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FINAL REPORT

DIAGNOSTIC/FEASIBILITY STUDY OF WEQUAQUET LAKE, BEARSE, AND LONG POND

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1.0 INTRODUCTION

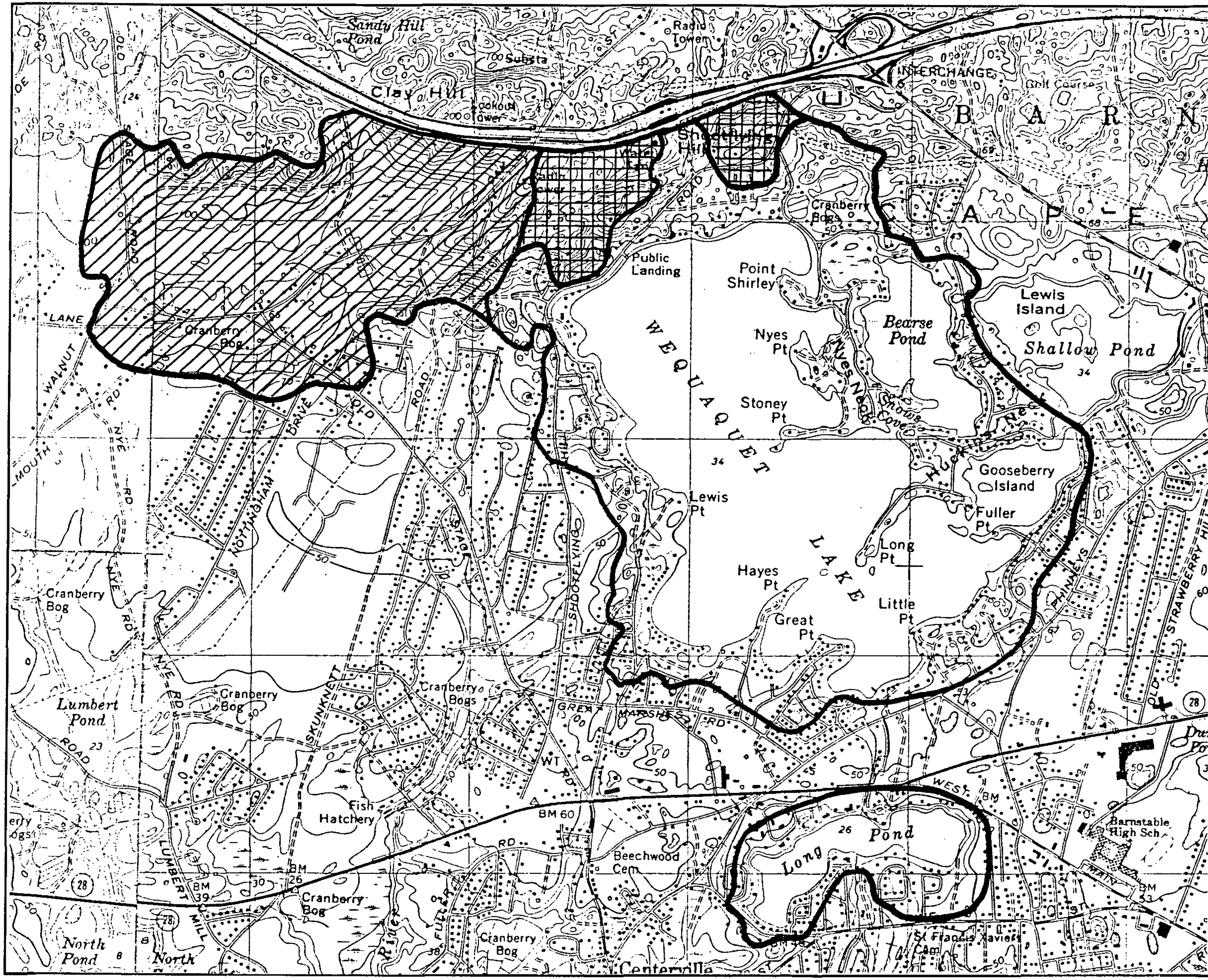
Wequaquet Lake, Bearse Pond, and Long Pond are components of a freshwater system located in Barnstable, Massachusetts (Figure 1). Wequaquet Lake and Bearse Pond are connected by a short channel. Surface discharge from Wequaquet Lake flows (seasonally) into Long Pond via a herring run. A separate section of the herring run discharges water from Long Pond into the Centerville River. Concern over the condition of the "Wequaquet Lakes" system prompted the Town of Barnstable to apply to the Massachusetts Division of Water Pollution Control (DWPC) for funding under the Massachusetts Clean Lakes and Great Ponds Program (Chapter 628) for a diagnostic/feasibility study. In October of 1985, IEP, Inc. and K-V Associates were retained to conduct this study. The following report documents the findings of the diagnostic portion of the study and details recommended management alternatives.

2.0 DESCRIPTION OF LAKE, WATERSHED, AND RECHARGE AREA

2.1 General Description, Morphometry, and Bathymetry

Wequaquet Lake is the third largest lake on Cape Cod (Chandler and Bones, 1983), with a surface area of 234.4 hectares (579 acres). The lake is connected with neighboring Bearse Pond (24 ha or 59 acres) by a surface water channel known as Snow's Cove. The outlet from Wequaquet Lake is located on the south shore of the lake and flows southward into Long Pond (19.8 ha or 49 acres), which in turn discharges to the Centerville River. These three water bodies form an interacting system that will henceforth be referred to as the "Wequaquet Lakes". All three water bodies are Great Ponds (larger than 10 acres in surface area), and as such can be used by the public for "fishing, fowling, boating, skating or riding upon the ice, taking of water for domestic or agricultural purposes, or for use in the arts and the cutting and taking of ice" (Chandler and Bones, 1983). The watershed of the Wequaquet Lakes has a total surface area of 1111 acres (449.7 hectares) and is shown in Figure 1. Morphometric measurements of the Wequaquet Lakes are summarized in Table 1.

Classification systems designed to define the trophic status of a lake or pond are all based on the biological productivity of the water body. Many criteria are used to evaluate the biological productivity of a freshwater system and assign it to a trophic category. The word eutrophic ("well-nourished") is commonly understood to indicate a water body that is highly productive and supports abundant growth of aquatic macrophytes and algae. Biological productivity is considered excessive in recreational water bodies when it reduces water transparency, adds color to the water, or interferes with activities such as swimming or boating. Generally, biological productivity in a freshwater system is driven by the input of nutrients, especially phosphorus. A freshwater system that receives only small amounts



DIAGNOSTIC/FEASIBILITY STUDY OF WEQUAQUET LAKE, BEARSE AND LONG PONDS

PREPARED FOR THE
TOWN OF BARNSTABLE
CONSERVATION COMMISSION

FIGURE 1

WATERSHED AREAS

LEGEND

CATCHMENT OF OAK STREET CULVERT SYSTEM (DISCHARGES AT STATION 6)

CATCHMENTS WITH DEPRESSIONS ACTING AS RUN OFF STORAGE AREAS

SCALE IN FEET

0 500 1000 1500 3000

SOURCE: U.S.G.S. QUADRANGLE, HYANNIS
COTUIT
SANDWICH

IEP inc.

TABLE 1 - MORPHOMETRY OF THE WEQUAQUET LAKES
(English units in parentheses)

	Wequaquet Lake	Bearse Pond	Long Pond
surface area	234.4 ha (579 a)	24.0 ha (59 a)	19.8 ha (49 a)
maximum depth	9 m (30 ft)	6 m (20 ft)	8 m (26 ft)
mean depth	3.7 m (12 ft)	3.0 m (10 ft)	2.6 m (9 ft)
volume (x 10)	8.600 cu m	0.715 cu m	0.518 cu m
total watershed area	449.7 ha (1111 a)		38.2 ha (94 a)
culvert catchment area (flowing in at station 6)	188.8 ha (466 a)		
groundwater recharge area	323.0 ha (798 a)		83.2 ha (206 a)
maximum length	2300 m (7544 ft)	888 m (2913 ft)	950 m (3116 ft)
maximum width	1400 m (4592 ft)	425 m (1394 ft)	350 m (1148 ft)
length of shoreline	11156 m (36600 ft)	2438 m (8000 ft)	2591 m (8500 ft)
development of shoreline (unitless)	2.0	1.3	1.6

of nutrients supports limited biological productivity. Such a lake typically exhibits great water clarity and minimal growth of aquatic vegetation. The term commonly applied to the lake described above is oligotrophic ("poorly-nourished"). A water body exhibiting biological productivity intermediate between the two extremes described above is commonly assigned to a category known as mesotrophic.

The Commonwealth of Massachusetts Summary of Water Quality for 1984 included all three of these ponds in its Lake Classification Program listing. This program classifies lakes as to trophic status according to results of a baseline limnologic survey, and rates water bodies by assigning "severity points" based on hypolimnetic dissolved oxygen, transparency, phytoplankton numbers, epilimnetic inorganic nitrogen concentrations, and epilimnetic total phosphorus concentrations. Based on the severity points assigned for each water body, Bearse and Wequaquet are oligotrophic and Long Pond is mesotrophic. Severity points assigned out of a possible 18 were 5 for Bearse Pond, 7 for Long Pond, and 5 for Wequaquet Lake. The borderline between oligotrophic and mesotrophic conditions for the trophic status index based on severity points is 6. Therefore, these three ponds are all borderline between the oligotrophic and mesotrophic classification. All three ponds were classified as unstratified.

These three ponds originated as deep depressions formed by isolated ice blocks left in the Barnstable Outwash Plain when the glaciers receded from the region about 12,000 years ago. Ponds formed in this way are known as "kettle ponds". The predominant source of inflow to these ponds is ground water because the outwash deposits are highly permeable. Outflow can be both as surface water flow through streams and as recharge to ground water.

Bathymetric measurements were taken from a boat using an electronic depth finder. Depth readings were recorded at 30 second intervals as the boat motored at a constant speed on a course corresponding to the transects approved by the DWPC. Compass bearings were used to confirm end points of certain transects when distinct landmarks were not apparent on shore. Timed recording along a transect was initiated and terminated out from shore to avoid grounding. These small distances to shore, at the beginning and end of a timed transect, were estimated from the boat. The total length of each transect was measured from the United States Geological Survey (USGS) topographic map (Hyannis quadrangle). The computation done to determine the distance (D) between each depth reading along the transect is given below:

$$D = \frac{\text{Total transect length (from USGS map)} - \text{Distance from shore at start and end of transect (estimated from boat)}}{\text{Number of depth readings (taken at beginning of timed transect and at 30 second intervals)} - 1}$$

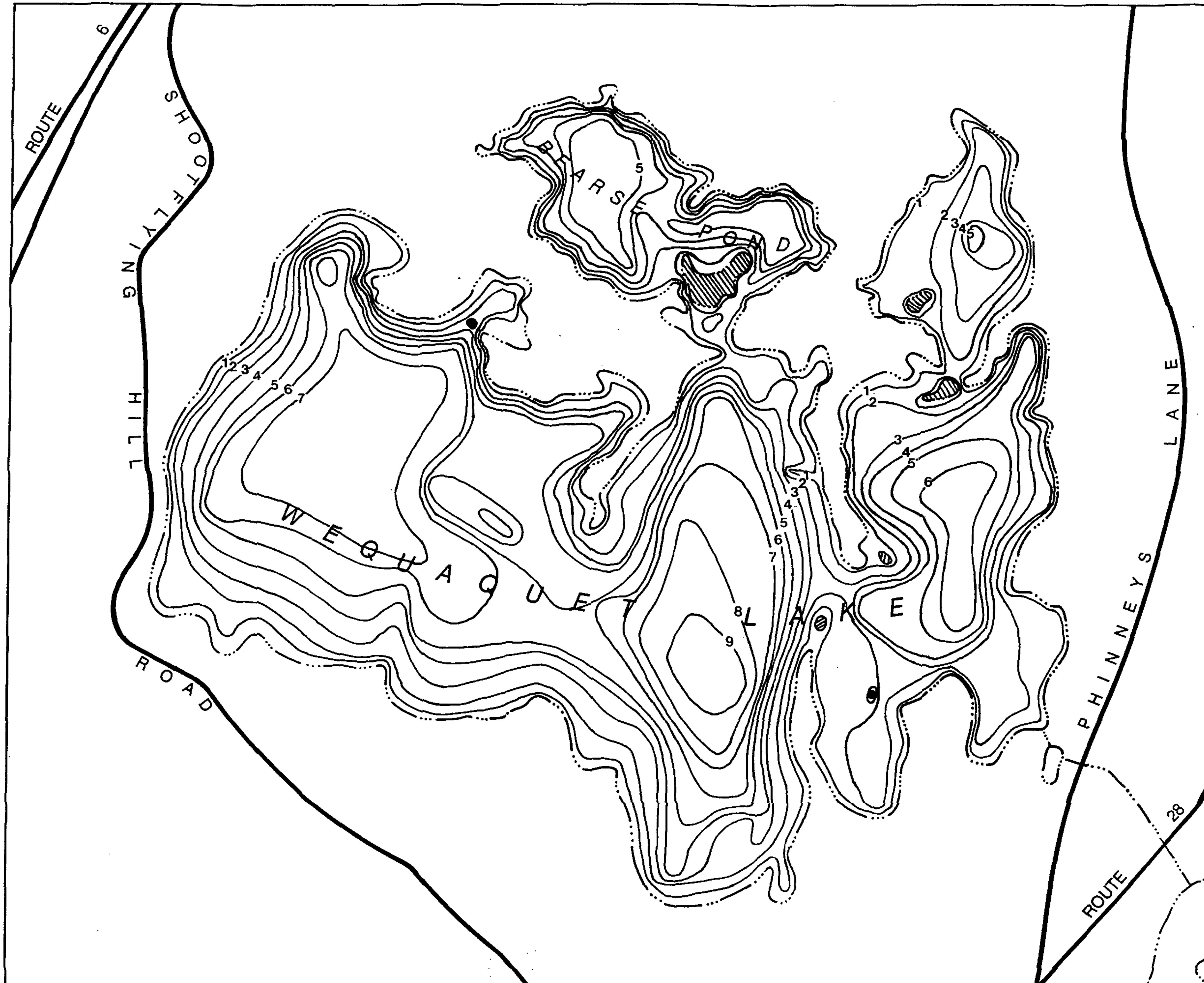
The major assumptions in this method are (1) uniform motion of the boat along a transect is maintained and (2) time for acceleration of boat to transect speed is negligible. The bathymethric map prepared from data obtained by the above method is shown in Figures 2 and 3.

2.2 Groundwater Recharge Area

The recharge map of the Wequaquet Lakes prepared by K-V Associates is shown in Figure 4. This map is based on watertable measurements and groundwater flow measurements conducted along the perimeter of Wequaquet Lake with the K-V Associates, Inc. groundwater flowmeter. Field methodology and a discussion of the results appear below.

Field Measurements

Direct flow measurements were obtained with a K-V Associates Model 40 2-D Groundwater Flow Meter. A groundwater flow survey was conducted in January of 1986, along the major recharge portion of shoreline of Wequaquet Lake at intervals of approximately 500 feet. At each shoreline station a hole was augered with a 3 inch earth auger to a depth below the water table. The flowmeter probe was inserted in this borehole and back-filled with sand taken from the borehole.



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WEQUAQUET LAKE AND BEARSE POND

SCALE IN FEET
0 2 4 6 800 1600

FIGURE 2 - BATHYMETRY OF WEQUAQUET LAKE

LEGEND:

- NAVIGATIONAL HAZARDS
- ISLANDS
- CONTOUR INTERVALS (METERS)

iEP inc.

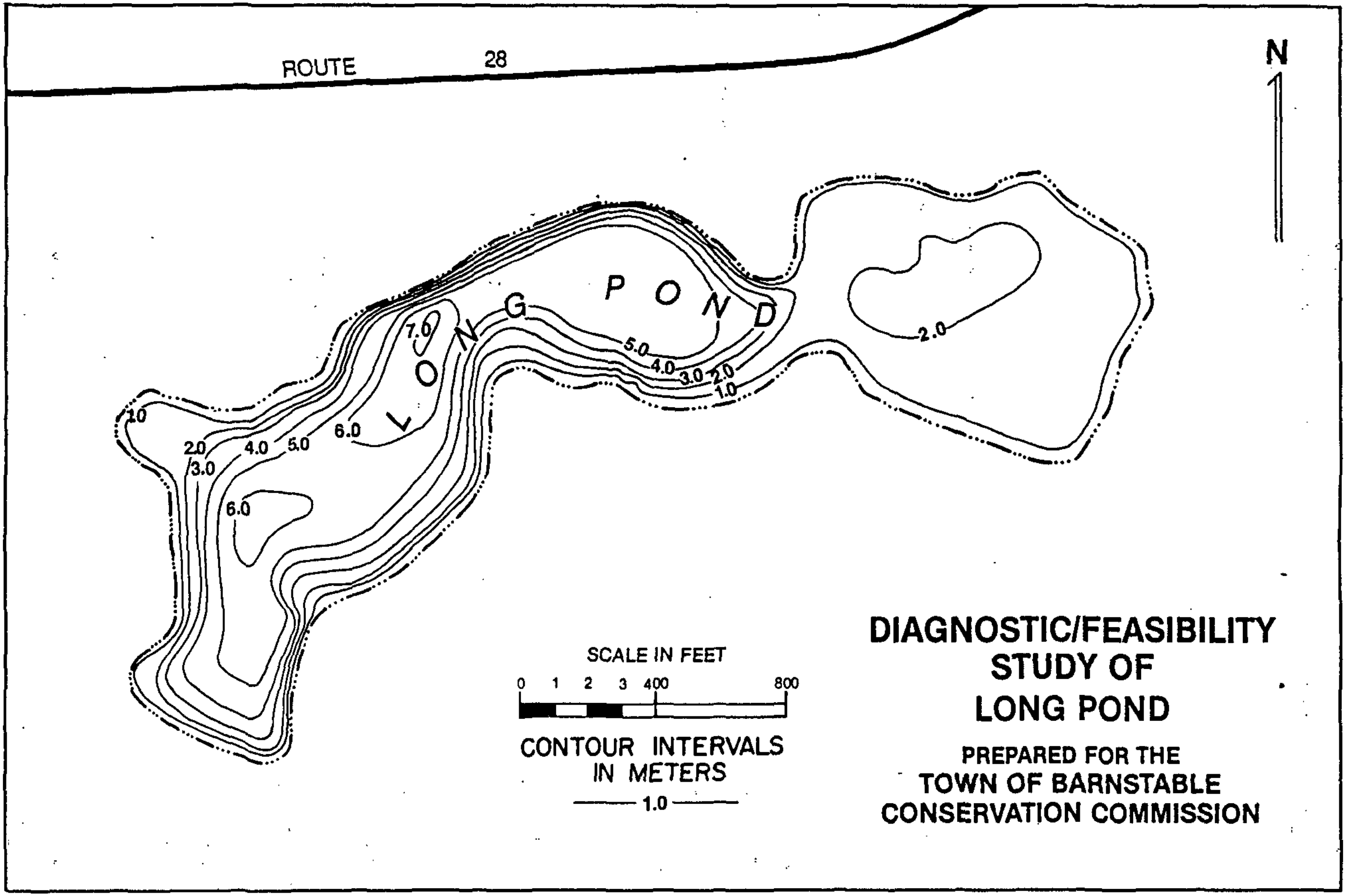
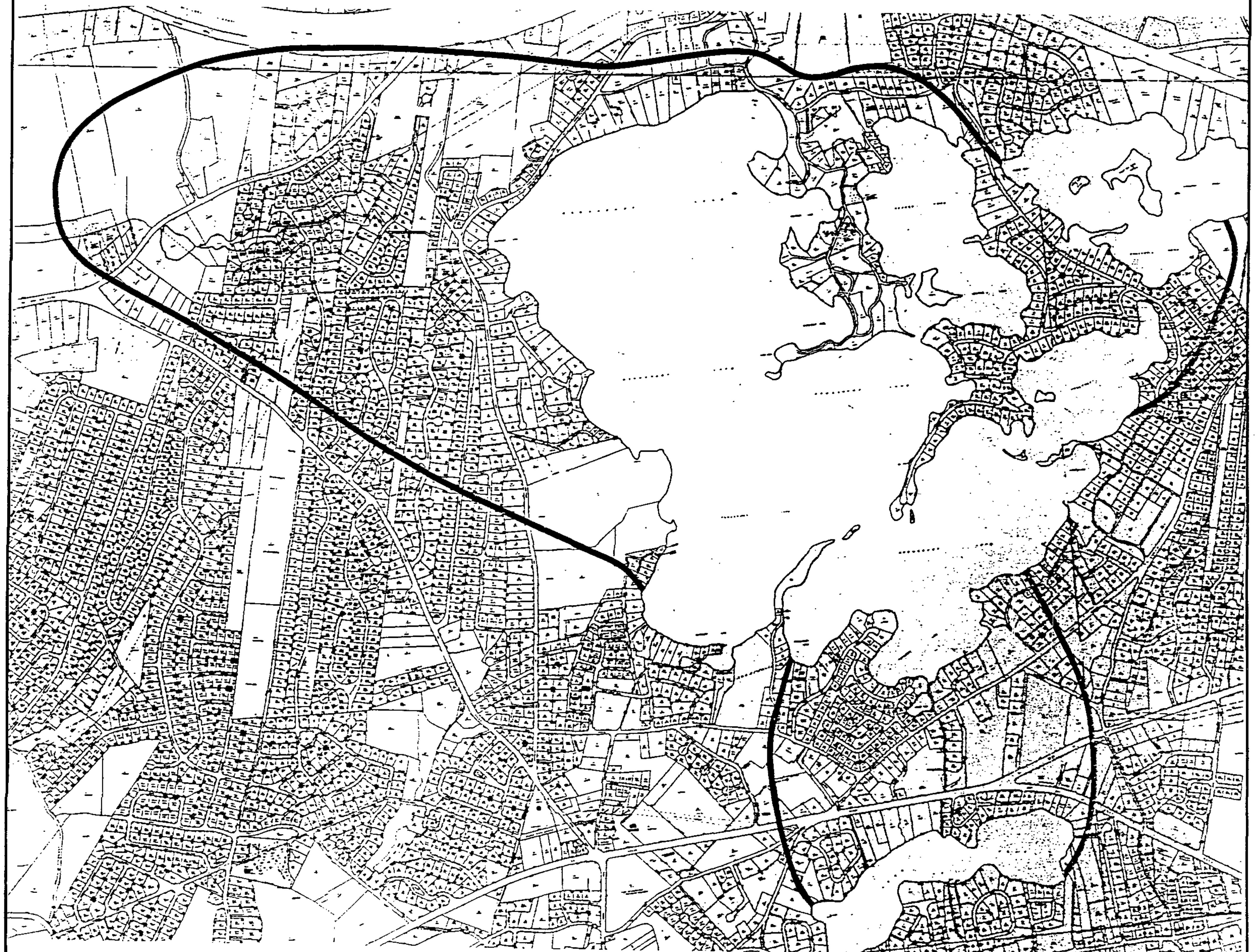


FIGURE 3 - BATHYMETRY OF LONG POND

IEP inc.



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WEQUAQUET LAKE, BEARSE POND AND LONG POND

SCALE IN FEET

0 2 4 6 800 600

FIGURE 4 - RECHARGE AREAS OF THE WEQUAQUET LAKES

iEP inc.

Figure 5 summarizes the flow measurements taken during the January survey. These measurements confirmed the wider spaced readings taken in 1981 (KVA, 1981). On the western side of the pond recharge, the boundary between recharge and discharge appears to have moved farther north. The average flow rate encountered during the January survey was 1.29 feet/day.

WEQUAQUET LAKE - FLOW MEASUREMENTS ALONG RECHARGE SHORELINE

Station	Direction (Mag)	Velocity
W-86-1	162	0.44 ft/day
*W-86-2	280	1.03 ft/day
W-86-3	174	0.88 ft/day
W-86-4	231	1.22 ft/day
W-86-5	45	0.38 ft/day
W-86-6	45	5.31 ft/day
W-86-7	178	0.81 ft/day
W-86-8	60	0.81 ft/day
W-86-9	21	2.00 ft/day
W-86-10	82	0.25 ft/day
W-86-11	107	0.79 ft/day

Average measured recharge velocity = 1.29 ft/day

*discharge occurring at this station

Monitoring Wells

Three monitoring wells (WW-1, WW-2, WW-3) were installed in the estimated recharge zone west of Wequaquet Lake in order to determine groundwater gradients and contour water levels in this region. The monitoring wells were installed by Blue Rock Drilling Company, and consisted of 2 inch pvc casing with 5 foot slotted (0.020 inch slots) pvc screens emplaced below the water table. Well head elevations were surveyed to a nearby bench mark.

Designation	Elev. M.P.	DTW	Elev. W.T.
Wequaquet Lake			33.76
WW-1	48.94	15.50	33.44
WW-2	67.31	31.39	35.92
WW-3	43.26	6.75	36.51

2.3 Historical and Current Uses

The Wequaquet Lakes have a rich history as part of the Town of Barnstable and continue to be an important recreational resource. They are used for a wide variety of activities including swimming, boating, water skiing, fishing and ice sailing.

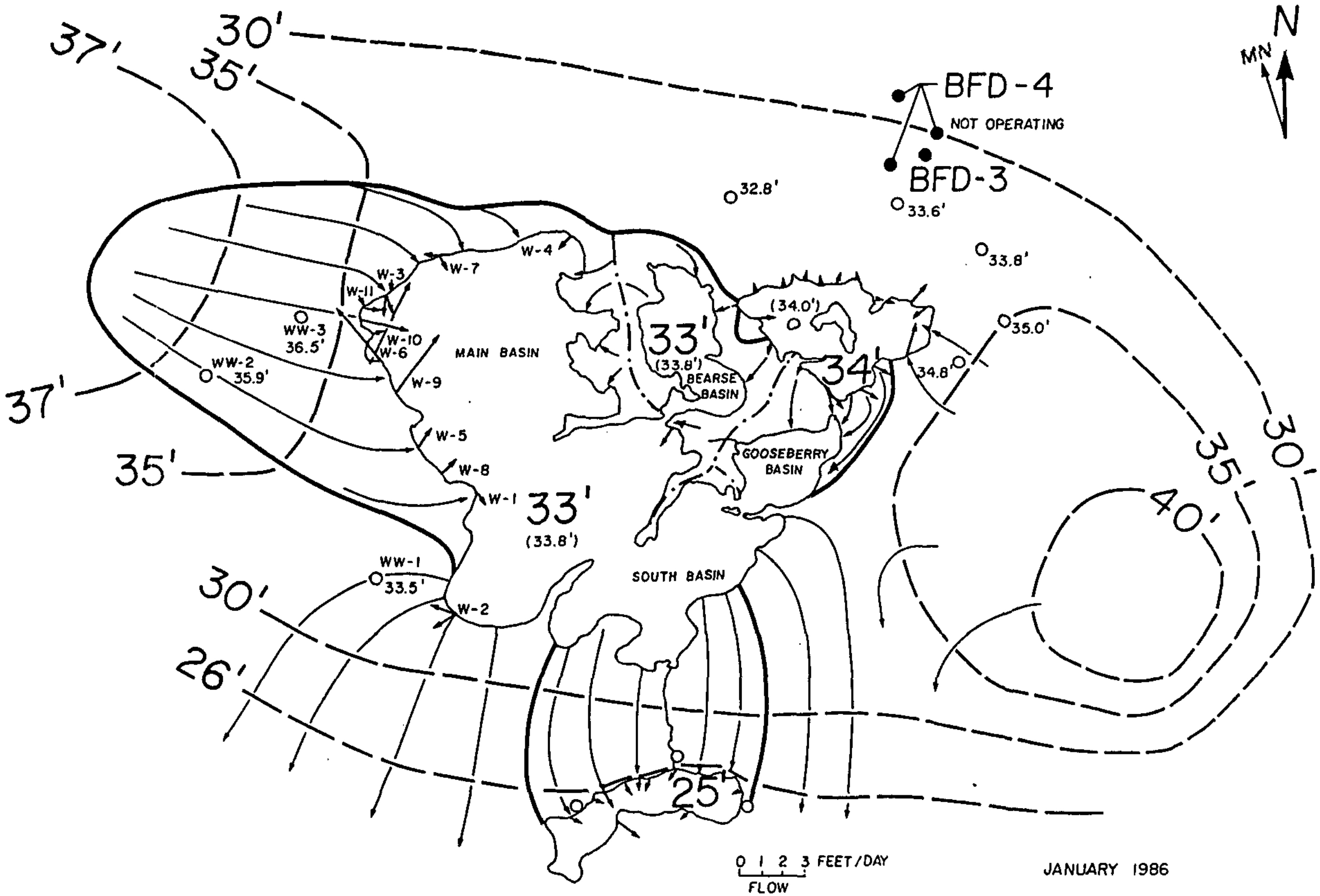


FIGURE 5 - GROUND WATER FLOW MEASUREMENTS

Wequaquet Lake has had a succession of names, going from Coopers Pond to Iyanough's Pond to Great Pond to Nine Mile Pond. In 1891, it was named Wequaquet Lake. Summer cottages were built along the lakeshore at least as early as the mid 1800's, and were used mostly by Barnstable residents who spent the winter in other parts of the town. In 1868 the Nine Mile Fishing Company was formed. About the same time, in 1867, the town hired Civil War veterans to build a herring run extending from the Centerville River to Long Pond and north into Wequaquet Lake. The feasibility of restoring the lower section (between Long Pond and the Centerville River) of the herring run is presently being studied by the town.

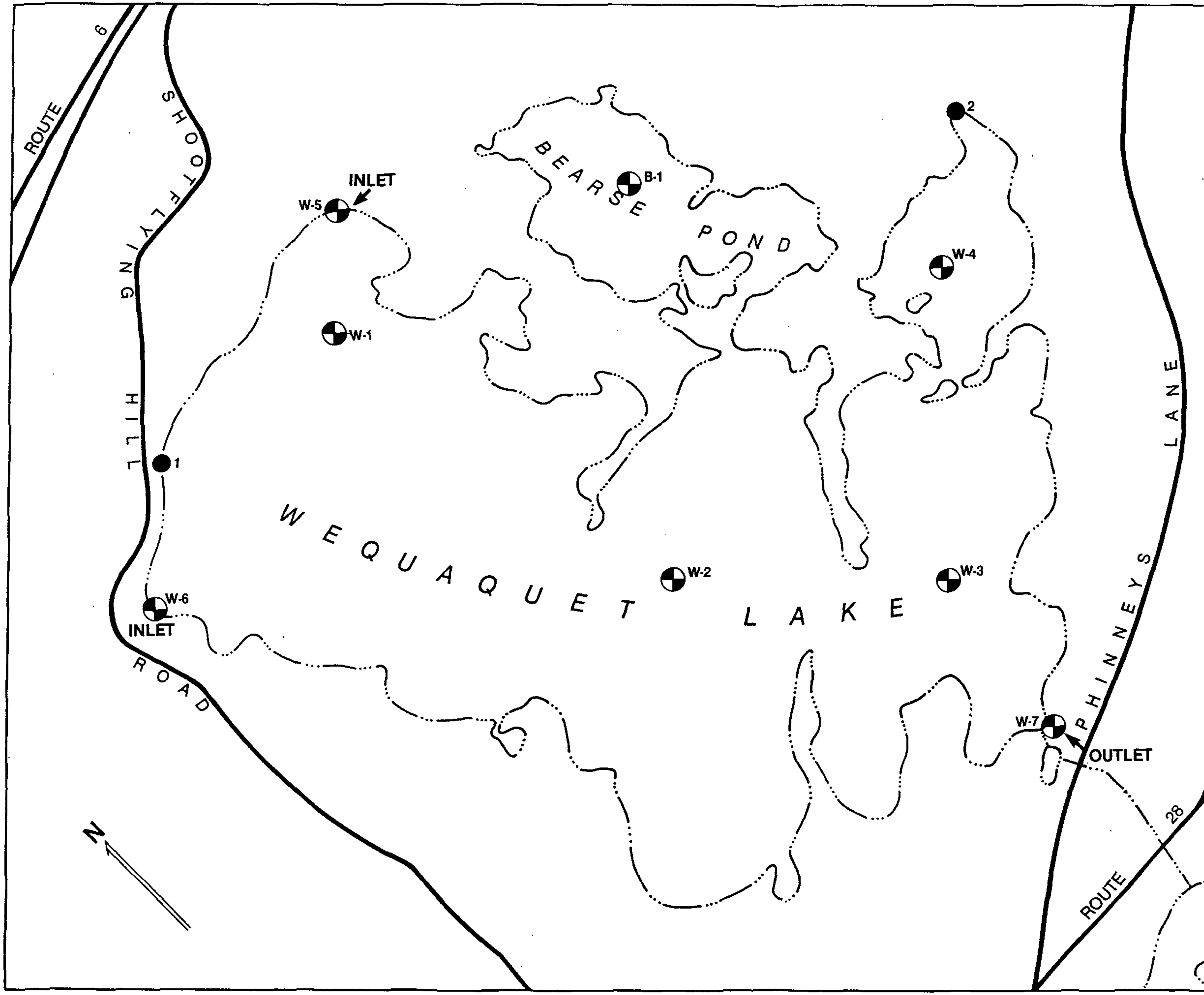
There are two points of public access to Wequaquet Lake (Figure 6). The largest access is a public beach and boat ramp located along Shoot Flying Hill Road, in the northwest area of the lake. The beach has a bathhouse and is supervised by lifeguards during the summer. Parking is provided for town residents only. The second access point is at the northeast corner of the lake, off Huckins Neck Road. This is a small unpaved way to water that provides access to Gooseberry Pond and the main body of the lake. There are also privately owned boat ramps, one owned by a homeowner's association and another by the Wequaquet Lake Yacht Club, a sailing association whose annual Sunfish regatta is nationally recognized. Access to Long Pond is provided at a point on the south shore off Dunaskin Road and along the eastern shore of the pond (Figure 7).

Boating is a popular activity on the Wequaquet Lakes, including everything from small boats and sailboats to power boats of all types. There is no motor size restriction for power boats on Wequaquet Lake or Bearse Pond. On Long Pond motors are restricted to 5 horsepower or less. Water skiing is popular on Wequaquet since the lake is more sheltered than rougher ocean waters. A growing number of jet-skis are also used on Wequaquet Lake.

Many people also use the lake for fishing. According to Mr. Ed Ruete, a homeowner on the lake, pickerel, perch and sunfish are plentiful and bass are caught occasionally. Further information on the importance of recreational fishing in the Wequaquet Lakes is addressed in Section 3.3 (Fish Inventory). In the winter the lake has a reputation throughout New England as an excellent location for ice sailing. The lake often freezes without any snow on top of the ice, offering an excellent surface for ice boats.

2.4 Geology and Soils

The geological composition of Cape Cod is unique. Formed from glacial action, the unconsolidated material is in stark contrast to the Massachusetts mainland where bedrock controls the landscape. The geologic history of the area has been discussed in detail by numerous authors (Mather



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WEQUAQUET LAKE AND BEARSE POND

SCALE IN FEET
0 2 4 6 800 1600

FIGURE 6

PUBLIC ACCESS AND SAMPLING STATIONS

LEGEND

- PUBLIC ACCESS
- SAMPLING STATIONS

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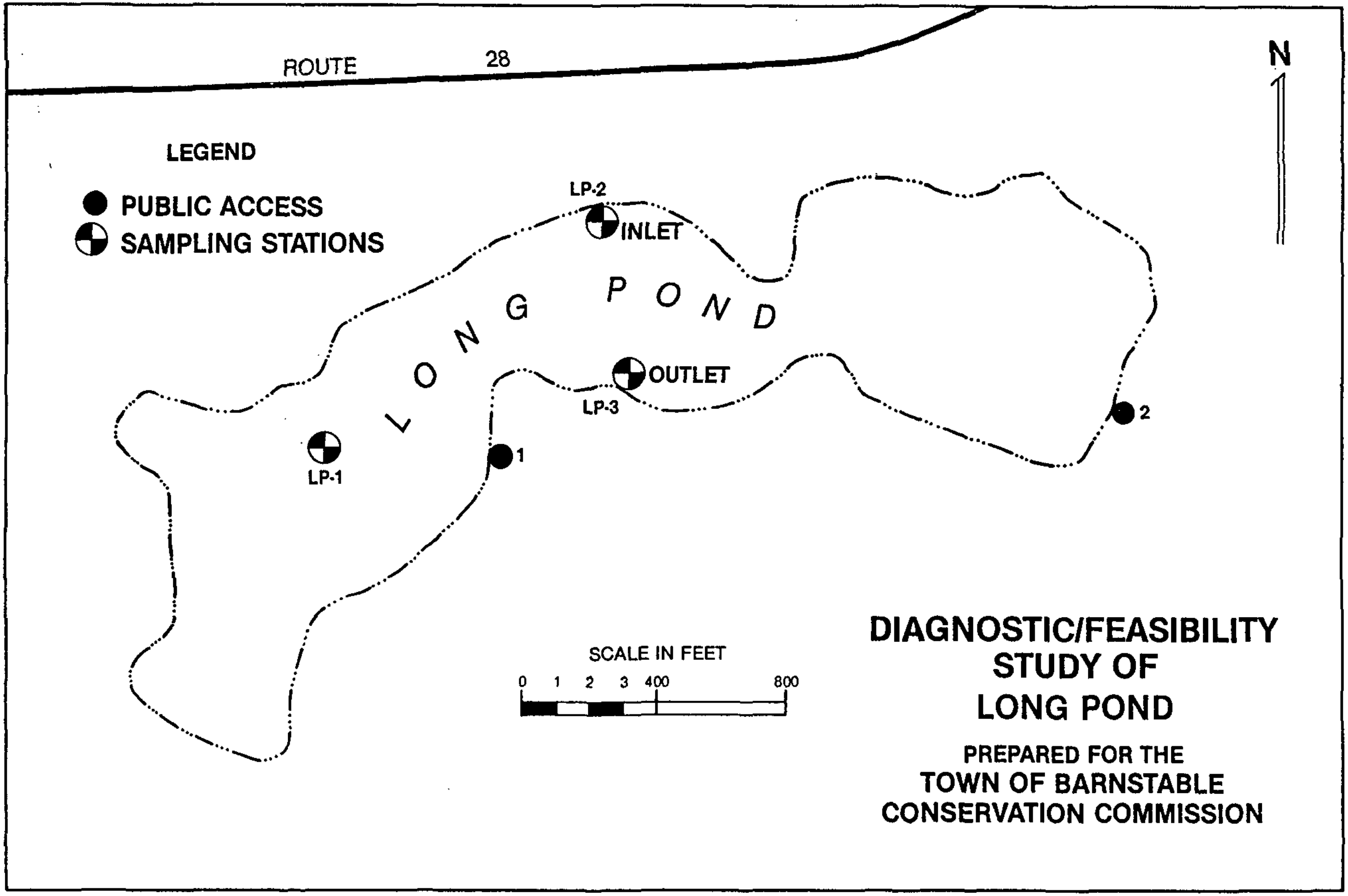

FIGURE 7 - LONG POND PUBLIC ACCESS AND SAMPLING STATIONS

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et al, 1940 and 1942; Oldale, 1976; Strahler, 1966). The thick deposits of sand, gravel, till, cobblestones, and boulders were laid down during the Wisconsin glaciation, a stage in the Pleistocene Epoch which originated about 75,000 years ago and ended about 12,000 years ago. Three lobes of the glaciation intruded into the Cape and Islands region. The Cape Cod Bay lobe was responsible for forming Barnstable and most of the Cape. Approximately 80% of the land in Barnstable is covered by glacial deposits (Comitta and Rado, 1972). The remaining areas consist of salt marshes (15%) or water and windlaid landforms (5%).

2.4.1 Surficial Geology

The glacial deposits within Barnstable fall into the following 8 categories (Oldale and Barlow, 1986):

Qb Beach Deposits - mostly sand includes some gravel and sparse boulders. Boulders locally abundant: post-glacial.

Qbn Barnstable Plain Deposits - mostly gravelly sand and pebble to cobble gravel - locally includes boulders.

Qd Dune Deposits - mostly sand: post glacial.

Qlu Cape Cod Bay Lake Deposits, Undifferentiated - mostly gravelly sand. Includes some fine to very fine sand, silt, and clay. Scattered boulders.

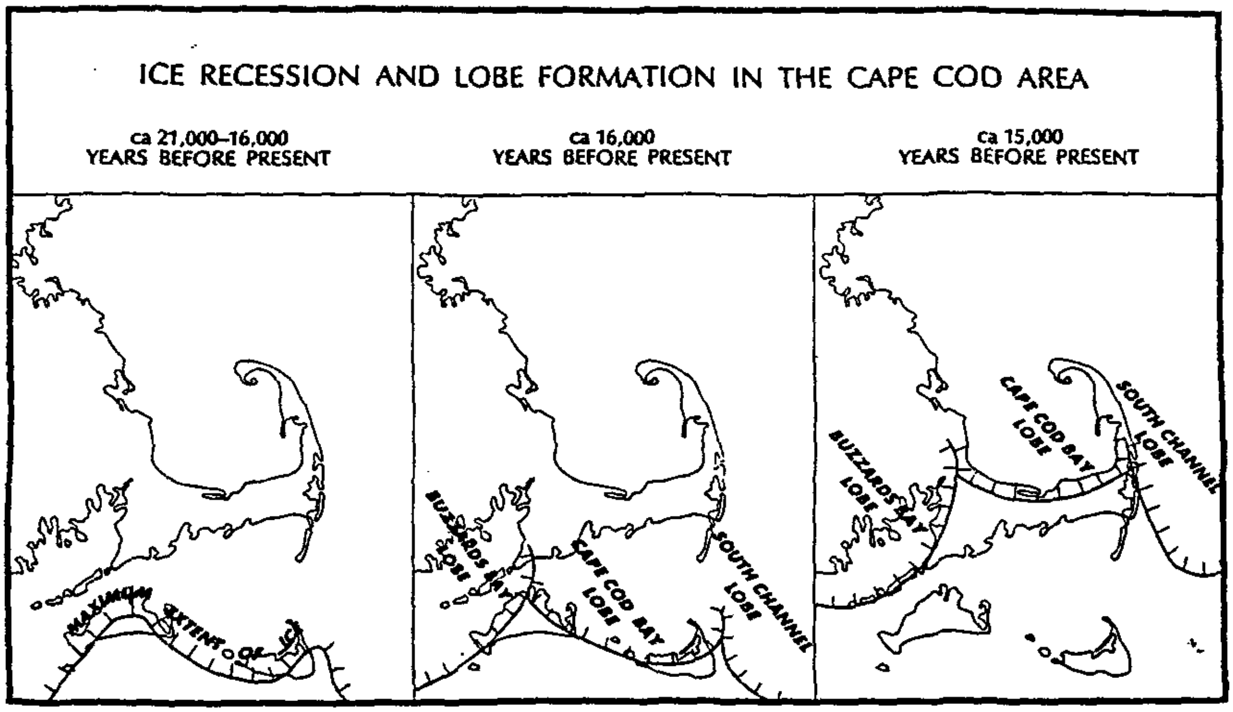
Qnd Nantucket Sound Ice - Contact Deposits - mostly sand and gravel, includes till and boulders.

Qs Marsh and Swamp Deposits - decaying salt marsh plants mixed with sand, silt, and clay. Includes some freshwater, marsh, and swamp deposits: post-glacial.

