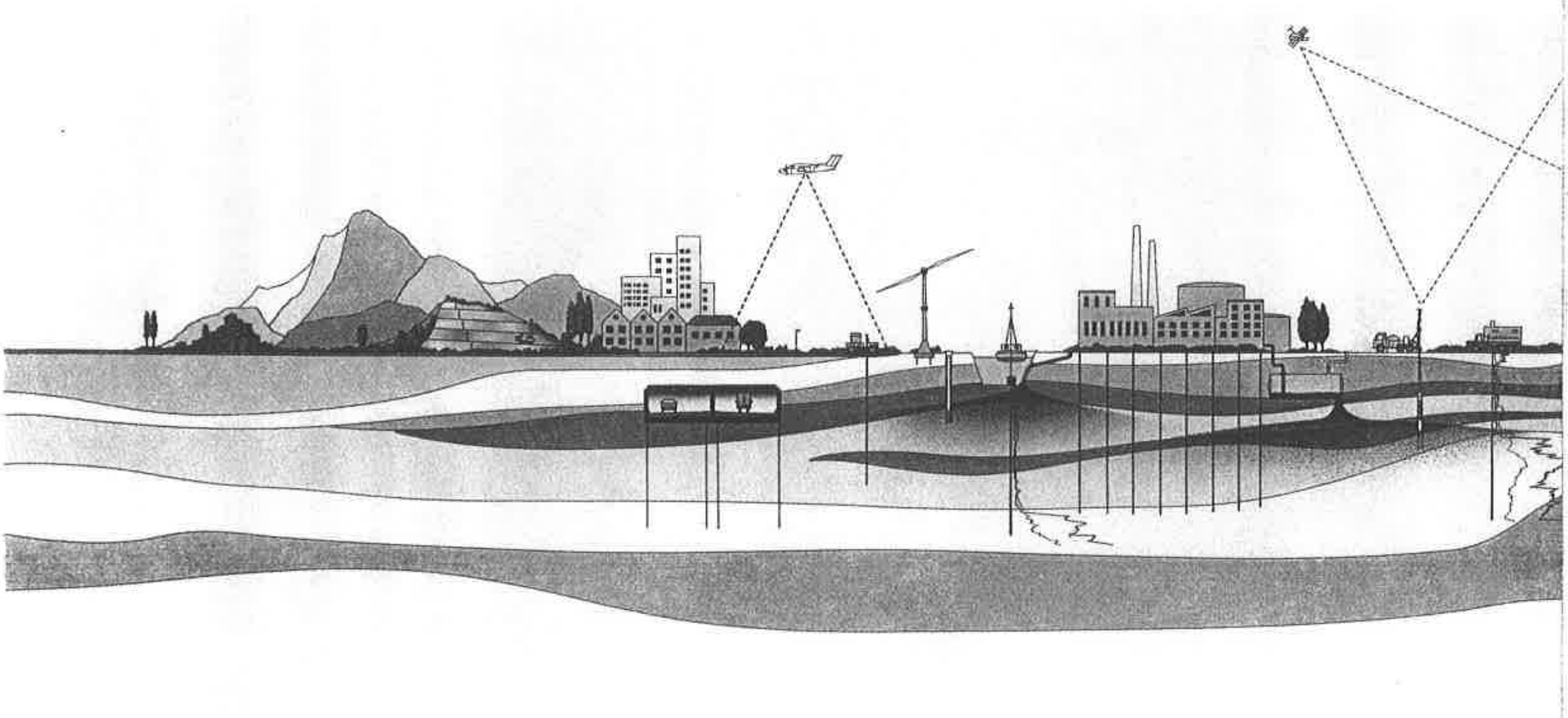
RESULTS OF THE 1995 LIMNOLOGICAL INVESTIGATION OF CRYSTAL LAKE AND AND ELGINWOOD POND PEABODY, MASSACHUSETTS

PREPARED FOR:

Mr. Curt T. Bellavance, City Planner
Department of Community Development and Planning
24 Lowell Street
Peabody, MA 01960



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PREPARED BY:

FUGRO EAST, INC.
6 MAPLE STREET
NORTHBOROUGH, MA 01532

DECEMBER 1995

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EXECUTIVE SUMMARY

Crystal Lake and Elginwood Pond were evaluated for important limnological parameters and the watershed draining into these water bodies was assessed for water and pollutant contributions. Both ponds are shallow, having deep muck deposits and excessive growths of floating, submerged and/or emergent plants. Water quality is sub-optimal, exhibiting low levels of oxygen in Crystal Lake and high levels of phosphorus and nitrogen in both ponds. Inputs associated with storm water are clearly unacceptable from a perspective of assumed management goals. Flushing rates are high, however, and the full impact of pollutant loading is not currently being expressed in these ponds.

Given the degraded condition of both ponds and the continuing elevated inputs of deleterious pollutants, management action is necessary on two levels: in-lake remediation and watershed level management of future inputs. Evaluation of in-lake management alternatives clearly indicates dredging as the only viable approach for handling existing problems of sediment accumulation and rooted plant growths. Management of incoming pollutant loads is likely to require some combination of source control and storm water treatment, although diversion of storm water may also be a possibility. Further study is necessary to determine the optimal combination of watershed management options, but off-line treatment systems which could treat a portion of the runoff and deliver it to the ponds at the end of storm events may be most cost-effective. Continued monitoring at a reduced level is also recommended for evaluating progress and needs.

The total cost of a restoration and management project may approach $1,000,000, with most of this amount devoted to dredging. Initial and on-going storm water management will require substantial funding as well, however, necessitating a long-term commitment by the residents of Peabody.

INTRODUCTION

A study of the physical, chemical, and biological features of Crystal Lake and Elginwood Pond and their watershed was undertaken by Fugro East from August to November of 1995. The information generated from this report will define existing conditions and provide a basis for management decisions.

Aside from general concern over preserving these ponds for the future, the need to devise a management strategy arose in part from years of soft sediment deposition resulting in heavy plant growth throughout the system. There are several ways to mitigate the growth and spread of plants, however, not all would be equally applicable or effective in Crystal Lake and Elginwood Pond. It has been suggested that the most effective method to control plant growth would be some method of soft sediment removal (dredging), which is the only method of plant control that increases pond depth. The goal of this study was to provide the information necessary to properly evaluate dredging and potential alternative management strategies. If dredging is an appropriate approach, this study would provide the basis for a biologically sound and economically feasible soft sediment remediation scheme which could be applied to the management of Crystal Lake and Elginwood Pond. Additionally, control of future soft sediment deposition is sought.

STUDY APPROACH

Background data and general lake and watershed information was compiled from existing sources and reviewed. Water depth and soft sediment depth were measured to enable accurate contours and cross sections of each pond to be drawn. Water quality monitoring stations were chosen and water quality was monitored in August and September to assess differences in the chemical (alkalinity, total phosphorus, nitrate nitrogen, total Kjeldahl nitrogen, turbidity, pH, conductivity, dissolved oxygen, and temperature) quality of water during dry and wet weather situations. Water quality provides insight into potential sources and the degree of pollutant loading to the system. While longer term measurement is desirable, this brief investigation provides sufficient data to make reasonable assumptions regarding pollutant inputs and in-lake water quality. Diversity, distribution and abundance of the aquatic plant community were measured by surveying along lines transecting the ponds. The information compiled during the survey was used to generate maps depicting size, location and species composition of major weed beds. Baseline data describing the aquatic insect and fish communities of the ponds was collected in August.

WATERSHED FEATURES

A United States Geological Survey (USGS) topographical map was used to identify the watershed of Crystal Lake and Elginwood Pond (Figure 1). Major land uses within the watershed were identified using Massachusetts state databases presented in Graphical Information System (GIS) format (Figure 2) which were ground checked to ensure reliability. The surrounding watershed (2500 acres) is nearly 120 times the size of the ponds (21 acres) and is densely populated. Most of the watershed land is allocated to residential and commercial uses (1175 acres and 122 acres respectively). Only 890 acres are forested or wetland, while 132 are covered by open water. There are several parks and recreational areas which cover a total of 120 acres. Generally, when more than 10-20% of the land in a watershed has been developed, the potential for significant impacts on pond water quality is greatly increased.

The watershed map was further divided into sub-watersheds (Figure 3). Sub-watersheds allow management to be targeted to specific areas of concern if any exist. Water flowing in the largest sub-watershed (sub-watershed 1, Figure 3) flows to Elginwood Pond after first passing through Suntaug Lake, Winona Pond and several smaller waterbodies. Water falling in the second largest sub-watershed (sub-watershed 3, Figure 3) flows to Crystal Lake without any significant water detention basins. The area of each sub-watershed contributing water to these ponds is listed in Table 1. The watersheds of these ponds appear to influence pond conditions on a day to day basis since daily inputs are large relative to pond volume. Small storms will have some immediate effect and pond conditions appear to reflect direct inputs

Figure 1. Outline of the Watershed of Crystal Lake and Elginwood Pond.

