This is to certify that the

thesis entitled

THE EFFECTS OF DREDGING AND PISCICIDE APPLICATION ON THE AESTHETIC CHARACTER OF AN ARTIFICIAL POND SYSTEM

presented by

G. DOUGLAS PULLMAN

has been accepted towards fulfillment
of the requirements for

M.S. degree in Fisheries and Wildlife

A. D. McNabb
Major professor

Date 3/20/1980

O-7639

THE EFFECTS OF DREDGING AND PISCICIDE APPLICATION ON THE AESTHETIC CHARACTER OF AN ARTIFICIAL POND SYSTEM

By

G. Douglas Pullman

A THESIS

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

MASTER OF SCIENCE

Department of Fisheries and Wildlife

1980

ABSTRACT

THE EFFECTS OF DREDGING AND PISCICIDE APPLICATION ON THE AESTHETIC CHARACTER OF AN ARTIFICIAL POND SYSTEM

By

G. Douglas Pullman

The Dow Gardens artificial pond and stream system was characterized by excessive growths of aquatic plants, poor water transparency, an overabundance of fish and a conspicuous absence of zooplankton. A portion of this system was deepened by dredging to remove obnoxious growths of aquatic macrophytes and loose organic sediments. Fish were partially eliminated from the pond system with a rotenone-based piscicide. The excessive predatory pressure exerted on the zooplankton populations by the overabundance of fish was diminished following the piscicide application, as evidenced by a modest recovery of zooplankton populations.

Data is given that shows that the overall effect of both management techniques, dredging and piscicide application, was a reduction in the primary productivity in the system and the subsequent improvement of its aesthetic appeal.

to my wife and parents

ACKNOWLEDGEMENTS

I sincerely thank Dr. Clarence D. McNabb, my major professor, for directing me through this project and for his invaluable assistance in the preparation of this manuscript.

I thank Dr. Charles Liston and Dr. Peter Murphy for serving on my graduate committee and for reviewing this manuscript.

I thank Doug Chapman, Director of Dow Gardens, for his observations, willingness to assist in the collecting of information, and his numerous suggestions.

I am grateful for the assistance given me by the staff and students of the Limnological Research Laboratory and especially to John Newsted and Maureen Wilson for their help and for the conversations we had that shortened the distance between Lansing and Midland.

Special thanks to Ted R. Batterson for his critical review of this manuscript, his example, encouragement and friendship.

Finally, I thank Janet, my wife, for her unfailing support and understanding.

This study was funded by a grant from the Herbert H. and Grace A. Dow Foundation, Midland, MI awarded to the Limnological Reserach Laboratory, Department of Fisheries and Wildlife, Michigan State University. Additional support was provided by the Michigan Agricultural Experiment Station under project No. 959, Department of Fisheries and Wildlife, Michigan State University.

TABLE OF CONTENTS

LIST OF TABLES

Table		Page

LIST OF FIGURES

INTRODUCTION

Dow Gardens is an ornamental garden located in Midland, Michigan. Development of the Gardens was begun in 1899 and it was opened to the public in 1930. A major reconstruction of the Gardens was begun in 1973 with landscape modification, introduction of new plant material, and the formation of expanded educational objectives.

An artificial pond and stream system courses through the Gardens. It was constructed to enhance the aesthetic appeal and provide irrigation water for the Gardens. A scaled diagram of the pond and stream system is shown in Figure 1. The water level of the system was maintained at the crest of the spillway, zero stage, by replacement water influent from two municipal input sources.

The total area of the system at zero stages was 15,082 m^2. The average depth and volume during 1978 was 0.82 m and 12,709 m^3 respectively. Areas 12 and 13 (cf. Figure 1) were deepended by dredging during the winter of 1978-1979. The mean depth and volume of the system was thereby increased to 1.02 m and 17,879 m^3.

The Dow Gardens pond system was connected end-to-end by a pump that could circulate the entire volume of the system at a rate greater than once every four days. Water was pumped from Area 12 to a waterfall at the head of a small cobble-filled stream channel through which it moved rapidly to Area 2. Water movement was barely perceptable

Figure 1. The Dow Gardens pond and stream system with the subdivisions that are used to identify the various Areas within the system.

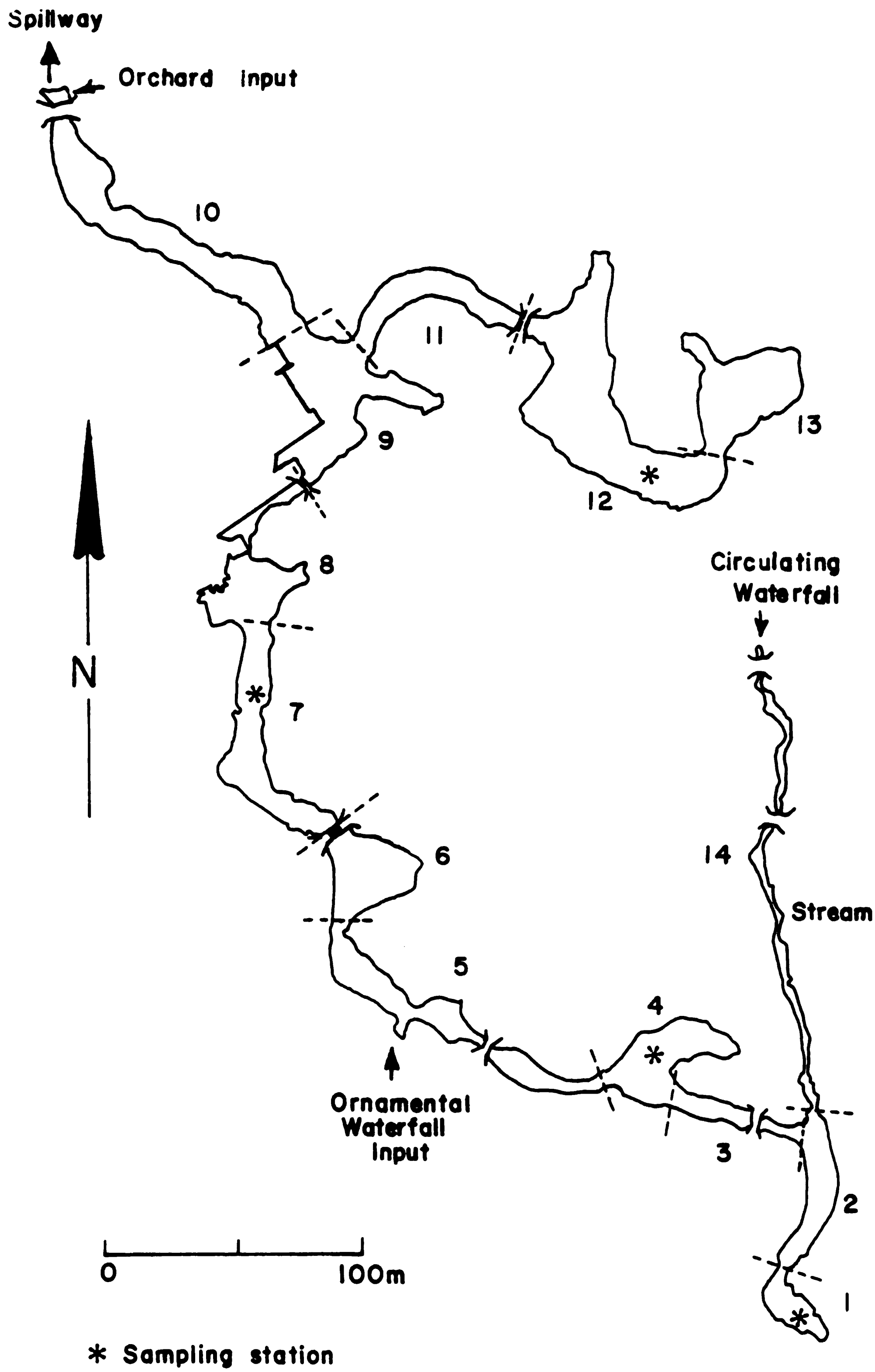

Spillway
Orchard Input
10
11
9
13
12
8
Circulating Waterfall
N
7
6
14
Stream
5
4
Ornamental Waterfall Input
3
2
0
100m
1
* Sampling station

Figure 1.

along the main course of circulation. The system contained several quiescent areas where water movement was not seen. These were Areas 1,2,4,6,11,12 and 13 (cf. Figure 1).

The pond and stream system contained overabundant growths of aquatic macrophytes and filamentous algae. It was also characterized by poor water clarity. These conditions were judged to be detrimental to the overall aesthetic and educational goals of the Gardens. A study was initiated in April 1978 to recommend and, when possible, implement freshwater management strategies that would rectify this situation. The intrinsic goals of this study were to 1) reduce biogenically-induced turbidity, 2) eradicate any biological pest species that were present in the system that were not consistent with the overall goals of the Gardens, 3) introduce new aquatic plant species that would be of educational and cosmetic interest, and 4) provide information to the public on artificial pond management. This paper addresses only the first of these goals, as listed above.

Information was compiled in the first year of this study to form a basis for the recommendation of aesthetically corrective management strategies for the pond and stream system. Because water from the pond system was used for irrigation purposes, non-herbicidal management strategies were given preference. Based on these recommendations, dreding and biomanipulative piscicide application techniques were implemented during the winter of 1978-1979. The efficacy of these treatments was monitored in the second year of this study. Particular emphasis was placed on the potential for the limitation of primary production and nutrient cycling within the system as a result of these techniques.

METHODS

Hydrologic and nutrient budgets were constructed to identify the major sources of water and mineral plant nutrient inputs to the system. These data were used in part, as a basis for the management of the productivity in the Gardens ponds. Precipitation data were provided by Dow Environmental Services, Dow Chemical Company, Inc., Midland, MI. Evaporation was estimated by isohyetal diagraming after a method for precipitation by Chow (1964). Raw data for the calculation of evaporation were found in *Climatological Data*, Vol. 93., Nos. 5 through 10 inclusive, National Oceanographic and Atmospheric Administration, Environmental Data and Information Service, National Climatic Center, Asheville, NC.

The water volume influent to the pond and stream system via the orchard input was calculated from meter readings provided by the City of Midland municipal water treatment plant. Water influent from the waterfall input was calculated by measuring its discharge rate and multiplying this value by its estimated operating time.

The area of the pond and stream system was estimated by planimetry based on contour maps made from aerial photographs of Dow Gardens. Depth estimates were made in the field with a digital depth sounder (Heathkit, model MI-101). These data were used to approximate the depth contours of the system which, in turn, were used to estimate the volume with planimetry.