Qsm Sandwich Moraine Deposits - mostly sand and gravel. Abundant very fine sand, silt, and clay. Till and boulders generally occur on top of stratified drift.

Qsu Sand and Gravel, Undifferentiated - mostly sand and gravel, includes some silt and clay. Generally floors, kettle holes, and valleys: post-glacial.

The major geological formations in the Wequaquet Lakes study area (see Figure 8) consist of the Sandwich moraine deposits (Qsm) and Barnstable Plain deposits (Qbn). Moraine deposits formed at the edge of a stalled glacier where debris carried by the ice sheet was released, resulting in a knob and kettle landscape. The moraine deposits occur just to the north of



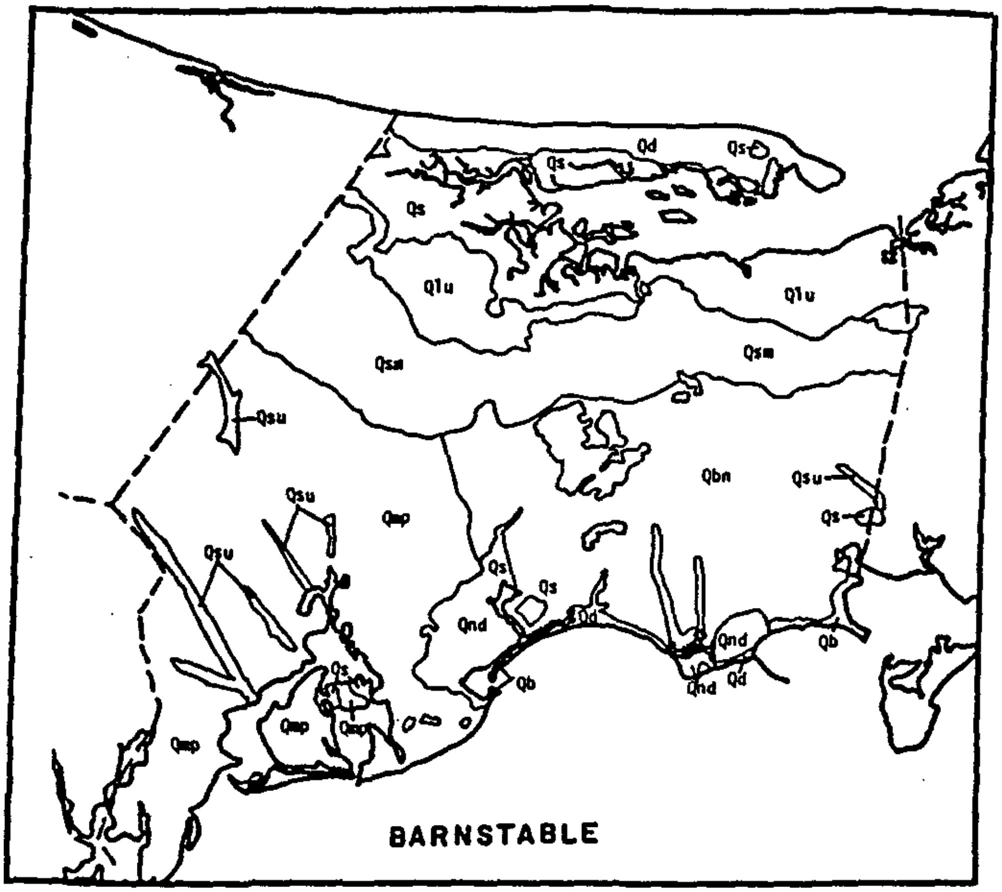


FIGURE 8 - SURFICIAL GEOLOGY (Modified from Oldale and Barlow, 1986)

Wequaquet Lake, bordering on the northern edge of the recharge area. They consist mostly of gravelly sand, but includes some clay, silt, gravel, till and boulders.

The broad Barnstable outwash plain (Qbn) covers most of the study area. The material is chiefly gravelly sand and pebbly to cobbly gravel. The material near the apex is coarser grained than that near the coast. The plain is dotted with kettle holes and kettle lakes. Wequaquet Lake consists of several kettle depressions which filled with ground water forming the freshwater lake and its basins. The depressions were formed from isolated blocks of ice left by the retreating glacier which were buried by sandy outwash deposits. Later, as the ice blocks melted, the blanketing sediments collapsed leaving a depression (Strahler, 1966).

The level of water in Wequaquet Lake is linked directly to groundwater elevation and both are components of a dynamic hydrologic system. The gravity leveling of water in a lake across a groundwater gradient induces rapid flow into the shorelines on the upgradient side. The local path and movement of ground water are determined by geological and hydraulic conditions of the different basins.

Although the lake level is about 10 meters (34 ft) above mean sea level and extends to a depth of about 9 m (30 ft) below the surface, this distance is only about one-tenth the depth to bedrock which exists at about 100 m (300 ft) beneath the surface. The bedrock is poorly permeable and consists primarily of granodiorite (Oldale, 1976). Ground water is forced to flow laterally and outwards towards the lower pressure levels of the marine waters.

A series of drillings at locations surrounding Wequaquet Lake and north of Long Pond have shown similar stratigraphy. Generally, the surface soils are sandy loams underlain by coarse sands, gravel, and interbedded cobblestones. The frequency of the cobblestone regions make drilling difficult particularly as the drill approaches static water depths. The stratification suggests that the meltwater from the glaciers was at a much higher velocity than the runoff waters which produced later deposits as the glaciers receded. Some of the segregation is also apparent in the soil types.

2.4.2 Soil Types

The United States Department of Agriculture, Soil Conservation Service (SCS), classifies soils according to their textural characteristics. The classification applies only to the uppermost soil layer, usually the top five feet. Each of the major groups can be divided into subgroups and characterized by degree of slope and phase.

There are four major soils types which exist in the immediate Wequaquet Lake watershed (Figure 9). They all are glacial outwash soils generally composed of coarse to medium sand with few particle sizes as small as silt. The four types are the following:

Pl - Plymouth sandy loam (light phase)

Ms - Merrimac sandy loam (light phase)

MS - Merrimac sandy loam

H - Hinkley sand

Plymouth Series

These are excessively drained soils which are formed in loose sandy or glacial till. They are nearly level to steep terminal moraines that have loamy sand surface soils. The upper part of the subsoil is loamy sand the lower part is coarse sand. They are underlain at a depth of about two feet by loose glacial till that is sand or gravelly sand. These soils contain moderate amounts of gravel, many stones and boulders throughout. Plymouth soils are closely associated with excessively drained conditions.

Merrimac Series

The Merrimac series consists of well-drained soils that formed in thick deposits of sand and gravel derived mainly from granite and gneiss. Below the shallow (1 inch) surface organic layer, fine granular acid sandy loam with 5 percent gravel is present to a depth of one foot. From one to four feet the soil consists of gravelly sandy loam grading to 15 to 20 percent cobblestones that are 3 to 6 inches in diameter. Below four feet, the soil is composed of gravelly sand with 40 percent subrounded granite gravel and cobblestones that are 3 to 6 inches in diameter.

Hinkley Series

The Hinkley series consists of droughty, level to steep gravelly soils that formed in thick deposits of water-sorted sand and gravel. They occur mainly on outwash plains and terraces. In wooded areas that were formerly cultivated, the organic litter is underlain by a gray mineral layer less than 1 inch thick. Below this, to about plow depth, is brown gravelly loamy sand. The subsoil is yellowish-brown gravelly loamy sand. Gravel and cobblestones make up about two-thirds or more of the substratum. The surface layer is about 25 percent gravel, by volume. In some places, there are cobblestones on the surface. These soils are low in moisture-holding capacity and are low in organic content.

FIGURE 9 - SOILS

The Plymouth, Merrimac, and Hinkley series are highly permeable soils that allow leachate from septic systems to rapidly percolate down to the water table. This characteristic minimizes the likelihood of surface breakout or overflows from septic systems. However, the coarse nature of these soils causes their adsorptive capacity for certain contaminants, such as phosphorus, to be lower than exists in finer soils. The potential for transport of contaminants to wellfields or ponds via ground water is greater in these soils.

2.5 Land Use

Land use within the recharge area is quantified in Table 2 below. These data were prepared using the resources of the Barnstable Department of Planning and Development with field checking done as necessary. Residential development dominates land usage within the recharge area to both Wequaquet Lake/Bearse Pond and Long Pond.

TABLE 2 - LAND USE IN THE WEQUAQUET LAKES RECHARGE AREAS

Type of Land Use	Area (ha)	Area (acres)	Percentage
Residential	309.5	765	76%
Roads	57.0	141	14%
Forest	29.6	73	7%
Commercial	4.5	11	1%
Parks	3.2	8	1%
Ponds	2.4	6	1%
Total	406.2	1,004	100%

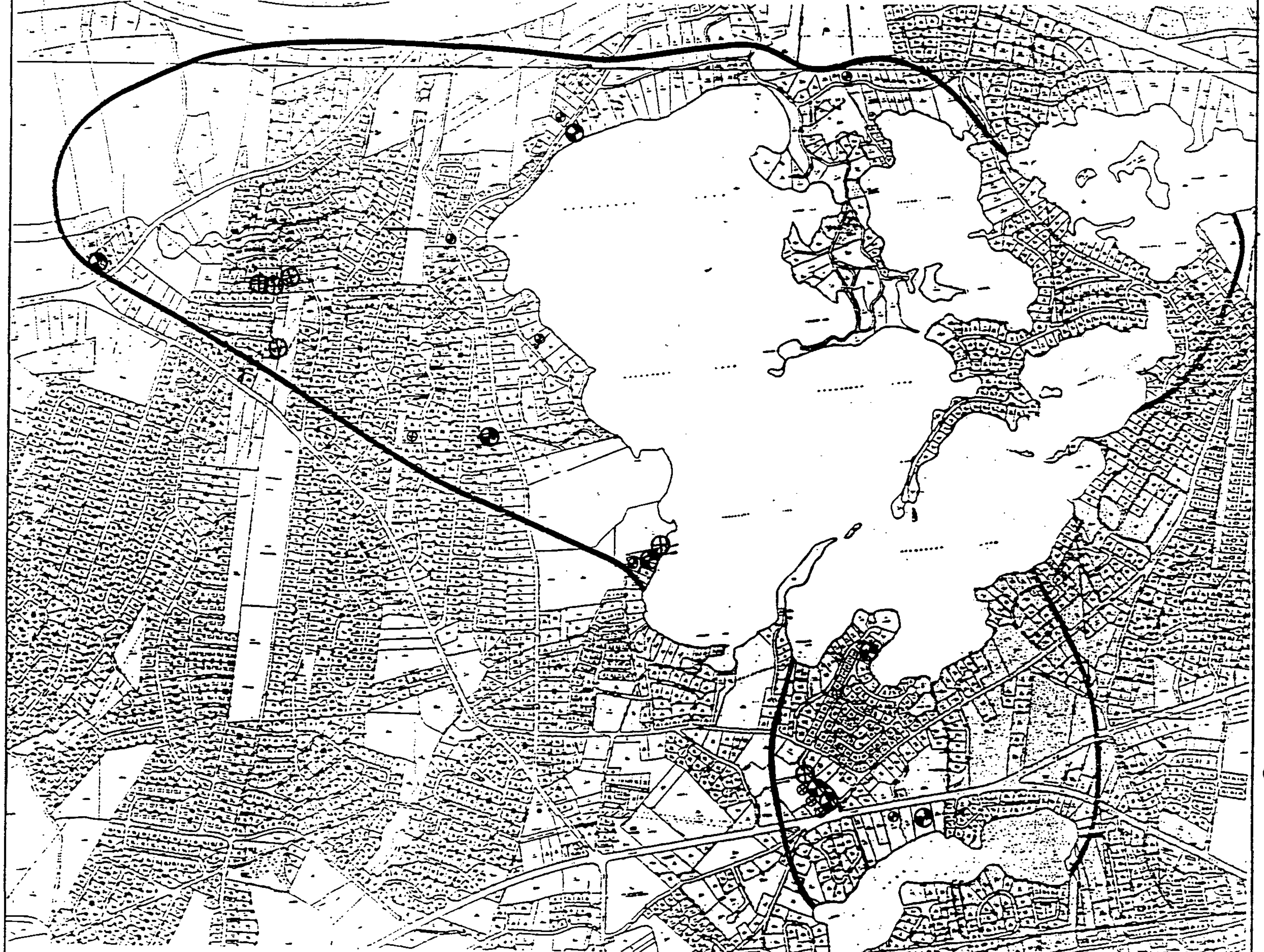
IEP has counted 859 existing units within the recharge area of Wequaquet Lake and another 148 lots of vacant land that are buildable under the current minimum lot size. This represents a total of 1,007 units already in place or "programmed" to be developed on 798 acres, the total recharge area (or 1 unit per 0.8 acres). Only about 110 acres of subdividable land can be found in the Wequaquet Lake recharge area. By assuming the one acre minimum lot size in this area, approximately 90 additional units could be subdivided on this acreage. Calculating the proportion of the total represented by the above additional units indicates that existing development accounts for 92 percent of the total buildout potential. All of the dwellings within the Wequaquet Lakes recharge area are served by on-site septic systems. The impact from the extensive development that exists in the recharge area is evaluated in Section 6.0 (Nutrient Budget).

Nutrient loading from "non-point" sources in the watershed can be estimated using the export coefficients of Reckhow et al (1980). These coefficients are derived from empirical studies of land use within watersheds and associated surface runoff quality. In the case of the Wequaquet lakes, the high permeability of the soils (Section 2.4 above) in the watershed reduce surface runoff to a minor component of total hydrologic inputs (see Section 5.0). Sandy soils, such as those of Cape Cod, "cause a general downward flow of water to the ground water" (Reckhow et al, 1980) and therefore loading from non-point sources is minimal except for shoreline lawn areas. The impacts of nutrient loading via ground water and surface runoff from lawns are evaluated in Section 6.0 (Nutrient Budget).

The locations of underground storage tanks within the recharge area to the Wequaquet Lakes were researched at Barnstable's Board of Health. A Town wide program has been enacted by the Board of Health which requires registration of all home heating oil storage tanks. Owners of the tanks were located through the home heating oil distributors. Each tank owner was mailed a registration form which was due by the end of May, 1988. Information on the registration cards includes address of the owner, map and parcel numbers of the property, and capacity and age of the tank. As of 6-July, 1988, only a small fraction of the registration cards had been returned. An updated list of tanks within the recharge area to the Wequaquet Lakes can be generated as the remainder of the registration cards are returned. All commercial properties with underground storage tanks are also registered with the Board of Health.

Information from the registration cards was used by IEP to map the location of the tanks currently registered with the Board of Health on a composite assessors map of the recharge area (Figure 10). Each tank was assigned a symbol which identifies to its age and size.

Tanks of ages fifteen years or older are vulnerable to corrosion, particularly if they are underground. Three of the underground tanks mapped by IEP are over fifteen years old and are located directly adjacent to the lake. These tanks threaten water quality due to their potential for leakage. Recommendations for protecting the Wequaquet Lakes from contamination by leaking underground storage tanks are presented in Section 8.1.1 (Land Use Management).



DIAGNOSTIC/FEASIBILITY STUDY OF WEQUAQUET LAKE, BEARSE AND LONG PONDS

PREPARED FOR THE
TOWN OF BARNSTABLE
CONSERVATION COMMISSION

WEQUAQUET LAKE, BEARSE POND AND LONG POND

FIGURE 10

SCALE IN FEET

0 2 4 6 800 800

UNDERGROUND STORAGE TANKS WITHIN THE RECHARGE AREAS OF THE WEQUAQUET LAKES

LEGEND

- *15 YEARS OR OLDER, MORE THAN 1000 GALLONS*
- *15 YEARS OR OLDER, 1000 GALLONS OR LESS*
- *LESS THAN 15 YEARS OLD, MORE THAN 1000 GALLONS*
- *LESS THAN 15 YEARS OLD, 1000 GALLONS OR MORE*

IEP inc.

3.0 LIMNOLOGIC DATA

3.1 Water Quality

3.1.1 Historical Water Quality Data

A compilation of limnological data from previous reports on Bearse and Long Ponds is given in Tables 3 through 5. In Bearse Pond, historical values for all parameters except chloride, pH, and conductivity are within ranges observed during the diagnostic study (October, 1985 to September, 1986). Samples taken in August, 1983 had lower chloride concentrations (Table 3) and samples taken in 1984 had higher pH and conductivity values (Table 5) than any observed during the diagnostic study. In Long Pond, the ranges observed during the diagnostic study encompass historical values for all parameters except ammonia (one value higher in 1983, Table 4), nitrate (one value higher in 1980, Table 4), pH (lower in 1983, Table 4), chloride (lower in 1980 and 1983, Table 4), and conductivity (higher in 1982, Table 5).

The DEQE baseline data collected July, 1980 on Wequaquet Lake (Duerring and Rojko, 1984; not tabulated) have also been evaluated. Historical values for all of the parameters analyzed during the diagnostic study are within the ranges observed from October, 1985 to September, 1986. Comparison of historical data to recent findings do not indicate any distinct changes or trends in water quality.

In addition to chemical properties, thermal properties of the water column correspond to those observed previously. None of the Wequaquet Lakes exhibited thermal stratification in previous surveys. This was again documented during our sampling rounds. Figure 11 shows the seasonal trend in temperature and dissolved oxygen at the deepest in-lake station of Wequaquet Lake (station 2). The above plot typifies all of the in-lake stations and demonstrates that surface and bottom water are generally homogeneous throughout the year. All the Wequaquet Lakes exhibited orthograde oxygen profiles (near saturation at all depths, see Figure 11) and a nearly uniform distribution of chemical concentrations in both surface and deep waters throughout the year of study. These observations indicate a continuous, wind-driven mixing of the water column.

TABLE 3

SUMMARY OF LIMNOLOGICAL DATA FROM PREVIOUS REPORTS: BEARSE POND

(Results as mg/L unless indicated)

	DEQE Study, Samples Taken August, 1983			
	Station 1 (South) Surface	Station 1 15 Feet	Station 2 (North) Surface	Station 2 15 Feet
Total Coliform (Colonies/100 ml)	80	--	5	--
Fecal Coliform (Colonies/100 ml)	<5	--	<5	--
Total Alkalinity	5.0	4.0	4.0	4.0
Total Suspended Solids	0.0	0.5	10	1.0
Total Solids	44	56	44	50
Ammonia as N	0.05	0.06	0.07	0.06
Nitrate as N	0.10	0.10	0.10	0.09
Chloride	14	13	14	13
pH (standard units)	6.7	6.2	6.6	6.3
Total Phosphate as P	0.04	0.04	0.04	0.03
Specific Conductance (umhos/cm)	80	80	79	78
Total Kjeldahl-Nitrogen as N	0.49	0.49	0.43	0.38
Total Hardness	13	13	13	13

Massachusetts Department of Environmental Quality Engineering, Division of Water Pollution Control. Baseline Water Quality Studies of Selected Lakes and Ponds in the Cape Cod Drainage Area. Volume 1, December, 1984.

TABLE 4

SUMMARY OF LIMNOLOGICAL DATA FROM PREVIOUS REPORTS: LONG POND

(Results as mg/L unless indicated)

	IEP Study, Samples Taken September, 1980		DEQE Study, Samples Taken in Western Basin August, 1983	
	Surface (East)	Surface (West)	Surface	20 Feet
Total Coliform (Colonies/100 ml)	<10	<10	300	--
Fecal Coliform (Colonies/100 ml)	<10	<10	10	--
Total Alkalinity	6	6	4	6
Total Suspended Solids	--	--	2.0	0.0
Total Solids	--	--	64	100
Ammonia as N	0.03	0.02	0.03	0.14
Nitrate as N	0.40	0.28	0.10	0.0
Chloride	20	20	20	21
pH (standard units)	6.4	6.3	5.2	5.8
Ortho-Phosphate	0.008	0.008	--	--
Total Phosphate as P	0.024	0.020	0.11	0.06
Specific Conductance (umhos/cm)	100	90	101	100
Total Kjeldahl-Nitrogen as N	--	--	0.66	0.59
Iron	0.08	0.07	--	--
Total Hardness	--	--	12	13

IEP, Inc., Baseline Water Quality/Aquatic Biological Studies of Selected Ponds and Lakes. November, 1980.

Massachusetts Department of Environmental Quality Engineering, Division of Water Pollution Control. Baseline Water Quality Studies of Selected Ponds in the Cape Cod Drainage Area. Volume 2, December 1984.

TABLE 5

SUMMARY OF LIMNOLOGICAL DATA: REPORTS BY K-V ASSOCIATES

	------- Bearse Pond (1984) ------		
	Station 1	Station 2	Station 3
pH (standard units)	7.35	7.20	7.10
Ortho-Phosphate (mg/L)	0.002	0.002	0.002
Total-Phosphate (mg/L)	0.011	0.009	0.012
Specific Conductance (umhos/cm)	100	100	105
Total Kjeldahl Nitrogen (mg/L)	0.214	0.211	0.202

	-------- Long Pond (1982) -------		
	Station 1	Station 2	Station 3
pH (standard units)	6.3	6.2	6.2
Total-Phosphate (mg/L)	0.008	0.009	0.009
Specific Conductance (umhos/cm)	160	160	160
Total Kjeldahl Nitrogen (mg/L)	0.580	0.461	0.423
Chlorophyll a (mg/cubic meters)	0.12	0.12	0.12

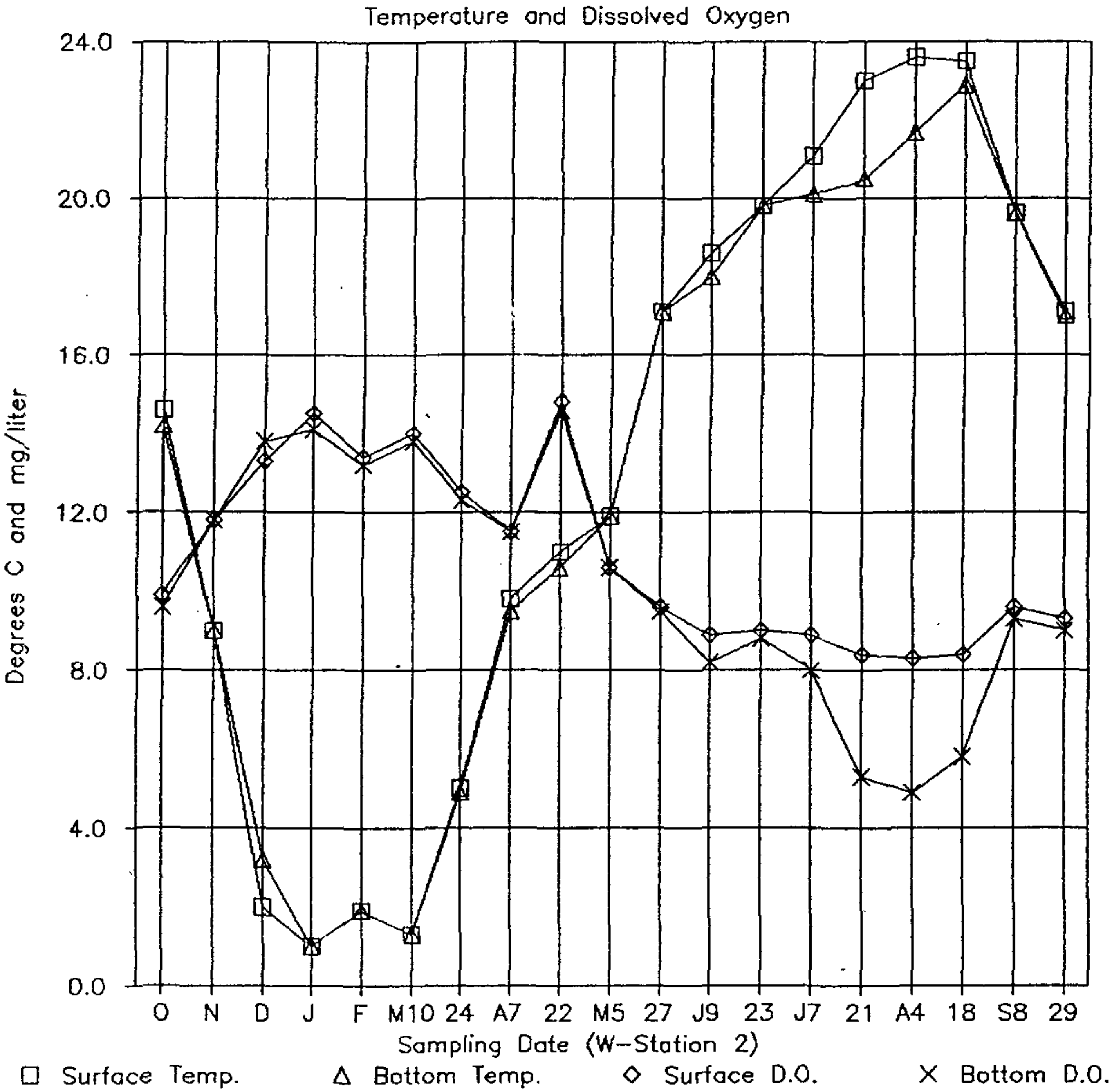


FIGURE 11 - Temperature and Dissolved Oxygen at Wequaquet Station 2

3.1.2 Baseline Sampling

Data collection began on 24 October 1985. The location of the sampling stations and public access points are shown in Figures 6 and 7 (on pages 12 and 13). These sampling stations are located within the major basins of the system and at inlets and outlets. A total of nineteen sampling rounds were completed. Stations 5 and 6 are located at points of episodic discharge into Wequaquet Lake from a managed cranberry bog and a storm drain system respectively. The above stations function as tributary inlets during periods of discharge and are evaluated in Section 3.1.3 (Tributary Assessment).

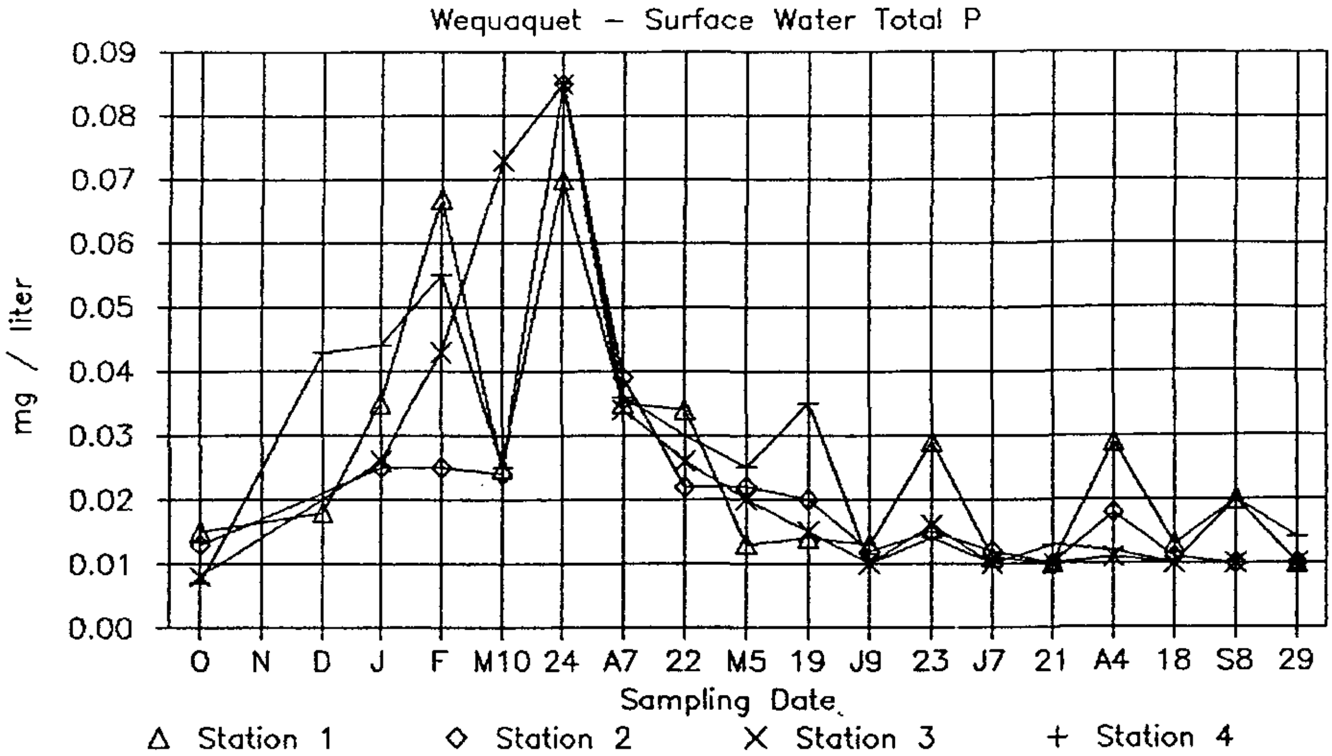
The monthly values of certain parameters monitored during the year of study are plotted in Figures 12 through 15. Results of laboratory analysis, from which the above graphs are generated, are given in Appendix A. The concentrations of the various parameters exhibited only minor variability between stations within the main body of Wequaquet Lake (stations 1 - 4). However, consistant differences in water quality were observed between the main body of Wequaquet Lake, Bearse Pond, and Long Pond.

Results indicate water chemistry characteristics that are typical of Cape Cod lakes in general. The waters of Bearse Pond, Long Pond, and Wequaquet Lake are of low alkalinity, have pH values between 6 and 7, and have relatively high chloride ion concentrations. These "softwater" features, which are exhibited by most lakes of the region, are determined by the unique geophysical setting of Cape Cod. Principally, it is the geologic history of the region and the close proximity to the sea that determine the features listed above. The glacially derived sand and gravel that compose the drainage basins of these lakes are poor sources of the ions contributing to alkalinity. Elevated chloride concentrations result from deposition of windblown sodium chloride molecules which are transported from the ocean about 1.5 miles distant. Data on pH and alkalinity within the Wequaquet Lakes are evaluated in Section 3.1.5 (Acidification Survey).

<u>Nutrients</u>

Phosphorus and nitrogen are vital elements in the nutrition of aquatic plants and algae. In most New England freshwater lakes, the supply of phosphorus in the water is exhausted by biological uptake earlier than other nutrients, and thus it is phosphorus that limits the growth of algae. Phosphorus limitation of biological productivity in the Wequaquet Lakes has been documented (see Section 6.1).

A summary of nutrient analyses for the Wequaquet Lakes is given in Table 6. The values for total phosphorus are generally in the range characteristic of mesotrophic/eutrophic water quality status (Wetzel, 1983). The results for phosphorus from samples taken in November are questionable due to use of inappropriate instrumentation at the laboratory. This oversight was



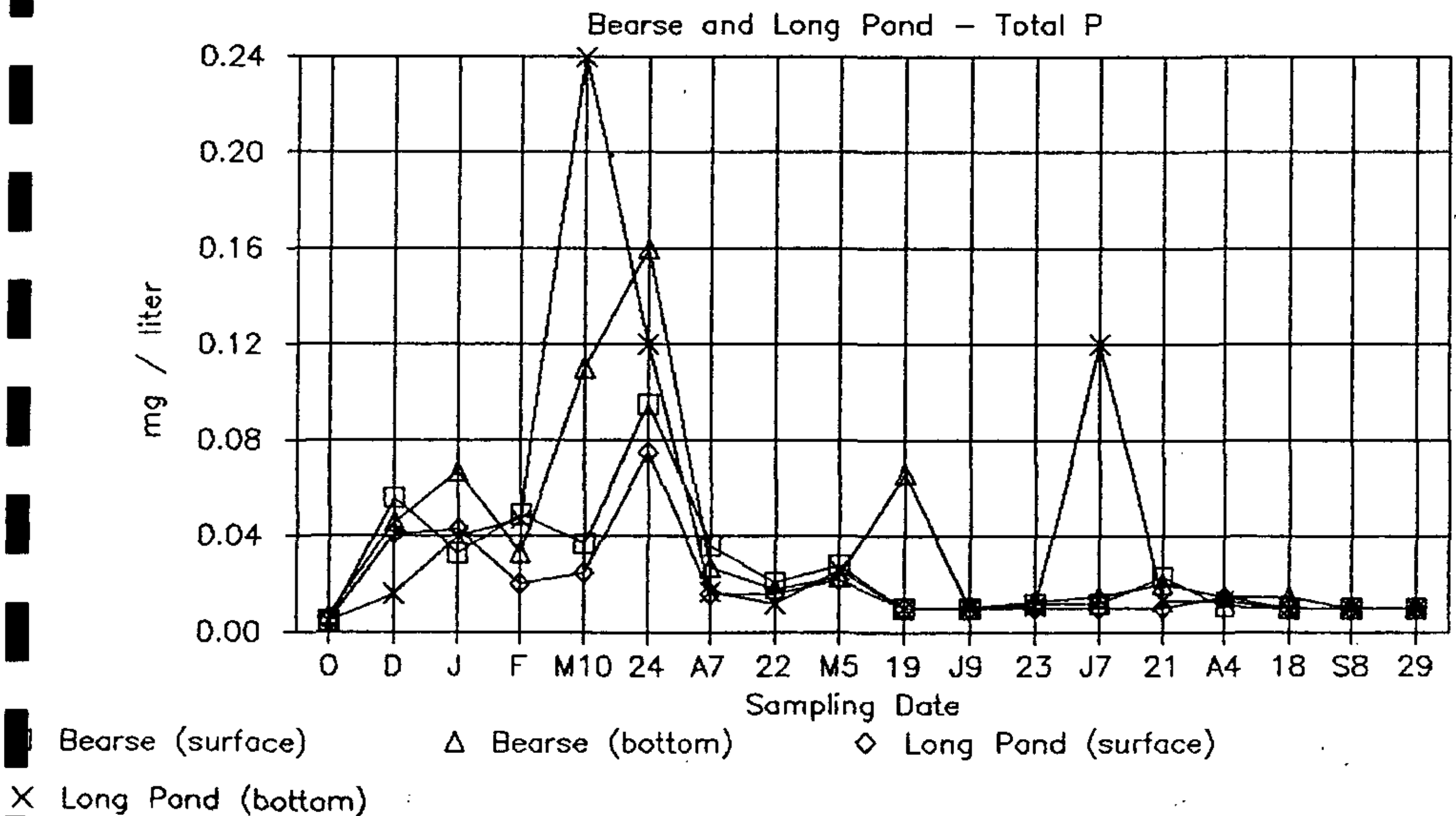
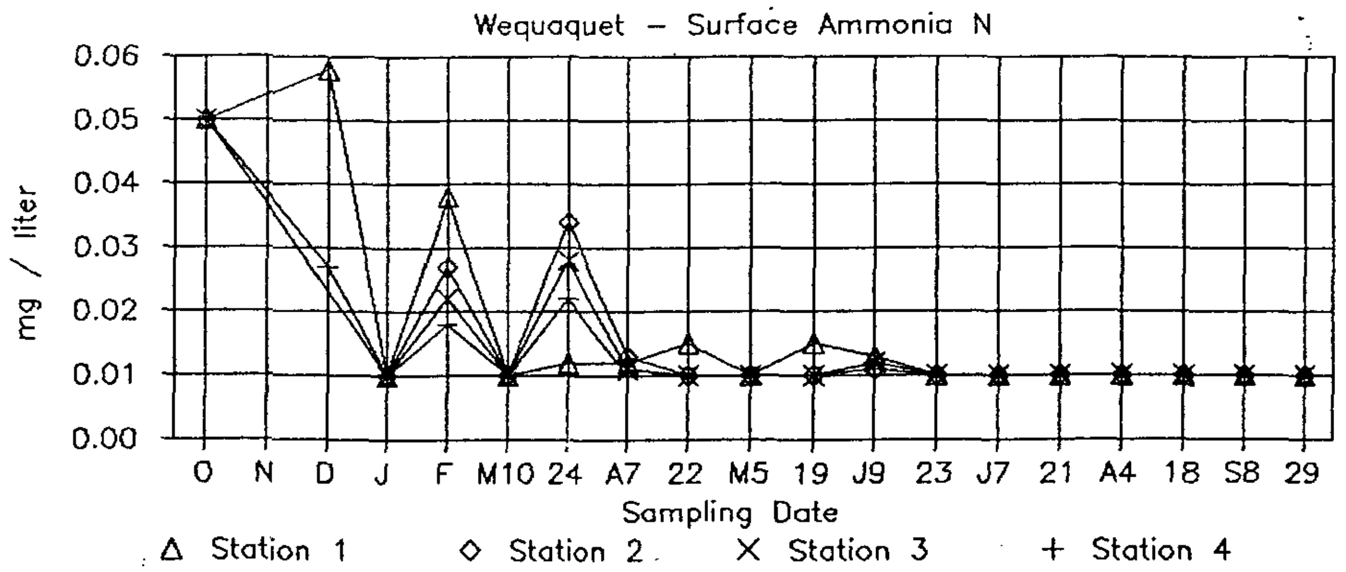
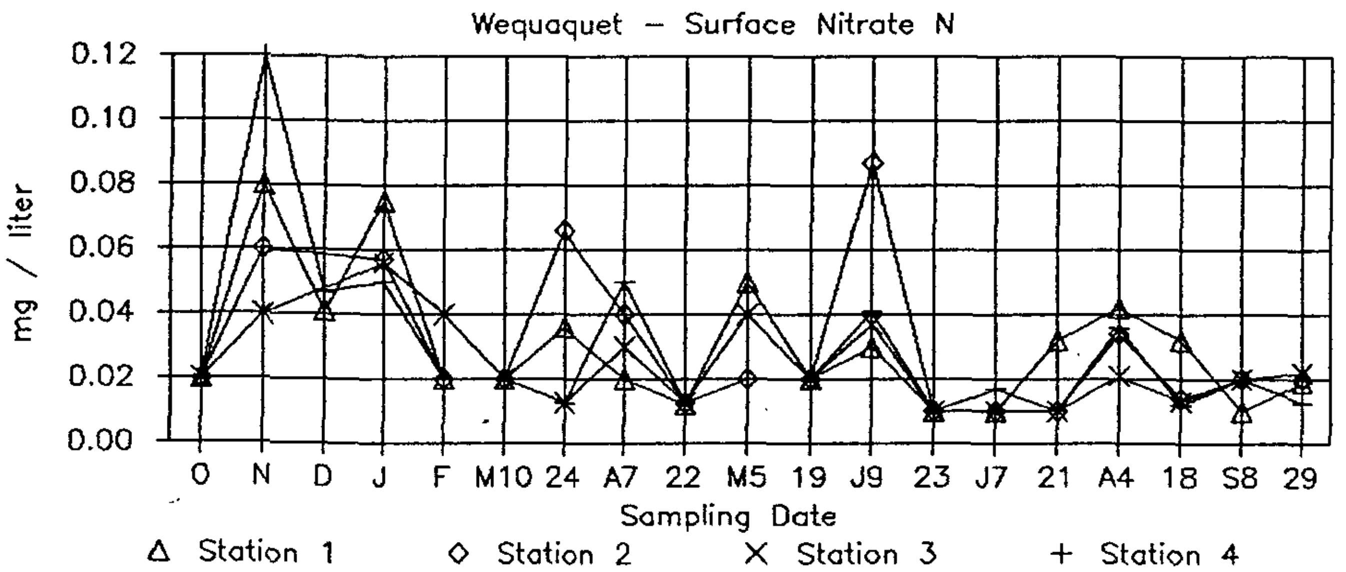


FIGURE 12 - TOTAL PHOSPHORUS





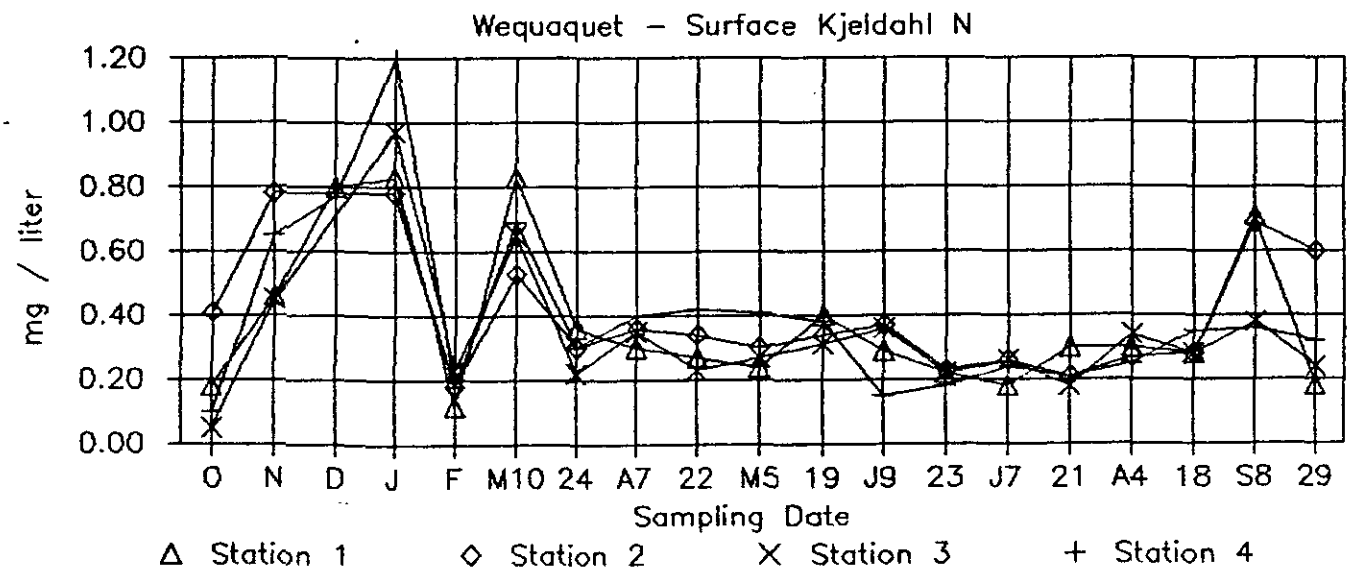
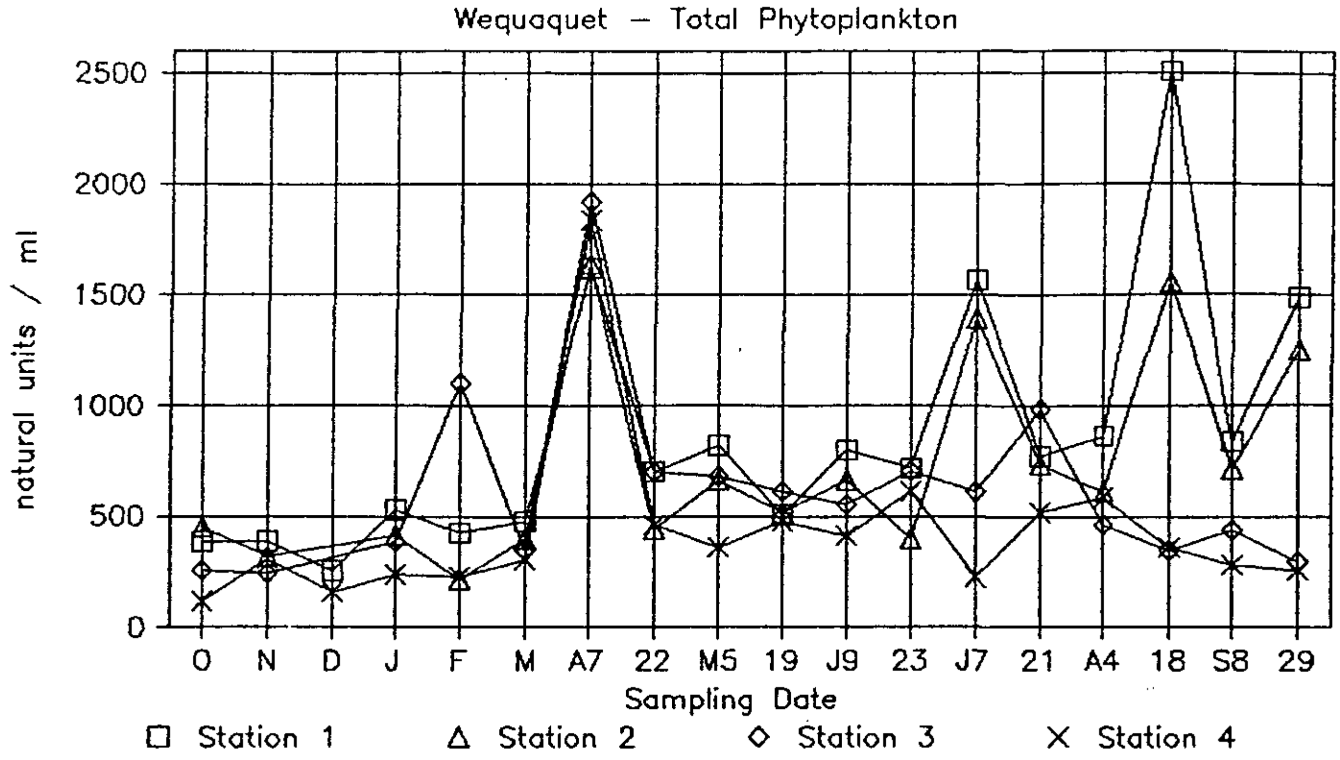