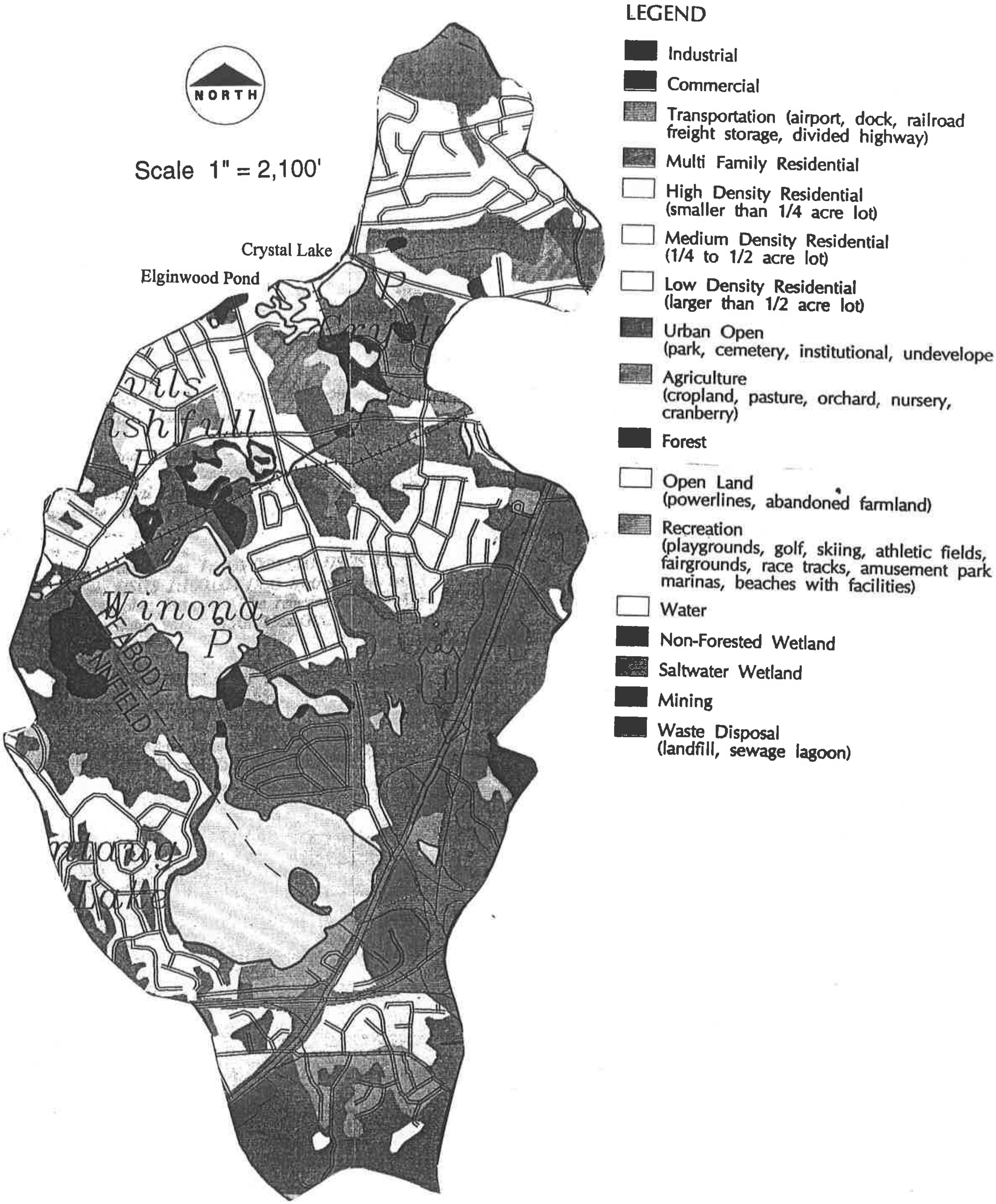


Figure 2. Major land uses within the Crystal Lake and Elginwood Pond Watershed.

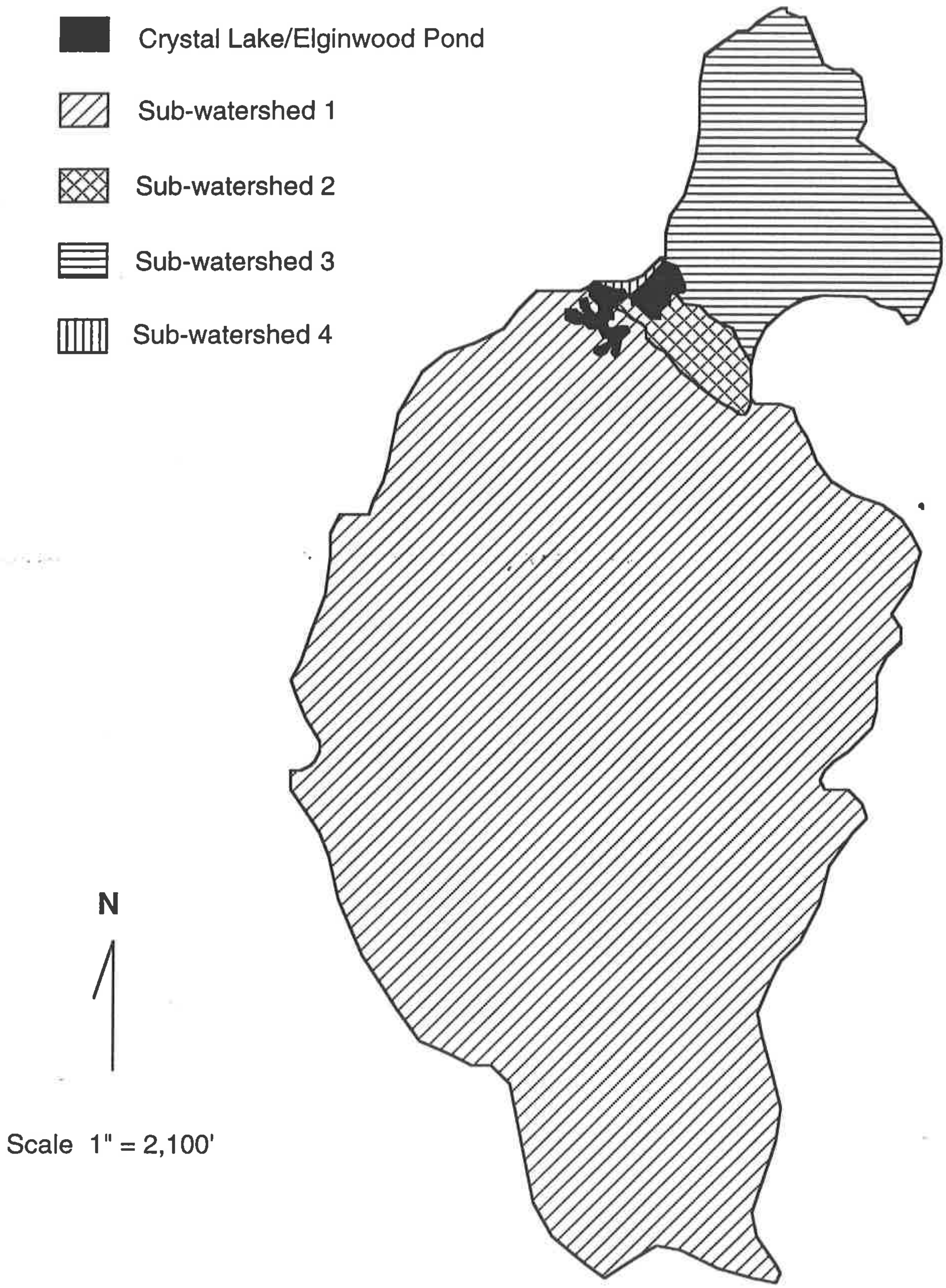


Figure 3. Sub-watershed map for Crystal Lake and Elginwood Pond

Table 1. Area of the watershed and sub-watersheds of Crystal Lake and Elginwood Pond.

Defined Area	Area (acres)	Area (sq. ft.)	% of Total (%)
Total Watershed	2500	108,927,000	
Sub-Watershed 1	2144	93,359,700	86
Sub-Watershed 2	38	1,640,520	2
Sub-Watershed 3	308	13,397,580	12
Sub-Watershed 4	1	52,920	0

with respect to both water quality and sediment deposition. Restoration of the ponds is therefore largely dependent upon watershed management for control of inputs to the ponds.

LAKE FEATURES

Physical Characteristics

Data necessary for sediment analysis of Crystal Lake and Elginwood Pond were collected by Fugro scientists during the last week of August 1995. Measurements included water depth, soft sediment (muck) depth, and a physical and chemical analysis of composite soft sediment core samples from each pond. Figures 4+5 show transect and sample point locations that were used to create soft sediment profiles. A bathymetric (water depth) map was constructed for each pond from the collected data (Figure 6+7). Mean depth in Crystal Lake was 2.08 ft. with a maximum depth of 4 ft, while mean depth in Elginwood Pond was 0.85 ft. with a maximum of 4 ft (Table 2). Crystal Lake has nearly double the water volume of Elginwood Pond (861,136 cu. ft. vs. 422,368 cu. ft.) (Tables 3+5).

The approximate volume of soft sediment in Crystal Lake that should be removed if dredging were to proceed is 1,812,272 cu. ft. or 67,121 cu. yds. (Table 4). The soft sediment volume present in Elginwood Pond is nearly half that of Crystal Lake at 1,046,432 cu. ft. or 38,757 cu. yds. (Table 6a-f). Several representative basin profiles were drafted to illustrate the volume of water in the ponds relative to the volume of soft sediment (Figure 8+9).

The physical and chemical analysis of the sediments revealed acceptable levels of contamination in both ponds as relates to disposal of any dredged material (Table 7). All sediment in the two ponds was of the sand size class (0.063 mm) or smaller, with the majority either silt (0.004 - 0.063 mm) or clay (<0.004 mm). The high sediment moisture content (89% for Crystal, 81% for Elginwood) indicates that dredged material will have a substantially smaller volume after desiccation.