Water samples were taken periodically with a one liter polyethylene Kemmerer sampling device from the sampling stations shown in Figure 1. These samples were placed on ice and transported back to the laboratory for analysis.

The following analyses were determined colorimetrically using a Varian Superscan 3 spectrophotometer. The methodology used is found in *Standard Methods for the Examination of Water and Wastewater* (APHA, 1975). Water used for the determination of total dissolved phosphorus was passed through pre-ignited, acid washed Reeve Angel 984H glass fiber filters with a pore size of approximately 0.5 μm. Total phosphorus and total dissolved phosphorus were determined by the ascorbic acid single reagent method following an ammonium persulfate acid digestion. Nitrite-nitrate nitrogen was determined from samples that were passed through cadmium reduction columns. Kjeldahl nitrogen was determined from digested samples after distillation and using Nessler's reagent. Ammonia was determined with Nessler's reagent after distillation. Particulate phosphorus concentrations were calculated as the difference between the total and total dissolved phosphorus fractions. Total inorganic nitrogen was calculated as the sum of nitrite-nitrate nitrogen and ammonia nitrogen. Nitrogen and phosphorus concentrations and discharge measurements were used to calculate data in the nutrient budget tables.

Total phosphorus and nitrite-nitrate nitrogen concentrations in water from the orchard and waterfall inputs were furnished by the City of Midland municipal water treatment plant. Total atmospheric nitrogen and phosphorus inputs were estimated from Chapin and Uttormark (1973). During 1979 atmospheric nitrogen and phosphorus collectors were set in triplicate near Area 10. Six liters of deionized, distilled water were added to each of the three acid-washed lexan containers with a combined surface area of 0.78 m^2. This water was allowed to stand in the covered containers for at least 24 hours to permit nutrient exchange between the water and the container walls. One liter of water was removed from each container just prior to their placement in the field. The three liters were composited into a single "initial" sample that was taken to the laboratory for routine nutrient analysis. The fallout collectors were retrieved after two weeks. The volume of the three containers was measured. Water was withdrawn from each container and composited into a "final" sample. Nutrient input to the system per m^2 was calculated from a knowledge of the combined total surface and total final water volume in the containers and the nutrient concentration in the fallout water as determined by the differnce between the "initial" and the "final" composite samples.

pH was determined with a Beckman Expandomatic pH meter using a combination electrode with a silver/silver chloride reference element. It was standardized against pH 7 and 10 standard buffer solutions. This instrument was calibrated before each series of measurements. Total alkalinity was measured by the dual pH end-point acid titration method commonly used in limnological investigation (APHA, 1975). Free carbon dioxide concentrations were calculated from pH, temperature and carbonate-bicarbonate alkalinity data using the equations of Harvey (1957) and Park (1969). Dissolved oxygen, temperature, and percent saturation of oxygen data are presented in the appendix. Dissolved oxygen and temperature were measured *in situ* with a YSI (Yellow Springs Instrument Company, Yellow Springs, Ohio) model 54A oxygen meter with a pressure-compensated Clark-type polargraphic oxygen sensor with submersible stirrer. An integral thermistor permitted temperature readout and corrected for temperature-dependent membrane diffusion effects and for differential oxygen solubility with temperature. During January and February of 1979 dissolved oxygen was measured by the azide modification of the Winkler method (APHA, 1975). Percent dissolved oxygen saturation was determined from the tables and methods of Truesdale, Downing, and Louden (1949) and Mortimer (1956).

Visual observations were used as a basis for the mapping of macrophytic distributions in the pond and stream system. Fish populations were also monitored by visual observations.

Zooplankton samples were collected in 1978 with a

Student plankton net, towed just below the surface of the water. These samples were preserved in 70% ethanol. Microscopic examination of these samples was performed to identify the dominant species. Quantification of samples taken in 1979 was made possible by the use of a Schindler-Patalas plankton trap made from plexiglass to reduce avoidance by the zooplankton. It had a 50 liter capacity and was equipped with a No. 20 net with apertures of 0.076 mm. In the laboratory, the contents of each sample were diluted to between 80 and 150 ml, depending on the density of the animals. These known volumes were then randomized by gentle mixing with a magnetic stirrer. A subsample of 2-6 ml was removed with a wide-mouthed Hensen-Stempel pipette and placed in a chambered counting cell (Gannon, 1971). The entire cell was counted using magnifications of 14x to 60x (Yusoff, 1979).

As a pond management technique, a rotenone-based piscicide was applied to the pond and stream system in February 1979. The piscicide was infused through the ice and paddles were used for dispersion. In November 1979 rotenone application was repeated. This time it was applied from a small boat and mixing was accomplished by the turbulence created by the outboard boat motor.

RESULTS AND DISCUSSION

This long-term goal of this study was to recommend and, when possible, implement freshwater management techniques that might improve the aesthetic appeal of the Dow Gardens pond and stream system. Overabundant plant growth was the chief concern and was symptomatic of a nutrient-rich condition. The nutrient dependence of primary productivity in lakes has been well-documented in the literature (Bachman and Jones, 1974; Hasler, 1947; Megard, 1972; Smith, 1979). Descriptive data were compiled as a basis for the recommendation of management techniques that would reduce nutrient concentrations in the pond and stream system and alleviate the symptoms of this condition.

Nutrient Budgets

Aspects of the hydrologic budget of the Dow Gardens pond and stream system were calculated for these portions of the growing seasons during which sampling for mineral plants nutrients was done. The results are given in Tables 1 and 2 for portions 1978 and 1979 respectively.

Evaporation exceeded precipitation during both sampling periods, resulting in water deficits in the pond system of 7,238 m^3 in 1978 and 2,735 m^3 in 1979. Water was also lost by withdrawal for irrigation. There was no water discharged over the retaining dam during these periods (cf. Figure 1). Water losses from the pond and stream system were replaced from two sources such that zero stage was maintained.

Table 1. Aspects of the hydrologic budget of the Dow Gardens pond and stream system for the interval May 1, 1978 to October 31, 1978.

Source	Inputs (+), Outputs (-), (m^3)
Total Precipitation[1]	+ 882
Water entering via the orchard input[2]	+19725
Water entering via the waterfall input[2]	nil
Evaporation[3]	- 8120
Irrigation and other losses[4]	-12487

1. Precipitation from Dow Environmental Services.

2. See Figure 1.

3. Evaporation by a modification of isohyetal diagraming and estimated from *Climatological Data*, Vol. 93, Nos. 5 through 10 inclusive, National Oceanographic and Atmospheric Administration, Environmental Data and Information Service, National Climatic Center, Ashville, N.C. 28801.

4. This value is the sum of the input and output volumes based on the assumption that the pond and stream system was maintained at a constant elevation, the height of the dam, by precipitation and water entering the system via the orchard input.

Table 2. Aspects of the hydrologic budget of the Dow Gardens pond and stream system for the interval May 1, 1979 to September 30, 1979.

Source	Inputs (+), Outputs (-), (m^3)
Total Precipitation[1]	+ 4260
Water entering via the orchard input[2]	+14992
Water entering via the waterfall input [2,3]	+11832
Evaporation[4]	- 6995
Irrigation and other losses	-24089

1. Precipitation from Dow Environmental Services.

2. See Figure 1.

3. Based on an input rate of 2.69 l $sec.^{-1}$ and assuming that the input was operating for an average of 8 hrs. day^{-1} for 153 days.

4. Data from the U.S.D.A. Weather Service, Stephen P. Nesbitt Bldg., Michigan State University, E. Lansing, MI 48824.

5. This value is the sum of the input and output volumes based on the assumption that the pond and stream system was maintained at a constant elevation, the height of the dam, by precipitation and water entering the system via the orchard and waterfall inputs.

The orchard input (cf. Figure 1 and Table 1) was the principal source of replacement water during both years of this study. It contributed 96% of the total known water input in 1978 and 48% in 1979. Water was supplied to the orchard input through an aquaduct that originated in Saginaw Bay, Lake Huron. Water was also influent from an ornamental waterfall located on the west side of the Gardens property and entered the pond and stream system in Area 5 (cf. Figure 1). This input was constructed in 1978 and operated only intermittently during that year. As a result, the total waterfall input volume was small and unmeasured. During 1979, however, the waterfall input contributed 38% of the known water input to the pond and stream system. It was supplied with water from the municipal water distribution system of the City of Midland.

The 1978 and 1979 nutrient budgets for the pond and stream system appear in Tables 3 and 4 respectively. The mean rate of input and total seasonal kilogram contribution are given for each of the sources described in these tables. The orchard input was the greatest source of total phosphorus in 1978, and the waterfall input contributed the greatest amount in 1979. Polyphosphates are often added to municipal water supplies to prevent the accumulation of deposits in transport conduits (Hem, 1970). This would explain the relatively high concentrations of phosphorus in the replacement water influent from the waterfall input.

Table 3. Aspects of the nutrient budget of the Dow Gardens pond and stream system for the interval May 1, 1978 to October 31, 1978.

Source	Form	Mean Rate[1] of Input or Export (gm day^{-1})	Nutrient Accrual (+) Losses (-) (kg)
Atmospheric Input[2]	Total Phosphorus	1.653	+ 0.304
	Total Nitrogen	95.037	+17.487
	Total Inorganic Nitrogen	53.717	+ 9.884
Orchard Input[3,4]	Total Phosphorus	10.707	+ 1.970
	Nitrite + Nitrate Nitrogen	53.587	+ 9.860
Waterfalls Input[3,5]	Total Phosphorus	nil	nil
	Nitrite + Nitrate Nitrogen	nil	nil
Total Known Inputs[6]	Total Phosphorus	12.360	+ 2.274
Nutrient Losses by Irrigation and Other Water Losses	Total Phosphorus	5.166	- 0.950
	Nitrite + Nitrate Nitrogen	2.228	- 0.410
Nutrient Losses in the System[7]	Total Phosphorus	7.196	- 1.324

1. Mean Rate is calculated as the total nutrient input in grams divided by the number of days in the described interval.

2. Estimated from Chapin, J.D. and P.D. Uttormark. 1973. Atmospheric contributions of nitrogen and phosphorus. Tech. Rep. 73-2, Water Resources Ctr., Univ. Wis., Madison. 35pp. Nitrogen data from Madison, Wisconsin and Total P taken from middle of range proposed by Chapin and Uttormark and confirmed in our studies at Lake Lansing, Ingham Co., Michigan.

Table 3 (cont'd.)

3. See Figure 1.

4. These values are based on data provided by the water treatment plant of the City of Midland, Michigan.

5. These values are based on mean nitrogen concentrations from samples taken 7-31-78, 8-28-78, and 9-11-78, and mean phosphorus concentrations from samples taken 7-18-78, 7-31-78, 8-28-78, 9-11-78, 9-25-78 and 10-9-78.