FIGURE 13 - NITROGEN AT WEQUAQUET STATIONS 1 - 4



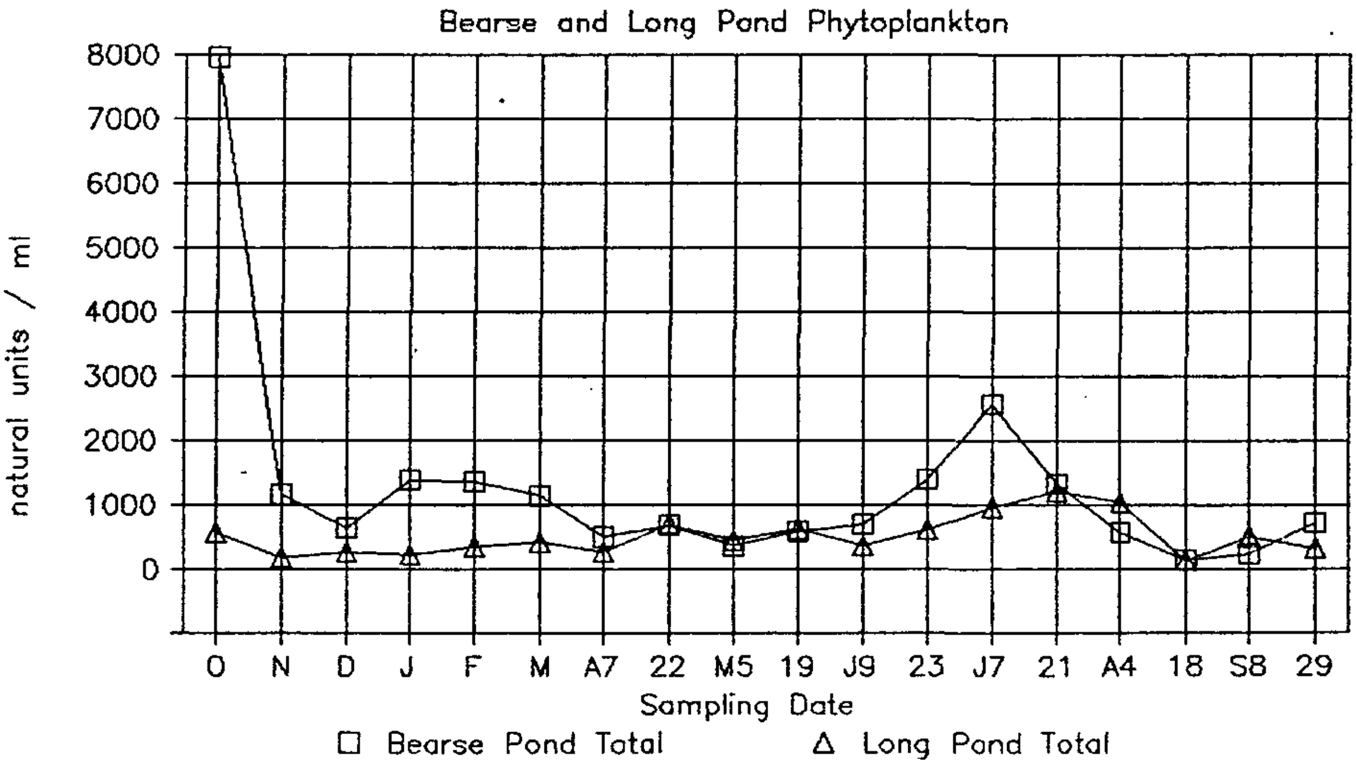


FIGURE 14 – PHYTOPLANKTON

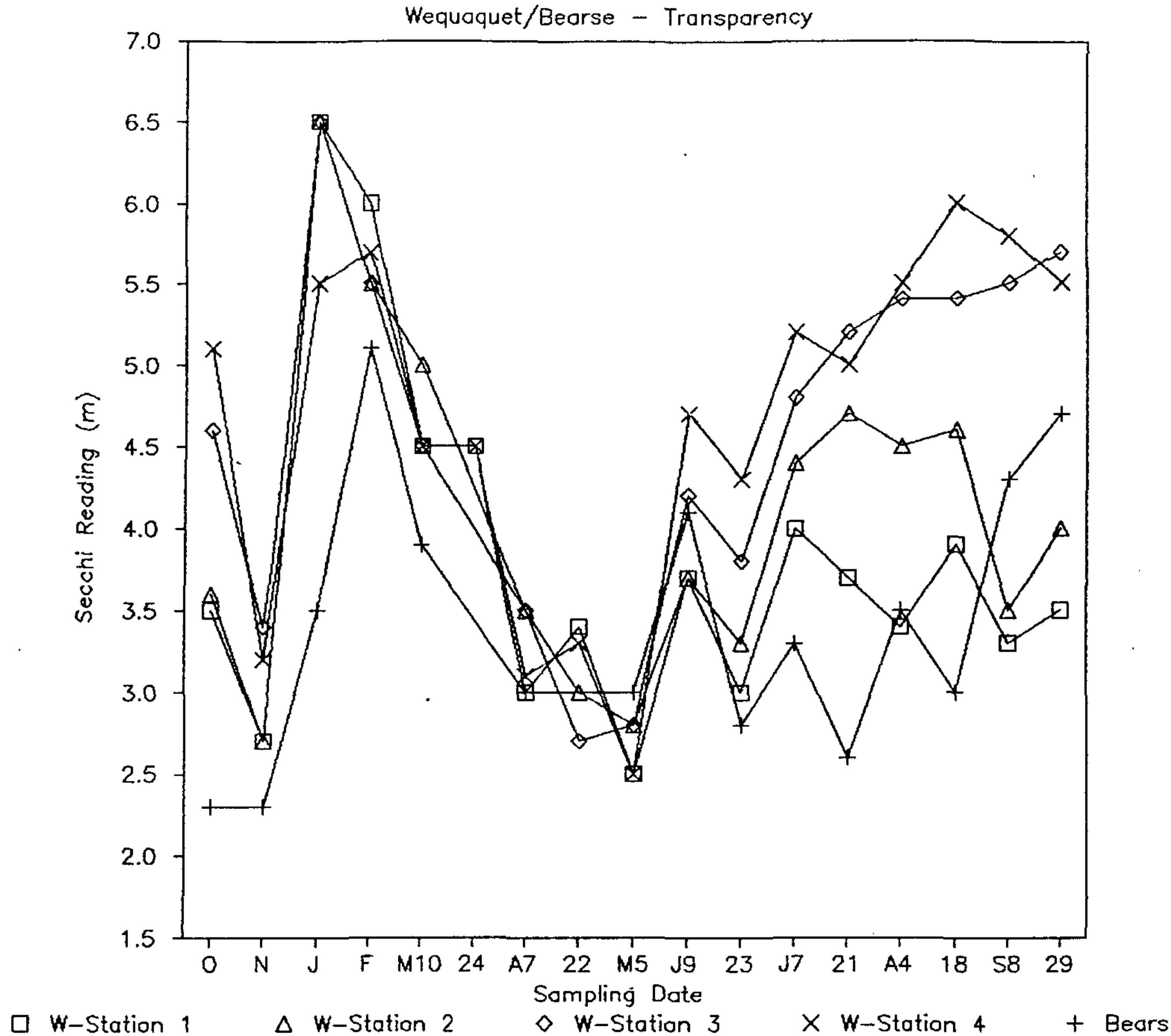


FIGURE 15 - TRANSPARENCY IN WEQUAQUET/BEARSE

TABLE 6

Summary of Nutrient Analyses
(mean of surface values for all sampling rounds in mg/L)

	Wequaquet (n = 76)	Bearse (n = 19)	Long (n = 19)
Total P	0.025	0.026	0.020
Ammonia N	0.015	0.021	0.017
Nitrate N	0.029	0.070	0.116
Kjeldahl N	0.38	0.46	0.46
Total Inorganic N	0.044	0.091	0.133
Ratio of Total N/P	16.4 / 1	20.4 / 1	28.8 / 1

Trophic State Categories (Wetzel, 1983):

	total P (epilimnetic)	total inorganic N (epilimnetic)
Ultraoligotrophic	< 0.005 mg/L	< 0.20 mg/L
Oligo/mesotrophic	0.005 - 0.010 mg/L	0.20 - 0.40 mg/L
Meso/eutrophic	0.010 - 0.030 mg/L	0.30 - 0.65 mg/L
Eutrophic	0.030 - 0.100 mg/L	0.50 - 1.50 mg/L
Hypereutrophic	> 0.100 mg/L	> 1.50 mg/L

remedied and all subsequent analyses were done using instrumentation with the required sensitivity. The November phosphorus data have been deleted from all calculations and figures. Figure 12 plots the monthly values for total phosphorus at various sampling points. Highest values were observed in spring (February-March). This is probably associated with snow melt and "ice-out" that releases phosphorus that has accumulated as bulk precipitation on the frozen surface of the lake (Scheider et al, 1979).

Figure 13 shows monthly values in Wequaquet in-lake stations of ammonia, nitrate, and Kjeldahl nitrogen. Kjeldahl nitrogen is composed of ammonia and organic forms of nitrogen. An inverse relationship between ammonia and Kjeldahl nitrogen is evident. This pattern is probably due to the opposing processes of ammonia uptake by phytoplankton and decomposition of phytoplankton by bacteria. Ammonia taken up by phytoplankton is assimilated into the cells of the algae as organic forms of nitrogen. High values of Kjeldahl nitrogen reflect, in part, the metabolic utilization of ammonia by phytoplankton. Bacterial decomposition of organic material, such as dead phytoplankton, releases ammonia. High values of this parameter often occur as a result of the decomposition of sources of organic nitrogen. Values of nitrate do not undergo a seasonal pattern as observed for phosphorus. The observed values for inorganic nitrogen (ammonia plus nitrate) are characteristic of ultra-oligotrophic water quality status (Wetzel, 1983).

Phytoplankton

The Wequaquet Lakes support a diverse phytoplankton flora. Many of the taxa observed are typically epiphytes and may have come apart from their attachment due to wind-induced water movements. Planktonic algae derived from epiphytes compose a component of the aquatic community known as metaphyton (= tychoplankton). In a continuously mixed system that supports extensive macrophyte beds, like the Wequaquet Lakes, an abundant metaphyton flora is to be expected.

Cyanophytes (blue-green algae) offer the greatest value for diagnosing the nutrient status of a freshwater system. Certain taxa within the Cyanophyta, capable of utilizing atmospheric nitrogen (nitrogen fixation), are minor components of a phosphorus limited community. A shift in the composition of the phytoplankton to dominance by these cyanophytes can be expected in a system changing from phosphorus limitation to nitrogen limitation. None of the nitrogen fixing cyanophytes were a significant component of the phytoplankton during the year of study.

A bloom of the colonial alga Volvox (Chlorophyta) was observed at all in-lake stations of Wequaquet Lake on 7 April (Figure 14). Phytoplankton numbers reached a peak density of 1,900 natural units/ml on this date. The bloom had subsided by 22 April, but phytoplankton numbers remain elevated in comparison to pre-bloom counts. Bearse Pond exibited dramatic fluctuations in phytoplankton numbers and composition (Figure 14). In this respect, Bearse Pond behaves as an independent system, although it is connected to the main body of Wequaquet Lake. This is probably due to a lower flushing rate and elevated nutrient input from a bog area (inactive) at the northern end (see Section 6.2). Note the difference in scale between vertical axes of the plots on Figure 14. The tremendous numbers observed in Bearse Pond in October were the result of the chrysophyte Dinobryon. After falling to below 1,000 natural units/ml in December, another bloom occurred in January. The January bloom was almost entirely due to the diatom Asterionella. A bloom observed on 23 June was due mainly to the chrysophyte Dinobryon, the cyanophyte Anacystis, and the chlorophyte Sphaerocystis.

Phytoplankton density in Long Pond was generally low compared to Wequaquet Lake and Bearse Pond. The relatively high Secchi disk transparency measured in Long Pond (see below) can be attributed to low densities of phytoplankton. Phytoplankton density reached 1,000 natural units/ml in Long Pond on only two sampling dates. On 21 July, phytoplankton numbered 1,210 natural units/ml with Centritractus (Chrysophyta) and Perdinium (Dinophyceae) the dominant genera. On the following sampling date (4 August), phytoplankton numbered 1,039 natural units/ml with the chrysophyte Dinobryon sharing dominance with Perdinium. The results of phytoplankton analyses performed during the year of study are given in Appendix F.

Unfortunately, the method used for chlorophyll-a analysis was inappropriate for freshwater samples so this measure of phytoplankton biomass is not available for comparison to the algae counts reported above. Chlorophyll-a and its degradation product, pheophytin-a, were measured fluorometrically by a subcontractor. The fluorometric method is applicable to marine samples in which chlorophyll-b is absent. Chlorophyll-b is present in many freshwater algae taxa. Pheophytin-b, the degradation product of chlorophyll-b, interferes with the fluorometric determination of pheophytin-a, and thus the determination of chlorophyll-a in freshwater samples (Standard Methods, 1985). The spectrophotometric method should be used for freshwater samples. This error was not recognized until the diagnostic year of sampling was completed.

Non-nutrient Water Quality Parameters

The results of non-nutrient water quality analyses are summarized in Table 7. Long Pond exhibited the greatest transparency of all in-lake stations. The minimum transparency observed in Long Pond was 2.8 meters on 22-April, 1986. Late April and early May was also the time when transparency values in Wequaquet and Bearse were at a minimum (Figure 15). Interestingly, the

TABLE 7

Summary of Non-nutrient Water Quality Analyses
(mean of all samples; range reported in parentheses)

Parameter	Wequaquet Lake	Bearse Pond	Long Pond
Secchi Disk Transparency (m)	4.2 (2.5 - 6.5)	3.4 (2.3 - 5.1)	5.6 (2.8 - 7.4)
Total Suspended Solids (mg/L)	2.6 (0.4 - 34)	2.2 (0.4 - 12)	1.7 (0.4 - 8)
Total Dissolved Solids (mg/L)	55 (13 - 121)	49 (8 - 88)	70.5 (39 - 153)
Chloride (mg/L)	17.2 (14 - 22)	17.7 (15 - 28)	24.0 (21 - 29)
Conductivity (umhos/cm)	77.7 (64 - 85)	78.1 (72 - 86)	101.5 (95 - 115)
pH (standard units; surface values only)	6.6 (5.9 - 7.2)	6.5 (6.1 - 7.0)	6.5 (5.9 - 7.0)
Alkalinity (mg/L; revised surface values only; see Appendix A)	5.5 (3.4 - 8.4)	5.7 (4.0 - 7.8)	4.8 (2.6 - 7.1)

minimum transparency values do not coincide with peak phytoplankton abundance or high concentrations of suspended solids. This unusual lack of correlation may be due to the sensitivity of Secchi disk transparency to the size of suspended particles as well as their concentration. The light attenuation effect of many tiny suspensoids at a concentration of 1 mg/L is greater than the same concentration composed of fewer, more massive particles. After the May minimum, each basin in the Wequaquet/Bearse system exhibited a trend in transparency unique to itself (Figure 15).

Values for total dissolved solids, chloride, and conductivity did not display any seasonal pattern of change, but values for these parameters are consistantly higher in Long Pond than in the Wequaquet/Bearse system (Table 7). The higher values in Long Pond are indicative of a pronounced impact from road runoff and the associated load of deicing salt. The two main sources of this road runoff are Route 28 and West Main Street. Drainage from these roads into Long Pond is evaluated in Section 3.1.4 (Storm Sampling).

Bacteria

Counts of bacteria were generally very low or zero at all in-lake stations. On one occasion counts of total coliform bacteria reached a maximum of 1,000 colonies/100 ml. This occurred in Wequaquet Lake (station 4) and Long Pond on 4 August, 1986. This type of bacteria is ubiquitous in soils and therefore is of little value in diagnosing septic system influence. Fecal coliform bacteria are derived only from the excrement of "warm-blooded" animals (birds and mammals) and are a more useful indicator of fecal contamination. Out of nineteen sampling rounds, fecal coliform bacteria were detected only four or five times at each station. Generally, the counts were low (2 to 5 colonies/100 ml), but reached 40 and 45 colonies/100 ml in October (1985) in Bearse Pond and Wequaquet Lake (station 1) respectively. The resident waterfowl population is probably responsible for episodes of high bacteria counts in localized areas.

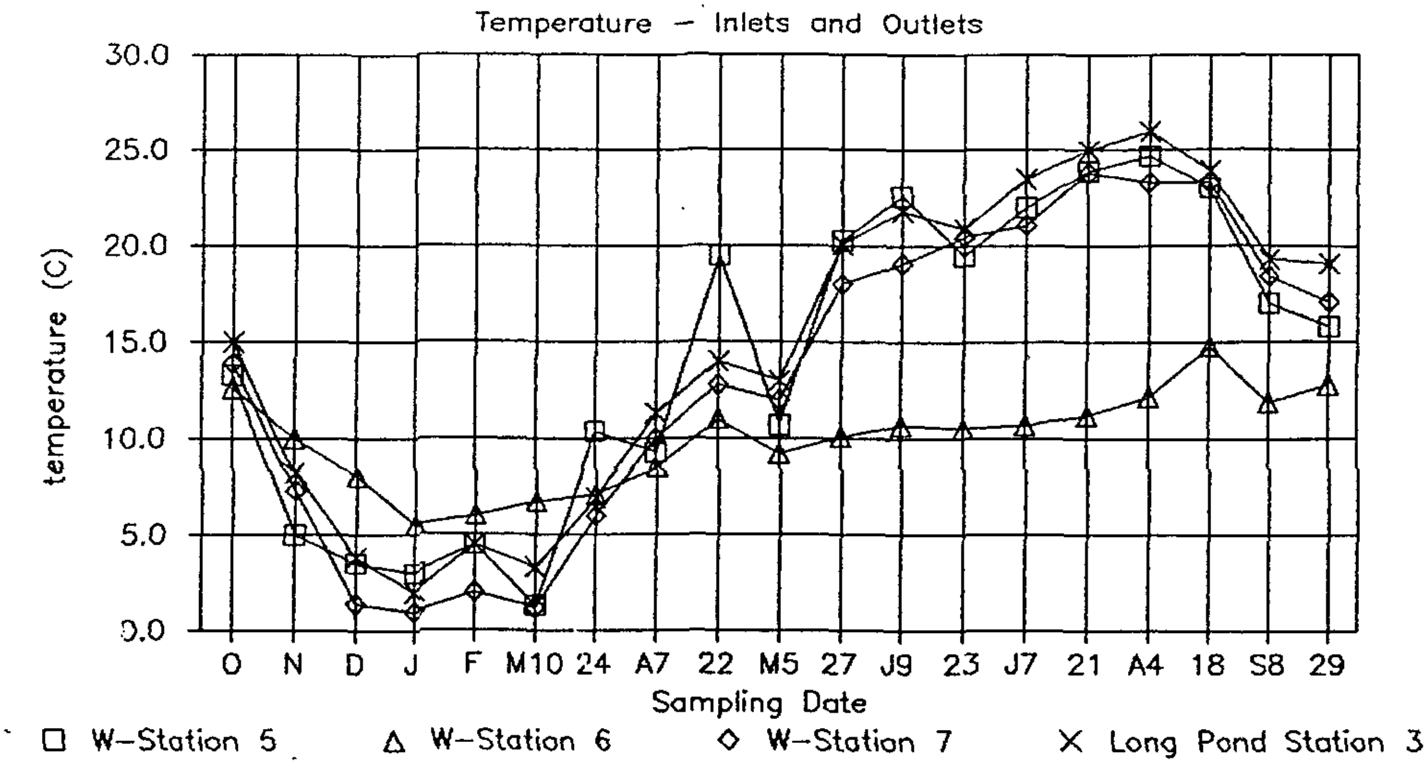
3.1.3 Tributary Assessment

Station 6 drains an area of 188.8 hectares (466 acres) due to an extensive culvert system that connects ponds and depressions located northwest of Wequaquet Lake along Oak Street. Figure 1 shows the watershed areas of Wequaquet Lake/Bearse Pond and Long Pond with the culvert catchment area hatched. On 30 December, 1986 the Hyannis NOAA station recorded 1.85 inches of rain which was enough to raise the level in the largest storage basin in the system up to the lip of its outflow culvert. Additional rainfall on 2 January, 1987 (2.45 inches by 12:30 pm) caused the entire system to flow and to discharge water into Wequaquet Lake at station 6 at a rate of 24 cubic feet/second. This water was readily observed in the lake proper as a cloudy, brown plume extending over 100 meters along the northern shore in the direction of the public boat ramp. A grab sample of the discharge from the station 6 culvert was taken during the storm and the results of lab analysis are given below:

pH (standard units) ----- 4.4		total dissolved
chloride (mg/L) --------- 10.9		solids (mg/L) - 22
conductivity (umhos/cm) - 62		
ammonia (mg/L) ---------- 0.11		total suspended
nitrate (mg/L) ---------- 0.09		solids (mg/L) - 8
Kjeldahl (mg/L) --------- 0.92		
total phosphorus (mg/L) - 0.02		
alkalinity (mg/L) ------- undetectable		

The low pH of this discharge and lack of detectable alkalinity represent a significant acidification threat to the system. Metals and bacteria were not significant in this discharge. Although the concentration of total suspended solids was a low 8 mg/L, the total load of particulates contributed to Wequaquet Lake by this storm was approximately 939 kg (2,066 lbs) due to the large volume of discharge. The culvert catchment area represents 42% of the total Wequaquet/Bearse watershed and, although infrequent, runoff from this system has a definite impact on water quality in Wequaquet Lake.

A slight volume of flow into the lake occurs at station 6 even without storm discharge. Measurements of water quality parameters taken at station 6 during regular sampling rounds indicate that this flow is mostly groundwater seepage. The uniformly colder temperatures and low dissolved oxygen values observed here (Figure 16) are characteristic of ground water. Also, levels of nitrate are consistantly elevated at this station (mean concentration = 0.48 mg/L) providing evidence of the high density of septic systems in areas upgradient. Groundwater seepage here is to be expected, as this point is located in the center of the interface between shoreline and recharge area (Figure 4).



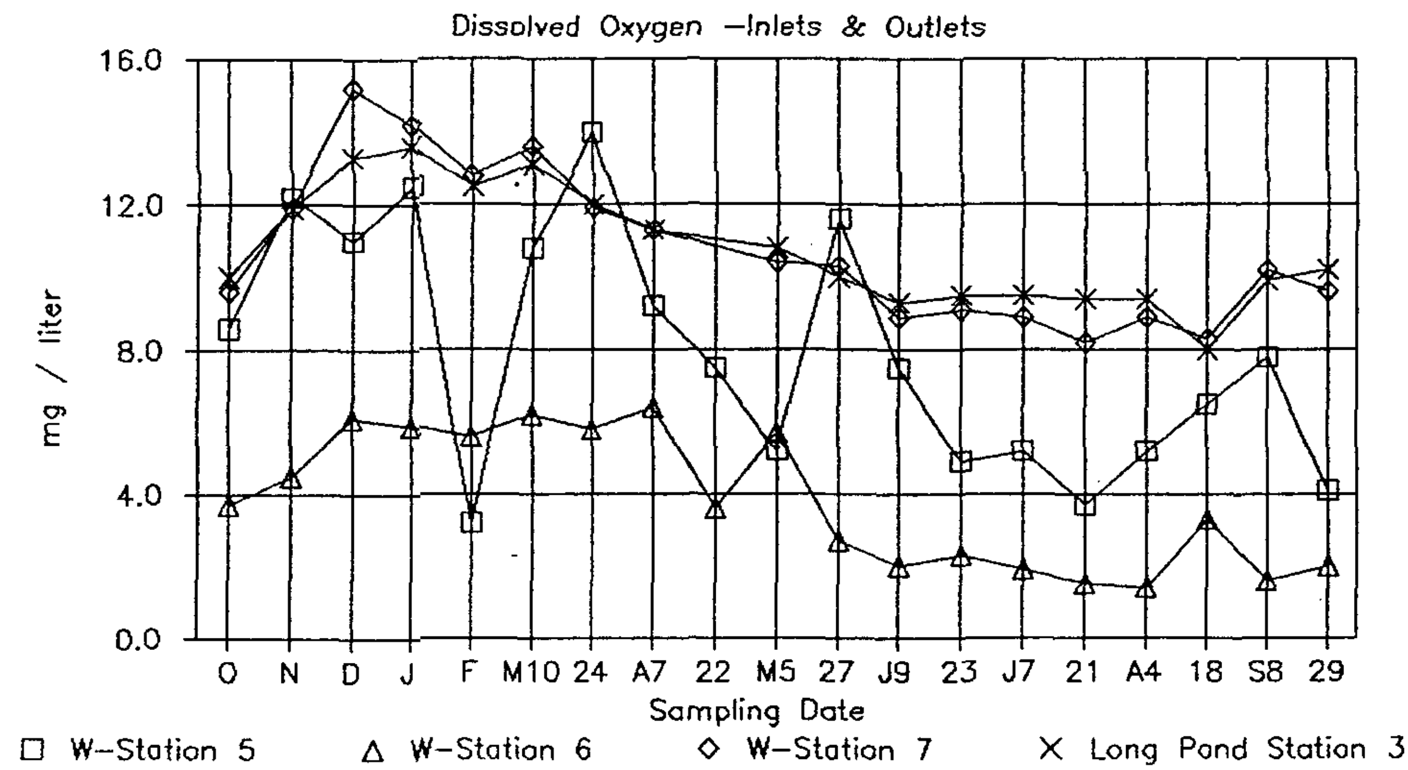


FIGURE 16 - TEMPERATURE AND DISSOLVED OXYGEN AT WEQUAQUET STATIONS 5, 6, AND 7 AND AT LONG POND STATION 3

Station 5 functions as a tributary only when water level in the ajoining bog is manipulated. All of the samples collected at this station consisted of "grabs" of water from the ditch immediately upstream of the control structure. Analysis of these samples document low values for pH and alkalinity, typical of bog habitats. Dissolved oxygen at this station varied unpredictably due to widely ranging temperature and biological activity in the bog ditch (Figure 16).

The nutrient load to Wequaquet Lake from the cranberry bog at station 5 has been quantified following discussions with Dr. Karl Deubert of the Cranberry Experiment Station in Wareham. Typically, significant outflow from cranberry bogs to ajoining water bodies occurs twice a year. These are the release of water used to flood the bog during the picking season (September-October) and the release of flood water which covers the bog in winter to protect the cranberry plants from dessication (released in March). For each of these management practices, the bog is flooded with approximately one foot of water. Thus, the volume of water released from a typical bog in a year is given by the following:

2 x 1 foot x area of bog

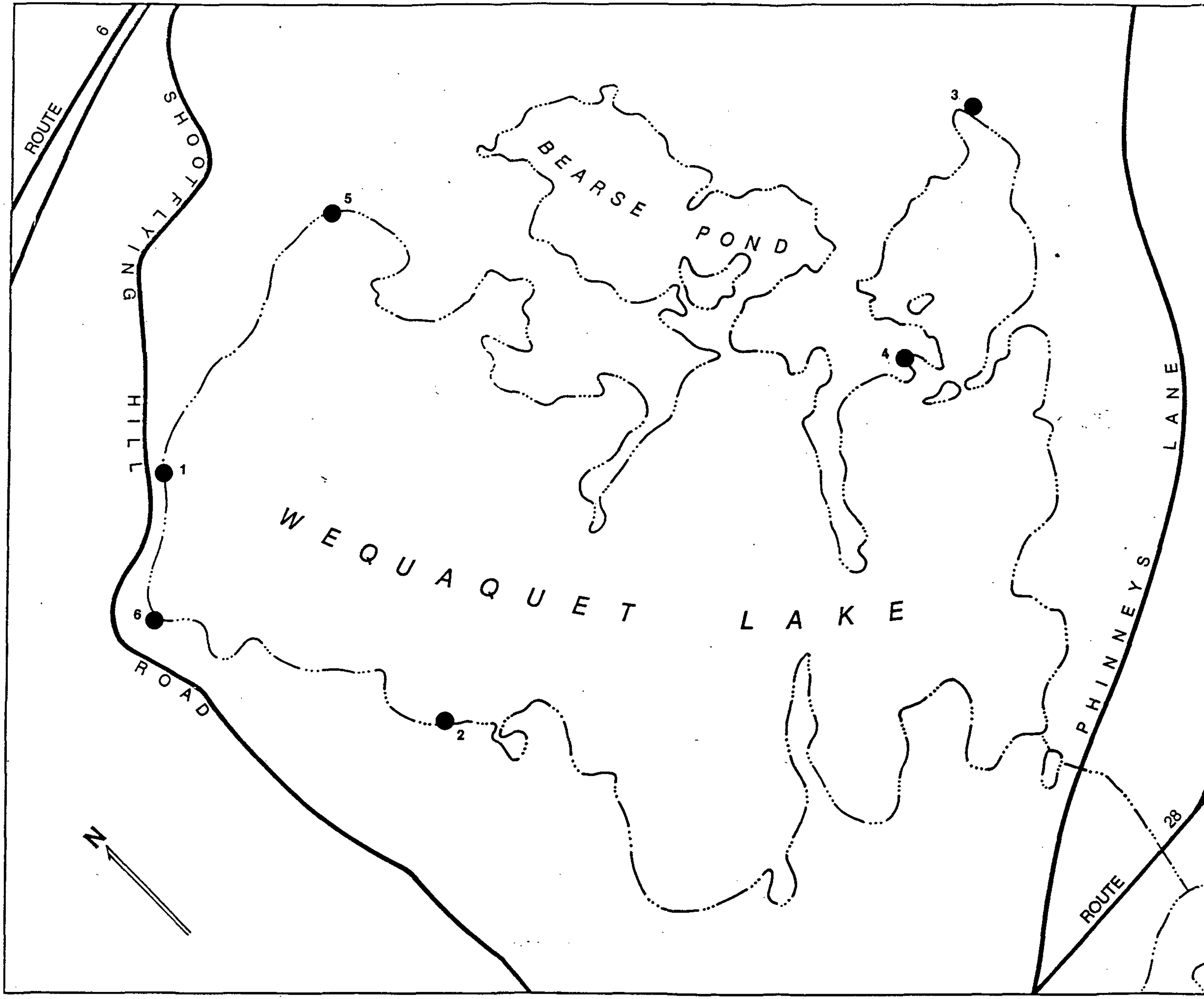
The volume of water released from the cranberry bog at station 5 (area = 7.7 acres), obtained using the above method, multiplied by the median phosphorus concentration (0.22 mg/L) observed during the 19 sampling rounds, gives the annual load from this source (see Section 6.0, Nutrient Budget). This calculation reflects typical water usage in the cranberry bog and is representative of loading under a variety of potential management practices.

3.1.4 Storm Sampling

Sources of storm runoff into Wequaquet Lake and Long Pond have been identified and are shown in Figures 17 and 18 respectively. Table 8 provides a summary of sampling results and a brief description of each sampling point. No points of significant storm drainage exist on Bearse Pond.

The first round of sampling was done during a storm that occurred on 27 August, 1986. This storm deposited only 0.02 inches of rain, but observation of runoff volume and analyses of water quality indicate which stations have significant impacts on Wequaquet Lake and Long Pond. The laboratory report on water quality analyses of the runoff samples is in Appendix B.

Station WS-1 (Wequaquet boat ramp) was highest in concentrations of suspended solids, total phosphorus and all metals, and has the potential to contribute significant volume during a heavy storm. Station LPS-1 (culvert located on northeast shore of Long Pond) had the highest concentrations of



DIAGNOSTIC/FEASIBILITY STUDY OF WEQUAQUET LAKE, BEARSE AND LONG PONDS

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WEQUAQUET LAKE AND BEARSE POND

FIGURE 17 - WEQUAQUET STORM RUNOFF LOCATIONS

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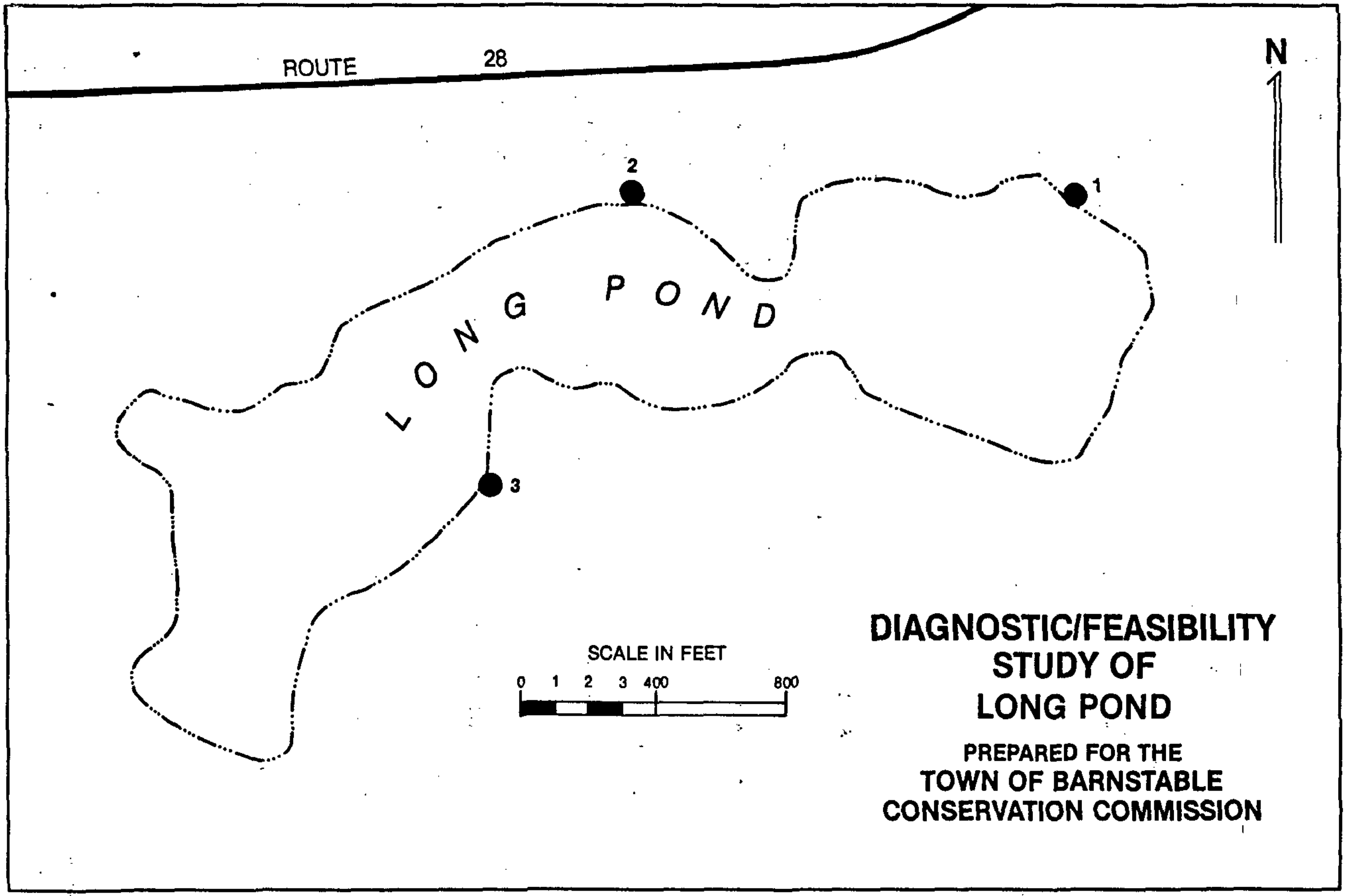

FIGURE 18 - LONG POND STORM RUNOFF LOCATIONS

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TABLE 8 - SUMMARY OF STORM SAMPLING RESULTS
(median total P concentration given in [mg/L])

Sampling Date	STATION NUMBER WS-1	WS-2	WS-3	WS-4	W-5	W-6	LPS-1	LP-2	LPS-3
27 Aug.'86 (0.02 inches)	[0.17] TSS, all forms of nitrogen, and metals significant	[0.02]	no flow	[0.16]	no flow	[0.07] discharge not from culvert system	[0.16] TDS and all forms of nitrogen significant	[0.08]	no flow
11 Nov.'86 (0.2 inches)	[0.13] fecal coliform significant	no flow	no flow	----	----	----	[0.20] fecal coliform significant	----	no flow
2 Jan.'87 (2.45 inches)	----	----	----	----	----	[0.02]	----	----	----

Station	Description	Drainage Area	Annual P Load	Additional Observations
WS-1	public boat ramp	3,680 sq. m	0.7 kg	concentrations of metals and other parameters are highly variable, runoff quality degraded in summer
WS-2	Lakewood Dr. swale	583 sq. m	<0.1 kg	insignificant volume
WS-3	Huckins Neck Rd. access point	-------	none	
WS-4	Lakeside Dr. ramp	584 sq. m	0.1 kg	insignificant volume
W-5	bog inlet	-------	4.2 kg	not contributed as storm runoff, see Section 3.1.3
W-6	Oak St. culvert	188.8 ha	2.4 kg	total P load contributed in one storm, see Section 3.1.3
LPS-1	West Main St. culvert	5,145 sq. m	1.1 kg	concentrations of oil and grease significant on both sampling dates (median value = 4.4 mg/L)
LP-2	Phinneys Lane crossing	5,542 sq. m	0.5 kg	runoff discharged into herring run, runoff to herring run from Route 28 not sampled
LPS-3	Dunaskin Rd. access	-------	none	

dissolved solids and all forms of nitrogen and contributed significant volume even during this brief storm. After consultation with the DWPC project officer, stations WS-1 and LPS-1 were selected for further sampling.

On 11 November, 1986 a second round of sampling was conducted during a storm that deposited 0.2 inches of rain. Analysis of the samples taken at stations WS-1 and LPS-1 document, for certain parameters, runoff characteristics improved over those measured during the first storm. Levels of nitrogen (all forms), solids, and metals were lower (Appendix B; samples labeled LP-1 through 10 are first flush and interval samples taken according to DEQE methods; samples W-1A, W-1B, and W-1C are samples of stormwater "breaking out" on the shoreline, from the northeast basin, and from the southwest basin respectively). However, runoff from the 11 November was higher in fecal coliform at both stations and station LPS-1 exhibited higher concentrations of total phosphorus than measured previously (Table 8). Station LPS-1 collects drainage from an extensive parking lot and, on both occasions, levels of oil and grease in the discharge were significant.

Station 5 was never observed to discharge during storm conditions and generally contributes water to Wequaquet Lake only twice a year during management of the cranberry bog (see Section 3.1.3, Tributary Assessment). Station 6 has the potential to greatly influence water quality in Wequaquet Lake due to its extensive drainage area. Discharge at this station was sampled 2 January, 1987 during a storm that deposited 2.45 inches of rain. Results of this sampling round and the impact from station 6 culvert system are evaluated in Section 3.1.3 (Tributary Assessment).

3.1.5 Acidification Survey

Alkalinity is a measure of the capacity of a solution to neutralize acid. Typically it is carbonate, bicarbonate, and hydroxyl ions that impart the property of alkalinity to freshwaters, but other titratable bases may also contribute. Ions contributing to alkalinity provide the principal mechanism for buffering fresh waters from changes in pH. Preliminary sampling results indicated that total alkalinity at all stations in Wequaquet Lake/Bearse Pond was less than 20 mg/L. Therefore, the analysis method was changed to a low alkalinity determination, which is more sensitive at low values. Sampling over the year of study indicated alkalinities consistently less than 10 mg/L, and occasionally less than 5 mg/L. This is in the range that is considered highly sensitive to acidic deposition, using the classification system developed by the Massachusetts Acid Rain Monitoring Project (Godfrey et al, 1984). The low alkalinity observed in the Wequaquet Lakes is typical of most Cape Cod lakes. The sand and gravel underlying the drainage basins of these lakes are poor sources of ions that contribute to alkalinity. Despite the low alkalinity, pH levels in the Wequaquet Lakes remained consistent throughout the year (Table 7).