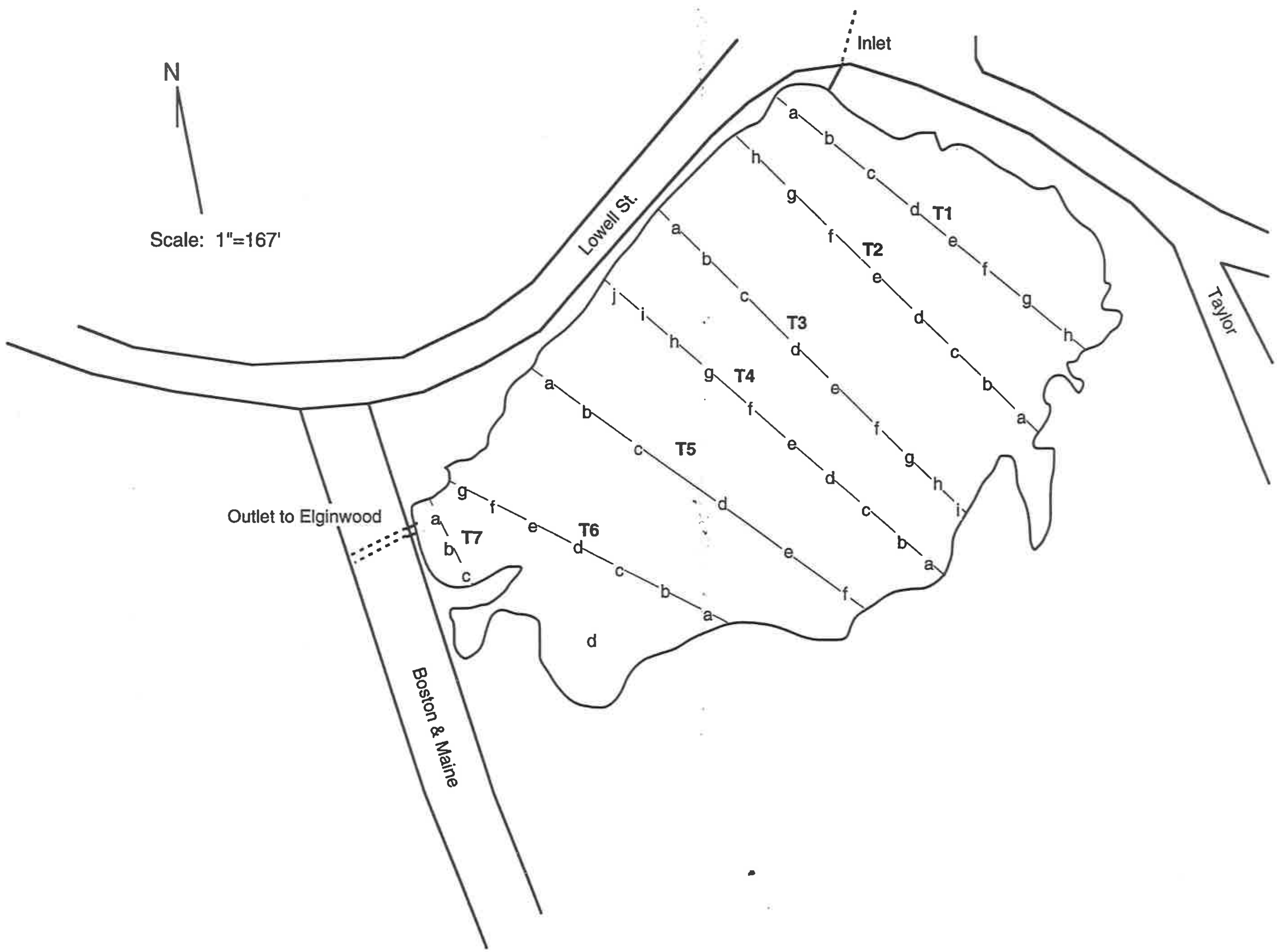


Figure 4. Transects and Sample Points for Crystal Lake - September 1995.

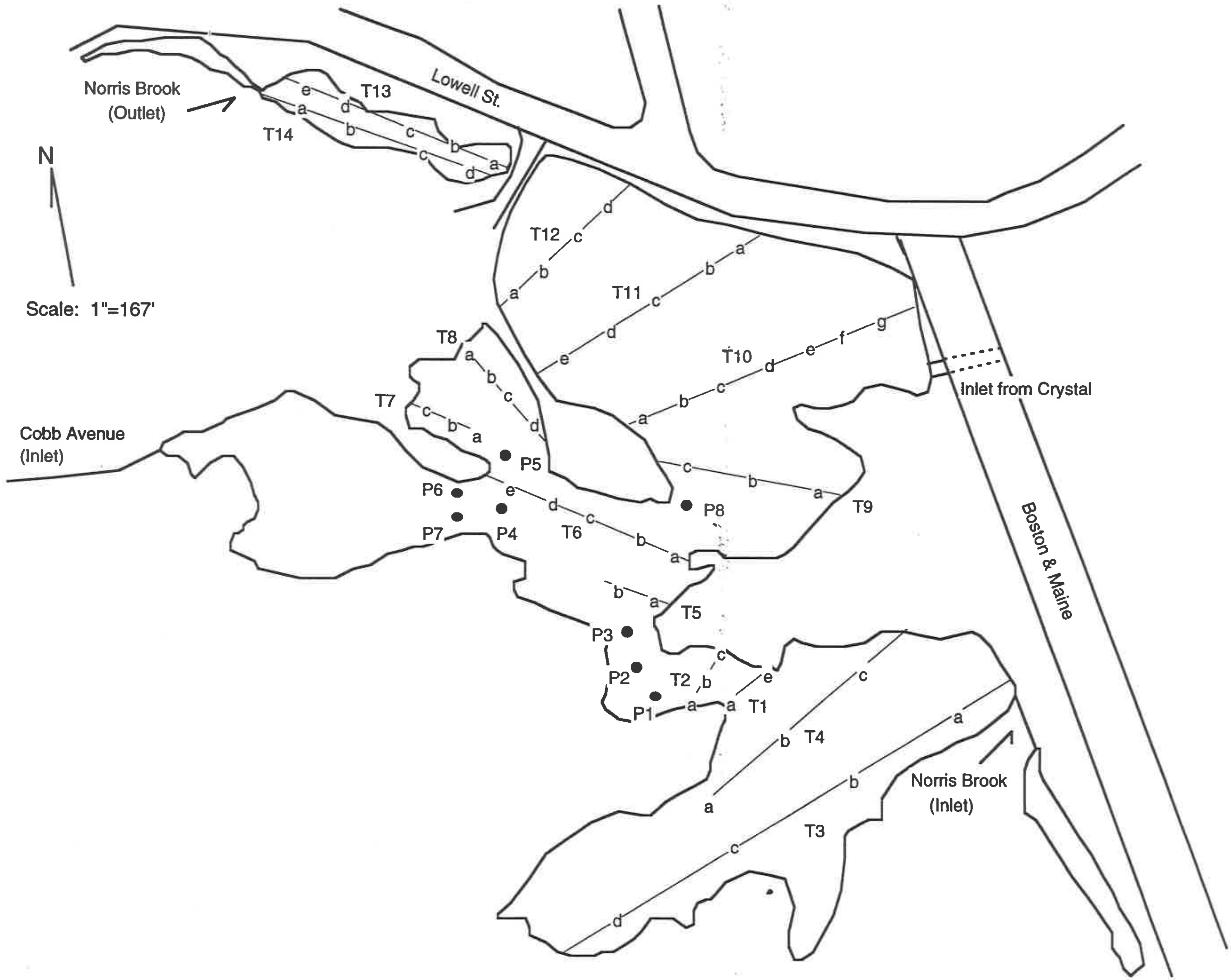


Figure 5. Transects, Transect Samples and Point Samples for Elginwood Pond - September 1995.

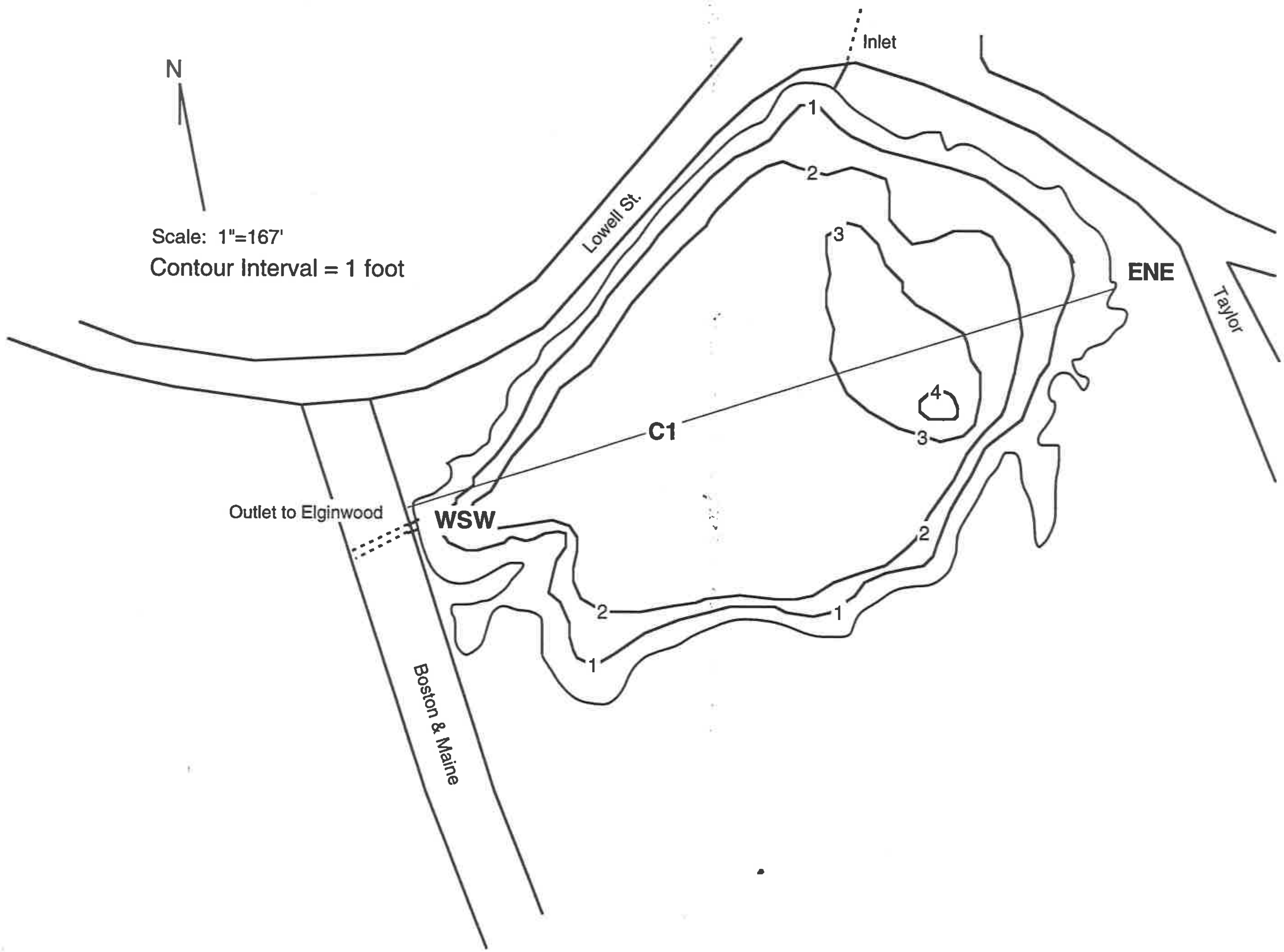


Figure 6. Bathymetric Map for Crystal Lake - September 1995.