6. Atmospheric Input + Orchard Input + Waterfalls Input.

7. Nutrient losses other than those that can be accounted for contained in known water losses from the system.

Table 4. Aspects of the nutrient budget of the Dow Gardens pond and stream system for the interval May 1, 1979 to September 30, 1979.

Source	Form	Mean Rate of Input or Export (gm day^{-1})	Nutrient Accrual (+) Losses (-) (kg)
Atmospheric Input[2]	Total Phosphorus	13.634	+ 2.086
	Total Nitrogen	146.111	+22.355
	Nitrite + Nitrate Nitrogen	6.176	+ 0.945
	Kjeldahl Nitrogen	141.882	+21.708
Orchard Input[3,4]	Total Phosphorus	13.719	+ 2.099
	Nitrite + Nitrate Nitrogen	140.118	+21.438
Waterfalls Input[3,4]	Total Phosphorus	50.268	+ 7.691
	Nitrite + Nitrate	85.059	+13.014
Total Known Inputs[5]	Total Phosphorus	77.621	+11.876
	Nitrite + Nitrate Nitrogen	231.353	+35.397
Nutrient Losses by Irrigation and Other Water Losses	Total Phosphorus	8.784	- 1.344
	Nitrite + Nitrate Nitrogen	3.719	- 0.569
Nutrient Losses in the System[6]	Total Phosphorus	74.529	-11.403
	Nitrite + Nitrate Nitrogen	230.092	-35.204

1. Mean Rate is calculated as the total nutrient input in grams divided by the number of days in the described interval.

2. These values were determined from samples taken from triplicate atmospheric fallout collectors with a total surface area of 0.78 m^2 placed near the orchard input (see Figure 2).

3. See Figure 1.

4. These values are based on data provided by the water treatment plant of the City of Midland, Michigan.

Table 4 (cont'd.)

5. Atmospheric Input + Orchard Input + Waterfalls Input.

6. Nutrient losses other than those that can be accounted for contained in known water losses from the system.

The orchard input contributed more nitrogen to the system than did the waterfall input during both the 1978 and 1979 nutrient sampling periods. Atmospheric and watershed inputs, however, were probably the main sources of nitrogen contribution to the system.

The land surrounding the Dow Gardens pond and stream system was a diffuse source of inorganic nutrients. These enter in runoff water following rain showers or irrigation, in seepage as leachates from soil, or as grass clippings and deciduous leaf litter. Leaf litter leachates and the subsequent contributions of nutrients from the microbial decomposition of this litter are often important sources of nitrogen in aquatic systems (Boling, 1975; Cummins et al., 1972). The leaf litter that carpeted much of the bottom was probably a significant source of nitrogen to the pond system.

The principal conduit through which phosphorus and nitrogen were exported from the pond and stream system was through the removal of water for irrigation. It is noteworthy that this practice contributed to the available mineral nutrient pool of the terrestrial portions of the Gardens.

The phosphorus and nitrogen that could not be accounted for in the seasonal input or export volumes, and that were in excess of the amounts that were estimated to be contained in the water of the system (cf. Tables 5 and 6), were assumed to be lost to sinks within the system. These

Table 5. Inorganic nitrogen concentrations in surface samples from the Dow Gardens pond and stream system during 1978 and 1979.[1]

Date	Nitrite + Nitrate (mg N l^{-1})	Ammonia (mg N l^{-1})	Total Inorganic Nitrogen (mg N l^{-1})
7-31-78	0.049	0.108	0.359
8-14-78	0.049	0.047	0.083
8-28-78	0.031	0.515	0.546
9-11-78	0.030	0.010	0.043
10-09-78		0.220	
10-23-78	0.022	0.495	0.517
4-23-79	0.089	0.020	0.109
5-07-79	0.133	0.018	0.151
5-21-79	0.026	0.048	0.074
6-18-79	0.005	0.000	0.005
7-02-79	0.022	0.070	0.092
7-16-79	0.018	0.110	0.128
7-30-79	0.010	0.156	0.166
8-13-79	0.000	0.124	0.124
8-27-79	0.000	0.118	0.118
9-17-79	0.000	0.098	0.098

1. Concentrations for dates 7-31-78 through 6-18-79 inclusive are means calculated from concentration values determined for each of the four sampling stations identified in Figure 1. Concentrations for the remaining sampling dates were determined from a single sample composited in the field from samples taken from each of the same four sampling stations.

Table 6. Phosphorus concentrations in surface samples from the Dow Gardens pond and stream system during 1978 and 1979.[1]

Date	Particulate Phosphorus (mg P l^{-1})	Total Dissolved Phosphorus (mg P l^{-1})	Total Phosphorus (mg P l^{-1})
6-06-78	0.036	0.014	0.050
7-05-78	0.039	0.017	0.056
7-31-78	0.068	0.019	0.081
8-28-78	0.079	0.025	0.105
9-11-78	0.069	0.000	0.069
9-25-78	0.073	0.016	0.089
10-09-78	0.066	0.014	0.080
10-23-78	0.083	0.012	0.095
4-23-79	0.033	0.018	0.051
5-07-79	0.019	0.017	0.036
5-21-79	0.036	0.013	0.049
6-18-79	0.011	0.022	0.033
7-02-79	0.023	0.027	0.050
7-16-79	0.042	0.028	0.070
7-30-79	0.042	0.029	0.071
8-13-79	0.033	0.028	0.061
8-27-79	0.078	0.011	0.089
9-17-79	0.022	0.017	0.039

1. Concentrations for dates 7-31-78 through 6-18-79 inclusive are means calculated from concentration values determined for each of the four sampling stations indentified in Figure 1. Concentrations for the remaining sampling dates were determined from a single sample composited in the field from samples taken from each of the same four sampling stations.

nutrients were presumably incorporated into the macrophyte-epiphyte community (Mickle and Wetzel, 1979; Wetzel and Hough, 1973), adsorbed to the sediments (Harter, 1968; 1979; Rosenfeld, 1979; Shulka *et al.*, 1971; and Williams *et al.*, 1971) or cycled between these two components of the system (Bristow, 1974; McRoy, 1972; Wium-Anderson, 1971).

Nutrient Limitation

Phosphorus and nitrogen concentrations in the surficial water of the Dow Gardens pond and stream system were determined periodically during 1978 and 1979. These data appear in Tables 5 and 6. Concentrations of the inorganic forms of these elements were two to three times higher than the levels generally thought to limit aesthetically unpleasing growths of aquatic plants (Sawyer, 1952; 1954).

Phosphorus, nitrogen, and carbon are usually the three nutritional elements required by aquatic photosynthetic primary producers that may be in short supply from time to time, relative to their respective concentrations. The ratios of abundance of phosphorus and nitrogen in the pond and stream system, with regard to the relative requirements of aquatic plants, appear in Table 7. Assuming that no other element was lacking, this exercise revealed that nitrogen concentrations were limiting to the growth of aquatic plants, relative to phosphorus.

The concentrations of free carbon dioxide (sum of the equilibrium concentrations of CO_2 gas and carbonic acid) in

Table 7. An analysis of the ratio of total inorganic nitrogen to total phosphorus in the Dow Gardens pond and stream system during 1978 and 1979.

Date	Observed TIN:TP	Deviation from TIN:TP of 16:1	Percent Excess Phosphorus[2] (%)
7-31-79	4.43	-11.57	361
8-28-78	5.31	-10.69	308
9-11-78	0.62	-15.38	257
10-23-78	5.48	-10.52	249
4-23-79	2.14	-13.86	749
5-07-79	4.19	-11.81	381
5-21-79	1.51	-14.49	1059
6-18-79	0.15	-15.85	10560
7-02-79	1.84	-14.16	870
7-16-79	1.83	-14.17	875
7-30-79	2.34	-13.66	684
8-13-79	2.03	-13.97	787
8-27-79	1.33	-14.67	1207
9-17-79	2.51	-13.49	637

1. Based on an assumed plant and algae nitrogen-phosphorus requirement as in King (1972) and Fuhs *et al.* (1972) and calculated as: Observed TIN:TP - 16 = Deviation from TIN:TP of 16.

2. The percentage of total phosphorus in the system found in excess of the hypothetical amount that would be required to fix all total inorganic nitrogen found in the system.

the pond system were calculated. These data are reported in Table 8 and suggest that carbon dioxide may have occasionally been limiting to some of the photosynthetic organisms in the ponds during 1978. When free carbon dioxide concentrations are low (7.5 umole CO_2 l^{-1} or less), blue-green algae are thought to have a competitive advantage over other algal groups due to their greater affinity for carbon (King, 1972; Shapiro, 1973). Microscopic examination of phytoplankton samples revealed the presence of one such alga, *Anabaena sp.* Obnoxious blue-green algal scums did not develop, however, on the ponds in 1978. At no time during 1979 were carbon dioxide concentrations so low as to impose limitations on the photosynthetic primary producers. The calculations of nitrogen-phosphorus ratios and the concentrations of free carbon dioxide in the system indicate that nitrogen was the principal nutrient element limiting to the potential for greater pirmary production and further degradation of the aesthetic character of the pond and stream system.

Comparisons of 1978 and 1979 Water Qualities

The mean phosphorus and nitrogen concentrations and the pH values determined for each sampling date were weighted arithmetically by the number of days between that date and the next sampling date. These weighted means were averaged over equivalent date-periods (ie. 6-1-78 to 7-31-78 and 6-1-79 to 7-31-79) for the comparison of 1978 and 1979

Table 8. Mean surface pH, alkalinity, and free CO_2 in the Dow Gardens pond and stream system during 1978 and 1979.[1]

Date	pH	Alkalinity (mg $CaCO_3$ l^{-1})	Free CO_2 (μmoles CO_2 l^{-1})
7-05-79	9.2	103	2.8
7-18-78	8.4	93	17.6
7-25-78	8.4	99	17.7
8-31-78	9.3	105	2.2
9-11-78	8.6	95	11.1
1-10-79	10.2	216	0.5
1-31-79	8.2	201	22.8
2-14-79	8.1	283	163.2
3-05-79	7.7	288	430.4
3-29-79	8.4	134	38.8
5-01-79	8.3	159	45.9
5-15-79	8.7	156	15.6
5-24-79	8.5	153	25.2
5-29-79	8.0	150	81.2
6-12-79	7.9	133	83.4
6-26-79	8.1	122	44.4
7-11-79	7.8	114	86.1
7-25-79	8.3	116	26.5
8-09-79	7.3	61	143.7
8-21-79	8.2	104	32.5
9-13-79	8.6	99	12.0
10-09-79	7.9	94	68.6
10-17-79	8.0	92	53.4
10-30-79	6.9	111	887.3

1. Means were calculated from values determined for each of the sampling sites identified on Figure 1.

seasonal data. These comparisons follow in the text below.

