1982

Management of a gravel-pit lake system to optimize future water quality

Larry Michael Antosch
Iowa State University

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MANAGEMENT OF A GRAVEL-PIT LAKE SYSTEM TO OPTIMIZE FUTURE WATER QUALITY

Iowa State University PH.D. 1982

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Management of a gravel-pit lake system
to optimize future water quality

by

Larry Michael Antosch

A Dissertation Submitted to the
Graduate Faculty in Partial Fulfillment of the
Requirements for the Degree of
DOCTOR OF PHILOSOPHY

Administrative Department: Civil Engineering
Interdepartmental Major: Water Resources

Approved:

In Charge of Major Work

For the Major Department

For the Graduate College

Iowa State University
Ames, Iowa

1982

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INTRODUCTION

The availability of surface waters for beneficial uses is a concern to man in many parts of the United States. In areas where natural surface waters are scarce, man has either impounded water or has relied on the groundwater resource. The extraction of construction materials in alluvial river valleys usually produces surface mine lakes which can serve as an important surface water resource, either while they are active or after they are abandoned. These resources are being used as a source of water for many beneficial uses which include: municipal and industrial water supply, irrigation of agricultural crops and golf courses, power production and places for outdoor recreational activities. The City of Ames, Iowa utilized one such resource, the nearby Hallett Quarry gravel-pit lake system, as a supplemental water supply during a period of severe drought. Consideration is now being given by the City to incorporate it into the permanent, long-term water source development plan to help meet the future water supply needs for the community.

The Hallett Quarry gravel-pit lake system and its associated watershed is located in central Iowa (Section 22, T84N, R24W, 5th P.M., Franklin Township, Story County) just north of the City of Ames (Figure 1). It is an active sand and gravel extraction operation which was started in 1956 by the Hallett Construction Company of Crosby, Minnesota. Before extraction began, this land was generally low lying and marshy, being part of the South Skunk River flood plain (drainage area 816 sq km, 315 sq mi). As a result of the sand and gravel extraction, three gravel-pit lakes have been produced (Photo 1). Presently, there are 32.5 hectares (80 acres)

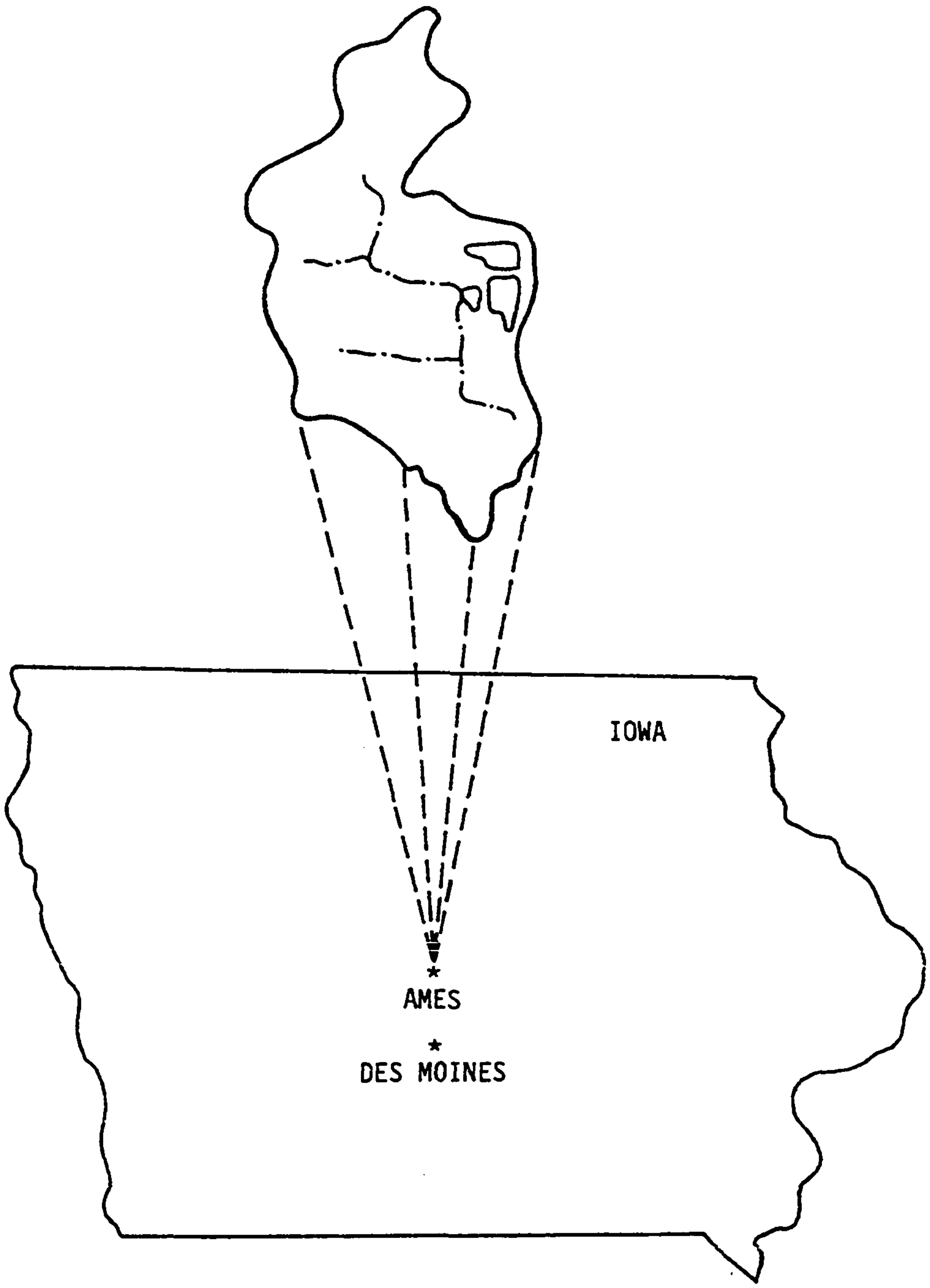


Figure 1. Hallett's Quarry watershed, located in Story County, Iowa

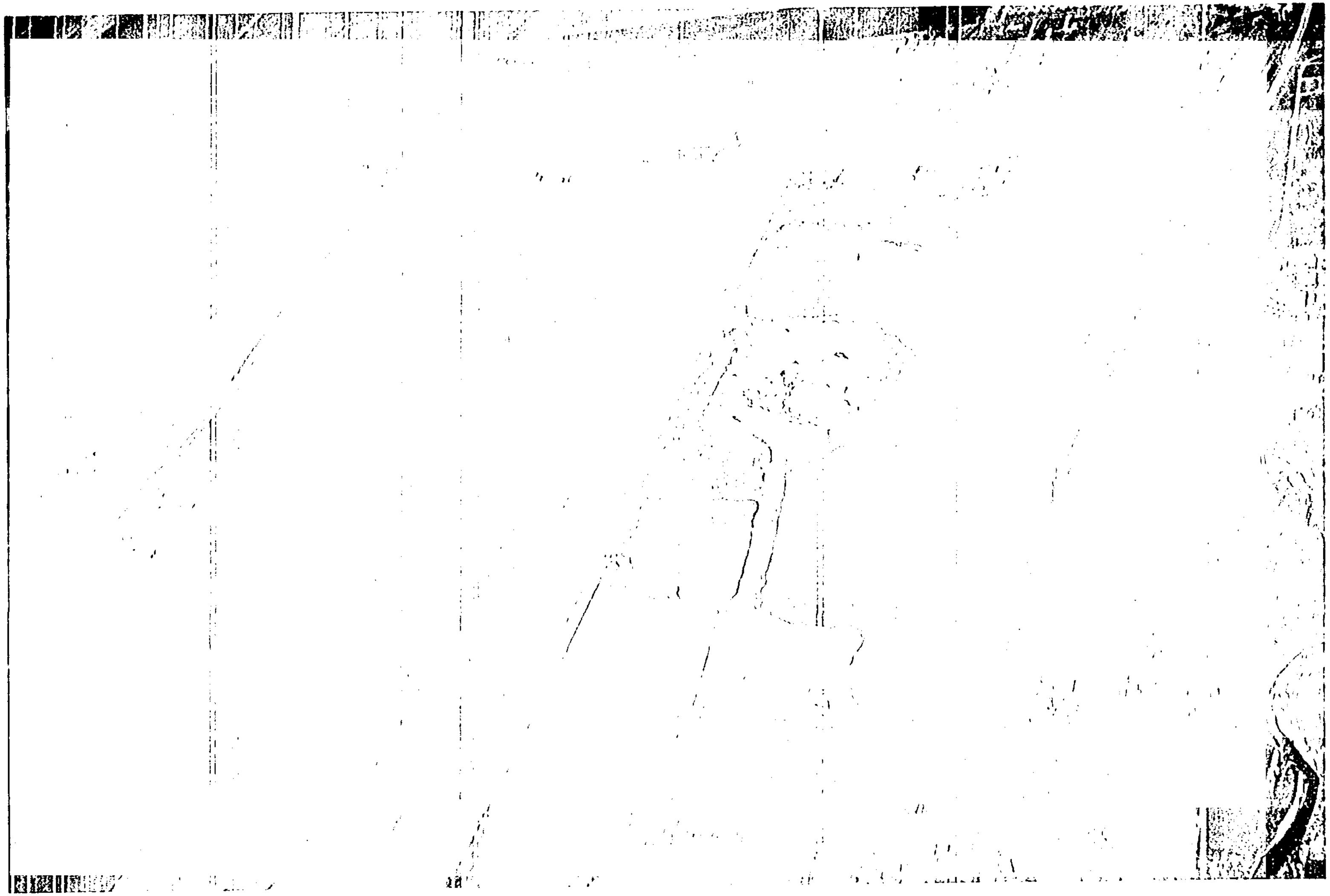


Photo 1. Aerial perspective of the Hallett Quarry gravel-pit lake system

of surface water, with a maximum depth of 15.2 meters (50 feet). At some future time when extraction is complete, the Hallett Construction Company envisions a single lake with approximately 65 hectares (160 acres) of surface area (Steve Beach, Geologist, Hallett Construction Company; Personal Communication).

Central Iowa experienced a severe drought in 1976 and 1977. A water shortage developed in the City of Ames as a result. Ames obtains its water from wells drilled into a surficial aquifer consisting of a buried channel covered by glacial till, but interconnected with the alluvial valleys of the South Skunk River and Squaw Creek. This system is recharged primarily by the South Skunk River along the northeastern edge of the city near 13th Street and to a lesser extent by Squaw Creek to the west and south. The streamflow of the South Skunk River and Squaw Creek was reduced as a result of the drought and as the rivers dried up, the recharge of the system ceased. As well pumping continued, the groundwater levels dropped to a depth of several feet below streambed. Eventually, the water levels in the municipal wells dropped almost to the level of the pump bowls, and the rate of water withdrawal had to be reduced. By late June 1977, it became necessary to implement an emergency drought relief plan.

The implemented relief plan contained several parts, one of which was a groundwater recharge scheme. This scheme consisted of the construction of a temporary low head sand dam, with an impervious plastic membrane facing, across the South Skunk River near 13th Street and the pumping of water from the south gravel-pit lake at Hallett's Quarry into the South

Skunk River. The pumped water flowed downstream, ponded behind the sand dam and successfully recharged and repressurized the City of Ames' municipal well field (Austin and Dougal, 1979).

Drought conditions occurred again in 1980 and 1981, during the course of this study, and once again the temporary low head sand dam was constructed (and reconstructed after it washed out) near 13th Street and water pumped from the south gravel-pit lake at Hallett's Quarry. This recharge scheme maintained adequate water levels in the city wells and induced a recharge rate of 0.08 to 0.14 cms (3 to 5 cfs). From these experiences, the value of the water resource at Hallett's Quarry as a supplemental water supply source to the City of Ames has been fully realized.

After the 1977 drought experience, it became apparent that a water quality and quantity management plan was needed for the Hallett Quarry area. One objective of such a plan should be to protect or optimize the future water quality of the Hallett Quarry gravel-pit lake system. Good future water quality is important because several possible future beneficial uses of the Hallett Quarry watershed and gravel-pit lake system are foreseen. One of these is serving as part of the future water supply for the City of Ames. It is because of this possible future use that careful attention must be given to the water quality relationships of the gravel-pit lake system and its watershed.

The purpose of this study is to develop a water quality management plan for the Hallett Quarry gravel-pit lake system. In order to accomplish this goal, the following specific objectives are established:

(1) determine the present water quality of the Hallett Quarry gravel-pit lake system,

(2) quantify the agricultural and urban stormwater pollutant loadings to the Hallett Quarry gravel-pit lake system, since the Hallett Construction Company recently diverted all of the watershed drainage into the gravel-pit lake system,

(3) predict the future water quality of the Hallett Quarry gravel-pit lake system based on various land use, drainage and lake configuration scenarios, and

(4) based on the results of objectives 1, 2 and 3, develop a water quality management plan to protect or optimize the future water quality of the Hallett Quarry gravel-pit lake system.

The water quality management plan developed as a result of this study will serve as a decision aid to the Ames City Council as well as the Planning and Zoning, Parks and Recreation, and Public Works Departments. A future land use policy plan also will have to be developed for this area. This plan should incorporate the results of this study, which is directed to optimizing the future water quality of the Hallett Quarry gravel-pit lake system.

LITERATURE REVIEW

Terminology

As man excavates materials from the earth for his use, he leaves behind depressions. These excavations, called surface mines, can be either wet or dry depending upon their location in relation to the water table. Surface mines located on valley terraces or in the uplands above the water table are usually dry, whereas those extending below the water table are wet and frequently require pumping of some sort to keep the water levels low enough for the extraction equipment to operate. As wet surface mines are abandoned and the pumping stops, the water table is re-established and lakes develop. Hutchinson (1957) classifies these lakes as Lake Type 74; lakes in artificial depressions which are produced by the complex behavior of higher organisms.

Names used for surface mines vary widely and are dependent upon the type of material which is being extracted from them. Historically, quarries were called quarpits (Rice, 1955). This term has been changed over time to become either quarry or pit. Quarries are surface mines from which building stone such as marble, granite, slate or limestone is extracted (American Geological Institute, 1976) whereas, surface mines for iron ore, clay, coal or sand and gravel are called pits (American Geological Institute, 1962). The lakes that are created when these surface mines are abandoned acquire the name of the parent mine type. Strip-mine lakes result from extraction operations at surface coal mines, quarry lakes from quarries, gravel-pit lakes from sand and gravel pits, and borrow-pit lakes from clay or dirt borrow pits.

Uses of Surface Mine Lakes

Surface mine lakes are being used for many beneficial purposes in countries around the world. In the Netherlands, for example, sandpits are used for the dumping of waste and sludge, the discharge of sewage water, the storage of drinking water, recreation and nature conservation (Leentvaar, 1973). Numerous oxbow and gravel-pit lakes exist on the flood plain of the Rhine River between Mannhein, Germany and Basle, Switzerland; many are being used for recreation (Jansen et al., 1979). Many borrow-pit lakes have also been created as clay and silt deposits have been used for brick and tile manufacturing. The United States, not being unlike these countries, also makes use of its surface mine lakes, especially in areas where natural surface waters are scarce (Reed, 1975).

The major usage of surface mine lakes in the United States appears to be recreational fishing. Although these lakes usually do not support large thriving fish populations (Lewis and Peters, 1954; Stockinger and Hays, 1960; Bennett, 1967; Gash and Bass, 1973), unusually large fish populations can sometimes be found (Carlander, 1951). The existence of a large population of fish in a surface mine lake is usually due to artificial stocking from nearby rivers as they overflow during flood periods, rather than from natural reproduction. Basin morphometry seems to be the reason for the reduced natural production. The lake basins are usually steep-sided which reduces the littoral zone and shallow areas suitable for fish spawning. This in turn sharply reduces the productivity of the fisheries (Burner and Leist, 1953; Maupin et al., 1954; Bell, 1956; Davis, 1971). It is possible to manage these lakes to provide a good recreational fishery. The State of Nebraska Game and Parks Commission is accomplishing this with the Interstate 80 borrow-pit lakes in the Platte River valley (McCarraher et al., 1974).

The Iowa Department of Soil Conservation (IDSC) reports that the State of Iowa has 1,215 active surface mines (IDSC, 1981). The location of these surface mines is shown in Figure 2 and the material produced from these surface mines is presented in Table 1. The mines are scattered over the state with the majority of them located in the northeastern part of the state and along the interior rivers. This distribution is not surprising since over 90 percent of the surface mines in Iowa produce either limestone, sand and/or gravel and it is in the northeast and along the interior rivers where these resources are found at or near the surface. This makes extraction less costly and economically favorable.

The location of the 625 sand and gravel pits and rock quarries which have a water withdrawal permit from the Iowa Natural Resources Council (INRC) is shown in Figure 3 (INRC, 1981). As can be seen, most of these are associated with the interior river valleys where the natural water table in the valley causes these pits and quarries to be filled with water. A summary of the dominant type of water use authorized by these permits is presented in Table 2. Over 84 percent of the permits are for either dewatering and/or processing water. The remaining permits are for other beneficial uses such as power production, municipal water supply or irrigation.

The City of Spencer in northwest Iowa utilizes a gravel-pit lake along the Little Sioux River as part of its municipal water supply system (Photo 2). Along with shallow alluvial or buried channel wells located on

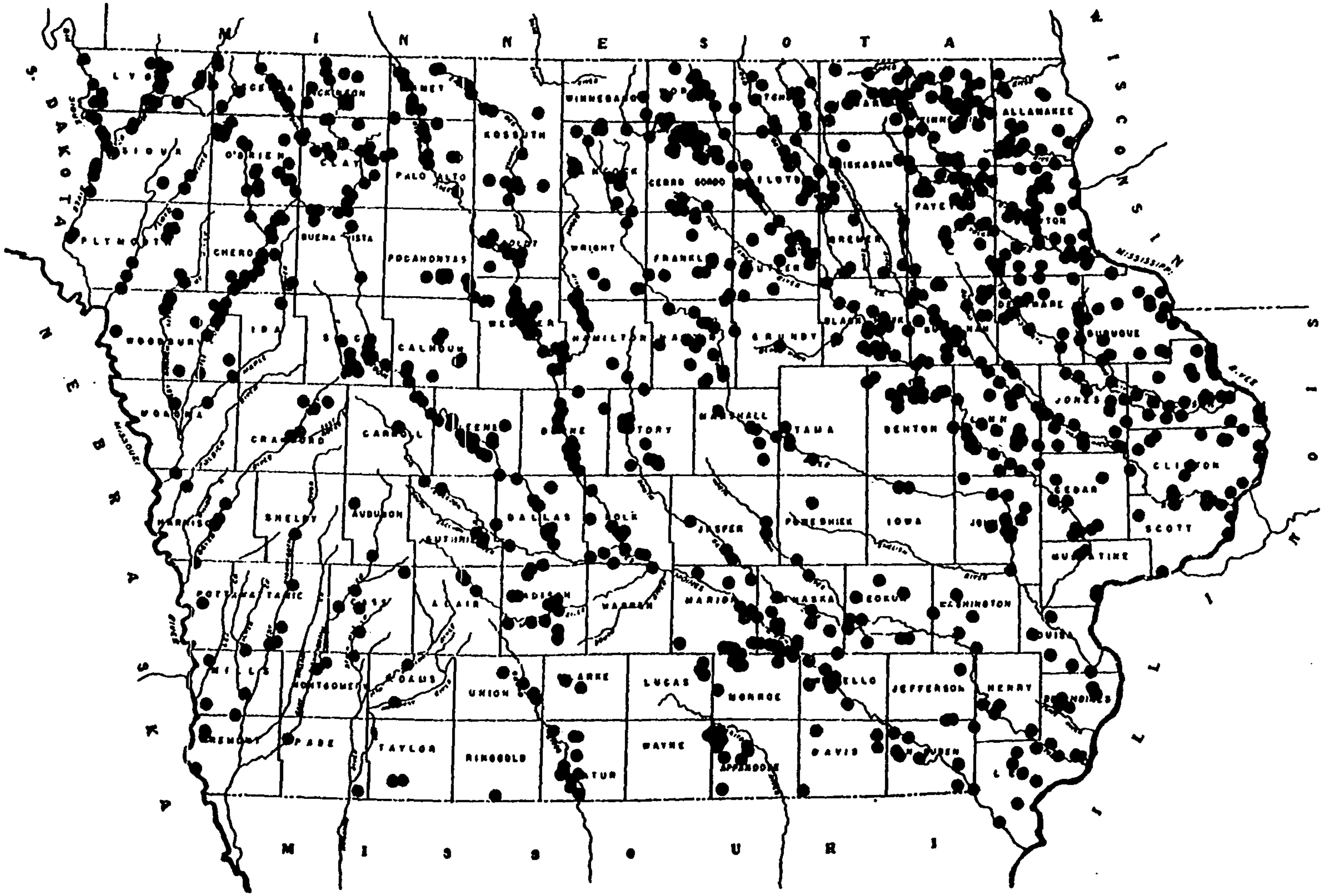


Figure 2. Location of existing active surface mines in Iowa, 1981

Table 1. Summary of material produced and number of sites of surface mines in Iowa, 1981