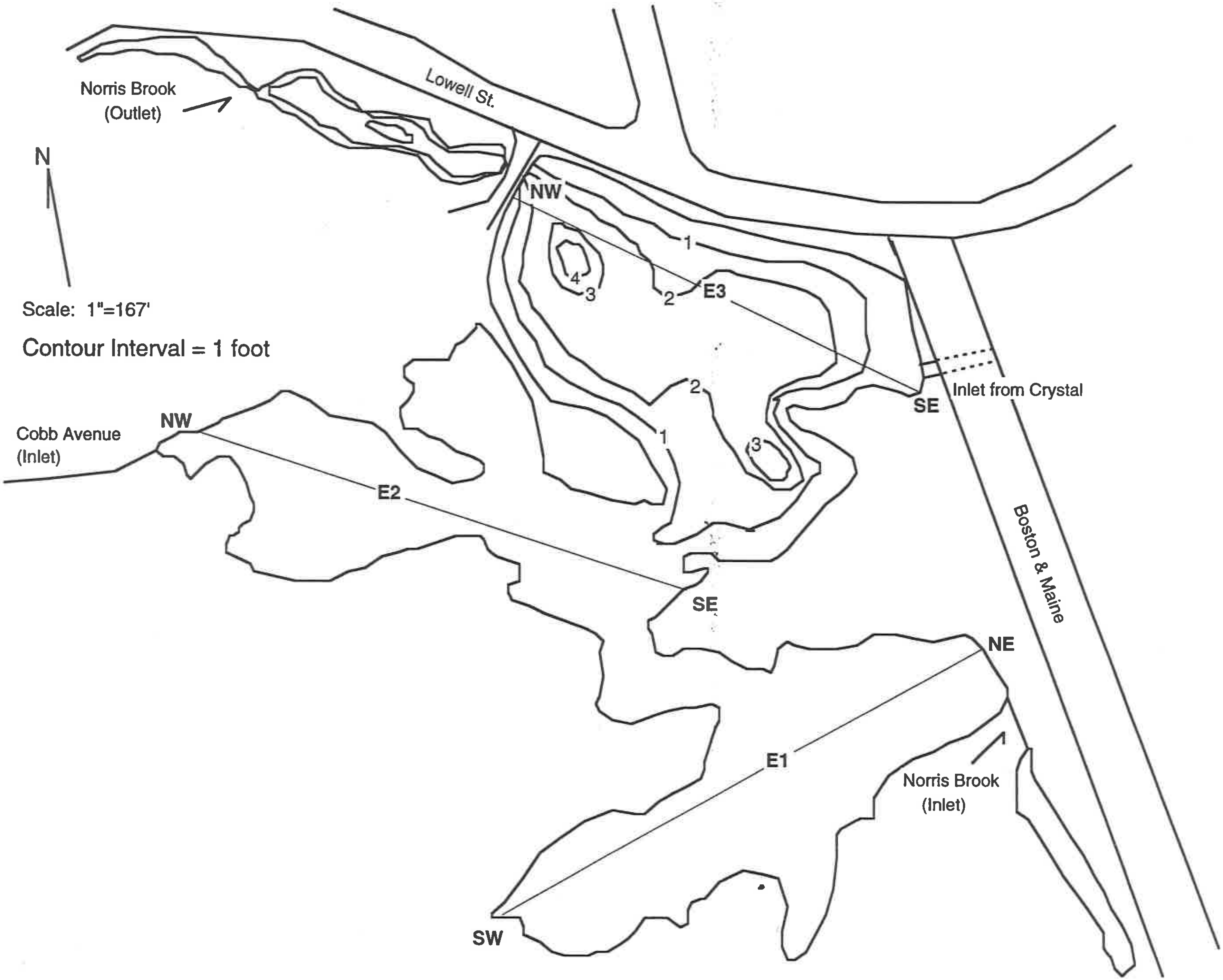


Figure 7. Bathymetric Map for Elginwood Pond - September 1995.

Table 2. Transect data for Crystal Lake - September 12, 1995

TRANSECT #	WATER DEPTH (inches)	SEDIMENT DEPTH (inches)	TOTAL DEPTH (inches)
T1-A	27	36	63
T1-B	20	28	48
T1-C	16	37	53
T1-D	22	86	108
T1-E	20	59	79
T1-F	27	69	96
T1-G	19	45	64
T1-H	7	31	38
T2-A	14	13	27
T2-B	27	62	89
T2-C	30	82	112
T2-D	28	74	102
T2-E	36	53	89
T2-F	31	59	90
T2-G	29	73	102
T2-H	19	37	56
T3-A	27	74	101
T3-B	31	68	99
T3-C	31	54	85
T3-D	35	0	35
T3-E	41	0	41
T3-F	42	76	118
T3-G	48	67	115
T3-H	39	63	102
T3-I	27	32	59

TRANSECT #	WATER DEPTH (inches)	SEDIMENT DEPTH (inches)	TOTAL DEPTH (inches)
T4-A	19	17	36
T4-B	27	70	97
T4-C	27	73	100
T4-D	33	80	113
T4-E	34	56	90
T4-F	31	91	122
T4-G	29	73	102
T4-H	27	> 93	> 120
T4-I	33	69	102
T4-J	18	68	86
T5-A	29	68	97
T5-B	35	> 85	> 120
T5-C	31	81	112
T5-D	34	80	114
T5-E	36	> 84	> 120
T5-F	21	4	25
T6-A	20	8	28
T6-B	26	60	86
T6-C	30	29	59
T6-D	12	0	12
T6-E	33	84	117
T6-F	28	22	50
T6-G	25	16	41
T7-A	23	33	56
T7-B	28	31	59
T7-C	31	68	99
T7-D	16	32	48

Table 2 (cont). Transect data for Elginwood Pond - September 12, 1995

TRANSECT #	WATER DEPTH (inches)	SEDIMENT DEPTH (inches)	TOTAL DEPTH (inches)
T1-A	0	35	35
T1-B	0	54	54
T1-C	2	44	46
T1-D	0	22	22
T1-E	1	28	29
T2-A	8	4	12
T2-B	8	16	24
T2-C	1	23	24
T3-A	1	45	46
T3-B	1	47	48
T3-C	2	40	42
T3-D	2	41	43
T4-A	2	45	47
T4-B	2	52	54
T4-C	2	45	47
P1	3	38	41
P2	4	42	46
P3	6	30	36
P4	2	40	42
P5	2	14	16
P6	0	29	29
P7	0	66	66
P8	0	33	33
T5-A	3	35	38
T5-B	1	21	22
T6-A	4	53	57
T6-B	1	56	57
T6-C	5	55	60
T6-D	1	17	18
T6-E	2	28	30
T7-A	3	42	45
T7-B	1	68	69
T7-C	8	60	68

TRANSECT #	WATER DEPTH (inches)	SEDIMENT DEPTH (inches)	TOTAL DEPTH (inches)
T8-A	16	65	81
T8-B	17	73	90
T8-C	18	67	85
T8-D	10	26	36
T9-A	38	> 70	> 108
T9-B	18	49	67
T9-C	18	60	78
T10-A	26	12	38
T10-B	24	33	57
T10-C	26	16	42
T10-D	30	7	37
T10-E	25	21	46
T10-F	10	30	40
T10-G	4	30	34
T11-A	34	12	46
T11-B	30	26	56
T11-C	24	30	54
T11-D	28	26	54
T11-E	27	15	42
T12-A	24	13	37
T12-B	42	37	79
T12-C	31	27	58
T12-D	24	15	39
T13-A	30	1	31
T13-B	27	1	28
T13-C	47	12	59
T13-D	31	7	38
T13-E	33	10	43
T14-A	30	1	31
T14-B	19	11	30
T14-C	27	10	37
T14-D	32	15	47

Table 3. Area and volume of water for Crystal Lake, 0.5 ft. depth contours.

Contour (feet below water level)	Area (sq. ft.)	Avg. Area (sq. ft.)	Incremental Volume (cu. ft.)	Cummalative Volume (cu. ft.)
3.5	4,032			
3.0	29,952	16,992	8,496	8,496
2.5	149,376	89,664	44,832	53,328
2.0	268,928	209,152	104,576	157,904
1.5	322,624	295,776	147,888	305,792
1.0	356,736	339,680	169,840	475,632
0.0	414,272	385,504	385,504	861,136

TOTAL WATER VOLUME IN CRYSTAL LAKE = 861,136 cu. ft.

Table 4. Area and volume of Crystal Lake Basin (water and soft sediment) at 0.5 ft. contours.

Contour (feet below water level)	Area (sq. ft.)	Avg. Area (sq. ft.)	Incremental Volume (cu. ft.)	Cummalative Volume (cu. ft.)
10.0	23,808			
9.0	90,048	56,928	56,928	56,928
8.0	174,400	132,224	132,224	189,152
7.0	229,440	201,920	201,920	391,072
6.0	258,688	244,064	244,064	635,136
5.0	290,432	274,560	274,560	909,696
4.0	314,048	302,240	302,240	1,211,936
3.0	339,328	326,688	326,688	1,538,624
2.0	363,264	351,296	351,296	1,889,920
1.0	396,480	379,872	379,872	2,269,792
0.0	410,752	403,616	403,616	2,673,408

TOTAL VOLUME OF BASIN = 2,673,408 cu. ft.
(Volume of Water and Soft Sediment)

VOLUME OF SOFT SEDIMENT = 1,812,272 cu. ft.
(Volume of Basin - Volume of Water)

Table 5. Area and volume of water for Elginwood Pond, 0.5 ft. depth contours.

Contour (feet below water level)	Area (sq. ft.)	Avg Area (sq. ft.)	Incremental Volume (cu. ft.)	Cummalative Volume (cu. ft.)
3.5	192			
3.0	7,936	4,064	2,032	2,032
2.5	26,048	16,992	8,496	10,528
2.0	102,464	64,256	32,128	42,656
1.5	127,360	114,912	57,456	100,112
1.0	160,192	143,776	71,888	172,000
0.5	172,672	166,432	83,216	255,216
0.0	495,936	334,304	167,152	422,368

TOTAL WATER VOLUME IN ELGINWOOD POND = 422,368 cu.ft.

Table 6 (A-F). Area and volume of Elginwood Pond Basin at 0.05 ft. contours.