Comparisons of 1978 and 1979 data show an appreciable decline in the various forms of nitrogen and phosphorus in the pond and stream system. Concentrations of ammonia dropped 34%, nitrite-nitrate dropped 93%, and total inorganic nitrogen dropped 55%. Concentrations of particulate phosphorus and total phosphorus dropped 28% and 13% respectively. Total dissolved phosphorus concentrations, however, increased 38%. Pursual of the 1978 and 1979 nutrient input budgets indicate an internal cause for these differences. Two management strategies, the deepening of Areas 12 and 13 and biotic manipulation, are implicated as causative factors.

Macrophytes covered approximately 90% of the bottom of the pond and stream system during the 1978 growing season. They were absent only from the deepest portions of Areas 2, 4 and 6 and from the firmer substrate areas (cf. Figures 2 and 3). Macrophytes, and their associated epiphytic flora, grew to the surface in Areas 12 and 13, forming unsightly mats. Deepening these areas by dredging was recommended to remove these nuisance growths and the underlying organic sediments.

Dredging was accomplished during the winter months of 1978 and 1979, resulting in the complete removal of the aquatic plant community. It was intended that, once removed, aquatic plant growths would be eliminated from the central portions of these areas by light attenuation at

Figure 2. A generalized diagram of the distributions of the principal macrophyte species and macrophyte species associations in the Dow Gardens pond and stream system during the early part of the 1978 growing season.

Elodea canadensis, Potamogeton foliosus and Potamogeton pectinatus

Chara sp.

Drepanocladus aduncus

Myriophyllum spicatum

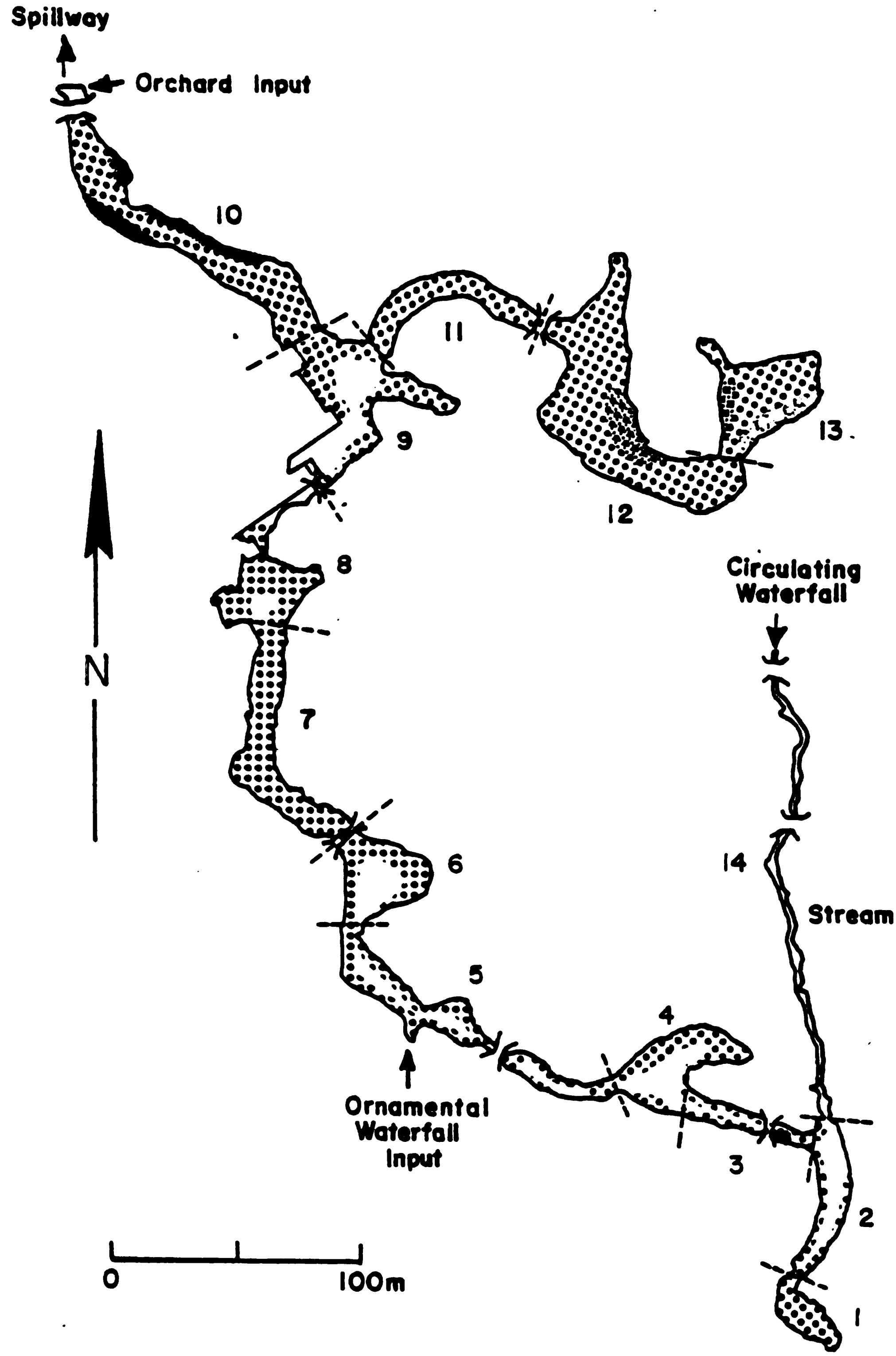

Spillway
Orchard Input
10
11
9
12
13
8
Circulating Waterfall
N
7
6
14
Stream
5
4
Ornamental Waterfall Input
3
2
0
100m
1

Figure 2.

Figure 3. A generalized diagram of the distribution of the principal macrophyte species and macrophyte species associations in the Dow Gardens pond and stream system during the later part of the 1978 growing season.

Elodea canadensis, Potamogeton foliosus and Potamogeton pectinatus

Chara sp.

Myriophyllum spicatum

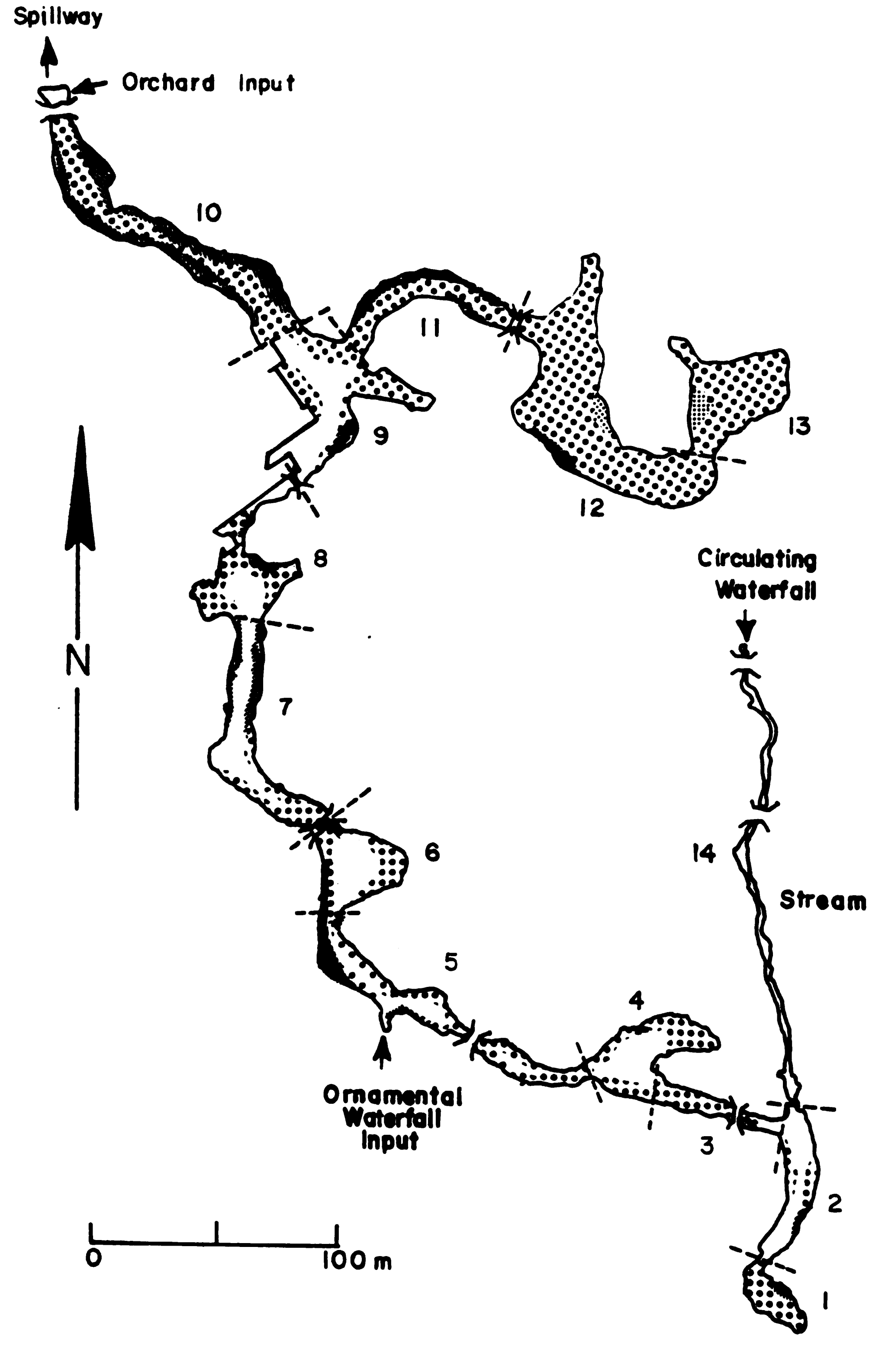

Spillway
Orchard Input
10
11
9
13
12
8
Circulating
Waterfall
N
7
6
14
Stream
5
4
Ornamental
Waterfall
Input
3
2
0
100 m
1

Figure 3.

increased depth. Recolonization of these areas during the 1979 growing season proceeded slowly (cf. Figures 4 and 5). By the end of the season, only a sparse band of vegetation, primarily *Chara sp.* and *Elodea canadensis*, had re-established populations in the shallow areas. *Drepanocladus aduncus*, a bryophyte, established populations at the water-land interface around the edges of both areas.

