlight penetrates to allow rooted plants to develop. Depth is also important in seasonal stratification where denser water is isolated from the air at the bottom and can develop low oxygen levels which has an immediate effect on the release of nutrients stored in the sediment as well as on aquatic life forms that need oxygen.

Note: Following figures not to scale.

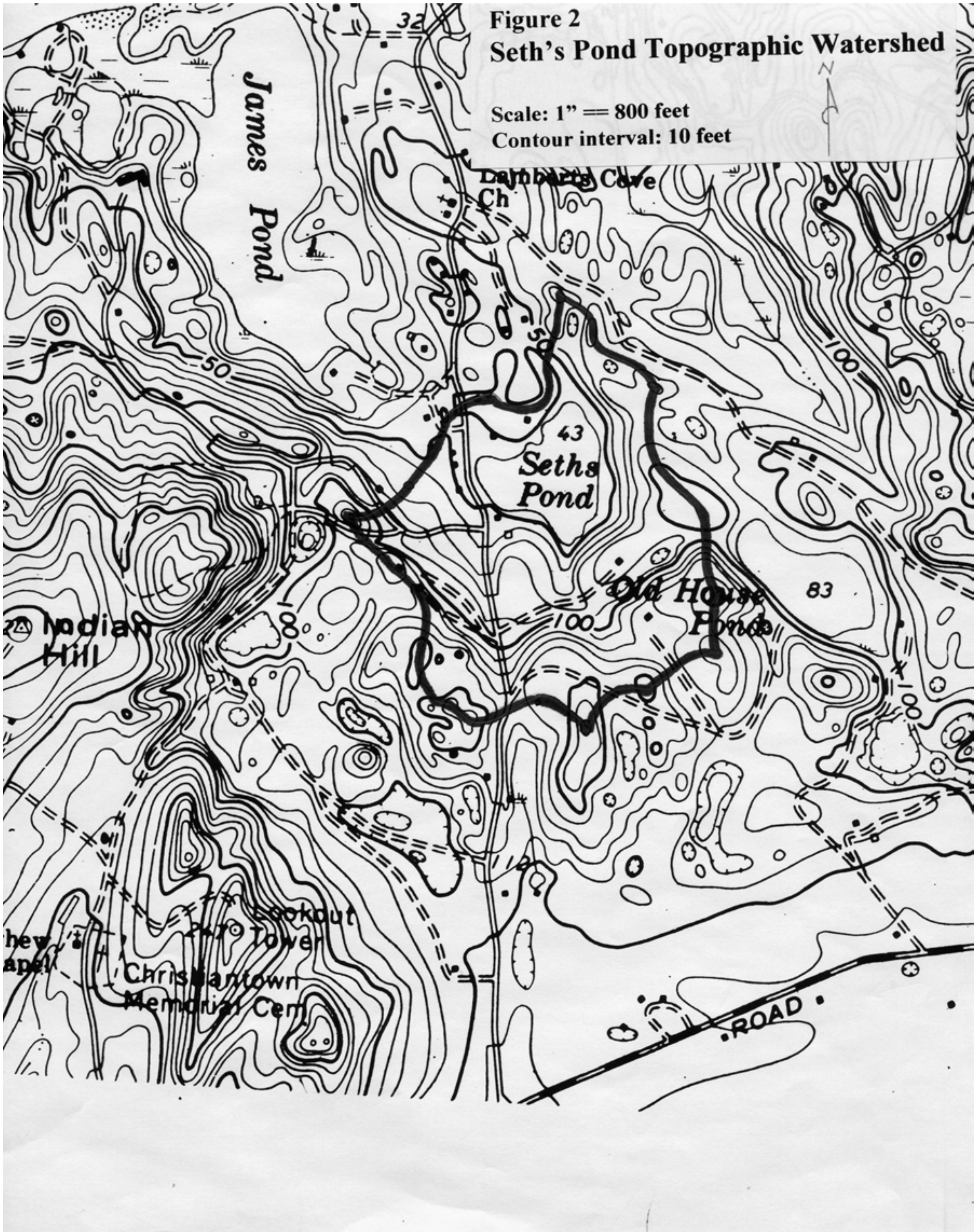
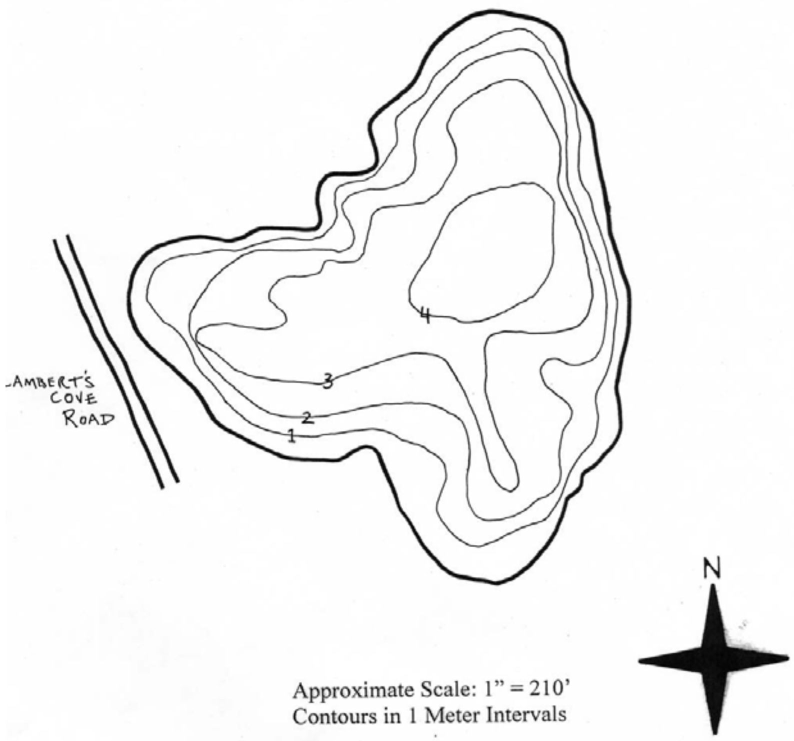


Figure 2
Seth's Pond Topographic Watershed
Scale: 1" = 800 feet
Contour interval: 10 feet
N
James Pond
Lamberts Cove
Ch
Seths Pond
43
Old House Pond
83
100
50
Indian Hill
Lookout Tower
Christiantown Memorial Cem
ROAD

Figure 3:

SETH'S POND BATHYMETRY

Martha's Vineyard Commission
2001



Approximate Scale: 1" = 210'
Contours in 1 Meter Intervals

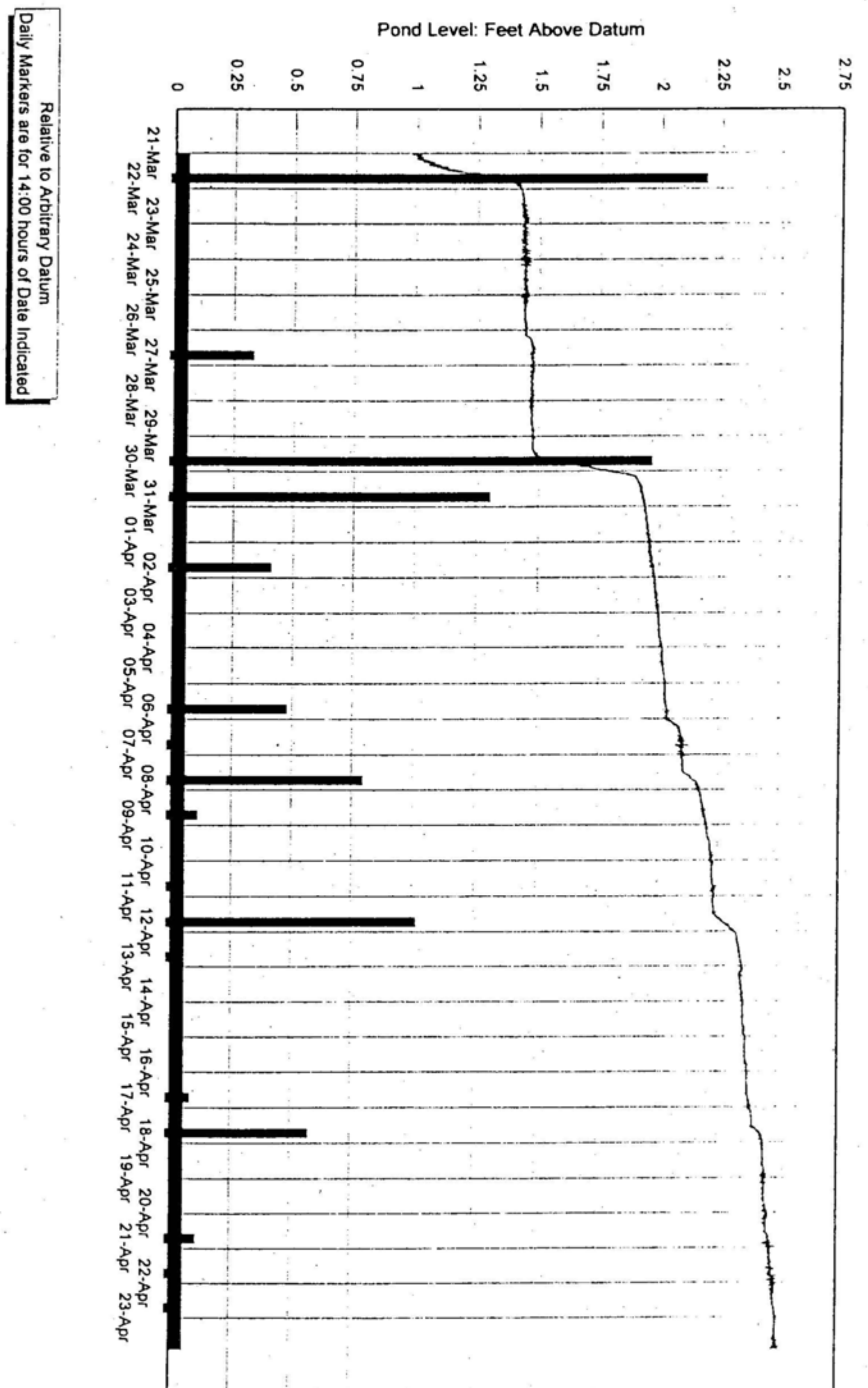


Figure 4: Seth's Pond Water Level
West Tisbury Massachusetts: Rainfall (bar graph) recorded in Edgartown

The raw depth data was used to construct a contour map of depth (Figure 3). The area within each contour interval was measured by planimeter. From the area information, the volume of the pond can be calculated using the standard formula for calculating pond volume based on the area of a sequence of contour intervals:

Volume for each layer == 1/3(H)(A1+A2 + Sqrt (A1*A2) (Reid, 1961 and Wetzel, 1983)

Where: A1 and A2 are the areas contained within two consecutive contours.
H is the depth interval between the two contours.

This formula takes the sloping pond bottom into account in the volume calculation. The Pond volume as of the survey on June 1 was 3.798 $\times 10^6$ cubic feet or 28.4 million gallons. The volume of the pond is important to estimate the amount of time required for a quantity of groundwater and stream flow equal in volume to the pond to enter and exit the system. This time interval is known as the residence time and can be thought of as the average age of a water particle in the pond. It is important to determining the systems tolerance for nutrient loading.

Seth's Pond Estimated Water Budget:

The water budget for the Pond consists of the inputs that add water to the Pond and the outputs that remove water from the system. The balance between inputs and outputs is a dynamic one that we see as the seasonal and year to year change in water level in the Pond. These factors are summarized as follows:

INPUTS	OUTPUTS
DIRECT RAINFALL	EVAPORATION
GROUNDWATER INFLOW	GROUNDWATER OUTFLOW
RUNOFF	

Putting numbers to these factors is very difficult as it depends on many variables that we do not know precisely. In actuality, precision is limited for all of the Inputs and Outputs listed above. Even the rainfall measured in Edgartown has been found to vary widely at rain gauges elsewhere on the Island particularly with the scattered showers that typify some of the cold front storms that we have here. One piece of precise and reliable data is the measured rise of the pond level over a 33 day period in late March and April, 2001 (see Figure 4). The rise is the net result of all these factors.

By examining the measured rise of the pond over an extended period of time and using reasonable estimates of the Inputs and Outputs, we can approximate a water budget for the pond. A recording, Global Water water-level gauge was placed in the Pond on March 21 and left in place for 33 days until April 23, 2001. (See Appendix B for water budget calculation details). The estimated values for the budget components are as follows for this time period:

INPUTS		OUTPUTS	
DIRECT RAINFALL	336320 feet^3	EVAPORATION	-112928 feet^3

GROUNDWATER INFLOW 693000 feet^3 OUTFLOW -258885 feet^3
RUNOFF 81650 feet^3
It is clear that, aside from groundwater, rain and evaporation are the dominant factors. From these figures, the ***net*** groundwater input over this time period adds 13155 cubic feet per day to the pond over this 33 day period. The net pond volume change from all factors is an increase of 22399 cubic feet per day.

See Appendix C for runoff figures from roadways.

The groundwater seepage loss from the Pond is not known. As it is the only means for soluble nutrients to exit the system, it is an important figure to determine the lifetime effects of new nutrients entering the system from acid rain, runoff or via groundwater seepage. The amount of time a given water molecule is in the system, called the residence time, is one way to assess the potential impact of a given pollutant that enters the system with that water. A simple way to estimate this time is to divide the total volume of the pond system by the daily output from groundwater and/or streams.

If our estimate of watershed recharge is close, then the groundwater seepage loss term is about 7000 to 8000 cubic feet per day during the month of April. The calculated number based on the assumptions described is 7845 cubic feet per day. The residence time based on the seepage loss is 484 days or 1.33 years (see Appendix B calculation sheet). The range of 7000 to 8000 cubic feet per day yields a range in residence time of 475 to 543 days.

As the rate of loss would vary in relative proportion to the height of the pond from season to season, a second series of pond levels were recorded over the summer and fall. During the period from 20 August through 3 December (105 days) the average discharge from the pond is estimated at 21700 cubic feet per day. This implies a residence time of 175 days or 0.48 years. This figure agrees closely with the 22400 cubic feet per day figure derived from the annual water budget. The differences may result from the groundwater input during the March/April period being greater than the estimate during a wet time. It may also result from a larger than expected volume of runoff entering the system from the steep slopes around the Pond. This is supported in Figure 4 where the pond rise in response to the 0.15 feet of rain on March 29 is nearly 0.4 feet.

The residence time term has been related to the ratio of the watershed area to the pond area for lakes in Wisconsin (Appendix B: Wisconsin DNR web site //WDNR - Retention time - Understanding Lake Data.htm). The rationale for using this ratio is that the larger the watershed, the more groundwater and stream flow enters the pond. Larger ratios imply faster flushing. The ratio for Seth's Pond is 7.6 to 8 depending on the time of year when the pond area is measured. Ratios of this size imply 1 to 2 year residence times for Wisconsin lakes. Our estimated 0.5 to 1.3 year residence time only partly agrees with the Wisconsin model.
The implications of the residence time are discussed in on page 33.

<u>Water Quality Data Collected in the Field</u>:
Field data collected on site includes: temperature, specific conductivity, dissolved oxygen, percent DO saturation and Secchi extinction depth. The first four are measured with a YSI 85 meter. The meter is self calibrating for dissolved oxygen and is calibrated for each use. The conductivity measurement was calibrated with a standard solution at the beginning of the field season and periodically checked against that standard before use in the field. The Secchi disk is an 8 inch diameter disk with white and black quadrants. The conductivity readings have a resolution to 0.1 micro Seimen per centimeter (uS) and 0.5 percent accuracy. The DO readings are accurate to within 0.3 milligrams per liter (mg/l) or 2 percent. Measurements were taken at 4 in-pond sampling stations and 1 ephemeral stream. The locations, which were repeatedly revisited over the 21/2 month study, are shown in Figure 5. Data collected in the field are included as Table D-1 in Appendix D, Water Quality Data.

Temperature: In general, surface water temperatures ranged between 24 and 26 degrees Centigrade (C) during July and August. During July and again in September, temperatures typically decreased by 1 degree C over the water column from top to bottom. Temperature stratification developed during or just before the August 6 sampling round where surface temperatures decreased by 3.1 degrees C at Station 1; 3 degrees C at Station 3; and 1.8 degrees C at Station 4. Stratification was not as marked during the August 20 sampling round and the top to bottom temperature decreased from 0.5 degree C to as much as 1.9 degrees C. By August 27, surface temperature had dropped to 24.5 degrees C and stratification was minimal (top to bottom temperature decrease of about 0.5 degrees C). This was also the case on September 10 and September 24. By the 24th, the surface temperature had decreased to 22.3 to 22.4 degrees Centigrade.

When flowing, the seepage that was sampled as Station 6, was between 17.3 and 19.5 degrees C. As this is well above the typical groundwater temperature of 7 to 8 degrees C, this source may be a mix of groundwater with near surface drainage or the sampling point may be sufficiently removed from the point where the groundwater reaches the surface, to allow it to begin to warm toward air temperature.

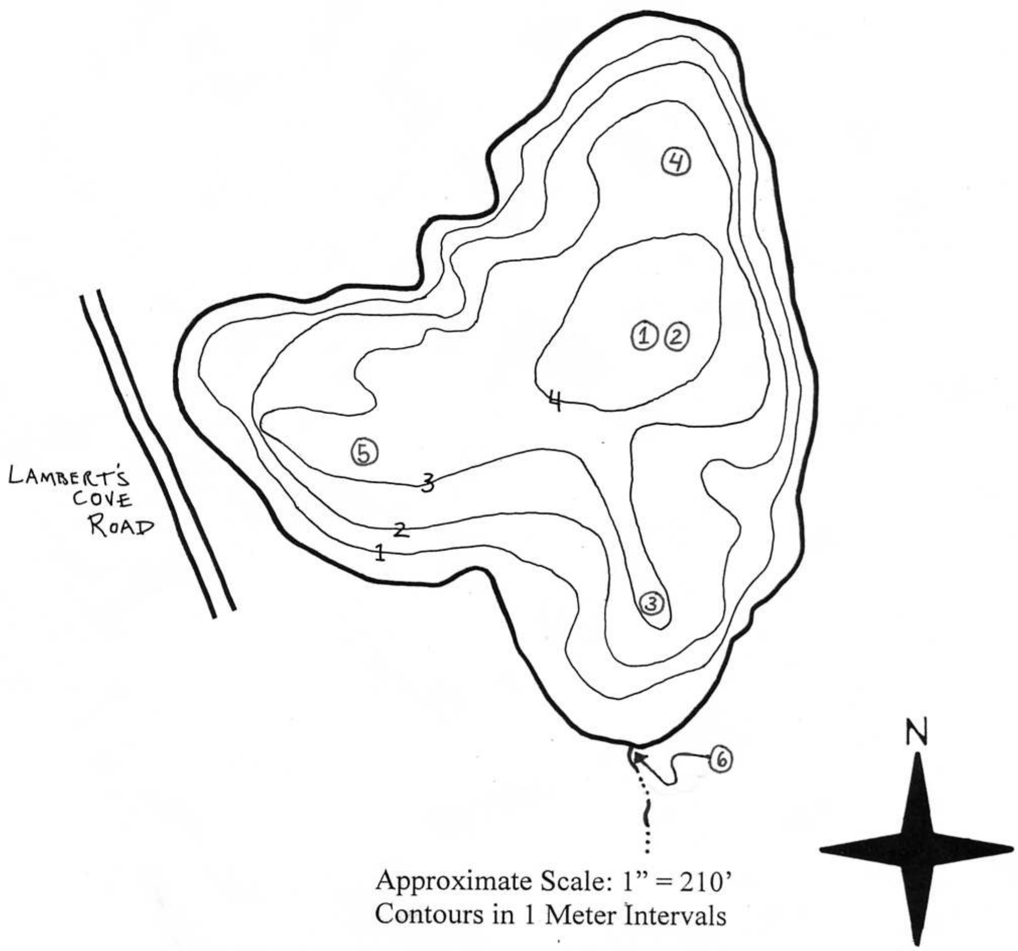
While we have no data to support it, Seth's Pond is probably dimictic, circulating freely in spring and fall. Wind mixing is probably important during times when there is no strong stratification.

Specific Conductivity: Conductivity measures the ease of passing an electric current through the water that varies directly with the amount of dissolved material in the water column. Conductivity typically ranged between 66 and 73 milli Seimens (KuS) at the surface. Conductivity rose in the lower portions of the water column particularly where dissolved oxygen was less than 50% saturation. During the stratification observed on 6 August, dissolved oxygen saturation fell below 1% and conductivity rose to 105.1 KuS. The odor of sulfur was noticed in the deep sample at this time and reinforces the

Figure 5:

SETH'S POND WATER QUALITY SAMPLE STATIONS

Martha's Vineyard Commission
2001



Approximate Scale: 1" = 210'
Contours in 1 Meter Intervals

**Note: Station 2 is at a depth of 3 meters below the surface.
Station 6 is an outflow of an ephemeral stream.**

Note: Not to scale.

likelihood of near anoxia at depth. The lack of oxygen would begin to release nutrients from the sediment into the water column and may account for the rise in conductivity.

Dissolved oxygen: Measurements were taken in the morning between 8:30 and 10:00 a.m. Oxygen saturation exceeded 100% at the surface throughout the pond on July 23. There was little change through the water column with the bottom readings over 90% at all stations except at the deep station (1) where saturation was 80% for the last 0.5 meter. By 6 August when stronger temperature stratification was noted, dissolved oxygen saturation fell below 40% for the bottom 0.5 meter throughout the pond and, at station 1, saturation was less than 1% for the bottom 1 meter. This condition continued with similar values on 20 August. The low oxygen condition improved somewhat at all stations except number 1 by 27 August. At that time, the saturation was below 30% for the bottom 1.5 meter and less than 1% for the final 0.5 meter. By 10 September, the condition had improved to the point where the lowest 0.5 meter varied from near 30% to as much as 80 to 90 percent saturation across the pond. Station 1 continued to show less than 30% for the bottom 1 meter and less than 1% for the bottom 0.5 meter. By 24 September, the lower 1.5 meters at Station 1 still had less than 50% saturation and less than 1% for the bottom 0.5 meter. The dissolved oxygen variation over time is plotted in Figure 6.