Material produced		Number of sites
Limestone		490
Gravel		286
Sand and gravel		234
Sand		63
Coal		34
Clay		20
Limestone and gravel		14
Limestone, sand and gravel		14
Gypsum		14
Crushed rock		11
Limestone and sand		10
Gravel and fill dirt		6
Sand, gravel and dirt		4
Clay and shale		3
Fill dirt		2
Clay, gravel and dirt		2
Shale		1
Sand and fill dirt		1
Clay and sand		1
Limestone, clay and gravel		1
Dolomite		1
Clay and gravel		1
Limestone and shale		1
Limestone and clay		1
	Total	1,215

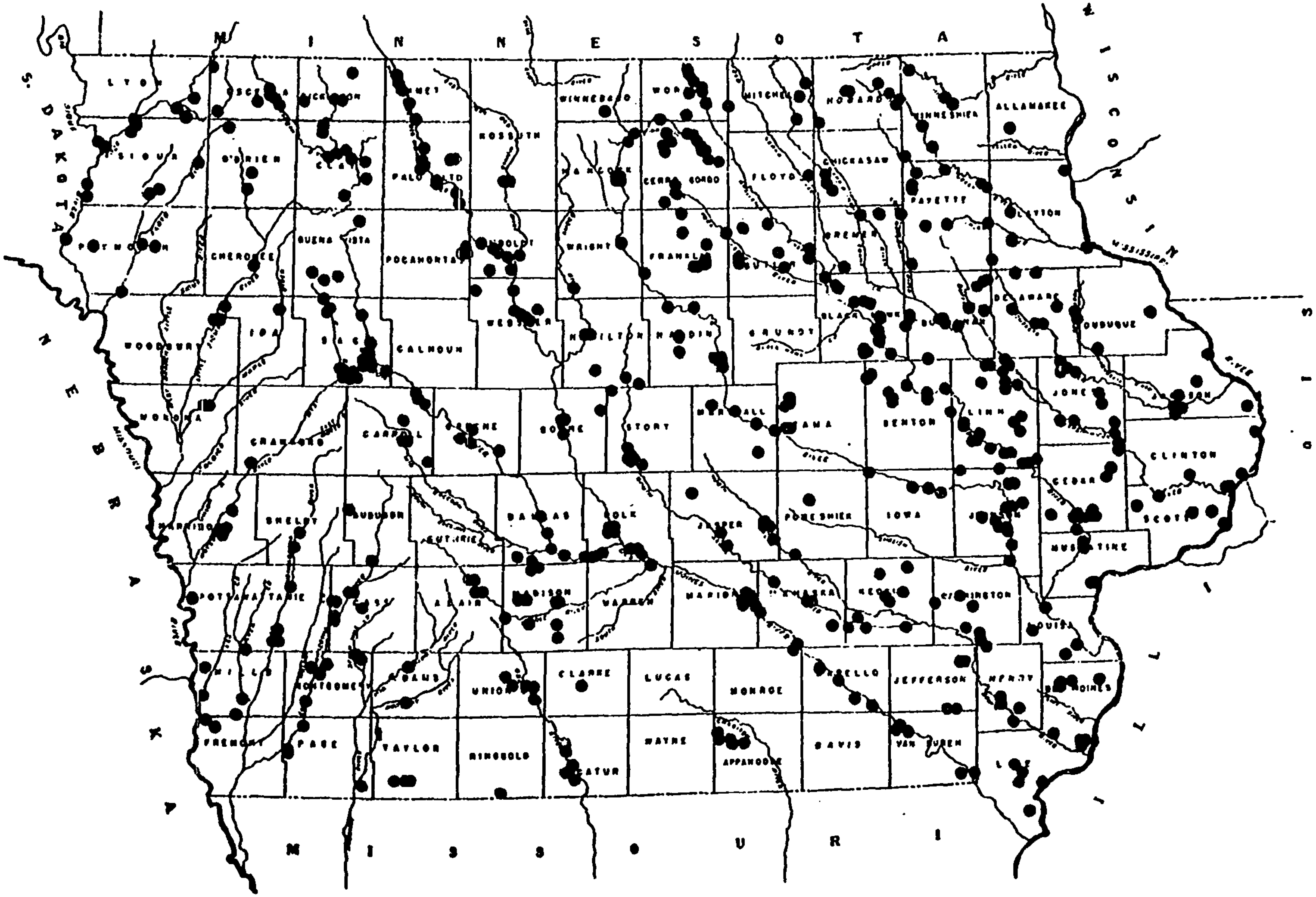


Figure 3. Location of INRC permits authorizing water withdrawal from gravel pit and rock quarries in Iowa, 1981

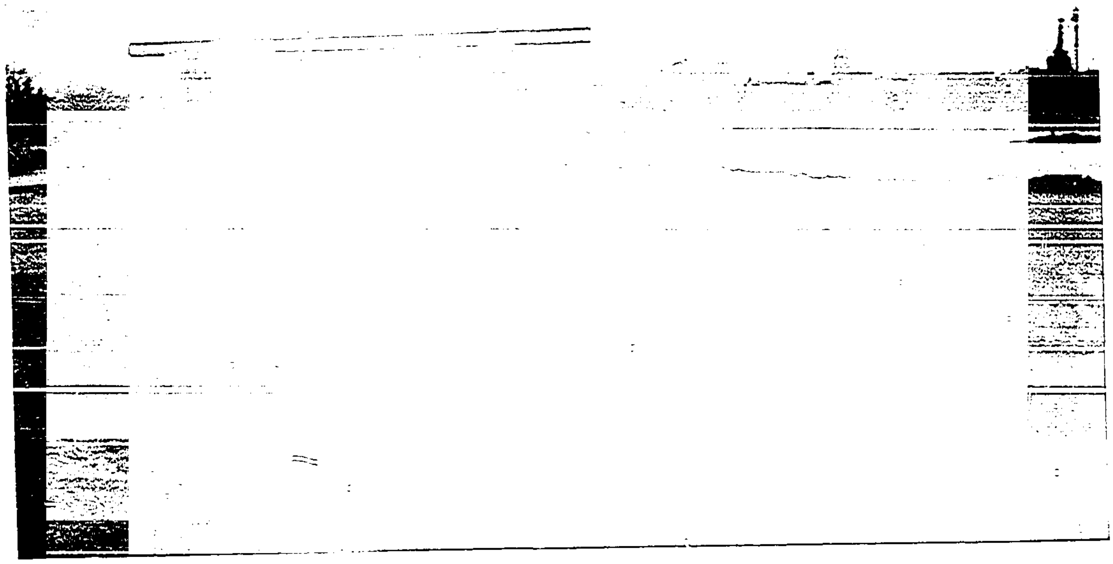
Table 2. Dominant type of water use authorized by the water withdrawal permits at the sand and gravel pits and rock quarries in Iowa, 1981

Water use	Sand and Gravel	Rock	Total
Material production			
Dewatering	28	36	64
Processing	127	94	221
Dewatering and processing	90	148	238
Power Production			
Electrical energy	1	1	2
Irrigation			
General farm crops	82	9	91
Specialty crops	3	1	4
Golf course	3	1	4
Municipal water supply	1	0	1
Totals	335	290	625

outwash terraces, the city has a direct water intake into the gravel-pit lake. This lake is shallow and experiences algal blooms during the summer. As a result, the treated water is warm and usually has a foul smell and taste in the late summer. Because of citizen complaints, the treatment plant must mix the gravel-pit water with the well water to overcome this problem. Interconnections in the raw water lines permit the mixing although most of the new wells were constructed solely for industrial use.

In addition to the withdrawal of water for beneficial uses, the surface water and land areas associated with several of the surface mines in

Iowa are being used for outdoor recreational activities. Examples of this type of usage occur at: Scharnberg Park in Clay County (Photo 3); May City and Ocheyedan Pit Areas in Osceola County (Photos 4 and 5); Gray's and Avon Lakes (Photo 6) in Polk County; Blackhawk Pits in Sac County; the "Old Grand River" quarry in Decatur County and the Peterson Pits in Story County. From the review of the various uses made of surface mine lakes in the State of Iowa, it is evident that in many parts of the state they serve as an important recreational and water resource. Their greatest physical and economic value is in the areas of the state which are lacking natural lakes or constructed impoundments.



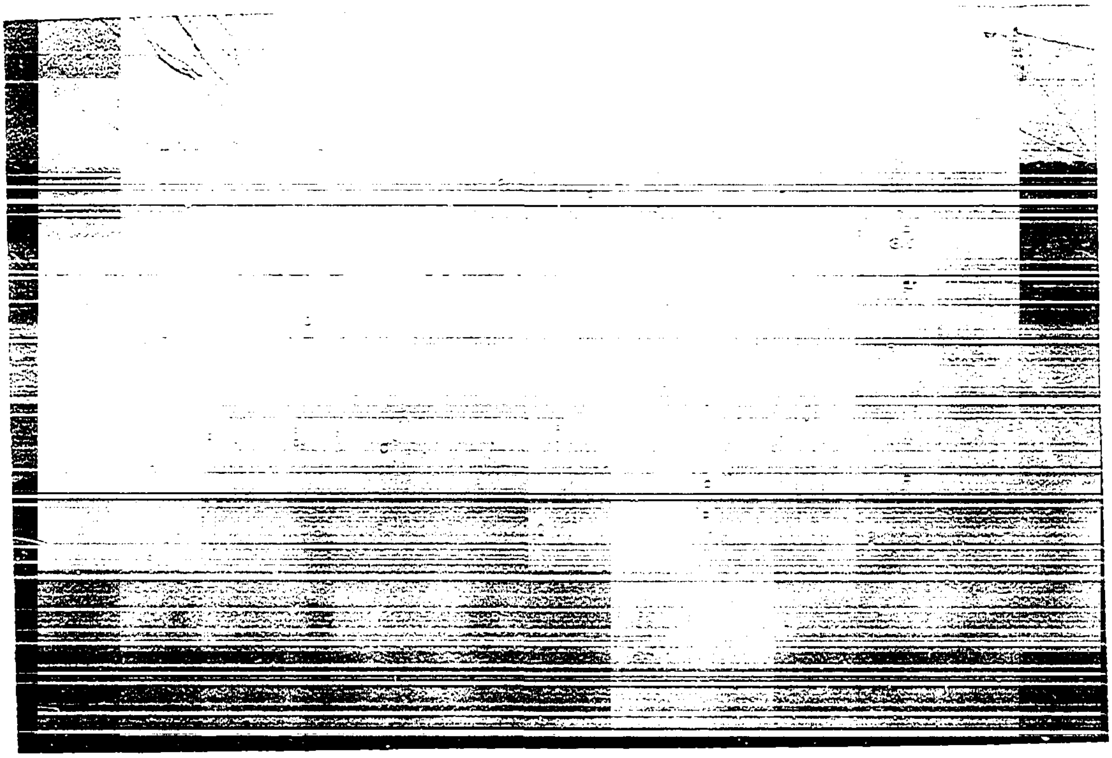
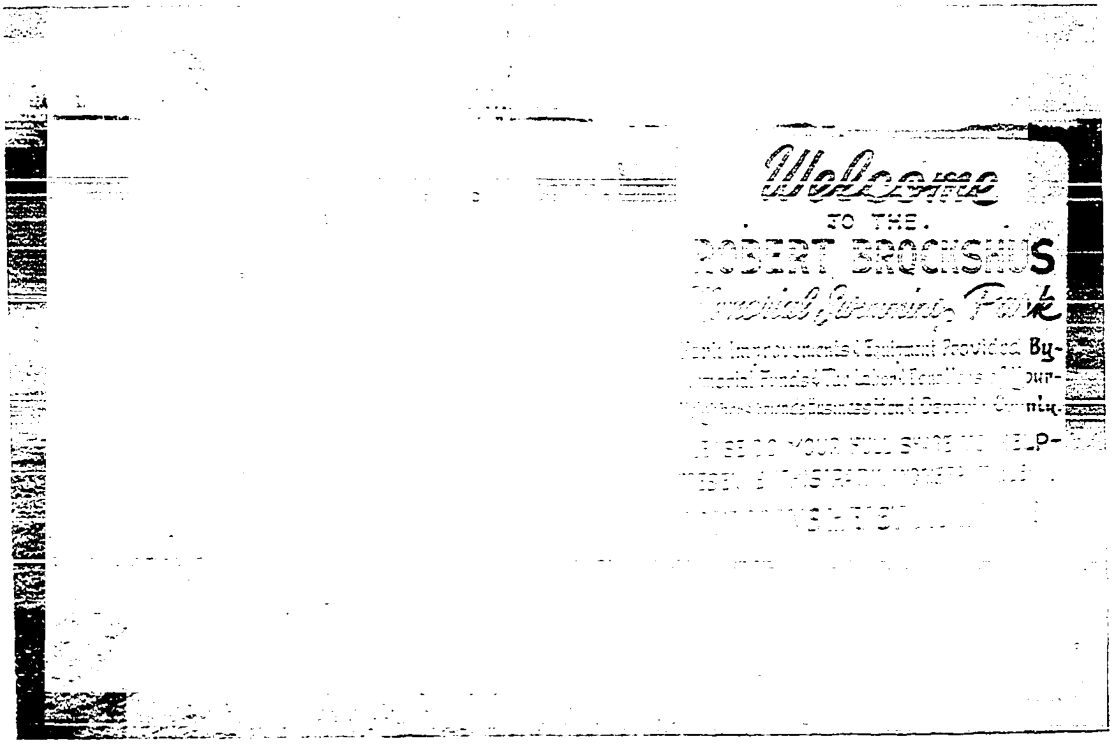
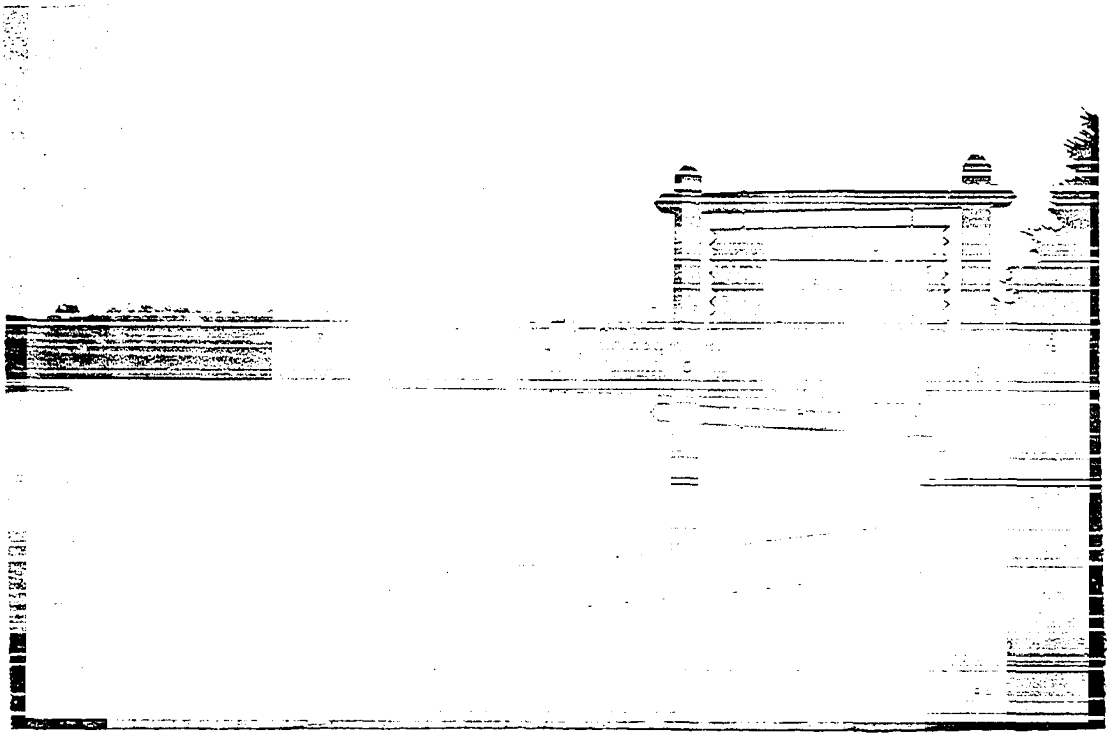


Photo 4. Robert Brockshus swimming area near
May City, Iowa

Photo 5. Ocheyedan Park recreational area near
Ocheyedan, Iowa


Welcome
TO THE
ROBERT BROCKSHUS
Park Improvements & Equipment Provided By-



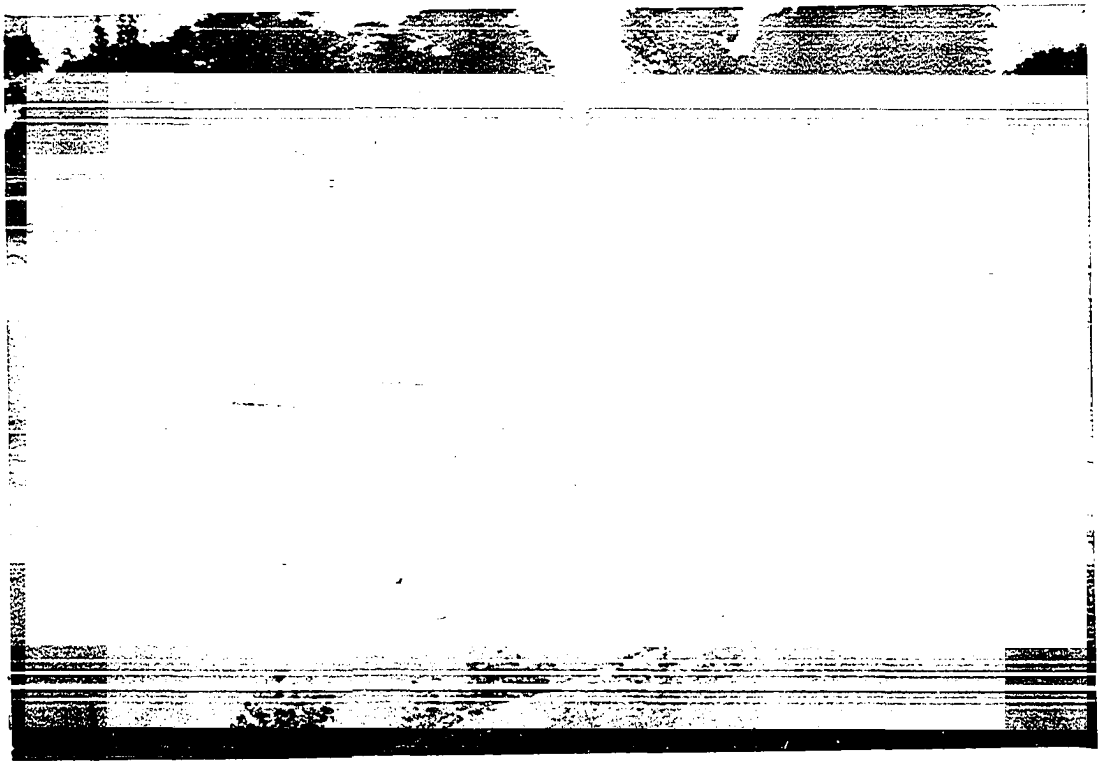


Photo 6. Swimming beach at Avon Lake, Iowa

DESCRIPTION OF THE STUDY AREA

Watershed Boundaries

The Hallett Quarry watershed is located in central Iowa about 0.4 kilometer (0.25 mile) north of the City of Ames (Figure 4). It has a total area of 9.79 sq km (3.78 sq mi). The watershed boundaries are, for the most part, defined by agricultural drainage tiles and city storm sewers instead of the topographic features of the area. The northern boundary of the watershed is defined by the drainage tile of Drainage District No. 65 (Del Jesperson, Story County Engineer; Personal Communication) and the City of Ames' storm sewer defines the southern boundary of the watershed (Arnold Chantland, Director of the City of Ames Department of Public Works; Personal Communication). The eastern boundary of the watershed is defined mostly by US Route No. 69 and it is only the western boundary which is defined by the topographic features of the area.

The original, natural watershed for the Hallett Quarry gravel-pit lake area was much smaller than the present watershed. Most of the drainage which now discharges directly into the gravel-pit lake system once discharged either directly into the South Skunk River through the Dawes Drive culvert, or ponded in a marshy area to the west of the present gravel-pit lake system. This left only a small area immediately adjacent to the gravel-pit lake system which served as a watershed.