3.2 Macrophyte Survey

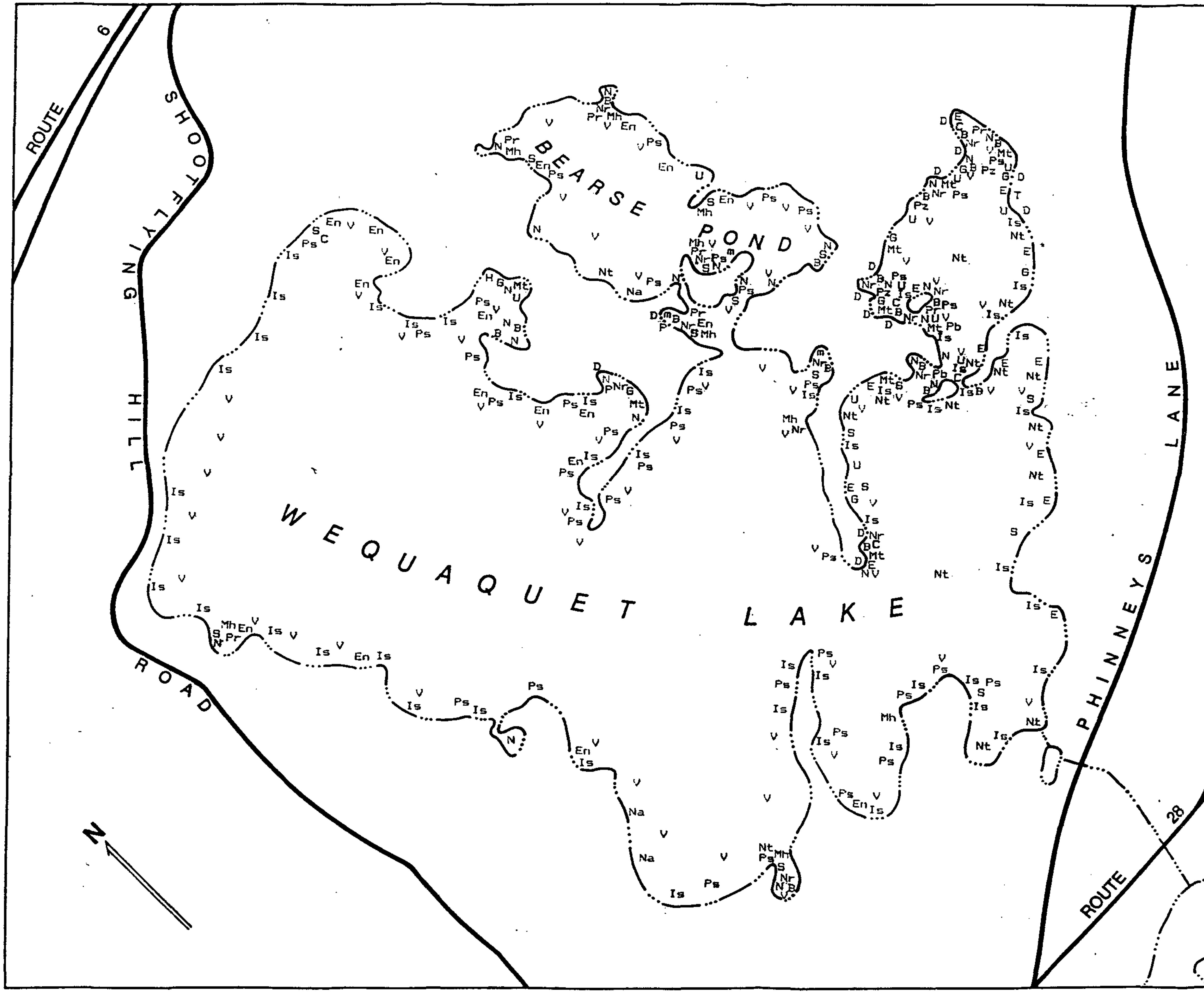
A survey of the macrophytes (aquatic plants) was performed from a boat from 29 August to 8 September. Observations were made through a viewing box as the boat motored slowly around the shoreline of the lake. Locations and approximate coverage of the various macrophyte genera were noted on a map of the lake. The results of this survey are depicted in Figures 19 through 22. Depth distributions and substrate preferences of the genera represented were also recorded.

Zonation in the distribution of the dominant species was often evident. Sagitteria teres and Isoetes sp. were most common in shallow water. A transition from these species to Elodea nuttallii, Potamogeton pusillus, and Myriophyllum humile was observed when moving into deeper water. At the greatest depth observable (approximately 12 to 15 feet) Vallisneria americana was the dominant species. Coverage varied generally from 40 to 90% and extended out of view into deep water. Three species of macrophyte with broad, floating leaves; Brasenia schreberi, Nymphaea odorata, and Nuphar variegata were abundant in coves and protected areas of the lake. Nitella sp. was often recovered on the anchor at stations 3 and 4 (water depth approximately 18 feet). Generally, all macrophyte species were observed growing in substrates that had an organic component. Macrophytes were scarce in areas where the substrate is composed of sand or gravel.

Sagitteria teres (Terete Arrowhead) is listed as a species of special concern by the Massachusetts Natural Heritage Program. In the Wequaquet Lakes this plant is abundant and covers extensive shallow water areas. Many specimens growing along the shoreline as emergents produced a small white flower in late summer.

Samples for biomass measurements were collected by a diver using SCUBA. The diver lowered a one square meter iron frame over the macrophytes to be sampled and collected, by hand, all the vegetation originating on the substrate within the quadrat. Areas sampled were selected because they contained the dominant species of the lake flora and were representative of the percent coverages observed most frequently.

For most plant species sampled, the vegetation collected consisted mainly of above-substrate tissue only (stems and leaves). When collecting certain species of plant, the roots would pull out of the sediment instead of breaking away cleanly (especially Sagittaria teres and Isoetes sp.). In these cases the entire plant was collected. Once the collection of plants within the quadrat was complete, the plants were taken to the surface, rinsed in the mesh collecting bag to wash away sediment, and transferred to a plastic bag.



DIAGNOSTIC/FEASIBILITY STUDY OF WEQUAQUET LAKE, BEARSE AND LONG PONDS

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WEQUAQUET LAKE AND BEARSE POND

SCALE IN FEET

0 2 4 6 800 1600

FIGURE 19 - MACROPHYTE DISTRIBUTION IN WEQUAQUET LAKE

Key to Macrophyte Symbols

B - Brasenia schreberi (water shield)
C - Ceratophyllum demersum (coontail)
D - Decodon sp. (water willow)
En - Elodea nuttallii (waterweed)
E - Eriocaulon sp. (pipewort)
G - Gratiola sp. (hedge hyssop)
H - Hydrocotyle sp. (water pennywort)
Is - Isoetes sp. (quillwort fern)
m - aquatic moss
Mh - Myriophyllum humile (water milfoil)
Mt - Myriophyllum tenellum (water milfoil)
N - Nymphaea odorata (white waterlily)
Na - Najas flexilis (naiad)
Nr - Nuphar variegata (yellow waterlily)
Nt - Nitella sp. (macroscopic alga)
P - Pontederia sp. (pickerelweed)
Pb - Potamogeton bicupulatus (pondweed)
Ps - Potamogeton pusillus (pondweed)
Pr - Potamogeton robbinsii (pondweed)
Pz - Potamogeton zosteriformes (pondweed)
S - Sagittaria teres (arrowhead)
T - Typha sp. (cattail)
U - Utricularia sp. (bladderwort)
V - Vallisneria americana (tapegrass)

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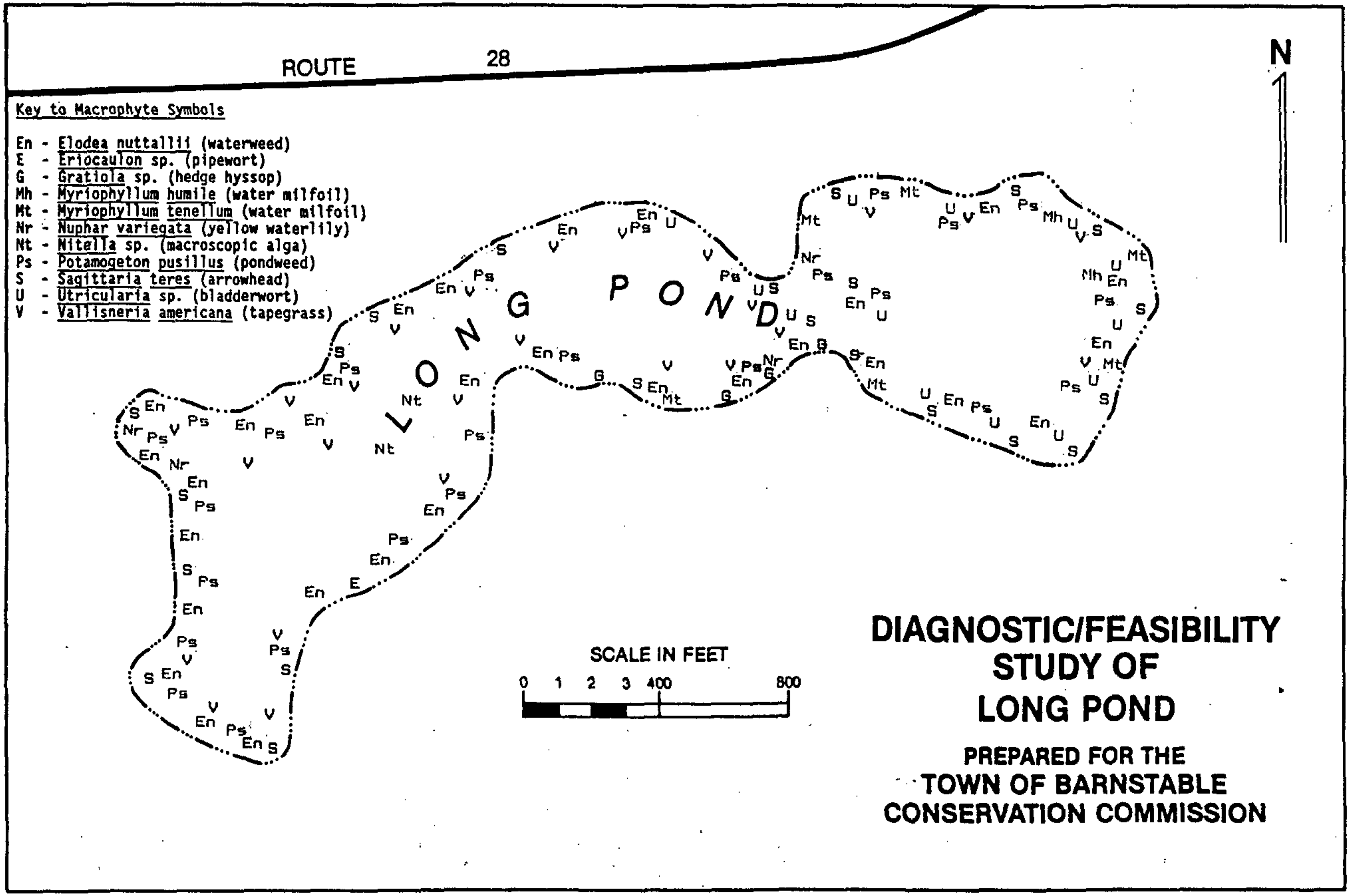
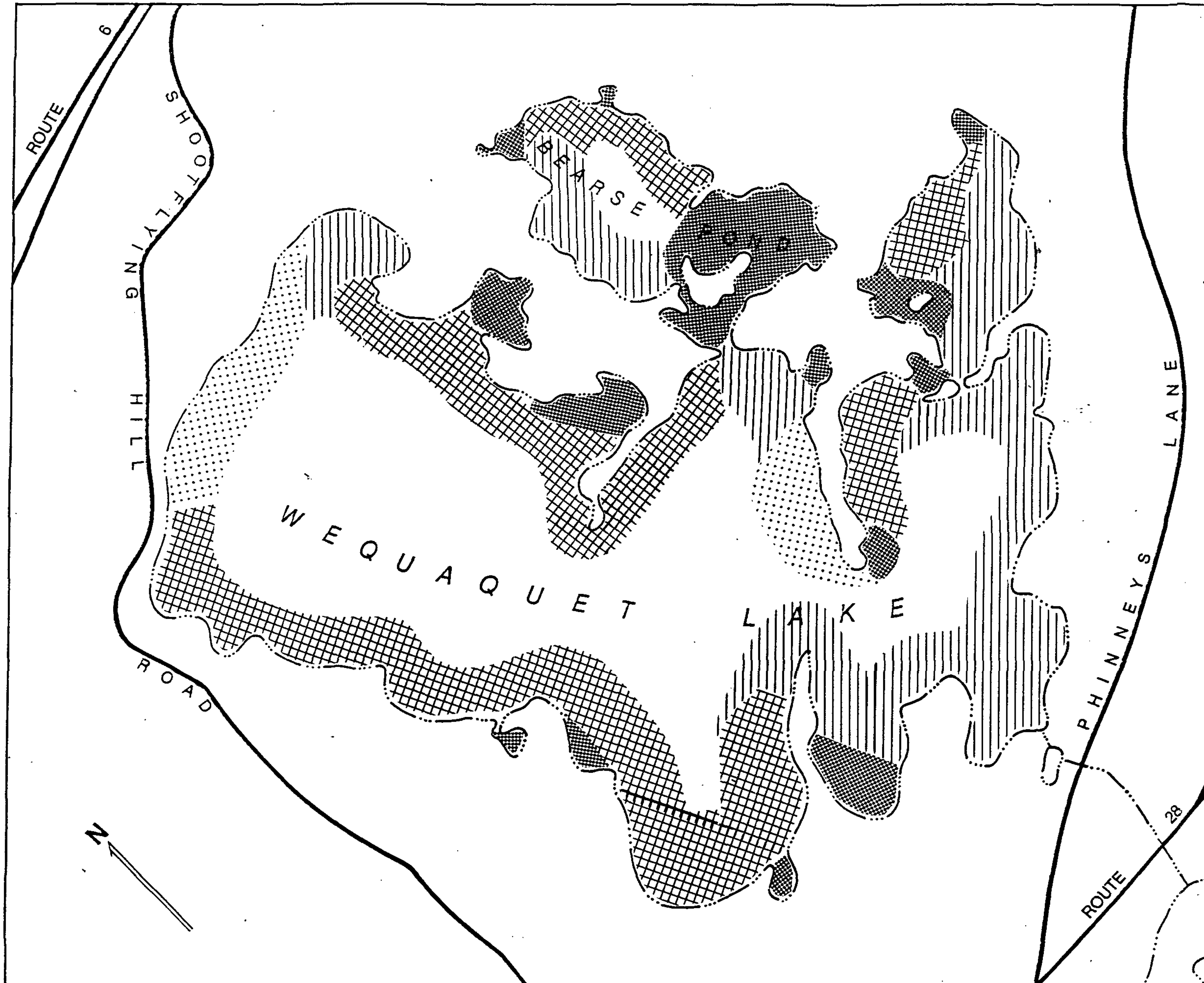


FIGURE 20 - MACROPHYTE DISTRIBUTION IN LONG POND



DIAGNOSTIC/FEASIBILITY STUDY OF WEQUAQUET LAKE, BEARSE AND LONG PONDS

PREPARED FOR THE TOWN OF BARNSTABLE CONSERVATION COMMISSION

WEQUAQUET LAKE AND BEARSE POND

SCALE IN FEET

0 2 4 6 800 1600

FIGURE 21 - MACROPHYTE DENSITY IN WEQUAQUET LAKE

Legend (% coverage)

0 to 25 %

25 to 50 %

50 to 75 %

75 to 100 %

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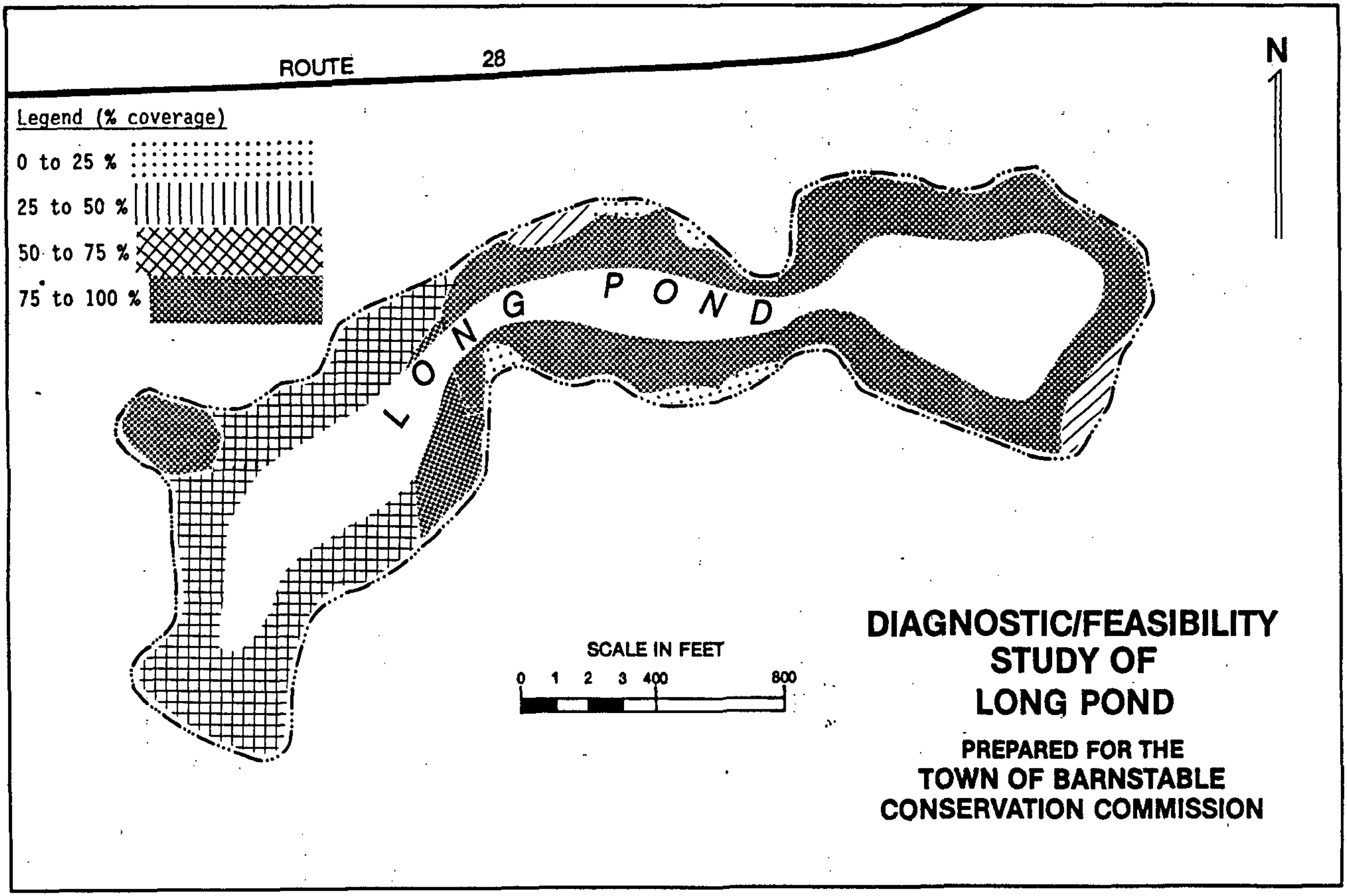


FIGURE 22 - MACROPHYTE DENSITY IN LONG POND

IEP inc.

The plastic bags containing the collected macrophytes were stored at 1 degree C until wet-weight measurement. Water associated with the plants was drained away before wet-weight measurement by spinning them at arms length in a mesh collecting bag. Spinning was continued until the water draining away was reduced to a fine spray. This procedure is analogous to the machine spinning recommended in Standard Methods. A Chatillon Model IN-6 spring scale was used to weigh all samples.

After measuring wet-weight, a subsample was taken for dry-weight determination. This subsample was weighed wet, placed in an oven at 125 degrees C for approximately 24 hours, and then reweighed after drying. Dry weight of the total sample was obtained by multiplying the total wet weight by the ratio of subsample dry weight to subsample wet weight. Results of biomass determinations are given in Table 9. The potential for nutrient removal by harvesting of macrophytes was evaluated using the method of Burton et al (1979). The results of these calculations are given in Table 10. The feasibility of nutrient removal by harvesting in the Wequaquet Lakes is evaluated in Section 8.2.1.

TABLE 9 - Macrophyte Biomass Measurements (all weights in kg)

sample #	quadrat wet wt.	quadrat dry wt.	description
Wequaquet Lake			
WM-1	0.88	0.05	almost 100% _Vallisneria_ _americana_ (_Isoetes_ sp. present)
WM-2	0.85	0.06	samples taken at a depth of 8 ft. in "Gooseberry Pond" near access point on 31-August
WM-3	1.14	0.07	
WM-4	1.92	0.21	mixed _Isoetes_ sp. (dominant) and _Potamogeton_ _pusillus_
WM-5	2.07	0.18	
WM-6	1.45	0.08	samples taken at a depth of 10 ft. south of Great Point on 2-September
Bearse Pond			
BM-1	4.60	0.24	mixed _Sagittaria_ _teres_ (dominant), _Najas_ _flexilis_, and _Isoetes_ sp.
BM-1 replicate		0.25	sample taken at a depth of 6 ft. in Snow's Cove on 31-August
Long Pond			
LPM-1	0.78	0.05	mixed _Elodea_ _nuttallii_ (dominant) and _Potamogeton_ _pusillus_ sample taken at a depth of 7 ft. off north shore of Long Pond on 4-September

TABLE 10 - Nutrient Removal By Harvesting of Macrophytes
(all values as kg/ha except % moisture)

Plot #	Wet Mass	Dry Mass	Percent Moisture	Total Phosphorus Removal Rate	Total Nitrogen Removal Rate
WM-1	8800	500	94%	1.5	15.0
WM-2	8500	600	93%	1.8	18.0
WM-3	11400	700	94%	2.1	21.0
WM-4	19200	2100	89%	6.3	63.0
WM-5	20700	1800	91%	5.4	54.0
WM-6	14500	800	94%	2.4	24.0
BM-1	46000	2400	95%	7.2	72.0
LPM-1	7800	500	94%	1.5	15.0

Three assumptions are incorporated into these calculations according to the method (Burton et al, 1979) used here. They are as follows:

1.) Harvesting is done in areas where there is 100% coverage of macrophytes.

2.) The average phosphorus content of all macrophytes is 0.3% of dry mass.

3.) The average nitrogen content of all macrophytes is 3.0% of dry mass.

3.3 Fish Inventory

The Wequaquet Lakes have been stocked with a variety of fish species dating back to 1931 (Table 11). According to Barnstable's Natural Resource Officer, Mr. Charles Millen, the fisheries status on Wequaquet, Bearse and Long Pond is very good (Table 12). Excellent pike and pickerel fishing through the ice has been observed in recent years on Wequaquet and Bearse Pond. Wequaquet contains many rocky shoal areas around Long Point, Hayes Point, and Stoney Point, which are ideal breeding habitat for largemouth and smallmouth bass, and white suckers. Shallow weedy areas and coves such as Snow's Cove, the inlet to Gooseberry Island Cove, and the cove near Lewis Point provide excellent breeding habitat for northern pike, chain pickerel, and yellow perch, as well as protective cover for juvenile fish and food source areas for predatory fish species. Over-abundant populations of stunted smallmouth bass and yellow perch have been declining in recent years on Wequaquet, along with the apparent extermination of the white perch population which may have coincided with the northern pike stocking and the failure of the herring run in the past several years. This has limited the numbers of a valuable forage species, the herring (alewife), which are preyed upon extensively by northern pike. In the absence of herring, pike will switch to alternate forage species like perch and small bass. The most likely cause of the disappearance of the white perch populations is the herring run itself, because white perch like to migrate to brackish or sea water to breed. The closing of the herring run in some years may have caused poor reproduction, from which the species could not recover.

Life-history Characteristics of the Alewife

Alewives (*Alosa pseudoharengus*) are anadromous fish that require use of the herring run at two times during the year in order to successfully complete their reproductive cycle. The spawning run by the adult fish entails migrating upstream from the sea to their breeding pond, spawning in shallow areas around the edge of the pond, and returning to salt water. The spawning season varies slightly from year to year, depending principally upon water temperature. The spawning run typically starts during the second week in April, although a run beginning as early as 19 March has been recorded. The majority of the fish have completed the spawning run by the first of June.

Young fry hatch from eggs deposited on the spawning grounds and grow rapidly during the summer months. Many of these juvenile fish are ready to begin their downstream passage to the sea as early as July, but the majority do not start this journey until September. Most of the juvenile fish have

TABLE 11

Stocking Information, Wequaquet, Bearse, and Long Pond*

Fish Species	Years Stocked	Total Numbers
Smallmouth Bass (*Micropterus dolomieui*)	1932-1947	16,350
Largemouth Bass (*Micropterus salmoides*)	1931	10,000
Brown Bullhead (*Ictalurus nebulosus*)	1940, 1944	8,200
White Perch (*Morone americana*)	1936-1947	7,300
Yellow Perch (*Perca flavescens*)	1932-1944	3,800
Chain Pickerel (*Esox niger*)	1940, 1944	200
Northern Pike (*Esox lucius*)	1978	**

* Long Pond has never been stocked by Massachusetts Fish & Wildlife, and Bearse is considered to be part of Wequaquet.

** No numbers given by Massachusetts Fish & Wildlife

TABLE 12

Fish species in Wequaquet, Bearse and Long Ponds

Fish Species	Wequaquet		Long	
Blueback Herring (*Alosa aestivalis*)	x	+	x	+
Alewife (*Alosa psuedoharengus*)	x	+	x	+
American Eel (*Anguilla rostrata*)	x	+	x	+
White Sucker (*Catostomus commersoni*)	x	+	x	+
Chain Pickerel (*Esox niger*)	x	+	x	+
Brown Bullhead (*Ictalurus nebulosus*)	x	+	x	+
Bluegill Sunfish (*Lepomis macrochirus*)		+		+
Pumpkinseed Sunfish (*Lepomis gibbosus*)		+		+
Smallmouth Bass (*Micropterus dolomieui*)	x	+	x	+
Largemouth Bass (*Micropterus salmoides*)	x	+		+
White Perch (*Morone americana*)	x		x	
Striped Bass (*Morone saxotilis*)		+		
Golden Shiner (*Notemigonus crysoleucas*)	x	+		+
Yellow Perch (*Perca flavescens*)	x	+	x	+
Northern Pike (*Esox lucius*)		+		

x = occurred historically

\+ = occurs presently, according to the Massachusetts Division of Fish & Wildlife, Natural Resource officer Charles Millen, and IEP questionnaire passed downstream by mid-October. The timing of the life-history characteristics outlined above can be summarized as follows:

2nd week of April to first of June		late April to late August		first of September to mid-October
spawning run by adults	-->	hatching of eggs and growth of fry	-->	downstream passage of juveniles

Passage of adults during their spawning run in spring and downstream passage of juveniles in fall necessitates a minimum level in Wequaquet of 33.8 feet MSL for the herring run to function. Unfortunately, storage of water at this level in the lake conflicts with other concerns for water level management. These concerns and the implications for management of the herring run are outlined in Section 5.4.

3.4 Sediment

3.4.1 Sediment Quality

Sediment sampling was conducted on 26 February, 1986. Samples of surficial sediment were taken at each of the in-lake stations (Figures 6 and 7) with an Ekman Grab. These samples were analyzed for the nutrient and metal parameters listed in the contract. Laboratory results of these analyses can be found in Appendix C.

The sediment of Long Pond has the highest values for the metals cadmium, chromium, copper, lead, and zinc among all the Wequaquet Lakes sampling stations (Table 13). Only iron and manganese were found in higher concentrations at sampling stations other than Long Pond. Few data are available on concentrations of metals in sediments from lakes of the region and standards for identifying "normal" or "background" levels have not been established. Concentrations of the metals cadmium, copper, and zinc in the Wequaquet Lakes sediment are similar to those found in the sediments of Canadarago Lake, N.Y. (Harr et al, 1980). Comparison with sediments of European lakes show metal concentrations in the Wequaquet Lakes sediment to be intermediate between higher values in Schohsee, Germany (Wetzel, 1983) and much lower values in Norwegian lakes (Fjerdingstad and Nilssen, 1983).

Gambrell et al (1983) compare metal concentrations in the sediment of City Park Lake, LA to proposed EPA guidelines for the acceptability of dredged sediments for open-water disposal. Although not directly applicable to metals in undisturbed sediments, these proposed EPA guidelines can be used as an approximation to levels that may be considered elevated. The maximum

TABLE 13

Sediment Metals Analysis

TOTAL (mg/kg)	W-1	W-2	W-3	W-4	Bearse	Long
Cadmium	<10	<4.7	<9.1	<9.4	<13	<18
Chromium	20	<4.7	9.1	<9.4	25	26
Copper	36	17	23	19	25	61
Iron	15,100	6,390	11,800	9,340	12,500	14,800
Lead	102	47	91	47	64	220
Manganese	137	66	87	75	147	79
Zinc	117	47	82	71	76	184

acceptable concentration proposed by the EPA for certain of these metals in sediments are the following (Gambrell et al, 1983):

chromium --- 100 mg/kg
copper ----- 50 mg/kg
lead ------- 50 mg/kg
zinc ------- 75 mg/kg
manganese -- 512 mg/kg
iron ----- 20000 mg/kg

According to the proposed EPA guidelines listed above, the levels of lead and zinc can be considered elevated at certain of the Wequaquet Lakes sampling stations (W-1, W-3, Bearse, and Long), particularly Long Pond. The level of copper in the Long Pond sediment also exceeds the proposed EPA guideline level. The concentrations of chromium, iron, and manganese in the Wequaquet Lakes sediments are lower than those found in the City Park Lake study (Gambrell et al, 1983) and are within acceptable levels in the proposed EPA guidelines. The proposed EPA guidelines cited in Gambrell et al (1983) are for determining the acceptability of open-water disposal of dredged sediments and are referred to here only because no standard exists for metals occurring naturally in sediments. None of the sediments of the Wequaquet Lakes are scheduled to be dredged and the metals incorporated in these sediments pose no threat if left undisturbed.

The Massachusetts DEQE developed a Sediment Pollution Index (SPI) that allows comparisons between sediment data from different areas and provides a basis for ranking sites according to the severity of metal pollution (McGinn, 1981). The SPI is a relative measure of the deviation from natural background concentrations of trace metals in sediment. Estimates of background levels are incorporated into the SPI formula through the use of the "Clarke Number" of each trace metal. The Clarke Number is a value, calculated by geochemists, that represents the average abundance of an element in the earth's crust. The Clarke Number of each of the metals evaluated in the SPI for the Wequaquet Lakes are as follows:

Chromium (Cr) - 100.0 mg/kg
Copper (Cu) --- 55.0 mg/kg
Lead (Pb) ----- 12.5 mg/kg
Zinc (Zn) ----- 70.0 mg/kg

Cadmium was not included in the SPI for the Wequaquet Lakes because only maximum levels and not absolute concentrations were measureable in laboratory analysis. The formula for the SPI and its calculation for each of the Wequaquet Lakes stations is given in Appendix C. Table 14 ranks the sampling stations according to the SPI.

TABLE 14 - SPI Values for Wequaquet Lakes Sediment

Sampling Station	SPI
Long Pond	5.40
W - 1	2.67
W - 3	2.24
Bearse Pond	1.73
W - 4	1.69
W - 2	1.56

Long Pond has the highest SPI value with 5.4 times the average composite concentration of trace metals in sediments. This is attributable mainly to a level of lead that is 17.6 times greater than the average background concentration (Clarke Number of lead = 12.5). With the exception of Long Pond, the SPI values for the Wequaquet Lakes are similar to values for the sediment of many river basins across the state (McGinn, 1981).

The elevated levels in Long Pond are exceptional in face of the uniform geology of the region and the lower levels of metals at the other sampling stations. This contrast indicates that a past or current activity of man in the immediate vicinity of Long Pond is responsible for the deposition of these metals. The source of the relatively high metal concentrations in

Long Pond sediment is probably road runoff entering Long Pond via the herring run and the drainage culvert on the northeast shore (see Section 3.1.4, Storm Sampling).

Concentrations of nutrients in the Wequaquet Lakes sediments are characteristic of eutrophic (highly productive) lakes. Organic solids (Figure 23) at all stations except W-2 are above 10% which is high compared to the findings of other studies. Hendricks and Silvey (1973) document organic solid percentages between 0.37 and 2.22 in reservoir sediments and Harr et al (1980) record 5% organic solids in the sediment of Canadargo Lake, N.Y. The organic compounds in the Wequaquet Lakes sediment are derived largely from the remains of littoral zone vegetation and from the remains and feces of planktonic organisms.

The high percentage of total solids (lowest water content) found at station W-2 (Figure 23) may be due to a process known as sediment focusing. Station W-2 is located over the deepest basin of Wequaquet Lake and sediments that have been suspended and transported from shallow areas can be redeposited here. This process results in a greater net accumulation of sediment in the deeper areas of the lake (Wetzel, 1983). Relatively low organic solids content (Figure 23) and low levels of nutrients (Figure 24) are also evident in the sediment of station W-2. This may be due to dilution of these concentrations by deposition of particles already degraded by microbes. It also may be the result of relatively greater microbial activity in the sediment at this station, decomposing the organics and releasing the nutrients into the overlying water.

The sediment of all stations other than W-2 (including Long Pond, not figured) have high values of Kjeldahl nitrogen (Figure 24). Most of this nitrogen is bound up in organic matter and is thus another indication of the high levels of organic solids in these sediments. Gambrell et al (1983) report Kjeldahl nitrogen levels of 3200 mg/kg in sediment from eutrophic City Pond Lake, LA and Hendricks and Silvey (1983) find values for Kjeldahl nitrogen in reservoir sediments to range from 470 to 4050 mg/kg. Bearse Pond sediment exhibits an extremely high level of total phosphate (Figure 23) which is more than ten times that at any other station. Gambrell et al (1983) report total phosphate concentrations similar to Bearse Pond in the sediment of eutrophic City Park Lake, LA.

3.4.2 Sediment Mapping

Due to the lack of ice cover, sediment thickness measurements could not be taken along the bathymetry transects approved by the DWPC. Instead, measurements were made around the perimeter of each lake, using shoreline features and the bathymetric map to locate the points of measurement on a map. Sediment thickness was measured by driving a metal probe to first refusal. Probing of the sediment was done in areas where the water depth was less than 20 feet. The type of substrate encountered, such as sand,

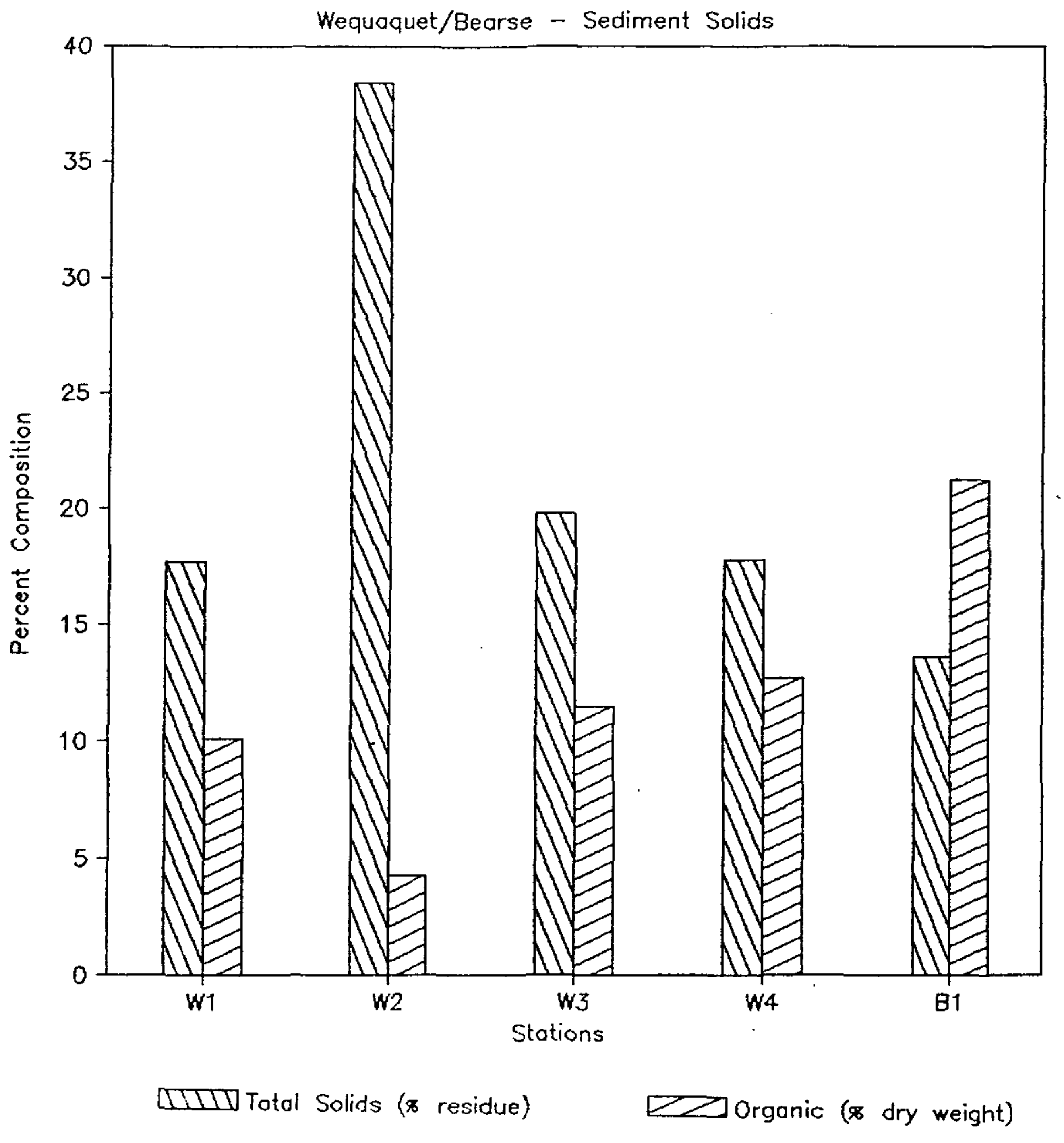


FIGURE 23 - ORGANIC AND TOTAL SOLIDS
IN SEDIMENT

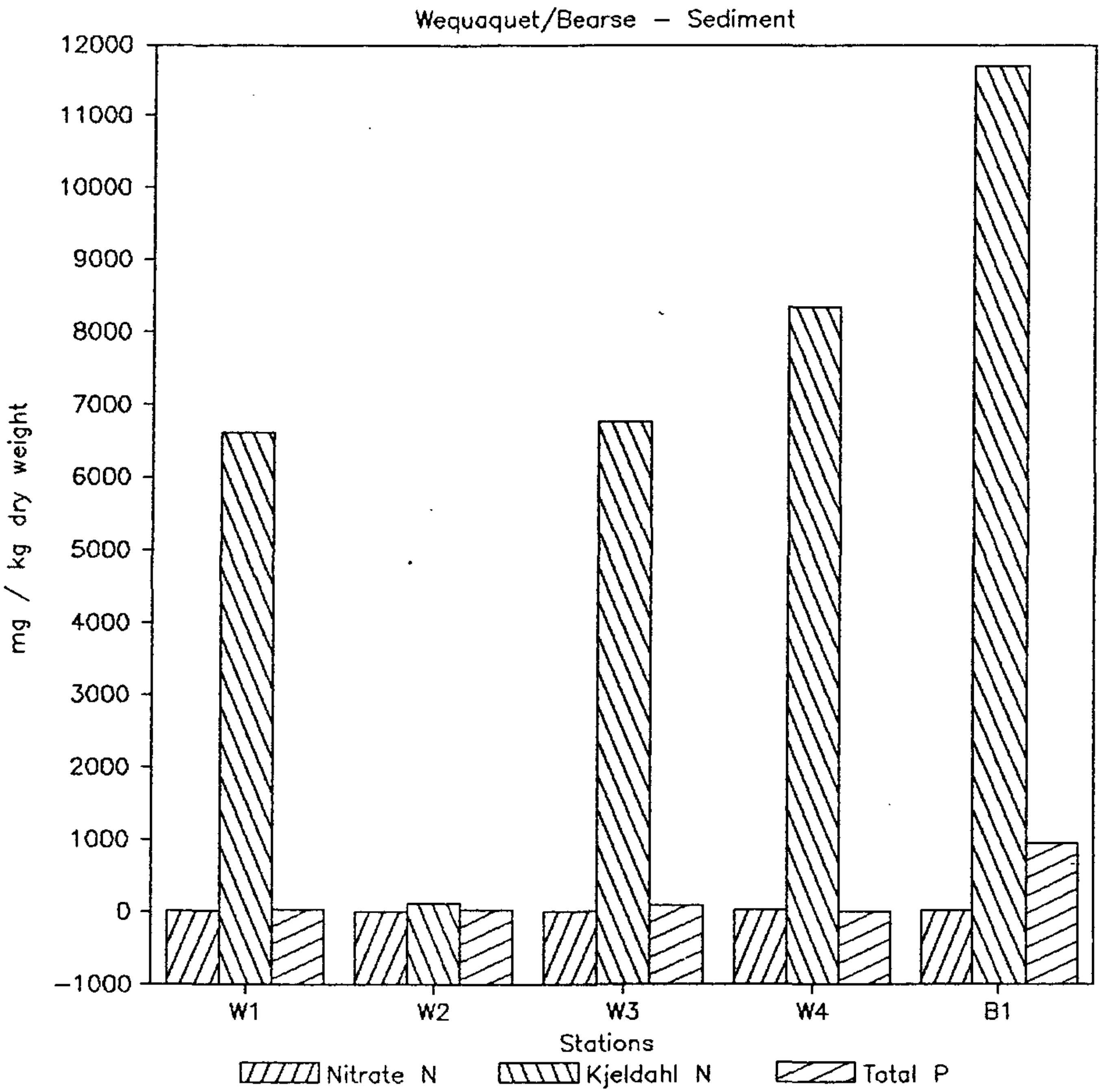
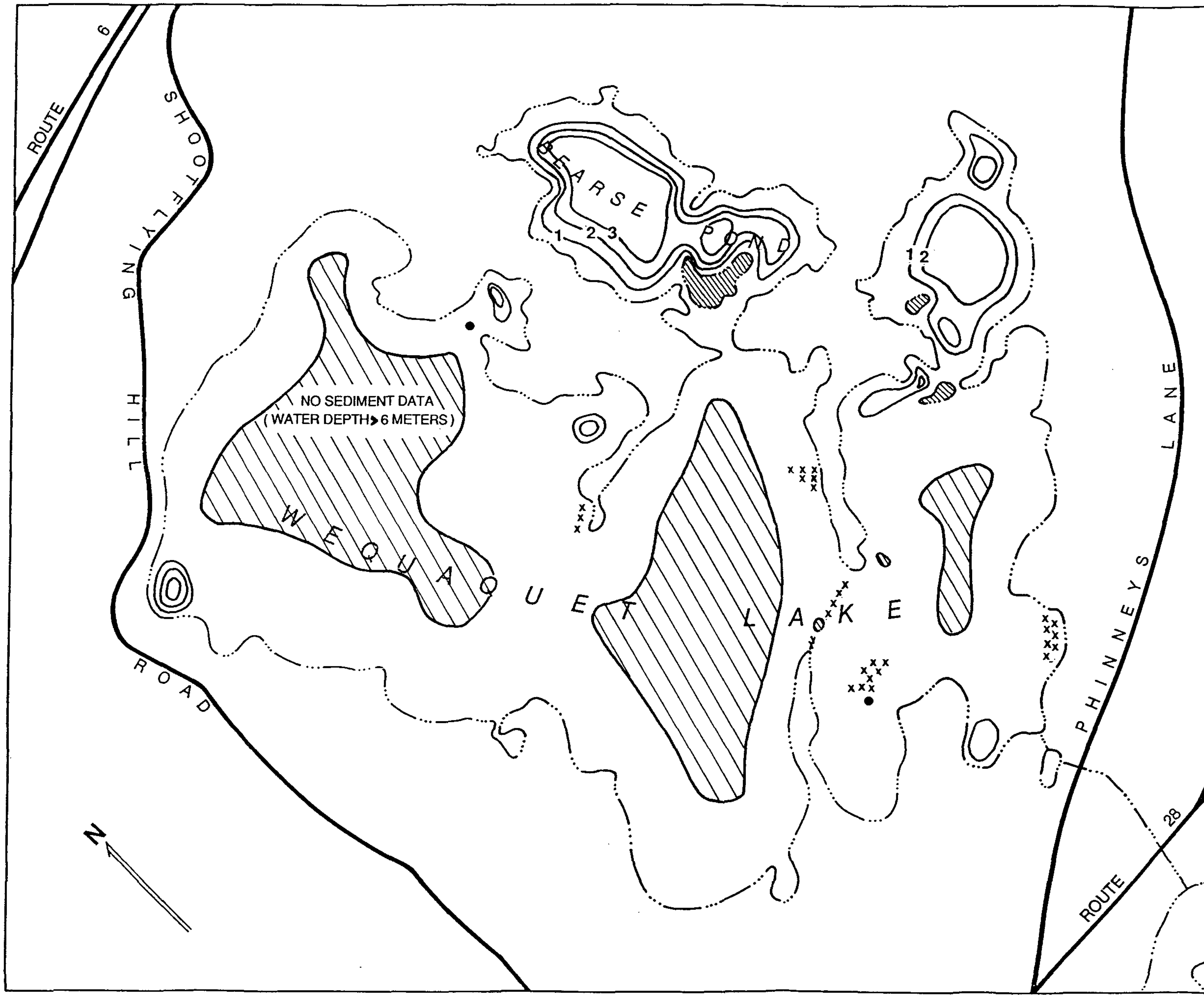


FIGURE 24 - NUTRIENT CONCENTRATIONS
IN SEDIMENT

cobble, or muck was also recorded. The sediment thickness map prepared from data obtained by the above method is shown in Figures 25 and 26.