Secchi Extinction Depth: This is the depth at which an 8 inch black and white disk can be seen in the water column. The extinction depths ranged from 1.3 to 1.4 meters throughout the pond on 23 July. By 6 August, extinction depth was below 0.7 meters. This condition prevailed through the 20 August sample round but improved to 1.2 to 1.3 meters on 27 August. Water clarity continued to improve and by 10 September it ranged from 1.6 to 1.8 meters. Similar values were found on 24 September. The decrease in water clarity coincided with the presence of an algae bloom through the month of August. The compensation depth can be derived from the Secchi extinction depth. This depth is equal to 2.5 times the extinction depth and is considered to be the maximum depth at which there is sufficient light to allow phytoplankton to photosynthesize. With a Secchi depth of 1.6 meters, all the area within the 4-meter contour has insufficient light over the last 0.5 meters of water. When the Secchi extinction depth is less than 1 meter, there is inadequate light below 2.5 meters, and plant survival within the 3 and 4-meter contours becomes very difficult. The average extinction depths throughout the pond are plotted in Figure 6. The swimming standard (105CMR 445.10(2b)) calls for 4 feet or 1.3 meters of water column visibility.

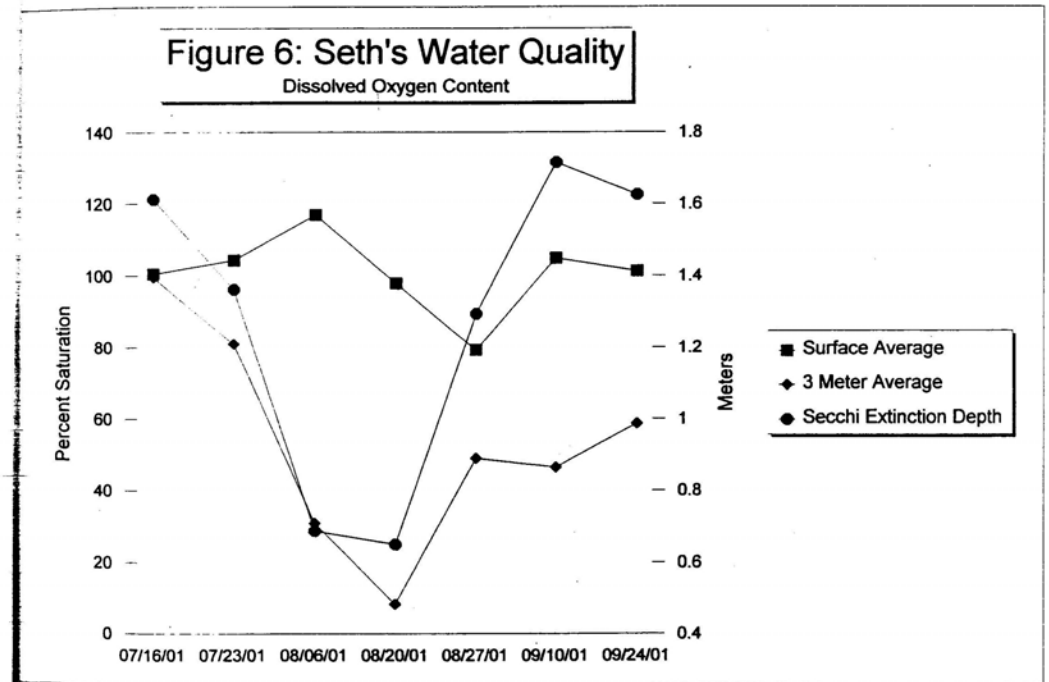


Figure 6: Seth's Water Quality
Dissolved Oxygen Content
Percent Saturation
Meters
140
120
100
80
60
40
20
0
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
07/16/01
07/23/01
08/06/01
08/20/01
08/27/01
09/10/01
09/24/01
Surface Average
3 Meter Average
Secchi Extinction Depth

pH: This is a measure of the acidity of the water. Environment Canada outlines the following progression of environmental effects from acidification of lakes:

- As the water pH approaches 6.0, crustaceans, insects, and some plankton species begin to disappear.
- As pH approaches 5.0, major changes in the makeup of the plankton community occur, less desirable species of mosses and plankton may begin to invade, and the progressive loss of some fish populations is likely, with the more highly valued species being generally the least tolerant of acidity.
- Below pH of 5.0, the water is largely devoid of fish, the bottom is covered with undecayed material, and the nearshore areas may be dominated by mosses.
- Terrestrial animals dependent on aquatic ecosystems are also affected. Waterfowl, for example, depend on aquatic organisms for nourishment and nutrients. As these food sources are reduced or eliminated, the quality of habitat declines and the reproductive success of the birds is affected.

Growth of slime coating algae becomes more prevalent as the grazers that keep it in check (such as snails) become less common.

This parameter was measured in the lab using Hanna Instruments, hand held pH probe. The accuracy of this instrument is in the range of +/- 2%. Repeat measurements of the probe after calibration to pH 7.0 on a pH 4.0 standard (and the reverse) indicate the accuracy is about 0.2 pH units. The pH was found to be below 5.0 pH units on the July 23 round throughout the pond. This low pH level was not repeated and raises a question of these readings as an aberration in either the instrument or a short-term water quality situation.

In August, coincident with the algae bloom, the pH rose to between 5.6 and 6.5 over the 20 August and 27 August sampling rounds. The September round ranged from 6.2 to 6.7. Over the entire period, the groundwater seep at Station 6 varied from 5.4 to 5.9. Most readings were taken from surface samples and so reflect the influence of photosynthetic activity. Measured pH is closely tied to alkalinity and the availability of aluminum.

Alkalinity: Alkalinity is the quantity of compounds in the water column that tend to shift the pH toward the alkaline side. These compounds are mainly carbonates, bicarbonates and hydroxides containing inorganic carbon. The carbon can provide a significant reservoir for the growth of phytoplankton. Alkalinity can be expressed as milligrams per liter. It can be thought of as a measure of the ability of the pond waters to resist the addition of acidity by rainfall. This is commonly called buffering capacity.

Total alkalinity measured in 1976 (Martha's Vineyard Water Quality Study, MVC/DEP) was 3.0 milligrams per liter (mg/l) in both August and December. In 1983, alkalinity was 3.0 mg/l while hardness was 11 mg/l (Mattson, personal communication 2002).

The term hardness is a related term used to describe the amount of calcium and magnesium in water. As these are mostly combined with carbonates and bicarbonates, the two alkalinity and hardness describe somewhat similar characteristics. The hardness of Seth's Pond was measured using Hach kit following Method 8030. On August 27th, the calcium hardness (as $CaCO_3$) was 12.8 mg/l. On September 10 calcium hardness (as $CaCO_3$) varied from 14.2 to 15.4 milligrams/liter (mg/l) at three sample stations across the Pond. Magnesium hardness was not measured. On September 24, calcium hardness varied from 6.7 to 7.2 while magnesium hardness ranged from 7.1 to 7.5 mg/l.

Although they are different measurements, these values and the earlier analyses indicate the pond is in the sensitive range in terms of buffering capacity.

Table 1: Alkalinity and Relative Buffering Capacity

Buffering Capacity	Alkalinity Range (mg/l)
Highly sensitive to endangered	Less than 10
Little Buffering	10 to 20
Very Well Buffered	Over 20

Source: Massachusetts Acid Rain Monitoring Project

Aluminum: Aluminum can be leached from poorly buffered soils by acid rain. Its solubility increases as the pond water becomes more acid and can eventually become toxic at rather low concentrations (Wetzel, 1983). Aluminum's toxic effects on fish are most dramatic at pH 5.0 to 5.2 at concentrations of 0.1 mg/l (Baker & Schofield, 1982) and continue to increase as pH drops and aluminum concentration rises. Susceptibility varies with the season and the life stage of the fish.

Aluminum concentration was tested with Hach kit following Method 8012. On 10 September the concentration at Station 1 was 0.027 mg/l while on 24 September it was 0.013 at Station 1 and 0.023 at Station 5. These values are below the concentrations where toxic effect may begin. During the 1 October rain event, aluminum was tested in the runoff from Lambert's Cove Road where it exited the upland and crossed the marsh. Repeat measurements ranged from 0.24 to 0.28 mg/l. Regular follow-up testing of pond pH and aluminum is recommended to assess the level of concern that should be attached to the short-term data collected here.

Water Quality Parameters Measured in the Lab: The project relied on the Marine Chemistry Lab at the University of Washington, Kathy Krogslund Lab Manager, for analyses for dissolved nutrients, both inorganic and organic, total nitrogen and phosphorus, particulate nitrogen and carbon and chlorophyll *a*. The actual data is included in Appendix D in spreadsheet form. Blind duplicate samples were sent to the lab to test their accuracy and are shown in the spreadsheets in Appendix D in *italics.* In general, the lab performance was very good. The data collected can be used to assess the current condition of the pond. One approach that will be used in this evaluation is the Trophic State Index (Carlson & Simpson, 1996). The data can also be compared to average conditions in other lakes and ponds in similar areas as provided by the NEIWPCC Data Synthesis Report for New England lakes and ponds (ENSR, 2000). It should be kept in mind that one season of samples only provides a snap shot in time of the pond condition which may change from year to year with weather patterns.

Variations in rainfall patterns, cloud cover and insolation all have substantial effect on water quality through stimulation or suppression of the growth of plankton.

Chlorophyll *a*: Chlorophyll is the chemical that is utilized by green plants to carry on photosynthesis—the conversion of water and carbon dioxide into sugars using the sun's energy to convert. Plankton bearing chlorophyll are at the base of the food chain in that they are grazed on by zooplankton which are eaten by insects which are eaten by fish which may be consumed by man or by osprey at the top of the chain. These plankton are vital to the health of the system but can explode in response to nutrient loading or other stimulus to create a condition wherein they consume the oxygen in the system over night and, during decay, severely impact oxygen dependent fish, larval insects, crayfish and other organisms living in the system.

Chlorophyll is an indirect measure of the amount of phytoplankton in the water column. It only measures the amount of chlorophyll bearing phytoplankton but there may be many plankton, fungi and bacteria in the water column that are not chlorophyll bearing. The amount of chlorophyll in the water has been used as a means of assessing the quality condition of both marine and fresh waters along with Total Phosphorus and Secchi Extinction Depth. The Trophic State Index (TSI) as proposed by Carlson and Simpson (1996) is another approach to rating the quality of a fresh water system. Wetzel (1983) tied the Mean quantity of chlorophyll to the trophic status of lakes as follows:

Oligotrophic	1.7 micrograms per liter (parts per billion—ug/l)
Mesotrophic	4.7 ug/l
Eutrophic	14.3 ug/l

Chlorophyll *a* values are plotted in Figure 7 along with other variables that are affected by or correlated with it. The chlorophyll values plotted are the averages for the five surface stations. Chlorophyll concentration peaks at 8.4 micrograms per liter (ug/l) on August 6, declines to 2.8 ug/l by 27 August before peaking at 15.9 ug/l on 10 September. These values place the pond in Wetzel's range of Mesotrophic to Eutrophic classification.

The remarkable data occurs at the deep station where a sample was collected from a depth of 3 to 3.5 meters. Here, the chlorophyll *a* values hit 13 ug/l on 27 August, increase sharply to 57 ug/l by 10 September and decrease slightly to 42 ug/l by the 24^{th}. The high values found correlate well with the oxygen deficiency found in the deeper waters throughout the central part of the pond. They may result from settling of plankton growing in the surface layer of the pond or, they may reflect in situ growth that came on as water clarity (Secchi extinction depth) improved from its low on 20 August (see Figure 6).

The Trophic State Index for chlorophyll is discussed in the Implications section (page 11) with the other indices and comparisons.

Phosphorus: This includes both the inorganic and organic forms including particulate matter such as plankton and dissolved phosphorus compounds. Phosphorus is necessary for the metabolic processes carried on by all living organisms and is a component of DNA. Phosphorus is usually thought of as the limiting factor in the growth of phytoplankton in fresh water systems. The concept of limiting nutrient is explained below with the implications of the data collected as to whether the system is limited by the availability of phosphorus or nitrogen. In short, the concept is that the major nutrients required for cell growth are: carbon, nitrogen, hydrogen, oxygen and phosphorus. Of these hydrogen and oxygen are readily available and carbon is usually adequate. The primary nutrients that limit growth are nitrogen and phosphorus. When one of the two is deficient, continued cell growth is limited until the lacking nutrient is supplied.

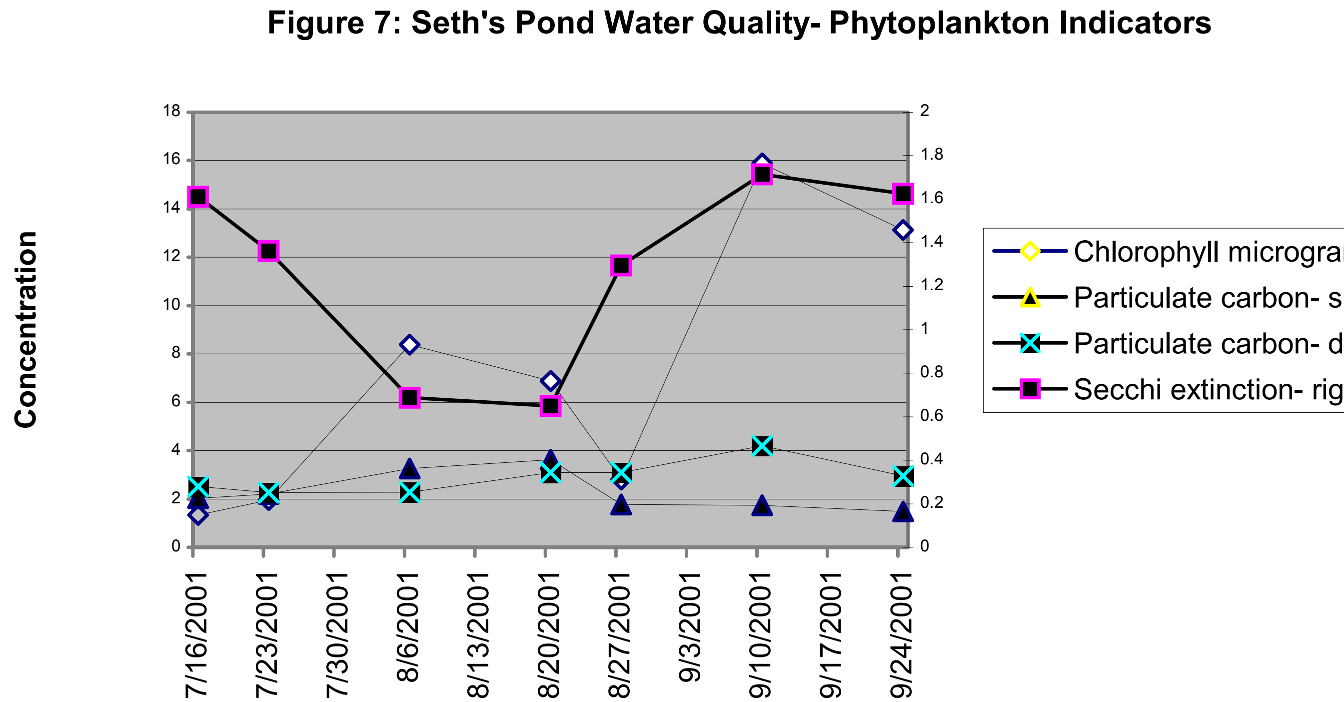
The major component of Total Phosphorus is usually the organic forms, both particulate and dissolved organic. Typically, dissolved inorganic phosphorus is less than 5% of Total Phosphorus (Wetzel, 1983). The exchange of phosphorus from sediments in the bottom of a lake and the water column is a major component of the cycle of phosphorus. Despite this, there is little correlation between the quantity of phosphorus in the sediment and the productivity of the overlying water (Wetzel, 1983). Movement of phosphorus into the water column from the sediment is related to biologic activity in the bottom muck, rooted plant growth and to the oxygen saturation in the overlying water column which drives the chemistry controlling the movement of phosphorus from sediment to pond water. Macrophytes draw nutrients from the sediment through their roots and use them to build foliage. When the plants senesce at the end of the growing season the nutrients, including phosphorus, are released into the water column as the foliage decays. Where the water column maintains higher percent saturation of oxygen, the oxidized zone at the very top of the bottom sediment limits the movement of phosphorus into the overlying water (Wetzel, 1983).

Phosphorus is introduced from outside the pond by runoff particularly if silt and particulate organic matter is carried with the runoff and by rainfall. Some phosphorus from nearby septic systems may reach the pond through the groundwater. There are no measurements of phosphorus from rainfall collected on the Vineyard. Measurements of phosphorus content taken from 39 samples of rainfall at Truro (USGS, 1995) indicate a concentration of 0.008 mg/l with a range of less than 0.001 to 0.095 mg/l. Of these, 22 samples were less than the detection limit of 0.001 mg/l.

Total phosphorus data is plotted in Figure 8. Both total phosphorus and total nitrogen in the deeper water increase dramatically after the lowest values of Secchi extinction and oxygen concentration are reached on 20 August (see Figure 6). This time frame correlates with the die off of the rooted plant foliage that progressed during the first two weeks of August (see discussion in Vegetation Section).

The concentration of dissolved inorganic phosphorus (ortho- in Figure 9) in the surface waters oscillates over the course of the sampling season. These cycles may reflect growth and decline of different phytoplankton populations. At depth, the orthophosphate concentration decreases as the algae bloom begins to gather speed and the Secchi disk extinction depth decreases from 23 July to a low on 20 August (Figure 7).

The ratio of total nitrogen to phosphorus averaged for the surface water stations indicates that phosphorus is limiting. In the deep water station, before the die off of the rooted plants, nitrogen was the limiting nutrient but afterward it was phosphorus. For further discussion, see Implications of the Data section below.



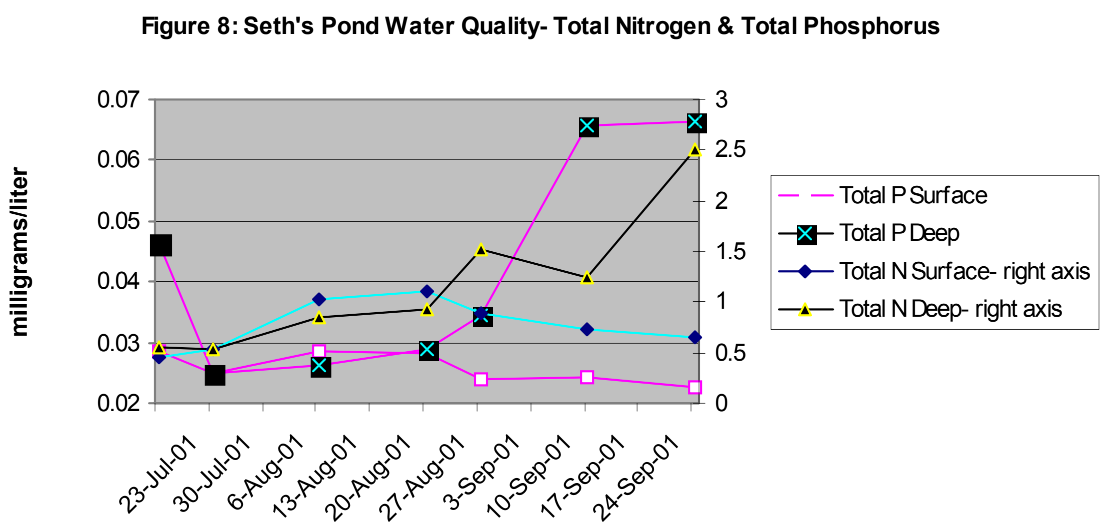
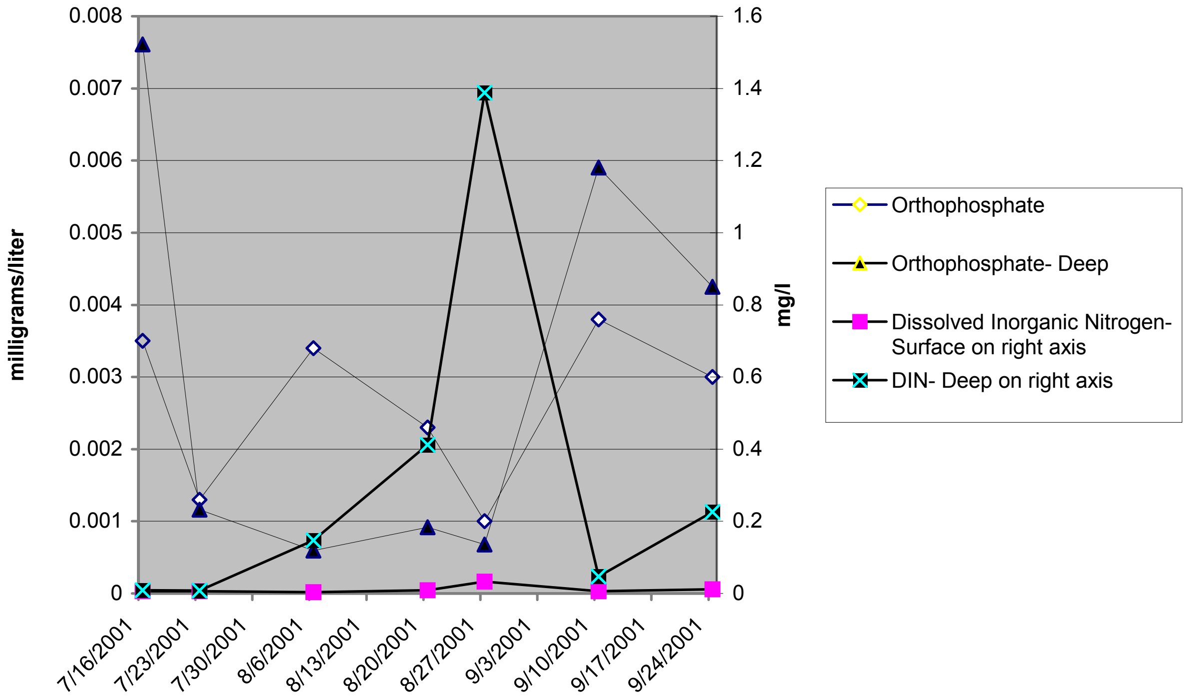


Figure 9: Seth's Pond Water Quality- Surface Averages & Deep Sample



Nitrogen: Nitrogen includes both the dissolved inorganic and organic forms and the particulate forms that include both living and dead plant and animals and their decay products. External sources of nitrogen include acid rain, septic system leachate, runoff and internal sources such as blue green algae and certain bacteria which can extract nitrogen from the air and turn it into living tissues. Nitrogen is a basic requirement for the formation of amino acids and proteins.

The nitrogen concentration found in the pond (see Figure 8) follows a pattern similar to total phosphorus over the course of the sampling season. In the surface waters, the concentration increases to 1.1 milligrams per liter (mg/l) by 20 August and then declines to 0.75 by 10 September. This pattern is very similar to the inverse of the Secchi extinction depth which reaches its lowest depth on 20 August and improves thereafter. The surface water chlorophyll *a* follows a similar pattern, rising to an early peak on 6 and 20 August before declining to a low on 27 August. After that time, the chlorophyll deviates rising to a very high level of just over 15 micrograms per liter on 10 September.