Surface Drainage

The natural surface drainage of the Hallett Quarry watershed has been altered initially through farm drainage work and since 1956 by the

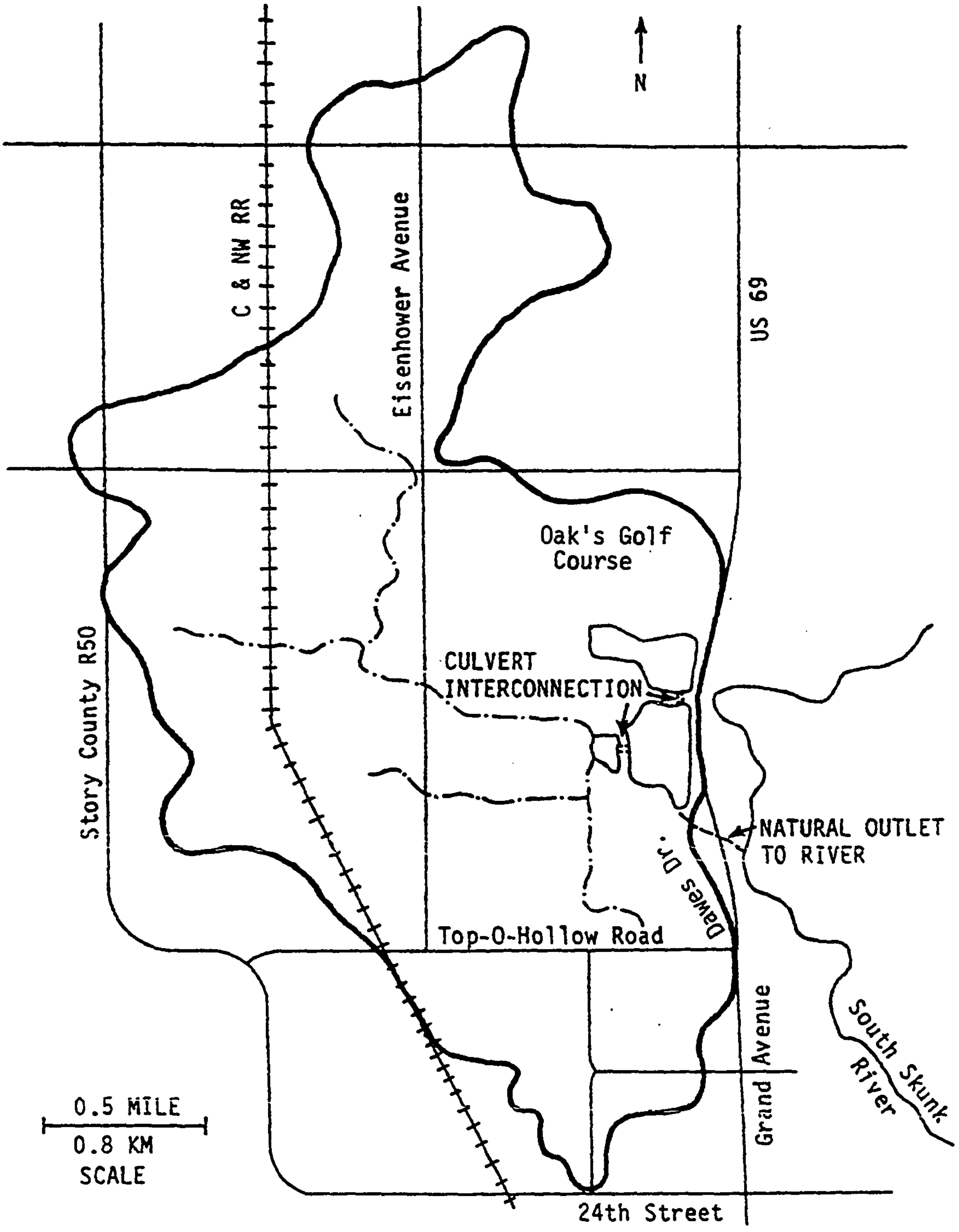


Figure 4. Hallett's Quarry watershed

extraction of sand and gravel.

Originally, the drainage from the northern part of the watershed emptied into a marshy area to the west of the present gravel-pit lake system with only flood overflows reaching the gravel-pit lake system. This drainage now empties into the west gravel-pit lake via a dredged drainage ditch. As gravel extraction operations moved to the south, the natural and modified drainage ways of the southern and western parts of the watershed were destroyed. Instead of bypassing the gravel-pit lake system as it once did through the Dawes Drive culvert system, this drainage now also empties into the west gravel-pit lake. The result of these surface drainage alterations is that stormwater runoff from the northern and western agricultural and southern urban areas of the watershed empties directly into the Hallett Quarry gravel-pit lake system and does not bypass it to the South Skunk River.

Subsurface Drainage

A considerable amount of research has been conducted at Iowa State University on the relationship between the South Skunk River and the groundwater resource at Ames, Iowa (Sendlein and Dougal, 1968; Dougal et al., 1971; Iowa State Water Resources Research Institute, 1973). From these studies, it is apparent that the Hallett Quarry sand and gravel extraction operation lies at the southern end of a buried channel which interconnects it to Peterson's Quarry to the northeast and to the South Skunk River valley to the east and southeast (Figure 5). Because of the interconnection to the South Skunk River, the water levels in the

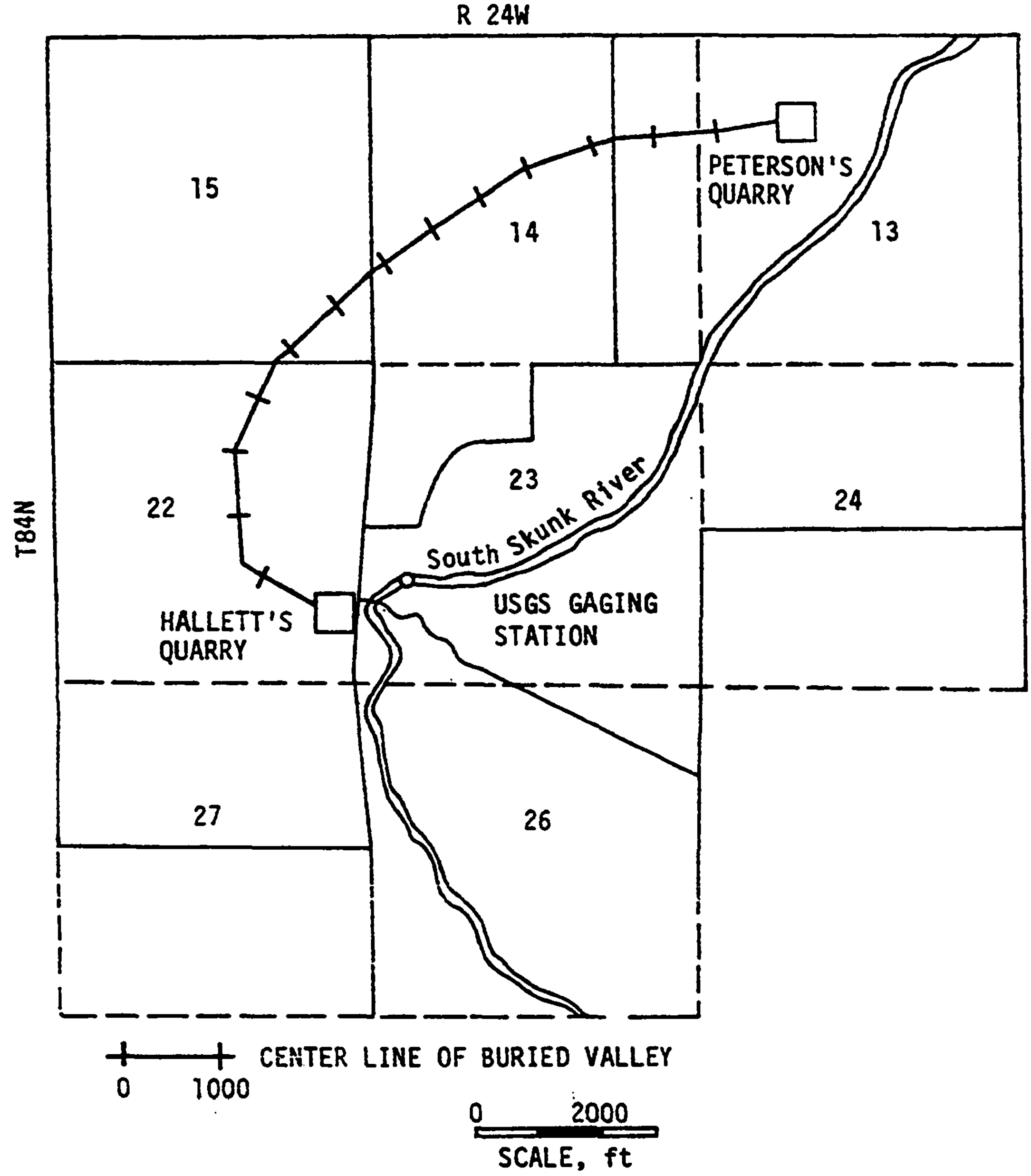


Figure 5. The center line of the buried channel system interconnecting Hallett's and Peterson's Quarries (Redrawn from Sendlein and Dougal, 1968)

gravel-pit lakes at Hallett's and Peterson's Quarries respond to changes in the water level of the South Skunk River. Figure 6 demonstrates this response during a localized flood on the South Skunk River. An increase in the river stage of 2.0 m (6.7 ft) resulted in a 1.2 m (3.8 ft) rise in the water level at Hallett's Quarry and a 0.8 m (2.5 ft) water level rise at Peterson's Quarry, all from groundwater subsurface seepage.

The subsurface interconnection between Hallett's and Peterson's Quarries has also been investigated (Sendlein and Dougal, 1968). In 1968, the main gravel-pit lake at Peterson's Quarry was dewatered dropping the water level in it about 2.4 m (8 ft). Static well water levels prior to pumping and the lowest water levels reached during dewatering were measured and are shown in Figure 7. The profile illustrates the existence of a groundwater "mound" between the two gravel-pit lake systems. Dougal attributed this to either vertical seepage from the overlying glacial till or to upward flow from the underlying bedrock aquifer. It was estimated that as much as 0.06 cms (2.0 cfs) would flow into the Hallett Quarry gravel-pit lake system during periods of excess precipitation.

These subsurface interactions produce a very complex subsurface drainage system for the Hallett Quarry gravel-pit lake system which would be difficult to analyze. The influence of precipitation and infiltration on the groundwater table in the remaining alluvium surrounding the gravel-pit lake system would also have to be considered in any comprehensive water balance analysis. These subsurface interconnections provide additional sources of water for the Hallett Quarry gravel-pit lake system. It would be impossible to raise the lake water levels at Hallett's Quarry without

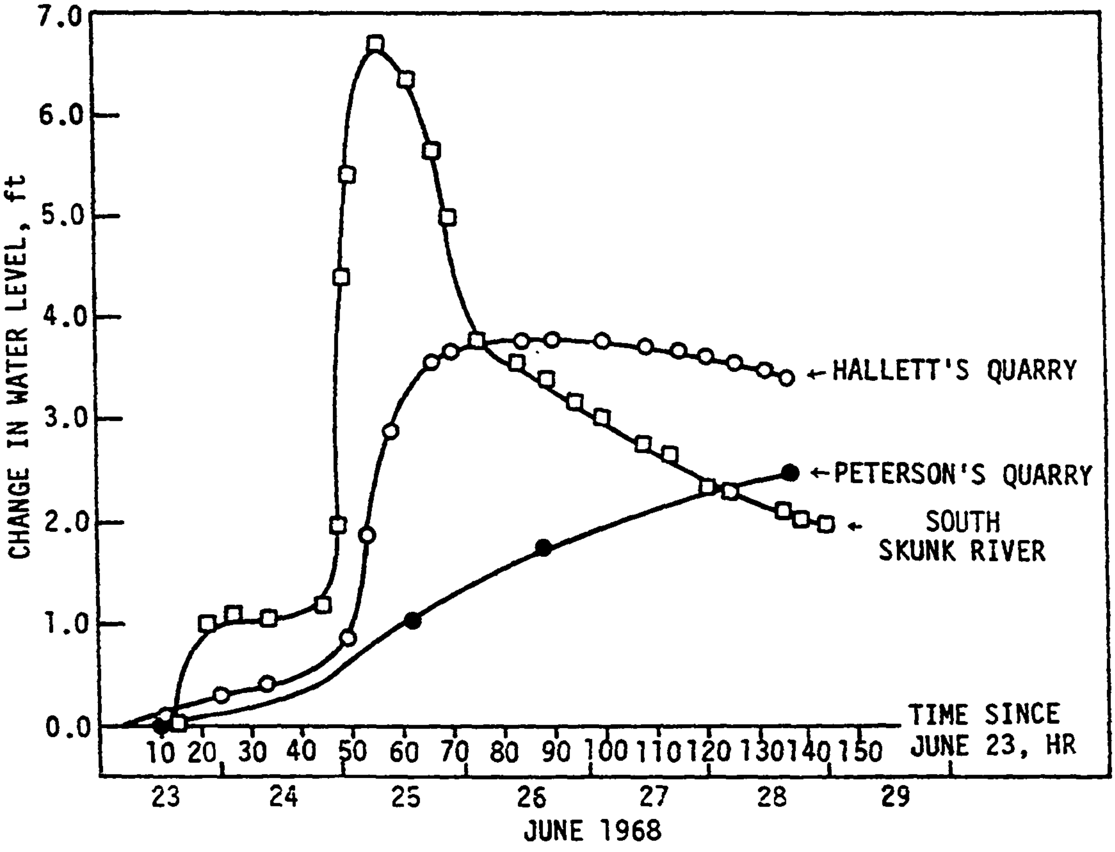


Figure 6. Relative differences in water level response to the flood of June 23-29, 1968
(Redrawn from Sendlein and Dougal, 1968)

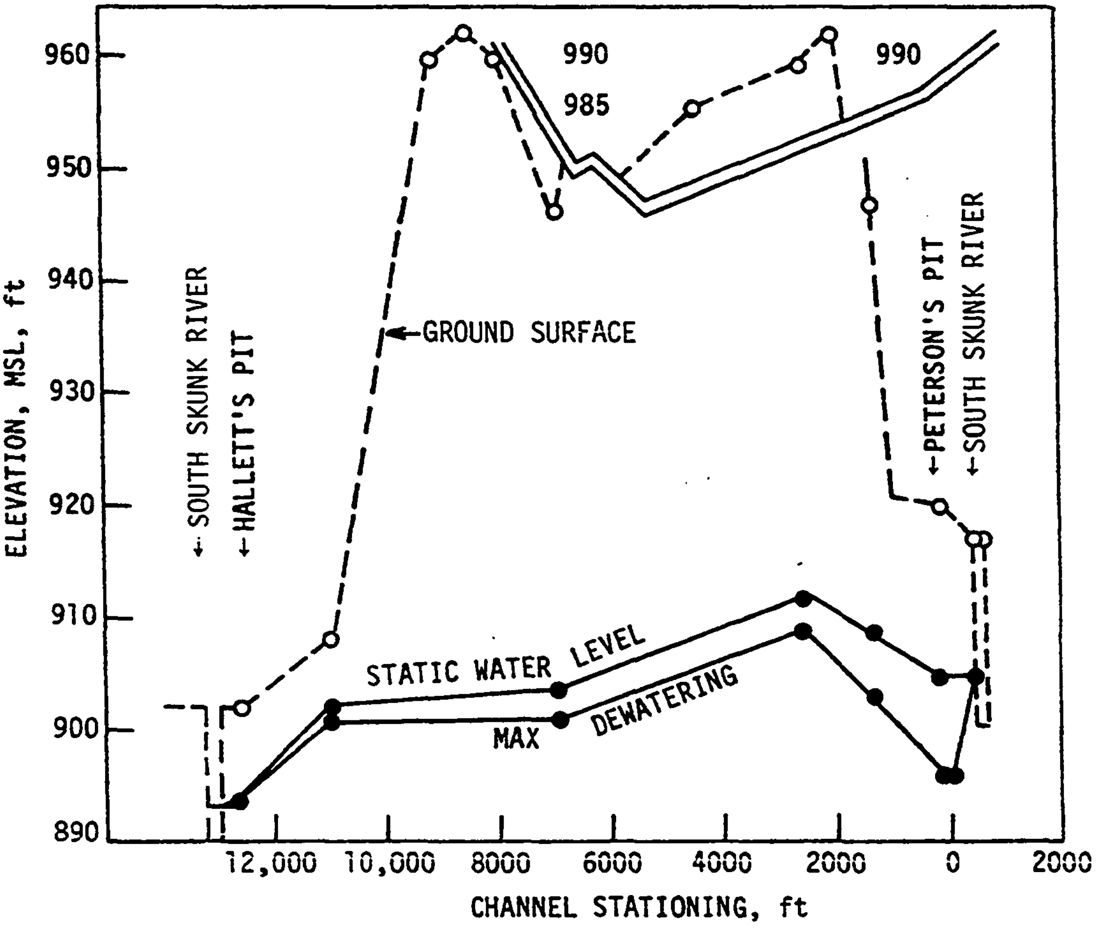


Figure 7. Water level observations, the Peterson Quarry dewatering, May 16-27, 1968
(Redrawn from Sendlein and Dougal, 1968)

first cutting off and sealing these interconnections which would be very difficult and expensive to attempt.

Land Use Inventory

A land use inventory of the Hallett Quarry watershed was conducted by obtaining 1980 aerial photographs of the area from the Story County office of the Agricultural Stabilization and Conservation Service (ASCS). The area of the watershed utilized for row crops (corn or soy beans), pasture, woods, feedlots, golf course, permanent water, land stripped for gravel extraction and storage, rural road and railroad right of way, and urban land uses was determined from these photographs. These values were verified by driving around the watershed.

The results of this inventory are presented in Table 3 and Figure 8. The major portion of the watershed, 73.0 percent, is under agricultural usage (row crop and pasture); urban residential land usage makes up the second major land use of the watershed, comprising 13.6 percent of the total area. The remainder of the watershed, 13.4 percent, is composed of parts of two golf courses, the three gravel-pit lakes, rural roads and railroad right of way, bare soil (feedlots and active gravel extraction and storage areas) and woodlot areas.

The urban section of the Hallett Quarry watershed is primarily the area south of Top-O-Hollow Road. The only urban areas which exist north of Top-O-Hollow Road are a row of houses on the north side of Top-O-Hollow Road, a group of houses west of Grand Avenue between Hallett's Quarry and Top-O-Hollow Road, and a small subdivision immediately west of the Oak's Golf Course. The northerly advancement of Ames' residential

Table 3. Land use in the Hallett Quarry watershed

Land use	Percent of watershed
Row crop	67.2
Urban	13.6
Golf course	6.8
Pasture	5.8
Water	3.1
Rural roads and railroad right of way	2.1
Bare soil[a]	0.8
Woods	0.6

[a] Feed lot and gravel extration and storage areas.

area first crossed 24th Street in the early 1960s and has progressed slowly and steadily to its present state. In the future, it is predicted that the urban area of the Hallett Quarry watershed will double. This increased growth will occur around Hallett's Quarry itself and to the area north of Top-O-Hollow Road from Grand Avenue to west of Eisenhower Avenue. The increase in urbanization is not envisioned to occur rapidly over the next 30 to 40 years unless the economic picture improves greatly.

The subdivision policies of the City of Ames include paved streets and curbs, concrete walks, and adequate storm sewers. Modern stormwater management methods are presently being studied and adopted. As the percentage of impervious area increases, increased volumes of stormwater runoff will be experienced. The rates of runoff will be controlled through stormwater detention.

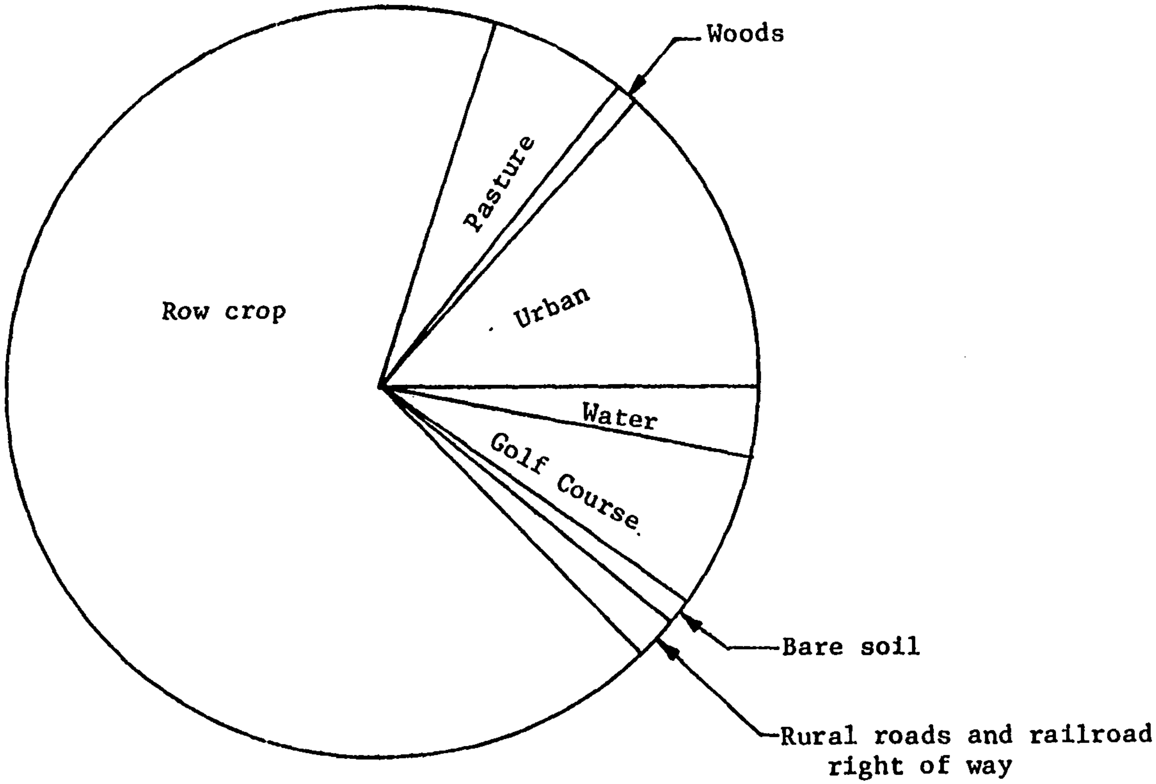


Figure 8. Land use in the Hallett Quarry watershed

LAKE LIMNOLOGICAL INVESTIGATION

Introduction

The south gravel-pit lake at Hallett's Quarry has served as the pump withdrawal point for use as a supplemental water supply for the City of Ames, Iowa in 1977, 1980 and 1981. From these experiences, the value of this water resource to the City has been realized. Data to assess the present water quality of the gravel-pit lake system were lacking, however. A sampling program was established to collect baseline water quality data for the three Hallett Quarry gravel-pit lakes and the west gravel-pit lake at Peterson's Quarry. The Peterson Quarry lake was included in this water quality survey because it lies at the opposite, upstream end of the buried channel that the Hallett Quarry gravel-pit lake system lies. It was of interest to see if any water quality differences exist between these two gravel-pit lake systems. The purpose of this part of the study was to collect baseline data to assess the present water quality of the Hallett Quarry gravel-pit lake system.