In most areas, probe refusal occurred within the top 10 cm of substrate material due to hard-packed sand and/or gravel. Exceptions to this were observed in protected coves along the eastern shore of Wequaquet Lake where sediment has accumulated to a thickness of a few feet. The greatest sediment accumulation was observed in the northeast corner of Wequaquet Lake directly offshore from station 6. An accumulation of over 6 feet was measured at this point. It is reasonably assumed that sediment-laden discharge from the Oak Street culvert system is the cause of this deposit.



DIAGNOSTIC/FEASIBILITY STUDY OF WEQUAQUET LAKE, BEARSE AND LONG PONDS

PREPARED FOR THE
TOWN OF BARNSTABLE
CONSERVATION COMMISSION

WEQUAQUET LAKE AND BEARSE POND

SCALE IN FEET
0 2 4 6 800 1600

FIGURE 25 - SEDIMENT THICKNESS IN WEQUAQUET LAKE

SEDIMENT THICKNESS

LEGEND:

- NAVIGATIONAL HAZARDS
- ISLANDS
- CONTOUR INTERVALS (FEET)
- xx ROCKS

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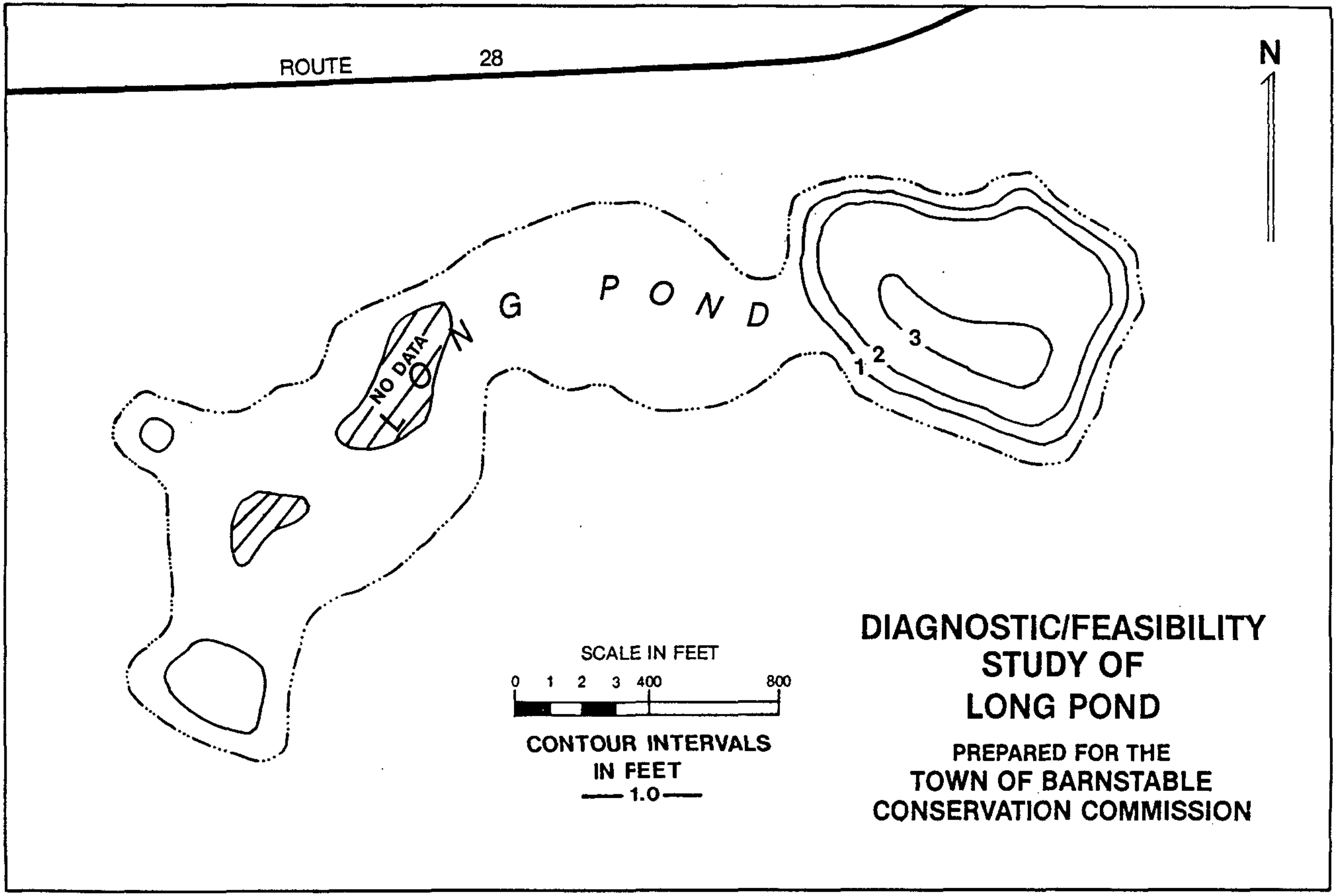


FIGURE 26 - SEDIMENT THICKNESS IN LONG POND

4.0 GROUNDWATER-LAKEWATER INTERRELATIONSHIPS

Water level in the Wequaquet Lakes is linked directly to groundwater elevation due to the permeable deposits comprising their basins. Both the hydrologic and nutrient budgets of the Wequaquet Lakes reflect this linkage to ground water. In the sections that follow, the groundwater components of the hydrologic budget and phosphorus budget of the Wequaquet Lakes are quantified.

4.1 Groundwater Inflow: Rate and Volume

Based upon the groundwater conditions observed during January, 1986, the following segregation of groundwater inflow by lake basin was made. The Wequaquet Lake basin was subdivided into four sub-basins: the main basin, south basin, Bearse Pond, and Gooseberry basin. Wind-induced circulation, chemical characteristics, and bathymetry support such a subdivision. The groundwater flow network for each was defined as described in Section 2.2 with additional information provided by the Barnstable Department of Public Works for easterly regions. Streamlines, monitoring well locations, and positions of groundwater flow measurements are shown on Figure 5. Direct flow measurements are indicated as vectors with the length being proportional to rate and direction shown by position relative to magnetic north. The steady-state volumes of groundwater inflow and outflow to the Wequaquet Lakes are shown in Table 15 below.

TABLE 15 - Annual Groundwater Inflow and Outflow by Basin

System Component	Inflow Volume (cu.m)	Percentage
Main Basin	1,145,403	77%
Bearse Basin	225,248	15%
Gooseberry Basin	97,914	7%
South Basin	17,235	1%
TOTAL	1,485,800	100%

Groundwater outflow volume
from Wequaquet/Bearse = 603,148 cubic meters

Groundwater inflow volume
to Long Pond = 354,719 cubic meters

Groundwater outflow volume
from Long Pond = 396,488 cubic meters

The main basin receives the largest groundwater contribution, followed by the Bearse basin and Gooseberry basin, with the south basin receiving the least. The southern basin actually discharges more ground water than it receives since the additional contributions come from (1) surface water from the main basin entering through the northwest gap and (2) surface water from the Gooseberry basin entering from the northeast.

The groundwater flow into and out of Long Pond can be complicated. It is determined by the balance between the volume of water received from Wequaquet Lake via the herring run and the volume of discharge to the Centerville River from Long Pond via the lower section of the herring run. Under conditions when the Wequaquet Lake section of the herring run is not contributing water, the groundwater inflow to Long Pond, per linear unit of shoreline, is similar to the groundwater discharge leaving Wequaquet Lake during a normal year.

Mean velocity = 1.56 ft/day
Groundwater gradient = 8.8/2000 ft = 0.0044
Field porosity = 0.25
$K = nV/(dh/dl) = (0.25)(1.56)/0.0044 = 89$ ft/day

length of north shoreline of pond x depth x velocity
= 4000 ft x 22 ft x 0.39
= 34,320 cubic ft/day
= 354,719 cubic meters/yr

4.2 Role of Oxidation-reduction (REDOX) Potential In Phosphorus Transport

The equilibrium redox potential, the free energy change per mole electron for a given reduction, represents the oxidizing intensity of the couple at equilibrium (Morris and Stumm, 1967). For instance, the redox potential of ground water determines the relative state of equilibrium of iron for a system such as:

$$Fe^{3+} + e^{-} = Fe^{2+}$$

In practice, the electromotive force is measured by the oxidation-reduction potential (ORP) of a process solution, as the millivolt signal, E , produced when a noble metal electrode and a reference electrode are placed in water. The millivolt signal produced can be represented as follows:

$$E_m = E^\circ + 2.3\frac{RT}{nf}\log A_{ox}/A_{red}$$

where:

E_m = ORP
E° = constant that depends upon the choice of reference electrodes
f = Faraday constant
R = gas constant
T = absolute temperature, degrees C + 273.15
n = number of electrons involved in process reaction
A_{ox} and A_{red} = activities of the reactants in the process

The role of Eh and pH in iron precipitation and solubility has a major significance in phosphorus mobility. Figure 27 shows the dependence of stability field on Eh and pH for various iron aqueous species. The shaded regions indicate regions of stability for solids (precipitates), and unshaded areas indicate the predominant dissolved forms. It is apparent by changing the Eh or pH of the water, different stability domains are encountered. The range of pH and Eh observed during water sampling during this study is indicated by the dashed lines. In uplands areas, the underlying ground waters are often rich in oxygen, causing iron to be immobile as iron hydroxide Fe(OH) . Under reducing conditions, encountered in or near bog deposits, iron becomes solubilized as Fe , eventually precipitating as FeS . In the trivalent state as ferric hydroxide, iron is a powerful precipitator of phosphorus as strengite (FePO .4H 0). However, in the reduced form of ferrous ion Fe , it is poorly reactant with phosphorus.

Soil conditions tend to become acidic in the vicinity of bog deposits or marshland areas. Under these conditions, phosphate precipitation is controlled by iron solubility. Patrick (1964) reported that below 200 mv redox potential the extractable phosphorus increased greatly. More than threefold increases in extractable phosphorus were found when the redox potential was -200 mv as compared to 200 mv. The sharp break in phosphate release curve at 200 mv, the same point at which ferric iron begins to be reduced, indicates the conversion of phosphorus to an extractable form is dependent upon the reduction of ferric compounds in the soil (Ellis, 1973).

The relationship between phosphorus content in the plumes and soluble iron is shown in Figure 28. This study was conducted as part of a septic leachate study of Ottertail Lake in midwestern Minnesota, a location with numerous individual sewage plumes from onsite septic systems in an acid-strengite soil water system (Kerfoot, 1980). Each dot represents the

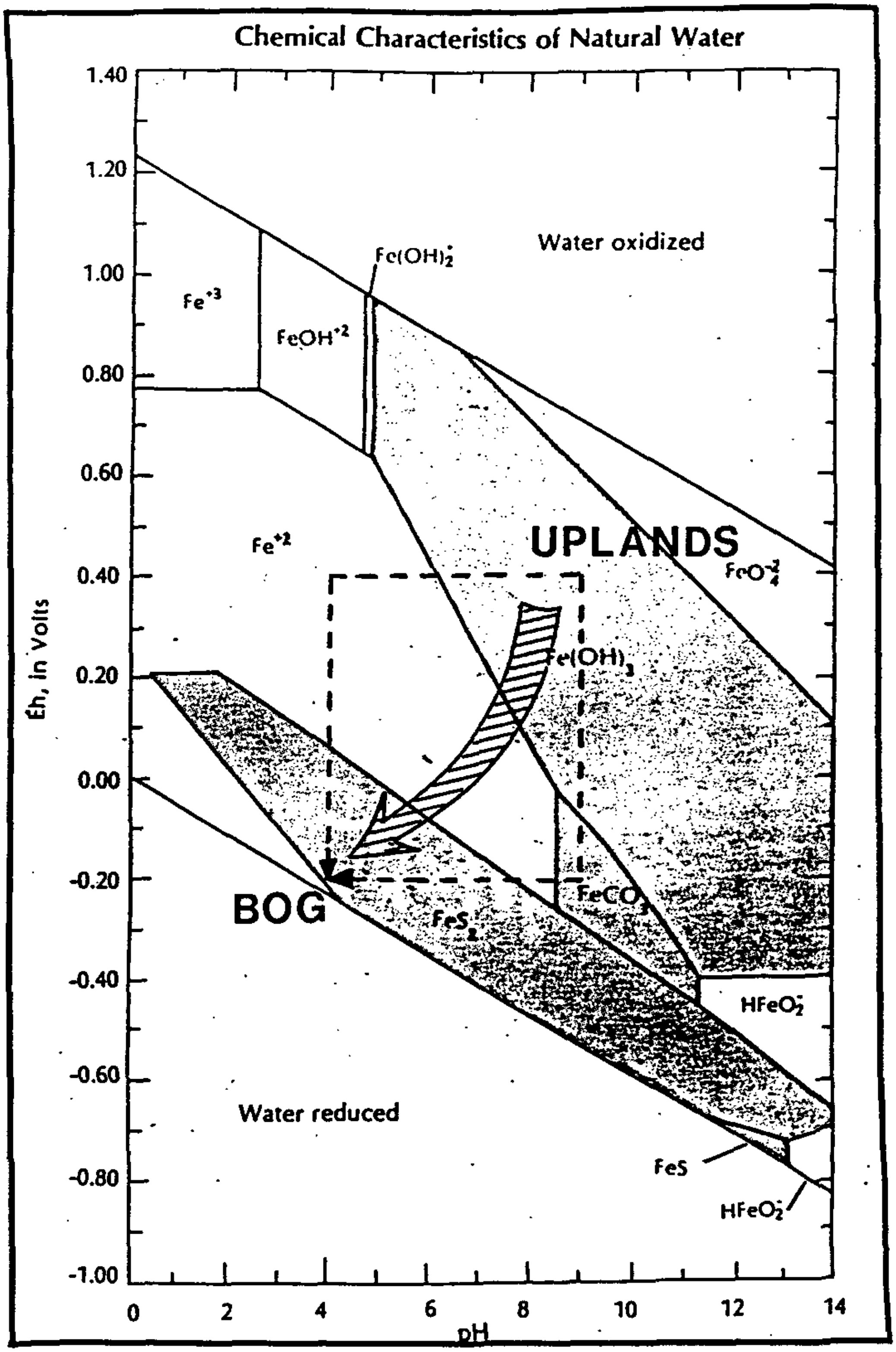


FIGURE 27

Fields of stability for solid and dissolved forms of iron as function of Eh and pH at 25°C and 1 atmosphere of pressure. Activity of sulfur species 96 mg/l as SO_4^{-2}, carbon dioxide species 1,000 mg/l as HCO_3-, and dissolved iron 0.0056 mg/l.

Modified from Bacon (1981).

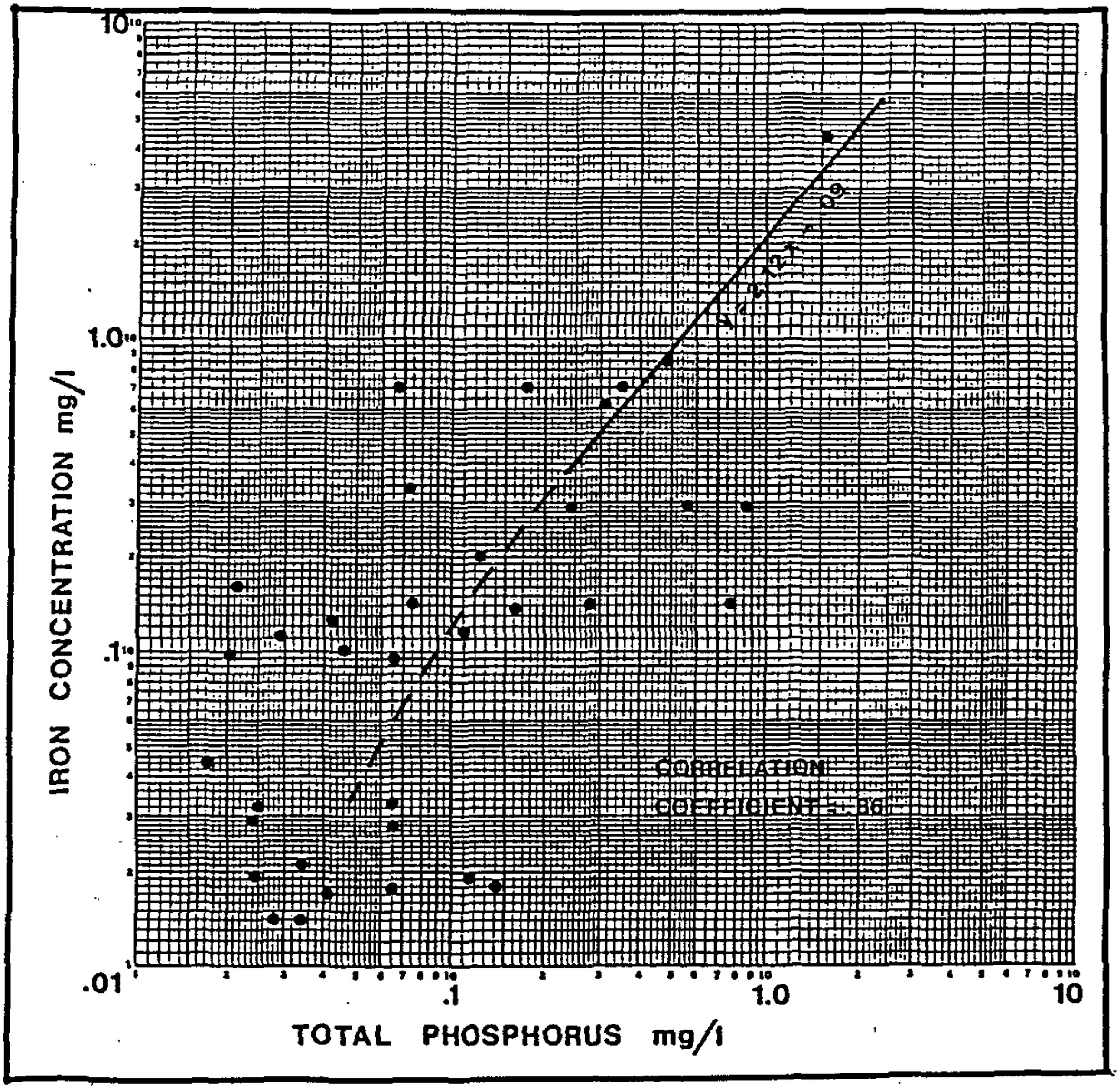


FIGURE 28

Total phosphorous (mg/l) versus iron concentration (mg/l) for Otter Tail Lake groundwater plume samples. April, 1981 concentration of iron (Fe) found in the plume groundwater sample versus the observed phosphate-phosphorus (as filtered TP) concentration.

A significant positive correlation (+0.86) exists between the soluble iron concentration and total phosphorus concentration found in the plume samples. Generally, the soluble iron tends to be present at twice the soluble phosphorus level, allowing sufficient excess to yield a rapid precipitation of the phosphorus if the sample is oxidized by exposure to air. The apparent curve of the linear regression line is solely due to its plotting on a log-log graph sheet.

The significant positive correlation between soluble iron concentration and total phosphorus concentration observed in ground water indicates that iron limits the solubility of phosphorus in ground water. Iron, abundant in the aquifer material, causes phosphorus to be immobilized in oxygenated ground waters. Since sewage discharge into ground water causes a biological oxygen demand (BOD), a direct relationship should exist between sewage loading rate and concentrations of phosphorus in ground water.

4.3 Relationship Between Groundwater Flow Rate and Phosphorus Transport

Special study has elucidated some of the factors contributing to high frequency occurrence of absorption failure of on-lot septic systems. *Groundwater flow provides the physical mechanism of transport of mobilized* phosphorus from underneath leaching fields to the lakewaters. The high rate of absorption failure appears related to the underlying natural ground water to be reduced in pH and redox potential before it receives wastewater flow. The more rapid the groundwater flow, the more likely the wastewater plumes are to reach the lake shoreline without becoming oxidized.

Even though the septic systems may be elevated some distance above static water level, if the background groundwater flow is in a substantially reduced condition, phosphorus seems capable of being transported laterally some distance to the shoreline. The degree of transport would be dependent upon the oxygen demand of the wastewater when it enters the ground water and the extent of oxidation capacity of the background ground water. Within regions upgradient of a freshwater body, where a reducing groundwater environment exists, one would not want to encourage rapid infiltration waste disposal systems unless steps were taken to insure oxidation of the waste stream. Aerobic treatment systems may be useful for on-lot disposal to assure phosphorus precipitation of the waste flow; however, if the system is seasonal, immobilized phosphorus may become mobilized as anoxic (reducing) background groundwater flow invades the discharge regions.

4.4 Extrapolation To Phosphorus Loading From Residential Housing

If the iron system (strengite system) is controlling phosphorus concentration in ground water, then there should be a correlation between sewage loading rate and background filterable total phosphorus concentration. Six different locations were considered, ranging from heavy sewage loading (infiltration beds-Otis ANG) to background conditions (WHOI-Otis control plot):

1) Sewage infiltration beds - Otis Air National Guard Base
2) Sewage infiltration beds - Fort Devens, Massachusetts
3) Craigville - Dense development (0.06 acre residential lots)
4) Craigville - Moderate dense development (0.25 acre lots)
5) Ashumet Valley - Rural development (density about 1.0 acre lots, 1978 study)
6) Background with precipitation loading (WHOI Study, 1975 and McVoy, 1980).

The mean groundwater concentrations of filterable total phosphorus from the above six locations coincide with the anticipated regression line (Figure 29). The concentration of phosphorus maintained in the ground water by the strengite reaction should not be confused with the saturated front accompanying adsorption to soil in the unsaturated zone as described by Ellis (1973) or employed by Tofflemire (1973). The phosphorus concentration is maintained by the oxygen demand of the organic-rich fluid discharged into the aquifer, controlling the soluble ferrous iron content.

The reaction can be decoupled by removing the oxygen demand of the wastewater and aerating it. During the WHOI study, the same effluent which went to the sand filter beds was additionally treated by lagooning and spray irrigating. No observable rise in phosphorus content in the ground water under the treated sites was observed (Dease et al, 1977).

On the other hand, in a groundwater environment maintained at low oxygen conditions, such as cranberry bogs, the mobile phosphorus in the ground water would be a direct consequence of phosphorus loading. Normally, 30 pounds of phosphorus per year per acre is added to operating cranberry bogs (Arthur Handy, personal communication). This computes to an annual P loading of 0.09 kg/ha/day, which should yield a phosphorus content in ground water of 0.085 mg/L. A groundwater sample from the Bearse Pond bog region measured 0.092 mg/L total phosphorus (filterable).

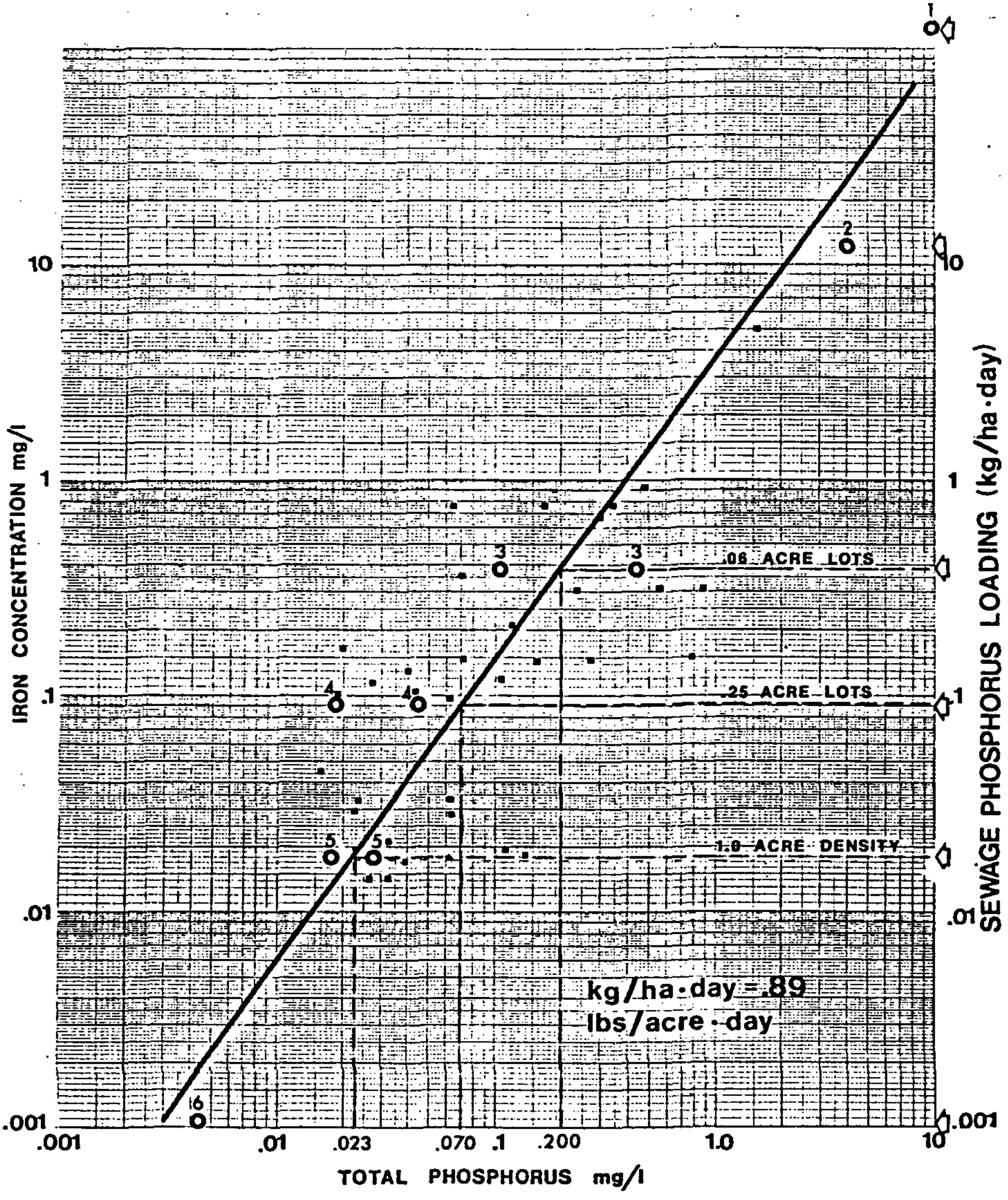


FIGURE 29 - PHOSPHORUS AND HOUSING DENSITY

5.0 HYDROLOGIC BUDGET

A hydrologic budget is an accounting of the inflow, storage, and outflow of water in a hydrologic system such as a lake. The principle components of a hydrologic budget are precipitation, evaporation, inlets, outlets, storm drains, runoff, ground water, and change in the lake storage. These components have been estimated utilizing meteorologic records and field data gathered during the diagnostic study. A mass balance approach is used to determine the volume of water entering and exiting the lake. This data, in conjunction with bathymetric data, enables calculation of the retention time and flushing rate of the lake (see Section 5.5 below). Table 16 lists the value calculated for each component of the Wequaquet/Bearse system. Components of the Long Pond hydrologic budget are listed in Table 17.

5.1 Hydrologic Inputs

Precipitation falling directly on the surface of Wequaquet Lake/Bearse Pond is the largest input to the system composing 60.4 percent of the total. Groundwater inflow comprises 33.1 percent of the total input to the system. The two easternmost basins of Wequaquet Lake, Bearse and Gooseberry, receive small inputs of groundwater originating from nearby Shallow Pond. Although there is no direct surface connection between Shallow Pond and the Wequaquet basins, ground water flows through the narrow isthmus that separates them. Generally, this contribution of ground water from Shallow Pond is limited to brief periods when the water level in Wequaquet Lake is lower than the level in Shallow Pond.

Barnstable Fire District Wells (BFD-3 and BFD-4) are located northeast of Wequaquet Lake and Shallow Pond and the potential impacts of these wells on ground water dynamics were investigated. Pumping of these wells exerts an influence on the flow of ground water to Shallow Pond, but no change in the normal inflow of ground water to Wequaquet Lake was detected.

The hydrologic budget of Long Pond is dominated by water received from Wequaquet Lake via the herring run. The discharge from the herring run accounts for 80 percent of the total volume entering Long Pond annually. This volume arrived in Long Pond over only a six month period, from January through June, 1986 during the year of study. At other times of the year water is "stored" in Wequaquet Lake and the herring run to Long Pond remains dry (see Section 5.4 below). The rate of discharge from Long Pond to the lower section of the herring run is responsive to the rate of input to Long Pond from the upper section and generally there is a close correspondence. Ground water comprises a secondary input to Long Pond contributing 12.6 percent annually.

TABLE 16 - Year Of Study Hydrologic Budget
For The Wequaquet/Bearse System

INPUTS	VOLUME (cubic m)	PERCENT OF TOTAL
a.) surface runoff/storm drains	293,342	6.5%
b.) direct precipitation	2,713,200	60.4%
c.) groundwater inflow	1,485,800	33.1%
LOSSES		
a.) herring run outlet	2,248,354	50.1%
b.) evaporation	1,640,840	36.5%
c.) groundwater outflow	603,148	13.4%

Total input/loss volume per year = 4,492,342 cubic meters
(assuming no change in storage volume)

Residence time (time necessary for complete
replacement of system volume) = 2.07 years

Hydraulic flushing rate (number of volume
replacements per year) = 0.48 volumes/year

TABLE 17 - Year Of Study Hydrologic Budget
For Long Pond

INPUTS	VOLUME (cubic m)	PERCENT OF TOTAL
a.) herring run inlet	2,248,354	80.0%
b.) direct precipitation	207,900	7.4%
c.) groundwater inflow	354,719	12.6%
d.) surface runoff is less than 1 percent of total inputs		
LOSSES		
a.) herring run outlet	2,288,755	81.4%
b.) evaporation	125,730	4.5%
c.) groundwater outflow	396,488	14.1%

Total input/loss volume per year = 2,810,973 cubic meters
(assuming no change in storage volume)

Residence time (time necessary for complete
replacement of system volume) = 0.18 years (about 9 weeks)

Hydraulic flushing rate (number of volume
replacements per year) = 5.43 volumes/year

5.2 Hydrologic Losses

Discharge of water into the herring run accounts for the greatest proportion (50.1 percent) of volume lost from the Wequaquet/Bearse system. As pointed out above, this loss occurs over a six month period due to management of the herring run. A large volume of water is lost from the system due to evaporation accounting for 36.5 percent of the volume lost annually.

In Long Pond, an even greater proportion (81.4 percent) of volume lost is due to discharge of water into the herring run. Control of flow out of Long Pond to the Centerville River is minimal due to the lack of an adequate control structure on this section of the herring run. Ground water comprises the next important output from Long Pond accounting for 14.1 percent of the volume lost annually.

5.3 Internal Circulation

The lack of thermal stratification in Wequaquet Lake (see Section 3.1.1) attests to the extent of wind-induced mixing in the lake. In large lakes, like Wequaquet, water currents at the surface are put in motion by wind, causing wind drift. In the northern hemisphere, the induced surface currents eventually flow at approximately 45 degree to the direction of the prevailing wind. Usually the greater the depth, the greater the shift of flow to an opposite direction to the wind. This generally results in a clockwise rotation of currents, down welling on the lee side and up welling on the windward side.

Wind directions follow a distinct temporal pattern on the Cape. A summary of mean direction and rate taken over 25 years by the National Weather Bureau (E.C. Jordan, 1986) is presented below.

Month	Prevailing Direction	Mean Speed (mph)
January	northwest	11
February	"	11
March	"	12
April	southwest	11
May	"	10
June	"	10
July	"	9
August	"	9
September	"	9
October	"	12
November	northwest	11
December	"	12

The predominant wind direction during summer (April-October) is from the southwest (SW) and switches to the northwest (NW) during winter (November-March). The mean velocity is 11 mph and ranges from an average of 9 mph from July through September to an average of nearly 12 mph in fall and winter (October to March).

Three types of wind-induced currents can be observed in surface water bodies: a) surface drift, b) surface seiches, and c) Langmuir Spirals. All of these combine to provide turbulent mixing in Wequaquet Lake and serve to transfer heat throughout the water column. Currents and seiches determine the local "flushing" conditions of coves and shorelines.

Generally speaking, the onset of turbulence in the lake is predictable through the application of a principle borrowed from fluid mechanics and known as the Reynolds Number. With a depth of less than 10 m (33 ft), turbulence would be induced at current velocities of greater than 0.1 cm/s. The extent of the current which can be developed is related to the distance of open water over which the wind blows, or commonly, fetch.

To measure the rate of wind-induced surface drift in Wequaquet Lake/Bearse Pond, a series of drifters were released and followed. The neutrally-buoyant drifters are constructed of plastic distilled water bottles with small air bubbles and a fishing weight (Figure 30). The bottle is tethered to a small surface bobber with a flag for easy identification. Each flag was numbered and the movement followed across the lake. The observations described above were made on 4 and 5 December, 1986. Estimated wind speed was 5 to 10 mph coming from 270 to 330 degrees magnetic north. The fetch in each basin and observed current velocities are listed below.

System Component	Fetch (m)	Observed Mean Velocity (cm/s)
Main Basin	1000	8.7
South Basin	640	4.6
Bearse Basin	265	1.4
Gooseberry Basin	330	3.1

The drift current directions vary across the lake. Typical with rectangular basins, a series of gyres are wind-induced. Figure 31 presents the directions consistent with the observed drift directions. Counter cyclonic rotations are occurring in the main basin, Gooseberry basin, and south basin. Bearse basin has the poorest mixing and does not exhibit any cyclonic cells.

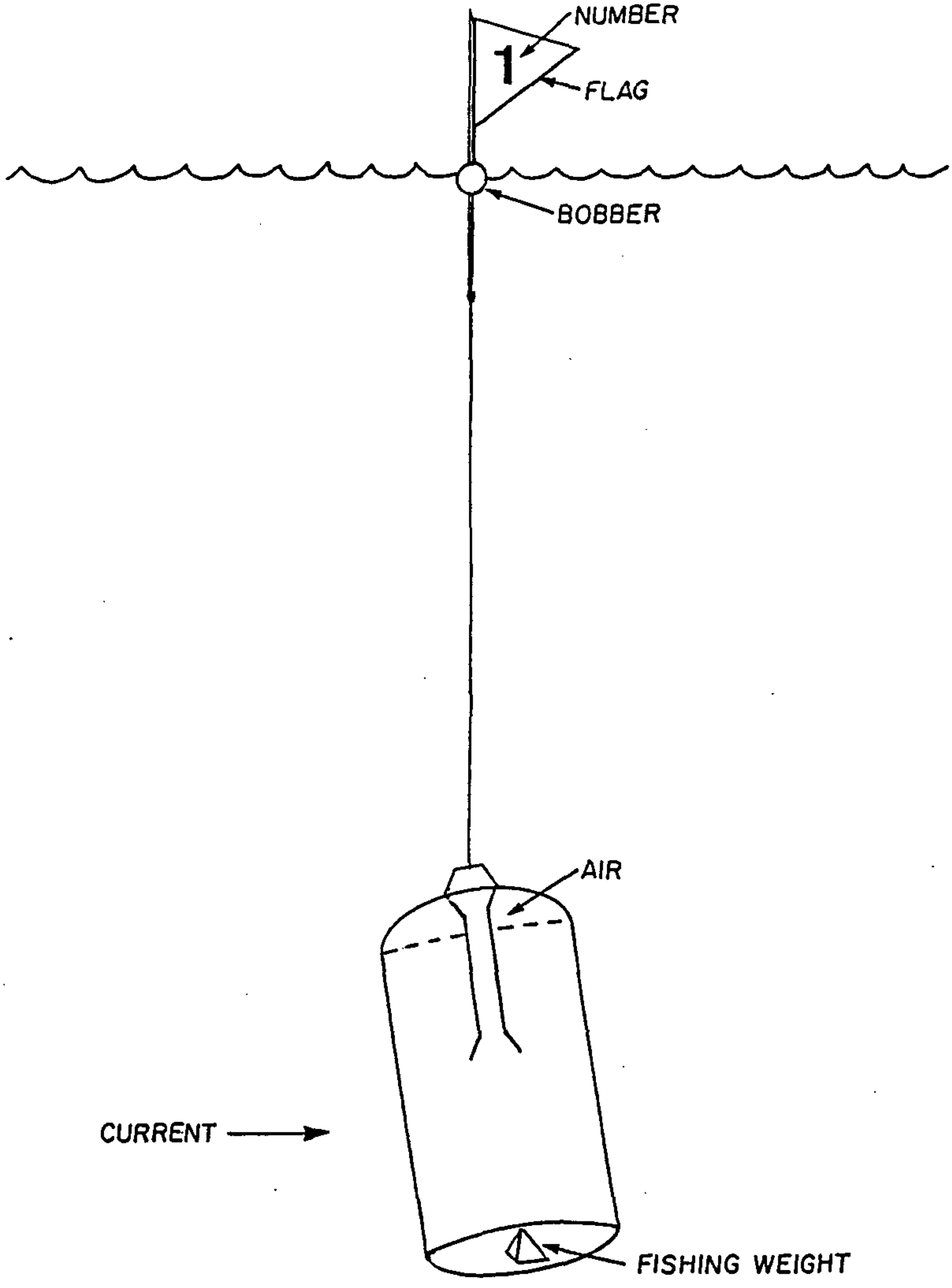


FIGURE 30 - DRIFTER CONSTRUCTION

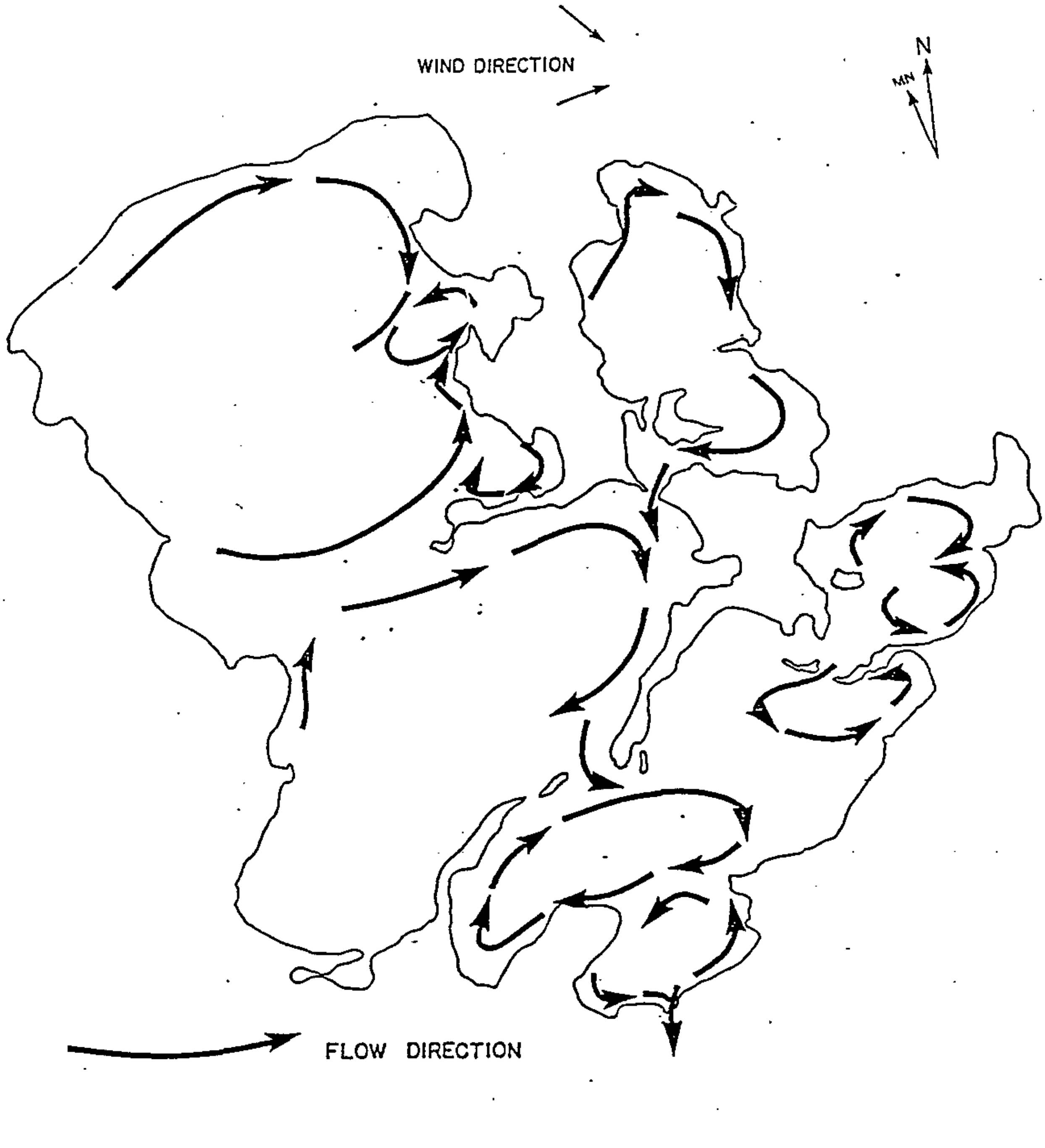


FIGURE 31 - WIND-INDUCED CURRENT DIRECTIONS

The fetch is significant in the main basin and can set up Langmuir spirals oriented parallel to the direction of the wind. The Langmuir Spirals would be expected to have the following dimensions: horizontal length (L) = 100 m, vertical = 10 m, period (T) = 10 s, and velocity (V) = 1 cm/s. The spirals are often evident by the presence of surface slicks fanning outwards in the direction of the prevailing wind. Significantly, these would reach to a depth of 10 m on Wequaquet Lake, virtually eliminating thermal stratification and development of a thermocline.

Seiches are commonly generated when winds blow fairly constantly from one direction, driving the surface water downwind. The piling up of water continues until the wind abates slightly and the water flows backwards under the influence of gravity. This generates a standing wave which oscillates back and forth. In lakes, the period of the surface seiches are given by:

$$T = \frac{2L}{\sqrt{gz}}$$

Where: T = Resonance period (seconds)
z = Mean lake depth where lake is a rectangular basin (meters)
L = Basin length (meters)
g = Acceleration due to gravity (9.8 m/sec2)

For Lake Wequaquet, where L and z are 2300 m and 3.7 m respectively, the period between seiches would be about 12.7 minutes.

$$T = \frac{2\ (2300)}{\sqrt{9.8 \times 3.7}} = \frac{4600}{6.02} = 764 \text{ seconds} = 12.7 \text{ minutes}$$

Surface seiches can have beneficial impacts (by increasing circulation and dispersing nutrients) or impacts that are destructive (ice damage or erosion along shorelines).