In the deep water, total nitrogen follows the same pattern as total phosphorus but peaks two weeks earlier on 27 August while total phosphorus continues to increase to 10 September. As with the phosphorus, the source of this tremendous nitrogen addition includes the decay products from the rooted plants and a huge increase in chlorophyll bearing phytoplankton which reaches 57 ug/l on 10 September and 42 ug/l on 24 September. The soluble, inorganic portion peaks on 27 August which appears to correlate with the post die-off rooted plant break up. It then declines drastically as the chlorophyll *a* at depth rises. Throughout August and September, the inorganic nitrogen at Station 2 (3.5 meters deep) is almost entirely in the ammonium form indicating the lack of oxygen in the deep water.

Implications of the Data Collected:
Interpretation of one season's data is difficult in light of the vagaries of weather and other natural cycles which can exert some control over the cycle of phytoplankton and rooted plants and, thereby, influence the nutrients and other parameters discussed above. To evaluate the data, I will first go through a method used to categorize fresh waters into the commonly known trophic states that range from eutrophic on one end to oligotrophic on the other. Then I will compare some of the key parameters measured to those found in other lakes in the area.

Trophic State Indices:
Trophic state is a description of the biological response to factors such as nutrient addition. The trophic state is described by the often used terms eutrophy, mesotrophy and oligotrophy. Typically, eutrophy is understood to be an excess of productivity while oligotrophy is a relative lack of productivity.

A classification process was developed by Carlson (1977) which used three variables to independently estimate the biomass of algae in the system. The formulas used produced Trohpic State Indices or TSI. The three variables used are chlorophyll pigments (Chl), Secchi extinction depth (Z) and total phosphorus (TP). The classification system is widely accepted but there are no absolute nutrient values or TSIs that define the trophic state of a specific pond. The indices were developed for lakes in general and should be applied with caution to Seth's Pond. Carlson gave priority to the chlorophyll indicator as being the most accurate predictor of algal biomass. The scale for the TSI ranges from 0 to 100 with values less than 30 indicating an oligotrophic condition and values over 50 indicating eutrophy or hypereutrophy. The formulas used to calculate the TSI values are:

Secchi TSI == 60 - 14.41*ln(Z)
Chlorophyll TSI == 9.81*ln(Chl) + 30.6
Total Phosphorus TSI == 14.42*ln(TP) + 4.15

The results of these equations should not be confused with "good" or "bad" water quality. Instead they indicate the biological condition of a water body. The TSI numbers are plotted in Figure 10. To the three mentioned above, a TSI for total nitrogen is included as was prepared by Kratzer and Brezonik (1981). The TSIs all indicate a pond system which borders on the mesotrophic-eutrophic boundary.

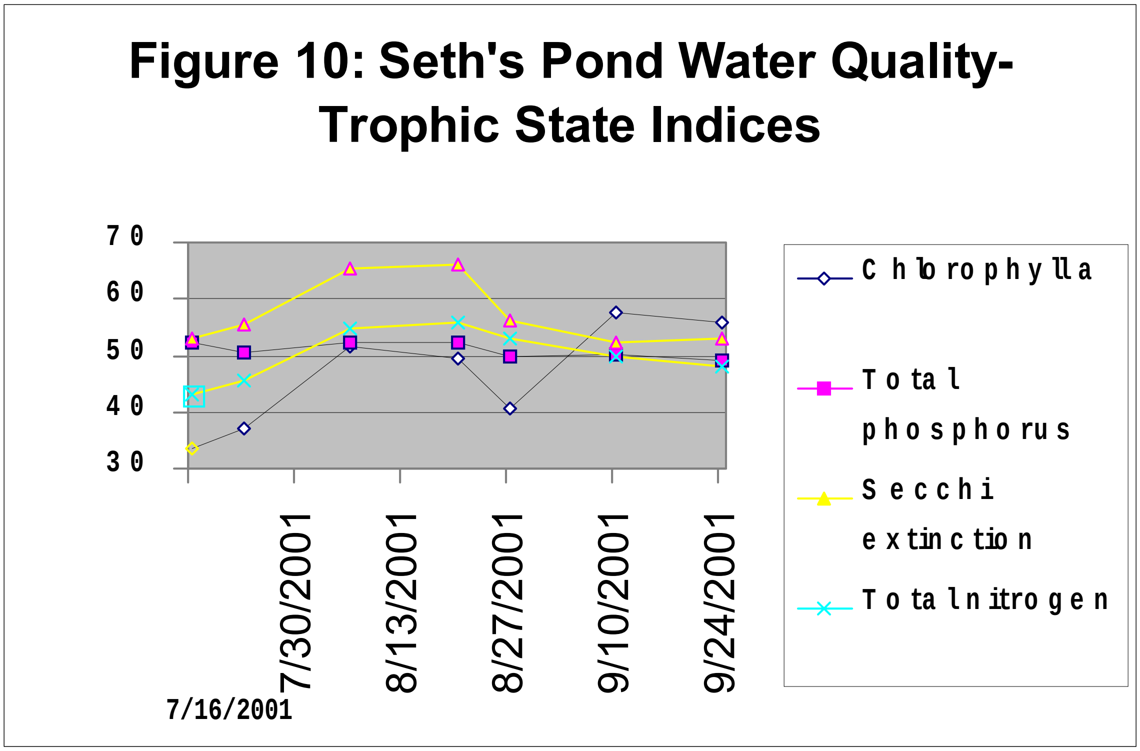
When applied to the surface sample site data collected for Seth's Pond (Appendix D), the chlorophyll TSI rises from 33 in mid-July to 37 at the end of the month and is at or near 50 through most of August. In September, the index rises to near 60. This indicates a condition of mesotrophy evolving into eutrophy as the algae bloom developed and the rooted macrophytes died out.

The TSI values for Total Phosphorus and Secchi extinction depth also follow this pattern with the extinction depth TSI reaching the mid 60's and the total phosphorus reaching the low 50's at the same time the chlorophyll TSI hits its highest values. The total nitrogen TSI mirrors the Secchi depth TSI.

Comparison with Average Conditions in Other Ponds in the Region:
Under a contract with the New England Interstate Water Pollution Control Commission, ENSR Corporation assembled data from ponds throughout the New England region. Peterson et al (1998) examined coastal lowland fresh waters throughout the northeast including New Jersey and New York as well as New England. ENSR (2000) used a July to September index period which is the same as the time period for the Seth's Pond study.

Table 2: Trophic State Indicators for the Northeast Compared to Seth's Pond

Parameter	NE Coastal Zone Lakes ENSR	Coastal Lowland Lakes Peterson et al 1998	Seth's Pond Summer 2001
Total Phosphorus Mean	26.38 ug/l	26.0 ug/l	26.36 ug/l
Total Phosphorus Std. Dev.	+/- 41.27 ug/l		
Total Nitrogen Mean	588.27 ug/l	502 ug/l	792.56 ug/l
Total Nitrogen Std. Dev.	+/-468.85 ug/l		
Chlorophyll *a* Mean	7.52 ug/l	7.7 ug/l	7.19 ug/l
Chlorophyll *a* Std. Dev.	14.56 ug/l		
Secchi Depth Mean	2.71 meters	1.5 meters	1.28 meters
Secchi Depth Std. Dev.	+/- 1.58 meters		



ENSR (2000) summarized the Trophic State system as follows:

Table 3: Trophic State Classification Based on Water Quality Variables (ENSR, 2000)

Variables	Oligotrophic TSI<30	Mesotrophic 30<TSI<50	Eutrophic TSI>50
Total P ug/l	<10	10 to 24	>24
Chlorophyll *a* ug/l	<1.5	1.5 to 7.2	>7.2
Secchi Depth meters	>6	2 to 6	<2

It appears that, from this summer's data Seth's Pond falls into the eutrophic category. This condition is very similar to that found on average throughout the coastal zone of New England as shown by the similarity of Seth's numbers with the averages from the region in Table 2.

Limiting Nutrient:

The ratio of nitrogen to phosphorus has been used to determine whether a given system needs nitrogen or phosphorus for additional phytoplankton growth. The ratio of DIN (inorganic nitrogen) to orthophosphate has some implications to the growth of phytoplankton. The inorganic forms are the most readily available to phytoplankton. Redfield (1963) found that the ratio averages around 16 to 1 for phytoplankton tissue. This implies that when the ratio is substantially less than 16, nitrogen is deficient and is limiting the growth of phytoplankton. Conversely, when the ratio is over 16, phosphorus is deficient and limits growth.

In addition, phosphorus is generally thought of as limiting when the ratio of Total Nitrogen to Total Phosphorus is greater than 10 to 1 (Carlson and Simpson, 1996). When the ratio is less than 10 to 1, nitrogen is limiting.

Usually, nitrogen is limiting in salt water ponds and phosphorus is limiting in fresh water systems. In Seth's Pond, the ratio of the inorganic forms ranged from 1 to 5 throughout the sampling period with the exception of 27 August when the ratio reached 31. This implies nitrogen limitation. On the other hand, at the deep station from 6 to 27 August, the ratios ranged from 249 up to 2044 implying large amounts of highly available nitrogen in a soluble form. In July, the ratio at the deep station ranged from 1.2 to 6.8.

When the ratios of total nitrogen and phosphorus are calculated, the surface average values ranged from just over 16 on 16 July up to 39.8 on August 20. These ratios imply that phosphorus is limiting. At the deeper station, the values are slightly different but the same conclusion holds.

INTERPRETATION: *Inorganic nitrogen enters the system from the groundwater (see Station 6 data in Appendix D) where it is 10 to 50 times the surface water concentration. It also enters in rainfall events see Station 7 on 14 August and 1 October. Inorganic nitrogen is scavenged out of the surface waters by phytoplankton. Clearly, a large source of soluble, inorganic nitrogen became available in late summer in the deeper waters either from phytoplankton settling down from the surface waters and decaying, from groundwater seepage or from the decay of the rooted plant foliage or a combination of these. I would hypothesize that the inorganic nitrogen was used in the surface layer to form plankton which settled into the bottom layer and became a conduit for moving nitrogen from the upper water column to the lower. This would account for the nitrogen deficiency in the surface sample and excess in the deep sample. This may have been augmented by the decay of the pond weed foliage. The increasing ratio of total nitrogen to total phosphorus indicates movement of inorganic forms into both dissolved and particulate nitrogen whose breakdown back to inorganic forms is delayed into the post-sampling period.*

Lambert's Cove Runoff Data:

The Road runs downhill from the south about 1700 feet to the depression in which the pond is found. From the north, the incline is more gentle and extends over a distance of 570 feet. In addition, there are 10 driveways that slope to the Road and contribute substantial runoff. From the south, the Highway Department has placed a number of roadside discharge chutes along both sides of Lambert's Cove Road. These appear to work during light rain but to become clogged with sediment from the driveways during heavier rain causing the runoff to bypass the discharge points. The roadway configuration is described in some detail in Appendix C. From the north, a discharge chute diverts a considerable portion of the runoff flowing from that direction before it reaches the infiltration swale and also serves as an overflow bypass for the swale.

The infiltration swale has been constructed at the road edge some 30 to 40 feet from the shore. The swale is intended to infiltrate the first flush of runoff to remove coarse contaminants and bacteria from the flow. This swale has a depth of about 3 to 4 inches, a width of about 6 feet and a length of about 60 feet. Its estimated capacity as storage is 90 to 120 cubic feet. During the time of the study it had an accumulation of silt in the gravel bed with fine sand and silt deposits associated with recent rainfall.

The runoff volume is estimated with the following assumptions:

- 95% runoff from paved areas and
- 32 % from dirt and gravel areas

With these assumptions, a one inch rain storm will produce 4850 cubic feet or 36280 gallons of runoff. The annual runoff volume from these surfaces is difficult to estimate because it depends on the number of rain events which exceed about ¼ inch which appears to be the point where runoff begins to be generated. At roughly ½ inch of rainfall, the infiltration swale may be bypassed. This depends to a great extent on the rate of rainfall. During the period from June 1999 through May 2000, forty five ¼ inch rain events occurred (National Weather Service, Edgartown Observatory). Of these, 24 rain events totaling 27.6 inches exceeded ½ inch. During that time period, 41.7 inches of precipitation were recorded. About 2/3 of the year's precipitation occurred during rain events that exceeded ½ inch total.

It appears that it is only those rainfall events that are heavy, short-term downpours or prolonged rainfall in excess of ½ inch total that have the potential to bypass the infiltration swale. Estimates of the runoff are based on the review of 1997 to 1999 data collected in Edgartown by the National Weather Observer and summarized in Appendix B as "Notes on Estimation of Precipitation Yielding Runoff". This amounts to approximately about 116400 cubic feet of runoff reaching the pond from the road system each year. The first ¼ inch is assumed to be diverted or infiltrated. Most of the pollutants carried to the pond will be in the dissolved fraction as, even when bypassing the treatment, the particulates carried in the runoff will settle in the swale or be filtered as the bypass water flows through the brush and marsh to the pond.

Two runoff events were sampled in an effort to determine the impact of runoff on Seth's Pond. These events were 0.8 inches (Personal gauge in West Tisbury) over the 36 hours prior to sampling on 14 August and 0.9 inches (Personal gauge in West Tisbury) over the 12 hours prior to sampling on 1 October. The National Weather Service tallied 1.05 inches for the record on the 13th and 14th of August and 0.92 inches for the 1st of October. During the August event, the rainfall had been spread out sufficiently so that, at the time of sampling, the runoff was contained by the infiltration swale at the roadside edge.

On 14 August, a sample of the runoff entering the infiltration swale was collected as Station 7 and a sample from the nearshore area as Station 8. At the time, standing water in the gravel infiltration bed formed a puddle approximately 20 feet long by 3 feet wide and 3 to 4 inches deep. The puddle had a noticeable hydrocarbon sheen at the surface. The runoff contained some 50 times the inorganic nitrogen (0.341 mg/l) found in the nearshore waters and 28 times the orthophosphate (0.0365 mg/l). Total phosphorus was 6 times the concentration in pond while total nitrogen was slightly less than in-pond.

On 1 October, the rainfall was more intense and the runoff was observed to bypass the roadside discharge chutes due to sediment clogging and the speed and volume of runoff. Runoff had filled the infiltration swale and was bypassing it at the north end. A substantial rivulet made its way through the brushy border and across the marsh to discharge directly into the pond. Total phosphorus entering the swale puddle was 0.27 mg/l and the flowage across the marsh was 0.19 mg/l compared to an in-pond TP of 0.05 mg/l. Total nitrogen actually increased from the swale to the flowage across the marsh, rising from 1.84 to 2.71 mg/l. The swale successfully removed suspended solids with the content dropping from 87.8 mg/l entering the swale to 33.8 mg/l crossing the marsh. The data from this runoff event is reported in Table 5 and Appendix D.

INTERPRETATION: *The infiltration swale appears to offer considerable removal of silt and nutrients during light rain events. Regular maintenance is necessary to remove accumulated sediment to encourage rapid infiltration. During heavy rainfall, the runoff bypasses the swale, flows across the marsh and enters the pond directly. It is not possible to estimate the amount of a heavy rainfall that will bypass the swale as this varies with the intensity and duration of rain. It appears that on one occasion, a rainfall of over 0.5 inch over the previous 12 hours set the stage for bypass to occur. If the swale catches the first ¼ inch of rain, a good deal of the pollutants entrained will be trapped in the infiltration gravel. However, the October sampling was conducted during the end of the rain event and a substantial flow was bypassing the swale and flowing across the marsh. Estimates of nitrogen and phosphorus loading are in Table 5.*

Pond Vegetation:

Pond weed was pulled up in substantial amounts at all in pond stations during the July sampling rounds. During late July and early August a severe algae bloom developed which reduced visibility from 1.5 meters on July 23 to 0.7 meters on August 6. By August 6 the deep water sample at Station 1 had a slight sulfurous odor and dissolved oxygen was down to less than 40% saturation throughout bottom 0.5 meter of the water column and, in the deepest area (within the 4 meter contour), the bottom water approached anoxia in the lower one meter. It was noted that there were floating patches of pondweed scattered around the surface of the pond. By August 20 there was no intact weed coming up on the anchor at any of the sampling stations. Instead, fragments of dark colored weed were stirred up off the bottom indicating that collapse of the stem structure and decay were well underway. It is possible that lack of sunlight brought on by the developing algae bloom may have caused the pondweed to die out creating a large oxygen demand and possibly releasing nutrients to further feed the development of the algae bloom.

Rooted Aquatic Vegetation:

In Seth's Pond, the submerged plant community is dominated by a narrow-leaf, rooted plant. This plant is identified as a pondweed (*Potamegeton*) and is believed to be small pondweed (*P. pusillus*). This identification is based on the flattened fruit which has a beak or projection at the tip. It is possible that the correct identification is Sago pondweed (*P. pectinatus* now *Stuckenia pectinatus*) but the leaves on all the specimens obtained were less than 2 inches in length and lack a sheath on the stem at the attachment of the leaf stalk. These plants are perennial reproducing by rhizomes and by seed. Both are considered valuable as food for waterfowl and habitat for fish species.

A rooted vegetation distribution/density map could not be made because the water column was obscured by the algae bloom which continued as the pondweed died off. In late July, coincident with this algae bloom which reduced Secchi extinction depth to less than 0.75 meters, the foliage of the pondweed died out and decayed. For this reason, the area where the pondweed is found cannot be precisely defined. Prior to that event, pondweed was pulled up with the anchor at all water quality sampling stations during late July. The quantity caught on the anchor was similar at each station. The pondweed was not present in-shore at depths less than 1 to 1.5 meters where the bottom was visible. The approximate area where the weed is found is considered to be within a line connecting the outer stations numbered 3, 4 and 5 (see Figure 5). Within this area, pondweed density is moderate to dense. The root system is probably still viable and will send up new top growth next season.

The die-off of the top growth of the pondweed in late July is probably premature. The normal cycle would extend into or through September. Rooted plants in general serve to extract nutrients from bottom sediments where they would otherwise be sequestered by the boundary between oxygenated and anoxic sediment. These nutrients are carried up into the leafy growth and released into the water column by the plant’s decay. Whether the early senescence of the pondweed was the result of reduced light transmission due to the phytoplankton bloom or the release of nutrients from the decaying pondweed stimulated the bloom is not clear. It is clear that this type of complete die-off, if it brings on a phytoplankton bloom, is not a desirable cycle. Sago pondweed begins senescence after bloom and following a 129 day growing season (early October in North Dakota) the entire plant community was senescent.

In shore, in shallow water about 0.5 feet deep, the plant community was dominated by pipe wort (*Eriocaulum species*). The marsh fringing the pond includes a large population of August-through-September flowering, pink tickseed (*Coreopsis rosea*) in addition to juncus, rice cutgrass and sedges. The wetland situated in the southeast corner supports jewelweed (*Impatiens species*) and rice cutgrass (*Leersia oryzoides*). Other plants may make a showing during a time of year outside of our study period and are not included. Surrounding woodlands include red maple, beetle bung, red/black and white oak with an understory including blueberry, huckleberry, viburnum and some swamp azalea.

Invertebrate & Vertebrate Observations:

Numerous bull frogs (*Rana catesbeiana*) were observed in the shallows. A green frog (*Rana clamitans*) is suspected from the croak made when it was surprised and jumped into the pond water. Painted turtles (*Chrysemys picta*) were seen sunning on the fallen trees and rocks at the water’s edge.

Late in the study period in September a number of pickerel were observed in the shallows near the bathing beach. At the same time, two probable large mouth bass and numerous small fish that probably include pumpkin seeds were seen. All of these fish were small in size with the pickerel ranging up toward an estimated 6 to 8 inches and the bass around 4 to 6 inches in length.

Throughout August large numbers of dragon flies (*Odonata)* and water beetles (*Coleoptera* and possibly *Hemiptera*) were observed but cannot be precisely identified.

Present Day Land Use within the Seth's Pond Watershed:
The watershed as defined by the surrounding topography amounts to 87 acres or 3.79 million square feet (see Figure 2). This includes approximately 1.9 acres of Lambert's Cove Road and its right of way. It does not include the pond itself. According to the 2000 Assessor's data, there are 22 existing dwellings on 35 lots with 6 other lots partially within the watershed. The development pattern is illustrated in Figure 11. Zoning within the entire watershed is 3 acre minimum lot size. A spreadsheet with the land use data and an extract of own zoning is included in Appendix E.

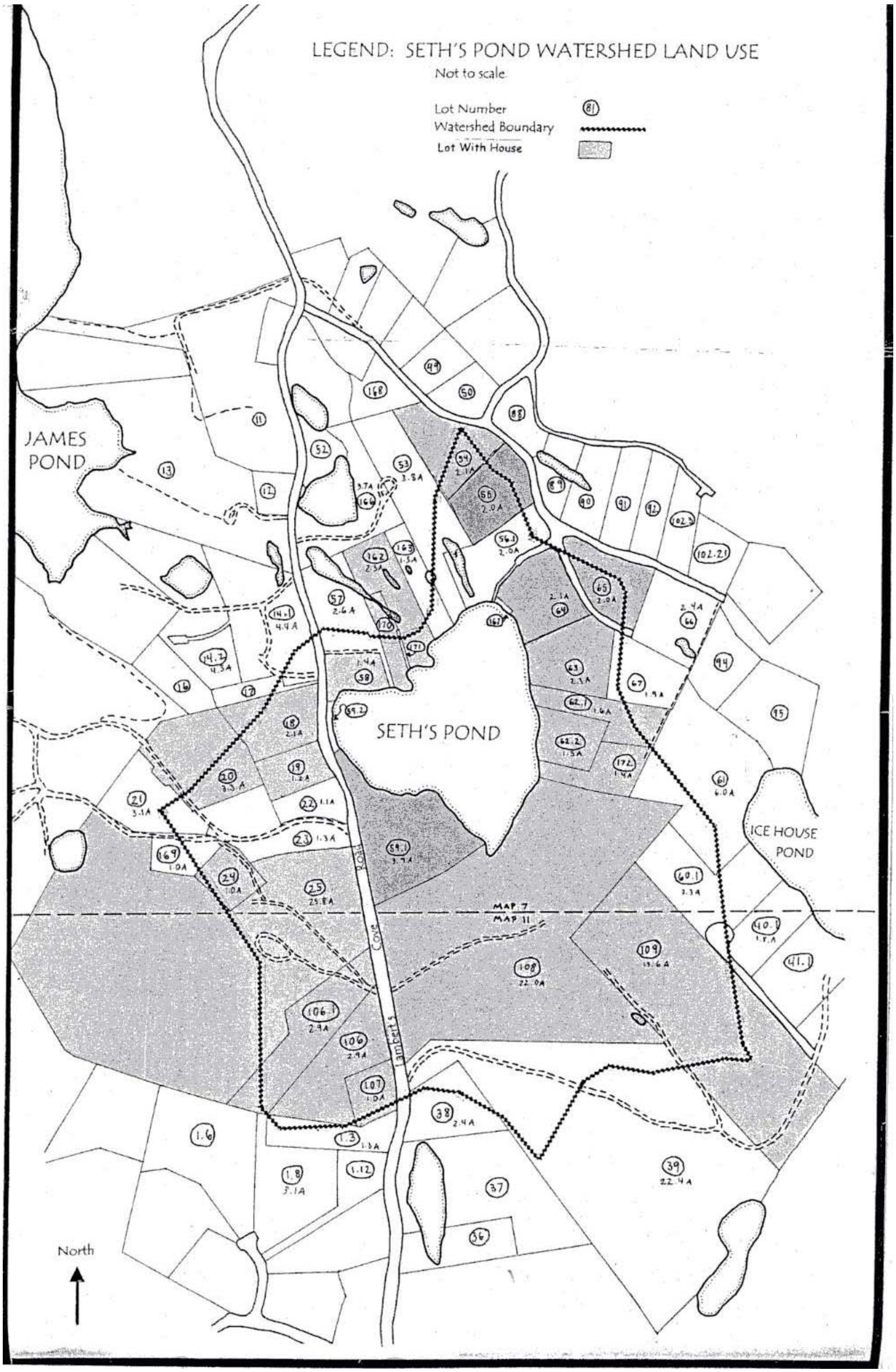
Growth Projection Assumptions:
The Focus Center is located within the watershed and includes dormitory and cafeteria facilities for approximately 110 people maximum. Over the course of 1994, enough people were on site to total an equivalent of 4102 days of use by one person. The projection is for the equivalent of 5190 people for a one day stay during the summer months and 1497 people for a one day stay in the off-season. This is roughly equivalent to 70 people on site for a 75 day stay in summer and an average of 5 people for the 290 day off-season. In the final buildout scenarios, this lot is evaluated in two ways. One is based on the maximum limit of 110 people in residence and, the other that the lot is assumed occupied by the seasonal equivalent of 70 people on a year-round basis. Table 4 summarizes these scenarios to develop a nitrogen loading estimate.