PART A:

Contour (feet below water level)	Area (sq. ft.)	Avg. Area (sq. ft.)	Incremental Volume (cu. ft)	Cummalative Volume (cu. ft.)
5.0	768			
4.5	3,456	2,112	1,056	1,056
4.0	15,872	9,664	4,832	5,888
3.5	55,168	35,520	17,760	23,648
3.0	70,720	62,944	31,472	55,120
2.5	84,224	77,472	38,736	93,856
2.0	96,896	90,560	45,280	139,136
0.0	144,896	120,896	241,792	380,928

SUB-BASIN A VOLUME = 380,928

PART B:

Contour (feet below water level)	Area (sq. ft.)	Avg. Area (sq. ft.)	Incremental Volume (cu. ft)	Cummalative Volume (cu. ft.)
5.0	1,408			
4.5	4,096	2,752	1,376	1,376
4.0	5,952	5,024	2,512	3,888
3.5	10,944	8,448	4,224	8,112
3.0	18,624	14,784	7,392	15,504
2.5	27,968	23,296	11,648	27,152
2.0	39,552	33,760	16,880	44,032
0.0	65,216	52,384	104,768	148,800

SUB-BASIN B VOLUME = 148,800

PART C:

Contour (feet below water level)	Area (sq. ft.)	Avg. Area (sq. ft.)	Incremental Volume (cu. ft)	Cummalative Volume (cu. ft.)
7.0	1,344			
6.0	2,880	2,112	2,112	2,112
5.0	6,656	4,768	4,768	6,880
4.0	8,960	7,808	7,808	14,688
3.0	11,584	10,272	10,272	24,960
2.0	15,872	13,728	13,728	38,688
0.0	24,448	20,160	40,320	79,008

SUB-BASIN C VOLUME = 79,008

PART D:

Contour (feet below water level)	Area (sq. ft.)	Avg. Area (sq. ft.)	Incremental Volume (cu. ft)	Cummalative Volume (cu. ft.)
8.5	1,216			
8.0	1,792	1,504	752	752
7.5	1,984	1,888	944	1,696
7.0	2,752	2,368	1,184	2,880
6.5	7,424	5,088	2,544	5,424
6.0	12,736	10,080	5,040	10,464
5.5	15,232	13,984	6,992	17,456
5.0	23,040	19,136	9,568	27,024
4.5	47,680	35,360	17,680	44,704
4.0	77,824	62,752	31,376	76,080
3.5	108,224	93,024	46,512	122,592
3.0	133,696	120,960	60,480	183,072
0.0	194,112	163,904	491,712	674,784

SUB-BASIN D VOLUME = 674,784

PART E:

Contour (feet below water level)	Area (sq. ft.)	Avg. Area (sq. ft.)	Incremental Volume (cu. ft)	Cummalative Volume (cu. ft.)
4.0	384			
3.0	6,208	3,296	3,296	3,296
2.0	10,688	8,448	8,448	11,744
1.0	16,768	13,728	13,728	25,472
0.0	19,648	18,208	18,208	43,680

SUB-BASIN E VOLUME = 43,680

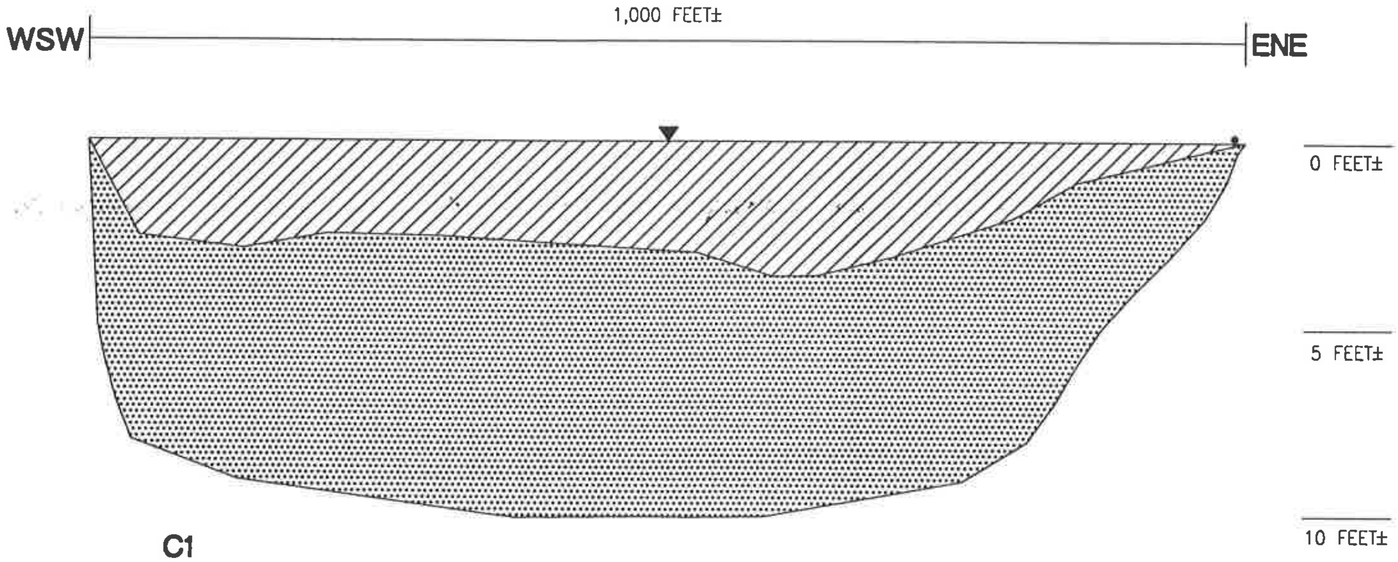
PART F:

Contour (feet below water level)	Area (sq. ft.)	Avg. Area (sq. ft.)	Incremental Volume (cu. ft)	Cummalative Volume (cu. ft.)
5.0	2,752			
4.0	12,096	7,424	7,424	7,424
3.0	23,040	17,568	17,568	24,992
2.0	32,000	27,520	27,520	52,512
1.0	43,968	37,984	37,984	90,496
0.0	58,240	51,104	51,104	141,600

SUB-BASIN F VOLUME = 141,600

TOTAL VOLUME OF BASIN = 1,468,800 cu. ft.

VOLUME OF SOFT SEDIMENT = 1,046,432 cu. ft.
(= Volume of Basin - Volume of Water)



LEGEND:

WATER TABLE

WATER

SEDIMENT

NOTE:
- All locations and dimensions are approximate.

SOURCE:
- Fugro field reconnaissance.

Client:
City of Peabody, Massachusetts

Cross Section
Crystal Lake

Peabody, Massachusetts

December 1995 | Job No. 16-16-9004

Figure 8

1" = 167'

FUGRO

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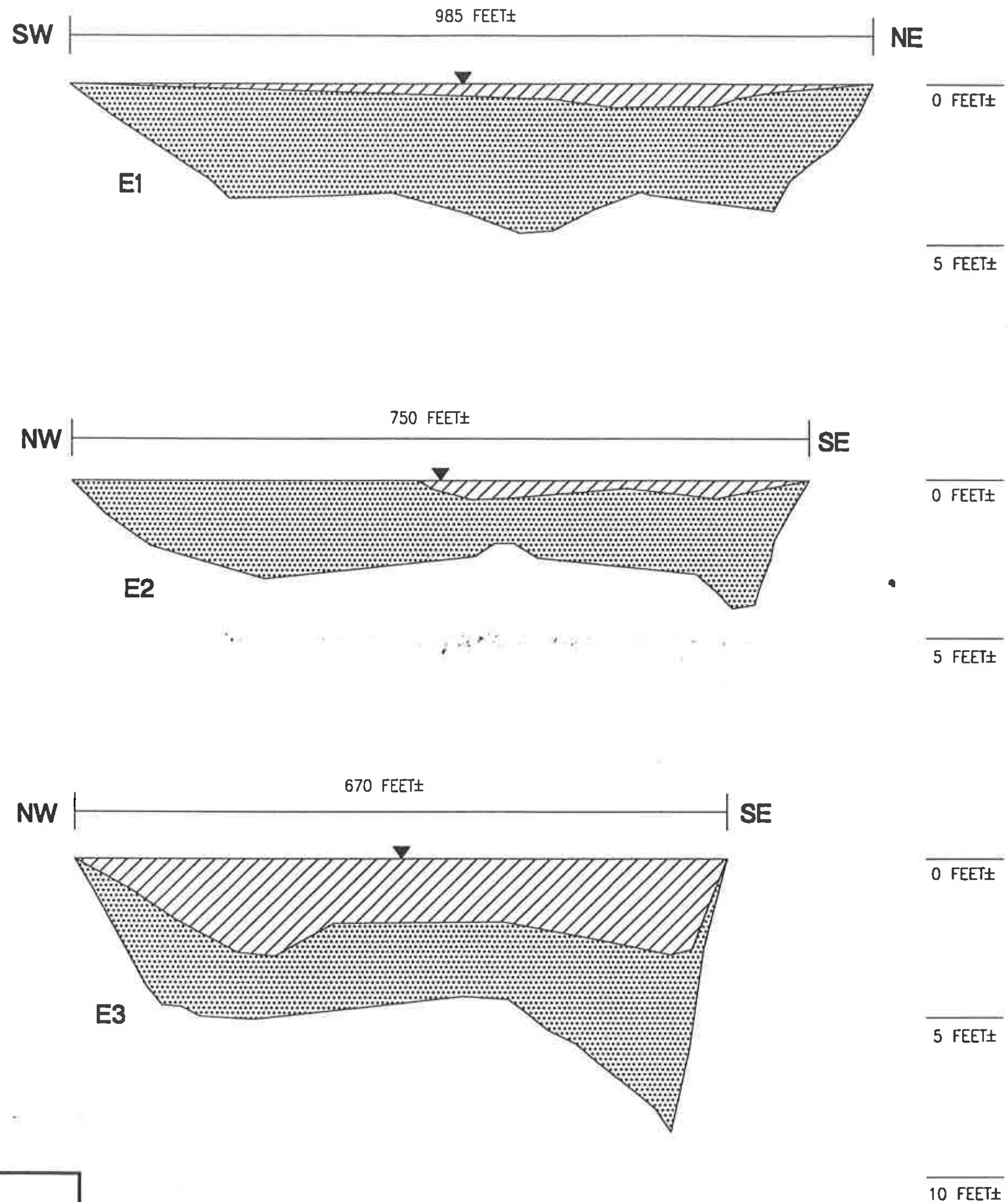

LEGEND:

- WATER TABLE
- WATER
- SEDIMENT

NOTE:
- All locations and dimensions are approximate.

SOURCE:
- Fugro field reconnaissance.

Client:
City of Peabody, Massachusetts

Cross Section
Elginwood Pond

Peabody, Massachusetts

December 1995 | Job No. 16-16-9004

Figure 9

1" = 167'

FUGRO

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Table 7. Results of sediment analysis for Crystal Lake and Elginwood Pond, 1995.