5.4 Water Level Fluctuations and the Herring Run

Monthly water level in Wequaquet Lake was recorded at the staff gauge located on the outlet structure passing under Phinney's Lane. Levels fluctuated between 33 feet, 2 inches in late September and 34 feet in February.

The herring run from the Centerville River to Long Pond was originally constructed in 1867. Between 1920 and 1930 the Nine Mile Pond Fishing Company hand dug the connecting herring run from Long Pond to Wequaquet Lake. The lower part of the run which enters the Centerville River was ditched again in 1984 by the Cape Cod Mosquito Control Project.

Historically, the many demands placed on Wequaquet Lake as a recreational resource, a source of groundwater recharge, and an alewife fishery have made water level management a prominent issue. Water level in Wequaquet Lake is regulated with a control structure located at the beginning of the herring run on the upstream side of Phinneys Lane. The herring run thus serves as a relief valve for excess water during periods of high lake level as well as its obvious function for the alewife fishery. Controversy over how the lake level is managed erupts at times when there is overlap between the opposing concerns of storing enough water to allow the run to function for the alewife fishery and discharging enough water to prevent flooding or erosion during periods of heavy rainfall. An understanding of certain life-history characteristics of the alewife is necessary in order to discern how the concerns stated above become opposed. A brief outline of these characteristics is given in Section 3.3.

Water Level Concerns Conflicting with Alewife Fishery

Water level fluctuation in Wequaquet Lake typically ranges between a maximum of 34 feet MSL and a minimum of 32 feet MSL. When the level approaches 34 feet, many lakeshore residents report flooding and/or erosion of their shoreline (or ice damage in winter). Although a level of 33.5 feet MSL is recognized officially, water is "stored" in the winter and early spring to have the 33.8 foot level required for the alewife spawning run. If a heavy rain occurs at this time, the discharge capacity of the herring run is not great enough to prevent water level in the lake from rising to the 34 foot "alarm level". If water is not "stored" in anticipation of the alewife spawning run, a heavy storm would not cause flooding/erosion problems, but a dry period in the spring would inhibit the function of the herring run due to insufficient water. The Natural Resources Officer is therefore caught between the conflicting demands of the alewife fishery and lakeshore residents and does not have an outlet structure that allows him to respond effectively to variation in seasonal precipitation.

This situation is repeated during the summer when water is again "stored" in anticipation of the downstream passage of juvenile alewives in the fall. At this time, in addition to variation in seasonal precipitation, the Natural Resources Officer must consider the effect of heavy water demands on lake level during the tourist season. The demand for water increases dramatically starting about 20 June and pumping of water from supply wells can cause the level in Wequaquet Lake to drop as much as 1/8 inch per day.

Low water levels are also of concern, but drought conditions that cause low water levels are not manageable phenomena. At lake levels approaching 32 feet MSL, motor boat activity is constrained in some areas due to exposed substrate and complaints about the receding waterline are reported. Water is not released from the outlet structure when the lake level falls below 33.5 feet and there is no management alternative to respond to drought conditions. The critical lake levels and concerns associated with each are summarized below:

<u>Critical Water Levels In Wequaquet Lake (feet above MSL)</u>

34.0 - high water; flooding/erosion/ice damage reported

33.8 - minimum level required for function of herring run

33.5 - "official" level

32.0 - low water; motor boat activity constrained, waterline receding

Bank erosion is severe along several sections of the run (Figure 32). The area undergoing the worst erosion is downstream from Pine Street. Construction of new houses along the banks of this portion of the run have contributed to the erosion problems, and there is leaf and brush accumulation in the stream. The other factor contributing to erosion is the regulation of water from the Wequaquet lakes. For most of the winter and summer the water is held back in the lakes, leaving the stream dry. When the water is let out in the spring and fall, the initial gush can cause damage to the stream banks. In 1983 and 1984, high rainfall caused a washout of the rock and cement weirs in the lower run (Millen, 1986 pers. com.).

Another problem with the herring run is its low gradient. The portion downstream from Long Pond has a 0.006 feet/foot slope, and the upstream portion from Long Pond has a 0.004 feet/foot slope. Anadromous fish, such as herring, need turbulence to navigate upstream. They use olefaction to find their way in from the ocean, but then need a strong current to find their way up their natal streams. As well as needing a strong current, the herring need resting pools. The herring run only has a few pool structures, which are in poor condition, in the lower portion of the run. Therefore, when the adult herring come in from the ocean in the spring the current is strong enough to guide them when water is initially let out of the Wequaquet Lakes, but is too strong for the fish to make their way up the run without resting pools.

The Barnstable Department of Natural Resources (DNR) and Department of Public Works (DPW) are proposing a restoration project on the herring run. Two separate channels are proposed in the run, one for normal flow and one for storm flow. In the normal flow channel either pool weir structures or fish ladders will be built and the stream banks will be stabilized to stop erosion. The slope from the Centerville River to Wequaquet Lake will be increased, and the outlet structure will be reconstructed at Long Pond to allow better water manipulation (Millen 1986, pers. com.). An evaluation of the restoration plan and a discussion of the issues surrounding water level control are presented in Section 8.5.

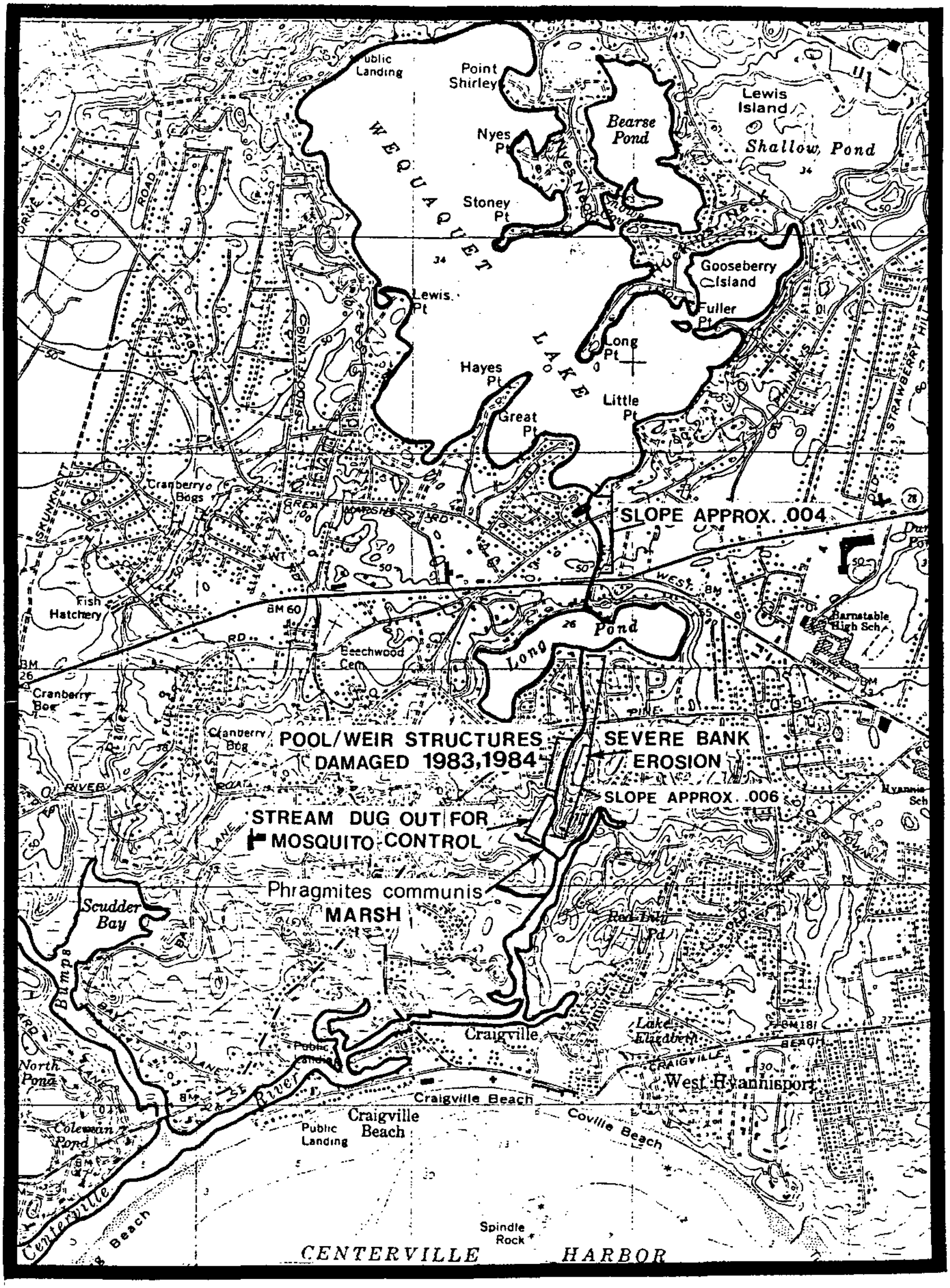


FIGURE 32

WEQUAQUET LAKE
HERRING RUN

IEP inc.

5.5 Residence Time and Flushing Rate

Residence time (also known as retention time or renewal time) is the time necessary for the total volume of water in a hydrologic system to be replaced. It is calculated by dividing the volume of the system by the total volume flowing through the system each year (annual input/loss volume). The residence time for the Wequaquet/Bearse system is 2.07 years. Long Pond has a residence time of only 0.18 years (approximately 9 weeks) due to the proportionally greater annual flow-through volume.

Flushing rate is the inverse of residence time. It is a measure of the rate at which the total volume of water in a hydrologic system is replenished. The flushing rate of a lake or pond is important in controlling biological productivity and, therefore, the trophic status of the system. Generally, systems with slow flushing rates are more productive and more susceptible to cultural eutrophication. The Wequaquet/Bearse system has a hydrologic flushing rate of 0.48 volumes per year. The flushing rate of Long Pond is 5.43 volumes per year.

6.0 NUTRIENT BUDGET

A nutrient budget is an accounting of the amount of an element which enters and leaves a biological system such as a lake. Components of the Wequaquet Lakes phosphorus budget include the following: wet and dry precipitation, inlets and outlets, storm drains, surface runoff, and ground water. Table 18 lists the value calculated for each component of the Wequaquet/Bearse system. Components of the Long Pond phosphorus budget are listed in Table 19.

The headings "shoreline septic systems" and "recharge area septic systems" of Tables 18 and 19 document loading predicted to occur in the future when "equilibrium" conditions are reached. At present, a portion of the load of phosphorus discharged from septic systems is attenuated by adsorption and chemical complexing in the soil before reaching the lake system (see Section 6.2.1 below). When the capacity for phosphorus uptake by the soil is exhausted, an "equilibrium" will exist such that discharge of phosphorus from septic systems will eventually result in a proportional load of phosphorus reaching the lake system.

Except under conditions of constant and high rates of discharge, the attenuation capacity of soil for phosphorus is never completely exhausted due to regeneration of phosphorus binding sites. Binding sites for phosphorus in soils are regenerated when they undergo a cycle of wetting and drying. The conditions promoting regeneration of phosphorus removal capacity in soils have not been quantified, but are dependent on factors such as mineral composition, particle size, oxygen conditions (oxidizing or reducing), and pH environment. The phosphorus load listed under "equilibrium" conditions represents the maximum estimated phosphorus load that could originate from septic systems.

6.1 Limiting Nutrient

As stated earlier in Section 3.1.2, of the nutrients nitrogen and phosphorus, it is the availability of phosphorus that limits the growth of algae in the Wequaquet Lakes. The weight ratio of total nitrogen to total phosphorus (N/P) in the water can be interpreted to indicate which of these nutrients is limiting. Assuming that the typical ratio of nitrogen to phosphorus in algal tissue is approximately 15 to 1, the EPA (1980) considers systems exhibiting ratios greater than this to be phosphorus limited while systems with a smaller N/P ratio are nitrogen limited.

The Wequaquet Lakes are phosphorus limited according to this criteria (see Table 6). An increase in phosphorus loading to the system will trigger a biological response and result in increased algae growth. Identifying sources of phosphorus and quantifying their loading rates are important steps in developing a plan for protecting the Wequaquet Lakes.

TABLE 18 - Year Of Study Phosphorus Budget
For The Wequaquet/Bearse System
(values in quotes represent future projections)

SOURCES	KG/YEAR	EXISTING PERCENTAGE	"EQUILIBRIUM" PERCENTAGE
1. Surface Inputs			
a.) direct precipitation	90.4	47.5%	32.9%
b.) station 5 cranberry bog	4.2	2.2%	1.5%
c.) waterfowl/gulls	9.0	4.7%	3.3%
d.) shoreline lawns	8.1	4.3%	2.9%
e.) storm drains	0.8	<1%	<1%
f.) Oak Street culvert system	2.3 *	1.2%	<1%
2. Groundwater Inputs			
a.) background flow into Main, Bearse, Gooseberry, and South basins	72.8	38.3%	26.5%
b.) Bearse Pond cranberry bog	2.7	1.4%	<1%
c.) shoreline septic systems (within 300 feet)	"78.8"	----	28.6%
d.) recharge area septic systems (beyond 300 feet of shore)	"6.0"	----	2.2%
TOTAL EXISTING LOAD	190.3 kg/year		
TOTAL LOAD AT EQUILIBRIUM	275.1 kg/year		
LOSSES			
a.) herring run outlet	56.2	29.5%	----
b.) groundwater outflow	30.2	15.9%	----
c.) sedimentation (retained in the system)	103.9	54.6%	----

* - calculated from storm observed in January, 1987

TABLE 19 - Year Of Study Phosphorus Budget
For Long Pond
(values in quotes represent future projections)

	KG/YEAR	EXISTING PERCENTAGE	"EQUILIBRIUM" PERCENTAGE
SOURCES			
1. Surface Inputs			
a.) herring run (from Wequaquet)	56.2	64.4%	54.1%
b.) direct precipitation	6.9	7.9%	6.6%
c.) waterfowl/gulls	1.8	2.1%	1.7%
d.) shoreline lawns	3.0	3.4%	2.9%
e.) storm drains	1.6	1.8%	1.5%
2. Groundwater Inputs			
a.) background flow	17.7	20.3%	17.0%
b.) shoreline septic systems (within 300 feet)	"13.6"	----	13.1%
c.) recharge area septic systems (beyond 300 feet of shore)	"3.1"	----	3.0%
TOTAL EXISTING LOAD	87.2 kg/year		
TOTAL LOAD AT EQUILIBRIUM	103.9 kg/year		
LOSSES			
a.) herring run outlet	45.8	52.5%	----
b.) groundwater outflow	19.8	22.7%	----
c.) sedimentation (retained in the system)	21.6	24.8%	----

6.2 Phosphorus Inputs

6.2.1 Septic Systems

In porous soils, groundwater inflows frequently convey wastewaters from nearshore septic units through bottom sediments and into lake waters, causing attached algae growth and algal blooms. The lake shoreline is a particularly sensitive area since: 1) the groundwater depth is shallow, encouraging soil water saturation and anaerobic conditions; 2) septic units and leaching fields are frequently located close to the water's edge, allowing only a short distance for bacterial degradation and soil absorption of potential contaminants; and 3) the recreational attractiveness of the lakeshore often induces temporary overcrowding of homes leading to hydraulically overloaded septic units. The results of the septic system inventory indicate that, of the dwellings served by septic systems sited within the critical 300 foot shoreline zone (see below), the majority have both a clothes washing machine and a dishwasher connected to the system (Appendix E). This exacerbates the problem of nutrient loading due to septic systems.

The capillary-like structure of sandy soils and horizontal groundwater movement induces a fairly narrow plume from malfunctioning septic units. The point of discharge along the shoreline is often through a small area of lake bottom, commonly forming an oval-shaped area several meters wide when the septic unit is close to the shoreline. In denser subdivisions, multiple discharges may overlap to form a broader plume.

Groundwater Plumes

Three different types of groundwater-related wastewater plumes are commonly encountered during a septic leachate survey: 1) erupting plumes, 2) dormant plumes, and 3) stream source plumes (Kerfoot and Skinner, 1981). As the soil becomes saturated with dissolved solids and organics during the aging process of leaching on-lot septic systems, a breakthrough of organics to the shoreline occurs first, followed by inorganic penetration (principally chlorides sodium, and other salts). An erupting plume is characterized by the dynamic transport of the combined organic and inorganic residues into the near-shore water column.

In seasonal dwellings where wastewater loads vary in time, a plume may be apparent during late summer when shoreline cottages sustain heavy use, but retreat during winter during low flow conditions. Residual organics from the wastewater often still remain attached to soil particles in the vicinity of the previous erupting plume, slowly releasing into the shoreline waters. This condition is known as a dormant plume and indicates a previous breakthrough, but sufficient treatment of the plume exists under current conditions so that no inorganic discharge is apparent. Stream source plumes refer to either groundwater leachings or near-stream septic leaching fields which enter into streams which then empty into the lake.

Runoff Plumes

Traditional failures of septic systems occur in tight soil conditions when the rate of inflow into the unit is greater than the soil percolation can accommodate. Often leakage occurs around the septic tank or leaching unit covers, creating standing pools of poorly-treated effluent ("break-out"). If sufficient drainage is present, the effluent may flow laterally across the surface into nearby waterways. In addition, rainfall or snow melt may also create an excess of surface water which can wash the standing effluent into water courses. In either case, the poorly-treated effluent contains elevated concentrations of fecal coliform bacteria and potentially some intestinal pathogens. This type of failure requires immediate attention in order to protect public health.

Special Survey Technique and Equipment

Wastewater effluent contains a mixture of near-UV fluorescent organics derived from whiteners, surfactants, and natural degradation products which are persistent under the combined conditions of low oxygen and limited microbial activity. The aged effluent percolating through sandy loam soil under anaerobic conditions reaches a stable ratio between the organic content and chlorides which are highly mobile anions. It is this stable ratio (conjoint signal) between fluorescence and conductivity that allows ready detection of leachate plumes by their conservative tracers. The septic leachate detector utilizes this principal. Such identified plumes are an early warning of potential nutrient breakthrough or public health problems. Septic surveys for shoreline wastewater discharges were conducted with a septic leachate detector, ENDECO R Type 2100 "Septic Snooper TM " or KVA Model 15 "Peeper Beeper", and the KVA Model 30 Groundwater Flow Meter.

The leachate detector can be operated out of any small boat. It consists of the subsurface probe (water intake system), the analyzer control unit, and an analog stripchart recorder. Initially the unit is calibrated against incremental additions of wastewater effluent of the type to be detected to the background lake water. Nationwide studies have indicated that a mixed effluent from a wastewater plant within the survey area receiving primarily domestic effluent represents the most "average" effluent for calibration (Krause and Peters, 1979). Because of differences in background water supplies and domestic products, the amplitude of conductance and fluorescence changes with geographic area. After calibration, the pump end of the probe unit is submerged in the lake water along the near shoreline. Ground water seeping through the shoreline bottom is drawn into the screened intake of the probe and travels upwards to the analyzer unit. As it passes through the analyzer, separate conductivity and fluorescence signals are generated. The responses are sent to the signal processor which registers the separate signals on a stripchart recorder as the boat moves forward. The analyzed water is continuously discharged from the unit back into the receiving water. The battery-powered unit used for field studies can record individual fluorescence and conductivity or a combination signal. It is calibrated in the field to operate under the conductivity conditions encountered at the site.

Results of Septic Survey

The leachate surveys were conducted during August and September of 1986. The shoreline of Wequaquet Lake was traversed from August 7th to the 24th. Long Pond was surveyed during the first week of September. Shorelines to be surveyed were selected based on wind conditions encountered in the field. Only shorelines protected from the wind were surveyed; any shoreline area receiving waves over 2 inches in height were avoided until quieter conditions prevailed.

The septic leachate survey identified 3 types of plume discharges into the Wequaquet/Bearse/Long Pond water system: on-site septic system groundwater plumes, bog discharges (both surface and ground water), and road runoff. Table 20 shows the results of the survey taken by K-V Associates. Isolated groundwater septic plumes were found around Wequaquet Lake (Figure 33). No runoff plumes (traditional failures characterized by overflow) were observed. A long retention time (slow flushing) is indicated for Bearse Pond since the bog disharge (#16) persists throughout the pond.

The major discharges to Long Pond (Figure 34) originate from road runoff. The condition appears to have improved since earlier measurements (KVA, 1982). In 1982, the entire northern shoreline received runoff from Route 28 via various curb cuts and drainage features. Since that time, berms and additional catch basins have been installed along much of Route 28.

Several locations along the Wequaquet shoreline showed increased levels of organics, generally without a corresponding conductivity rise. Fluorescent scanning of water samples indicated a bog origin. Some of these sites were not sampled for bacteria or nutrient levels because either the intensity of the reading was not high enough or scanning fluorescence analysis in the lab indicated that they were not septic in origin. They are included in the report as supplemental information for although each source may not be large

TABLE 20 - Results of K-V Associates Septic Leachate Survey

Station #		Conductivity (μmhos/cm)	NO_3-N (mg/l)	NH_4-N (mg/l)	TKN (mg/l)	TP (mg/l)	DP (mg/l)	TC (counts pm 100 ml)	FC	Source*
Wequaquet Lake										
	5S	-	.10	.17	.68	.016	BDL			-
	5G	-	.09	2.25	3.50	.046	.027	-	-	S
	6S		BDL	.46	2.66	.496	.447	210	10	Sb
	7S	84	.06	.28	.60	.032	.021			b
	7G	-	BDL	.15	1.14	.170	.087	-	-	b
Bearse Pond										
Background		89								
BP	9S	84	BDL	.20	.68	.015	BDL	18	10	-
BP	9G	85	.42	2.54	3.13	.024	.024	-	-	S
BP	11S	84	.58	.07	.72	.020	.008	20	20	-
BP	11G	-	.54	.34	.72	.010	.008	-	-	b
BP	13S	80	BDL	.10	1.94	.15	2.39	270	170	S
BP	13G	-	BDL	1.94	3.50	.130	.076	-	-	-
BP	16S	90	BDL	.15	.70	.024	.007	170	20	b
BP	16G	-	BDL	2.39	3.41	.092	.092	-	-	-
Long Pond										
LP	S4	125	.37	.03	.28	.008	.006	230	78	r
LP	G4	88	.37	.24	2.61	.660	.032	-	-	-
LP	S5	183	.75	.16	.37	.022	.018	790	40	r
LP	G5	91	22.0	.06	.28	.007	BDL	-	-	-

BDL - below detection limit

* Source indicated by strongest signal in surface or groundwater sample

b = Bog

S = Septic

r = Road runoff

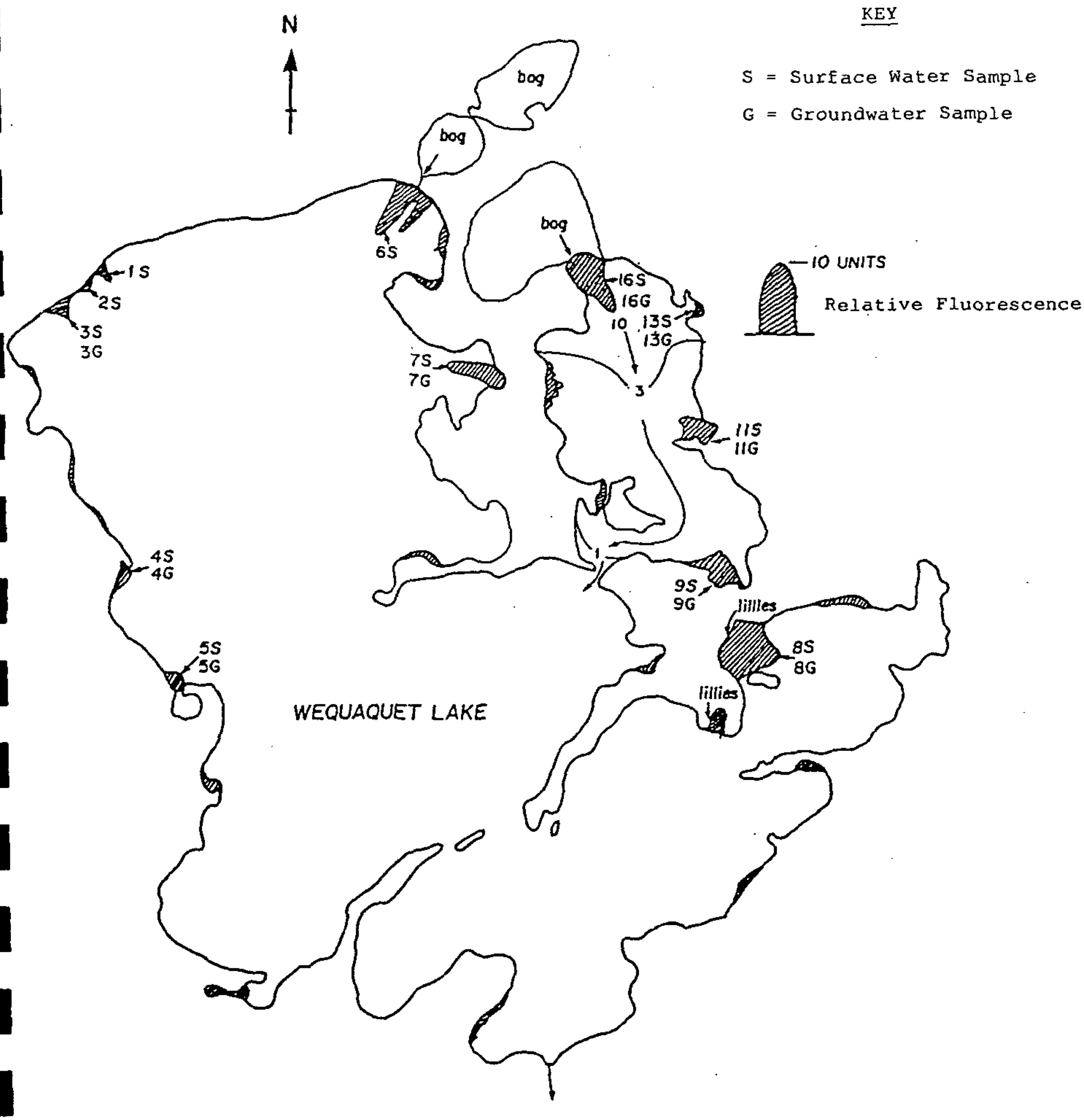


FIGURE 33 - SEPTIC LEACHATE SURVEY IN WEQUAQUET/BEARSE

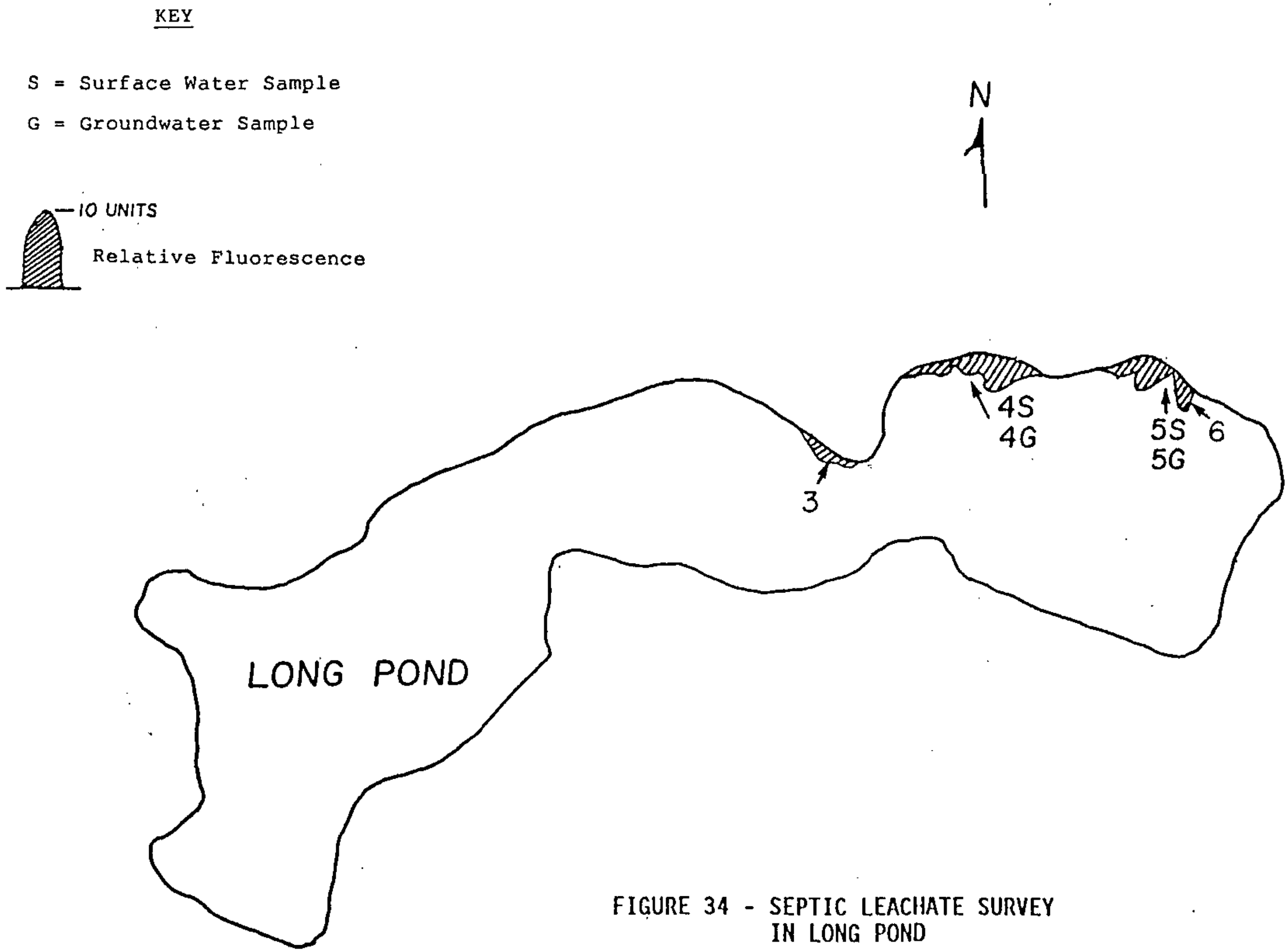


FIGURE 34 - SEPTIC LEACHATE SURVEY
IN LONG POND

at the time of our sampling, the sum input into the lake may be significant and they may be sites to consider if future problems arise.

Specifically, these areas are the following:

1) Along Shoot Flying Hill Road where it runs directly along the lake at the northern end (Figure 33, numbers 1,2 and 3). Measurements in this area indicated a diffuse increase in organics associated with three road drainages west of the public boat ramp.

2) Along the western shore in a small undeveloped cove was a region of windrowed muck and organic debris associated with water lilies and non-rooted vascular macrophytes (Figure 33, number 5). This area is low in topography and the high organic content may be a result of runoff from the wetlands.

3) The south side of the drive leading out to this small point (Figure 33, number 4) showed a diffuse pattern of increased organics similar to that observed along Shoot Flying Hill Road.

4) The northern shore of Gooseberry Pond showed a low level increase along the whole shore with slightly higher peaks in both coves (Figure 33, number 8). Aquatic vegetation is quite lush here and may be a secondary response to high nutrients. Caution should be used with interpretation of aquatic plant distribution as wind protection and lake currents are also major factors.

5) Bearse Pond overall exhibited a higher organic response on the septic leachate detector than Wequaquet Lake proper, with the highest levels in coves along shoreline side (Figure 33, numbers 9, 11, 13, and 16). Again heavy aquatic growth occurs here the signal was diffuse. However, considering the heavy development around this pond (and Gooseberry Pond), leachate from septic systems and runoff from lawns may carry constant low levels of nutrients that may contribute significantly to the growth of algae in this part of the system.

6) The northern cove of Bearse Pond along with the adjacent waters showed a higher than background level of organics (Figure 33, number 16). This may be similar to station W-5 (appearing as number 6 in Figure 33) where bog areas surrounding the cove may be adding nutrients both through groundwater seepage and surface discharge.

Phosphorus Loading from Septic Systems

The phosphorus load to the Wequaquet Lakes from septic systems is quantified in Table 21. This table lists loads estimated from two areas of different loading intensity: within 300 feet of the shoreline ("near field") and beyond 300 feet of the shoreline ("far field"). The EPA (1983) assumes that

TABLE 21. Phosphorus Loading from Septic Systems .

Flow Pathways	Number of Developed Lots: No. Developed Lots within 300 ft. of Shoreline	Number of Developed Lots: No. Developed Lots beyond 300 ft. of Shoreline	Shoreline Length (feet)	Area of Each Flow Pathway: Total Acres Within 300' of Shoreline	Area of Each Flow Pathway: Total Acres Beyond 300' of Shoreline	Density in Far Field Acres per Dwelling Beyond 300' of Shoreline	Cumulative Loading: A Cumulative Loading within 300' of Shoreline (lbs/yr) +	Cumulative Loading: B Cumulative Loading Beyond 300' of Shoreline (lbs/yr) =	Cumulative Loading: C Total Loading In Flow Pathway (lbs/yr)	Loading per 100' of Shoreline (lbs/yr)	Loading per Acre of Flow Pathway (lbs/yr)
WEQUAQUET LAKE											
No. 1	8	25	1680	8.6	33.7	1.35	6.0	.6	6.6	.39	.16
2	9	97	1500	9.3	77.7	.80	6.8	3.2	10.0	.67	.11
3	8	115	1380	4.0	79.3	.69	6.0	4.4	10.4	.75	.12
4	11	50	1500	5.6	79.3	1.59	8.3	1.2	9.5	.63	.11
5	9 (45)	69 (356)	720	5.3	82.0	1.19	6.8	1.8	8.6	1.19	.10
6	6	24	660	4.3	69.4	2.89	4.5	.2	4.7	.71	.06
7	8	9	780	5.0	48.9	5.43	6.0	.1	6.1	.78	.11
8	6	2	900	5.3	9.3	4.65	4.5	0.	4.5	.50	.31
9	7	1	960	6.9	.3	.3	5.3	.1	5.4	.56	.75
10	5 (32)	1 (37)	780	5.3	6.9	6.9	3.8	0.	3.8	.49	.31
11	9	1	3720	7.9	2.7	2.7	6.8	0.	6.8	.02	.63
12	4	0	1560	7.3	3.3	-	3.0	-	3.0	.19	.28
13	2	0	3180	4.6	0.	-	1.5	-	1.5	.05	.33
14	7	0	4500	8.3	0.	-	5.3	-	5.3	.12	.64
15A	5 (27)	0 (1)	1140	5.6	0.	-	3.8	-	3.8	.33	.68
15B	7	4	780	4.3	4.3	1.1	5.3	.1	5.4	.69	.63
16	6	3	1200	6.6	2.3	0.8	4.5	.1	4.6	.38	.52
17	9	0	1260	6.0	.7	-	6.8	-	6.8	.48	.90
18	15	11	1560	6.9	6.6	0.6	11.3	.5	11.8	.76	.87
19	10 (47)	5 (23)	840	4.0	3.0	0.6	7.5	.2	7.7	.92	1.10
20	10	0	1140	5.0	.7	-	7.5	-	7.5	.66	1.32
21	9	0	1620	6.9	0.	-	6.8	-	6.8	.42	.99
22	7	0	3660	3.3	0.	-	5.3	-	5.3	.15	1.61
23	9	0	2160	4.6	0.	-	6.8	-	6.8	.32	1.48
24	13 (48)	2 (2)	1620	5.0	2.7	1.4	9.8	.1	9.9	.61	1.23
25	13	7	1020	6.3	5.0	.7	9.8	.2	10.0	.98	.85
26	10	12	660	.4	15.6	1.3	7.5	.3	7.8	.12	.49
27	9 (32)	7 (26)	1020	2.7	.3	?	6.8	-	6.8	-	-
TOTAL:	231	445	43,500								
								Total Load:	186.4 lbs/yr or 84.7 kg P/yr		
LONG POND											
No. 1	9	45	840	5.6	40.7	.90	6.8	1.4	8.2	.98	.17
2 (max)	5	85	780	6.0	44.0	.52	3.8	4.2	8.0	1.03	.16
3	14	29	1200	6.9	33.4	1.15	10.5	0.8	11.3	.94	.23
4	8	19	840	5.0	44.0	2.32	6.0	0.3	6.3	.75	.13
5	4	10	840	3.6	15.2	1.52	3.0	0.2	3.2	.38	.17
TOTAL	40	188									
								Total Load:	37.0 lbs/yr or 16.8 kg P/yr		

0.25 pounds of phosphorus enters a lake on an annual basis from every person served by on-site septic systems that are within 300 feet of shore. Based on the EPA study and analyses of ground water entering Wequaquet Lake, this loading rate is assumed to be the maximum potential load that could be delivered from properly functioning septic systems within 300 feet of shore. Thus, phosphorus loading within the 300 foot near field was estimated at 0.25 lbs/capita or 0.75 lbs/dwelling per year. For far field estimation of loading (beyond 300 feet), values were obtained from a graphic solution of the regression line observed for Cape Cod ground waters (see Figure 29, Section 4.4). This 300 foot demarkation between "near field" and "far field" is based on empirical data and emphasizes that nearshore septic systems have the greatest potential for delivering phosphorus.

The solubility and transport of phosphorus in ground water is dependent on the oxidation/reduction environment in the aquifer. In aerated ground water systems, phosphorus is immobilized due to chemical precipitation with iron (see Section 4.0) and physical adsorption onto soil particles. The adsorption capacity of a soil under oxidizing conditions can be estimated by a laboratory procedure that measures the loss of phosphorus from a solution agitated with a sample of the soil (Tofflemeyer, T.J. and M. Chen, 1978). Anoxic conditions in ground water greatly enhance the solubility and transport of phosphorus (see Section 4.0). The load of organic material associated with wastewater discharge from septic systems in the recharge area impairs the adsorption capacity of the soils and hastens the eventual passage of phosphorus to Wequaquet Lake via ground water.

To obtain the total phosphorus load per unit area, "flow pathways" were delineated (numbered 1 through 27 for Wequaquet Lake and 1 through 5 for Long Pond). These are depicted in Figures 35 and 36. The light regions represent existing subdivisions and dwellings. The dark regions indicate undeveloped areas. The total annual phosphorus load predicted for all flow pathways to Wequaquet/Bearse is 84.8 kg. A total annual phosphorus load of 16.7 kg is predicted from all flow pathways to Long Pond. The above loads are predicted to reach the receiving waters at some time in the future, under "equilibrium" conditions when the soil attenuation capacity has been exhausted (Tables 18 and 19).

6.2.2 Other Groundwater Inputs

Measurements of phosphorus concentrations in ground water by the U.S.G.S. (Frimpter and Gay, 1979) have been relied on to estimate the existing load reaching the Wequaquet Lakes via ground water. The median value of 0.05 mg/L dissolved phosphorus in ground water (75 sampling sites) has been incorporated into the nutrient budgets of the Wequaquet/Bearse system and Long Pond (Appendix D). Background flow of ground water into the Wequaquet/Bearse system accounts for 38.3 percent of the existing phosphorus load. In Long Pond, background flow of ground water accounts for 20.3 percent of the existing phosphorus load.

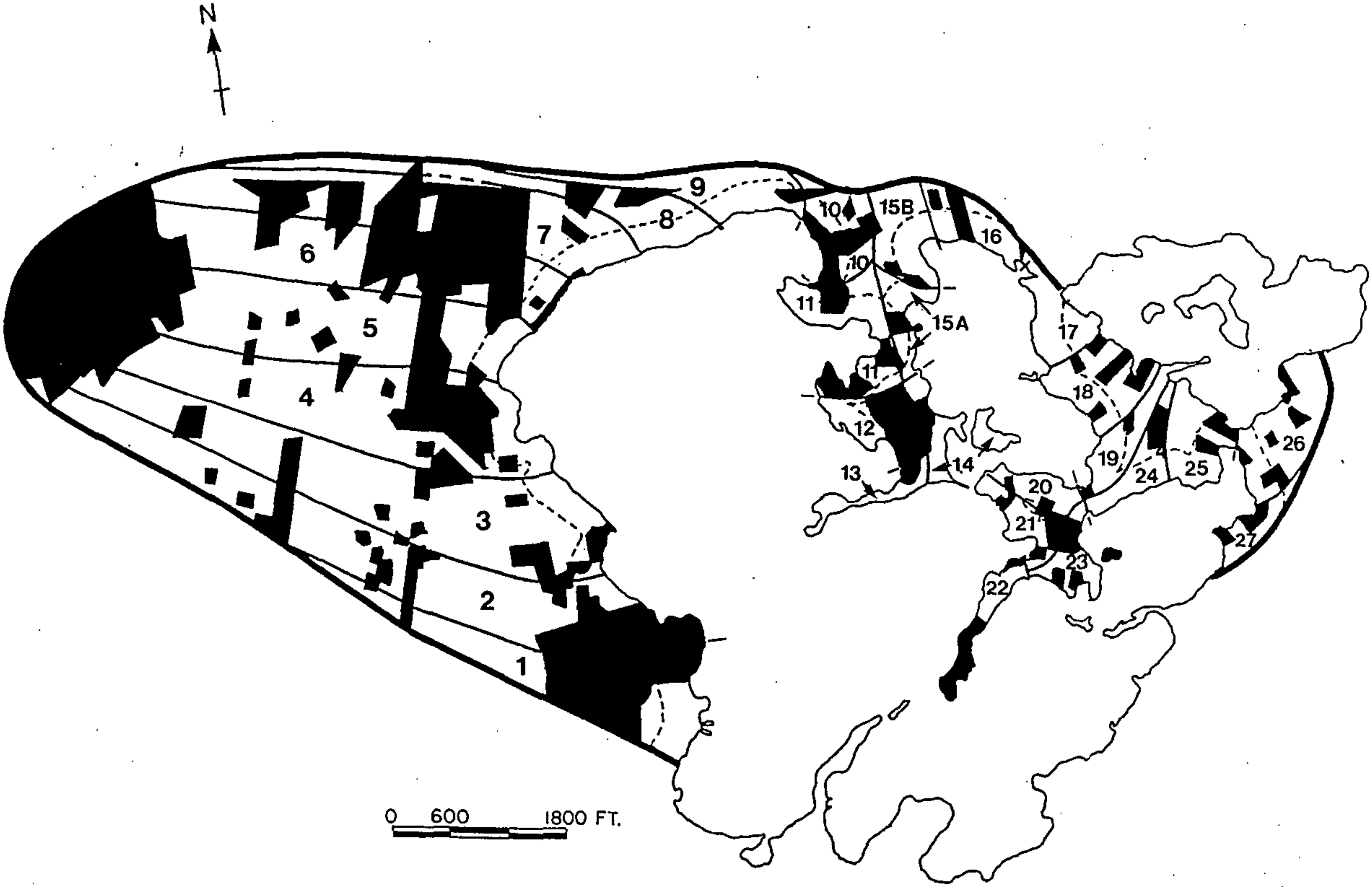


FIGURE 35 - FLOW PATHWAYS TO WEQUAQUET/BEARSE

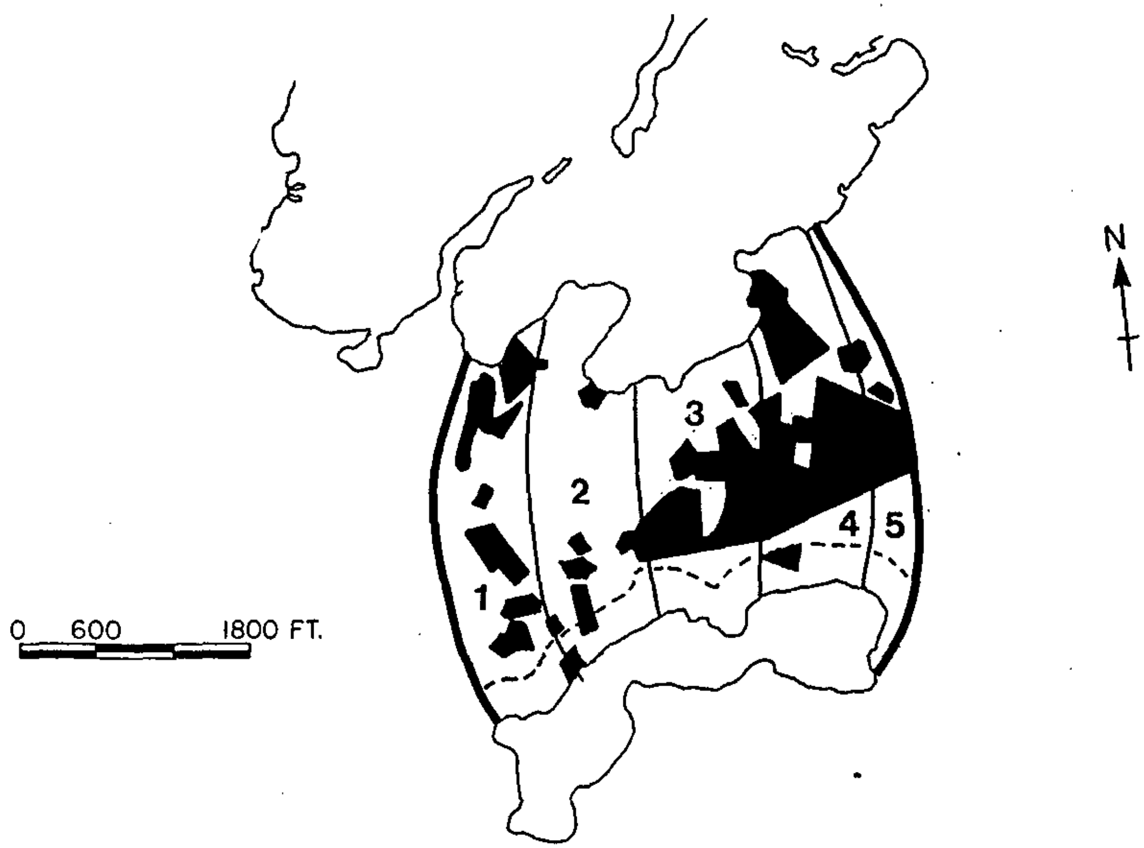


FIGURE 36 - FLOW PATHWAYS TO LONG POND

The Bearse Pond northern bog region occupies about 1.9 percent of the entire Wequaquet Lake recharge area. Assuming 18 inches of recharge per year (LeBlanc et al, 1986), the groundwater discharge from the bog would be about one million cubic feet per year, about 1/8 of the total groundwater discharge into Bearse Pond. Groundwater samples show a phosphorus concentration of 0.092 mg/L (see Section 4.4). The phosphorus loading from this groundwater source is estimated to be 2.7 kg annually (Appendix D).