In order to arrive at a future estimate of the amount of nitrogen and phosphorus that may be added from human sources, High and Low growth projections are necessary. Projections develop from predictions of the future which is difficult. The High and Low projections are used to try to bracket the potential future but they both are real possible outcomes and should be viewed as such.

Under the Low projection, the only added primary dwellings are those built on vacant lots that exceed 1.0 acre in size. No further subdivision of lots is assumed to occur. Lots that exceed 3.5 acres are assumed to have a guest house. Only 50 percent of the lots between 2 and 3.5 acres are assumed to build a guest house. Lots less than 2 acres are assumed to have no guest house.

Under the High projection, vacant lots are assumed to subdivide to the 3 acre lot size allowed under zoning. Where the portion of the lot within the watershed is large enough, the new lots are considered to be in the watershed. All lots exceeding 2 acres are assumed to eventually have a guest house as well as 50 percent of those between 1.5 and 2 acres.

The maximum buildout within the watershed calls for an additional 14 dwellings to bring the total to 36. At a minimum, another 7 dwellings are expected to bring the total to 29. Some of these lots are cut by the watershed boundary. When this occurs, the projected dwelling is assumed to be in the watershed if the portion of the lot in the watershed is more than 50% of the total lot area. If more than 50% of the lot area is outside the watershed then the future dwelling is counted as occurring outside the watershed.


LEGEND: SETH'S POND WATERSHED LAND USE
Not to scale
Lot Number
Watershed Boundary
Lot With House
JAMES POND
SETH'S POND
ICE HOUSE POND
MAP 7
MAP 11
Lambert's Cove Road
North

Potential Guest Houses:
Under Permitted Accessory Uses (Section 3.120, Town Zoning), subordinate dwellings are allowed on lots which meet zoning area requirements and, for lots below minimum area, down to 60,000 square feet (Section 3.124). Habitable floor area is limited to 800 square feet. The guest houses are expected to be no larger than two bedroom dwellings due to the floor area limitation. For this reason, the maximum number of occupants in a guest is projected to be the average year round dwelling population which is 2.38 people.

A total of 14 lots meet this area requirement today however, within the probable buildout projection, only 10 are assumed to actually be built. In the maximum projection, new lots are added that are large enough for a guest house and the total number of guest houses is 23.

Table 4 NITROGEN INPUT SCENARIOS

	Type of D.U.	# Dwellings	People/du	Flow/cap.	#Units Year Rnd.	Flow Total Year Rnd.	Flow Year Rnd.
SETH'S LOWER BUILDOUT						**Gal/yr.**	**Liters/yr.**
	Prime Units	**28**	2.38	48	16	667162	**25285**
			4.77	48	0	0	
	Guest	10	2.38	48	6	250186	9482
	'TOTALS	**38**			22	917347	34767
	FOCUS	**1**	70	48	1	1226400	4
	FOCUS		70	48	1		
	Total Focus						**4**
SETH'S MAXIMUM BUILDOUT							
	Prime Units	35	2.38	48	20	833952	3160
			4.77	48	0	0	
	Guest	23	2.38	48	13	542069	20544
		58			33	1376021	52151
	FOCUS	**1**	110	48	1	1927200	7
			0	48	1		
							7
SETH'S TODAY							
	Prime unit	21	2.38	48	12	500371	18964
			4.77	48			
			2.38	48	10		
						500371	18964
	FOCUS	**1**	5	48	1	87600	
			70	48	1		

Acid Rain 45.8/12 X 500.94 x10^3 s.f. X28.317 X 0.74 mg/l == 40.1 kg
Lawns: # @ 5000 s.f.each @ 0.68 kg/year X .25
Runoff: as in text

Projected Nutrient Loading:
Nutrient sources primarily include acid rain, septic system effluent and fertilizers. There are no farms within the watershed. A seasonal stream flows into the southeast corner of the Pond at Station 6. The most significant nutrients that influence water quality in the system are phosphorus and nitrogen. The ratio of total nitrogen to total phosphorus (TN/TP) in the surface waters is consistently in excess of 16 and over the course of the sampling averages over 30. Phosphorus is thought to be limiting at TN/TP ratios of more than 10 (Carlson & Simpson, 1996). This implies that phosphorus is the limiting nutrient. The ratio of inorganic nitrogen to phosphorus is well below 10. Although this ratio is probably less reliable during the growing season than TN/TP, it does imply that inorganic nitrogen is a limiting factor during the sampling program. For further discussion of system limits to growth see pages 13 and 33.

Septic system nutrient loading is dependent on the annual number of occupants in the projected dwellings and the number of days the dwelling is occupied each year. In addition, as phosphorus does not travel far through the soils, the phosphorus loading is controlled by the proximity of the dwellings to the shoreline. On average, West Tisbury has approximately 44% seasonal dwellings and 56% year round (2000 Census profile). The average occupation rate for the year round dwellings is 2.38 people per dwelling (US Census).

The seasonal dwelling population is more difficult to estimate. A survey in Oak Bluffs found an average of 4.77 people per seasonal dwelling. An evaluation of MVC Town population estimates (1998) suggests an even higher occupation rate ranging from 6 to 7.5 people per seasonal dwelling depending on assumptions. For purposes of estimating nitrogen loading, an average of 4.77 people per seasonal dwelling will be assumed for a 75 day period. As the shoulder season has become increasingly popular, the seasonal dwellings are also assumed to house 2.38 people for a period of 40 days (25 days for the lower projection). The remainder of the year, these dwellings are assumed to be empty and produce no nitrogen.

Phosphorus Loading #1: NPSLAKE Model Approach
Calculation sheets are included in Appendix F.
There are several approaches available to estimate phosphorus loading from the watershed. All approaches consider the number of dwellings, the amount of developed land that will generate runoff and the area of open land within the watershed. Perhaps the simplest approach is a formula derived by DEP (Mattson & Isaac, 1999) which is intended to estimate phosphorus export from the watershed. A number of models were screened to select export coefficients which most closely predicted the measured total phosphorus concentration in 16 Massachusetts lakes. The final model developed was:

$$\textbf{P Load kg/yr.} == \textbf{0.5 kg/yr.* Dwellings + 0.13 kg/ha/yr.*forest hectares +}$$
$$\textbf{0.3kg/ha/yr.*(rural hectares) +14* (urban hectares)}^{0.5}$$

The numbers plugged into the formula are:

Dwellings within 100 meters == 8 + Focus complex
Forest land area in hectares == 77.5 acres (31.4 hectares)
Rural area in hectares == 9.5 acres (3.8 hectares)
Urban area in hectares == 0

Assumptions used in this estimate are first, that each dwelling in the watershed equals ¼ acre of rural land, that Focus is equivalent to 2 acres and that the roads add another 2 acres to the rural area. This totals 9.45 acres. The sewage flow today from Focus is roughly equivalent to 7 dwellings.

The predicted phosphorus load from the model equation is 12.8 kilograms per year. This load is external and does not account for sediment release of phosphorus into the water column. The 7.5 kilograms predicted from septic systems is probably an overestimate as approximately 44% of the dwellings are seasonal. A reduction of the septic load by 1/3 is suggested to compensate for the reduced sewage loading associated with seasonal use and to allow for the composting toilets at Focus. The resulting watershed loading would be 10.3 kilograms per year.

As a check, this predicted load can be inserted into a formula developed by Reckhow (1979) which predicts total phosphorus concentration in a lake based on the annual phosphorus loading to the system. Reckhow's formula uses the annual water flow into the system plus a constant to predict the dilution of the annual load as follows:

$$\textbf{Lake TP} == \frac{\textbf{Load in grams/meter}^2\textbf{/year}}{\textbf{11.6 + 1.2q}}$$

In this formula, the load is in terms of the area of the lake. 11.6 is a constant meant to compensate for the settling rate of phosphorus into the bottom sediment. The letter "q" is equal to the amount of new water entering the lake system in meters per year. This formula probably best applies to ponds where there are substantial streams adding water. If we insert the predicted load of 12.8 kilograms/year into the formula and divide it by the area of the pond (46135 square meters), the Load value is 0.277 grams /meter^2/year. The stream flow entering the system is virtually zero but, if the estimated runoff plus the groundwater seepage is substituted, an annual water load of 4.3 meters results. The predicted total phosphorus in the system would be 0.017 milligrams per liter. If 10.3 kilograms per year is inserted as the annual load, the formula predicts 0.013 mg/l. The measured TP averaged 0.026 mg/l over the sampling rounds.

Another approach was employed by Vollenweider (1975) which uses the flushing time and mean depth as the predicted dilution of the annual phosphorus load. The model formula is very similar to Reckhow's:

$$\textbf{Lake TP} == \frac{\textbf{L}}{\textbf{10 + ZF}}$$

Where Z is Mean Depth or 2.4 meters
F is the flushings/year or 2.08/year

Inserting a Load of 12.8 kilograms per year, the predicted Total Phosphorus is 0.019 milligrams/liter.

The difference between the observed lake TP and the model predictions may be due to phosphorus released from the sediment. The formula can be adjusted to use the measured TP and to predict the annual loading. If we insert 0.026 mg/l, the Reckhow model predicts the annual loading is 0.436 grams/square meter or a total of 20.1 kilograms. The Vollenweider model predicts a loading of 18 kilograms. Sediment release may therefore be between 3 and 9 kilograms per year. This is equivalent to a release rate of 0.07 to 0.2 grams per meter square per year.

Phosphate Loading #2: Dillon-Rigler Model
The Dillon-Rigler (1974) model formula takes into account the phosphorus retention in the system, the mean depth of the pond and the flushing time of the system. The formula used in the model is:

$$\mathbf{TP} == \frac{L_{PO4} * (1 - (0.426e^{-0.0271Z/T} + 0.574\, e^{-0.00949Z/T}))}{Z/T}$$

In this formula, Z is the mean depth of the pond or 2.4 meters in Seth's and T is the flushing time in years. This figure is estimated to range from 0.48 to 1.33 years. If we use the known value of 0.026 mg/l for the TP, we can estimate what is the required loading to satisfy the equation. The annual load ranges from 12.4 to 17.5 kilograms per year.

From the formulas used, the predicted annual phosphorus loading ranges from 12.4 to 20.1 kilograms including sediment release.

Phosphorus Loading #3: Separate Source Estimate
This approach will use other estimates of source concentration of phosphorus applied to estimates of septic flow, runoff and rainfall to estimate annual loading. The present day loading is projected into the future to provide a range of possible loading from the sources in the watershed. The phosphorus sources with the greatest range of uncertainty drive the differences between the high and low projections. These are sewage and background sources.

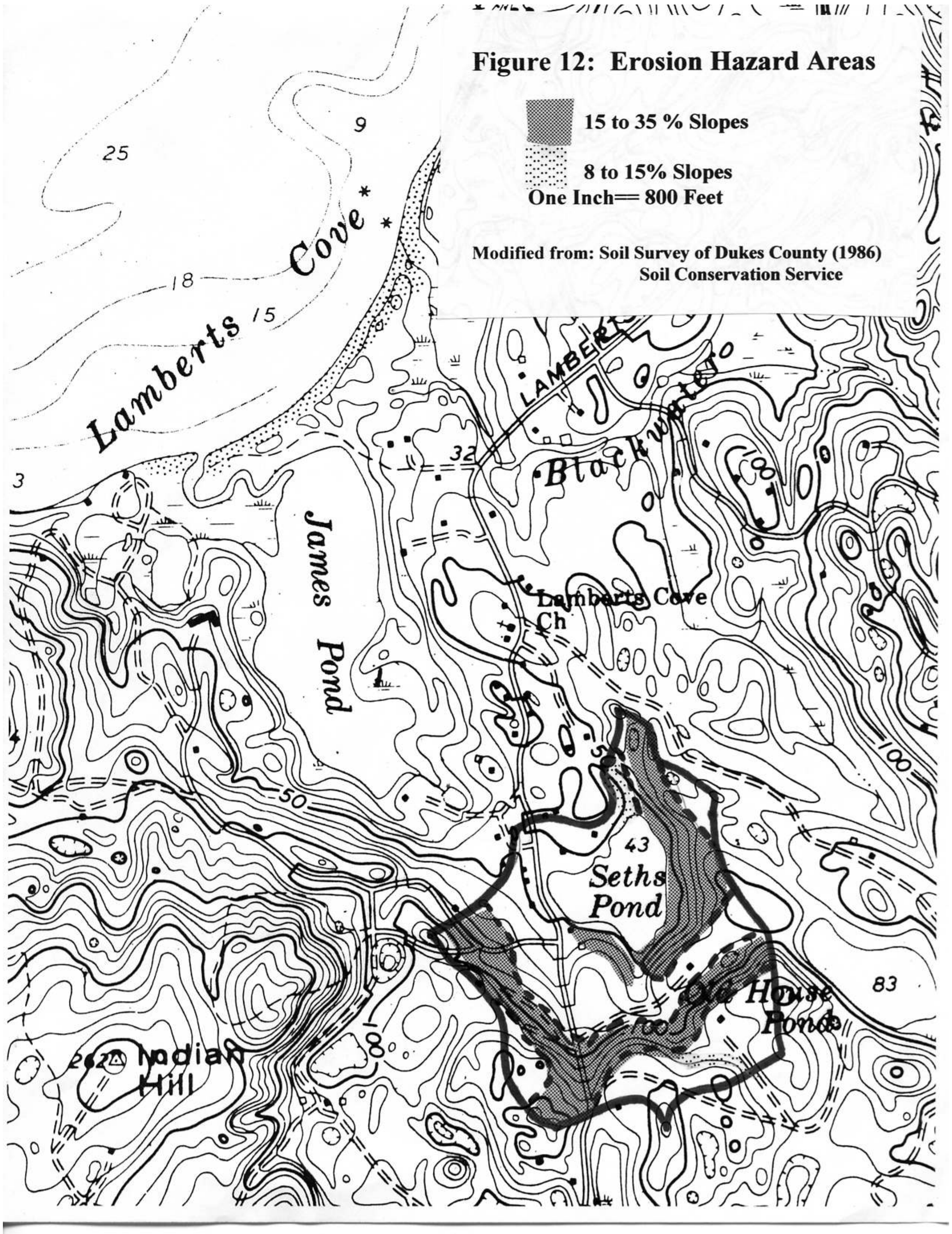
Sources: Street and Agricultural Runoff
Phosphorus may comprise 0.01 to 0.2 percent by weight of natural soils (EPA, 1993). Most cropped soils have increased phosphorus content to high or very high levels due to past fertilizer practices (Sims, 1992). In soils phosphorus occurs as dissolved inorganic, colloidal and in particulate forms. Phosphorus is strongly bonded in acidic soils to aluminum and iron creating an insoluble precipitate. Phosphorus is also relatively insoluble in water (10 to 15 ppb). For these reasons, it is not considered a mobile nutrient. Orthophosphate (dissolved inorganic) is the form directly available to algae.

Because of this tendency to bind in the soil, erosion and runoff of soil particles directly into water resources is the prime means of entry from agricultural, forestry and other disturbed sites. The amount of phosphorus released from a site is proportional to the area disturbed and the nature and sufficiency of phosphorus removing treatments such as buffer strips and infiltration basins which bring the phosphorus discharge into contact with the soils which can bind it. Prevention of erosion and sedimentation, carrying phosphorus into the pond must be a priority. Property that slopes directly to the pond in excess of 7 percent (DEP, 2001) has the potential to contribute sediment to the pond. These locations should receive careful oversight during construction involving soil disturbance. The approximate area of concern is illustrated in Figure 12. Individual sites should be confirmed by inspection.

Runoff from paved areas discharging directly to surface waters is a source of nutrients. In addition to heavy metals, salt, sediment, bacteria and other pathogenic organisms, nutrients are carried with the rain as it washes down the streets. Suburban areas generate runoff with total phosphorus concentrations of about 0.26 mg/l and orthophosphate about 0.12 (Schueler, 1987). Runoff also carries dissolved inorganic nitrogen (0.74 mg/l) about equal to the nitrogen content of the rain and total nitrogen (2 mg/L).

The only known discharge of street runoff directly to Seth’s Pond is the Lambert’s Cove Road and adjoining driveways that do not have a negative grade where they join the Road. Presently runoff flowing toward Seth’s Pond is ponded somewhat at the roadside and allowed to flow into a gravel bed, and, under heavy rainfall events, through a vegetated area as a means of filtering out sediment, bacteria and as much of the nutrient load as possible. However, the discharge bypasses the gravel bed after approximately ½ inch of rain has filled the swale. This excess runoff flows through some bordering vegetation, across the fringing marsh and into the pond.

A one inch rainfall will generate approximately 4850 cubic feet of runoff (36300 gallons). The infiltration swale has a standing capacity of approximately 90 to 120 cubic feet (6 feet by 60 feet by 3 to 4 inches). At an infiltration rate of 1 inch per minute, the swale can handle a maximum of 1800 cubic feet per hour. The swale will accommodate about 0.4 inches per hour. Under some less intense rainfall conditions, the roadside chutes along Lambert’s Cove Road combined with the swale’s infiltration capacity will probably handle most of the runoff. Infiltration will remove a large portion of the phosphorus entrained in the runoff. During 1999, as much as two thirds of the year’s precipitation came in rainfall events of 0.5 inches or more over the twenty four hour record period. I estimate that somewhere between 12 inches and 24 inches of runoff is generated annually that overwhelms the system and flows to the pond (see Notes in Appendix B). This amounts to around 58000 to 116400 cubic feet.



Note: Not to scale.

During the two runoff events on 14 August and 1 October, the concentrations of phosphorus in the runoff and the implied loading for the year at each concentration are as follows:

Table 5: Nutrient Loading from Two Runoff Events in kilograms

	parameter	concentration	@58000 c.f.	@116400c.f.
8/14	orthophosphate	0.0365 mg/l	0.06 kg.	0.12 kg.
8/14	total phosphorus	0.122 mg/l	0.2 kg	0.4 kg
10/1	orthophosphate			
10/1	total phosphorus	0.189 mg/l	0.3 kg.	0.62 kg
8/14	Inorganic nitrogen	0.34 mg/l	0.56 kg.	1.12 kg.
8/14	Total Nitrogen	0.744 mg/l	1.2 kg	2.45 kg.
10/1	Inorganic nitrogen			
10/1	Total Nitrogen	2.71 mg/l	4.5 kg.	8.9 kg.

When compared to the other sources, runoff is a relatively small source of phosphorus. However, it carries other undesirable pollutants including metals, hydrocarbons, coliform bacteria and perhaps occasionally silt to the pond. The portion from the driveways can readily be corrected.

Agricultural operations do not exist in the recharge area. Lawn fertilizers are not believed to add to phosphorus loading because the fertilizer is applied to the surface of the soil where it is taken into the turf or immobilized in the soil.

Sources: Groundwater

Phosphorus tends to be attenuated in all but the very coarsest soils through precipitation reactions with aluminum and iron and inorganic adsorption (Environmental Inorganic Chemistry, 1988). If steadily supplied, phosphorus can overwhelm these retention mechanisms and over time move further out away from the source. The complexity of the attenuation processes makes it very difficult to model the movement of phosphorus without an enormous input of information to calibrate the model. Simpler models that ignore the detailed mechanisms of attenuation and reflect the overall behavior of the pollutant have been developed (Freundlich and Langmuir models). The behavior of phosphate may follow one type of formula at low concentrations (Freundlich) and a linear formula at high concentrations (Shayan and Davey,1978). In the field, phosphate has **both** been identified as a pollutant in the ground water and has been found to be an insignificant addition.

Weiskel and Howes (1992) found that phosphate was strongly retained by soils and aquifer materials in the Indian Heights study area in the Buzzard's Bay watershed. The watershed was sited on medium to coarse sandy soils similar to those in part of the Seth's Pond recharge area. The housing density was on the order of one dwelling per quarter acre and had been constant for about 10 years. Weiskel and Howes (1992) found that the effluent phosphate content from the septic system studied was 5.1 mg/liter while the groundwater concentration 1 meter down gradient was 1.33 milligrams per liter. Further down gradient, the phosphorus content was least at the water table and increased to a maximum at about 35 centimeters below the water table. They found support for the loss of phosphate due to oxidation at the upper level of the groundwater. They attributed the high attenuation rate to inorganic adsorption and precipitation which was so dramatic that the post development increase in phosphate flux was found to be insignificant.

Valiela et al (1990) found that the ratio of nitrogen to phosphorus increased by a factor of 3 to 4 in transit from the point of discharge in the watershed to the point of release at a coastal pond. The increase noted implies a mechanism either removing phosphorus or adding nitrogen. The data was developed from sites where sewage was the dominant source of nutrients.

Sewage Phosphorus Source:

One logical way to address these different conclusions is to assume that effluent discharged from septic systems within a certain distance of the pond will eventually release phosphate into the pond. This approach was used in a Falmouth zoning bylaw where dwellings within 300 feet were considered to be phosphate sources. It was also used in a Massachusetts modeling effort (Mattson & Isaac, 1999). From an examination of aerial photographs of the Seth's Pond shoreline, there are 8 houses and the Focus Center within 300 feet of the shore. The maximum phosphorus loading from the residences would occur if all 8 were occupied year round with the average residence population for West Tisbury (2.38 people).