There is some evidence that aquatic macrophytes, with their associated epiphytes, may act as nutrient pumps, transporting inorganic nutrients held by the sediments, into the water (S. Wium-Anderson, 1971; Bristow, 1974; Wetzel and Hough, 1973). The removal of the macrophytes from these areas may have been partly responsible for the decrease in the plant nutrient concentrations observed during the 1979 growing season (cf. Tables 5 and 6).

The sediments of ponds are reserviors for the mineral nutrients required for aquatic plant growth. They become enriched by the fallout of various inorganic and organic forms of these elements. Organic sediments tend to be richer sources of nutrients than inorganic sediments. This trend occurs, not because of higher concentrations of these elements (e.g. mg kg^{-1}), but because they are more loosely adsorbed (Harter, 1969; Shulka et al., 1971; Rosenfield, 1979; and Williams et al., 1971). Furthermore, the activity of greater numbers of decomposers (i.e. bacteria) on organic substrates promote high release rates of nutrients.

Figure 4. A generalized diagram of the distribution of the principal macrophyte species and macrophyte species associations in the Dow Gardens pond and stream system early in the 1979 growing season.

Elodea canadensis, *Potamogeton foliosus*, and *Potamogeton pectinatus*

Chara sp.

Drepanocladus aduncus

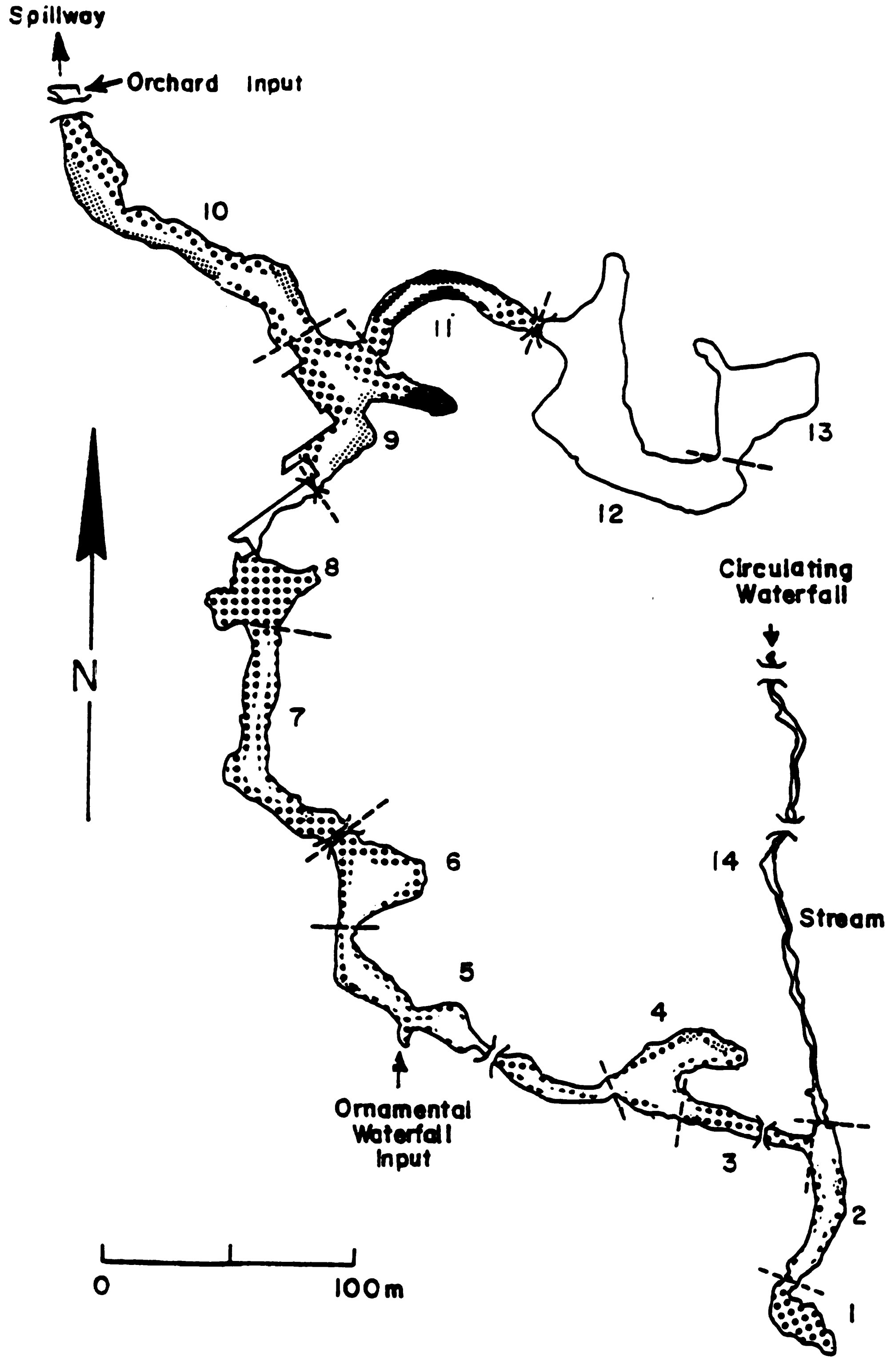

Spillway
Orchard Input
10
11
9
12
13
8
Circulating Waterfall
N
7
6
14
Stream
5
4
Ornamental Waterfall Input
3
2
1
0
100m

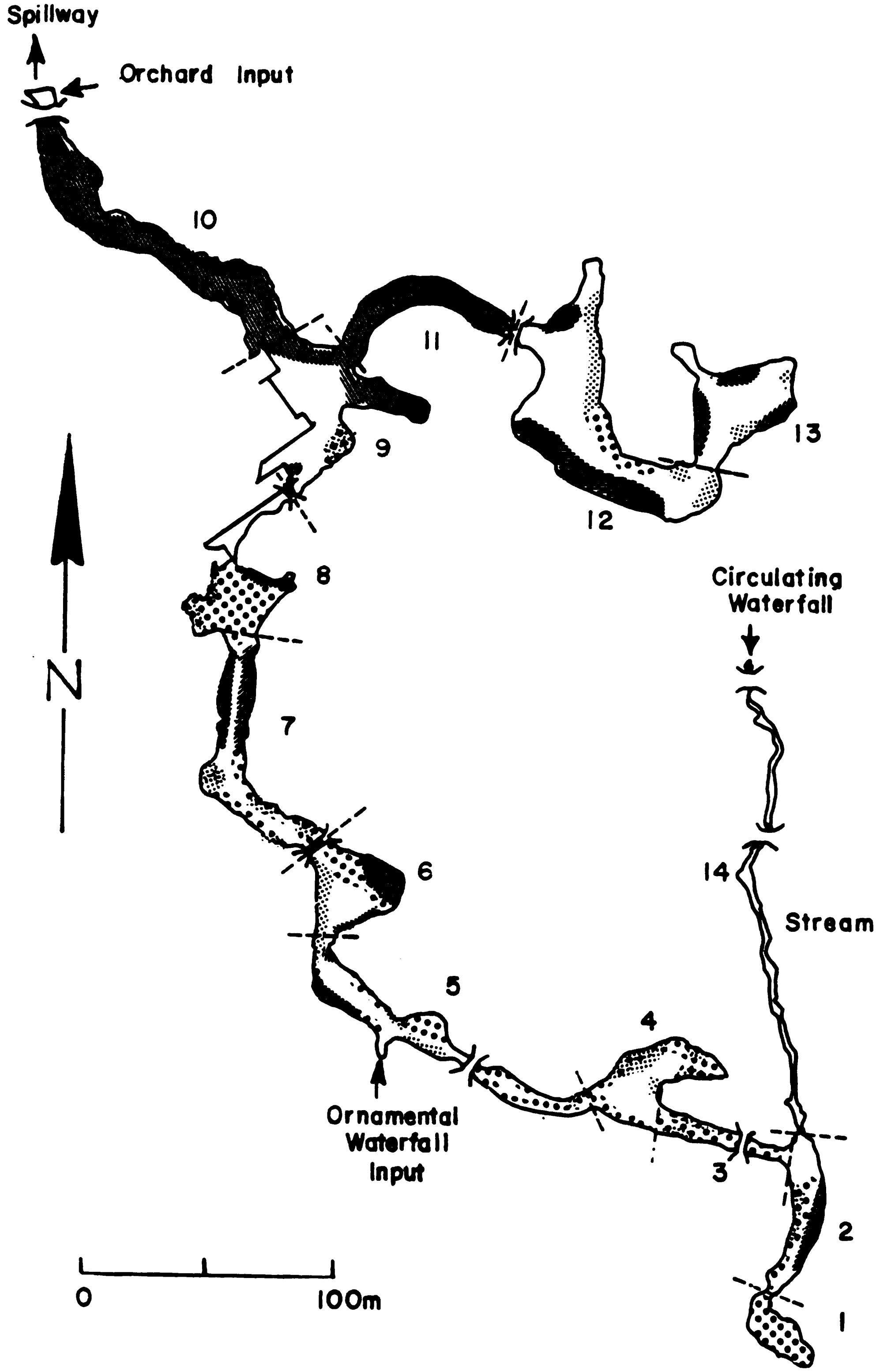
Figure 4.

Figure 5. A generalized diagram of the distribution of the principal macrophyte species and macrophyte species associations in the Dow Gardens pond and stream system during the later part of the 1979 growing season.

Elodea canadensis, Potamogeton foliosus, and *Potamogeton pectinatus*

Chara sp.

Drepanocladus aduncus



Spillway
Orchard Input
10
11
9
12
13
8
Circulating Waterfall
N
7
6
14
Stream
5
4
Ornamental Waterfall Input
3
2
1
0
100m

Figure 5.

Maps of the sediments of the Dow Gardens pond and stream system appear in Figures 6 and 7 and reveal two general types. A highly organic ooze mixed with, or overlain by, organic particles of terrestrial origin (leaf litter), was characteristic of the quiescent water areas. A firmer substrate of clay, with a thin surface layer of fine organic particles, was common in a channel that ran the main course of circulation within the system. It appears that this current is sufficient to prevent the accrual of loose organic sediments in the course of circulation.

The removal of the organic sediments in Areas 12 and 13 exposed an expansive area of primarily inorganic clays. It follows that the removal of these sediments also removed a source of nutrient supply in this system. Under aerobic conditions, clays can provide numerous sites for the adsorption of inorganic plant nutrients (Harter, 1968; 1969; Rosenfeld, 1979; Shulka et al., 1979). The exposure of these unbound adsorption sites could also help to explain the decrease in nutrient concentrations observed in the system from 1978 and 1979.