Methods and Materials

Sampling method

The limnological investigation of the three gravel-pit lakes at Hallett's Quarry and the west gravel-pit lake at Peterson's Quarry consisted of 29 biweekly sampling trips to the south gravel-pit lake at Hallett's, 15 monthly sampling trips to the north and west gravel-pit lakes at Hallett's and 14 monthly sampling trips to the west gravel-pit lake at Peterson's. The sampling program began in late June, 1980 and ended in late October, 1981. Samples were usually collected between 9 a.m. and 12 noon and were immediately returned to the laboratory for chemical analysis. Field observations and sample preservation were made as necessary at the time of sampling.

One sampling station was chosen at each of the sampled gravel-pit lakes. This station was either located at the "deep hole" or at the deepest part of the lake away from the area of ongoing active dragline gravel extraction.

Water samples were collected in a 2.2 liter nonmetallic, clear acrylic Kemmerer sampling bottle. The collected water was placed in 0.5 liter sterilized polyethylene bottles for bacterial analysis, 1.0 and 2.0 liter acid washed polyethylene bottles for chemical analysis, 4.0 liter rinsed polyethylene bottles for algal pigment extraction and rinsed glass BOD bottles for dissolved oxygen, pH, alkalinity, hardness and turbidity analyses. See Table 4 for a listing of all water quality parameters evaluated in this study.

On each sampling visit, a vertical series of samples for dissolved oxygen and temperature determinations were collected at 2 meter intervals, from the surface to the bottom of the gravel-pit lake. These vertical profiles were used to locate the depth of the thermocline which then served as the depth for the collection of the "mid-depth" chemical sample. Water samples for chemical analyses were collected from the surface, middle and bottom of each gravel-pit lake while water samples for algal pigments were collected at the surface and at the 1 and 2 meter depths. Vertical transparency was determined with a standard 20 cm Secchi disc painted alternately black and white.

Chemical and bacteriological analysis

Upon returning to the university, pH, total alkalinity, total hardness, turbidity and dissolved oxygen analyses were conducted in the sanitary engineering and water resources laboratory. The remaining analyses (total solids, suspended solids, specific conductance, biochemical oxygen demand, chemical oxygen demand, Kjeldahl nitrogen, ammonia nitrogen, nitrite plus nitrate nitrogen, total phosphorus, orthophosphate, chloride, silica, phytoplankton pigments and fecal coliform bacteria) were conducted by the Analytical Services Laboratory of the Engineering Research Institute (ERI-ASL) at Iowa State University.

The ERI-ASL uses the following quality control measures:

1. Replicate Determinations. Usually two or three replicate determinations are made on each sample. Only single determinations are normally made on phytoplankton pigments and chloride.

2. Internal Standardization. All stock solutions of standard solutions are registered in a permanent record book which gives the composition, serial number and date of preparation. Stock solutions and working dilutions prepared from these standards are assigned fixed expiration dates according to written laboratory policy. Storage times range from two weeks for low-range ammonia standards to one year for some heavy metal stock solutions. A few standard solutions are prepared fresh for each use. All tests are standardized each day, usually two or three times during the analysis of a set of samples. As a minimum, standard curves are run before and after each set of samples. All standardizations are documented on the technicians' data sheets, as well as on computer printouts of the calculated results. Standard curves are computer generated by a best fit procedure. Computer printouts serve as documentation for the raw data, the calculated equation and the deviations of the individual points from the curve.

3. External Standardization. Periodically, EPA quality control standards are analyzed as an independent means of checking the accuracy of the laboratory's own standards. The ERI-ASL is certified by the State of Iowa under the provisions of the Safe Drinking Water Act. The maintenance of certification involves periodic on-site inspections by state officials and annual analysis of EPA performance evaluation standards.

Table 4 lists the source and method for the analysis of each parameter analyzed for in the water samples collected from the gravel-pit lakes at Hallett's and Peterson's Quarries.

Statistical analyses

Statistical analyses were performed on the data by using the Statistical Analysis System (SAS) software package at the Iowa State University Computation Center. The univariate procedure was used to reduce the data into a workable form and the *t*-test procedure was used to test for differences in the means of each of the water quality parameters between the four gravel-pit lakes. The use of these procedures greatly reduce the time needed to perform these analyses.

Mapping of lake bottoms

Bathymetric maps for the three Hallett Quarry gravel-pit lakes were prepared during the summer of 1981. The shoreline instrument survey was conducted by locating successive points along the shoreline by simultaneously measuring two angles with two shore located transits. This same procedure was used during the echo sounding of the gravel-pit lakes. The location of the boat with the sonar was determined in this case by simultaneously measuring two angles with the same two shore located transits

Table 4. Method of analysis of water quality parameters

Parameter	Method	Reference
Temperature	Mercury-filled thermometer	APHA, 1976, p. 125
Turbidity	Nephelometric method	APHA, 1976, p. 132
Total solids	Evaporation and weighing	APHA, 1976, p. 91
Suspended solids	Glass fiber filter; nonfilterable residue	APHA, 1976, p. 94
Dissolved oxygen	Azide modified Winkler	APHA, 1976, p. 443
Biochemical oxygen demand	Incubation, 20°C, 5 days, nitrification suppressed	APHA, 1976, p. 543
Chemical oxygen demand	Dichromate reflux	APHA, 1976, p. 500
Specific conductance	Electrometric	APHA, 1976, p. 71
pH	Potentiometric	APHA, 1976, p. 460
Total alkalinity	Potentiometric titration	APHA, 1976, p. 289
Total hardness	EDTA titration	APHA, 1976, p. 189
Kjeldahl nitrogen	Automated phenate method	US EPA, 1979, p. 351.2
Ammonia nitrogen	Automated phenate method	US EPA, 1979, p. 350.1
Nitrite plus nitrate nitrogen	Automated cadmium reduction method	US EPA, 1979, p. 353.2

Table 4. continued

Parameter	Method	Reference
Total phosphorus	Semi-automated block digester AAII colorimetric	US EPA, 1979, p. 365.4
Orthophosphate	Ascorbic acid, molybdate	US EPA, 1979, p. 365.1
Chloride	Potentiometric titration	APHA, 1976, p. 408
Silica	Modified and automated molybdosilicate method	APHA, 1976, p. 487
Phytoplankton pigments	Spectrophotometric determination	APHA, 1976, p. 1030
Fecal coliform bacteria	Membrane filter	APHA, 1976, p. 937

used in the shoreline survey. Welch (1948) describes this procedure in greater detail.

Results and Discussion

Morphological and hydrological features

The morphological and hydrological features of the Hallett Quarry gravel-pit lake system are summarized in Table 5. Bathymetric maps of each of the gravel-pit lakes are presented in Figures 9, 10 and 11. All three of the gravel-pit lakes are similar in their basin characteristics. Their mean depths range from 7.0 to 7.9 meters (23 to 26 feet) and their maximum depths range from 14.0 to 15.2 meters (46 to 50 feet). The ratio of mean depth to maximum depth ($\bar{z}:z_m$) ranges from 0.47 to 0.52 for the three gravel-pit lakes while the volume development index ranges from 1.41 to 1.57. The volume development index compares the shape of the lake basin to an inverted cone with a height equal to the maximum depth and a base equal to the lake's surface area. This value is calculated by the equation:

$$D_v = 3\frac{\bar{z}}{z_m} \qquad (1)$$

where

$\bar{z}$ = mean depth

z_m = maximum depth

A lake volume equal to this hypothetical cone has a value equal to 1.0, a volume greater than this cone has a value greater than 1.0, and a

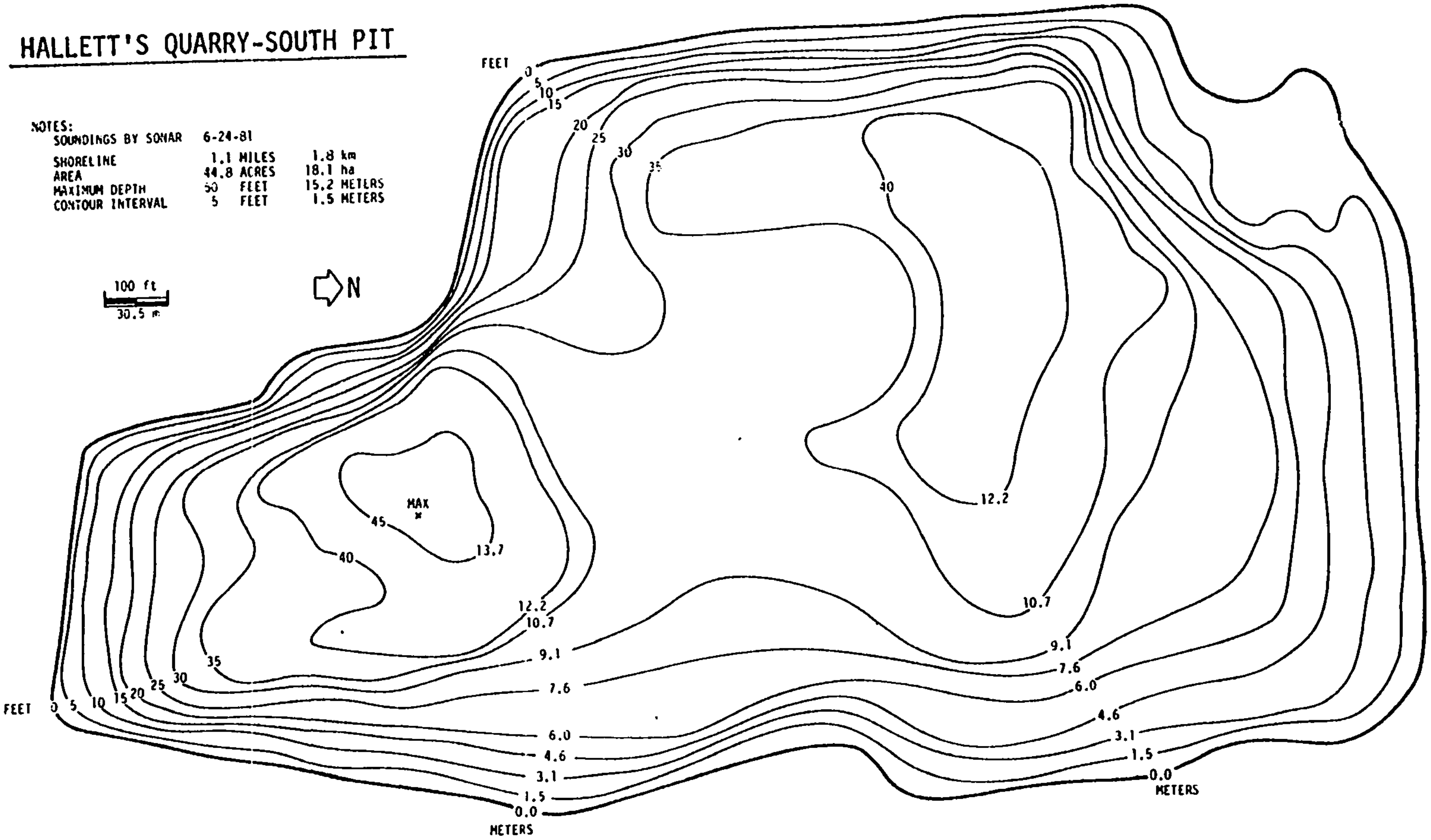
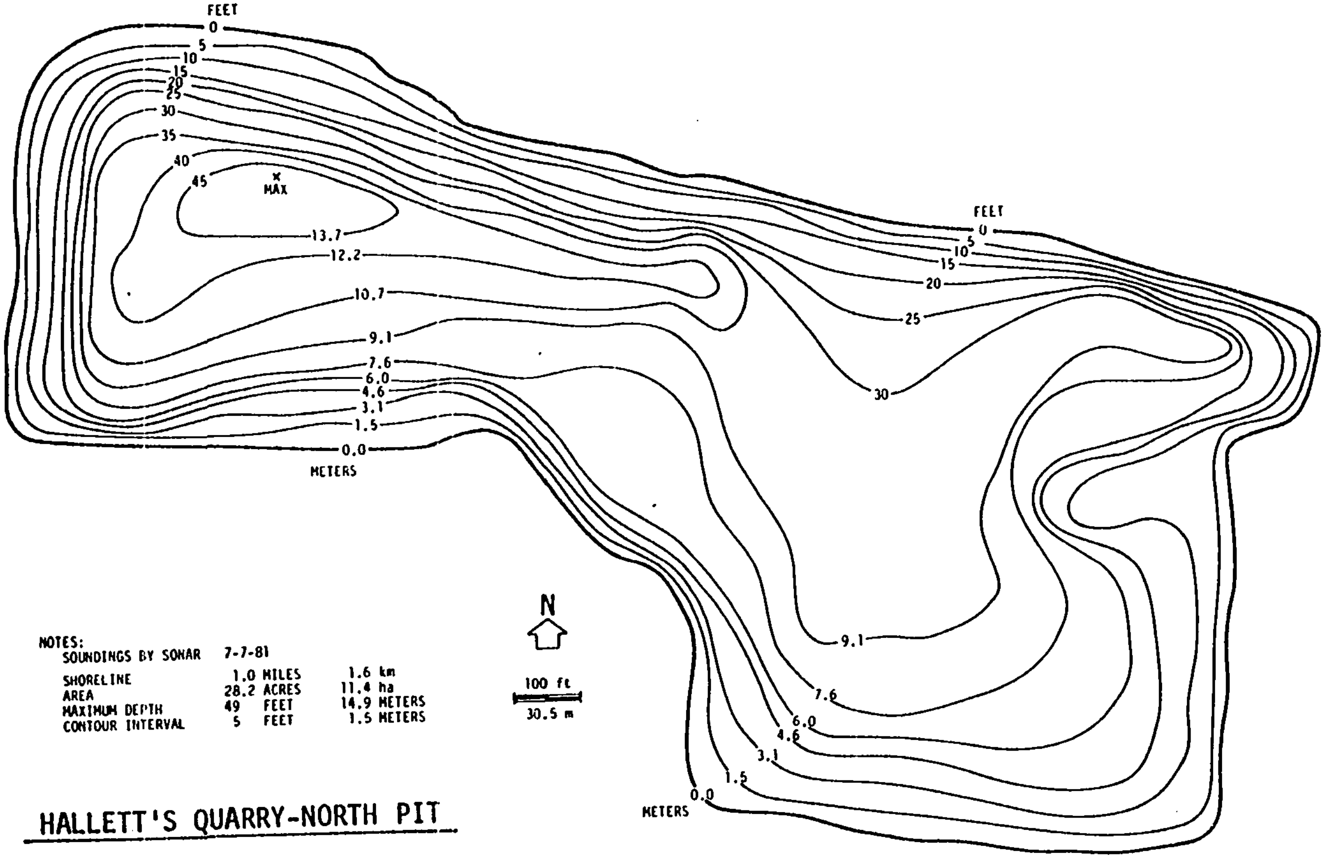


Figure 9. Bathymetric map of Hallett's Quarry-South Pit

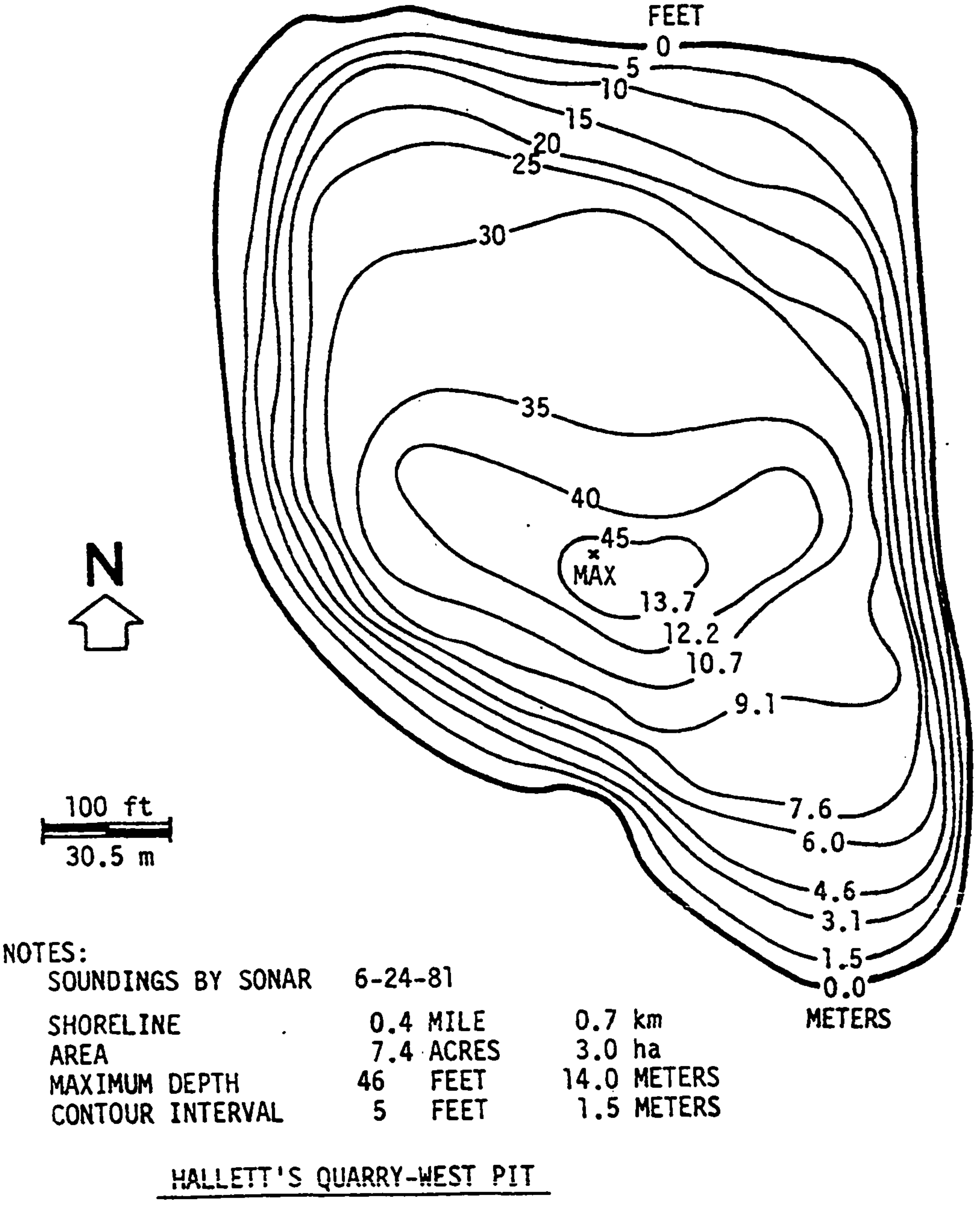


NOTES:

SOUNDINGS BY SONAR	7-7-81	
SHORELINE	1.0 MILES	1.6 km
AREA	28.2 ACRES	11.4 ha
MAXIMUM DEPTH	49 FEET	14.9 METERS
CONTOUR INTERVAL	5 FEET	1.5 METERS

HALLETT'S QUARRY-NORTH PIT

Figure 10. Bathymetric map of Hallett's Quarry-North Pit



NOTES:

SOUNDINGS BY SONAR 6-24-81

SHORELINE	0.4 MILE	0.7 km
AREA	7.4 ACRES	3.0 ha
MAXIMUM DEPTH	46 FEET	14.0 METERS
CONTOUR INTERVAL	5 FEET	1.5 METERS

HALLETT'S QUARRY-WEST PIT

Figure 11. Bathymetric map of Hallett's Quarry-West Pit

Table 5. Morphometric parameters of the Hallett Quarry gravel-pit lakes

	South Pit	North Pit	West Pit
Shoreline	1.8 km 1.1 mile	1.6 km 1.0 mile	0.7 km 0.4 mile
Surface area	18.1 ha 44.8 ac	11.4 ha 28.2 ac	3.0 ha 7.4 ac
Volume	1.42×10^6 m^3 5.02×10^7 ft^3	0.79×10^6 m^3 2.80×10^7 ft^3	0.22×10^6 m^3 0.77×10^7 ft^3
Mean depth ($\bar{z}$)	7.9 meters 26 feet	7.0 meters 23 feet	7.3 meters 24 feet
Maximum depth (z_m)	15.2 meters 50 feet	14.9 meters 49 feet	14.0 meters 46 feet
$\bar{z}:z_m$	0.52	0.47	0.52
Volume developmemt (D_v)	1.56	1.41	1.57
Estimated turnover time[a]	0.38 years 139 days	0.67 years 245 days	0.09 years 33 days

[a] Based on average annual precipitation, average annual runoff and average permeability of the buried channel aquifer (INRC, 1978; Sendlein and Dougal, 1968), assuming all surface runoff discharges into the gravel-pit lake system.

volume less than this cone has a value less than 1.0. Values near 0.5 for the mean to maximum depth ratio and near 1.50 for the volume development index indicate that the three gravel-pit lakes have steep-sided, deep basins (Cole, 1975). This feature is also indicated on the bathymetric maps of each of the gravel-pit lakes by the closeness of the contour lines near shore.