The Focus Center includes septic systems as well as 6 compost toilets. I am estimating that approximately 15% of the total site flow is diverted to the composters which do not contribute to the groundwater. The site capacity is 110 people. The average stay for the maximum 110 people is uncertain but in 1994, the average daily occupation over the year was equal to about 11.25 people for 365 days. The projection from Focus is for an equivalent of 5190 people for a 1 day stay in the summer and 1497 people for a 1 day stay in the off-season. This is equivalent to 70 people for the 75 day summer season and 5 people for the remaining 290 days in the year.

The average person releases 3.5 pounds of total phosphorus in their waste per year. The EPA National Eutrophication Survey (1978) estimated that 0.25 pounds (7%) of the total phosphorus in the discharge could reach a surface water body. If Focus were occupied at the present-day rate, about 24.75 kilograms of phosphorus would be generated annually from sewage but perhaps as little as 1.7 kilograms would reach the Pond. The 8 residences contribute 30.2 kilograms of the total loading but only 2.1 kilograms reach the pond after phosphorus extraction mechanisms are applied. Total loading is 3.9 kilos.

There are uncertainties in these estimates from the limited understanding of phosphorus movement through the soil and groundwater. Over time, as the soil bonding sites between the source and the pond become saturated with phosphorus, it is conceivable that the annual percentage reaching the pond would increase. To attempt to cover this eventuality, the higher sewage loading, both for Today and Projected will assume 15% of the annual load reaches the pond. The present-day loading from 8 residences and the Focus Center at this rate is about 8.24 kilograms reaching the pond.

At buildout, the Focus Center could be occupied by a maximum of 110 people on a year-round basis. The 8 residences would increase to 11 and there would be 7 guest houses occupied by an average of 2 people per dwelling. The potential phosphorus load from sewage entering the pond is estimated at 15% of the source or 31.8 kilograms. For the lower projected loading estimate, only 6 of the 11 projected dwellings are occupied year round while 5 are seasonal. Only 3 guest houses are added to the lots close enough to the pond to add phosphorus. Focus is assumed to be occupied by an average of 70 people on a year round basis. At 7% reaching the pond, the total phosphorus loading from all sewage sources is 9.0 kilograms.

Rainfall Sources:

Rainfall is a source of many chemical compounds that are put in the atmosphere by natural processes and by man-made activities that release waste products into the air from internal combustion exhaust, stack emissions from manufacturing processes and dust from construction and excavation. Two nutrients necessary for growth of plankton at the base of the food chain that are supplied from the atmosphere are nitrogen and phosphorus. The path of the storm has a strong influence on the concentration of nutrients in the rainfall (USGS, 1994). Data collected in Truro (USGS, 1995) during 1983 through 1985 included 54 samples for dissolved inorganic nitrogen and 39 samples for inorganic phosphorus. The annual loading over the 2 year period averaged 337.4 milligrams per meter square for dissolved inorganic nitrogen and 2.89 milligrams per meter square for orthophosphate. Given the size of Seth's Pond (11.4 acres), the annual loading for inorganic nitrogen is 15.6 kilograms and 0.13 kilograms of phosphorus.

Nixon (1995) sited a study in Narragansett Bay which measured the deposition of total phosphorus from the atmosphere at 390 micro-moles (12.1 milligrams) per meter square per year. The difference may be accounted for by filtration at the Truro site through a 0.4 micron filter prior to analyses (therefore it does not include particulate phosphorus). If this higher loading rate is used, the annual phosphorus deposition is 0.56 kilograms.

Background Orthophosphate Content in the Groundwater:

Background total phosphorus content in groundwater on the Vineyard was estimated at 0 to 0.09 milligrams per liter (Main, 1986). A survey of private wells found total phosphorus ranging from 0 to 0.08 mg/l (Mass. Div. of water Pollution Control, 1975). The USGS (Open File Report 95-290) indicated background orthophosphate levels at 0.02 mg/l. Mattson and Isaac (1999) used a figure of 0.13 kilograms per hectare of forest land to allow for natural sources. At our recharge rate, this equates to a background of about 0.023 milligrams per liter.

With estimated annual discharge from the Pond's recharge area of 52.45 million gallons, the loading from background phosphorus content is estimated at 3.97 to 17.87 kilograms per year. I believe the most likely loading from this source is toward the low end of this range.

Table 6 summarizes the loading estimates from all three methods discussed above and uses the NPSLAKE and the third method to project a range for the future build out. In both, the assumptions for buildout are the range of dwellings at buildout within the 300 foot zone discussed in the Section titled "Sewage Phosphorus Source" and in the watershed build out figures in Table 4.

Table 6: Range of Phosphorus Loading: In Kilograms/Year

	PRESENT	DAY	FUTURE	PROJECTED
SOURCES	HIGHEST	LOWEST	HIGHEST	LOWEST
Rainfall	0.56	0.13	0.56	0.13
Sewage	8.24	3.86	31.82	9.03
Runoff	0.6	0.3	0.6	0.3
Background	17.87	3.97	17.87	3.97
Model 3 TOTAL	**27.3**	**8.3**	**50.9**	**13.4**
Mattson & Isaac Model	***12.8***	***10.3***	***33.5***	***23.5***
Reckhow Model	***20.1***			
Dillon-Rigler Model	***17.5***	***12.4***		

Sediment Source Phosphorus:
The sediment in a pond can be a substantial source of phosphorus release to the water column. This happens through the suspension of phosphorus with sediment disturbed on the bottom, through phosphorus pumping by rooted plants which bring it up into their foliage and release it as the leaves decay and, during times of anoxia, when the chemical barrier to sediment phosphorus dissolving into the water column breaks down. Heavy growth of rooted plants is most often found where the bottom sediments are rich in organic matter. The literature indicates a wide range of amounts of phosphorus from sediment. It is possible that the annual release could equal or exceed the amount delivered from the watershed. Whitman & Howard (Bare Hill Pond, 1987) summarized the range of values cited in the literature as -2.0 to 9.6 milligrams per meter square per day. In re-evaluating their work, DEP deduced that sediment recycling at Bare Hill Pond amounted to 0.72 milligrams per meter square per day. At a similar rate, the sediment in Seth's Pond would release 12.1 kilograms into the water column per year. If 12 kilograms are added to the models that do not include sediment source phosphorus (Mattson & Isaac and third model) there is closer agreement between these models low estimates and Reckhow's model which includes sediment source.

During the time when the bottom 1 to 1.5 meters of the water column became nearly anoxic, total phosphorus (TP) in the deeper sample station doubled from 0.034 mg/l (27 August) to 0.066 mg/l (10 September). The volume of water containing this "excess" TP is approximately 150000 square feet by 1 meter thick or about 14000 cubic meters. The addition of 0.032 milligrams per liter to this volume is equivalent to the addition of about

0.5 kilograms. Some of the TP would be from the decay of the foliage of the rooted plants but some might be from chemical release from the bottom sediments. An annual sediment load of between 5 and 10 kilograms is probably in the right range.

Nitrogen Loading:

Attached Table 4, breaks down all sources of nitrogen.

Nitrogen is a naturally occurring gas in the atmosphere comprising some 78 percent of the air we breathe. However, as a gas, it is not soluble in water. It reaches water resources by conversion in the atmosphere to nitrate by lightning, by conversion from the air by nitrogen fixing bacteria and, once it is in vegetation, by way of the food chain waste cycle or by burning fossil fuels. Once it is converted from nitrogen to nitrate or ammonium, it is very soluble and can move freely through the groundwater.

This means there are natural as well as man made sources of nitrogen which are soluble and can reach surface water resources. The sources which we have some control over include:

- fertilizers
- acid rain
- sewage effluent
- road runoff

Acid rain is a national level issue over which we, at the local level, can only exert influence by the legislative process. This leaves sewage, runoff and both farm and landscape fertilizer application as the main focus of any effort to reduce the loading to our ponds. In the sections which follow, loading from acid rain, sewage, runoff and from fertilizers are estimated to assemble a nitrogen loading estimate at buildout within the watershed. This figure is then compared with the measured nitrogen content of the Pond to determine the replacement rate for nitrogen in the system.

<u>Rainfall as a Source of Nitrogen Loading</u>

Acid rain is a source of nitrogen to the recharge area and also to the Pond by direct precipitation on its surface. There is no high quality acid rain data available for the Vineyard specifically so, we rely on the quality of rainfall being a regional phenomenon. The variables which are not calibrated for the Town but rather for the region include: the volume of recharge and the amount of nitrogen in the recharge.

Precipitation and Recharge:

The average annual precipitation as recorded in Edgartown was 46.94 inches from 1951 to 1998 (New England Climatic Service- Climatological Summary). The portion of this rainfall reaching the water table is not precisely known but estimations made for the vicinity are listed in Table 7 below.

Table 7: Annual Recharge in Inches

Source	Location	Recharge
USGS, 1980	Vineyard	22.2
Leblanc, et al '86	Cape Cod west	22.2
Leblanc et al '86	Cape Cod east	18
Delaney et al '72	Truro	18.3
Leblanc 1982	Otis AFB	21
C. C.Comm '92	Falmouth	21

Using a figure of 22.2 inches of recharge per year in the Seth's Pond watershed (87 acre recharge area) yields an annual average recharge of just over 7 million cubic feet or 52.4 million gallons. This figure should approximate the annual discharge from the groundwater into the Pond. Of 5559 groundwater samples analyzed by the Barnstable County Laboratory, twenty five percent contained less than 0.05 milligrams per liter of nitrate nitrogen (Horsley et al, 1991). Many of the low concentration nitrate samples came from wells in undeveloped areas. This suggested that the rainfall nitrogen content was converted to nitrate by the vegetative growth and decline cycle and that this figure is the natural background level. Given the small watershed and the probable dilute concentration in recharging rain water, this source will be dwarfed by the direct rain fall on the pond surface. The estimated annual loading from recharge at a nitrogen concentration of 0.05 mg/l is about 21.8 pounds (9.9 kilograms).

Road runoff discharges from Lambert's Cove Road to the pond. The volume and contributory sources are described in Appendix B and C. The minimum nitrogen content of road runoff should be the concentration found in the rainfall itself. In addition, particulate sources from organic road debris are likely to add to the total nitrogen content. In the August 14 runoff event, a sample of the water entering the infiltration swale contained 0.34 mg/l of inorganic nitrogen and 0.74 mg/l of total nitrogen. The October event carried 2.7 mg/l of total nitrogen. The estimated 4850 cubic feet of runoff generated by a 1 inch rain would carry from 0.1 kilograms (August loading) to 0.37 kilograms (October event) of nitrogen. Given that some of the runoff would be discharged off the road and its nitrogen removed in the vegetation, the analysis of this event indicates a relatively small nitrogen addition. A total estimate of 12 to 24 inches of runoff each year yields an annual loading range of 1.2 to 8.9 kilograms of nitrogen.

On October 1, a second rainfall runoff event was sampled. Data is reported in Table 5 and in Appendix D. The sample of interest is that collected from the small runoff stream running across the marsh after bypassing the swale. The annual nitrogen loading to the system from the runoff bypassing the swale with this amount of nitrogen is estimated from 4.4 to 7.4 kilograms (as total nitrogen) depending on the quantity of runoff that annually bypasses the swale.

Nitrogen Content of Precipitation:
Acid rain contains nitrogen as inorganic and organic compounds in both dissolved form and as particulates. Rain falling directly on the Pond introduces all of its nitrogen into the nutrient cycle. Estimates of nitrogen concentration in rainfall vary widely as summarized in Table 8.

Table 8: Nitrogen Content of Rain in Milligrams/Liter

Reference	Location	Form	Loading
Gay &Melching '95	Mass	DIN	0.27
Risley et al '94	Quabbin	DIN	0.4
IEP 1987	Yarmouth	TN	0.74
Flipse et al 1984	Long Island	TN	0.87
Loehr, 1974	Lit. Review	TN	0.73 to 1.27
Howes et al 1995	Nantucket	DIN	0.46
Buttermilk Bay 1991	Wareham	DIN	0.3

Paerl (1993) discussed the importance of atmospheric nitrogen deposition to coastal eutrophication and estimated this source of nitrogen at 10 to 50 percent of the annual external nitrogen load. He reported a range of annual deposition for the eastern U. S. from North Carolina up to Maine at 25 to 37 millimoles per square meter per year. These rates amount to direct deposits on an 11.4 acre pond of 16 to 24 kilograms per year.

Nixon et al (1995) cited a study which found annual nitrogen deposition into Narragansett Bay averaging 91 millimoles/m^2/year and ranging from 73 to 110. Using his lower end figures we get an annual deposition of 47 kilograms per year on the pond. To all of these figures we must add in the "background" nitrogen level in the groundwater which derives from the natural soil-vegetation release cycle which is estimated as 9.9 kilos.

Selected Rainfall Loading:
With an annual rainfall of 46.94 inches and using a figure of 0.74 mg/l in rain falling directly on the ponds, the total annual direct nitrogen loads are as in Table 4. If the recharging rain or natural cycle release load is added, the totals increase. The figures used are near Nixon's estimates, Paerl's figure and many of the references cited in Table 8 above. The higher figure being a more conservative one was selected for the final nitrogen loading estimates. The loading from rain is 39.9 kilograms and background levels in recharge add another 9.9 kilograms for a total of 49.8 kilograms (109.8 pounds). See Table 4.

Projected Nitrogen from On-Lot Wastewater:
Nitrogen is the most mobile nutrient that is expected to be introduced from the recharge area development. A literature review indicates that nitrogen concentration in raw sewage ranges from 20 to 100 mg/l (milligrams per liter). In a properly functioning system, 30 to 60 percent of this nitrogen is removed (Andreoli et al, 1979). Table 9, modified from The Buttermilk Bay Project (Horsley, Witten, Hegemann, Inc. 1991) indicates the range of nitrogen concentrations in the leaching area or in the groundwater immediately below the leach area.

Table 9: Total Nitrogen Concentrations in Leaching Field Effluent **mg/l milligrams/liter**

SOURCE	Concentration mg/l	SOURCE	mg/l
Bouma et al 1972	30	Ellis 1982	34
Walker et al 1973	40	Canter &Knox 1986	40
Dudley & Stevenson'73	14	Nelson et al 1988	34
Magdoff 1974	31	Andreoli et al 1979	38.2
Magdoff 1974	41	SuffolkCty.Health '83	34.7
Reneau 1977	23	Weiskel&Howes'92	36.9
Brown & Assoc. 1980	37	**Average**	**33.4**

Kroeger (1998) estimated that 66 percent of the nitrogen in wastewater was removed by the septic system, the soils and while in transit to Green Pond, Cape Cod. This estimate was based on groundwater sampling compared to loading estimates within the recharge areas. Applied to our range of 20 to 100 milligrams per liter in the original wastewater, we arrive at a range of 7 to 34 milligrams per liter for the pond loading calculation.

Flow through a fringing marsh such as occurs around a portion of the shore of Seth's Pond may be a major sink (removal) for nitrogen in groundwater. Portnoy et al (1998) found that this potential was circumvented by high velocity seeps which carried a large portion of the total groundwater seepage. Without documentation by thermal infrared aerial survey to determine where the groundwater seeps are in the pond, a conservative approach is suggested. In addition, the presence of fringing marshes around the pond is highly variable. Because of this variability and the potential for nitrogen in groundwater to bypass the marsh sediment as seeps, no removal of wastewater and fertilizer nitrogen by wetlands is assumed to occur.

The Buttermilk Bay Project selected a value of 40 mg/l as a conservative yet defensible value. For our calculations, I have selected a value of 35 mg/l as the nitrogen concentration in wastewater effluent reaching the groundwater from septic systems. This figure is intended to characterize the wastewater after any plant uptake in the leaching field and evaporative losses occur. The volume of wastewater in which this concentration of nitrogen is found determines the total load going to the system on an annual basis. We have selected a daily per capita water use of 60 gallons and a 20 percent evaporation loss figure to arrive at 48 gallons (181.7 liters) per capita per day discharging from the septic leaching system. Evaporation actually acts to concentrate the nitrogen in the remaining liquid effluent so the assumed effluent concentration leaving the leaching pipe is lower than 35 mg/l.

This assumption of 35 milligrams per liter and 48 gallons per person per day yields an annual per person nitrogen release that is very close to 2.27 kilograms per person per year. This figure is at the low end of a range of estimates that extends up to 4.24 kilograms (EPA, 1997). This figure provides a per capita nitrogen load estimate from the on lot sewage source that is toward the low end of the range of figures used. Combining the growth and watershed population figures with these sewage nitrogen concentrations yields a range of nitrogen loading from sewage from 454 kilograms

(1001 pounds) to 327 kilograms (721 pounds). See Table 4. Focus population range is assumed to be 70 people for the lower projection and 110 for the higher estimate.

Nitrogen from Lawn Fertilization Practices:
Standard recommendations for lawn fertilizer are 3 pounds (1.36 kilos) of actual nitrogen per 1000 square feet per year. Standard assumptions for nitrogen loading use 6500 square feet of lawn area per lot to estimate nitrogen from this source. Horsley et al (1991) reviewed the literature on nitrogen fertilizer lost via leaching from turf and reported a range from zero to 81 percent of the applied nitrogen. They selected a loss rate of 30 percent for the Buttermilk Bay Project. The actual amount leached depends on the type of fertilizer used (quick release versus timed release), the quantity applied and the irrigation practices or rainfall events that occur after the fertilizer is applied. A leaching loss rate of 25 percent was selected as a conservative figure for this study.

In Edgartown, a total of 34 lawns were examined on lots situated away from the shore. Lawn condition and expected fertilizer application breakdown for these lawns is detailed in Table 10. Average lawn size surveyed was only 2700 square feet. These application rate figures are used to estimate the lowest expected input from turf in the watershed of the pond.

TABLE 10: LAWN SIZE & PROBABLE FERTILIZER APPLICATION RATES—*As in Edgartown Great Pond Watershed*

CONDITION	#/1000 sq. ft.	%	Kg. of N applied/yr.
Good	3	8.8	1.36
Ave. +	5	14.7	0.91
Ave.	6	17.6	0.45
Poor	13	38.2	0
None	7	20.6	0

A similar examination of the lawns in the Chilmark Pond watershed was made using aerial photography both black and white and infrared. Of 145 lots examined in the Chilmark Pond watershed, 46 or 32 percent showed signs of being fertilized at regular intervals. The maintained area found for the fertilized lawns was substantially larger than found in Edgartown, averaging 16000 square feet. Lawns of this size and estimated condition are expected to receive 2 pounds (about 0.9 kilograms) of nitrogen per 1000 square feet or 32 pounds total for the average lawn. Another 43 or 30 percent of the Chilmark lawns, appeared to receive irregular fertilization. These lawn areas average nearly 22000 square feet.

For the lawn loading calculations, I have assumed that all lots have lawns which average 5000 square feet in area and are fertilized at about half the recommended agronomic rate of 3 pounds of nitrogen per 1000 square feet. Of the applied nitrogen fertilizer, 25 percent is assumed to reach the groundwater. The total projected nitrogen loading from lawn fertilization practices is projected to range from 30.6 kilograms (67.5 pounds) to 24.7 kilograms (54.4 pounds).

Table 11: Range of Nitrogen Loading: In Kilograms/Year

	PRESENT	DAY	FUTURE	PROJECTED
SOURCES	HIGHEST	LOWEST	HIGHEST	LOWEST
Rainfall	39.9	24	39.9	24
Sewage	283*	130	454	327
Lawn	24.8	18.7	30.6	24.7
Runoff	8.9	1.2	8.9	1.2
Background	9.9	9.9	9.9	9.9
TOTAL	**366.5**	**183.8**	**543.3**	**386.8**

*** assumes all residences are in use year round and Focus is occupied by an average of 70 people for the year**

The Present Day estimates assume that the existing dwellings that are within the watershed today are adding nitrogen to the pond regardless of how long they have been in existence. In reality, at a flow rate of about 300 to 400 feet per year, sewage discharged at the furthest parts of the watershed would require 3 to 4 years to reach the pond. Similarly, the Future Projected loads assume an equilibrium nitrogen discharge.

Nutrient Budget Discussion:

The focus of a nutrient management plan for Seth's Pond should be on phosphorus as it is more easily addressed than nitrogen. This is a result of both it's retention in the watershed if properly managed and the lack of a significant source from acid rainfall. In terms of its concentration relative to nitrogen, it is the nutrient which limits the growth of phytoplankton in the system.

The current range of phosphorus loading from the watershed extends from a low of 8 up to 28 kilograms per year (see Table 6). The middle range, from 12.8 to 20.1 kilograms is the most likely loading. If the sediment source is on the order of 5 to 10 kilograms, the total from all sources is 18 to 30 kilograms. The Reckhow formula supports 20.1 kilograms per year. The Dillon-Rigler model indicates from 12.4 to 17.5 kilograms per year. However, the output from both of these models is based on only one season of study where TP averaged 0.026 milligrams per liter. The total mass of phosphorus in the water column (107.55 million liters) is about 2.8 kilograms on average during the summer. At the estimated rate of input, there are approximately 5 to13 turnovers of the phosphorus in the water column added each year based on the estimated annual load. The phosphorus "lost" is added to the sediment at the pond bottom from where it can be added back into the system under the right conditions.

The range of present day nitrogen loading is from 184 to 367 kilograms per year. The ratio of the nitrogen to phosphorus loading ranges from 10 to 20. The ratio of total N to total P in the pond averaged 16 to 40 over the course of the summer 2001. The average content of total nitrogen in the water column was 0.8 milligrams per liter over the course of the study. This indicates a total water column mass of nitrogen of 86 kilograms. At the estimated rate of input, there are 2 to 4 turnovers of the nitrogen in the water column added annually by the load. Some is incorporated in the sediment while the soluble fraction may exit the system with groundwater seepage leaving the pond.

When the Trophic State Indices (TSI) are compared for chlorophyll, phosphorus and Secchi extinction depth, during the July and August study, the TSI for chlorophyll are smaller than either the phosphorus or the Secchi depth. This implies situations where phosphorus may not be limiting chlorophyll. However, over the same time period, the chlorophyll TSI is also less than the nitrogen TSI which implies that nitrogen may not be limiting growth either. Over the entire course of the sampling, the silica to orthophosphate ratios are in excess of 30 indicating that silica is not limiting. It may be that the limiting nutrient during the time of the algae bloom became one of the micronutrients which unfortunately were not tested. Additional field work would be helpful to gain a better understanding of the limiting nutrient.

From the current and projected nutrient loading to the pond, the limiting nutrient will be phosphorus unless anoxic events release excess amounts of phosphorus from the bottom sediment.