6.2.3 Surface Inputs

Atmospheric input of phosphorus to the Wequaquet/Bearse system is predominant over other sources due to the large surface area of the water bodies and the relatively small watershed area. The surface of the Wequaquet/Bearse system (258.4 ha total) intercepts both wet and dry deposition contributing an annual phosphorus load of 90.4 kg (Appendix D). This represents 47.5 percent of the total annual load under existing conditions.

Phosphorus applied to lawns as fertilizer is generally resistant to leaching due to plant uptake and binding to soil particles. The main mechanism of phosphorus transport from soils is through erosion. Storm runoff that carries soil particles causes some of the phosphorus applied to shoreline lawns to be delivered to the Wequaquet Lakes.

Generally, lawn care specialists recommend applying chemical fertilizer twice during the year (Better Homes and Gardens Books, 1971). When grass starts to green in the spring, usually ten pounds of a complete plant food is applied per 1,000 square feet of lawn. The packed fertilizer comes identified by a ratio of percent nutrient by weight. For instance, 20-10-10 is 20% nitrogen (N), 10% phosphorus (P), and 10% potassium (K). If the consumer is applying this fertilizer, he is applying 2 pounds N, one pound P, and one pound K for each 1,000 square feet.

During the late summer or early fall, a 10-10-10 nutrient ratio is recommended. Too much nitrogen in the fall results in excessive top growth which is susceptible to winter damage. This would result in one pound N, one pound P, and one pound K being applied per 1,000 square feet of lawn. The total annual additions would be 3 pounds N, 2 pounds P, and 2 pounds K per 1,000 square feet of lawn. Phosphorus loading to the Wequaquet Lakes from fertilizer was estimated assuming that 0.5 lb per 3,000 square feet of lawn is lost annually via surface runoff. This represents a loss of approximately 8 percent of the phosphorus applied as fertilizer each year (Holt et al, 1970 and Ryden et al, 1973). Runoff from lawn areas along the shoreline of Wequaquet/Bearse is estimated to contribute 8.1 kg phosphorus annually.

An annual phosphorus load of approximately 9.0 kg is contributed to the Wequaquet/Bearse system from a year-round waterfowl/gull population estimated to be 100 animals. The remaining surface sources of phosphorus, listed in Table 18, are documented in Section 3.1.3 (Tributary Assessment) and Section 3.1.4 (Storm Sampling).

The predominant source of phosphorus to Long Pond is the water received from Wequaquet Lake via the herring run. Water from Wequaquet, discharging via the herring run for a period of six months, contributed a phosphorus load of 56.2 kg during the year of study (Appendix D). This represents 64.4 percent of the total annual load under existing conditions. Atmospheric input to Long Pond occurs as wet and dry deposition on the surface (area = 19.8 ha) and amounts to 6.9 kg annually. Runoff from lawn areas along the shoreline contributes 3.0 kg of phosphorus per year (calculated as above at 0.5 lb/3,000 sq.ft). A year-round waterfowl/gull population estimated to be 20 animals contributes an additional 1.8 kg of phosphorus annually. Phosphorus loading from storm drainage into Long Pond is quantified in Section 3.1.4 (Storm Sampling).

6.3 Phosphorus Losses

The principal avenue of phosphorus loss from the Wequaquet/Bearse system is sedimentation. Phosphorus incorporated into cellular matter by the biota of the system is deposited on the bottom when the organisms die. Fecal material from the animal life of the system also contributes to the total amount of phosphorus deposited in the sediment. In this sense, the sediment of the system acts as a phosphorus "sink". Phosphorus retention is a measure of the proportion of the total phosphorus budget lost to the sediment. Within the Wequaquet/Bearse system phosphorus retention is estimated to be 55 percent.

Within Long Pond, phosphorus retention is estimated to be 25 percent. The lower value for Long Pond results from the large amount of phosphorus lost via discharge to the lower section of the herring run. Water flowing out of Long Pond down the herring run to the Centerville River exports an estimated 45.8 kg of phosphorus annually from the system. This represents 52.5 percent of the total phosphorus budget of Long Pond. The phosphorus losses from both the Wequaquet/Bearse system and Long Pond are documented in Appendix D.

6.4 Trophic Status

Classification systems designed to define the trophic status of a lake or pond are all based on the biological productivity of the water body. The concept of trophic state and classification terminology have been introduced in Section 2.1. The fact that excessive productivity is symptomatic of excess nutrient loading has resulted in criteria which define trophic states by the phosphorus concentration of the water. Based on water quality criteria established by Wetzel (1983) the current trophic status of the Wequaquet Lakes is meso/eutrophic (Table 6, Section 3.1). In conjunction with models that enable the prediction of phosphorus concentration in the water column, trophic state classification systems indicate the probable response of a freshwater system to increased or reduced phosphorus loading.

The original phosphorus model of Vollenweider has been modified by the work of Dillon and Rigler (1974) to incorporate a phosphorus retention coefficient instead of a phosphorus sedimentation rate. This modified model accurately predicted phosphorus concentrations in eleven southern Ontario and four Swiss lakes. The model takes the following form:

$$[P] = \frac{L\,(1 - R)}{(z)(p)}$$

where [P] = predicted phosphorus concentration (mg/L)
L = areal phosphorus loading (g/m2-yr)
R = phosphorus retention coefficient (unitless)
z = mean depth (m)
p = flushing rate (volumes/yr)

The above model has been employed to evaluate calculations based on data from the year of study and to assess the impact from increasing phosphorus loads predicted to arrive via ground water (Section 6.0, Nutrient Budget).

Variables entered into the model under "existing" and "equilibrium" conditions and the phosphorus concentration predicted in each case are given in Table 22.

TABLE 22 - Variables for the Dillon/Rigler Phosphorus Model

Variable	Wequaquet/Bearse	Long Pond
existing areal phosphorus loading	0.074 g/m2-yr	0.440 g/m2-yr
"equilibrium" areal phosphorus loading	0.106 g/m2-yr	0.525 g/m2-yr
phosphorus retention coefficient	0.55	0.25
mean depth	3.6 m	2.6 m
flushing rate	0.48 volumes/yr	5.43 volumes/yr
predicted [P] under existing conditions	0.019 mg/L	0.023 mg/L
predicted [P] under "equilibrium" conditions	0.027 mg/L	0.028 mg/L (does not include loading from herring run with Wequaquet at "equilibrium")

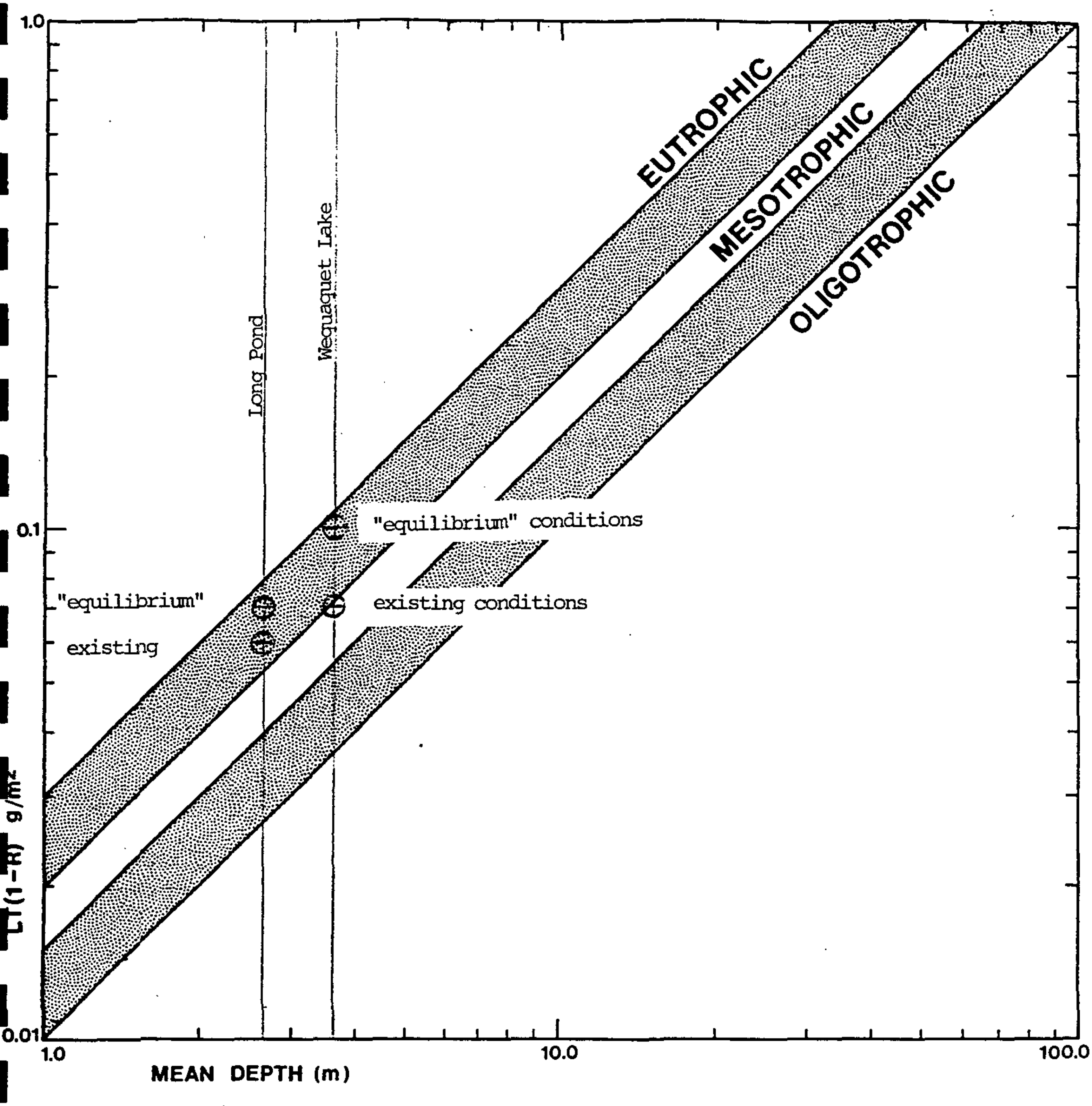
The mean phosphorus concentration observed during the year of study (0.025 mg/L; see Table 6) in Wequaquet/Bearse falls within the range of phosphorus concentrations predicted for existing and "equilibrium" conditions. This indicates that most of the phosphorus load derived from septic systems under predicted "equilibrium" conditions is already being delivered to Wequaquet/Bearse. Approximately 25 percent of the predicted load delivered to Wequaquet/Bearse from septic systems has yet to be realized.

The predicted value for existing conditions in Long Pond is slightly higher than the mean phosphorus concentration observed during the year of study (0.02 mg/L; see Table 6). This may be due to an overestimate of loading from background concentrations of phosphorus in ground water flowing into Long Pond. The background concentration of phosphorus in groundwater is assumed to be 0.05 mg/L (Frimpter and Gay, 1979). However, since most of the ground water received by Long Pond is discharge from Wequaquet Lake, it may have a lower background concentration of phosphorus. By being directly upgradient of Long Pond, Wequaquet Lake may function as a phosphorus "retention basin" that removes phosphorus from water before supplying it to Long Pond as ground water.

If the mean concentration of phosphorus in Wequaquet/Bearse becomes 0.027 mg/L as predicted under "equilibrium" conditions this will contribute an additional 4.5 kg of phosphorus to Long Pond via the herring run discharge. This, in conjunction with predicted "equilibrium" phosphorus loads (Table 19) to Long Pond will result in a mean phosphorus concentration of 0.029 mg/L according to the Dillon/Rigler (1974) model.

Figure 37 displays the position of the Wequaquet/Bearse system and Long Pond under existing conditions in a trophic status system designed by Dillon and Rigler. The trophic state of the Wequaquet/Bearse system and Long Pond predicted for "equilibrium" conditions are also displayed.

A shift in trophic status towards eutrophy occurs in the Wequaquet/Bearse system under "equilibrium" conditions. This indicates that the loading of phosphorus to Wequaquet/Bearse from septic systems in the recharge area and within 300 feet of shore can potentially trigger excessive biological productivity. As stated earlier, the mean phosphorus concentration documented during the year of study lies within the range predicted for existing and "equilibrium" phosphorus loads. Therefore, at present, the actual trophic status of Wequaquet/Bearse is between the points depicted on Figure 37. A shift in trophic status towards eutrophy also occurs in Long Pond. However, the shift is smaller and, according to empirical data generated during the year of study, the existing trophic status of Long Pond is more toward the mesotrophic range than depicted on Figure 37.



L = AREAL PHOSPHORUS LOADING ($g/m^2/yr$)
R = PHOSPHORUS RETENTION COEFFICIENT (DIMENSIONLESS)
T = HYDRAULIC RETENTION TIME (yr)

FIGURE 37 DILLON/RIGLER TROPHIC STATUS

7.0 DIAGNOSTIC CONCLUSIONS

The Wequaquet Lakes are beautiful examples of the type of freshwater system unique to an environmental setting such as Cape Cod. Principal features composing their unique character are the following:

1.) direct response to groundwater influence including water level elevation, hydrologic inputs and losses, and nutrient flux;

2.) minimal influence from the watershed due to low topography and highly permeable soils;

3.) chemical composition of the water exhibiting "softwater" characteristics due to the glacially derived sand and gravel composing their basins;

4.) proximity to the ocean results in addition of ions carried by the wind and frequent wind-driven mixing of the water column prevents thermal stratification in summer.

The Wequaquet Lakes possess excellent water quality and are valuable resources both for human recreation and as habitat for a unique flora and fauna. Symptoms of cultural eutrophication such as excessive algae growth or turbidity are minimal.

Both the Wequaquet/Bearse system and Long Pond share the qualities listed above. In contrast, the hydrologic and nutrient budgets of these two components of the Wequaquet Lakes are greatly different. The Wequaquet/Bearse system receives the greatest proportion of its water and phosphorus from direct atmospheric inputs. The fact that other sources of water and phosphorus are subordinate to the atmospheric influence on Wequaquet/Bearse is reflected in the low areal phosphorus loading rate, high phosphorus retention coefficient, and low flushing rate of this system. Conversely, the hydrologic and nutrient budgets of Long Pond are dominated by inputs received through the herring run from Wequaquet Lake. Long Pond functions as a temporary holding basin for water flowing from Wequaquet/Bearse down to its eventual discharge to the Centerville River. The influence of this large annual flux of water is reflected in the high areal phosphorus loading rate, low phosphorus retention coefficient, and high flushing rate of Long Pond.

The focus of the feasibility study in the following sections is the preservation of the water quality that exists in the Wequaquet Lakes. Major phosphorus inputs to the Wequaquet Lakes that are managable are septic systems, shoreline lawns, and storm drainage. Preventing the phosphorus load from these sources from increasing or reducing them will protect the Wequaquet Lakes from degradation of water quality.

8.0 IDENTIFICATION AND EVALUATION OF FEASIBILE MANAGEMENT ALTERNATIVES

8.1 Watershed/Recharge Area Management Strategies

The diagnostic study has shown that activities in the watershed and recharge area impact the Wequaquet Lakes and the quality of inflowing surface and ground waters. A number of land use practices, including wastewater disposal, lawn fertilization, and stormwater management contribute to the load of nutrients, suspended solids, chloride, and other contaminants entering the system. This section of the report presents actions which the Town and individual residents may take to limit, and in some cases reduce the impacts of land use on the lakes.

8.1.1 Land Use Management

General Zoning

Rezoning of land within the watershed/recharge area to a lake is a fundamental measure in any strategy recommended for water quality protection. This alternative has the potential to lower the density of new dwelling units within the area and thus reduce the load of nutrients that eventually reach the lake. Zoning regulates the use and density of land development by establishing minimum lot sizes, building dimensions, and setbacks from property boundaries, streets, and sensitive resource areas. When established in a manner respectful of the land's natural capacity to attenuate wastewater and other pollutants, zoning can be one of the most effective tools available to a community to preserve critical natural resources and protect the public health.

Unfortunately, the pattern of development in the watershed/recharge area to the Wequaquet Lakes minimize the potential benefits of this option. This is primarily due to the great number of existing dwelling units and also units protected under MGL Chapter 40A, Section 6. This law provides broad protection of uses and structures lawfully in existence at the time of adoption of new zoning regulations. (For instance, a lot of 5,000 square feet could possibly be built upon, even though the zoning is currently 43,560 square feet.) IEP has counted 859 existing units within the watershed/recharge area and another 148 lots of vacant land which are buildable under the current minimum lot size. This represents a total of 1,007 units already in place or "programmed" to be developed on 798 acres, the total recharge area (1 unit per 0.8 acres). Only about 110 acres of subdividable land can be found in the watershed/recharge area. By calculating the one acre minimum lot sizes in this area, approximately 90 additional units could be subdivided on this acreage. This represents only 8% of the total buildout potential. To rezone this area for a reduction of perhaps 40-50 units would be of limited benefit to the lakes.

Although dwelling density within the watershed/recharge area is approaching buildout conditions, there is one addition to the General Provisions of the Barnstable Zoning Bylaw that could reduce pollutant loading to the Wequaquet Lakes from an important source: fertilizer and pesticide-laden runoff from shoreline lawn areas. We recommend that a buffer be required between areas receiving fertilizer (lawns and gardens) and the shoreline of lakes, ponds, and streams. An additional subsection is recommended for Section 2-3.7 as follows:

3) All lawns, gardens, or other cultivated areas which may receive fertilizers and/or pesticides shall be setback a minimum of 50 feet from the mean high water line of surface waters.

This recommended setback distance is consistant with the setback distance imposed by the Barnstable Conservation Commission in its administration of the Wetlands Protection Act (MGL Chapter 31, Section 4.0).

Lake Protection Overlay District

The uses within the watershed/recharge area are governed by the regulations covering the RC, RD-1, RF (Residential districts, 1 acre lot size) and to a lesser degree the HB (Highway Business) districts found within the Town of Barnstable Zoning Bylaw. The residential districts, for the most part, allow by right one-family detached dwellings and also the renting of rooms for not more than three lodgers [3-1.1(2)(A)]. The potential for a reduction in the density of development is minimal due to the near buildout condition of the watershed/recharge area. However, there is a need to control certain activities around the Wequaquet Lakes and other water bodies in Barnstable.

Specifically, within recharge areas, activities that involve the use, generation, or storage of hazardous materials pose a potential threat to water quality. Contaminants such as petroleum products, solvents, and road salts are mobile in ground water. A spill or leakage of this type of contaminant will be transported to downgradient lakes via ground water and can have a toxic effect on lake biota. We recommend the creation of a Lake Protection Overlay District for the recharge areas of all lakes and ponds. At this time, only those waterbodies that have had their recharge areas delineated would be included within the jurisdiction of the bylaw. As other studies are performed, additional lakes and ponds could be included.
A mechanism for lake protection can be formulated within the existing Groundwater Protection Overlay Districts (Section 3-5.2 of the Barnstable Zoning Bylaw). We suggest adding a subsection (Subsection 8, see below) to this regulation and incorporate, by reference, all of the bylaw's prohibitions. Protection measures for ground water are also protective of surface waters in Barnstable due to the direct linkage between ground water and recharge to seepage lakes and ponds.

We recommend adding to Section 3-5.2 (Groundwater Protection Overlay Districts) the following subsection:

8) LP Lake Protection Overlay District Regulations:
The LP Lake Protection Overlay District consists of the delineated recharge areas of the following lakes and ponds within the town: Wequaquet Lake, Bearse Pond, Long Pond, Lake Elizabeth, Red Lily Pond, and Shallow Pond.

A) Permitted Uses:
The following uses are permitted in the LP Lake Protection Overlay District:
a) Any use allowed in the underlying zoning districts

B) Prohibited Uses:
The following uses are prohibited in the LP Lake Protection Overlay District:
a) Any use probibited in the underlying zoning districts.
b) All uses prohibited in Section 3-5.2(7)(B) herein.

The prohibited uses, briefly summarized, are as follows: sanitary landfills, junk and salvage yards, mining and quarrying, underground fuel storage tanks, sewage treatment facilities, feedlots, road salt storage, metal plating, chemical and bacteriological laboratories, vehicle service and repair, dry-cleaning, parking for fuel and hazardous substance transport vehicles, and any other use that involves the generation, storage, use, treatment, transportation, or disposal of hazardous materials.

IEP recommends that the Town continue the registration program for all home heating oil tanks and commercial tanks that currently exist in the recharge area to the Wequaquet Lakes (see Section 2.5). Individuals who own tanks within the recharge area should be alerted to the potential for damage to the Wequaquet Lakes and whom to notify should leakage occur. The three tanks identified in Section 2.5 should be routinely inspected or monitored. The close proximity of these tanks to Wequaquet Lake allows little opportunity to detect leakage before contamination occurs. If possible, they should be removed or replaced with corrosion-resistant tanks.

Non-Conforming Uses

A further recommendation deals with the control of non-conforming uses protected under MGL Chapter 40A, Section 6. Section 4-4 of the Barnstable Zoning Bylaw sets forth specific requirements for changing non-conforming uses. It allows for the modification, under certain conditions, of pre-existing non-conforming uses. We believe this mechanism offers the potential to improve these uses from the standpoint of water quality. The Zoning Board of Appeals needs to be mindful of not allowing different uses that would pose greater threats to water quality. This regulatory tool should be used to encourage the conversion of a non-conforming use to another use that poses minimal threat to water quality. In particular, the uses which are prohibited in the Lake Protection Overlay District, recommended above as Section 3-5.2(8), should never be allowed as a new non-conforming use.

Use Variances

Barnstable allows the Zoning Board of Appeals to grant "use" variances under Section 5-3.2(5) of the Zoning Bylaw. Use variances detract from the basic purpose of zoning, which is to keep non-compatible uses away from each other and from sensitive natural resources. Use variances are generally not allowed under Massachusetts law. In fact, a Town Meeting must explicitly state that the power to grant them is authorized. Without authorization from Town Meeting, granting of use variances is not allowed. We recommend that use variances not be allowed in the Town of Barnstable. They constitute "spot zoning", which is the arbitrary allowance of inappropriate uses in zoning districts. It is an unfortunate loophole in many zoning bylaws and can defeat Barnstable's overall strategy for protecting water quality.

If the Zoning Board of Appeals is allowed to continue granting use variances they should attach conditions to the issuance of such a variance. Uses that are prohibited in the Lake Protection Overlay District, recommended above as Section 3-5.2(8), should never be allowed as a use variance.

Land Acquisition

This alternative involves the acquisition and public or non-profit ownership of watershed/recharge area land. It is the most effective means of protecting the lakeshore, streambanks, and other environmentally sensitive areas from development, but it is also the most costly. Land values in Barnstable are high and are rising. Despite this, the Town has shown a commitment and willingness to purchase open space over the past two years (17 million dollars in 1986, 5.6 million dollars in 1987). This option would need to be pursued on a selective basis as part of the 1984 Open Space Plan that targets especially critical parcels for direct (fee simple) purchase and other, less sensitive areas for protection by other means (e.g. purchase of development rights, easements, conservation restrictions etc.).

Watershed/recharge area lands presently under private ownership, and either undeveloped or having additional development potential, have been identified on Town Assessor's sheets and ranked according to their water quality significance. These open, undeveloped parcels are listed in the IEP communications sent to Diane Boretos, former Conservation Commission Administrator (27 January, 1987), and Jacalyn Barton of the Barnstable Conservation Foundation, serving as open space consultant to the Commission (24 June, 1987). For the most part, the list contains only small parcels that would have a limited impact on water quality. However, three parcels have great potential for impact on lake-water quality and should be targeted for early acquisition or protection by other appropriate means. First, in the parcel containing 30.69 acres approximately 26 units could be developed on this parcel if it were to remain in private ownership. If acquired, the parcel could provide valuable access to Wequaquet Lake; a priority noted in the 1987 update of the Barnstable Open Space Plan. Adjacent to this parcel is a 14 acre parcel. Additional parcels worthy of consideration because of their size and because of the access they may potentially create are denoted with an asterisk in the communications mentioned above. Some parcels are primarily wetland, making them unsuitable for development. However, the Town may wish to either purchase or create easements/restrictions in these areas to ensure their protection and create access.

As mentioned previously, the means of acquiring these lands is somewhat limited. The Town's 1987 Open Space Plan update provides Barnstable eligibility for Self-Help funds until the year 1992. Although no lands surrounding Wequaquet are specifically targeted for acquisition/regulation within the Open Space Plan, the need for improved access to Wequaquet is discussed. The above named parcels would seem to be worthy of inclusion in any open space planning effort.

The updated Open Space Plan is useful in other regards. Mentioned within the plan is the effort to transfer tax title properties to Conservation Commission jurisdiction. It would be beneficial for the Town to examine such opportunities within the Wequaquet Lakes watershed/recharge area. This can apply to tax title lands currently under Town control as well as development of tax properties in the future. This represents a possible means for the establishment of beach access and also to limit development in the watershed/recharge area.

Another opportunity for the preservation of land within the watershed/recharge area is to promote the use of conservation restrictions. A conservation restriction allows the owner to continue to maintain the property (title remains with the owner) and give up, by sale or gift, the right to develop the property. The Selectmen and State Secretary of Environmental Affairs must accept the restriction. Put simply, the tax benefit for a donation of a conservation restriction is a deduction for the value of the property's development rights. According to the updated Open Space Plan, this method of open space preservation has not been utilized to its fullest extent. Conservation restrictions might be useful for several properties within the Wequaquet Lakes watershed/recharge area. One specific parcel (7 acres), is located adjacent to the 30.69 acre parcel mentioned previously as a possible acquisition. Although this parcel is partially developed, a restriction might be placed on other portions of the land to create contiguous open space in this area.

A final land acquisition strategy the Town might pursue would need the active involvement of the Planning Board. Under MGL, Chapter 41, Section 81-U, a town may require that a developer set aside an amount of open space within subdivisions for recreation. This land, usually an open lot, must remain open for a period of three years, after which, if not purchased by the Town or donated, it may be developed. Within a heavily developed (and subdivided) area, a number of these lots may be evident. It is recommended that: (1) the Planning Board require these open spaces within any proposed subdivisions in the Wequaquet Lakes watershed/recharge area and (2) the Town examine this area for any of these open lots and purchase them if feasible.

The Planning Board should encourage any future subdivisions to become Open Space Residential Developments under Section 3-1.6 of the Barnstable Zoning Bylaw. By utilizing the cluster concept, lots can be situated as far from delicate resource areas as possible.

The small amount of undeveloped land within the watershed/recharge area makes land acquisition an important alternative. Land acquisition, in combination with the promotion of conservation restrictions, could preserve some of the few remaining lakefront parcels on Wequaquet Lake. The Town may wish to focus research on the transfer of tax title properties to the Conservation Commission and provisions under MGL, Chapter 41, Section 81-U for the preservation of open space parcels within subdivisions. These last two options, while not impacting to a great degree the water quality of the lakes, may provide for open space/access within a heavily developed area.

Wetlands Protection

This alternative involves the continued administration of the Wetlands Protection Act (M.G.L. Chapter 131, Section 40) by the Conservation Commission. The purpose of this Act is to preserve the critical natural functions of wetlands and the interests they represent, including: protection of public or private water supplies and groundwater, flood control, storm damage prevention, prevention of pollution, protection of land containing shellfish, protection of fisheries, and protection of land supporting wildlife habitat. The Conservation Commission is empowered to review and set conditions on development proposals within 100 feet of defined Resource Areas which might significantly impair these interests.

The Barnstable Conservation Commission executes its responsibility under the Wetlands Protection Act. It reviews development proposals having the potential to alter or impair these areas and, imposes Orders of Conditions on projects posing a threat to water quality or other wetland interests. Barnstable's local wetland protection bylaw, amended in 1987, adds considerable additional review authority to the Conservation Commission.

In the context of protection for surface waters, we recommend that the Conservation Commission pay particular attention to setbacks for buildings and landscaping activities near resource areas. Existing setbacks are 35 feet from wetlands and 50 feet from the shoreline of Great Ponds, such as the Wequaquet Lakes. As stated previously, the maintenance of these setbacks will reduce the inputs of nutrients and pesticides to surface waters from shoreline lawn areas. As part of the comprehensive management plan for the Wequaquet Lakes, it is recommended that the Conservation Commission continue its administration of the Wetlands Protection Act.

Homeowner Practices/Public Awareness

This alternative involves the development and dissemination of educational materials to the homeowners within the watershed/recharge area. These materials would increase public awareness about the influence of their activities on the Wequaquet Lakes. Specific topics to be included in the educational materials are the following: use of no-phosphorus detergents, discontinuing use of garbage grinders, avoiding use of septic system "cleaners", discriminant application of lawn fertilizer and pesticides, maintenance of vegetated buffer zones along shorelines, and septic system maintenance. As a result of this instruction, a significant reduction in nutrients entering the Wequaquet Lakes from septic systems and shoreline lawns can be expected.

The use of phosphate detergents in homes relying on septic systems decreases the effective operating life of the systems' soil adsorption fields. Once the phosphorus attenuation capacity of an adsorption field is reached, additional inputs of phosphorus flow unabated from the site, resulting in accelerated deterioration of the receiving water. We recommend the distribution of an information brochure, prepared by IEP, that describes the impact of phosphorus detergent on water quality and lists alternative, no-phosphorus detergents. Also to be included in the brochure is information about the proper use and maintenance of on-site septic systems. The brochure could also include information on fertilization impacts to lakes and describe sensible lawn care practices (see below). This measure is a feasible, low cost means of educating the public and achieving a reduction of phosphorus loading to the lakes.

Commercial fertilizers applied on lawns and gardens contain phosphorus, nitrogen, and potassium in varying amounts (see Section 6.2.3). These nutrients contribute not only to greener lawns but to the growth of algae in lakes when washed from the land by storms. In the Wequaquet Lakes watershed/recharge area, there are extensive lawn areas to which fertilizers are applied throughout the growing season. Lawns associated with dwellings along the shoreline are significant sources of phosphorus due to the high potential for delivery to the lake system in surface runoff. Shoreline lawns cover approximately 106,800 square feet around Wequaquet Lake/Bearse Pond and 39,400 square feet around Long Pond. Phosphorus inputs from these lawns are quantified in Section 6.0 (Nutrient Budget).

Professional contractors often use liquid forms of inorganic fertilizers, which are more concentrated than organic fertilizers and tend to leach out of the soil more quickly. They may also contain other chemicals, such as pesticides, herbicides, and fungicides, that can impair the lake environment. In contrast, organic fertilizers (well composted animal manure, bonemeal, etc.) provide a slow-release source of nutrients which have a longer residual effect in the soil and are less susceptible to leaching.

The use of both kinds of fertilizers, but specifically inorganic fertilizers, should be kept to a minimum, especially on shoreline lawns. In addition, application of fertilizers within 50 feet of the shoreline should be discouraged, as nutrients are most likely to enter the lakes directly in surface runoff along the immediate lake margin. Shoreline residents should be encouraged to maintain a vegetated buffer zone between lawn areas and the water's edge. Buffer zones vegetated with shrubs and/or trees will trap and hold pollutants in surface runoff before they reach the Wequaquet Lakes. These practices can be promoted in an educational brochure as part of the educational materials described above.

One of the important announcements in this brochure will be the availability of a new lawn care product called "Lakeside Lawn Fertilizer" developed by Aquatic Chemicals, Inc. of Caledonia, Michigan. This fertilizer contains a slow-release nitrogen and no phosphorus. It was specifically developed for use in sensitive watershed areas where even low levels of phosphorus can promote problem weed and algae growth. According to the manufacturer, a 50-pound bag will cover 5,000 to 8,000 square feet of lawn and will need to be applied only twice per season (spring and fall) under normal soil and rainfall conditions. Research has shown that on a well-established lawn, little if any additional phosphorus is required to maintain the vitality of the lawn. Nitrogen is the key ingredient to keeping the lawn green and this element is available in adequate supply in the Lakeside Lawn Fertilizer.

Cape Cod Commission

The Cape Cod Commission represents a future regulatory tool for Barnstable, although it is now stalled in the state legislature. The creation of the Cape Cod Commission could increase regional authority over projects that have potentially significant impacts to our water supply. The residents of Barnstable, particularly those with an interest in preserving the Wequaquet Lakes, should strongly support such a concept.

8.1.2 Wastewater Disposal

On-site wastewater disposal systems are contributing significant amounts of phosphorus to the Wequaquet Lakes at the present (Section 6.0, Nutrient Budget). Aging of septic system leach fields, and future development of more systems will cause increases in this source over time. This section discusses use of alternative systems and municipal sewerage as means of minimizing the impact of wastewater disposal within the watershed/recharge area. Regulatory measures to improve the efficiency and expand the life span of existing systems are also outlined.

The following discussion of wastewater disposal alternatives only deals with those septic systems located within a 300-foot shoreline zone around the Wequaquet Lakes. The U.S. Environmental Protection Agency (1983) has determined that only those septic systems within 300 feet of a freshwater system represent significant sources of phosphorus. Although K-V Associates have documented transport of phosphorus over distances greater than 300 feet (in a reducing groundwater environment, see Section 6.2.1), priority must be assigned to measures for mitigating the impacts from septic systems within the 300 foot "buffer" zone around the Wequaquet Lakes. These septic systems pose the most immediate threat to lake water quality due to incomplete attenuation of phosphorus in ground water moving this distance. It is important that they be inspected and, where found deficient (failing or improperly sited), placed in proper operating condition as soon as possible. At present 231 septic systems exist within the 300-foot buffer zone to Wequaquet Lake and Bearse Pond. There are 40 septic systems within the 300-foot buffer zone to Long Pond.

Alternative Systems

This option involves the use of holding tanks, nondischarge toilets, or communal septic systems where septic systems are failing or leaching facilities are poorly sited. From a technical standpoint, it would be possible to install holding tanks at each residence located within 300 feet of the lakes. This would eliminate all future wastewater discharges from these homes and reduce the flow of phosphorus to the lakes. However, such installation would require submission of a request for a variance (310 CMR 15.20) to the DEQE by the Barnstable Board of Health on behalf of the homeowner, and it would be up to the individual homeowner to implement this measure. Costs would be on the order of $2,500 per residence for equipment and installation, and an additional $150 per month for septage pumping. Obviously, this represents a heavy financial burden to the homeowner, and it is unlikely that this alternative would be acceptable to a majority of the homeowners involved. Therefore, rather than requiring its application by all waterfront property owners, it is recommended that the Board of Health consider this measure on an individual case-by-case basis. For example, where a particular septic system is subject to frequent failure, but lacks an alternative adsorption field suitable for system relocation.

A second alternative for reducing shoreline nutrient loadings is to retrofit all conventional toilet fixtures with nondischarging toilets. Impacts include the cost and inconvenience to the homeowners during conversion as well as potential aesthetic and odor problems sometimes associated with improperly operated or poorly functioning nondischarging systems. Like the holding tank alternative cited above, the only realistic application for this option is on an individual voluntary basis or if ordered by the Board of Health. Installation of chemical or humus toilets is regulated by the Board of Health through 310 CMR 15.16-17.

The construction of communal septic systems is technically feasible, and can be effective where existing systems are old and have exhausted the phosphorus attenuation capacity of their soil adsorption fields. It would be easier for the Board of Health to inspect and enforce the maintenance on a single communal system than to regulate a series of individual systems experiencing problems. Application of this option would be feasible on only a limited basis; where several systems are failing and where a suitable site exists for installing the communal system.

At this time, the widespread use of alternative systems in the watershed/recharge area does not appear to be feasible or warranted, and is not recommended. Instead, we recommend that the Board of Health remain flexible in its approach to regulating wastewater disposal so that, should the need arise, these systems can be instituted, as appropriate, on an individual case-by-case basis.

<u>Municipal Sewerage</u>

A permanent solution to the subsurface wastewater disposal problem in the Wequaquet Lakes watershed/recharge area is to connect all households and businesses to the municipal sewerage system. Unfortunately, sewering is not a feasible alternative based on the present plans for the Town Sewage Treatment Plant and accompanying sewers. Whitman and Howard, Inc. has recently completed a report for Barnstable outlining the capabilities of the Town's sewerage system and the priorities for future sewer extensions (Whitman and Howard, Inc., 1987). This report recommends three areas for sewer extensions in order of priority:

I. Sea Street/Gosnold Street
II. Area surrounding Bearses Way in Hyannis
III. Craigville Beach Road, west to Jackson Avenue

These three areas were given priority based on the number of malfunctioning systems in the area that cannot be upgraded, the potential for nitrate contamination of public water supplies from on-site septic systems and nitrate contamination from the plume originating at the sewage treatment plant. Residential and commercial density and depth to ground water were also important considerations.

The Wequaquet Lakes area is not one of the three sewering priorities and none of the priorities will bring sewer lines near the area. According to Frank Lambert, Barnstable Town Engineer, it will be a considerable time (ten to twenty years) before the three priority sewer extensions will be completed. At this time the capacity of the treatment plant may limit additional connections to the system.

Restrictions on phosphate detergents and garbage grinders, the selective use of alternative systems, and regular maintenance of septic systems, will all help to reduce the amount of phosphorus reaching the Wequaquet Lakes.

Board of Health Regulations

This alternative involves the adoption and enforcement of additional or stricter Board of Health regulations to prevent pollution of the Wequaquet Lakes and the herring run by improperly sited or maintained on-site septic systems. Municipal Boards of Health are authorized by the Massachusetts General Laws (MGL Chapter 111, sections 31, 127, and 127A) to adopt and enforce reasonable health regulations. Such regulations may include provisions to meet or exceed the minimum requirements for septic system maintenance as established by Title 5 of the State Environmental Code - "Minimum Requirements for the Subsurface Disposal of Sanitary Sewage." Where local conditions warrant, the Board may adopt stricter standards to ensure that septic systems are "maintained in a manner that will not ... cause the works to become a source of pollution to any of the waters of the Commonwealth."

Currently, the Board of Health is involved in review of septic system plans or inspection of systems only during the permit process for new structures or alterations to existing ones (John Kelly, former director of the Barnstable Health Department, telephone communication on 11- May, 1987). There is no program of routine inspection or maintenance to assure that septic systems in the watershed/recharge area are functioning properly. The only existing mechanism by which the Board of Health learns of a problem is notification by the treatment plant of receipt of septage from a system more than once a year. The Board of Health considers a system which must be pumped two or more times per year to be a failing system.

We recommend the adoption of a mandatory septic system inspection and maintenance regulation focused on systems within the 300-foot buffer zone. The widespread use of septic systems in the buffer zone, and their potentially significant contribution (estimated at 28.6% in Wequaquet/Bearse and 13.1% in Long Pond under "equilibrium" conditions; see Section 6.2.1) to the total phosphorus input to the lakes, demonstrates the need for this particular control measure. Although even a properly functioning system within the 300-foot buffer will contribute phosphorus to the Wequaquet Lakes, the inspection program will insure that failing systems do not contribute even greater loads via surface runoff of standing effluent. Also, this inspection program will allow the Board of Health to identify poorly sited systems and order the installation of a holding tank or non-discharging toilet in situations where discharge to the lakes from a leaching facility is unavoidable. Only through this approach can the Board of Health be reasonably assured that all existing and future septic systems in the buffer zone are kept in proper operating condition and are treating domestic wastewater as effectively as possible.

This proposed regulation calls for the Board's inspection of all septic systems within the 300-foot buffer zone within two (2) years of the effective date of the regulation and every three (3) years thereafter. The regulation also requires the mandatory pumping of each system within the 300-foot buffer zone at least once every three years by a licensed septage hauler at the owner's expense. Problem systems may be required to be pumped more frequently per order of the Board of Health. The owner of each system will be required to sign a receipt, to be furnished by the septage hauler, certifying that the system has been pumped. A copy of the receipt will be forwarded to the Board of Health. It is recommended that the Board create a central file containing an individual record of each septic system in the watershed/recharge area. These records can be maintained on separate, standardized cards that identify the property location of the system and means of access, street address, lot number, owner's name, and relevant inspection and maintenance information.

The cards can be designed so that, when folded, the property location is uppermost for ease of filing and retrieval. The field inspector should not remove these permanent cards from the file, but instead carry a copy of the card into the field. Maintenance record information, system location information, and comments and recommended actions noted on the field copy by the inspector can later be transcribed onto the original card so that a complete record of all systems is always available in the Board of Health office.