Parameter	Crystal Lake	Elginwood Pond	Detection Limit
Total Solids (%)	11	19	0.10
Total Volitile Solids (%)	75	28	0.10
Total Hydrocarbons (mg/kg)	380	830	210
Moisture (%)	89	81	0.10
Particle Size Analysis (%)			
Coarse Gravel (>64 mm)	0	0	0.10
Fine Gravel (2-64 mm)	0	0	0.10
Sand (0.063 mm)	23.2	25	0.10
Silt (0.004 - 0.063 mm)	44.5	39	0.10
Clay (<0.004 mm)	32.3	36	0.10
Oil and Grease - Hexane (mg/kg)			
Oil and Grease	2900	3900	1664
Total Metals (mg/kg)			
Arsenic	8.2	13	1.1
Cadmium	ND	ND	2.1
Chromium	22	85	4.2
Copper	18	44	4.2
Lead	40	110	11.0
Mercury	ND	ND	1.3
Nickel	ND	85	11.0
Vanadium	29	46	2.1
Zinc	43	140	2.1

ND = non-detectible

Chemical Characteristics

Pondwater Analysis

Water quality was monitored in August at 6 pre-defined sites in Crystal Lake and Elginwood Pond or their tributaries. Sites included one in-lake station in each pond and all inlets and outlets (Figures 10+11). The Elginwood Pond site designated EP-2 (inlet from Crystal Lake) was dropped from analysis since it was not different from the Crystal Lake site CL-2 (outlet to Elginwood Pond). Parameters examined included alkalinity, total phosphorus, nitrate nitrogen, total Kjeldahl nitrogen, turbidity, pH, conductivity, dissolved oxygen, and temperature (Table 8).

Stormwater Analysis

Stormwater sampling locations were pre-determined based on the watershed characteristics of Crystal Lake and Elginwood Pond (Figures 10+11). All three inlets were sampled after the significant rainfall event on 17 September 1995. These samples were analyzed for the following parameters: alkalinity, total phosphorus, nitrate, and total Kjeldahl nitrate. Total phosphorus was high in all stormwater samples collected, and very high (1.2 mg/L) at the inlet to Elginwood Pond near Cobb Avenue.

Dissolved oxygen is the amount of molecular oxygen (O_2) dissolved in water. Dissolved oxygen below 5 mg/L is generally considered unsuitable for many forms of aquatic life. Additionally, release of phosphorus from bottom sediments can often be a problem under anoxic or very low oxygen (<1.0 mg/L) conditions. Low levels of dissolved oxygen were documented in Crystal Lake during the August samplings of 1995, probably as a consequence of active decomposition during a period of limited water inputs or aeration. This is not unusual for lakes in this region or a major threat to water quality at this time, but is cause for future concern. Dissolved oxygen levels in Elginwood Pond were at levels which could support a healthy biotic community; this water body exhibited greater flushing than Crystal Lake during the sampling period.

Conductivity is the indirect measure of dissolved solids in water. Conductivity values in Crystal Lake and Elginwood Pond suggest relatively high fertility. Values from the inlet stations were similar to those of the in-lake stations, with values ranging from 380-500 μmhos/cm.

Alkalinity is a measure of the water's ability to neutralize acids. Waters with an alkalinity >25 mg/L are generally not susceptible to acid precipitation. Alkalinity values at all sampling locations were moderate to high during dry weather sampling; however, values were significantly lower during periods of stormwater input. Buffering capacity (ability to withstand acid inputs) appears adequate.

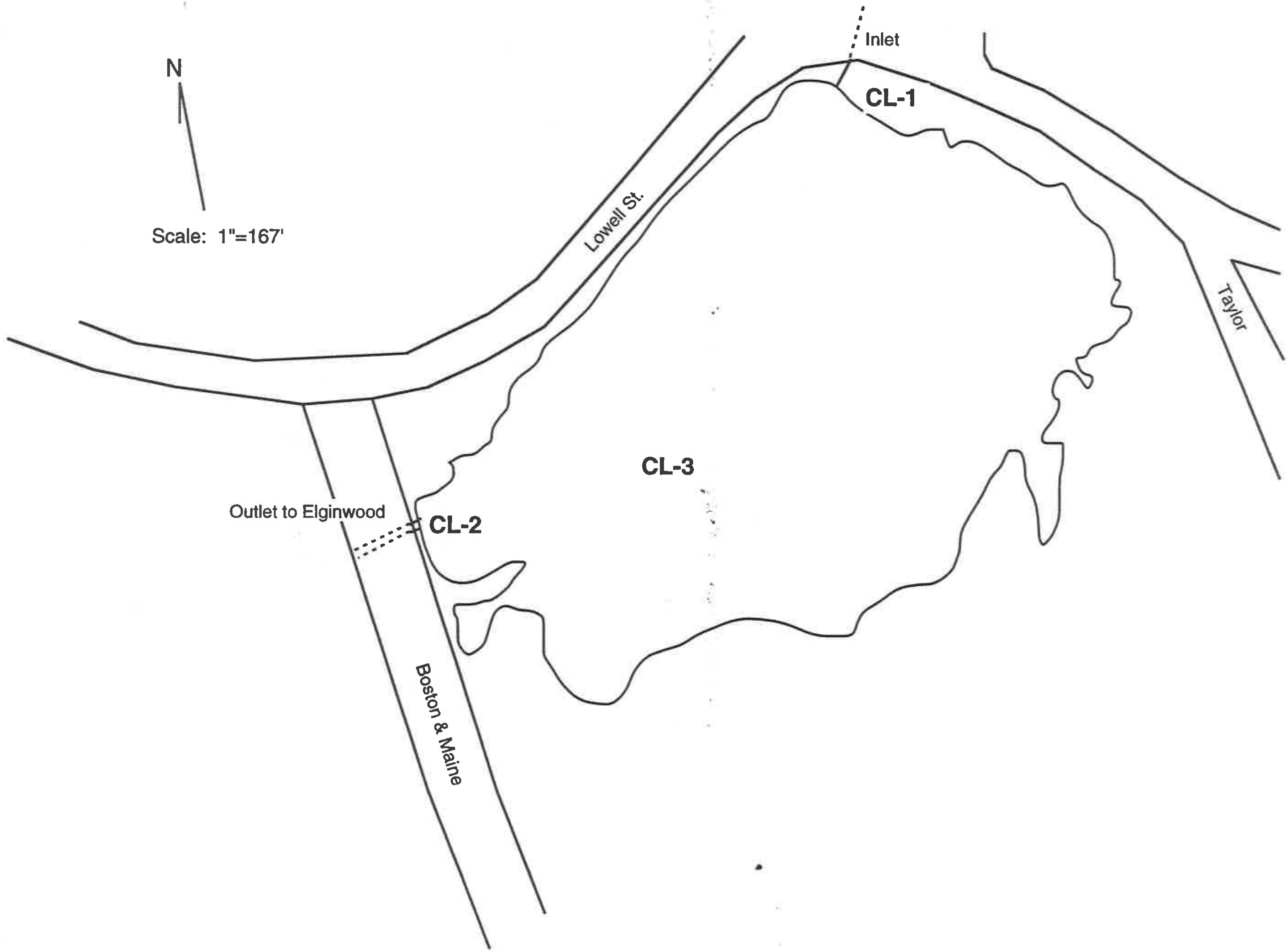


Figure 10. Water Quality Monitoring Sites for Crystal Lake - 1995.

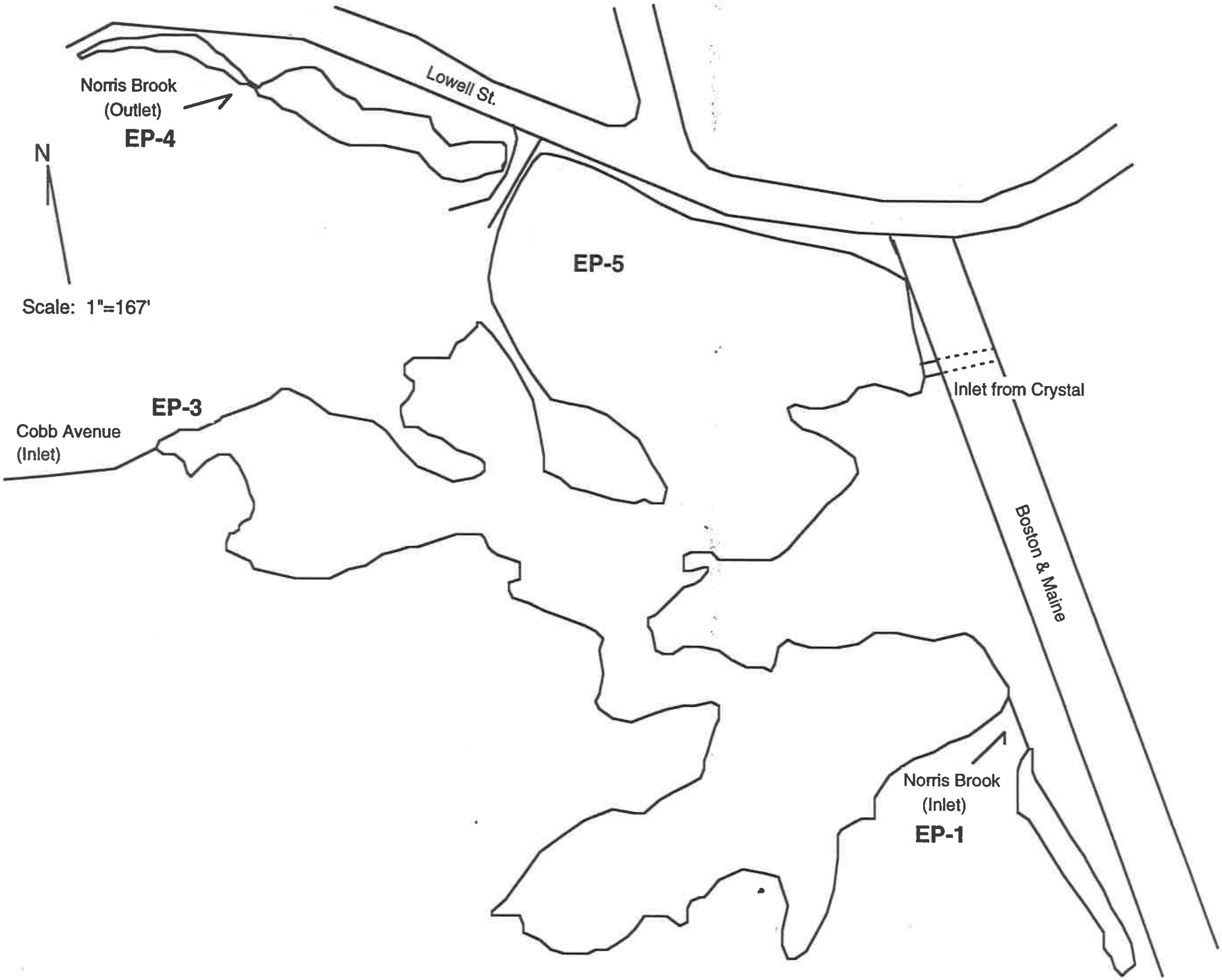


Figure 11. Water Quality Monitoring Sites for Elginwood Pond - 1995.