Fish populations were manipulated in this study to indirectly reduce nutrient cycling between the water and sediments and to increase water transparancy. Visual observations made in 1978 revealed a great abundance of fishes. The codominant species were *Carassius auratus*, goldfish, and

Figure 6. Locations of the loose organic sediments in the Dow Gardens pond and stream system during 1978.

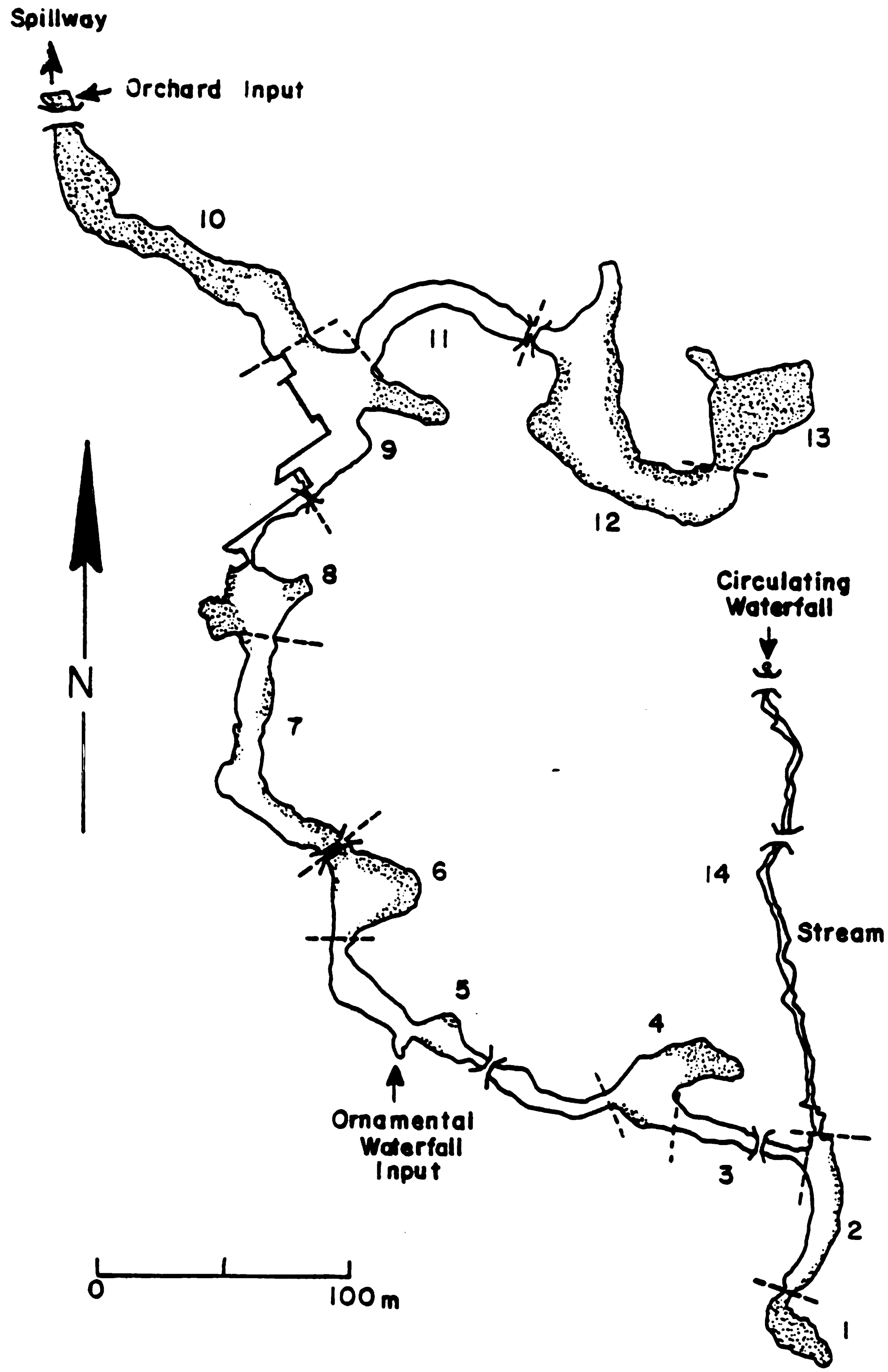

Spillway
Orchard Input
10
11
9
12
13
8
Circulating Waterfall
N
7
6
14
Stream
5
4
Ornamental Waterfall Input
3
2
1
0
100m

Figure 6.

Figure 7. Locations of the loose organic sediments in the Dow Gardens pond and stream system during 1979.

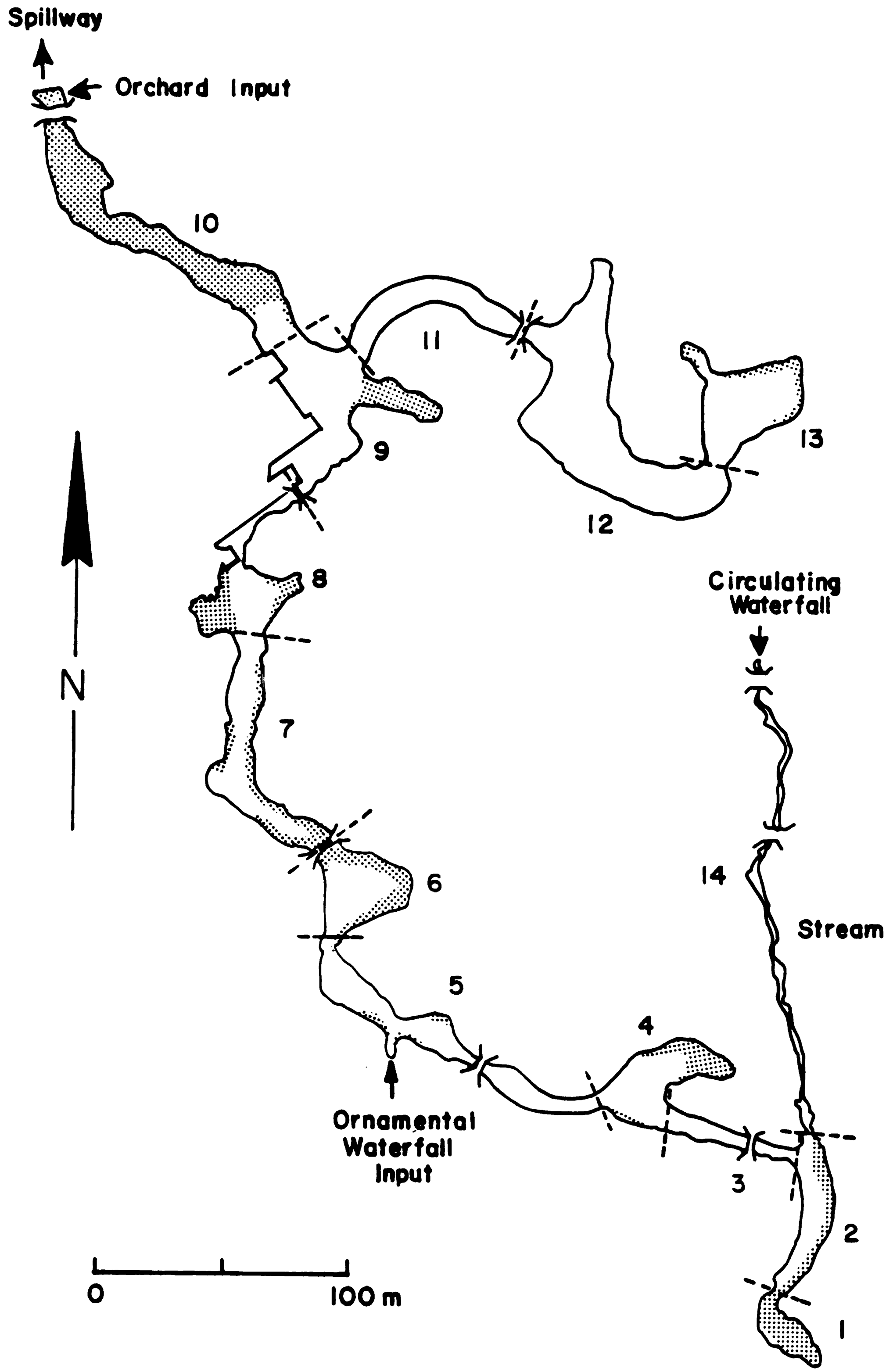

Spillway
Orchard Input
10
11
12
13
9
8
7
6
5
4
3
2
1
14
N
Circulating Waterfall
Stream
Ornamental Waterfall Input
0
100 m

Figure 7.

Ictalurus sp., bullheads. Fathead minnows, *Pimephales promelas,* were also abundant. Adult fish were observed roiling the bottom sediments, thus contributing to the turbidity of the overlying water. Nutrients loosely held by these sediments were likely released to the overlying water by this activity. Furthermore, the digestive activity of fish with similar habits to these species have been found to contribut to the nutrient loading of lakes (Lamarra, 1975). It is likely that the re-suspension of nutrient-rich sediments, and the nutrient loading effect of fish digestion contributed to the overall primary productivity in the pond system by the acceleration of nutrient cycling.

Fish predation can virtually eliminate zooplankton populations from aquatic systems. Zooplankton feed on microscopic organisms and detrital particles that contribute to water turbidity. It follows then that, when fish predatory pressure is such that zooplankton populations are greatly reduced, there is a concominant increase in turbidity in these aquatic systems (Archibald, 1975; Helfrich, 1976; Hrbacek *et al.,* 1961; 1962; Pennington, 1944). The conspicuous absence of zooplankton, the great abundance of fish and a high level of turbidity in the system during 1978 led to the recommendation that fish be removed.

Pro-Noxfish, a rotenone-based piscicide, was infused through the ice, which covered the system, in February 1979. Rotenone-based piscicides have been proven effective in warm waters (Rounsfell and Everhart, 1953; Spitler, 1970), but little attention has been given to its use under ice (Hacker, personal communication). The treatment of Dow Gardens eliminated most of the fish from the system, but was not 100% effective. Bullheads and fathead minnows were present in the system during the 1979 growing season. Pro-Noxfish was applied once more during November 1979. There was a modest recovery of zooplankton populations in the pond and stream system following piscicide application. These data appear in Tables A-10 and A-11.

Zooplankton species that occurred in samples taken in 1979 were principally copepods and rotifers. The reasons for the absence of cladaoceran species is not clear, but may be explained by the predatory activity of the remaining fish or the composition of the phytoplankton or seston on which they feel (Goldman *et al.,* 1979). The return of zooplankton to the pond system was accomplished by an increase in water transparancy.