The estimated staffing requirements and costs involved in setting up and operating the mandatory inspection and maintenance program are as follows:

One (1) full-time inspector (sanitary engineer or registered sanitarian)	\$20,000 - \$30,000
One (1) half-time clerk/secretary	\$ 5,000 - \$ 6,000
Record-keeping system (file cabinet, file folders, printed standardized record cards) ..	\$ 500 - \$ 750
Mileage and mailing costs (third-year reminder notices to system owners)	\$ 250 - \$ 400

To facilitate administration of the program, it is recommended that the Wequaquet Lakes buffer zone be divided into three (3) maintenance districts of approximately the same number of residences on septic systems. One maintenance district can be completed each year. At the end of each three-year cycle, all septic systems will have been inspected and pumped at least once. Certain problem systems will require more frequent attention.

Beginning immediately, all septage haulers licensed to operate in Barnstable should be notified in writing of their responsibility to submit a signed and dated receipt for each septic system pumped out. These receipts should be kept on file until such time that they can be incorporated into the individual septic system file folders to be created when the record-keeping system for the inspection and maintenance program becomes operational.

This inspection and maintenance program is a feasible method of assuring that all septic systems in the 300-foot buffer zone are functioning efficiently. Properly administered, this program will help to extend the useful operating life of these systems and forestall the need for costlier centralized treatment facilities. We recommend that this program be implemented as soon as is practicable.

In conjunction with the regulation proposed above, a regulation should be formulated requiring that, prior to a change of ownership, septic systems be brought into compliance with Title 5. This regulation will expand the power of the Board to regulate the up-grading of substandard septic systems. At present, this is possible only if there are obvious signs of system failure or unless the homeowner requests a building permit to expand their home. If site conditions make this impossible, variances may be granted, provided that systems are set as far back as possible from the shoreline. Mounded systems may be appropriate in order to meet the requirement for vertical separation.

A final recommendation concerns the distance required for separating septic systems from shorelines. The Board of Health presently requires a minimum septic system setback of 100 feet from surface waters. This is a more stringent standard than the DEQE Title 5 minimum requirement, and has afforded an added degree of protection to surface waters that would otherwise not have existed. Nevertheless, there is technical evidence available to suggest that even these longer setback distances may not adequately protect lakes and ponds from wastewater-derived pollutants. As discussed above, the EPA (1983) studies have shown a 300-foot non-discharge zone to be a more reasonable standard for protecting receiving water quality. Accordingly, we recommend that the Board of Health amend its septic system siting regulation to require a minimum leaching facility setback extending 300 feet horizontally from the annual mean high water mark of all surface water bodies. This is a feasible means of protecting the lakes and ponds of Barnstable from future wastewater discharges, and can be implemented by the Board in the short term. This regulation, by its incorporation with Title 5, will become part of the review process for subdivision approval under the Subdivision Rules & Regulations Section 3.C.3. Suggested wording to be added to the present subsurface disposal regulations is as follows:

> "No part of the leaching facility shall be less than 300 feet measured horizontally to the mean high water mark of lakes and ponds."

8.1.3 Stormwater Management

Three points of stormwater drainage into the Wequaquet Lakes require special consideration due to their immediate and pronounced negative impact on water quality. These are the Oak Street culvert system that drains into Wequaquet Lake at station 6, the section of Route 28 that drains into the herring run at the point where the herring run passes under the road and bike path upstream of Long Pond, and lastly, the section of West Main Street that drains into Long Pond through a culvert on the northeast shore.

The detrimental effects of these stormwater sources have been documented in the diagnostic section. The Oak Street culvert system contributes significant loads of acidic water, nutrients, and suspended solids to Wequaquet Lake during major storms. Runoff from route 28, entering Long Pond via the herring run, and discharge from the culvert on the northeast shore of Long Pond have resulted in relatively high concentrations of lead accumulating in the sediment and elevated levels of chloride in the water column.

<u>Oak Street Culvert System</u>

Mitigation of input from the Oak Street culvert system involves more stringent control of water levels in the three basins connected by the culverts. Control structures employing flashboards are located at the outlet of each basin in the system and are accessable, but no management of water level occurs during storm events. Each basin in the system has potential for greater storage capacity than at the levels currently allowed. This applies particularly to the middle basin of the system which is located within the powerline easement (Figure 1).

The above basins should be managed as retention-infiltration impoundments during storm events with their maximum storage capacity utilized. Utilization of this additional storage will increase the volume of precipitation required to cause the system to discharge into Wequaquet Lake. Currently, water level in the middle basin is the critical factor determining system storage capacity. A storm event greater than 1.85 inches causes this basin to overflow and the system to discharge. Storm events greater than 1.85 inches occur, on average, only 2 or 3 times per year. Management of the basins to maximize their storage would insure that only rare, high volume storm events could cause the system to discharge and would reduce the volume of discharge received by Wequaquet Lake. Specific steps required to implement this recommendation are the following:

1) Establish appropriate water levels or an acceptable range of levels for each basin in the system. Facilitate a review process so that the levels established for each basin have taken into account the concerns of all townspeople affected by the decision.

2) Delegate an appropriate town official as the one responsible for managing the control structures of each basin and insuring that full use of the storage capacity of the system is utilized before allowing discharge into Wequaquet Lake.

Route 28

At a distance of only 125 meters upgradient of Long Pond, the herring run receives road runoff and sediment from Route 28 and the bicycle path. Storm runoff washes large amounts of sediment over the retaining wall such that water flowing in the herring run is often forced to meander through the sediment deposited at the mouth of the herring run culvert. Drainage from Route 28 into Long Pond via the herring run contributes to the elevated levels of lead in the sediment and chloride in the water column. Additional evidence of this impact was obtained during the septic leachate survey conducted by K-V Associates. A plume exhibiting high conductivity was detected at the point where the herring run discharges into Long Pond (Figure 34).

Installation of curbing and two leaching catch basins (Figure 38) on Route 28 is recommended to mitigate the above impact. The recommended structures are designed to infiltrate the frequent, small rainfall events and the "first flush" of larger storms. It is the first flush (first 0.5 inches of precipitation) that carries the bulk of contaminants into receiving waters (Schueler, 1987). Estimates of the dimensions and cost of the structures involved are given below.

Drainage area = 300 feet x 30 feet = 9,000 square feet

Volume of runoff (assuming 0.5 inches of precipitation) = 375 cu. feet

Bottom area required for infiltration = 23 square feet
(infiltration rate = 8 inches/hour, Maryland WRA, 1984)

Cost, including labor,
for 600 feet of bitumen curb = $2.25/foot x 600 feet = $1,350
(300 feet on each side; 12 inches wide and 3-6 inches high)

Cost, including labor, for each leaching catch basin = $1,600 to $1,800
(excavation and installation)

TOTAL COST ESTIMATE = $4,600 to $5,000 for two leaching catch basins and
600 feet of bitumen curb

West Main Street

The culvert discharging on the northeast shore of Long Pond receives drainage from a section of West Main Street and an extensive parking area for a commercial produce market. The total area contributing runoff to this discharge is approximately 5,145 square meters. The discharge from the above culvert was sampled during two storms as station LPS-1 (see Section 3.1.4, Storm Sampling). The water quality impacts resulting from the discharge of storm runoff at this point are similar to those described above for the herring run. At this point also, a plume exhibiting high conductivity was detected during the septic leachate survey. That much of the runoff is derived from a parking area is indicated by the significant levels of oil and grease measured in samples taken during both storms.

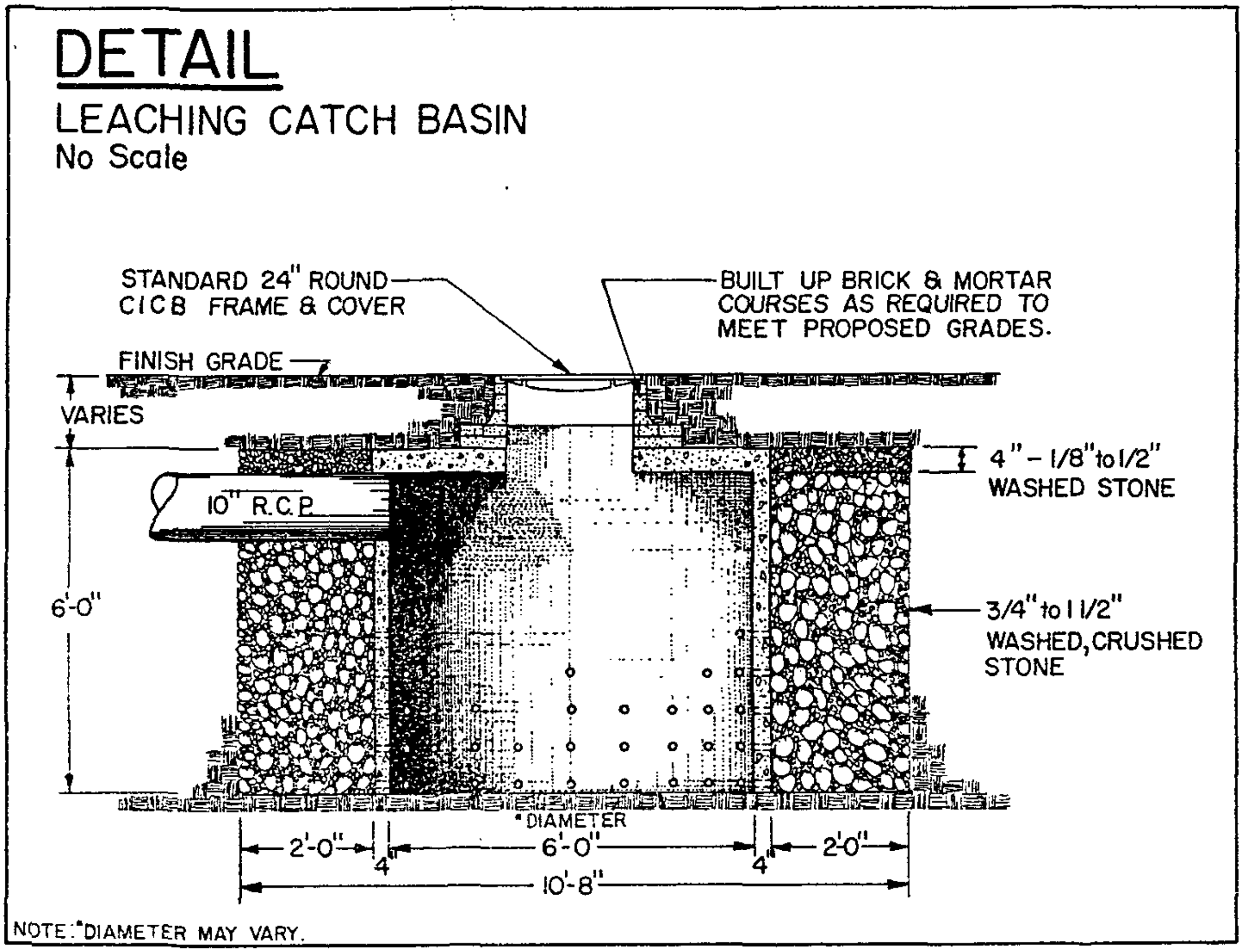


FIGURE 38 - DETAIL OF CATCH BASIN

Installation of two leaching catch basins in series is recommended to mitigate the impact from the above culvert. Estimates of the dimensions and cost of the structures involved are given below.

Drainage area = 5,145 square meters = 55,352 square feet

Volume of runoff (assuming 0.5 inches of precipitation) = 2,300 cu. feet

Bottom area required for infiltration = 140 square feet
(infiltration rate = 8 inches/hour, Maryland WRA, 1984)

Cost, including labor, for each leaching catch basin = $1,600 to $1,800
(excavation and installation)

Cost for manhole = $1,600

TOTAL COST ESTIMATE = $4,800 to $5,200 for manhole *and* two leaching catch basins in series

Ideally, one of the two catch basins would be installed at the edge of the parking lot and would have an overflow pipe leading under West Main Street to the second catch basin of the series. This second catch basin could be open to drainage from West Main Street in addition to receiving overflow from the first catch basin. Finally, the series could be connected to the existing culvert that eventually discharges into Long Pond. The addition of the two catch basin series would insure that contaminants associated with the "first flush" of storm runoff would be forced to infiltrate rather than be discharged directly into Long Pond. The series arrangement of catch basins will prevent any storm discharge from this area to Long Pond in all but the largest storms.

The cost estimates for curbing, catch basins, and manholes given above are based on "Means Site Work Cost Data - 1987" from the R.S. Means Company, Inc., Kingston, MA. The cost data are taken in individual pieces from small to very large projects. For the relatively small projects outlined above, mobilization and overhead for contractors may be proportionally greater, therefore the above cost estimates should be considered to be the minimum.

Street Sweeping and Catch Basin Maintenance

This alternative involves increased mechanical cleaning of streets and catch basins within the watershed/recharge area by the Barnstable Department of Public Works. Its purpose would be to further reduce the accumulation of sediment and organic material that might otherwise wash into and degrade water quality in the Wequaquet Lakes during storm events and snowmelt.

Presently, all of the main roads in Barnstable (totalling approximately 140 miles) are cleaned once each year using two mechanical brush sweepers owned and operated by the Highway Department (William Doiron, telephone communication on 11-May, 1987). Total coverage of the 400-500 miles of roadway in Barnstable takes place over a three-year period. The one major problem which does exist is the highway crew's inability to attend to the roads within the watershed/recharge area as early in the season as they would like. As a result, much of the accumulated sediment from the winter sanding program is washed off of the streets by heavy storms or snowmelt before the highway crew can attend to them. In recognition of the need for more frequent and efficient street cleaning, the Town has arranged for a town-wide sweeping by private contractor, to be performed each year in the early spring. This will significantly reduce the potential inflow of high nutrient and sediment loads into the lakes and herring run during spring storms and snowmelt. In addition, we recommend that the Highway Department employ its two machines to sweep critical areas on a routine basis throughout the non-winter months. These critical areas are the following: (1) Shoot Flying Hill Road, (2) Huckins Neck Road, (3) Phinneys Lane, (4) Route 28 along the herring run overpass, and (5) West Main Street along the eastern end of Long Pond. Given the potential for runoff of suspended solids, metals, and nutrients with stormwater, it is imperative that the Highway Department give the five areas listed above high priority when scheduling clean-up efforts. Monthly cleaning may be adequate, but the frequency of cleaning can be determined by the Highway Department based on their experience and observations of sediment and litter buildup in these areas.

Currently, the capacity of the Highway Department to keep up with catch basin maintenance is overextended. Town-wide catch basin cleaning requires a three to four-year period to complete. This is done using two machines (one mechanical and one vacuum type) owned and operated by the Highway Department. Infrequent cleaning increases the chance that catch basins in trouble spots will become full and lose their effectiveness before they can be attended to. This problem has also been recognized by the Town and catch basin maintenance by private contractor is being considered. It is recommended that this measure be adopted and that all catch basins be cleaned at least once a year. Catch basins which accumulate sediment more frequently, such as those at the base of hills or near active construction sites, should be cleaned more regularly. The Highway Department should monitor the buildup of sediment after storms and periods of snowmelt, and clean any catch basins that are full or nearly full with their own machines.

Those areas currently undergoing construction (or recently developed) where slope conditions may not have fully stabilized or vegetative cover become permanently established should be periodically inspected by the Highway Department for accumulated sediment to determine the need for additional street sweeping. Areas where the localized buildup is found to be particularly pronounced should be swept clean at that time, rather than waiting for a routine quarterly cleanup. This could be accommodated within the existing operational framework of the Highway Department without the need for additional personnel and equipment.

As a means of gauging the overall efficiency of the department's sediment removal program, it is recommended that the Highway Department record the amount removed by street and catch basin cleaning the next spring. The difference between the amount applied during the winter sanding program and the amount collected during spring cleaning would provide a reasonable estimate of the amount of sediment that is not successfully retrieved by the annual cleanup program. The difference can be expected to eventually reach the Wequaquet Lakes via runoff. Should this constitute a significant percentage of the total amount of sand applied each year, it would be an indication that the overall efficiency of the cleanup program is too low and would need to be improved.

8.2 In-Lake Management Strategies

In-lake management/restoration alternatives are generally focused on the reduction of algae and/or macrophyte growth in an aquatic system. They can be divided into two categories, short-term and long term. The first group includes techniques such as mechanical harvesting or herbicide treatment, which provide short-term weed control and generally must be repeated annually or once every two years at a reoccurring expense. Sediment removal (dredging), fall-winter drawdown, and in some cases, mechanical weed raking, are usually considered long-term in-lake control strategies. The initial cost for design and implementation of these restoration techniques may be high, but the expense for continuing annual maintenance of a water body is often reduced or eliminated. The evaluation of these different in-lake strategies first requires a well defined management goal that takes into account the primary uses of the water body. The Wequaquet Lakes are valued for recreational activities such as boating and fishing.

Macrophytes in the Wequaquet Lakes are limited to shallow water areas (littoral zone) due to light limitation at greater depths (see Section 3.2). Within the littoral zone, macrophyte distribution is controlled by a suite of environmental factors including substrate composition, nutrient availability, temperature, and water turbulence. Except for localized areas of the lakes, macrophyte growth is not excessive and does not interfere with recreational uses of the lake. Further, no exotic plant types, such as Eurasian milfoil, were observed in the Wequaqet Lakes. The presence of exotic plant species often warrant some form of control to retard or possibly eliminate the infestation. In view of the above considerations, in-lake management techniques are not necessary. What follows is a review of in-lake techniques and an evaluation of which may be appropriate in the future.

8.2.1 Physical Techniques

Mechanical Weed Control

Mechanical weed control (i.e. weed harvesting and weed raking) are techniques commonly utilized in lake management programs. Both techniques have a decided advantage over chemical (herbicide) application in that they remove vegetation from the water body and do not add any potentially toxic materials to the water. The Wequaquet Lakes do not have a problem with excessive aquatic vegetation at the present time. The existing macrophyte flora is diverse and provides valuable habitat for fish and wildlife. Exotic species such as Eurasian water milfoil are absent. Nutrient removal by macrophyte harvesting is an appropriate technique for lake systems exhibiting heavy accumulations of vegetation. The relatively low density growth of macrophytes in the Wequaquet Lakes render this technique inappropriate. We do not recommend mechanical weed control methods at this time.

In certain protected areas of the Wequaquet Lakes, such as Gooseberry Pond, macrophyte growth interferes with the ability of shoreline residents to use their docks. In this situation, local residents may wish to organize themselves and hire a contractor for localized weed harvesting or hydroraking. This approach is appropriate for localized control and would not be detrimental to the Wequaquet Lakes system as a whole.

Aeration

Mechanical aeration/destratification systems have been used with some success in lakes and reservoirs to reduce densities of microscopic algae and improve water quality. This technique can reduce phosphorus release from sediments in a strongly stratified lake with hypolimnetic anoxia. Similarly, this technique may also reduce the amount of iron and manganese released from bottom sediments into the hypolimnion. The Wequaquet Lakes are thoroughly mixed by wind and thermal stratification has not been observed. Therefore, releases of phosphorus from the sediments are minimal. Based upon these considerations, aeration will not significantly improve water quality in the Wequaquet Lakes.

8.2.2 Chemical Techniques

Herbicides/Algicides

Use of herbicides is not recommended in the Wequaquet Lakes due to the potential water quality impacts to ground water which may ultimately contribute to public water supply. Additionally, significant amounts of nuisance aquatic vegetation is lacking in most areas of the system. High algal densities have been observed only rarely in the Wequaquet Lakes. These algae blooms are temporary and do not represent a significant degradation in water quality. Use of algicides is not recommended.

Phosphorus Inactivation/Bottom Sealing

Aluminum sulfate (alum) has been applied to a number of recreational ponds and lakes to strip the water column of phosphorus and other colloidal/suspended matter. After binding to these particles in solution, the resulting "floc" precipitates out and covers the bottom sediments. This "floc" cover forms an effective barrier to phosphorus release from sediments and is commonly used to remove color and suspended solids in drinking water. The comparatively low internal phosphorus load recycled in the Wequaquet Lakes rules against the use of this technique.

8.2.3 Water Level Control

Lowering water level during the fall and winter has been used with some success in controlling several species of aquatic vegetation. With a portion of the littoral zone uncovered, macrophytes are exposed to the combined effect of freezing and desiccation (drying). The dominant macrophyte types found the Wequaquet Lakes are not controlled well by fall/winter drawdown and no significant reduction in plant biomass could be expected. Furthermore, drawdown would interfere with the management of water levels required by the herring fishery.

8.2.4 Sediment Removal

Dredging or sediment removal is appropriate for systems with a high sedimentation rate. Dredging can usually be accomplished in one of two ways: (1) with conventional excavating equipment once the water level has been lowered or pumped down or (2) with hydraulic dredge apparatus with the lake full. Both these techniques are costly and involve an extensive dewatering and disposal for the dredge spoils. Sedimentation rates within the Wequaquet Lakes are relative low and, as with the other in-lake techniques, a minimal improvement in water quality warrants against the implementation of sediment removal techniques.

8.3 Management of Acidification

The development of a liming program is not recommended for the Wequaquet Lakes. Low alkalinity in the lakes does not appear to be interfering with the desired uses of the lakes (see Section 3.1.5, Acidification Survey). There are insufficient fisheries data to show any fisheries decline that might be related to acid deposition. The large cost, uncertain longevity, and questionable results that might be expected from a liming program raise questions about cost-effectiveness. A long-term solution to human induced acidification of water bodies depends upon regional efforts to decrease air pollutant loadings, both within New England and in the midwestern United States.

8.4 Water Level Management and Herring Run Reconstruction

The present condition of the herring runs between Wequaquet Lake, Long Pond and the Centerville River is not always conducive to a successful spawning run (see Section 5.4, Water Level Fluctuations and the Herring Run). The primary limitation on the proper functioning of the herring runs appears to be the inability to provide sufficient flow at certain critical times. The geometry of the existing channel is such that considerable flows are necessary to provide adequate conditions for fish migration. The flow of water down the herring run draws water from Wequaquet Lake and Long Pond. Storage of excess water in these waterbodies for later release to the herring run can cause other problems on shoreline properties if heavy rainfall occurs while the water levels are high.

The objective of any improvements to the hydraulic characteristics of the herring run is to make optimal use of the limited supply of water available to the run. Modifications need to provide conditions which enhance the migration of herring both up and down the run. To accomplish this, the herring run and outlet structures must enable more precise management of water levels in Wequaquet Lake and Long Pond.

There are a number of ways that alterations of the existing herring run could improve the hydraulic performance of the run from the perspective of the migrating herring. As the fish move up the run, there is a need for adequate depth of flow and scattered resting places that have lower water velocities. Modifications which increase the roughness of the channel and/or restrict the width will increase the depth of flow for a given discharge. The placement of rockfill as a lining for the channel will increase the roughness of the streambed.

The roughness can be further increased and the width of a low-flow channel readily restricted by use of rockfilled gabions. These wire baskets, which are available in various sizes, including 3'x1.5'x12' can be placed end to end alternating from one side of the channel to the other, as is shown in

Figure 39. This line of gabions would cause increased water depths for a given discharge rate in the low-flow range, which can be seen in Figure 40.

Analysis of the Wequaquet Lake discharge regieme shows that, with a constricted channel, the water volume available in the lake is sufficient for the herring run function. With the gabions in place, a discharge rate of about 2 cfs would provide adequate conditions for the alewife migration. The volume of storage in Wequaquet Lake is approximate 53 acre-feet per inch of water elevation (in the range of elevation around the outlet elevation). This is equivalent to a flow volume of 1 cfs continuously for a period of about 27 days or a discharge of 2 cfs for about 14 days. Therefore, even during relatively long periods of little or no inflow to the lake, releases downstream could take place without substantial drawdown of the lake.

Another area of modification that could be done to enhance the herring runs is the upgrading of the waterbody outlet structures. It appears that the outlet structure for Wequaquet Lake provides adequate, although not very precise control of water outflow volume. The outlet structure on Long Pond, however does need to be repaired or replaced since it recently sustained damage. Reconstruction of this control structure to again allow use of flash boards should be sufficient.

The modifications to the herring run that were proposed by Tibbetts Engineering (1986) for the lower section would, in general, provide better conditions for the use of the run by the fish. There are a few refinements or changes to their recommendations that could create even a better situation.

At very low flows the baffle structures as shown on the plan would create a series of quiet pools, that would have a maximum depth of 2 feet and a depth of about 1 foot at the next upstream baffle. This should function quite well for the steeper sections of the run. But for the sections that have a more gentle slope, such as the first 1,400 feet below Long Pond, which has a slope of only 0.0007, the quiet pools may become sedimentation basins. The result may be undesirable accumulations of sediment and debris. These flatter sections would likely function better with alternating gabions as IEP has proposed for the upper section. The upper section may also require a mixture of the two treatments, depending on slopes. A possible breakpoint between the two is for the gabion system to be used where slopes are less than 0.01.

As part of the lower section analysis, the report stated that at 2-3 cfs flow the expected depth through the baffles would be 6-8 inches. This depth should be quite good for fish movement. Flows in this range could be sustained in the herring run for extended periods, though probably not for the duration calculated by Tibbetts Engineering. The report stated that 3.5 cfs flowing continuously for 360 days would be equivalent to 1 foot of storage in Long Pond. Apparently, an error was made because that flow rate

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6 Maple Street
Northborough, MA 01532
393-8558

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Ckd. ____ Rev. ____

FIGURE 1
TYPICAL CHANNEL REACH

SCALE: 1" = 10'

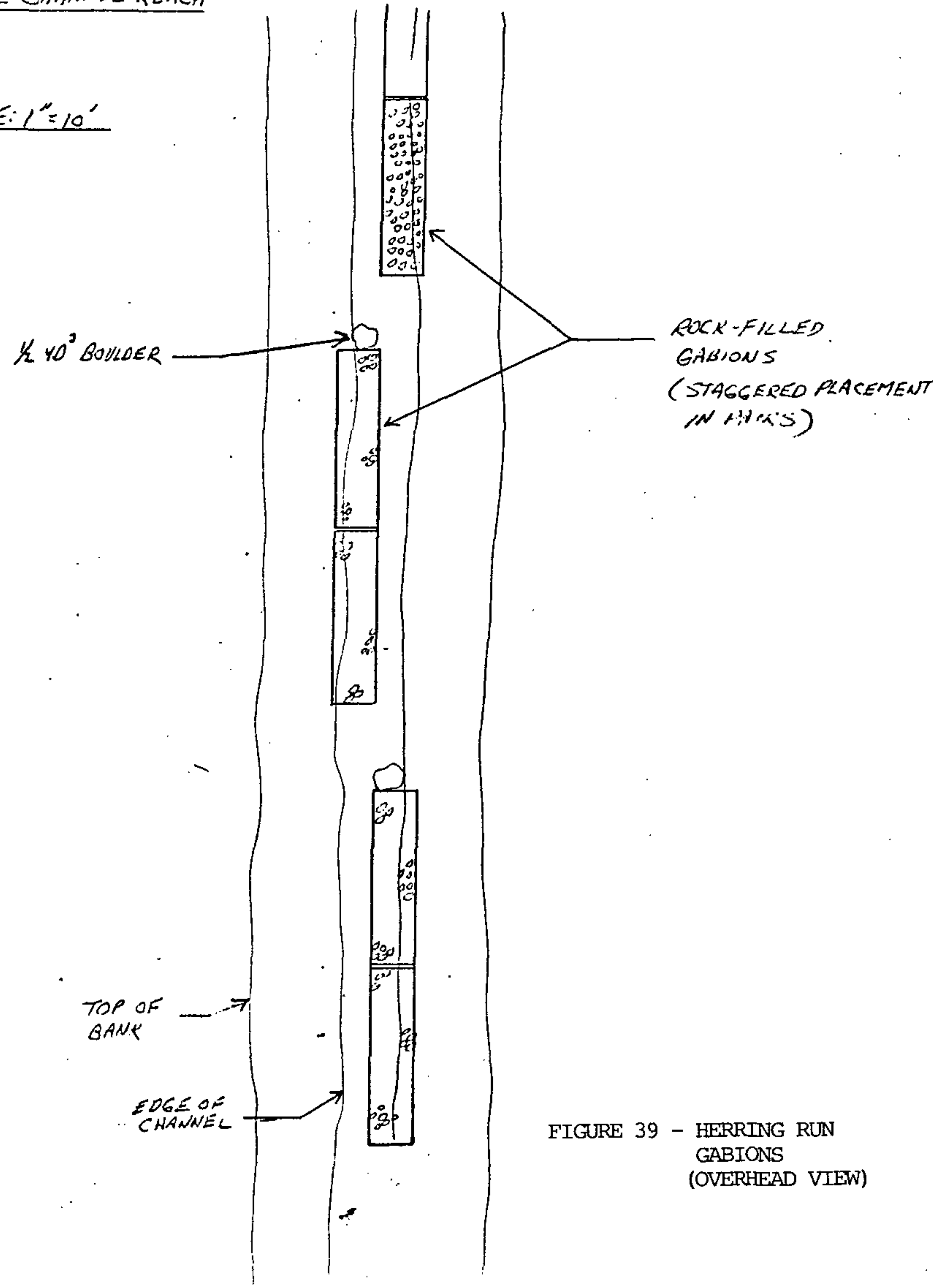

FIGURE 39 - HERRING RUN
GABIONS
(OVERHEAD VIEW)

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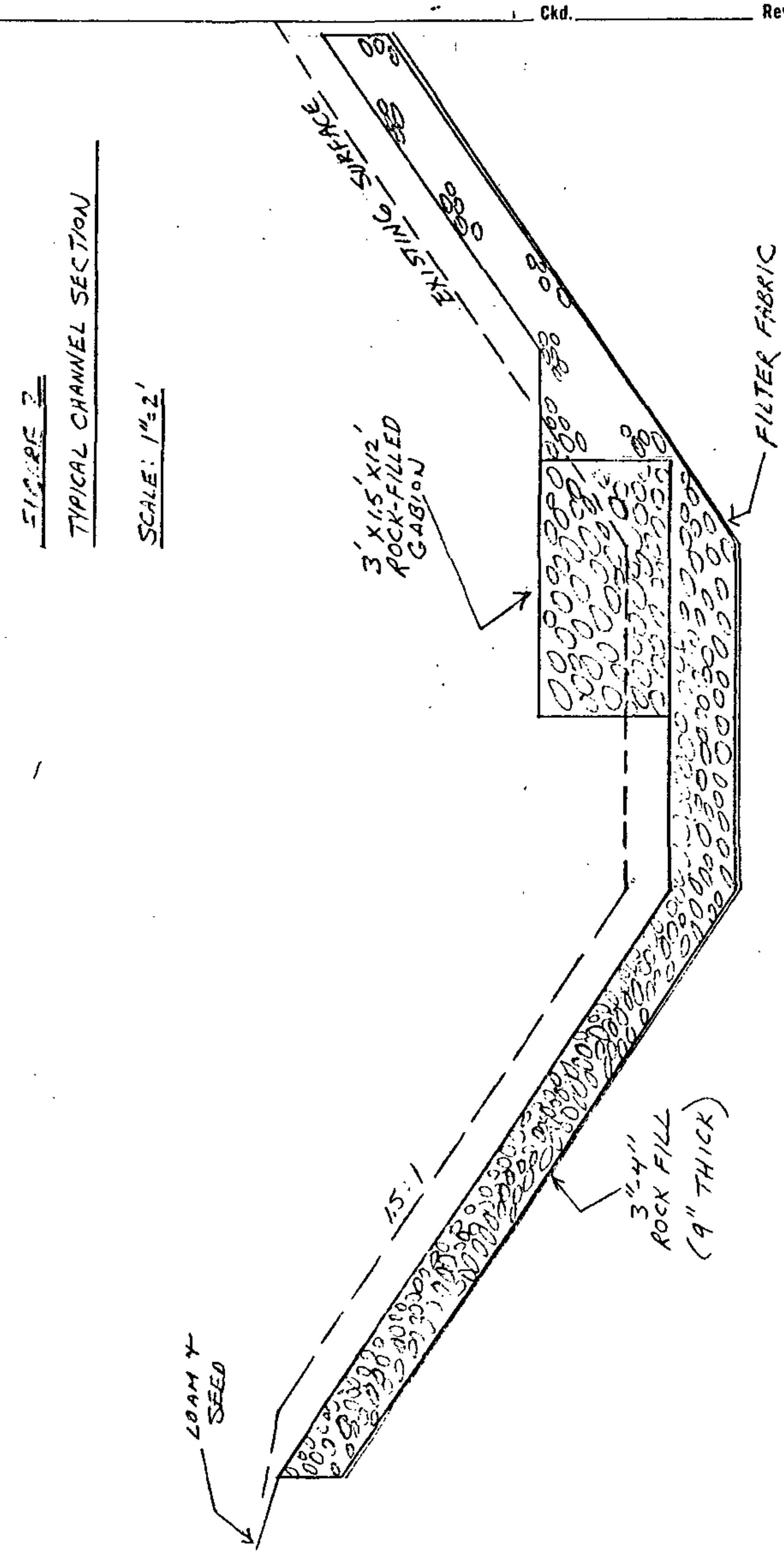

FIGURE 40 - HERRING RUN GABIONS (SECTION VIEW)

for that period is equal to about 2,500 acre-feet and Long Pond's surface area is not nearly 2,500 acres. Instead, 6 inches of storage in Wequaquet could provide a 3 cfs flow for about 7 weeks.

Among the options evaluated by the Tibbetts Engineering plan were concrete, loose rock, and gabion linings for the channel. Based upon cost considerations and hydraulic considerations, the preferable option would be the loose rock lining, which should be more than adequate to remedy existing erosion problems.

8.5 Public Participation

Three public meetings were held during the course of the project. All meetings were convened in the auditorium of Barnstable Town Hall in Hyannis and were proceeded by new bulletins in local newspapers. Topics of concern raised by townspeople at all meetings were management of water level, water clarity, macrophyte growth, sedimentation, and measures available to the lakeshore resident for protecting water quality. Details of each meeting are summarized below.

First Public Meeting - 30 January 1986

The agenda of this meeting focused on informing those in attendance of the nature, scope, and schedule of the study. A questionnaire was distributed and residents were encouraged to contribute historical information, photographs, and current observations by contacting IEP. Preliminary findings of the initial sampling rounds were presented. This meeting was attended by approximately 30 people.

Second Public Meeting - Attempted 11 December 1986

The cold, rainy weather on the evening of this meeting discouraged all but nine residents from attending this meeting. In view of the sparse attendance, it was decided to reschedule the second meeting for a later date. A formal presentation of the results of the diagnostic study had been planned for this meeting, but a question and answer period was substituted.

Second Public Meeting - 15 April 1987

The agenda of this meeting focused on a presentation of the results of the 12 months of diagnostic study. This included a discussion of hydrologic and nutrient budgets, trophic status and water quality, and the macrophyte survey. The presentation was accompanied by slides and posters. Lake management alternatives to be considered in the feasibility study were also presented. Dr. Kerfoot, of K-V Associates, made a similar presentation on the study of Shallow Pond in Barnstable. This meeting was attended by approximately 30 people.

Third Public Meeting - 25 May 1988

This, the final meeting, entailed a review of the diagnostic findings, a discussion of strategies for protection of water quality, and a presentation of the recommended management plan. Reprints of the DWPC publications, Fertilizers and Your Lake, Septic Systems and Your Lake, and Detergents and Your Lake, were distributed. Information on "Lakeside" fertilizer (no phosphorus) manufactured by Aquatic Chemicals, Inc., was also distributed. This meeting was attended by 15 people.

9.0 RECOMMENDED MANAGEMENT PROGRAM

9.1 Evaluation of Recommended Alternatives

The components of the recommended management program designed to preserve the water quality of the Wequaquet Lakes fall into three main categories. They are the following: land use management, waste water disposal, and storm water management. All components within these categories are watershed/recharge area techniques aimed at limiting or reducing the amount of nutrients, sediment, or contaminants reaching the Wequaquet Lakes. In-lake management techniques, appropriate for restoration of water bodies exhibiting symptoms of eutrophication, are not required. Revitalization of the herring run is an important component of the recommended management program. Although it will not improve water quality in the Wequaquet Lakes, a reconstructed herring run will help to resolve the conflict between human uses of the system and the requirements of the herring fishery. Table 23 lists the components of the recommended management program, an estimate of their cost, and expected benefits.

None of the components of the recommended management program, taken singly, will significantly protect or improve the trophic status of the Wequaquet Lakes. Taken collectively, however, the components substantially limit and/or reduce the phosphorus load to the Wequaquet Lakes and provide for long-term protection of water quality. Certain components of the recommended management program serve to restrict or eliminate additional sources of phosphorus which could potentially contribute to the load received by the Wequaquet Lakes in the future. Components of the management program functioning in this way are zoning and land acquisition.

Other components of the management plan may serve to reduce the load from existing phosphorus sources, but are difficult to quantify. These components include homeowner education, Board of Health regulations, street sweeping, catch basin maintenance, and prioritization of street maintenance.

Three components of the recommended management will reduce phosphorus loading to the Wequaquet Lakes and can be quantified. They involve stormwater management at the Oak Street culvert system, the Route 28 crossing of the herring run, and the West Main Street culvert (see Section 8.1.3). The potential reductions of phosphorus and other detrimental stormwater constituents are summarized below.

Oak Street culvert system - Depending on the severity of storm events, implementation of the recommended management plan has the potential to eliminate 2.4 kg of phosphorus annually, eliminate 939 kg of suspended solids annually, and eliminate a volume of 117,355 cubic meters of acidic water (pH of only 4.4) annually from Wequaquet Lake.

TABLE 23

RECOMMENDED MANAGEMENT PROGRAM

Program Components	Cost	Benefit
LAND USE MANAGEMENT		
o Zoning (Overlay District)	none	Protect against leakage of hazardous materials in recharge area.
o Land Acquisition	high	Preserve open space, provide public access.
o Homeowner Education Brochure	none	Reduce septic system phosphorus, reduce runoff phosphorus.
WASTE WATER DISPOSAL		
o Increase Title 5 Setback	none	Prevent phosphorus loading from septic systems within 300 feet of shore.
o Inspection and Compliance Documentation	$26-37K	Maximize efficiency and life expectancy of on-site systems, up-grading of failing systems.
STORM WATER MANAGEMENT		
o Street Sweeping	standard	Increase sediment collection, improve runoff quality.
o Catch Basin Maintenance	standard	Increase efficiency and life expectancy.
o Prioritize Watershed Areas for Maintenance	none	Increase sediment collection, improve runoff quality.
o Oak Street Culvert System Maintenance	standard	Reduce volume of discharge into Wequaquet Lake.
o Route 28, Catch Basin Installation	$4.6-5.0K	Reduce/eliminate impacts of road runoff to Long Pond (metals, chloride, and conductivity).
o West Main Street, Catch Basin Installation	$4.8-5.2K	Reduce/eliminate impacts of road runoff to Long Pond (metals, chloride, conductivity, oil, and grease).
HERRING RUN RECONSTRUCTION		
o Grading and Stabilization of Upper Section and Installation of Gabions	$200-300K	Enhanced control of water level and discharge rate for herring.
o Grading, Stabilization, and Construction of Lower Section (Tibbett's Plan)	$270-410K	Enhanced control of water level and discharge rate for herring.

Route 28 crossing of the herring run - Implementation of the recommended management plan will eliminate approximately 2 kg of phosphorus annually from Long Pond. In addition, the input of metals and chloride from this source, found at elevated levels in the sediment and water column of Long Pond respectively, will be eliminated.

West Main Street culvert - Implementation of the recommended management plan has the potential to eliminate approximately 1.1 kg of phosphorus annually from Long Pond. In addition, significant inputs of oil and grease will be eliminated as will inputs of metals and chloride.

9.2 Environmental Evaluation, Permits, and Funding Sources for Management Alternatives

Whereas each of the recommended program components is designed to have a positive environmental impact on the Wequaquet Lakes, the potential for adverse impacts also exist. Excess noise and traffic will accompany the construction activities for installation of catch basins and improvements to the herring run. Also some erosion will occur as a result of construction activities, but these impacts will be temporary and can be minimized by standard erosion control practices (staked hay bales, silt fences, etc.). A summary of potential impacts from the recommended alternatives as well as permits required and funding sources is given in Table 24.

9.3 Monitoring Program

An ongoing program of water quality monitoring should be implemented for the Wequaquet Lakes. The purpose of such a program would be to, (1) monitor the effectiveness of watershed/recharge area management techniques which are implemented and redirect their efforts as necessary, and (2) monitor continuing impacts to Wequaquet Lakes from existing and future land uses and as the attenuation capacity of soils for phosphorus in wastewater is depleted.

We recommend quarterly sampling at certain stations established for the diagnostic study. They are the following: Wequaquet Stations 1 through 4 and Long Pond Stations 1 through 3. Due to the absence of thermal stratification, surface "grab" samples will suffice at all stations. The samples should be analyzed for most of the parameters included in the diagnostic study, with the most critical being total phosphorus, nitrate-nitrogen, Kjeldhal-nitrogen, pH, alkalinity, chloride, conductivity, bacteria, suspended solids, and phytoplankton. Field measurements of temperature, dissolved oxygen, and Secchi disk transparency should also be taken to augment the interpretaion of chemical data.

Table 24 - SUMMARY OF IMPACTS, PERMITS, AND FUNDING SOURCES FOR RECOMMENDED MANAGEMENT ALTERNATIVES

Program Components	Potential Impacts					Permits/Actions Required								Funding Sources		
	Noise	Traffic	Water Quality	Erosion	Wildlife	Town Meeting	Planning Bd. Hearing	Bd. Health Vote	Barnstable DPW	Notice of Intent (Ch. 131, S. 40)	Army Corps 404	MEPA (ENF/EIR)	Clean Air Act Amendments	Clean Lakes Ch. 628 Phase II	ALA (310 CMR 24.00) (Aquifer Land Acquisition DEQE)	Self Help (Division of Conservation Services)
LAND USE MANAGEMENT																
Zoning		o	●		●	●	●									
Land Acquisition			●		●	o									o	o
Education Brochure			●													
WASTE WATER DISPOSAL																
Board of Health Regulations			●					●								
Septic System Inspection and Compliance Documentation			●			o		●								
STORM WATER MANAGEMENT																
Street Sweeping	o	o	●						●							
Catch Basin Maintenance			●						●							
Prioritization of Maintenance			●			o			●							
Oak Street Culvert System Maintenance			●			o			●							
Route 28, Catch Basin Installation	o	o	●	o		o			●	●				o		
West Main Street, Catch Basin Installation	o	o	●	o		o			●	●				o		
Herring Run Reconstruction	o	o	●	o	●					●	●	o				
Acid Precipitation Management			●		●								●			

o Maybe Applicable
● Definitely Applicable

In addition to water quality sampling, monitoring of flow conditions during storm events at critical discharge points should be conducted. Specifically, the volume of storm runoff at Stations W-6 (Oak Street culvert system), LP-2 (runoff from Route 28 into the herring run), and LPS-1 (West Main Street culvert) should be documented to verify the effectiveness of measures recommended to reduce or eliminate storm water discharge at these points. This would consist simply of visual observations made during significant storm events, with quantitative documentation done additionally if necessary.

The cost of a Town-run program would depend on the availability of existing equipment and trained personnel. Should an outside consultant be retained, such a monitoring program would cost in the order of $6,500 per year including sample collection, laboratory analysis, and preparation of an annual report. Another approach would be to hire a consultant for a year to perform the work in conjunction with a Town employee, training that person to eventually assume complete responsibility for the program.

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