Table 8. Water Quality Monitoring Results for Crystal Lake and Elginwood Pond, 1995.

Station	Date	Flow *cfs*	D.O. *mg/L*	Saturation *%*	Temperature *Celsius*	Conductivity *umhos/cm*	Turbidity *NTU*	pH *SU*	Alkalinity *mg/L*	Total P *mg/L*	Nitrate *mg/L*	TKN *mg/L*
CL-2	8/31/95	0.4	1.4	15.3	22.1	500	1.7	7.0	82	0.05	<0.01	1.40
CL-3	8/31/95	0.0	2.1	24.2	21.6	428	1.7	7.0	84	0.04	<0.01	1.50
EP-1	8/31/95	0.4	5.6	59.9	21.0	380	2.3	6.9	68	0.10	0.03	1.20
EP-3	8/31/95	0.1	10.0	103.5	17.3	380	4.8	7.6	66	0.03	1.80	0.14
EP-4	8/31/95	0.7	7.1	74.4	21.6	382	1.1	7.2	66	0.03	0.11	0.50
EP-5	8/31/95	<0.1	7.1	88.9	21.3	412	20.8	6.9	72	0.28	0.38	3.30
CL-1	9/18/95	NM	NM	NM	NM	NM	NM	NM	60	0.65	0.95	6.80
EP-1	9/18/95	NM	NM	NM	NM	NM	NM	NM	27	0.36	0.25	2.20
EP-3	9/18/95	NM	NM	NM	NM	NM	NM	NM	21	1.20	0.70	5.40
EP-4	9/18/95	NM	NM	NM	NM	NM	NM	NM	35	0.13	1.80	0.80

NM= Not Measured

CL-1 = Crystal Lake - Inlet by Lowell Street
CL-2 = Crystal Lake - Outlet to Elginwood Pond
CL-3 = Crystal Lake - Deep hole, integrated grab
EP-1 = Elginwood Pond - Inlet from Norris Brook
EP-3 = Elginwood Pond - Inlet by Cobb Avenue
EP-4 = Elginwood Pond - Outlet to Norris Brook
EP-5 = Elginwood Pond, center grab

The pH is a measure of the water's acidity. In general, pH values for most lakes and streams in eastern Massachusetts range from 6.0 to 7.5 SU; however, values near 7.0 SU (near neutral) are most common in urban areas. In-lake monitoring stations had pH values around 7.0 SU at the surface during the August sampling. Water entering the pond via the three inlets was nearly neutral as well, ranging from 6.9 - 7.6 SU.

Phosphorus and nitrogen are essential plant nutrients. Excessive concentrations of these nutrients can often fuel undesirable growths of algae in the water column, and accumulations in the bottom sediments can promote rooted plant growths. Total phosphorus ranged from 0.03 to 0.28 mg/L with a mean value of 0.16 mg/L for the in-lake stations (CL3 + EP5), and concentrations as high as 1.2 mg/L in the inlet by Cobb Avenue during storm flow. The mean phosphorus value for all stations was 0.09 mg/L during dry weather and 0.60 mg/L during storm flow. Values no greater than 0.02 mg/L are desirable for low algal biomass and high water clarity, while concentrations above 0.05 mg/L are considered excessive. Values for nitrate-nitrogen were also not within the desirable range (<0.3 mg/L) for most stations. Nitrate-nitrogen values ranged from <0.01 to 1.80 mg/L with a mean value of 0.39 during dry weather and 0.74 during storm flow. Total Kjeldahl nitrogen (TKN) values for several sampling locations were out of the desirable range (typically <1 mg/L), with a mean value of 1.34 mg/L during dry weather and 3.04 mg/L during storm flow.

Hydrologic and Nutrient Loading

It is possible to estimate the amount (load) of nitrogen and phosphorus being contributed to Crystal Lake and Elginwood Pond by their watershed when an estimate of water flowing into the ponds and the concentration of each nutrient in the water is known. Water flowing into a lake comes from three primary sources: surface water, ground water, and direct precipitation. Surface water flows are estimated from actual data and known relationships for water yield from similar watersheds. Ground water inputs are estimated from the known physical features of the lake and permeability of area soils. Direct precipitation is estimated from long-term climatological data and the area of the lake.

Estimated average water input to the entire Crystal/Elginwood system from surface water, ground water and direct precipitation is 5.8, 0.5 and 0.07 cfs, respectively, for a total flow of 6.37 cfs. This total represents the expected long term average at the outlet to Elginwood Pond, exclusive of any evaporative or outseepage losses, which should be minimal. Estimated average water input to Crystal Lake from surface water, ground water and direct precipitation is 0.8, 0.2, and 0.03 cfs, respectively, for a total flow of 1.03 cfs. These flow estimates may vary appreciably among seasons and weather conditions, but are still relatively large in comparison to pond volume.

Based on the volume and flow through these ponds, average detention time was calculated to be approximately 9.7 days for Crystal Lake and 0.8 days for Elginwood Pond. Detention time represents the duration of time necessary exchange the volume of water in the pond one time. Flushing rate is the inverse of detention time, and represents the number of times per year the lake volume is replaced; for Crystal Lake, the flushing rate is about 38/yr, while for Elginwood Pond the flushing rate is about 474/yr. When detention time is known, a calculation can be made to determine response time (time needed for a lake to respond to nutrient inputs), which for Crystal Lake is between 18 and 29 days and for Elginwood Pond ranges between 1.5 and 2.6 days. Since detention time is significantly less than response time, the effect of any nutrient entering these ponds may not have the opportunity to be fully expressed and conditions in the ponds will reflect very recent inputs.

The nutrient data presented in Table 8 can be placed into perspective once the values are interpreted as a measurement of the nutrient load to the Crystal/Elginwood system. A calculation of minimum nutrient load was made by multiplying the volume of the pond by its flushing rate and the mean concentration of each nutrient. The minimum phosphorus and nitrogen loads delivered to Crystal Lake were determined to be 297 kg/yr and 3,595 kg/yr, respectively, based on the concentration data collected during this study. The minimum phosphorus and nitrogen loads delivered to Elginwood Pond were determined to be 1,606 kg/yr and 10,941 kg/yr, respectively, based on the concentration data collected during this study. The actual load of nitrogen or phosphorus is likely to exceed the estimated minimum load as a consequence of loss processes which reduce the in-lake concentration over time, and these estimates are based on only limited data, but the apparent loads are very high.

An alternative estimate of nutrient loading can be obtained using in-lake modeling theory in which nutrient loads are calculated based on nutrient values measured within the lake and hydraulic features of the lake, which affect transport and removal within the system The predicted phosphorus load necessary to achieve the values found in Crystal Lake range between 305 kg/yr and 357 kg/yr (Vollenweider 1975, Larsen and Mercier 1976, Jones and Bachmann 1976) based on this approach. The predicted phosphorus load necessary to achieve the values found in Elginwood Pond range between 1,708 kg/yr and 2,031 kg/yr (Vollenweider 1975, Larsen and Mercier 1976, Jones and Bachmann 1976). The nitrogen load necessary to achieve observed concentrations for Crystal and Elginwood was estimated to be 3,620 kg/yr and 10,969 kg/yr, respectively (Bachmann 1980). These are not appreciably different than the minimum load estimates, mainly as a consequence of very rapid flushing.

Vollenweider (1968) established criteria for calculating the phosphorus load below which no productivity problems were expected (permissible load) and above which productivity problems were almost certain to occur (critical load). These loading limits are also based on the hydraulic properties of the lake and depend upon mean depth and detention time. The phosphorus load estimated for Crystal Lake by in-lake modeling is far above the permissible level of 17.3 kg/yr, as well as the critical level of 34.7 kg/yr. The phosphorus load estimated for the Elginwood Pond by in-lake modeling is also far above the permissible level of 55.3 kg/yr, as well as the critical level of 110.6 kg/yr. Consequently, Crystal Lake and Elginwood Pond are both well above the transition range, and any increase in the rate of phosphorus input to the system is not likely to cause further detriment (Table 9). Likewise, a major improvement in the quality of stormwater entering the ponds through watershed management

Table 9. Hydrologic and nutrient loads for Crystal Lake and Elginwood Pond calculated from pre-dredging and post-dredging characteristics.

Variable	Crystal Lake Pre-dredging	Crystal Lake Post-dredging	Elginwood Pond Pre-dredging	Elginwood Pond Post-dredging
Flow to pond *cfs*	1.03	1.03	6.37	6.37
Mean depth *meters*	0.63	1.97	0.26	0.90
Max. depth *meters*	1.2	3.2	1.2	2.6
Basin volume *million cu. ft.*	0.86	2.67	0.42	1.47
Detention time *days*	9.7	30	0.8	2.7
Flushing rate *times/year*	38	12	474	135
Response time *days*	18-29	44-73	1.5-2.6	5.5-9.0
In-lake phosphorus *(mg/L)*	0.32	0.26-0.30	0.30	0.28-0.33
In-lake nitrogen *(mg/L)*	3.88	3.83	1.93	1.95
Min. load phosphorus *kg/yr*	297	297	1,606	1,606
Min. load nitrate *kg/yr*	3,595	3,595	10,941	10,941
Larsen and Mercier (P) *kg/yr*	340	340	1,774	1,774
Jones and Bachmann (P) *kg/yr*	357	357	2,031	2,031
Vollenweider (P) *kg/yr*	305	305	1,708	1,708
Bachmann (N) *kg/yr*	3,620	3,620	10,969	10,969
Vollenweider's permissible				
phosphorus load *kg/yr*	17.3	18.5	55.3	54.4
phosphorus concentration *mg/L*	0.019	0.020	0.010	0.010
Vollenweider's critical				
phosphorus load *kg/yr*	34.7	37.0	110.6	108.7
phosphorus concentration *mg/L*	0.037	0.040	0.020	0.019

would be necessary to produce significant improvement in the water quality within the ponds on a regular basis.

Similar loading limits for nitrogen have not been established due to the less predictable relationship between nitrogen, lake hydrology, and primary productivity. Although nitrogen data are very useful in understanding lake conditions and processes, phosphorus is the logical target of management actions aimed at controlling algal biomass.