Temperature

Isotherm plots for the Hallett and Peterson Quarry gravel-pit lakes are presented in Figures 12, 13, 14 and 15. The original temperature data are presented in Tables A.1, A.2, A.3 and A.4 in Appendix A. The annual temperature cycle observed in each of the studied gravel-pit lakes is what would be expected for dimictic lakes in the cool temperate regions of the world (Cole, 1975; Wetzel, 1975). Thermal stratification begins in mid to late May and continues through the summer months until late September or early October. Periods of complete mixing occur in the spring and fall. The degree of thermal stratification is weakest in the north gravel-pit lake at Hallett's Quarry, since the deepest part of the lake was not sampled due to active dragline gravel extraction, no absolute conclusion can be drawn. There is an indication that stronger thermal stratification does exist in the deep hole region of this lake since one set of samples was taken there before extraction started in July, 1980. In all four of the studied gravel-pit lakes, the thermocline establishes between the 6 and 8 meter depths.

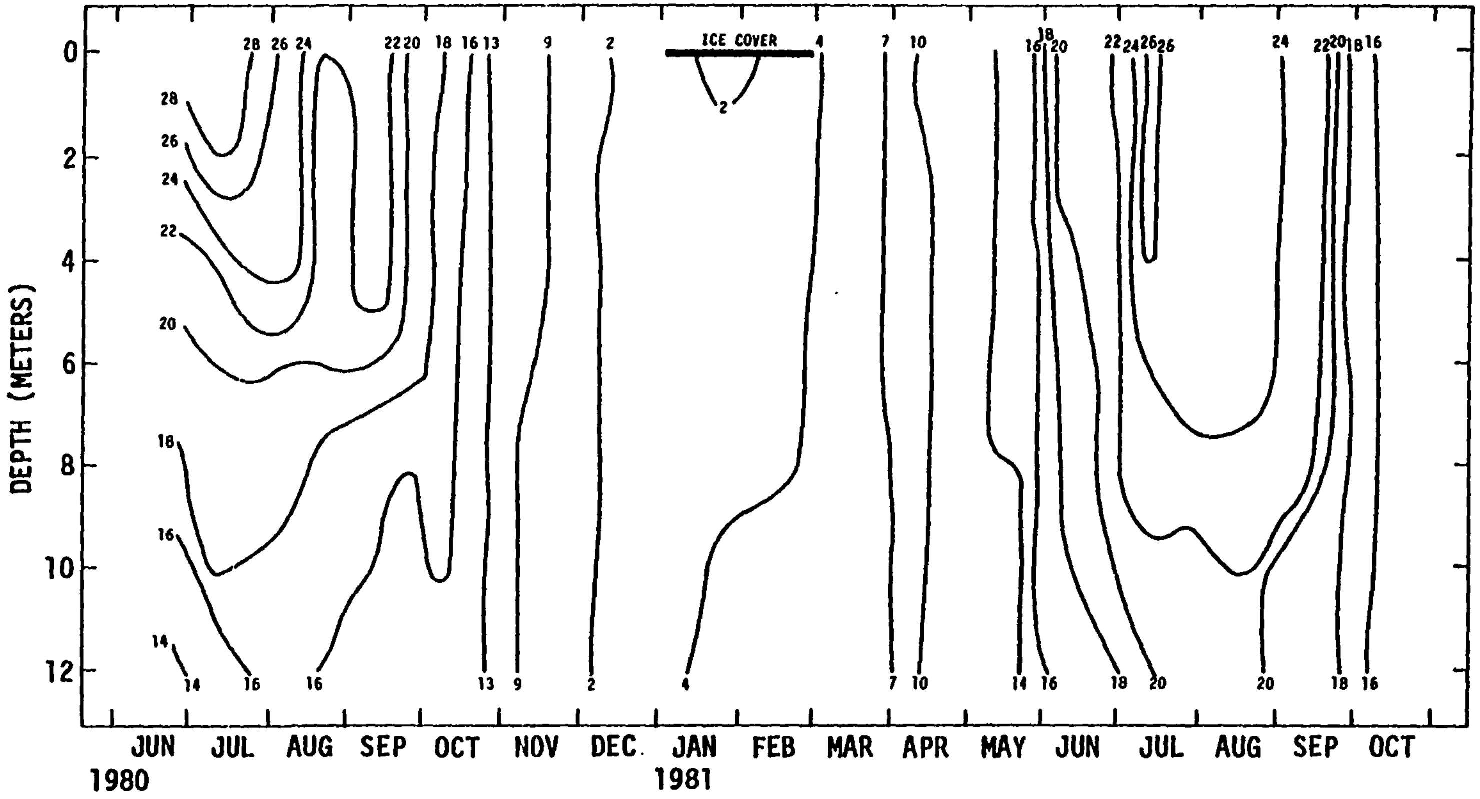


Figure 12. Isotherm plot in °C for Hallett Quarry-South Pit

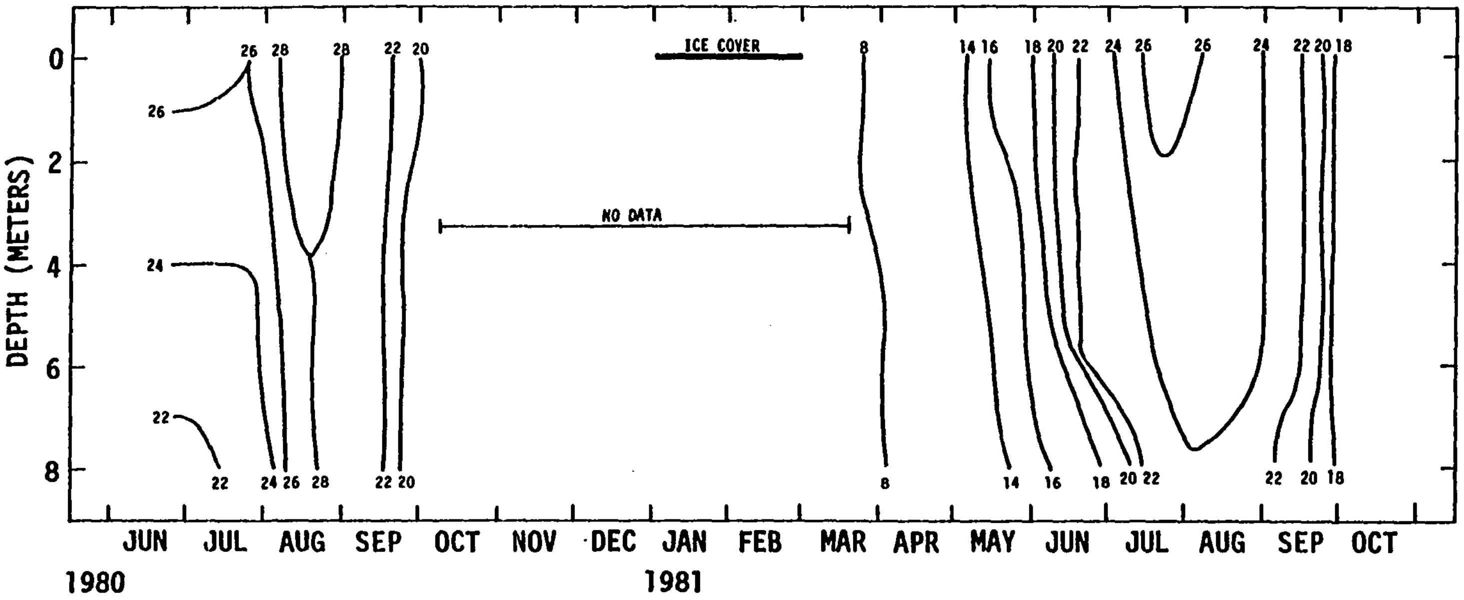


Figure 13. Isotherm plot in °C for Hallett Quarry-North Pit

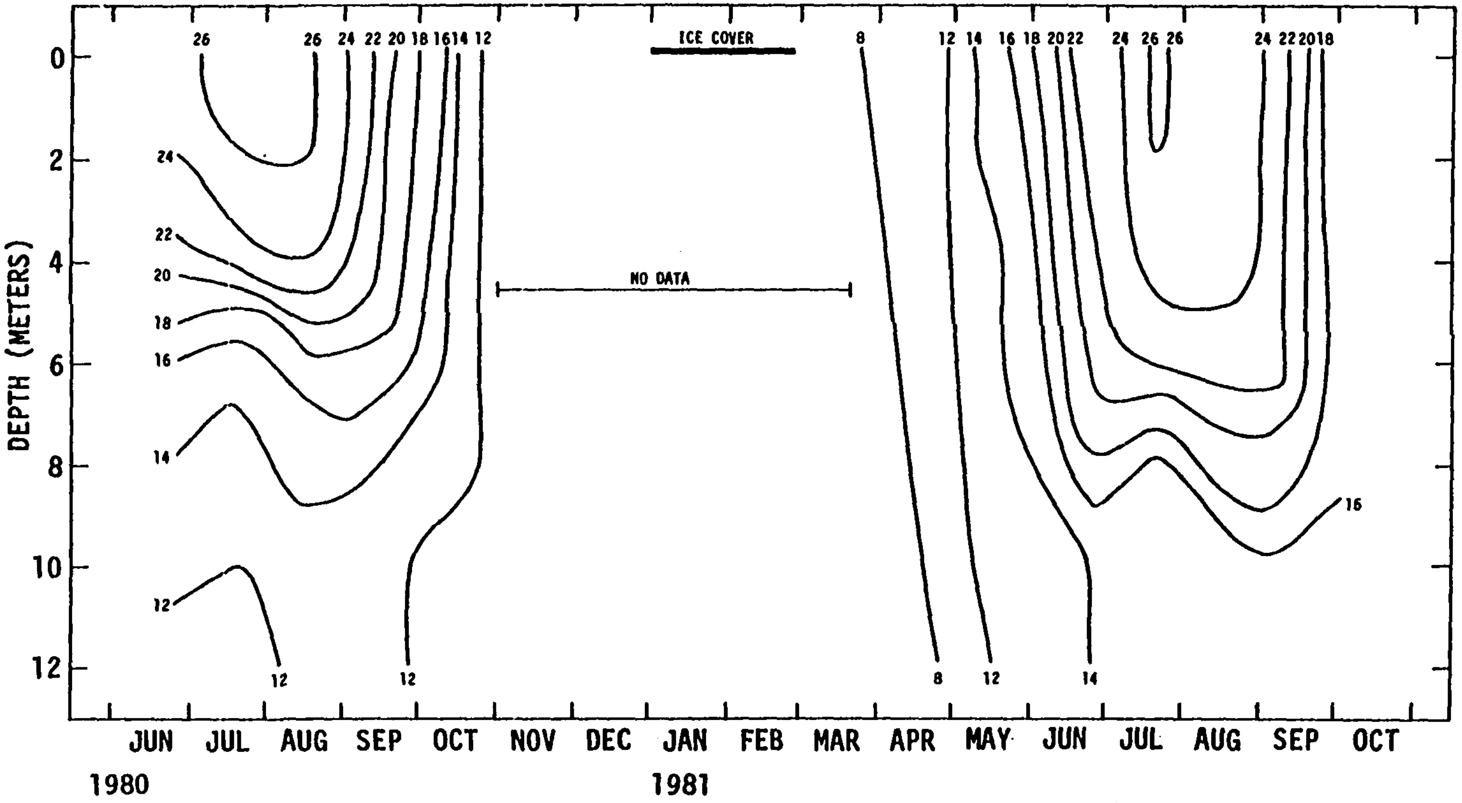


Figure 14. Isotherm plot in ^{o}C for Hallett Quarry-West Pit

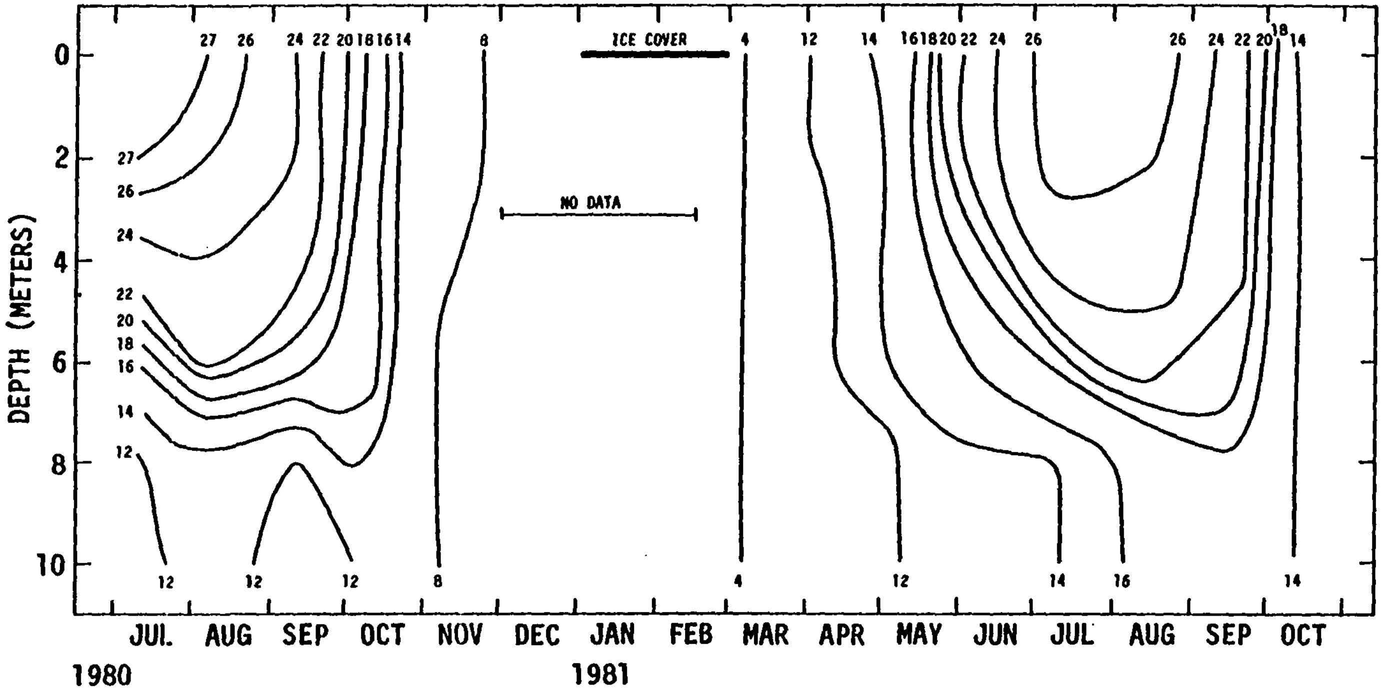


Figure 15. Isotherm plot in °C for Peterson Quarry-West Pit

Dissolved oxygen

Dissolved oxygen isopleth plots for the Hallett and Peterson Quarry gravel-pit lakes are presented in Figures 16, 17, 18 and 19. The original dissolved oxygen data are presented in Tables A.5, A.6, A.7 and A.8 in Appendix A. The annual dissolved oxygen cycle observed in these lakes is what would be expected from dimictic, cool, north temperate, eutrophic lakes (Cole, 1975; Wetzel, 1975). In those lakes which strongly thermally stratify (Hallett-South Pit, Hallett-West Pit and Peterson-West Pit), clinograde oxygen profiles were observed with dissolved oxygen concentrations declining to near zero below the thermocline for most of the summer. In the spring and fall when the lakes were completely mixed, the dissolved oxygen concentrations were uniform from the surface to the bottom of each of the studied lakes.

Water quality

Statistical summaries of the water quality parameters for the Hallett and Peterson Quarry gravel-pit lakes are presented in Tables 6, 7, 8 and 9. The original data for these water quality parameters are presented in Tables A.9 to A.27 in Appendix A. Total phosphorus data are not presented in Tables 6, 7, 8 and 9 because values below 0.2 mg/l as PO_4 could not be accurately determined by ERI-ASL. Several trends are evident in all of the lakes as the depth increases from the surface to the bottom. As the depth increases, the pH decreases; total alkalinity, total hardness, solids, turbidity, soluble silica and orthophosphate increase while the oxidized forms of nitrogen (nitrite and nitrate) decrease and the reduced