Loading Limits:
Desirable limits to loading from watershed sources of phosphorus can be derived from the Carlson TSI formulae to clarify the level of effort to maintain the system as it is or to try to turn back the clock into the mesotrophic state. As the organic sediments present in the pond are a source of phosphorus, any management scheme to lower the TSI into the mesotrophic range will be slow to respond due to internal phosphorus sources which will persist for some time despite reductions in annual loading.

The suggested goal is to maintain the TSI at or below 50 which is the point where mesotrophic conditions begin to be replaced by eutrophic conditions. To reach this goal, a TP concentration of 0.023 mg/l, a Secchi extinction depth of over 2 meters, a chlorophyll *a* concentration of 7.1 micrograms per liter and a TN of 0.75 mg/l are the other targets. As the Secchi depth and the chlorophyll TSI are at least somewhat derivative from the phosphorus and nitrogen concentrations, a focus on these two nutrients is initially appropriate.

A surface concentration of total phosphorus (TP) of 0.023 milligrams per liter is very close to what was measured on average during the water sampling program this summer. If we utilize the Vollenweider (1975) model, the loading that is predicted to lead to this concentration of phosphorus can be calculated as follows:

$$\mathbf{TP == \frac{L}{10 + ZF}}$$

Where: Z is the mean depth or 2.4 meters
F is the flushing time or 0.48 years or 2.08/year

The formula indicates that the annual load necessary is 0.26 grams/meter^2/ year. When multiplied by the area of the pond (46135 meter^2), the annual loading is 15.9 kilograms.

As this is at the low end of the range of the current estimated annual loading, there may be some potential for the pond to hit this target in other years with different combinations of weather and timing of the onset of the algae bloom. The higher levels seen this year may have been influenced by the release of unusually large amounts of phosphorus during the anoxic event or when the rooted aquatic plants decayed.

The probable total phosphorus content of the water column can be derived from the future loading from the watershed. The Vollenweider (1975) formula is used as follows:

$$\mathbf{TP} == \frac{\mathbf{Load}}{\mathbf{10 + \quad ZF}}$$

Where Z is the mean depth which is 2.4 meters and
F is the number of flushes/year which is 1/0.48

The projected total phosphorus content in the pond water at an annual loading of 23.5 kilograms (Mattson & Isaac model Lower Future Load) from the watershed plus 10 from internal sediment sources would be 0.048 milligrams per liter, an increase of about 80% over what was found during the sampling period and exceeding the suggested target of 0.023 mg/l. The Carlson Trophic State Index (TSI) for this amount of total phosphorus is at the upper end of the range of 50 to 60, further toward the eutrophic end of that range than where the pond was found this past summer (Carlson and Simpson, 1996).

If the flushing rate is slower and closer to the 1.33 years estimate from the April data, the average concentration of phosphorus would increase to about 0.055 mg/l. At a TP concentration of 0.040 mg/l the 4 foot visibility standard for use of the pond as a swimming resources will begin to be compromised on a more regular basis.

At the lower projection loading of 13.4 kilograms per year plus 10 from the sediment, a total phosphorus concentration of 0.034 mg/l is predicted. The TSI would be in the middle of the 50 to 60 range and water quality somewhat like this past summer could be expected. At this loading rate, the 4 foot water column visibility guideline should be met for most of the summer season.

Wetzel (page 291, 1983) references a formula that can be used to identify loading limits based on desired chlorophyll *a* concentration. The formula is:

$$\mathbf{Chl}\boldsymbol{a} == \mathbf{0.55\ [\ (P_i)/(1 + sqrt\ T)^{0.76}]}$$

If we enter 10 micrograms per liter as the desired chlorophyll concentration and use an average residence time, T, of 0.48 years, the phosphorus loading, P_i is 24.2 kilograms per year. This concentration of chlorophyll *a* is just over the goal of a TSI of 50. If 7.5 ug/l is the desired target, then the annual loading required is 14.5 kilograms. The lower target approximates a TSI of 50 but will be very difficult to meet at buildout in the watershed.

Until there is a clearer indication that the algae bloom observed this past year is becoming an annual event, the recommended approach is to implement simple, low cost options to limit the phosphorus load such as the diversion of the runoff from driveways and regular maintenance of the infiltration swale. An attempt to manage the pond to avoid anoxia is also suggested through the suppression of the algae bloom and mixing the water column to maintain oxygen levels.

Increases of nearshore sewage sources should be carefully screened and some consideration given to requiring phosphorus removing systems where a substantial increase in flow will result.

<u>Recommendations</u>:

1. Limit runoff and sediment discharge from driveways sloping to Lambert’s Cove Road by requiring design and construction of diversions, infiltration swales or leaching facilities satisfactory to the Town to cut runoff from these sources to the absolute minimum. These can be simple berms discharging to heavily vegetated roadsides. Despite the fact that runoff is a small source of nutrient loading, it adds other undesirable pollutants and it can be effectively limited at low cost.
2. Maintain existing roadside discharge shoots so they do not clog with sediment, leaves and small branches to the point where they cannot carry a portion of the storm water off Lambert’s Cove Road.
3. At the time the road is to be paved, shape the road to obtain better discharge to roadside grassed swales or infiltration basins to minimize the amount of storm runoff reaching the bottom of the hill. The current discharge to the west side of the road opposite the parking area has potential to accept additional runoff with either the installation of a catch basin and leaching system or a grass infiltration swale. Cost share for such a project (up to 60%) may be available under the DEP 319 program.
4. Maintain the infiltrative capacity of the gravel infiltration swale at the pond edge by periodically removing accumulated silt, organic matter and other fine debris which will limit its infiltrative capacity. An inspection schedule of three times per year is suggested until evidence indicates the appropriate schedule.
5. On properties which have slopes direct to the pond in excess of 7%, require an erosion and sedimentation plan for construction involving soil disturbance. The plan should include periodic inspection and reporting to the Conservation Commission either by a hired consultant or by the Commission’s agent.
6. Educate abutting homeowners about low maintenance landscaping options and encourage them to use minimal amounts of slow release lawn fertilizer.
7. Follow up sampling in the pond during late July, August and September 2002, at the surface and deep sample site at Station 1. Weekly sampling is suggested.
8. Request and support frequent testing by the Retired Senior Volunteer Program of the Pond for pH, alkalinity, aluminum, dissolved oxygen, temperature and Secchi extinction depth.
9. Should the evidence from this testing indicate that the Pond has seasonal low pH and/or elevated aluminum, evaluate the addition of powdered limestone at a rate of 15 grams/cubic meter or 1.75 tons per treatment.
10. Further study including fish population and macro-invertebrate surveys would help to characterize the current condition of the system and develop a base line for future comparisons.

11. Inspect sewage disposal systems that are elevated 10 feet or less above the pond level. Consider dye testing these systems to evaluate their potential impact on the pond.
12. As sewage systems in the vicinity (within 300 feet) of the Pond are to be replaced, they should be upgraded to advanced sewage systems to further reduce the nutrient loading to the Pond. Priority systems are those closest to the Pond as they offer the least opportunity for effluent renovation. Generally systems to the east, west and south of the Pond are in areas where groundwater is highly likely to enter the Pond. Systems to the north are lower priority as groundwater flow may well be flowing away from Seth's Pond. Where possible, substantial increases in sewage flow such as from a guest house should be upgraded to nitrogen and phosphorus removal capability.
13. Installation of any new impervious surface areas, either roads or parking, should be required to remove phosphorus through the use of infiltration systems installed in appropriately prepared soils. Installations within a few hundred feet of the pond shore should infiltrate the runoff into heavily vegetated swales designed to accommodate the flow. In no case should any new installation contribute runoff to Lambert's Cove Road or to an existing driveway that discharges to the Road.

Seth's Pond Management Plan:

Any management plan should be built around a means to respond to evolving conditions that may result from a change in water quality, changes in the watershed or the addition of new uses and demands on the resource. The data accumulated by this project represent a first step in defining an appropriate plan but they are necessarily based on the situation at a particular moment in time which represents a point along a trajectory of changing conditions. For this reason, additional sampling next summer is an important plan recommendation. The plan itself should be adjusted periodically to reflect changes in water quality or demands on the resource. The fundamental goals for the Pond which form the basis of this plan include:

- maintenance of conditions suitable for swimming/skating
- enhancement of fish resources in the system for recreational fishing
- protection of the pond itself as an aesthetic and wildlife habitat resource

Town agencies which have significant interests in the Pond and roles in the plan include:

1. The Conservation Commission which oversees uses within the buffer zone that affect the wetlands.
2. The Park and Recreation which sponsors the summer swimming program.
3. The Board of Health which oversees testing the pond for fecal coliform content to assure safe swimming.
4. The Town DPW which maintains the road, runoff discharge points and the infiltration swale.

WATER RESOURCE QUALITY TARGETS:

The following goals for water quality parameters are suggested to support one or more of the three identified goals:

1. Water column transparency: Maintain Secchi extinction depths in excess of 1 meter throughout the summer. A target of an average of 2 meters during the June through September period should be the ultimate goal. At least 1.3 meters is necessary for swimming.
2. Dissolved oxygen: Maintain dissolved oxygen at or above 75% throughout the upper 2 meters of the water column during the summer. The occurrence of hypoxic or anoxic events should be targeted for elimination.
3. Agal growth: Avoid development of algal scum which cause taste and odor problems.
4. Macrophyte growth: Minimize in-pond vegetation growth into the upper, swimming zone of the pond.
5. Pond pH: Maintain pH above 5.5 units.

ASSOCIATED ECOSYSTEM GOALS:
1. Maintain the population of predator fishes currently in the system which include large mouth bass and pickerel.
2. Increase the population of grazers in the system such as snails.
3. Reduce or eliminate the bull frog population as a way to increase the population of other amphibians.
4. Eradicate invasive plant and animal species as they appear.
5. Limit boat power types to manpower and small electric power motors only.

ASSOCIATED WATERSHED GOALS:
1. Minimize Lambert's Cove road runoff impact on the pond.
2. Maintain current practice of minimal application of landscape fertilizers.
3. Avoid siltation impacts from soil disturbance in the immediate watershed.
4. Minimize future nutrient loading from septic system wastewater.

Implementation Program to Attain Water Resource Quality Targets:
A one time assessment is probably inadequate as a basis for widespread change in current practices. Therefore, the first recommendation is to continue the monitoring project into a second phase. The suggested program is to include at least another 5 sampling rounds in July, August and September of 2002. An on-going summer season monitoring program should be set up with the Retired Senior Volunteer Program's Senior Environment Corps (SEC). This follow-on program would include monthly measurements from surface to bottom at Station 1 for dissolved oxygen, temperature, conductivity and Secchi extinction depth. In addition, samples should be collected for pH and alkalinity analyses either through SEC or the Dukes County Water Testing Lab. The SEC monitoring program is suggested for the years 2003 through 2005. This amount of information should allow a more precise determination of the current water quality state of the system and should be followed by a re-evaluation of the goals outlined as Water Quality Targets.

The water quality goals, particularly 1, 2 and 3, are intimately tied together. They are separated as goals primarily because they represent three discrete measures of pond quality and the success of the management program.

Goal 1: Water Column Transparency

This goal is desirable to maintain the attractiveness of the resource for swimming. Any additional phytoplankton in the water column create discoloration and lack of visibility which have an adverse impact on the swimming experience. Attaining this goal will also positively affect goal 2, dissolved oxygen availability. In addition, it is likely that the onset of the algae bloom initiated the die-off of the rooted plants which played a major role in the anoxia in the deeper water.

To attain this goal, nutrient loading from the watershed should be maintained at the current level or be slightly reduced. The easiest initial steps are to encourage watershed homeowners to limit the application of lawn fertilizer to a single application of slow release nitrogen fertilizer in either spring or fall (see Goal 12). In addition, the runoff control program described in Goal 11 should be implemented to limit phosphorus and nitrogen additions from that source. Finally, some steps should be taken to assess the need to upgrade septic systems in the watershed (see Goal 14).

A simple bioenhancement which may suppress algae involves the placement of barley straw contained in tube netting in the pond in mid-April at a rate of 225 pounds per surface acre. A total of 1.25 tons (about 45 bales) is necessary. The barley straw apparently releases a chemical that inhibits algae growth as it decays. The chemical is not known to be injurious to rooted aquatic plants, zooplankton, insect larvae or fish. Details are included in Appendix G.

Goal 2: Dissolved Oxygen Saturation

Dissolved oxygen (DO) is crucial to the survival of the organisms that live in the system and are not air breathers. The anoxic event during August fortunately did not include the upper levels of the water column but future blooms, even if only somewhat more severe, could create overnight deficits in DO that will stress even those animals which can move up toward the surface to escape the anoxic zone. It is not yet clear if the anoxia may have been a one-time occurrence that will not recur annually. Anoxia increases the rate of release of nutrients from bottom sediments into the water column where they can increase the algae population even further.

Steps that will reduce this phenomenon in the long term are those outlined in Goals 11, 12 and 14 which address the nutrient input to the pond. A short term reduction in algae as described in Goal 3 will also have positive effects on DO and water column transparency.

Dissolved oxygen shortfalls can be addressed by such aeration systems as Vertex or Otterbine (no endorsement intended). One system diffuses air through a device at the bottom which causes the water column to mix and brings the low oxygen water up to the surface where oxygen is added naturally. The other draws water in and sprays it into the air which both circulates the system and directly adds air in the fountain. The well-oxygenated water column reduces the movement of phosphorus out of bottom sediments and into the water column and, in this way, reduces that stimulus to growth of algae.

Goal 3: Algal Growth

It appears that the growth of algae in the upper portion of the water column started the decline of the rooted plants by shading them which then began a cascade of events culminating in the anoxia found in the lower strata of the pond in August. The nutrient reduction steps outlined in goals 11, 12 and 14 should address this issue.

Other short term measures which suppress the algae include the use of a product such as Aqua Shade which reduces the light availability and thereby decreases the intensity of the algae bloom or placement of barley straw (see Goal 1 above and Appendix G). The aeration equipment described in Goal 2 may also offer some reduction in the algae population. The use of algaecides such as Cutrine Plus (TM- no endorsement intended) are not recommended initially until other options are exhausted and the condition recurs regularly.

Goal 4: Growth of Rooted Plants

The submerged rooted plant currently in the system is a desirable one for both cover and as a food source. Its extent in the pond is generally defined by the 2.5 or 3 meter contour line. The only undesirable aspect is the die off, nutrient build up and anoxia which occurred during the past summer. Limiting the development of algae blooms will probably reduce or eliminate this problem.

Should the plant spread to the point where it interferes with swimming or invades spawning areas, suggested options for removal include harvesting, either mechanical cutting or raking with root removal, bottom screening a portion of the pond or weed rolling. For spawning areas, the first option (harvesting) is the best option as long as it is completed during a time when spawning activity is finished. Each of these options has positive and negative considerations that range from stirring up the bottom (rolling and raking), to cost (mechanical raking) to elimination of part of the benthos population (screening).

Goal 5: Minimize Pond Acidification

This goal may already be attained but additional pH readings across a longer time period are needed to clarify this situation. Acidification may be decreased through support of State and National air pollution control regulations. At the local level, more complete diversion of the Lambert's Cove Road runoff to cause a large portion to infiltrate will gain some buffering from the soil. Should these efforts fail to keep the pond pH above 5.5, it may be manipulated by the addition of finely ground limestone at a rate of 15 grams per cubic meter of pond volume. In Scandinavia, where this method has been used to improve the health of severely acidified lakes, the treatment has been found to persist for about three turnover times—or, in the case of Seth's Pond, about 525 days. At the rate recommended, about 1.75 tons of lime are needed. Two applications at half rate with intervening pH measurements are recommended to effect a gradual rise in pH.

<u>Implementation Program to Attain Associated Ecosystem Goals:</u>

These goals will be more attainable should the Water Resource Quality goals also be attained. Water quality sets the stage for overall enhancement of the ecosystem. Some of these goals will be more easily reached when man's manipulation of the pond environment is limited while others may call for intervention. An adequate biological survey has not been done as it was outside the scope of this project. A survey of benthic invertebrates, insects, fish and amphibians should follow as a next step in assessing the pond.

Goal 6: Maintain Predator Fish Species

As these fishes fall at the top of the aquatic food chain, this goal implies the preservation of the necessary food chain from plankton to insects to small fishes and ultimately to the predator fishes. This builds from the preservation of good water quality levels. A needed first step is an assessment of the fish population and of the availability and quality of spawning habitat for all the fishes both prey and predator.

If the population is below desirable levels, stocking the pond with available species should be evaluated.

Goal 7: Increase the Population of Grazers

A survey of the macro-invertebrates in the system is a desirable first step. Although snails were not observed, a survey of this sort was not part of this project and adequate time was not devoted to clearly establishing the current population. This group is sensitive to pond acidification and will be enhanced by pond pH above 5.5. Until a survey is done, meeting the acidification Goal (5) will aid in attaining this goal.

Goal 8: Balance the Amphibian Population

As with the grazers, a population survey of amphibians was not part of this project but should proceed as a next step. The pond contains a substantial population of bullfrogs which are known to be territorial predators who prey on smaller frogs and tadpoles. At least one green frog was observed but, over the course of the water sampling, over 30 bull frogs were observed. The implication is that the pond amphibian population is dominated by the bullfrogs.

Bullfrogs are not native to the Vineyard but probably escaped from backyard ponds where they were purchased as generic frogs to add to the natural setting. They are forced to leave the waters where they are born by the predation of the adults. They can travel by way of vernal pools and make their way over a considerable distance of otherwise dry upland to reach a new pond to colonize. They are tolerant of warmer water temperatures than other frogs and prefer heavier aquatic vegetation that is found in eutrophic waters.

Typically bullfrogs require one to two years as tadpoles before transforming into juvenile frogs and another two to four years to reach sexual maturity. The frogs observed were relatively small and the bullfrog community may not yet have reached the point where they are a self-reproducing population. Eradication of the bullfrog population is probably possible as they do not appear to be reproducing yet. Such a program would need to address the nearby kettle holes and vernal pools in order to be successful over the longer term. A discussion with an amphibian expert is needed as a first step which should be taken soon. Dr. Scott Jackson, UMass Department of Natural Resources and Environmental Conservation is suggested.

Nurseries selling man-made pond equipment, plants and fish should be contacted to request that they not sell bullfrogs. The general public should be made aware of the potential impact these frogs can have on surrounding natural ponds and should seek out only those amphibians which already occur naturally such as green frogs, spring peepers and leopard frogs.

Goal 9: Eradicate Invasive Plant and Animal Populations

No invasive species of plants were noted over the course of the study. The course of study was limited to the late summer months and may have missed invasives. Other ponds on the Vineyard are either experiencing substantial growth of phragmites (Chilmark Pond, Farm Pond and Crystal Lake) or are in the initial stages of loosestrife invasion (Chilmark and Edgartown Great Ponds). The SEC or other pond watcher group should keep a watchful eye out for non-native or invasive species including emergents such as phragmites and purple loosestrife and submerged plants such as Eurasian milfoil. These plants should be ruthlessly removed.

Seth's Pond is surrounded by a number of small kettle holes and wetlands that conceivably could provide habitat for invasive plants as well as bullfrogs. An eradication effort would necessarily have to address these areas also.

Goal 10: Limit Recreational Boating

The suggestion is to prohibit motor driven boats that use gasoline. The reason for this recommendation is that these motors release hydrocarbons into the water column possibly including some harmful additives or derivatives created during combustion and stir the bottom in shallow areas releasing nutrients and silt into the water column and even may cause shoreline erosion. They are generally incompatible with public swimming areas.

<u>Implementation Program to Attain Associated Watershed Goals:</u>

The problems found in the pond relate closely to activities in the watershed. Some of the goals identified here are easily accomplished others are costly and may be more difficult. The goals that address issues near the pond are the most urgent to address as they have the most immediate impact.

Goal 11: Lambert's Cove Road Runoff

Runoff is a source of nutrients, hydrocarbons, bacteria and silt unless adequately filtered before reaching the pond. The first step suggested is to eliminate driveway runoff throughout the length of Lambert's Cove Road where it slopes to Seth's Pond. This will require some public education to explain that the runoff contains silt and fine sand which fills the roadside chutes and prevents them from removing runoff flowing along Lambert's Cove Road. All contributing driveways should be bermed with diversions to remove runoff into vegetated roadside areas or into infiltration basins before the runoff reaches the Road.

The next necessary step is to maintain the existing infiltration swale along the roadside at the edge of the Pond by periodic removal of silt and the surface layer of gravel sufficiently to eliminate the clogging effect of siltation. With a reduction in runoff from driveways, this feature should better be able to handle the first ½ inch of runoff which carries much of the pollutant load from a given rainfall.

When Lambert's Cove Road is to be paved, a more lasting solution is suggested which includes shaping the road to discharge the runoff to roadside first flush basins. A project of this sort may well be suited to a grant application to State Environmental agency programs. The 319 program administered by DEP offers matching funds up to 60% of the approved project cost.

Goal 12: Minimize Landscape Fertilizer Applications

Current lawn care practices indicate that excessive fertilization is not in use. This should be encouraged by a public education project which promotes minimal turf areas, use of native grasses to vegetate desired open vistas and the use of low maintenance shrubs in the landscape. There are existing landscape firms which offer services and plant materials suited to minimizing landscape impacts.

Goal 13: Eliminate Erosion and Sedimentation from Future Development

The steep slopes which border the south and west margins of the pond could contribute to a situation where eroded sediment reaches the Pond. This results from both the steepness of the slopes (over 15%) and the extent of sloping ground without a break. Where development proposals are within the Conservation Commission jurisdiction, a sedimentation/erosion plan should be required for soil disturbance activities. The plan should address the size of the disturbed area, erosion control techniques to be used and the need for phasing the soil disturbance process. For those projects which are situated on the slope but are outside the Conservation Commission jurisdiction, some process for requiring a plan for projects on slopes over 7% and including soil disturbance in excess of 100 feet at the time a building permit is issued is recommended.

Goal 14: Limit Nutrient Loading from Wastewater Disposal

Wastewater disposal is an important source of nitrogen. The buildout nitrogen load will exceed the current load by 197 to 323 kilograms (434 to 712 pounds). At this time, new wastewater disposal systems in the watershed should not be required to install advanced wastewater systems unless they are within 300 feet of the pond. Expansion of flow due to construction of guest houses should be carefully reviewed to assess the potential for the use of nutrient removal technology.

An inspection of low lying septic systems where the grade is less than 10 feet above the pond level and they are near the shore is suggested as the initial program. Dye testing some of these systems with rhodamine dye and the use of a fluorometer to detect break out in the pond system may also be necessary to evaluate which systems are draining into the pond.