CONCLUSIONS

Based on the preceding data and the argument that follows, it appears that dredging Areas 12 and 13 and the removal of fish decreased the overall primary productivity of the pond and stream system from 1978 to 1979. The effect was to improve the aesthetic appeal of the system.

The dredging project physically removed an obnoxious stand of aquatic macrophytes and rendered most of Areas 12 and 13 unsuitable for recolonization due to light attenuation at these increased depths. Removal of the fish and the excessive predatory pressures that they exerted permitted a modest recovery in the zooplankton populations. It is likely that the grazing activities of the zooplankton may have diminished some of the turbidity in the pond system. The elimination of fish also prevented the re-suspension of nutrient-rich sediments by their activities.

The overall decline in nutrient concentrations due to the improvement of internal nutrient sinks was also an important factor in limiting of primary production in the pond system. This was accomplished by removing the organic sediment in Areas 12 and 13 and, thereby, exposing inorganic clays to nutrient exchange and adsorption of nutrients in the overlying water.

Evidence that primary productivity was decreased is also found in the relative concentrations of the various nutrient fractions. While all other phosphorus and nitrogen fractions decreased from 1978 tc 1979, total dissolved phosphorus increased in the pond and stream system. It was stated earlier that nitrogen was limiting to photosynthetic organisms relative to phosphorus. This relative limitation was even more acute in 1979. As the nitrogen limitation to the plants increased, there was an accompanying decrease in the amount of phosphorus incorporated into the algae. This incorporated, or fixed, phosphorus is roughly equivalent to particulate phosphorus concentrations. The remaining phosphorus was left to the dissolved pool. Because phosphorus did not decrease at the same rate as nitrogen concentrations relative to the metabolic requirements of the plants, the ratio of total dissolved to particulate phosphorus increased markedly from 1978 to 1979. Because total phosphorus concentrations did not increase but, in fact, decreased during this time, it is very likely that the increase in this ratio is a reflection of decreased algal production in the pond and stream system. This was evidenced by an increase in Secchi disc transparancy measurements from a range of 90 to 110 cm in 1978, to 200 to 270 cm in 1979.

Additional evidence of a decrease in primary production in the pond and stream system is found in the pH data. Comparison of weighted seasonal mean pH values show a decrease of 8.6 to 7.8 from 1978 to 1979. Because aquatic plants are known to elevate the pH of small ponds as a by-product of photosynthesis (O'Brien and de Noyelles, 1972), such a decline in pH could be explained by a reduction in the abundance of aquatic plants in the pond system during this period.

Finally, observations of macrophyte distributions showed a 25% decrease in the percent coverage of the bottom of the pond and stream system from 1978 to 1979.

Deepening by dredging and the removal of an overabundance of fish from the Dow Gardens pond and stream system resulted in an apparent decline in primary productivity which was manifested in a reduction in biogenically-induced turbidity and the density of aquatic macrophytes. The overall effect was a significant improvement in the aesthetic character of the pond and stream system.

LITERATURE CITED

American Public Health Association. 1975. Standard methods for the examination of water and wastewater. 14th edition. APHA, New York.

Archibald, C.P. 1975. Experimental observations on the effects of predation by goldfish (*Crassius auratus*) on zooplankton of a small saline lake. J. Fish. Res. Bd. Canada 32:1589-1594.

Bachmann, W. and R. Jones. 1974. Phosphorus inputs and algal blooms in lakes. Iowa State Journal of Research. 49(2):155-160.

Boling, R.H., E.D. Goodman, J.O. Zimmer, K.W. Cummins, R.C. Petersen, J.A. VanSickle and S.R. Reice. 1975. Toward a model of detritus processing in a woodland stream. Ecology 56:141-151.

Bristow, J.M. 1974. The structure and function of roots in aquatic vascular plants. Mimeo. Manuscript, 23 pp.

Chapin, J.D. and P.D. Uttormark. 1973. Atmospheric contributions of nitrogen and phosphorus. Tech. Rep. 73-2, Water Resources Ctr., Univ. Wisc., Madison. 35 pp.

Chow, V.T. 1964 ed. Handbook of hydrology. McGraw-Hill Book Co. New York.

Cummins, K.W. 1977. From headwater streams to rivers. Am. Biol. Teacher 39:305-312.

Cummins, K.W., M.J. Klug, R.G. Wetzel, R.C. Petersen, K.F. Suberkropp, B.A. Manny, J.C. Wuycheck and F.O. Howard. 1972. Organic enrichment with leaf leachate in experimental lotic ecosystems. BioScience 22:719-722.

Cummins, K.W., R.C. Petersen, G.L. Spengler, G.M. Ward, R.H. King and D.L. King. 1978a. Microbial processing in a first order woodland stream. Oikos.

Fogg, G.E. and W.D. Steward. 1965. Nitrogen fixation in the blue-green algae. Sci. Progr., 53:191-201.

Fuhs, G.W., S.D. Demmerle, E. Canelli and M. Chen. 1972. Characterization of phosphorus limited plankton algae. In Nutrients and Eutrophication. Special Symposia, The American Society of Limnology and Oceanography, Inc. Vol. 1.

Gannon, J.L. 1971. Two counting cells for enumeration of zooplankton micro-Crustacea. Trans. Am. Microsc. Soc. 90(4):486-490.

Goldman, C.R., M.D. Morgan, S.T. Threlkeld, and N. Angeli. 1979. A population dynamics analysis of the cladoceran disappearance from Lake Tahoe, California-Nevada. Limnol. Oceanogr., 24(2):289-297.

Hacker, V. 1978. Personal communication regarding the use of piscicides while ice is covering the surface of treated water bodies, State of Wisconsin, Department of Natural Resources, Oskosh, Wisc.

Harter, R.D. 1968. Adsorption of phosphorus by lake sediments. Soil Sci. Soc. Am. Proc. 32:514-518.

Harter, R.D. 1969. Phosphorus adsorption sites in soils. Soil Sci. Soc. Am. Proc. 33:630-631.

Harvey, H.W. 1975. Chemistry and fertility of sea waters. 2nd edition. Cambridge University Press, Cambridge, England. 234 pp.

Hasler, A.D. 1947. Eutrophication of lakes by domestic drainage. Ecology 28(4):383-395.

Helfrich, L.A. 1976. Effects of predation by fathead minnows, *Pimephales promelas,* on planktonic communities in small, eutrophic ponds. PhD Thesis, Mich. State. Univ., E. Lansing. 59 pp.

Hem, J.D. 1970. Study and interpretation of the chemical characteristics of natural water, 2nd edition. Geological Survey Water Supply Paper 1472. U.S. Government Printing Office, Washington, D.C. 363 pp.

Hrbacek, J. 1962. Species composition and the amount of zooplankton in relation to fish stocks. Rozpr. Cesk. Akad. Ved., Rada. Mat. Prir. Ved. 72:11-116.

Hrbacek, J., M. Duorakova, V. Korinek, and L. Prochazdova. 1961. Demonstration of the effect of fish stock on the species composition of zooplankton and the intensity of metabolism of the whole plankton association. Int. Ver. Theor. Angew. Limnol. Verh. 14:192-195.

King, D.L. 1970. The role of carbon in eutrophication. J. Water Pollut. Cont. Fed. 42:2035-2051.

King, D.L. 1972. Carbon limitation in sewage lagoons. In G. Likens (ed.), Nutrients and Eutrophication, ASLO Special Symp. 1:98-110.

Lamarra, Jr., V.A. 1975. Digestive activities of carp as a major contributor to the nutrient loading of lakes. Verh. Internat. Verein. Limnol. 19:2461-2468.

McRoy, CP., R.J. Barsdate, and M. Nebert. 1972. Phosphorus cycling in an ecosystem. *(Zostera marina* L.) ecosystem. Limnol. Oceanogr. 17:58-67.

Megard, R.O. 1972. Phytoplankton, Photosynthesis, and Phosphorus in Lake Minnetonka, Minnesota. Limnol. Oceangr. 17:68-87.

Mickle, A.M. and R.G. Wetzel. 1978. Effectiveness of submersed angiosperm-epiphyte complexes on exchange of nutrients and organic carbon in littoral systems. I. Inorganic nutrients. Aquat. Bot. 4:303-316.

Mortimer, C.H. 1956. The O_2 content of air-saturated freshwaters and aids in calculating percent sat. Mitt. Int. Ver. Limnol. 620 pp.

O'Brien, J.W. and F. de Noyelles. 1972. Photosynthetically elevated pH as a factor in zooplankton mortality in nutrient-enriched ponds. Ecology 53:605-614.

Odum, E.P. 1971. Fundamentals of ecology. (3rd ed.). W.B. Saunders Co. Philadelphia, PA. 574 pp.

Park, K. 1969. Oceanic CO_2 system: An evaluation of ten methods of investigation. Limnol. Oceanogr. 14:179-186.

Pennington, W. 1944. The control of numbers of freshwater phytoplankton by small invertebrate animals. J. Eco. 29:204-211.

Rice, E.L. and S.K. Pancholy. 1972. Inhibition of nitrification by climax ecosystems. Amer. J. Bot., 59:1033-1040.

Rice, E.L. and S.K. Pancholy. 1973. Inhibition of nitrification by climax ecosystems. II. Additional evidence and possible role of tannins. Amer. J. Bot., 60:691.702.

Rosenfeld, J.K. 1979. Ammonium adsorption in nearshore anoxic sediments. Limnol. Oceanogr. 24(2):356-364.

Rounsefell, G.A. and W.A. Everhart. 1953. Fisheries science: its method and application. John Wiley & Sons, New York. 251-255 pp.

Sawyer, C.N. 1952. Some aspects of phosphates in relation to lake fertilization. Sewage and Industrial Wastes. 24(6):768-776.

Sawyer, C.N. 1954. Factors involved in disposal of sewage effluents to lakes. Sewage and Industrial Wastes. 26(3):317-325.

Shapiro, J. 1973. Blue-green algae: why they become dominant. Science 179:382-384.

Shulka, S.S., J.K. Syers, J.D. Williams, D.E. Armstrong and R.F. Harris. 1971. Sorption of inorganic phosphate by lake sediments. Soil Sci. Soc. Am. Proc. 35:244.249.

Smith, V.H. 1979. Nutrient dependence of primary productivity in lakes. Limnol. Oceanogr. 24(6):1051-1064.

Spitler, R.J. 1970. An analysis of rotenone treatments for elimination of fish populations in southern Michigan lakes, 1957-1967. Michigan Academician. 3(1):77-82.