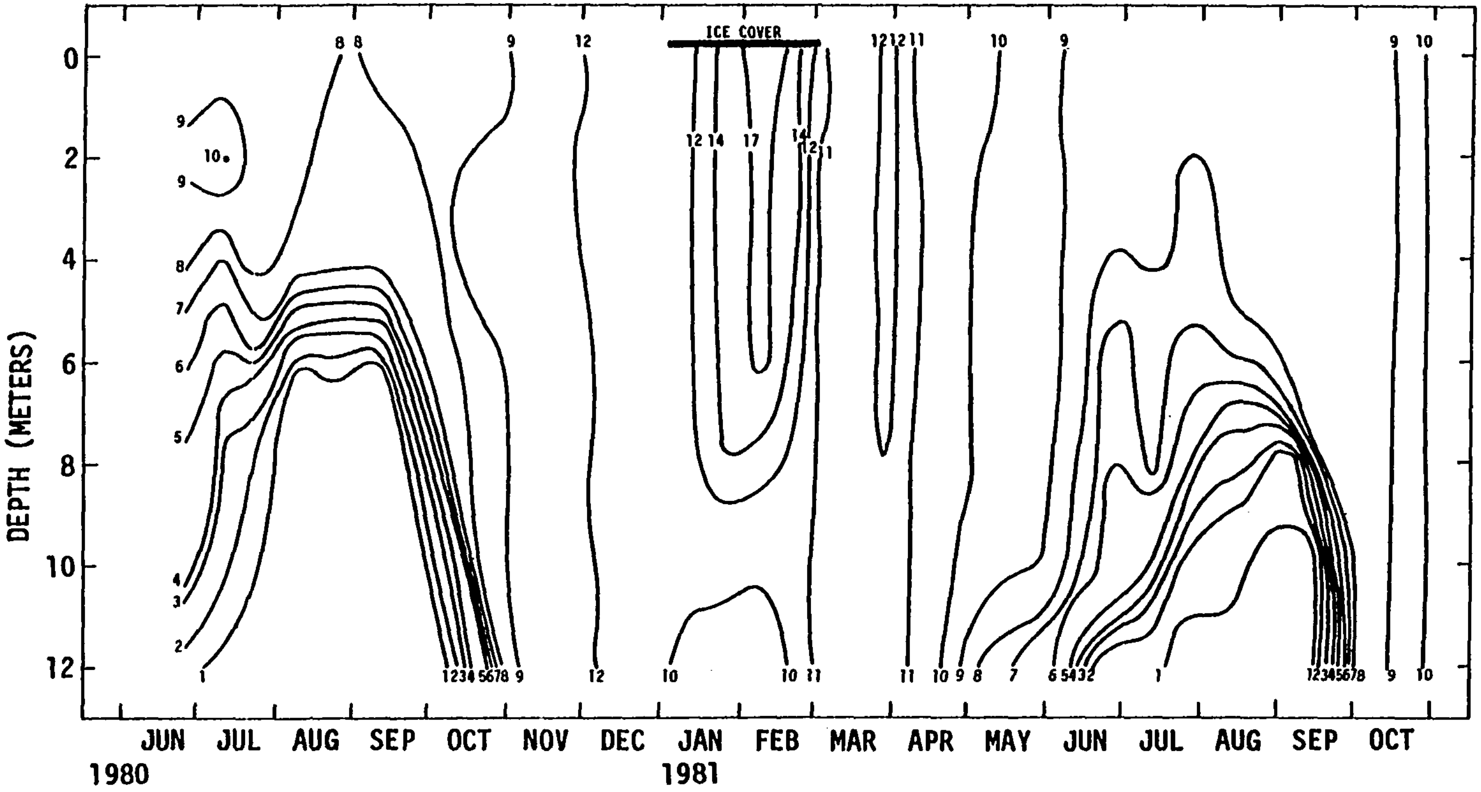


Figure 16. Isopleths of dissolved oxygen in mg/1 for Hallett Quarry-South Pit

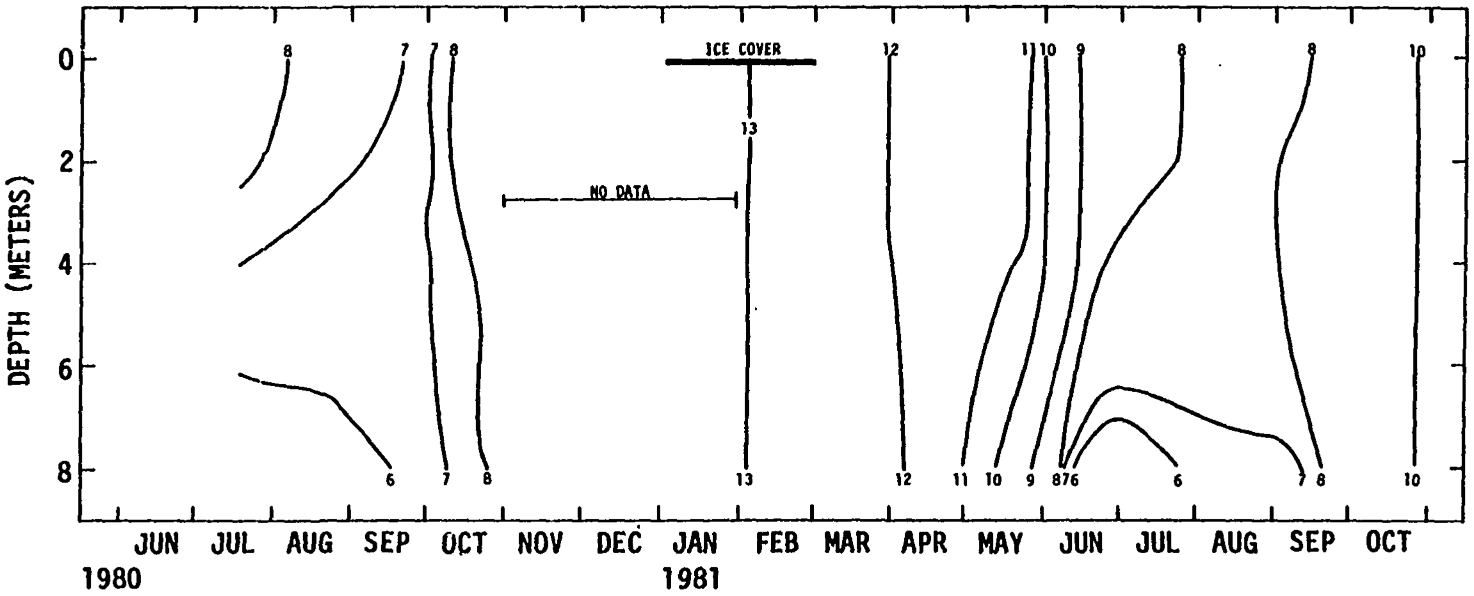


Figure 17. Isopleths of dissolved oxygen in mg/l for Hallett Quarry-North Pit

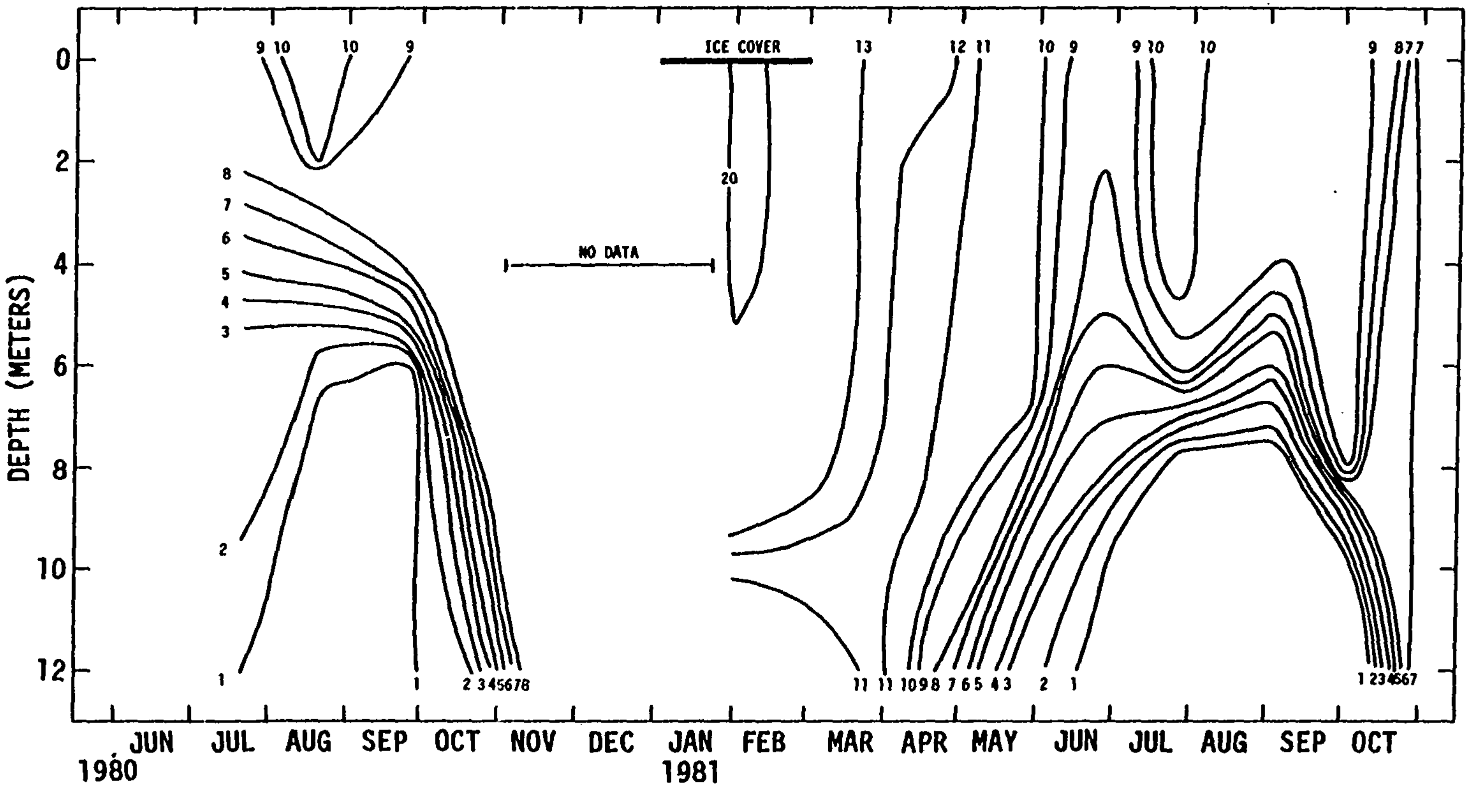


Figure 18. Isopleths of dissolved oxygen in mg/l for Hallett Quarry-West Pit

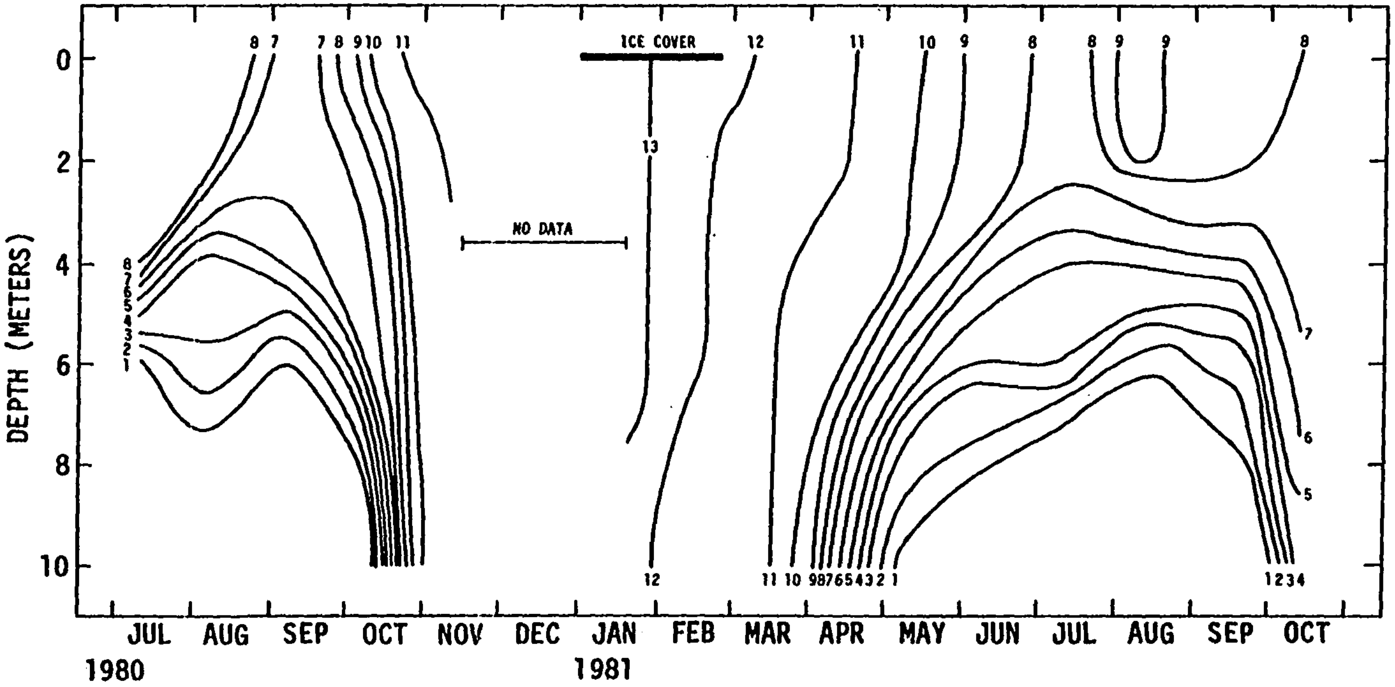


Figure 19. Isopleths of dissolved oxygen in mg/l for Peterson Quarry-West Pit

Table 6. Mean concentrations of water quality parameters, Hallett's Quarry-South Pit

	Surface	Middle	Bottom
pH	7.9 ± 0.2[a]	7.8 ± 0.3	7.5 ± 0.3
Total Alkalinity (mg/l as $CaCO_3$)	196 ± 35	212 ± 29	235 ± 29
Total Hardness (mg/l as $CaCO_3$)	301 ± 26	307 ± 21	324 ± 18
Total Solids (mg/l)	402 ± 21	419 ± 19	432 ± 31
Suspended Solids (mg/l)	7.7 ± 6.3	8.8 ± 6.8	11.0 ± 8.4
Specific Conductance (μ mhos/cm)	600 ± 46	616 ± 45	641 ± 44
Turbidity (NTU)	4.3 ± 3.6	4.4 ± 3.3	6.0 ± 4.4
Ortho PO_4 (mg/l as PO_4)	0.11 ± 0.05	0.12 ± 0.07	0.13 ± 0.05
NO_2 + NO_3-N (mg/l N)	0.60 ± 0.51	0.58 ± 0.41	0.38 ± 0.24
NH_4-N (mg/l N)	0.21 ± 0.15	0.20 ± 0.14	0.46 ± 0.35
Kjel-N (mg/l N)	0.48 ± 0.18	0.48 ± 0.17	0.70 ± 0.32
Chloride (mg/l)	18.5 ± 0.6	18.1 ± 1.8	18.2 ± 3.9
Soluble SiO_2 (mg/l)	16.2 ± 1.1	16.7 ± 0.9	18.0 ± 1.5
Fecal Coliforms (organisms/100 ml)	3 ± 8	1 ± 2	2 ± 3

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[a] Mean ± standard deviation.

Table 6. continued

	Surface	Middle	Bottom
BOD (mg/l)	1.26 ± 1.28	1.05 ± 0.54	1.18 ± 1.11
COD (mg/l)	7.43 ± 2.31	7.11 ± 2.03	7.16 ± 2.56
Corrected Chl *a*[b] (mg/m^3)	3.5 ± 2.5	4.1 ± 2.9	4.6 ± 4.7
Secchi Depth (m)	1.59 ± 0.51		

[b] Samples taken at 0, 1, and 2 meters.

Table 7. Mean concentrations of water quality parameters, Hallett's Quarry-North Pit

	Surface	Middle	Bottom
pH	8.1 ± 0.2[a]	8.0 ± 0.2	7.8 ± 0.3
Total Alkalinity (mg/l as $CaCO_3$)	166 ± 17	165 ± 18	173 ± 17
Total Hardness (mg/l as $CaCO_3$)	289 ± 15	291 ± 16	295 ± 14
Total Solids (mg/l)	416 ± 23	415 ± 16	439 ± 55
Suspended Solids (mg/l)	8.4 ± 6.7	8.6 ± 5.3	13.0 ± 10.6
Specific Conductance (μ mhos/cm)	591 ± 22	602 ± 23	604 ± 21
Turbidity (NTU)	6.1 ± 5.5	5.8 ± 5.0	9.6 ± 8.2
Ortho PO_4 (mg/l as PO_4)	0.09 ± 0.04	0.10 ± 0.05	0.09 ± 0.05
NO_2 + NO_3-N (mg/l N)	0.12 ± 0.10	0.10 ± 0.08	0.11 ± 0.08
NH_4-N (mg/l N)	0.15 ± 0.11	0.10 ± 0.05	0.15 ± 0.12
Kjel-N (mg/l N)	0.35 ± 0.13	0.29 ± 0.10	0.32 ± 0.11
Chloride (mg/l)	23.0 ± 2.5	23.3 ± 2.6	22.5 ± 3.0
Soluble SiO_2 (mg/l)	12.9 ± 0.4	12.9 ± 0.7	13.0 ± 0.5
Fecal Coliforms (organisms/100 ml)	1 ± 2	2 ± 3	1 ± 2

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[a] Mean ± standard deviation.

Table 7. continued

	Surface	Middle	Bottom
BOD (mg/l)	1.09 ± 0.73	0.95 ± 0.27	0.91 ± 0.27
COD (mg/l)	7.30 ± 3.15	6.06 ± 2.79	7.39 ± 3.33
Corrected Chl *a*[b] (mg/m^3)	5.8 ± 12.5	5.2 ± 10.8	5.6 ± 12.5
Secchi Depth (m)	1.24 ± 0.64		

[b] Samples taken at 0, 1 and 2 meters.

Table 8. Mean concentrations of water quality parameters, Hallett's Quarry-West Pit

	Surface	Middle	Bottom
pH	8.1 ± 0.2[a]	7.8 ± 0.3	7.4 ± 0.2
Total Alkalinity (mg/l as $CaCO_3$)	202 ± 48	222 ± 46	277 ± 37
Total Hardness (mg/l as $CaCO_3$)	270 ± 48	288 ± 55	334 ± 35
Total Solids (mg/l)	339 ± 47	369 ± 55	415 ± 44
Suspended Solids (mg/l)	6.6 ± 4.9	7.8 ± 6.6	8.6 ± 5.3
Specific Conductance (μ mhos/cm)	530 ± 98	558 ± 119	638 ± 69
Turbidity (NTU)	3.2 ± 2.2	3.4 ± 2.7	7.7 ± 5.7
Ortho PO_4 (mg/l as PO_4)	0.13 ± 0.07	0.14 ± 0.08	0.46 ± 0.26
NO_2 + NO_3-N (mg/l N)	2.85 ± 3.28	1.80 ± 1.23	1.11 ± 1.50
NH_4-N (mg/l N)	0.29 ± 0.25	0.30 ± 0.17	1.49 ± 0.78
Kjel-N (mg/l N)	0.74 ± 0.21	0.84 ± 0.21	1.80 ± 0.69
Chloride (mg/l)	21.6 ± 3.0	20.5 ± 2.4	20.2 ± 1.7
Soluble SiO_2 (mg/l)	13.7 ± 3.9	16.4 ± 3.4	19.7 ± 3.5
Fecal Coliforms (organisms/100 ml)	46 ± 97	61 ± 92	308 ± 521

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[a] Mean ± standard deviation.

Table 8. continued

	Surface	Middle	Bottom
BOD (mg/l)	1.48 ± 0.44	1.47 ± 0.39	1.45 ± 0.72
COD (mg/l)	13.41 ± 3.07	12.92 ± 3.76	13.48 ± 3.92
Corrected Chl a[b] (mg/m^3)	7.2 ± 6.3	7.7 ± 6.6	7.6 ± 6.1
Secchi Depth (m)	1.94 ± 0.92		

[b] Samples taken at 0, 1 and 2 meters.

Table 9. Mean concentrations of water quality parameters, Peterson's Quarry-West Pit

	Surface	Middle	Bottom
pH	8.1 ± 0.3[a]	7.6 ± 0.4	7.5 ± 0.4
Total Alkalinity (mg/l as $CaCO_3$)	204 ± 34	218 ± 20	269 ± 40
Total Hardness (mg/l as $CaCO_3$)	262 ± 24	283 ± 17	307 ± 41
Total Solids (mg/l)	371 ± 20	380 ± 18	421 ± 51
Suspended Solids (mg/l)	7.1 ± 2.3	8.3 ± 3.2	13.6 ± 6.3
Specific Conductance (μ mhos/cm)	601 ± 61	623 ± 55	687 ± 88
Turbidity (NTU)	5.3 ± 4.1	5.2 ± 3.7	10.9 ± 7.1
Ortho PO_4 (mg/l as PO_4)	0.03 ± 0.02	0.05 ± 0.06	0.35 ± 0.44
$NO_2 + NO_3$-N (mg/l N)	0.06 ± 0.05	0.06 ± 0.05	0.06 ± 0.05
NH_4-N (mg/l N)	0.16 ± 0.14	0.21 ± 0.14	1.69 ± 1.46
Kjel-N (mg/l N)	0.61 ± 0.15	0.71 ± 0.16	1.89 ± 1.14
Chloride (mg/l)	31.2 ± 1.1	30.0 ± 3.6	30.5 ± 1.6
Soluble SiO_2 (mg/l)	1.7 ± 0.9	2.9 ± 1.8	8.5 ± 5.7
Fecal Coliforms (organisms/100 ml)	1 ± 1	2 ± 3	12 ± 23

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[a] Mean ± standard deviation.

Table 9. continued

	Surface	Middle	Bottom
BOD (mg/1)	2.20 ± 0.67	2.02 ± 0.68	1.60 ± 0.55
COD (mg/1)	15.28 ± 7.37	14.89 ± 6.82	14.42 ± 2.01
Corrected Chl *a*[b] (mg/m^3)	14.8 ± 9.5	16.8 ± 10.7	17.4 ± 10.5
Secchi Depth (m)	1.16 ± 0.38		

[b] Samples taken at 0, 1 and 2 meters.

form (ammonia) increases. The observed trends are related to the fact that all four of the studied gravel-pit lakes stratify.

Paired *t*-tests were performed on the data to test, at the 90 percent significance level, the null hypothesis that the mean value for each of the monitored water quality parameters were the same between the four studied gravel-pit lakes. This analysis revealed that the water quality of the west gravel-pit lake at Hallett's Quarry is most like the water quality of the west gravel-pit lake at Peterson's Quarry having 8 of the tested 18 water quality parameters not being significantly different. The water quality of the north gravel-pit lake at Hallett's Quarry is least like the west gravel-pit lake at Peterson's Quarry having only 6 parameters which are not significantly different. When comparing the three gravel-pit lakes at Hallett's Quarry, it was found that the water quality of the north and south gravel-pit lakes is most similar (9 of the 18 parameters not being significantly different) and that the water quality of the north and west gravel-pit lakes is least similar (5 of the 18 parameters not being significantly different).

Plant nutrient (nitrogen and phosphorus), silica and chloride concentrations are different in each of the four studied gravel-pit lakes while specific conductance and turbidity values are not, when tested at the 90 percent significance level. BOD, COD, total solids and fecal coliform concentrations are the same in the north and south gravel-pit lake at Hallett's Quarry and different in the west gravel-pit lake. The observed differences in the west gravel-pit lake seems to be linked to the addition of stormwater runoff.

Comparison to other Iowa water bodies

The mean surface water concentrations of several of the water quality parameters measured in the four study gravel-pit lakes were compared to other Iowa water bodies on the Wisconsin glacial sheet, the groundwater in the buried channel aquifer up and down gradient of the study gravel-pit lakes and the South Skunk River. Table 10 presents these values. When compared to the other water bodies on the Wisconsin glacial sheet, the four gravel-pit lakes have higher total alkalinity, total hardness, specific conductance and nitrite plus nitrate nitrogen concentrations, as well as greater Secchi depths. The chlorophyll *a*, Kjeldahl nitrogen, phosphorus and turbidity values are lower in the gravel-pit lakes while the ammonia and chloride concentrations are all about the same. This indicates that the four study gravel-pit lakes are less productive than the rest of the Iowa water bodies on the Wisconsin glacial sheet.

The groundwater samples taken north of the Hallett Quarry gravel-pit lake system have relatively the same values for phosphorus, Kjeldahl nitrogen and specific conductance as the four gravel-pit lakes. The ammonia, total hardness and total alkalinity values are higher in the groundwater samples while the nitrite plus nitrate nitrogen and chloride values are lower. The total hardness and total alkalinity values for the raw City of Ames' municipal water supply well water are higher than those observed in the gravel-pit lakes while the chloride concentration is about the same.

The total hardness, total alkalinity, ammonia and phosphorus concentrations are higher in the South Skunk River than what was observed in the gravel-pit lakes during the course of this study. The chloride

Table 10. Means of several water quality parameters in water bodies on the Wisconsin glacial sheet, four study gravel-pit lakes, groundwater in buried channel aquifer and Skunk River

	Secchi Depth meters	Chl a mg/m^3	Total P mg/l PO_4	Ortho P mg/l PO_4	Kjel-N mg/l	NH_4-N mg/l	NO_2+NO_3-N mg/l
Iowa lakes within Wisconsin glacial sheet n = 39	-	-	-	-	-	-	-
Iowa natural lakes within Wisconsin glacial sheet n = 25	0.66	93.9	0.49	-	2.79	-	0.03
Iowa natural lakes within Wisconsin glacial sheet n = 24	0.9	58.3	0.37	-	1.3	0.2	0.3
Hallett Quarry							
South Pit	1.59	3.5	-	0.11	0.48	0.21	0.60
North Pit	1.24	5.8	-	0.09	0.35	0.15	0.12
West Pit	1.94	7.2	-	0.13	0.74	0.29	2.85
Peterson Quarry							
West Pit	1.16	14.8	-	0.03	0.61	0.16	0.06
Groundwater samples	-	-	-	0.13	0.49	0.47	<0.005
City of Ames raw water samples	-	-	-	-	-	-	-
Skunk River	-	-	-	0.54	-	0.54	-

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[a] Neumann, Tom. Assistant Water Plant Operator, City of Ames, Iowa, Personal Communication.