If failed septic systems are identified by this methodology, those within 300 feet of the pond shore should be upgraded to advanced wastewater treatment systems. This will add somewhere between 7 and 10 thousand dollars to the cost of a new system. Some of these systems will also remove up to 70% of the total phosphorus in the effluent (information from Waterloo Biofilter—no endorsement intended). Phosphorus removal is more critical for systems within a few hundred feet of the pond shore. Funding assistance may be available through the Community Septic Management Loan Program.

Placement of observation wells along the shore may also offer a means to assess the impact of sewage disposal systems on the pond. Ideally they would be placed in pairs with the shallow well at the water table and the deeper well 5 to 10 feet deeper. It may be difficult to drive the wells in the ground due to presence of boulders and large cobbles. Analyses of residential drinking water wells may allow the assessment to expand its scope. Observation wells will allow an estimate of the nutrient level entering the pond system only if they intersect a representative portion of the groundwater moving into the pond.

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GLOSSARY OF TERMS USED

mg/l is a concentration of milligrams per liter which is equivalent to parts per million
ug/l is a concentration of micrograms per liter which is equivalent to parts per billion.
c.f. is a volume of 1 **cubic foot** which is equal to 7.48 gallons.
"TSI" Trophic State Indices an indicator of the level of production of plant biomass in a pond. The indices relate to the states of eutrophy, mesotrophy and oligotrophy.

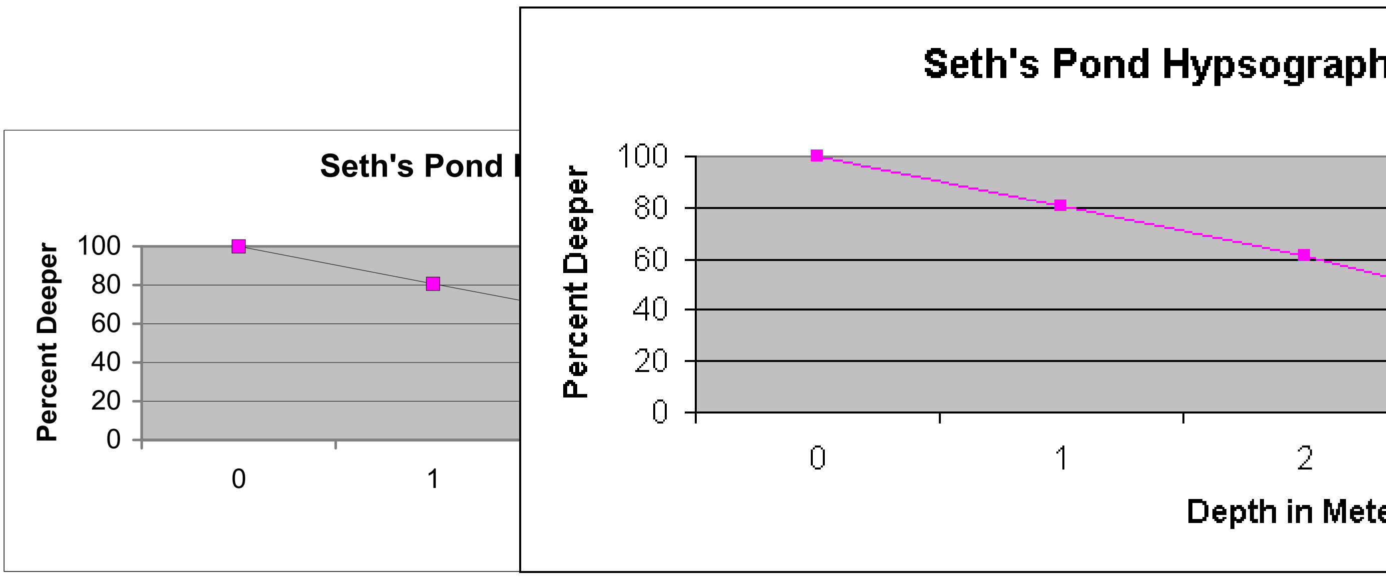
"Eutrophic" means a trophic status characterized by moderately high algal productivity, more serious oxygen depletion in the bottom waters, some recreational use impairment, summer chlorophyll **a** concentration greater than 10 micrograms/liter, a summer Secchi depth of <2 meters, and a winter total phosphorus concentration greater than 20 micrograms/liter.
"hectare" a metric measure of area which is equal to 2.471 acres.
"Hypereutrophic" means a trophic status characterized by high algal productivity, intense algal blooms, fish kills due to oxygen depletion in the bottom waters, frequent recreational use impairment, summer chlorophyll **a** concentration greater than 10 micrograms/liter, a summer Secchi depth generally less than 2 meters, and a winter total phosphorus concentrations greater than 30 micrograms/liter.
"Mesotrophic" means a trophic status characterized by moderate algal productivity, oxygen depletion in the bottom waters, usually no recreational use impairment, summer chlorophyll **a** concentration averaging 4-10 micrograms/liter, a summer Secchi depth of 2-5 meters, and a winter total phosphorus concentrations ranging from 10-20 micrograms/liter.
"Oligotrophic" means a trophic status characterized by low algal productivity, algal blooms are rare, water clarity is high, all recreational uses unimpaired, summer chlorophyll *a* concentration average less than 4 micrograms/liter, a summer Secchi depth greater than 5 meters, and a winter total phosphorus concentrations ranging from 0-10 micrograms/liter.
"Phosphorus" means elemental phosphorus and for the purposes of this rule shall be measured as total phosphorus.
"Phosphorus Concentration" means the mass of phosphorus per liquid volume.
"Phosphorus Loading" means the total mass of phosphorus per time basis.
"Phytoplankton" microscopic plants at the base of a pond's food chain.
"Secchi Disk" is a 8 to 12 inch diameter disk with black and white quadrants which is lowered over the side of a boat until it cannot be seen. This depth is called the extinction depth and indicates how much light is penetrating and if rooted plants and phytoplankton at the bottom are getting enough light to grow.
"Total Phosphorus" means the phosphorus concentration as determined by a state certified analytical laboratory using EPA 365.3 or SM 4500-P-B,E or an equivalent method.
"Trophic State Index" means a classification system which uses algal biomass as the basis for classification which can be independently measured by chlorophyll **a**, Secchi depth, and total phosphorus concentration.
"Trophic Status" means a classification which defines lake quality by the degree of biological productivity.

Appendix A

Seth's Pond Physical Data

SETH'S POND BATHYMETRY
June 2001

Contour INT. Meters	Depth Avg. Feet	Thickness of Interval	AREA Sq. Feet*10^3		Volume 10^6 A*AvgD MHW	Vol. seg. #1 Ft 10^3	Volum Seg #2 Feet ^
0 to 1	1.64	3.28	498.188	0	**NA**	984.372	
1 to 2	4.92	3.28	402.152	3.28		775.31	
2 to 3	8.2	3.28	306.973	6.56		537.649	
3 to 4	11.48	3.28	184.779	9.84		249.369	
Over 4	14.27	2.3	43.302	13.12		16.5991	
			1435.39	14.27		2563.3	



APPENDIX B

WATER BUDGET

<u>Seth's Pond Water Budget</u>: Calculations

Over the time of the study there are two discrete time periods for which we have data on the amount of water in the system and can develop estimates of the inputs to and outputs from the system. In addition, we can estimate the budget from an annual perspective. From these figures, estimates of residence time can be developed. The formula used to view the water budget and from which groundwater outflows are calculated for all time periods is:

Pond Net Rise = GW_{IN} + RAIN +RUNOFF - (GW_{OUT} + EVAPORATION)

Or adjusting terms in the equation:

GW_{IN}- GW_{OUT} == Pond Net Rise - RAIN - RUNOFF + EVAPORATION

<u>March/April 2001 Water Budget:</u>

Total increase in pond height:	**1.5 feet (see pond level chart)**
Time period:	**33 days**
Area of Pond during this period:	**492777 feet^2 (11.3 acres)**
Net volume added:	**739166 feet^3**

Direct rain March 21 through April 23 (Edgartown) == 8.19 inches or + 336320 feet^3

Lambert's Cove Road Runoff for rain events over ½ inch with 90% assumed to reach pond: 6.91 inches over 49962 feet^2 +25893 feet^3

Driveways for more severe rain totaling 6.43 inches +5761 feet^3

Upland runoff:

Area of 606000 feet^2 15 to 35% slopes for rain over 1" total with 15% of total reaching pond == +44000 feet^3

Area of 83000 feet^2 of heavier soil on 0 to 3% slopes for rain over 1" with 15% reaching the pond == +5996 feet^3

Evaporation for April @ 2.5 inches plus 10% for added three days == 2.75" -112928 feet^3

Net groundwater input == 739166 feet^3 + 112928 feet^3 - 336320 feet^3 - 25893 feet^3 - 5761 feet^3 - 44000 feet^3 - 5996 feet^3 == 434124 feet^3 over 33 days == 13155 feet^3/ day

Net recharge for April estimated at 9% of annual (Gaines, 1995)

Recharge == 1.85 feet over 3.7897 X10^6 feet^2 == 7.011 X10^6 feet^3

April @ $\frac{0.09 \text{ X } 7.011 \text{ X}10^6 \text{ feet}^3}{30 \text{ days}}$ == 21000 feet^3/ day

Groundwater seepage loss == Gw_{in} - Gw_{net} == 21000 -13155 == <u>7845 feet^3/ day</u>

<u>April Data Discussion:</u>

The seepage loss term is considerably smaller than is calculated either on an annual estimate or from the August to December data as discussed below. Possible corrections to the assumptions made above that would increase the Seepage term include:

1. Groundwater input is underestimated. If the groundwater discharge to a small watershed with some low permeability soils such as Seth's Pond was more strongly seasonal and the other terms remained the same, the Seepage loss would be larger to maintain the net increase of 13155 feet^3/ day. It is possible that instead of 9% of the annual groundwater discharge occurring in April, 12% or even 15% might be a more accurate estimate.
2. Runoff Term is a larger number. In Figure 4, it is apparent that the pond response to the rainfall recorded on 21 March and again on 29 March is greater than the quantity of rain would call for. For example, on 21 March 0.159 feet of rain was recorded at 7:30 a.m. on 22 March. The pond rise from 14:00 on 21 March to 14:00 on 22 March is from 1.04 feet to 1.42 feet. So, the pond response is 0.22 feet more than the actual rainfall. Over an 11.4 acre pond, this is an additional 109250 cubic feet. For example, if the runoff term were increased from 81650 to 109000 cubic feet, the Net groundwater input would decrease to 12326 cubic feet. If the groundwater Input were 21000 cubic feet per day, the seepage loss term would be 8674 cubic feet.

Some combination of 1 and 2 could lead to the April Seepage loss term moving considerably closer to the August-December term.

August 20 through December 3:

During the period from August 20 to December 3 (105 days), the pond level was measured relative to the top of the end post of the chain link fence along the south edge of the public access. While not as accurate or continuous as the recording gauge, these figures give good approximation of the loss of pond water from the system over this time period. These measurements can be converted to volume changes and, when combined with rainfall records, estimates of evaporation and runoff, can provide an estimate of groundwater flux. The dates and the measurements made are as follows:

Date	Pond Level in Feet
3 Dec.	5.333
15 Nov.	5.167
24 Sept.	4.25
10 Sept.	4.083
20 Aug.	3.667

The drop in pond level over this period was 1.667 feet. The area of the pond at the start of this period and at the end was estimated based on a perimeter and area measurement of the pond with GPS made on 1 June when the pond level was 3.5 feet below the post. The area at that time was 498157 square feet. An adjustment between the measured area on 1 June and 20 August was based on the change in area in response to the slight change in pond level over the period from 1 April to 1 June when the area was measured at 492777 square feet and the pond was 4.308 feet below the post.

The estimated change in area of the pond calculated in this way was a decrease of 11093 square feet between 20 August and 3 December. The area of the pond decreased from about 497048 to 485955 square feet. The pond level dropped 1.667 feet between these two dates. The volume change was estimated by the formula:

$$\text{Volume} = h/3\ (A_1 + A_2 + \text{SQRT}A_1 * A_2)$$

The volume exiting the system from all losses was 819316 cubic feet in excess of the inputs during this time. The average daily net loss is 7803 cubic feet.

The rainfall record over that period was approximately 5.94 inches or 0.495 feet while normal rainfall over this period would be over 13 inches. The rain figure is based primarily on the TTOR rain gauge at Long Point. Evaporation over the same period under normal rainfall is estimated at 9.4 inches or 0.783 feet (Visher, 1966). As the rainfall during the time period was about one half the normal 13.34 inches, the evaporative losses would have been greater perhaps as much as double the typical. An evaporative loss of 1.5 times normal or 1.17 feet is used for this estimate. Net runoff from the roadways using only rainfall over 0.75 inches was 3 inches which adds 13930 cubic feet to the system. Runoff from surrounding sloping ground is estimated at 23000 cubic feet using the same restrictions described for the March-April period..

Groundwater inflow is based on the 3.79 million square feet in the watershed recharging 1.85 feet of water to the aquifer each year (USGS 1980). Gaines (1995) estimated that, during the time frame under consideration, about 25% of the annual discharge to a coastal pond would occur. This amounts to about 16700 cubic feet per day.

Sources	**Additive c.f.**	**Negative c.f.**
Groundwater IN	1750000	
Rainfall direct	243290	
Runoff roads & upland	36930	
Evaporation		~570000
Groundwater OUT		?????
TOTAL	2030220	

The positive inputs that would add to the pond level total 2030220 cubic feet while the negative effect of evaporative loss is approximately 570000 cubic feet. The net loss of pond volume attributable to groundwater outflow is the difference between the Inputs and Outflows (1460220 cubic feet) plus the drop in pond volume over the 105 days (819316 cubic feet) or 21700 cubic feet per day.

Annual Water Budget: **Assumes an equilibrium over time but in actuality the budget swings from times of excess inputs when the pond stands higher and times when outputs exceed inputs and the pond stands at lower levels. This calculation provides a check on the results from the previous fixed period calculations.**

INPUTS:

Average Annual rainfall == 46.94" == 3.91' applied to area of Seth's Pond
11.4 acres X 3.91' = 1.942 X 10^6 cubic feet

Runoff:
Lambert's Cove Road == 49962 feet^2
Driveways:
Dirt == 11216 feet^2
Paved == 7137 feet^2
Sloping Upland:
>15% slopes == 606000 feet^2
0 to 3% slopes == 83600 feet^2

Days with > 1' rain == 10 on average range is 4 to 17
Days with thunder storms == 20 may generate > 0.5 inch/hour rate

Annual Estimated Runoff (see Notes below):
Net Runoff Roads = 24" X 4850 cubic feet/inch == 116400 cubic feet
Net Runoff From 1" or greater storms:
(1.33')* (689600 X 10^6 square feet) * (0.15) == 138000 cubic feet

Groundwater:
Basin size is 87 acres or 3.79 X 10^6 square feet
Annual recharge is 1.85 feet or 7.011 X 10^6 cubic feet

ANNUAL TOTAL: 9.207 X 10^6 cubic feet

OUTPUTS:

Evaporation: **25 inches X 11.4 acres == 1.035 X 10^6 cubic feet**

Groundwater seepage loss:
== (9.207 X 10^6 cubic feet) - (1.035 X 10^6 cubic feet) == 8.172 X 10^6 cubic feet
== 22400 cubic feet per day for steady state water level

Note on Estimation of Precipitation Yielding Runoff: The weather data for 1997 through 1999 were examined as reported by the National Weather Service for Edgartown.

1999: The year as a whole was drier than normal with a total of 40.5 inches of rain. There were 11 rainfall records exceeding 1 inch with the total being 16.6 inches of precipitation. There were 17 rain days exceeding 0.5 inches with the total rain volume in these events totaling 12.7 inches.

1998: The year was slightly wetter than normal with 47.54 inches of precipitation. There were 14 storms with more than 1" with the total precipitation delivered in these storms of 18.15 inches. There were 28 storms that exceeded 0.5 inches with the precipitation total being 19.85 inches.

1997: The year was wetter than normal with total precipitation being 49.11 inches. There were 15 storms exceeding 1" with a total of 22.98 inches of precipitation from them. There were only 11 storms that dropped over 0.5 inches with the total precipitation being 7.31 inches.

The average annual precipitation for these three years that dropped in storms delivering over 1 inch total was 19.24 inches. On average there were 13 storms of this magnitude. The average annual precipitation from storms exceeding 0.5 inches was 13.29 inches dropped in 18 storms.

If the first 0.25 inches were diverted from the roads, retained or infiltrated, the runoff total would be 16 inches from the precipitation events exceeding 1" and 8.8 inches from the ½ inch rainfall events. Total runoff would be 24.8 inches.

Estimated Residence or Flushing Times:

The residence time is the length of time on average that a particle of water entering the system spends in the pond before it exits. The assumption is that the residence time of water entering the system and carrying dissolved nutrients such as nitrogen is relevant to the length of time that these nutrients are available to be taken up by aquatic plants and phytoplankton to build new tissue and organisms. For less soluble nutrients like phosphorus, the flushing time derived from the water budget is less relevant and the time for settling to the bottom of the pond of phosphorus as organic debris is a more important consideration. In this way, the tolerance of the system to nutrient loading can be estimated. For Seth's Pond, the only loss of water from the system is by groundwater seepage or by evaporation. There are no stream outlets.

$$\textbf{April Residence time} == \frac{\textbf{Pond Volume}}{Gw_{out}} == \frac{3798000 \text{ feet}^3}{7845 \text{ feet}^3/\text{day}} == \textbf{484 days}$$

$$\textbf{Fall Residence time} == \frac{\textbf{Pond Volume}}{Gw_{out}} == \frac{3798000 \text{ feet}^3}{21700} == \textbf{175 days}$$

The considerable difference in groundwater outflows estimated during the two time periods studied implies that some of our assumed terms are probably in error over the shorter time frames considered. It may well be that during wet times such as the March-April period, groundwater discharge rates from the nearby portions of the watershed result in a larger daily input than is estimated based on the entire year. I believe that the actual residence time is probably closer to that calculated for the August-December period which agrees closely with the year-long estimate.

Appendix C

Watershed Runoff Calculations

Approximate Capacity of the Gravel Infiltration Swale:

Swale Holding Capacity
Swale maximum depth 3 to 4 inches
Swale holding capacity @ 3 inches == 60' X 6' X 3/12' == 90 cubic feet
Swale holding capacity @ 4 inches == 60' X 6' X 4/12' == 120 cubic feet

Infiltration rate
At 1 inch/minute== 60'X6'X1/12' X 60 minutes/hour == 1800 cubic feet/hour

At ½ inch/minute == 60'X6'X0.5/12' X 60 minutes/hour == 900 cubic feet/hour

Approximate Runoff Generation:
See Road runoff calculation table for estimate of runoff generation for 1 inch storm (4850 cubic feet). Days with 1 inch or more rainfall average 10 each year (Climatological Summary, State Climatologist,1975). There are 20 days with thunderstorms on average which could generate the ½ inch per hour rate which is estimated to exceed the capacity of the infiltration swale. Note: it appears that rainfall less than about ½ inch per hour will mostly be discharged to the vegetation at the roadsides and/or handled by the infiltration swale if the discharge chutes are kept clear. This statement is based on limited observations and should be considered an estimate.

@ ½ inch per hour == 4850/2 cubic feet == 2425 cubic feet - exceeds infiltration rate plus holding capacity

@ ¼ inch per hour ==4850/4 cubic feet == 1213 cubic feet - meets capacity at 1 inch/minute infiltration rate

The tentative conclusion is that at ¼ inch per hour or slightly higher rates, the combination of the roadside discharge chutes and the capacity of the infiltration swale will probably handle the runoff generated. At ½ inch per hour it is highly likely that the swales capacity will be exceeded and runoff will discharge across the marsh and directly into the Pond. The difficult questions that cannot be answered at this point involve persistent rain that doesn't hit the ½ inch per hour rate but exceeds that total over a period of a few hours. Observations on 1 October indicate that 0.86 inches of rain overnight with most coming in the 2 hours before the observation was made did result in runoff bypassing the infiltration swale. The rate was probably less than ½ inch per hour but the result still was bypassing.

Lambert's Cove Road/Seth's Pond Runoff Report: 8/14/01

At 8 a.m. 0.25 inches of rain had fallen over the last 3+/- hours. West Tisbury rain gauge. Previous rain is 0.54 inches collected at 8 a.m. on 8/13/01 plus additional small amounts on previous two days. Soil conditions probably at or near field capacity.

Rain is light but steady throughout the evaluation. Runoff is flowing at edges of road pretty much throughout the 1600 feet of road that runs down to Seth's. Width of rivulet is about 6 to 10 inches and ½ inch deep +/-.

EAST SIDE:

All of flow along east roadside is being successfully diverted into the chutes down to the Focus driveway. Focus drive is 370 paces from gravel infiltration bed. However, noted evidence of sediment deposits (sand) that indicate that, at heavy flow rates, a good deal of the flow is bypassing these outlets. Just South of the diamond shape "Caution Children" sign, all of flow is being carried off the Road by two roadside chutes. North of this discharge point for a distance of 160 paces (430 feet +/-) <u>all</u> runoff goes to the gravel bed infiltration area. The north most of these two discharges has standing water backed up in it with no indication of steady removal of this water. Therefore this discharge is undoubtedly exceeded by anything much heavier than this rate of rainfall. The southern discharge has a sediment wedge that indicates it is probably bypassed somewhat by a heavier rate of flow.

Gravel bed infiltration area had a 3 inch deep puddle approx. 20 feet long and 3 feet wide ponded at the site. Noticeable hydrocarbon sheen at surface. Steady, slow flow coming into the puddle from up hill. Collected a sample here by skimming one inch into puddle.

WEST SIDE:

Approximately 50% of west side runoff <u>above</u> (south) of Focus drive is being successfully carried off the road side at the chutes. Below Focus, very little of the runoff is being removed. Mohu drive showing steady trickle of discolored runoff under these conditions. The last west side discharge chute is clogged with leaf litter and debris and runoff is bypassing it -- not working to its potential to remove water from the road. This discharges into a grassy area where runoff is now ponded and probably would have its holding capacity exceeded by anything more than this rate of rain fall / runoff.

Second sample collected from Seth's Pond in about 12 to 15 inches of water with a plunge and scoop motion. The locus is directly below the infiltration bed. No indication of runoff bypassing the infiltration bed and coming through the vegetation down to this spot.

Runoff Event on 1 October 2001

Scattered light rain had generated very little runoff by 8:30 p.m. on the evening of 30 September. Rainfall increased to steady overnight and by 8 a.m. 0.86 inches of rain had fallen at my rain gauge in West Tisbury. Rain was steady and falling at a moderate rate.