Steward, W.D.P. 1973. Nitrogen fixation. In N.G. Carr and B.A. Whitten, eds. The Biology of the Blue Green Algae. Univ. of Calif. Press, Berkeley, 260-278 pp.

Truesdale, G.A., A.L. Downing, and G.F. Lowden. 1955. The solubility of oxygen in pure water and sea water. J. Appl. Chem. 5:53-62.

Wetzel, R.G. 1975. Limnology. W.B. Saunders Co. Philadelphia, PA. 743 pp.

Wetzel, R.G. and R.A. Hough. 1973. Producitivty and role of aquatic macrophytes in lakes. An assessment. Pol Arch. Hydrbiol. 20:9-19.

Wium-Anderson, S. 1971. Photosynthetic uptake of free CO_2 by roots of *Lobelia dortmanna*. Physiol. Plant 25:245-248.

Williams, J.D.H., J.K. Syers, R.F. Harris and D.E. Armstrong. 1971. Fractionation of inorganic phosphate in calcareous lake sediments. Soil Sci. Amer. Proc. 35:250-.255.

Yusoff, F. Md. 1979. Crustacean zooplankton of Lake Lansing, Michigan. Master's thesis. Michigan State University. 62 pp.

APPENDIX

Table A-1. Morphometric features of the Dow Gardens pond and stream system, 1978.

Site Number[1]	Area (m^2)	Mean Depth (m)	Volume (m^3)
1	353	0.76	270
2	651	0.99	647
3	409	0.76	318
4	909	1.07	973
5	1180	0.84	991
6	833	1.45	1210
7	1175	0.76	898
8	937	0.76	716
9	1573	0.84	1323
10	1941	0.69	1336
11	731	0.69	503
12	2822	0.91	2589
13	1197	0.69	824
14	371	0.30	111
System Totals	15082	0.82	12709

1. As per Figure 1.

Table A-2. Morphometric features of the Dow Gardens pond and stream system, 1979.

Site Number[1]	Area (m^2)	Mean Depth (m)	Volume (m^3)
1	353	0.76	270
2	651	0.99	647
3	409	0.76	318
4	909	1.07	973
5	1180	0.84	991
6	833	1.45	1210
7	1175	0.76	898
8	937	0.76	716
9	1573	0.84	1323
10	1941	0.69	1336
11	731	0.69	503
12	2822	2.00	5768
13	1197	2.35	2815
14	371	0.30	111
System Totals	15082	1.02	17879

1. As per Figure 1.

Table A-3. Mean surface[1] water temperature, dissolved oxygen concentration, and percent oxygen saturation in the Dow Gardens pond and stream system during 1978.

Date	Temperature (^{o}C)	Dissolved Oxygen (mg O_2 l^{-1})	Percent Saturation (%)
4-12-78	7.8	12.3	109
4-28-78	14.3	12.7	131
5-10-78	12.1	10.9	107
5-24-78	19.3	9.9	114
7-13-78	21.0	7.3	86
7-18-78	21.7	6.9	82
7-25-78	24.9	9.4	119
8-06-78	23.5	9.9	123
8-31-78	20.6	9.6	112
9-11-78	22.0	7.8	99
9-21-78	17.5	8.9	99
10-11-78	11.3	10.4	95
10-18-78	9.0	10.7	96
10-26-78	9.0	11.1	101
11-09-78	7.6	11.4	100
11-21-78	3.5	12.9	103

1. A mean of samples taken from depths from 0.5 m to the water surface at 2 to 8 stations in the pond and stream system.

Table A-4. Mean surface[1] water temperature, dissolved oxygen concentration, and percent oxygen saturation in the Dow Gardens pond and stream system during 1979.

Date	Temperature (^{o}C)	Dissolved Oxygen (mg O_2 l^{-1})	Percent Saturation (%)
1-10-79	2.5	3.3	26
1-31-79	2.0		
2-14-79	1.0	0.8	6
3-05-79	1.5	1.0	
3-29-79	2.8	13.9	100
4-23-79	9.3	16.6	153
5-01-79	10.4	8.2	78
5-15-79	16.8	12.1	132
5-24-79	14.9	10.1	106
5-29-79	13.9	9.0	92
6-12-79	19.8	8.6	99
6-26-79	19.3	9.1	104
7-11-79	22.6	7.4	89
7-25-79	24.3	7.3	91
8-09-79	23.6	9.0	111
8-21-79	19.6	9.0	104
9-13-79	20.0	9.3	108
10-09-79	10.5	8.2	85
10-17-79	10.3	10.5	99
10-30-79	7.0	9.6	83
11-13-79	7.0	11.3	98

1. A mean of samples taken from depths from 0.5 m to the water surface at 2 to 8 stations in the pond and stream system.

Table A-5. Water temperature, dissolved oxygen concentration and percent saturation at 3.0 m depth in Area 12 of the Dow Gardens pond and stream system during 1979.[1]

Date	Temperature (^{o}C)	Dissolved Oxygen (mg O_2 l^{-1})	Percent Saturation (%)
4-16-79	5.0	1.2	10
4-23-79	5.0	1.2	10
5-01-79	6.5	2.1	18
5-24-79	6.5	0.8	6
6-12-79	13.0	1.3	13
6-26-79	16.0	1.2	13
7-11-79	17.0	1.3	14
7-25-79	18.5	0.6	7
8-09-79	19.0	0.2	2
8-21-79	18.0	0.2	2
9-13-79	17.3	2.5	28
10-09-79	11.0	7.4	71
10-17-79	8.7	8.3	75

1. See Figure 1.

Table A-6. pH, alkalinity, and free CO_2 concentrations at 3.0 m depth in Area 12 of the Dow Gardens pond and stream system during 1979.[1]

Date	pH	Alkalinity (mg $CaCO_2$ l^{-1})	Free CO_2 (μmoles CO_2 l^{-1})
7-11-79	7.4	134	276.6
8-09-79	6.8	93	246.4
8-21-79	7.7	113	115.3
9-13-79	8.5	97	15.5
10-09-79	7.9	91	65.8
10-17-79	8.1	92	44.1

1. See Figure 1.

Table A-7. Inorganic nitrogen concentrations at 2.5 m depth in Area 12 of the Dow Gardens pond and stream system during 1979.[1]

Date	Nitrite-Nitrate ($mg\ N\ l^{-1}$)	Ammonia ($mg\ N\ l^{-1}$)	Total Inorganic Nitrogen ($mg\ N\ l^{-1}$)
7-02-79	0.104	0.076	0.180
7-16-79	0.004	0.766	0.770
7-30-79	0.023	0.149	0.172
8-13-79	0.000	0.331	0.331
8-27-79	0.000	0.052	0.052
9-17-79	0.000	0.057	0.057

1. See Figure 1.

Table A-8. Phosphorus concentrations at 2.5 m depth, in Area 12 of the Dow Gardens pond and stream system during 1979.[1]

Date	Particulate Phosphorus ($mg\ P\ l^{-1}$)	Total Dissolved Phosphorus ($mg\ P\ l^{-1}$)	Total Phosphorus ($mg\ P\ l^{-1}$)
7-02-79	0.042	0.015	0.057
7-16-79	0.047	0.011	0.058
7-30-79	0.070	0.030	0.100
8-13-79	0.105	0.023	0.128
8-27-79	0.059	0.019	0.078
9-17-79	0.045	0.022	0.067

1. See Figure 1.

Table A-9. Some events that were relevant to or that had a significant impact on the water quality of the Dow Gardens pond and stream system during 1979.

Date	Event
2-10-79	A fish toxicant was applied to all areas but Areas 12 and 13 which were drained to facilitate their being deepened at that time. Pro-Noxfish, a sulfoxide-synergized rotenone formulation with 10% active ingredients, was applied through the ice at 15 separate sites. The desired concentration of Pro-Noxfish was 1.69 ppm.
3-22-79	Areas 12 and 13 were filled with water after being deepened to approximately 3.35 m.
3-29-79	Fertilizer was applied to the lawns around the Gardens.
5-10-79	Fifty lbs. of Aqua-Kleen, 2,4-D, were applied to Area 10 for the eradication of *Myriophyllum spicatum*.
6-12-79	Bridge construction over Area 5 was begun. Dams were constructed to permit foundation work. Water was pumped from the south side of the site, over the dams, and into the northern portion of Area 5. This area was very turbid.
7-03-79	Diquat, a contact herbicide, was applied to that pond system in the vicinity of the bridge between Areas 6 and 7 for the removal of a dense growth of *Elodea*. Within days this treatment appeared to have impacted most of the tracheophytes of the entire system severely diminishing these plant populations. Approximate concentrations of Diquat were calculated as follows; near the bridge 4.8 ppm, 1.46 ppm in Area 7, and 0.06 for the entire system.
7-30-79	Bridge construction over Area 5 completed and dams and pumps removed.
8-27-79	Fertilizer was applied to the lawns around the Gardens.
11-24-79	Pro-Noxfish was reapplied at a rate of 2.07 ppm in the pond system.

Table A-10. Zooplankton concentrations in surface samples taken during 1979 from the Dow Gardens pond and stream system.

Species	Individuals Liter^{-1}										
	4-16	5-01	5-15	5-24	6-12	6-26	7-11	7-25	8-07	8-21	9-13
Calanoid Copepods											1
Cyclopoid Copepods	1	1	3	12	11	2	2	1	1	4	2
Harpacticoid Copepods			1								
Copepod Nauupli		1	7	15	8	1	1	2	3	6	8
Bosmina sp.		1									
Chydorus sp.		1									
Daphnia sp.				1							
Asplanchna sp.		1	53			2	2	18	3	4	1
Brachionus sp.				2		2	5	4	3	2	

Table A-10 (cont'd.)

Species	Individuals Liter^{-1}										
	4-16	5-01	5-15	5-24	6-12	6-26	7-11	7-25	8-07	8-21	9-13
Filinia sp.				1	5						
Keratella sp.		67	4	1					1	1	1
Ostracobs	1				1		1	1		1	

Table A-11. Zooplankton concentrations in samples taken from Area 12, at 2.5 m deep, in the Dow Gardens pond and stream system during 1979.

	Individuals Liter^{-1}						
Species	6-12	6-26	7-11	7-25	8-07	8-21	9-13
Calanoid Copepods							4
Cyclopoid Copepods	21	12	4	20	2	8	25
Copepod Naupuli	18	12	2	93	3	27	33
Bosmina sp.			1				
Asplanchna sp.		2		160	14	23	8
Brachionus sp,		3	141	125	6	1	
Keratella sp.		1				2	