Turbidity NTU	Total Hardness mg/l $CaCO_3$	Total Alkalinity mg/l $CaCO_3$	Specific Conductance µ mhos/cm	Chloride mg/l	Reference
-	199	160	409	5.9	Bachmann, 1965
-	208	160	407	17.1	Jones & Bachmann, 1978b
13.3	222	170	410	19.8	Bachmann et al., 1980
4.3	301	196	600	18.5	This study
6.1	289	166	591	23.0	
3.2	270	202	530	21.6	
5.3	262	204	601	31.2	This study
-	326	309	573	1.3	This study
-	404	288	-	19	Neumann[a]
-	372	257	-	14	Dougal, 1969

concentration of the South Skunk River was lower than that in the four study gravel-pit lakes.

Trophic state

All four of the studied gravel-pit lakes can be classified as eutrophic. The degree of eutrophication is different for each of the four lakes, however. The potential for algal growth can be measured by determining the concentration of plant nutrients (nitrogen and phosphorus). Biochemical and chemical oxygen demands and corrected chlorophyll a concentrations are an indication of the actual amount of algal growth achieved. Secchi depth has been shown to be inversely related to chlorophyll a concentration by numerous investigators (Jones, 1974; Dillon and Rigler, 1975; Jones and Bachmann, 1978a and 1978b). These parameters can be used to rank the four gravel-pit lkaes in order of increasing state of eutrophication. This order is: Hallett-North Pit, Hallett-South Pit, Peterson-West Pit and Hallett-West Pit.

The west gravel-pit lake at Peterson's Quarry has the lowest plant nutrient concentrations and Secchi depths of the four studied gravel-pit lakes but it also has the highest chlorophyll a concentration and biochemical and chemical oxygen demands of the four gravel-pit lakes. This indicates that the potential algal growth in the Hallett Quarry gravel-pit lake system is much higher than what was actually observed during the course of this study. One possible explanation for this is that, through observation, large zooplankton species were present in all three of the Hallett Quarry gravle-pit lakes but not in the Peterson Quarry gravel-pit lake. These large zooplankton may be actively grazing on the growing planktonic algae thus reducing their density, which will appear as lower corrected chlorophyll a concentrations and greater Secchi depths in these gravel-pit lakes. It is speculated that differences in the fisheries of the two gravel-pit lake systems account for the observed differences in the zooplankton communities.

STORMWATER RUNOFF INVESTIGATION

Introduction

The natural drainage system for the Hallett Quarry gravel-pit lake system has been altered during the course of gravel extraction. Presently, all of the stormwater runoff from both the agricultural and urban areas of the watershed enters the west gravel-pit lake. From there it can seep to the east into the south gravel-pit lake.

Agricultural and urban stormwater runoff has been found to be high in plant nutrients, suspended solids, biochemical and chemical oxygen demand, bacteria, hydrocarbons, pesticides and heavy metals (Weibel et al., 1964; Weibel et al., 1966; Kluesener and Lee, 1974; Grizzard et al., 1978; Rimer et al., 1978, Wanielista, 1978; Baker et al., 1979; Hunter et al., 1979; Austin et al., 1981). Degraded levels of water quality in the receiving water has been a common result of stormwater runoff inputs. The observed impact of the stormwater runoff inputs into the Hallett Quarry gravel-pit lake system has been equally dramatic.

The purpose of this part of the study was to quantify the stormwater pollutant loads to the west gravel-pit lake at Hallett's Quarry. With these data, the future water quality of the gravel-pit lake system will be predicted for alternative use scenarios.

Methods and Materials

Sampling methods

Stormwater runoff samples were collected by lowering a sampling bucket, attached to a rope, from the streambank into the stream during periods of runoff. The time period between samples depended upon the degree of runoff but was usually between 5 and 15 minutes. A total of eight samples were collected per storm runoff event with at least half of them coming on the rising limb of the hydrograph. The collected water was placed in 0.5 liter sterilized polyethylene bottles for bacterial analysis and 1.0 and 2.0 liter acid washed polyethylene bottles for chemical analysis.

Good mixing is achieved at the point of sampling because the streams are small and the flows are turbulent during periods of storm runoff. A single grab sample was considered sufficient at any one time to represent the average water quality in the stream cross section.

Chemical and bacteriological analyses

All chemical and bacteriological analyses were conducted by the Analytical Services Laboratory of the Engineering Research Institute (ERI-ASL) at Iowa State University. The parameters determined by ERI-ASL are the same as those for the limnological investigation of the gravel-pit lakes, with the exception of phytoplankton pigments which were not included.

Instrumentation

Three sets of non-recording precipitation gauges and one recording precipitation gauge were installed at various locations in the Hallett Quarry watershed (Figure 20). The recording precipitation gauge is a weighing-type gauge produced by the Belfort Instrument Company. The sets of plastic non-recording precipitation gauges are made up of one

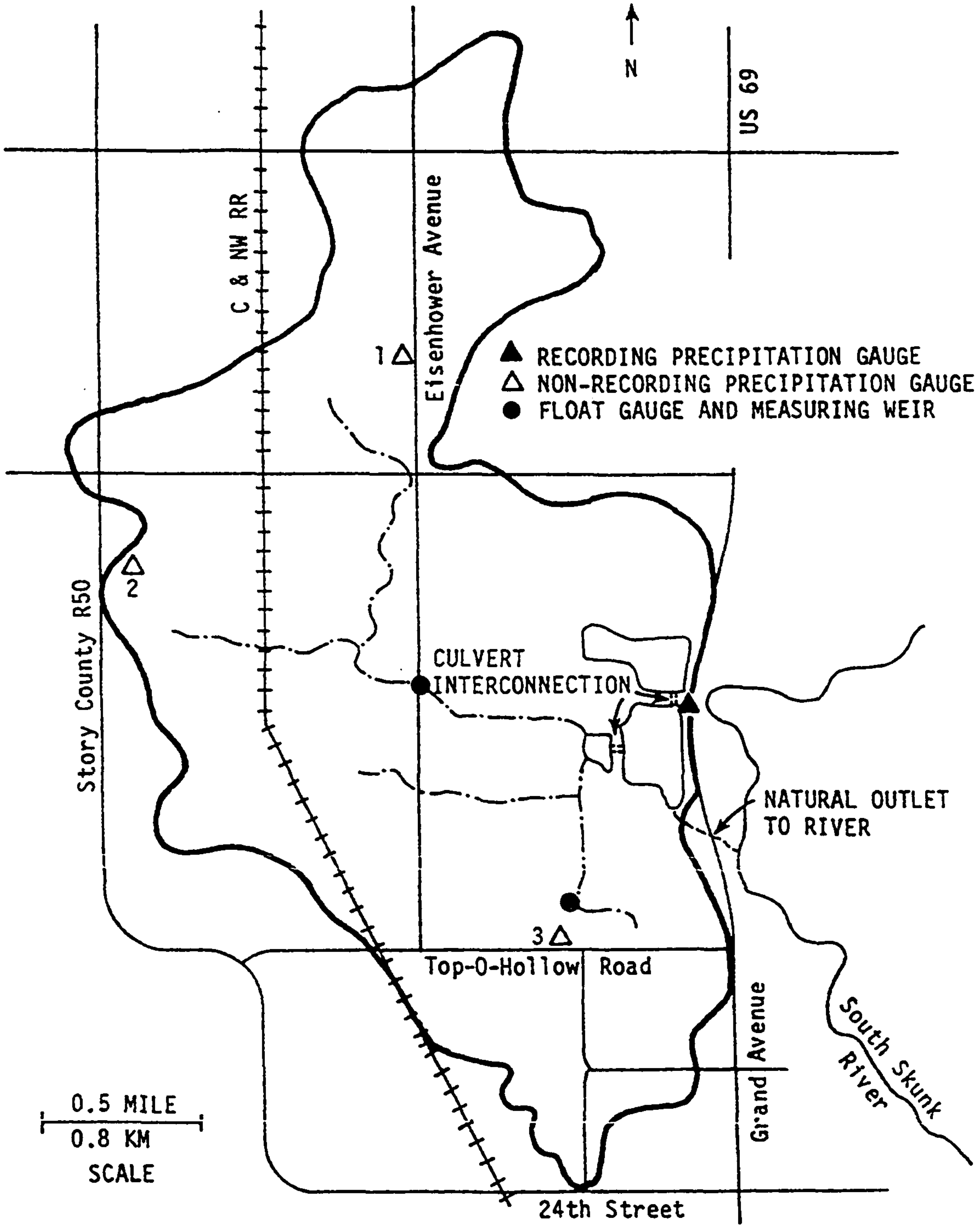


Figure 20. Location of precipitation and streamflow instrumentation

"Tru-Check" and one "All Weather" gauge. The two different types of gauges were selected in order to make a comparison between them for future research work.

Two stream stage recording stations were also established, one on the southern urban drainage stream and one on the northern agricultural drainage stream (Figure 20). Each station consists of a low flow measuring weir, Stevens' Type F water level recorder and staff gauge.

Stage-discharge curves

Stage-discharge curves for the two low flow measuring weirs were developed to aid in the analysis of stormwater runoff pollutant loadings. In order to develop these curves, models of each of the weirs were constructed out of 3.175 mm plexiglass. The models were placed into the 9.1 meter adjustable slope flume in the water resources laboratory at Iowa State University and the flow rate of water passing over each model at increasing stages was determined. The stage-discharge curves for each of the weirs (Figures B.1 and B.2) are presented in Appendix B.

Results and Discussion

Precipitation

The monthly precipitation values observed at the City of Ames Water Pollution Control Plant, the recording precipitation gauge at Hallett's Quarry and the three sets of non-recording precipitation gauges on the Hallett Quarry watershed during the course of this study are presented in Table 11. The 1931 to 1960 normal monthly precipitation for the City of Ames has also been included for comparison. During the period of this

Table 11. Monthly precipitation in millimeters

Month	Precipitation at indicated site					1931-1960 Normal
	WPCP[a]	HQ[b]	#1[c]	#2[c]	#3[c]	
August, 1980	102.1	*[d]	124.7	144.3	148.1	97.8
September, 1980	48.5	*	49.0	56.1	10.4	83.8
October, 1980	33.0	*	33.0	*	12.5	50.8
November, 1980	11.4	*	20.6	*	19.8	41.1
December, 1980	4.1	*	*	*	3.8	25.9
January, 1981	0.5	1.8	*	*	*	27.4
February, 1981	26.4	8.1	*	*	0.8	24.9
March, 1981	14.0	15.2	*	*	21.1	47.8
April, 1981	81.5	60.2	51.1	*	89.7	65.8
May, 1981	26.2	14.5	18.8	*	25.4	108.7
June, 1981	103.6	73.7	90.7	*	90.4	132.3
July, 1981	104.1	71.1	88.1	*	78.7	84.1
August, 1981	118.6	108.5	126.8	*	141.7	97.8
September, 1981	52.8	57.7	63.2	*	61.0	83.9
October, 1981	54.4	35.6	32.8	*	33.0	50.8
November, 1981	39.9	50.6	*	*	*	41.1
Percent of normal	77	65	78	*	74	100

[a] City of Ames Water Pollution Control Plant.

[b] Recording precipitation gauge at Hallett's Quarry.

[c] Non-recording precipitation gauges, see Figure 20 for location.

[d] No measurements taken.

study, below normal amounts of precipitation were received. For the period from August, 1980 to November, 1981, 65 to 78 percent of normal precipitation (692 to 830 mm vs 1064 mm) occurred over the Hallett Quarry watershed. This made stormwater sampling difficult since most of the precipitation that was received occurred in amounts and intensities that were too low to result in direct surface runoff. It was not until August, 1981, when above normal precipitation occurred, that stormwater samples for water quality analysis could be collected.

Stormwater quality

Runoff from a total of five storms was sampled to quantify the stormwater pollutant loadings to the Hallett Quarry gravel-pit lake system. Three of the storm runoff events were on the agricultural drainage stream and the other two runoff events were on the urban drainage stream. Table 12 presents summaries of the storms from which runoff samples were collected.

The streams were sampled during different storm events making a true comparison of water quality during a runoff event impossible. This is because the nature of the runoff is dependent upon the storm characteristics (storm duration, intensity of precipitation and total precipitation), the antecedent moisture conditions and the time of the year. To overcome this problem, time and flow weighted average concentrations were calculated for each runoff event based on the methods described by Huber et al. (1979). These values are obtained by using the following formulas:

Table 12. Summary of agricultural and urban storm events

Storm event	Agricultural			Urban	
	No. 1	No. 2	No. 3	No. 4	No. 5
Start of precipitation					
Date	07-27-81	08-14-81	08-28-81	09-24-81	11-03-81
Time, CDT	10:30	21:00	11:20	18:20	07:45[a]
End of precipitation					
Date	07-27-81	08-15-81	08-28-81	09-24-81	11-03-81
Time, CDT	21:30	02:20	13:25	22:40	09:10
Total precipitation (mm)	23.4	40.1	28.2	20.3	7.1
(in)	0.92	1.58	1.11	0.80	0.28
Total five day antecedent precipitation (mm)	46.7	1.0	15.5	0	18.5
(in)	1.84	0.04	0.61	0	0.73
Previous dry days	1	4	0	16	0

[a] CST used in November.

$$\bar{C} = \frac{\Sigma C_i \; Q_i \; \Delta t_i}{\Sigma Q_i \; \Delta t_i} \qquad (2)$$

where

$\bar{C}$ = average concentration of the parameter

C_i = concentration of parameter at sample number i

Q_i = flow rate at sample number i

Δt_i = time interval at sample number i

and

$$\Delta t_i = (t_{i+1} - t_{i-1})/2 \qquad (3)$$

where

t_i = time at sample number i.

The calculated time and flow weighted average concentrations are presented in Tables 13 and 14. The stream flow and times at which each sample was collected are presented in Tables C.1 and C.2 and the original water quality data are presented in Tables C.3 to C.7 in Appendix C. It should be noted that since the samples were collected manually after the onset of the rainfall, background concentrations could not be subtracted from the calculated values.

In order to compare the stormwater quality of the two streams, grand average time and flow weighted concentrations for the three agricultural and two urban storm runoff events were calculated. These values are presented in Table 15. The concentrations for the agricultural stream are from 10 to 100 times greater than those for the urban stream. Several

Table 13. Time and flow weighted average concentrations for each agricultural storm event

Parameter	Time and flow weighted concentrations on each storm date 07-27-81	08-14-81	08-28-81
BOD mg/l	>16.2	>130.4	180.9
COD mg/l	50.8	2905.9	792.1
Total solids mg/l	2055	10683	2730
Suspended solids mg/l	1532	8320	2294
Total PO_4 mg/l as PO_4	39.70	254.28	64.37
Ortho PO_4 mg/l as PO_4	9.63	59.69	16.94
NO_2 + NO_3-N mg/l N	7.43	1.99	2.71
NH_4-N mg/l N	4.99	30.95	4.74
Kjel-N mg/l N	29.60	237.3	49.46
Fecal coliforms organisms/100 ml	TNTC[a]	>1.99E6	19.5

[a] Too numerous to count.

Table 14. Time and flow weighted average concentrations for each urban storm event

Parameter	Time and flow weighted concentrations on each storm date 09-24-81	11-03-81
BOD mg/l	10.99	7.58
COD mg/l	88.51	50.47
Total solids mg/l	566	251
Suspended solids mg/l	421	147
Total PO_4 mg/l as PO_4	1.92	0.86
Ortho PO_4 mg/l as PO_4	0.51	0.28
NO_2 + NO_3-N mg/l N	0.41	0.97
NH_4-N mg/l N	0.50	0.36
Kjel-N mg/l N	2.72	1.50
Fecal coliforms organisms/100 ml	>0.27	0.03
Fecal strep organisms/100 ml	0.31	*[a]

[a] Not determined for this storm event.

Table 15. Time and flow weighted average concentration for all sampled storm events

Parameters	Agricultural	Urban
Number of events	3	2
BOD mg/l	>130.32	9.96
COD mg/l	2877.70	76.96
Total solids mg/l	10586	470
Suspended solids mg/l	8246	338
Total PO_4 mg/l as PO_4	251.93	1.60
Ortho PO_4 mg/l as PO_4	59.16	0.44
NO_2 + NO_3-N mg/l N	2.02	0.58
NH_4-N mg/l N	30.64	0.46
Kjel-N mg/l N	235.04	2.35
Fecal coliforms organisms/100 ml	>1.98E6[a]	>0.20
Fecal strep organisms/100 ml	*[b]	0.31[c]

[a] Based on two storm events.

[b] Not determined for these storm events.

[c] Based on one storm event.

reasons account for these large differences. First of all, the sampling station for the agricultural stream is located directly downstream of a large, open hog lot. The initial stormwater runoff collected for water quality analysis is essentially all runoff from this hog lot. Later, after sampling was completed, surface and tile flows reach the sampling site from the areas to the north. This means that the agricultural stormwater quality monitored is not typical of other agricultural areas but is typical of the stormwater quality entering Hallett's Quarry from this specific drainage stream.

A second reason for the large differences in the time and flow weighted averages between the agricultural and urban areas is the total amount of runoff experienced during a storm sampling event. Since below normal amounts of precipitation were received during this study, most of the precipitation falling on the agricultural area infiltrated. It was only the short intense bursts of precipitation during a storm which caused direct surface runoff. These lower amounts of total surface runoff contained high concentrations of pollutants resulting in large time and flow weighted average concentrations. On the other hand, due to the increased area of impervious surfaces in the urban portion of the watershed, a greater percentage of the precipitation contributed to direct surface runoff. This resulted in relatively larger volumes of runoff from the urban area. Therefore, the urban stormwater runoff contains lower concentrations of pollutants, resulting in lower time and flow weighted averages.

Effects on gravel-pit water quality

The stormwater quality data that were collected during the course of this study indicates that large amounts of fecal coliform bacteria, sediment, plant nutrients and chemical and biochemical oxygen demanding substances are being transported during runoff events into the west gravel-pit lake at Hallett's Quarry. A comparison was made between the three gravel-pit lakes at Hallett's Quarry for these water quality parameters over time to see what, if any, differences exist. Figures 21, 22, 23, 24 and 25 present these comparisons. A precipitation histogram is included in these figures to aid in the comparison. In all of the figures, bottom concentrations are plotted because the stormwater inflow traveled to the bottom of the west gravel-pit lake due to its density.

Fecal coliform bacteria Figure 21 presents the comparison of fecal coliform bacteria in the bottom waters between the three gravel-pit lakes. As can be seen, the concentrations of fecal coliform bacteria in the north and south gravel-pit lakes remain low (below 10 organisms per 100 ml) throughout the entire study period. In the west gravel-pit lake however, quite a different trend was observed. After periods of precipitation (August, 1980; June to September, 1981), the fecal coliform bacteria concentrations increased dramatically. Since these increases occur after periods of precipitation, it is logical to conclude that they are due to the stormwater input into the west gravel-pit lake.