The same general runoff pattern as described for the August event was once again observed with two general exceptions. First, I noted that Lambert’s Cove Road runoff was essentially bypassing the small roadside chutes at this rainfall rate. A good portion was discharging into the grassy roadside area on the west side of the road below Mohu Road. Second, enough rain had fallen and accumulated in the gravel infiltration bed that the puddle extended out into the Road and runoff from the south was bypassing the gravel bed and flowing further north within the puddle. At the low spot there, runoff flowing south met the runoff flowing north and flowed into a roadside cut at a rapid rate (enough to generate a trickling brook sound).

On checking the marsh area immediately downhill from the roadside gravel infiltration swale, runoff was observed flowing across the marsh into the pond at a steady rate, about 1 inch in depth and 18 to 24 inches wide. Width of bushes and vegetation through which the runoff travels on leaving the road was estimated at 20 feet. It then flows across about 12 to 15 feet of marsh to enter the pond. Samples collected include:

10 In-Pond about 12 feet out from shore in 1 foot of water directly in from point where runoff is discharging.

15 Stormwater flow coming from the south just at point where it enters the “puddle” ponded at the gravel infiltration bed.

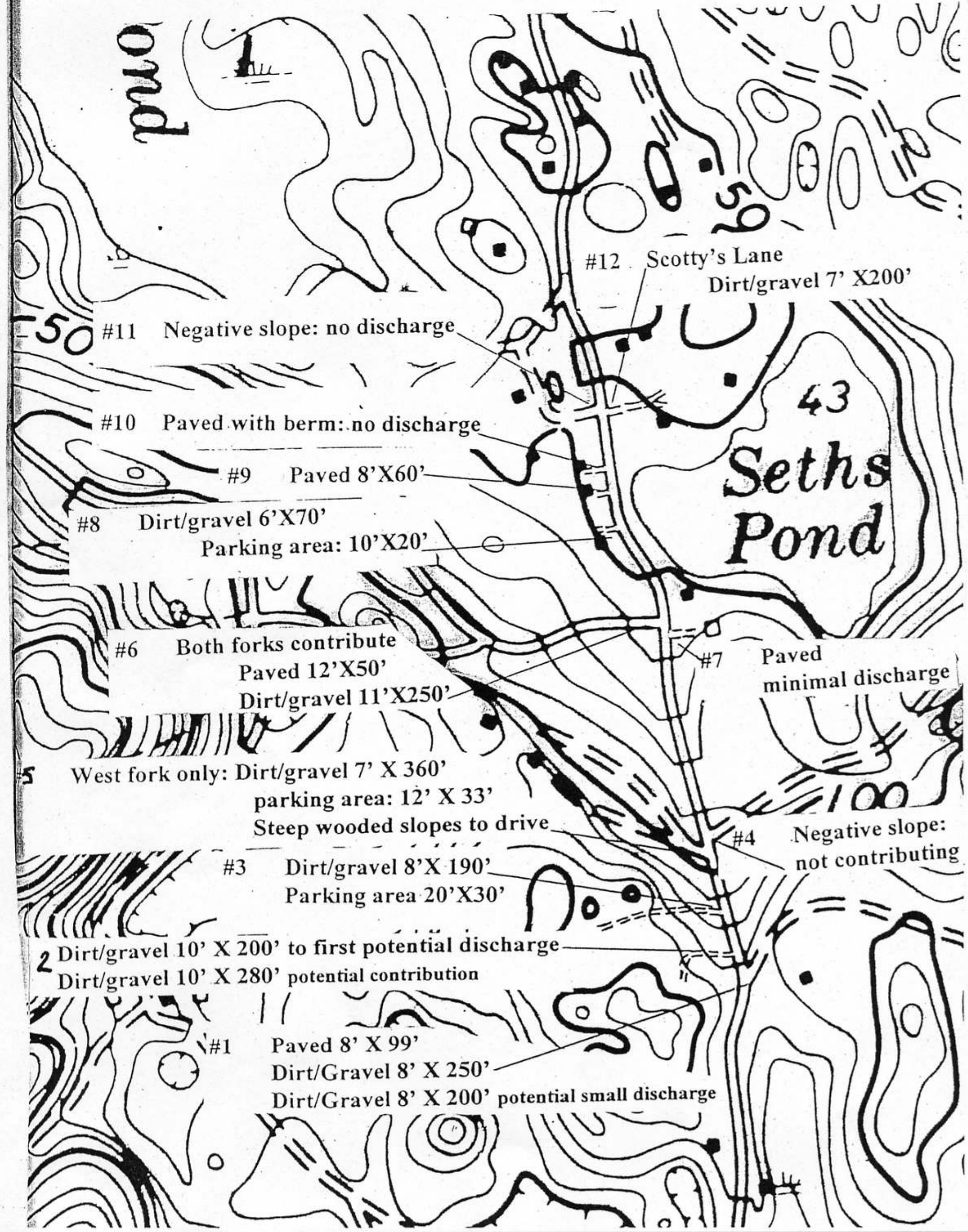
16 Flowage of stormwater flowing across the marsh surface at about midway point between the end of the bushes/beginning of marsh and the pond edge.

EstimatedLambert's Cove Road and Driveway Runoff Contribution from One Inch Storm: Excludes runoff fro

Drive #	Owner	Surface Type	Road Length	Road Width	Road Area	Road Run-off	Parking Length	Parking Width
NEW			Feet	Feet	Square Feet	1in. storm in ft^3	Feet	Feet
2		Paved	479.7	10	4797	379.76	None	
3	Russillo ?	Dirt/Gravel	187	8	1496	39.89	30	
1	Wortzel	Paved	99	8	792	62.70	None	
1	Wortzel	Dirt/Gravel	458	7	3206	85.49	None	
5		Dirt/Gravel	360	7	2520	67.20	33	
6	Mohu	Paved	89	12	1068	84.55	None	
6	Mohu	Dirt/Gravel	204	11	2244	59.84	None	
8		Gravel	70	6	420	11.20	20	
9		Paved	60	8	480	38.00	None	
12	Scotty's	Dirt	190	7	1330	35.47		
					17023	864.11		
						31.89		
L.C. Road	to south	Paved	1698	22	37356	2957.35		
	to north	Paved	573	22	12606	997.98		
					TOTAL Feet^3	4851.32		

Assumed 95% runoff from paved and 32% from dirt/gravel.

Seth’s Pond Driveway Runoff Schematic
1” == 400 feet



Appendix D

Seth's Pond Water Quality Data

Seth's Pond Water Quality Survey 2001

Analyses performed by: Marine Chemistry Lab, Univ. of Washington
Funded by: DEM Lakes & Ponds Grant and Town of West Tisbu
Commission

					Calculated Values [mg/l]			mg/l	Calculated
Station	**Date**	**NOTES**	**[PO4-P]**	**[Si(OH)4-Si]**	**[NO3-N]**	**[NO2-N]**	**[NH4-N]**	**DIN**	**[TP]**
STS1	16-Jul-01		0.002907	0.16623	0.001331	0.000139	0.004177	0.005647	0.029
STS2	16-Jul-01		0.007608	0.141516	0.001355	0.00013	0.007672	0.009157	0.04625
STS3	16-Jul-01		0.003726	0.141237	0.001379	0.000122	0.004028	0.005528	0.029143
STS4	16-Jul-01		0.003927	0.104304	0.000867	0.000113	0.004782	0.005762	0.028656
STS5	16-Jul-01		0.00329	0.096694	0.000355	0.000104	0.006046	0.006505	0.02705
	16-Jul-01	Surface Average	0.0035	0.1271	0.001	0.0001	0.0048	0.0059	0.0285
STS 6	16-Jul-01		0.006945	0.440954	0.001671	0.000947	0.079266	0.081883	0.035032
STS7	16-Jul-01	Dissolved Dup. of 4	0.002853	0.113241	0.000696	0.00033	0.004749	0.005775	
STS1	23-Jul-01		0.000964	0.173103	0.002183	0.00025	0.00474	0.007173	0.025076
STS2	23-Jul-01		0.001163	0.091107	0.00098	0.00025	0.006624	0.007854	0.025068
STS3	23-Jul-01		0.001153	0.100217	0.000988	0.000188	0.005808	0.006983	0.023303
STS4	23-Jul-01		0.001561	0.150326	0.000996	0.000125	0.005637	0.006758	0.025851
STS5	23-Jul-01		0.001446	0.091107	0.000941	0.000125	0.00441	0.005477	0.025524
	23-Jul-01	Surface Average	0.0013	0.1287	0.0013	0.0002	0.0051	0.0066	0.0249
STS 6	23-Jul-01		0.008429	0.40998	0.001993	0.001315	0.092982	0.09629	0.038779
STS6"	23-Jul-01	CHN Dup of 1							
STS1	6-Aug-01		0.004029	0.330866	0	0.000224	0.002069	0.002293	0.029061
STS2	6-Aug-01		0.000593	0.123269	0	0.000464	0.146727	0.147191	0.026268
STS3	6-Aug-01		0.002976	0.324928	0	0.000395	0.002305	0.0027	0.027885
STS4	6-Aug-01		0.002988	0.329352	0	0.000203	0.003538	0.003741	0.023438
STS5	6-Aug-01		0.003539	0.323924	0	0.000196	0.005246	0.005441	0.033048
	6-Aug-01	Surface Average	0.0034	0.3273	0	0.0003	0.0033	0.0035	0.0284
STS 6	6-Aug-01		0.002797	0.151127	0.014508	0.000436	0.007943	0.022888	0.013855
STS7	14-Aug-01	runoff at swale	0.036542	0.155617	0.250604	0.007364	0.083452	0.341419	0.122139
STS8	14-Aug-01	in pond	0.002605	0.258477	0.000157	0.00067	0.005383	0.006211	0.026735

STS1	20-Aug-01		0.002845	0.296846	0.000974	0.000656	0.005486	0.007116	0.028903
STS2	20-Aug-01		0.000917	0.114588	0	0.000649	0.411727	0.412377	0.028866
STS3	20-Aug-01		0.0019	0.207475	0.002429	0.000642	0.009708	0.012779	0.02497
STS4	20-Aug-01		0.002343	0.310103	0	0.000573	0.011784	0.012357	0.029894
STS5	20-Aug-01		0.002139	0.255635	0	0.000505	0.004204	0.004709	0.029031
	20-Aug-01	Surface Average	0.0023	0.2675	0.0009	0.0006	0.0078	0.0092	0.0282
STS 6	20-Aug-01		0.006139	0.27478	0.004976	0.00155	0.02238	0.028906	0.045807
STS6"	20-Aug-01	CHLa Dup of 5							
STS1	27-Aug-01		0.00099	0.224814	0	0.000546	0.029448	0.029993	0.024133
STS2	27-Aug-01		0.000679	0.253746	0	0.003201	1.384655	1.387856	0.034432
STS3	27-Aug-01		0.001014	0.214102	0	0.000841	0.035809	0.03665	0.024197
STS4	27-Aug-01		0.001134	0.194069	0	0.000587	0.033517	0.034103	0.025814
STS5	27-Aug-01		0.001039	0.188729	0	0.000518	0.028723	0.029241	0.021229
	27-Aug-01	Surface Average	0.001	0.2054	0	0.0006	0.0319	0.0325	0.0238
STS 6	27-Aug-01		0.007517	0.594198	0	0.001254	0.214747	0.216	0.04586
STS7	27-Aug-01	Dissolved DUP of 1	0.003218	0.236726	0	0.000566	0.015387	0.015953	
STS6"	27-Aug-01	CHLa DUP of 3							
STS1	10-Sep-01		0.004748	0.407602	0.003956	0.000434	0.006218	0.010608	0.025066
STS2	10-Sep-01		0.005905	0.298438	0.001022	0.000234	0.04615	0.047406	0.06561
STS3	10-Sep-01		0.003013	0.400361	0.000402	0.000226	0.004658	0.005286	0.022965
STS4	10-Sep-01		0.004703	0.463136	0.000475	0.000154	0.005004	0.005632	0.024894
STS5	10-Sep-01		0.00277	0.506333	0	0.000146	0.003942	0.004088	0.024416
	10-Sep-01	Surface Average	0.0038	0.4444	0.0012	0.0002	0.005	0.0064	0.0243
STS 6	10-Sep-01		0.002861	0.658735	0	0.000267	0.195116	0.195382	
STS6"	10-Sep-01	TNP & CHLa DUP of 1							0.057226
STS6"	10-Sep-01	CHN dup. of #5							

STS1	24-Sep-01		0.002166	0.19513	0	4.48E-05	0.007365	0.00741	0.0186
STS2	24-Sep-01		0.004249	0.14287	0	0.000611	0.225287	0.225898	0.0664
STS3	24-Sep-01		0.004832	0.176571	0.000621	0.000416	0.018656	0.019693	0.0248
STS4	24-Sep-01		0.002333	0.231058	0	0.000221	0.007838	0.008059	0.0217
STS5	24-Sep-01		0.002749	0.241277	0	0.000216	0.009731	0.009947	0.0251
	24-Sep-01	Surface Average	0.003	0.211	0.0002	0.0002	0.0109	0.0113	0.0225
STS6	24-Sep-01		0.003082	0.196892	0	0.000212	0.015391	0.015602	0.028
STS6"	24-Sep-01	Chla Dup. of #5							
STS 7	24-Sep-01	Dissolved Dup of 1	0.002	0.2071	0	0.0002	0.0078	0.007969	
STS7	1-Oct-01	runoff into Swale	0.001999	0.207118	0	0.000207	0.007762	0.007969	0.2663
STS8	1-Oct-01	Flowage across marsh							0.189
STS9	1-Oct-01	In pond							0.0551
ICE-1	16-Aug-01		0.003403	0.024666	0.00181	0.00046	0.011395	0.013665	
ICE-1D	16-Aug-01		0.001906	0.019302	0.014902	0.000205	0	0.015107	
Averages	Summary								
	16-Jul-01	Surface Average	0.0035	0.1271	0.001	0.0001	0.0048	0.0059	0.0285
	23-Jul-01	Surface Average	0.0013	0.1287	0.0013	0.0002	0.0051	0.0066	0.0249
	6-Aug-01	Surface Average	0.0034	0.3273	0	0.0003	0.0033	0.0035	0.0284
	20-Aug-01	Surface Average	0.0023	0.2675	0.0009	0.0006	0.0078	0.0092	0.0282
	27-Aug-01	Surface Average	0.001	0.2054	0	0.0006	0.0319	0.0325	0.0238
	10-Sep-01	Surface Average	0.0038	0.4444	0.0012	0.0002	0.005	0.0064	0.0243
	24-Sep-01	Surface Average	0.003	0.211	0.0002	0.0002	0.0109	0.0113	0.0225
		Average of Averages							0.025811
Deep Station									
STS2	16-Jul		0.007608	0.141516	0.001355	0.00013	0.007672	0.009157	0.04625
STS2	23-Jul		0.001163	0.091107	0.00098	0.00025	0.006624	0.007854	0.025068
STS2	6-Aug		0.000593	0.123269	0	0.000464	0.146727	0.147191	0.026268
STS2	20-Aug		0.000917	0.114588	0	0.000649	0.411727	0.412377	0.028866

STS2	27-Aug	0.000679	0.253746	0	0.003201	1.384655	1.387856	0.034432
STS2	10-Sep	0.005905	0.298438	0.001022	0.000234	0.04615	0.047406	0.06561
STS2	24-Sep	0.004249	0.14287	0	0.000611	0.225287	0.225898	0.0664

Appendix E

Watershed Land Use

Land Use in Seths Pond Watershed Based on FY 2000 Assessor's Book

Map	Lot	Acres	Built	Vac	Open Space	AG.	Notes Acres in/out	Future dwellings Likely	Future dwellings Max.	Guest Dwellings Likely	Guest Dwellings Max
7	14.1	0.5					3.9 out w. house				
7	54	0.7	1				1.4 out				1
7	55	1.5	1				0.5 out				1
7	56.1	1.7		1			0.3 out	1	1		1
7	64	2.1	1							1	1
7	167	0.2		1							
7	63	2.3	1								1
7	67	0.35		1			1.55 out				
7	62.1	1.4	1				0.2 out				
7	62.2	1.5	1								1
7	65	0.9	1				1.1 out				
7	172	1.4	1								
7	61	1.5		1			4.5 out	1	1	1	1
7	60.1	1.7		1			1.6 out	1	1	1	1
11	1.3	0.05					1.25 out				
11	109	8	1				5.6 out		3	2	3
11	108	22	1				FOCUS				
11	39	4		1			18.4 out	1	2	1	2
11	38	0.8					1.6 out w. house				
11	107	1	1								
11	106	2.9	1								1
11	106.1	2.7	1				0.2 out			1	1
7	25	7.5	1				bldg $1900?		1	2	2
7	24	1	1								
7	169	0.4		1			0.5 out		1		
7	21	1.5		1			1.6 out	1	1		1
7	20	1.3	1				2 out				1
7	17	0.1					0.8 out w. house				
7	18	1.5	1				0.6 out				1
7	19	1.2	1								
7	22	1.1		1				1	1		
7	23	1.3		1				1	1		
7	59.1	3.9	1							1	1
7	59.2	0.1		1	1						
7	58	1.4	1								

7	57	0.9				1.7 out w. house				1
7	170	0.4	1			0.4 out				
7	171	0.04		1						
7	162	0.45	1			1.85 out				
7	163	0.5		1		1 out		1		
7	53	1				2.8 out w. house				1
TOTALS		**84.79**	**22**	**13**	**1**		**7**	**14**	**10**	**23**

LC Road	40 foot row	1.85
Seths Ln.	30 foot row	0.35
		86.99

Appendix F

Phosphorus Loading Calculations

Calculated Phosphorus Loads:

Reckhow Model:

Lake Total P == $$\frac{L}{11.6 + 1.2Q}$$

Where L == P load in grams/meter^2
Q == Water load to pond in meters/year = 4.3

$$0.026 == \frac{L}{11.6 + 1.2(4.3)} == \frac{L}{16.76}$$

0.476 g/m^2 == L with pond area == 46135 m^2
Load == 20.1 kilograms per year

Dillon-Rigler Model:

#1 Lake Total P == $$\frac{\text{Load} * (1 - (0.426\, e^{-0.271Z/T} + 0.574\, e^{-0.00949Z/T}))}{Z/T}$$

Where Z == mean depth == 2.4 meters
T == Flushing time == 0.48 years

0.026(5) == Load (1- (0.1099 + 0.5472) == Load (0.3429)

0.379 g/m^2 == L with pond area == 46135 m^2 == 17.49 kilograms/year

#2 Lake Total P == $$\frac{\text{Load} * (1 - (0.426\, e^{-0.271Z/T} + 0.574\, e^{-0.00949Z/T}))}{Z/T}$$

Where Z == mean depth == 2.4 meters
T == Flushing time == 1.33 years

0.026(1.81) == Load (1- (0.2612 + 0.5642) == Load (0. 175)

0.268g/m^2 == L with pond area == 46135 m^2 == 12.37 kilograms/year

<u>Mattson-Isaac Model</u>: Note this model is for load from watershed—it does not include the pond sediment release.
P_{load} == 0.5 kg.*#septics + 0.13kg* forest ha. + 0.3kg. * rural ha.

Where: P_{load} == Annual phosphorus export to the pond from the watershed
septic == number of systems within 300 meters of shore Focus counted as 7 units based on flow.
forest == wooded area in hectares in watershed
rural == developed area in hectares in watershed

P_{load} == 0.5 kg.*15 + 0.13kg* 31.4+ 0.3kg. *3.8

== 7.5 + 4.1 + 1.15 == 12.75 kilograms/year

If septic load is reduced to consider seasonal use:
== 5 + 4.1 + 1.15 == 10.25 kilograms/year

<u>Sediment Source</u>:
Release of phosphorus from the sediment due to pumping by rooted plants, natural chemical and physical release and release during anoxic events accounts for the difference between the external load using the Mattson & Isaac formula and the required loading as calculated to satisfy the observed average total phosphorus. This difference amounts to 3 to 9 kilograms per year.

<u>Loading Limits Predicted by the Models:</u>
Here, we work the models to suggest loading limits that are appropriate to meet desired water quality.

1: <u>Model from Wetzel (page 291, 1983)</u>

$$\mathbf{chl}\textbf{\textit{a}} == 0.55^* [\, P_i/(1 + \mathrm{sqrt}\ T_W)]^{0.76}$$

Where chl*a* is the desired chlorophyll concentration
T_W is the average residence time or 0.48 years
P_i is the annual phosphorus load in mg/m^3

Setting chl*a* to 10 ug/l:

$$\frac{0.55\, P_i^{0.76}}{1 + \mathrm{sqrt}\ 0.48} == \frac{0.55\, P_i^{0.76}}{4^{th}\ \mathrm{root}\ (1.693^3)} == 3^{rd}\ \mathrm{root}\ 10^4$$

$$\frac{0.55\, P_i^{0.76}}{1.485} == 21.544$$

$$\frac{31.993}{0.55} == 58.1688 == P_i^{0.76}$$

$$P_i^3 == (58.1688)^4 == 11448812$$

$$P_i == 225.38\ mg/m^3 * 107.548\ X10^6\ \text{liters}$$

$$P_i == 24.24\ \text{kilograms}$$

Setting chl*a* to 7.5 ug/l:

$$\frac{0.55\, P_i^{0.76}}{1 + \mathrm{sqrt}\ 0.48} == \frac{0.55\, P_i^{0.76}}{4^{th}\ \mathrm{root}\ (1.693^3)} == 3^{rd}\ \mathrm{root}\ 7.5^4$$

$$P_i == 135.15\ mg/m^3 * 107.548\ X10^6\ \text{liters}$$

$$P_i == 14.54\ \text{kilograms}$$

2: <u>Reckhow Model</u>:

$$\text{Lake Total P} == \frac{L}{11.6 + 1.2Q}$$

Where L == P load in grams/meter^2
Q == Water load to pond in meters/year = 4.3
Desired phosphorus concentration is 0.023 mg/l (TSI of 50)

$$0.023 == \frac{L}{11.6 + 1.2(4.3)} == \frac{L}{16.76}$$

0.385 g/m² == L with pond area == 46135 m²
Load == 17.8 kilograms per year

3: <u>Vollenweider Model:</u>

<u>If the flushing rate is 175 days:</u>

$$\text{Lake TP} == \frac{L}{10 + Z*F}$$

Where: L is Load
Z is mean depth or 2.4 meters
F is Flushes/year or 2.08

$$0.023 == \frac{L}{14.99}$$

L == 0.3448 g/m^2 * 46135m^2 == 15.9 kilograms

<u>If the flushing rate is 484 days:</u>

$$0.023 == \frac{L}{10 + Z*F}$$

Where: L is load
Z is mean depth or 2.4 meters
F is flushes/year or 0.75

$$0.023 == \frac{L}{11.8}$$

L == 0.271 g/m^2 * 46135m^2 == 12.52 kilograms

Appendix G

Pond Bioenhancement Options

SEE:
http://www.agric.gov.ab.ca.agdex/400/485_716.html

http://www.ianr.unl.edu/pubs/Wildlife/NF429.HTM