The dynamics of the nutrient budget can be significantly altered by creating a deeper system through dredging. Dredging will increase the mean depth and thus detention time of the system, thereby slowing down the speed at which nutrients pass through the system. This can be beneficial since it can decrease pollution reserves, reduce sediment oxygen demand and can also increase the efficiency of some management techniques. However, increased detention time might result in algal blooms associated with decreased flushing and the associated tightening of the nutrient spiral, that is, holding the nutrients in the lake for a longer period of time could allow impact of those nutrients to be more fully expressed as detention time approaches response time.

Estimates of the post-dredging depths, detention times and response times that should be achieved for each pond are presented in Table 9. The estimated post-dredging mean depth which could be achieved is roughly 3 times deeper for Crystal Lake and 3.5 times deeper for Elginwood Pond than the pre-dredging state. The increased depth should nearly triple the estimated detention time and more than double the estimated response times for the ponds (Table 8).

The postulated post-dredging concentrations of phoshorus and nitrogen for Crystal Lake are estimated to be 0.26-0.30 mg/L phosphorus and 3.83 mg/L nitrogen. The post-dredging concentrations of phoshorus and nitrogen for Elginwood Pond are estimated to be 0.28-0.33 mg/L phosphorus and 1.95 mg/L nitrogen. In-lake modeling theory predicts that the post-dredging phosphorus and nitrogen concentrations will be similar to the pre-dredging concentrations for both lakes; increased losses of phosphorus and nitrogen to sediment are offset by increased detention and more complete response to inputs. Unless actual loads of Phosphorus and nitrogen are reduced, dredging alone will not yield appreciable water quality improvements.

To get an idea of where nutrient loads such as those estimated above have their origin, a land use-loading analysis was conducted using watershed land use (Figure 2) and export coefficients. Nearly half (1175 acres) of the watershed's 2500 acres are occupied by single-family and multi-family residences in an urban setting. Land used in this fashion will export an estimated minimum of 523 kg/yr phosphorus and 2,615 kg/yr nitrogen. However, since this area is densely populated, the actual value exported to the Crystal/Elginwood system is likely to approach the maximum of 2,962 kg/yr phosphorus and 18,292 kg/yr nitrogen. Commercial land in the watershed is likely to contribute an additional 54 kg/yr phosphorus and 272 kg/yr nitrogen. Also, land used for parks and recreation as well as undeveloped forests and forested wetlands are likely to add 104 kg/yr phosphorus and 1,138 kg/yr nitrogen to the total nutrient export. The total nutrient load being exported from the watershed to the ponds is likely to range between 691 - 3,130 kg/yr of phosphorus and 4,025 - 19,702 kg/yr of nitrogen. The loads estimated by empirical data and in-lake models fall within these anticipated ranges, and are considered to represent a reasonable estimate of loads.

A portion of these nutrients may not actually reach the Crytstal/Elginwood system. Instead, the nutrient load may be lessened by the presence of several ponds in the watershed upstream of the system. The upstream ponds are likely to act as detention basins in which stormwater can be contained, and nutrients can be removed either physically through settling and adhesion or biologically through plant and algal uptake. Substantial attenuation of loads by upstream detention is likely to be occurring now only in sub-watershed #1, which contains several ponds through which inputs pass. Even then, the predicted generation of phosphorus and nitrogen in the watershed is not far greater than the estimated inputs to the ponds; far more attenuation of pollutant loads is necessary to appreciably alter water quality in these lakes.

Biological Characteristics

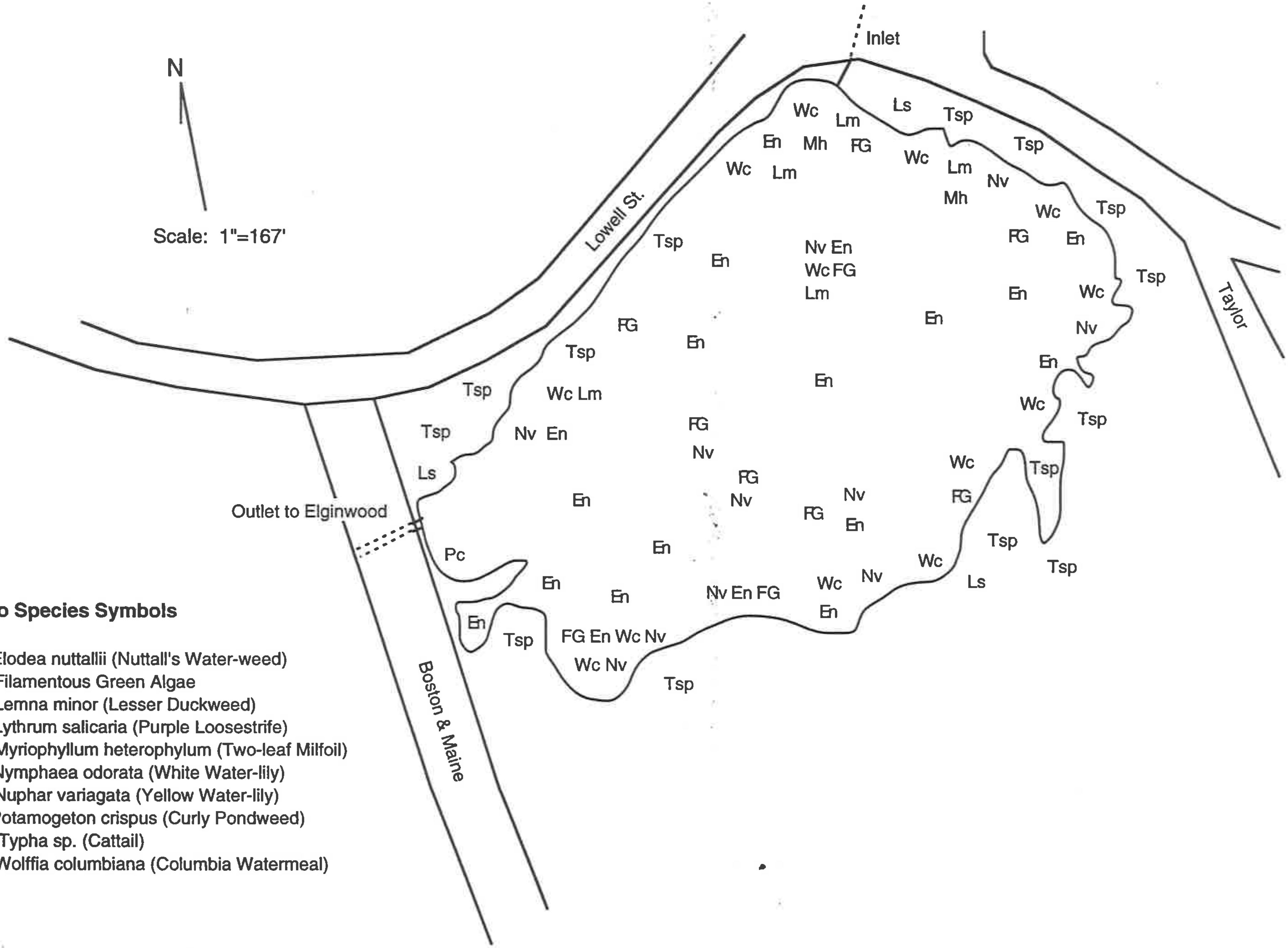
The biological survey of Crystal Lake and Elginwood Pond was designed to identify the baseline biological community which existed in the two ponds prior to any management planning or action. The information from the assessment was of a level necessary to support evaluation of management options and permit filings. The three primary areas which were focused upon were rooted aquatic and semi-aquatic macrophytes (plants), macrofauna (fish and macroinvertebrates), and microfauna (phytoplankton and zooplankton). Field survey activities occurred on August 25 and 31, 1995.

Vascular Plants

Aquatic plants in and around the two ponds were mapped on 25 August 1995. A description of the location and size (amount of area covered) of various plant beds was noted along with an estimate of plant biomass (portion of water column filled by plant). Data from the plant survey are presented in Figures 12-15. A list of all plant species identified in and around Crystal Lake and Elginwood Pond is provided on Figures 12+13.

The aquatic plant community in Crystal Lake was dominated by Waterweed (*Elodea nuttalii*), Yellow Water Lily (*Nuphar variegatum*) and Water Meal (*Wolffia columbiana*). Nearly 100% of the area available to plant colonization, based on depth and substrate data, was occupied by plant cover at densities of 50% or greater (Table 10). The volume of water column filled by submergent plants ranged from 75-100% in most instances. The emergent plant community was predominantly Cattail (*Typha* sp.) which occupied roughly 90% of Crystal Lake's perimeter. Purple Loosestrife (*Lythrum salicaria*) and Pickerel weed (*Pontederia cordata*) filled in the perimeter's remaining 10%.

Elginwood Pond had a slightly different plant community than Crystal Lake, probably the result of Elginwood's very minimal water depth. The plant cover in Elginwood Pond was much more patchy than that of Crystal Lake. Some areas were covered only partially by plants, leaving exposed mud patches covered by only 1-4 inches of water and the small (2-4 mm) floating plant species Water Meal (*Wolffia columbiana*) and Duckweed (*Lemna minor*). Areas that were occupied by larger aquatic plants were dominated by the Waterweed species *Elodea canadensis*. Additionally, Elginwood Pond had two species of Water Lily (*Nuphar variegatum* and *Nymphaea odorata*) compared with Crystal's one species (*Nuphar variegatum*). Roughly 3/4 of Elginwood Pond was covered with plant densities greater than 75% (Table 10). The emergent plants surrounding Elginwood were similar in composition to those around Crystal Lake. However, Elginwood's perimeter had several houses with yards cleared to the water's edge. An estimated 80% of the pond's perimeter was occupied by emergent plants.



Key to Species Symbols

En = Elodea nuttallii (Nuttall's Water-weed)
FG = Filamentous Green Algae
Lm = Lemna minor (Lesser Duckweed)
Ls = Lythrum salicaria (Purple Loosestrife)
Mh = Myriophyllum heterophylum (Two-leaf Milfoil)
No = Nymphaea odorata (White Water-lily)
NV = Nuphar variagata (Yellow Water-lily)
Pc = Potamogeton crispus (Curly Pondweed)
Tsp = Typha sp. (Cattail)
Wc = Wolffia columbiana (Columbia Watermeal)

Figure 12. Aquatic Plant Distribution for Crystal Lake - September 1995.