Turbidity The comparison of bottom water turbidity values between the three gravel-pit lakes is presented in Figure 22. The same trend that is evident with the fecal coliform bacteria is seen with turbidity in the west gravel-pit lake. The turbidity increases in the west gravel-pit

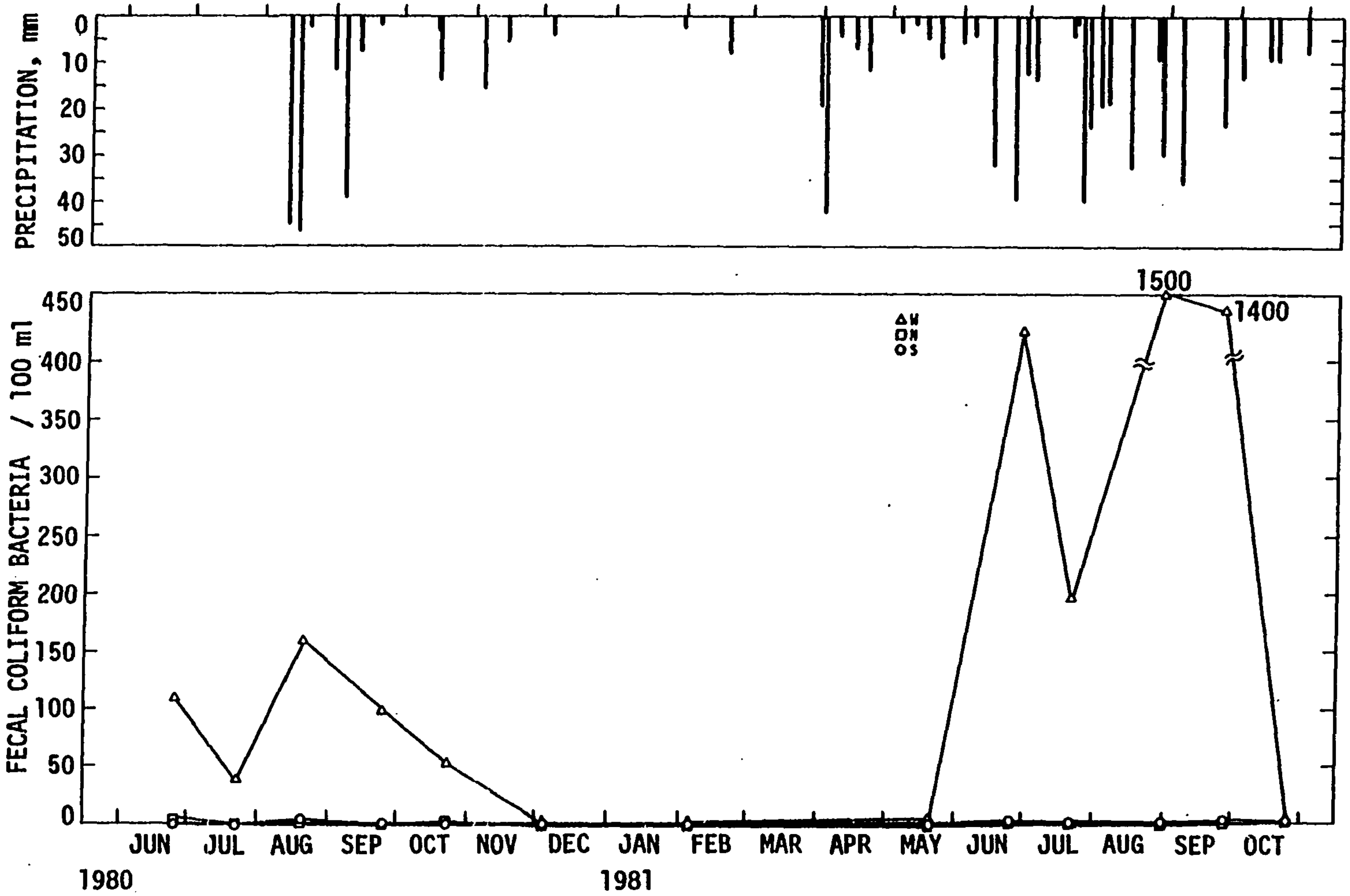


Figure 21. Comparison of fecal coliform bacteria concentrations between the three Hallett Quarry gravel-pit lakes

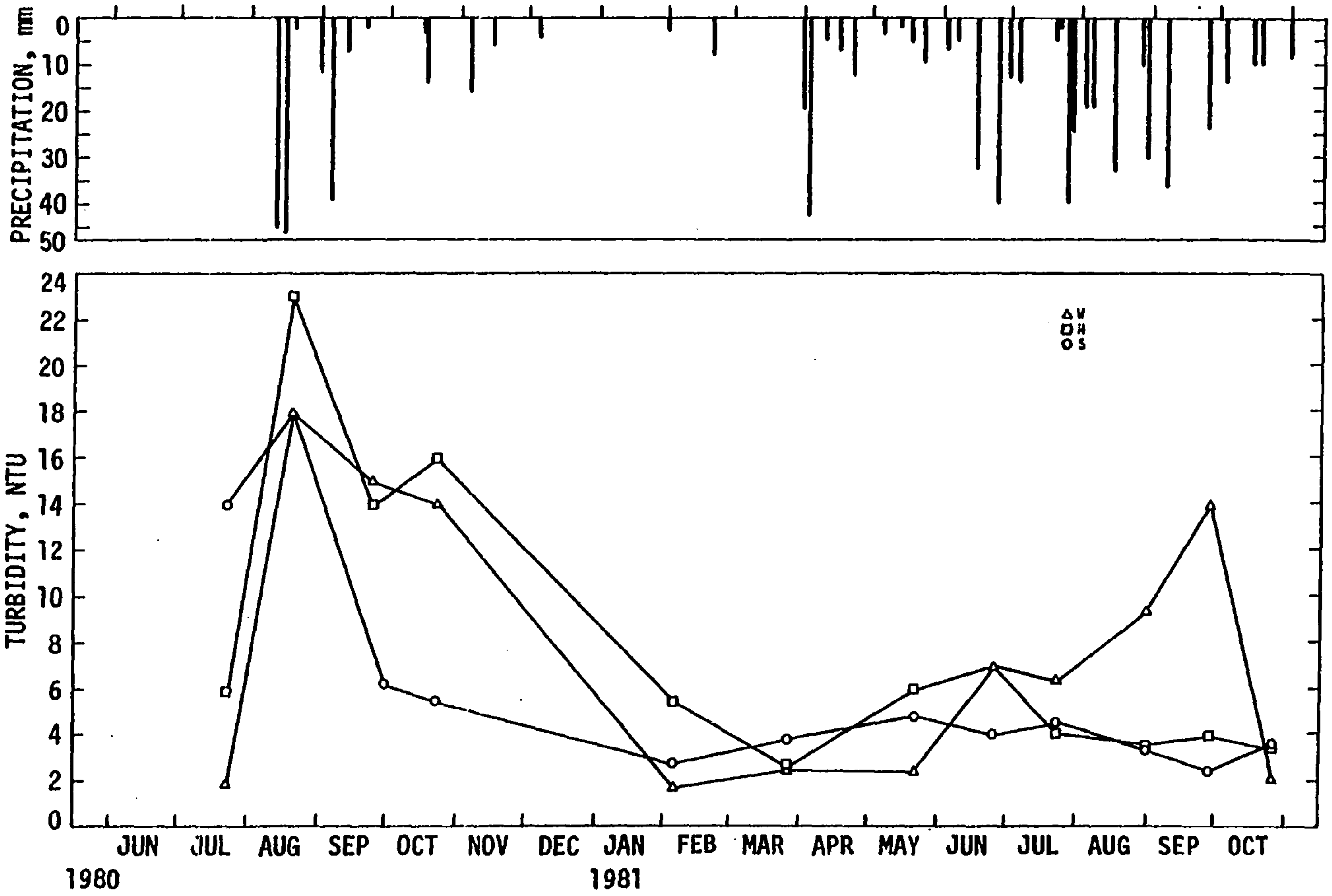


Figure 22. Comparison of turbidity values between the three Hallett Quarry gravel-pit lakes

lake after periods of precipitation. However, the turbidity values also fluctuate in the north and south gravel-pit lakes during the course of this study. Since these two lakes are actively being mined for sand and gravel, it is not surprising that they would have fluctuating turbidity values. The dragline used in the excavation process stirs up the bottom sediments when extraction is taking place increasing the turbidity.

Orthophosphate During the course of this study, the concentrations of orthophosphate in the north and south gravel-pit lakes were similar, never being greater than 0.05 mg/l as PO_4 different from each other, whereas the concentrations in the west gravel-pit lake increased dramatically during periods of precipitation (Figure 23). Both the south and west gravel-pit lakes thermally stratify and have anoxic hypolimnions during the summer. The increase in orthophosphate concentrations can not be attributed to releases from the sediments under anoxic conditions because the concentration does not increase in the south gravel-pit lake during the same time period.

Total nitrogen The comparison of total nitrogen concentrations in the bottom waters between the three gravel-pit lakes is presented in Figure 24. The general trend of the concentrations increasing dramatically after periods of precipitation in the west gravel-pit lake is not seen with total nitrogen. Overall, the total nitrogen concentrations are highest in the west gravel-pit lake and lowest in the north gravel-pit lake with the south gravel-pit lake being intermediate.

Chemical oxygen demand The chemical oxygen demand values in the three gravel-pit lakes behaved similar to the total nitrogen concentrations (Figure 25). While there is some indication of increased values

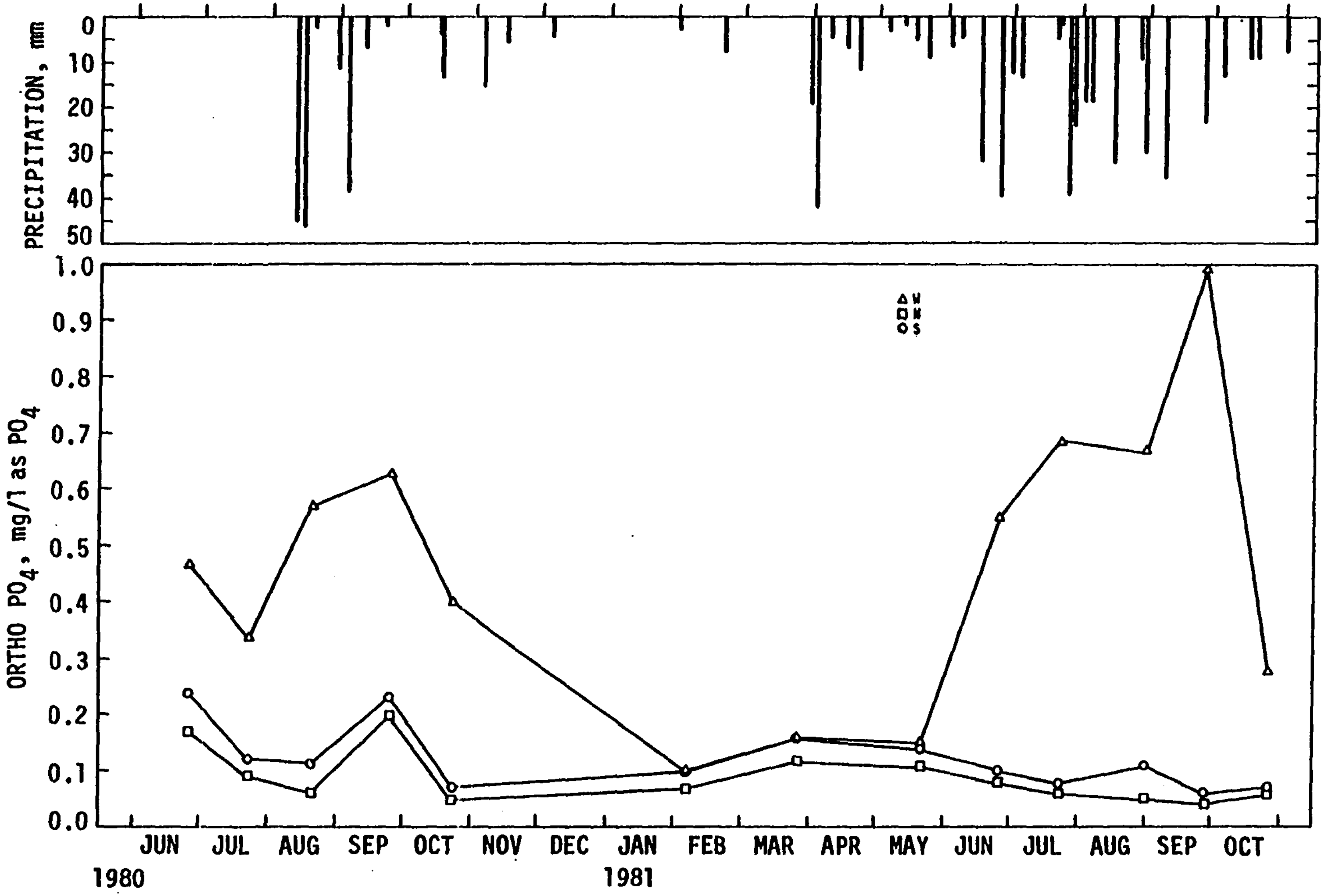


Figure 23. Comparison of orthophosphate concentrations between the three Hallett Quarry gravel-pit lakes

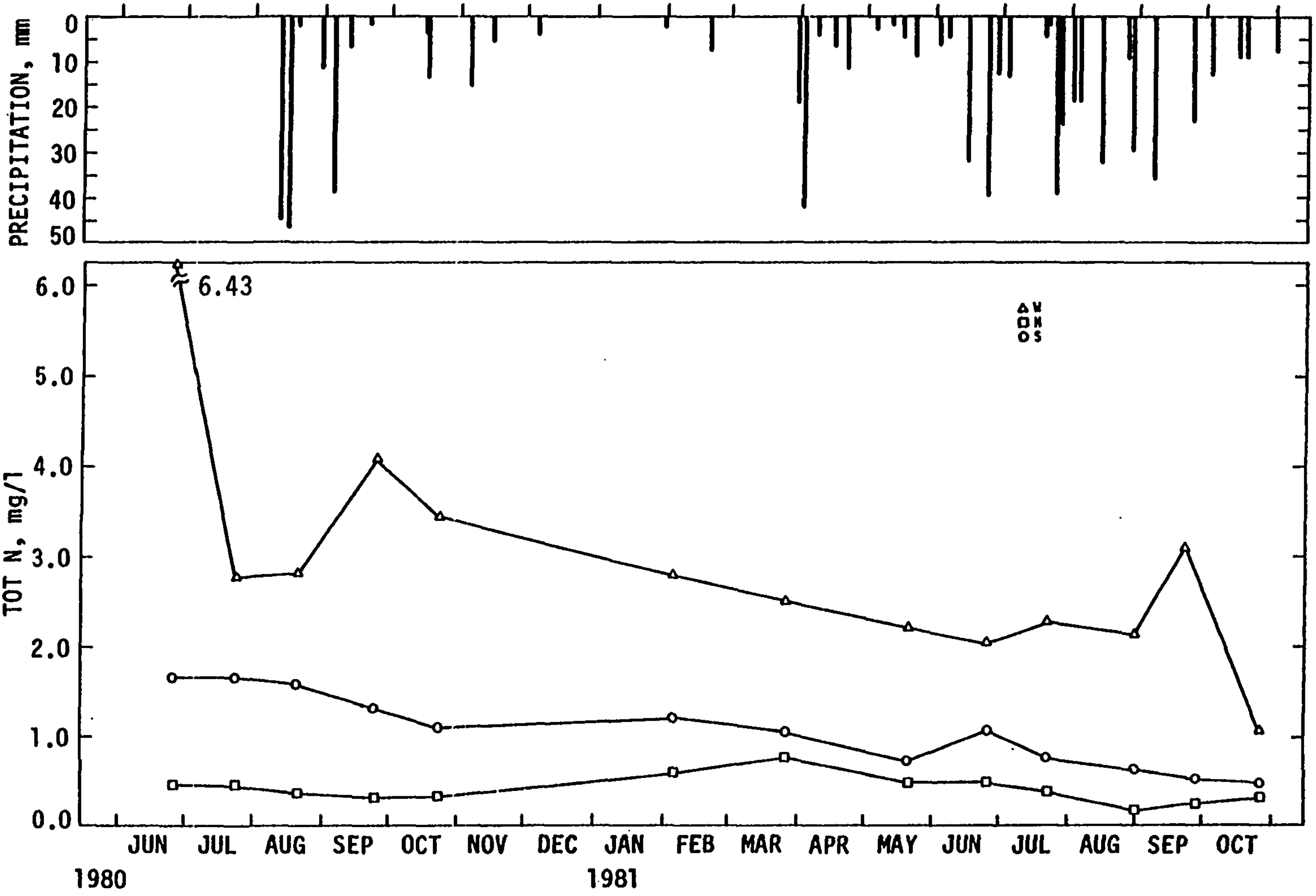


Figure 24. Comparison of total nitrogen concentrations between the three Hallett Quarry gravel-pit lakes

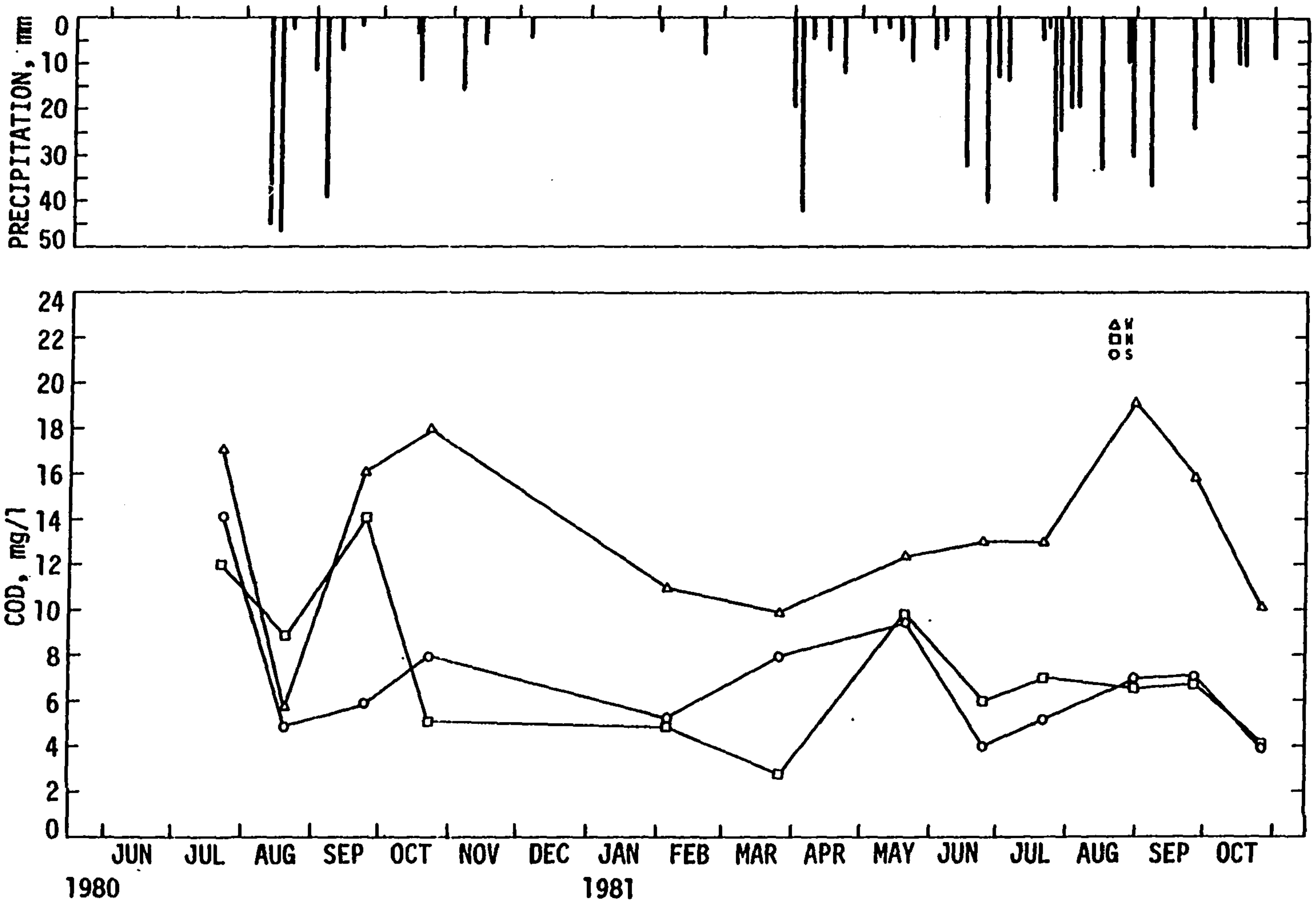


Figure 25. Comparison of chemical oxygen demand values between the three Hallett Quarry gravel-pit lakes

after periods of precipitation in the west gravel-pit lake, the trend is not as pronounced as the fecal coliform bacteria and orthophosphate. Overall, the chemical oxygen demand values are similar in the south and north gravel-pit lakes and highest in the west gravel-pit lake.

MANAGEMENT ALTERNATIVES

Water Quantity

General

One proposed use for the Hallett Quarry gravel-pit lake system is to use it as a supplemental water supply source for the City of Ames, Iowa. The northeast and southeast portions of the Ames' municipal well field are recharged by the South Skunk River near 13th Street and the west and south portions are recharged by Squaw Creek. The average discharge of the South Skunk River near (just upstream of) Ames is 4.3 cms (152 cfs) (USGS, 1981). This flow does not include the Squaw Creek tributary which discharges into the South Skunk River southeast of Ames.

The average water demand for the City of Ames in 1976 was 0.28 cms (9.7 cfs). This water demand is projected to increase to 0.61 cms (21.5 cfs) by the year 2020. Comparison of the water demand values to the average discharge illustrates that the City of Ames will use from 6 to 14 percent of the average flow in the South Skunk River for its water supply and should have sufficient water for either direct withdrawal use or indirect groundwater recharge purposes. However, this is not the case.

Inspection of the flow-duration data and curve for the South Skunk River near Ames shows that the percent of the time when the present and projected future water demands are equaled or exceeded by the stream discharge range from 75 to 63 percent (INRC, 1979). Conversely, the percent of time when the discharge of the South Skunk River is below the water demand for Ames ranges from 25 to 37 percent of the time. This means that over extended periods of time, the aquifer serving Ames is partially dewatered. The Hallett Quarry gravel-pit lake system can serve as a long-term source of water to recharge the aquifer, as it was indicated in 1977.

Two analyses were conducted to determine the amount of storage which is needed to supply a flow of 0.085, 0.142, and 0.227 cms (3, 5, and 8 cfs). The two analyses consisted of a period of record analysis and a frequency analysis. The three flow rates were chosen because it was felt that a flow rate of 0.085 cms (3 cfs) would be the minimum amount needed to recharge the municipal well field, 0.142 cms (5 cfs) was a maximum amount needed to recharge the municipal well field when the new low head dam is in place, and 0.227 cms (8 cfs) would recharge the present municipal well field and provide additional recharge capacity for the new southeast well field.

Historic analysis

The worst experienced low flow period of record for the South Skunk River was the period from July, 1955 to January, 1957. A Rippl diagram, which is a graph of accumulated inflow plotted against time, was constructed for this period (Figure 26). While Rippl diagrams are used for on-stream reservoir sizing, it was felt that it could be applied to the off-stream Hallett Quarry gravel-pit lake system with the understanding that the expected recovery of the system would not be as rapid as the diagram but would occur at or near the same point in time. Groundwater seepage from the alluvium around the perimeter of the Hallett Quarry gravel-pit lake system was not included in this analysis. From the Rippl diagram, the volume of storage which is needed to supply each of the

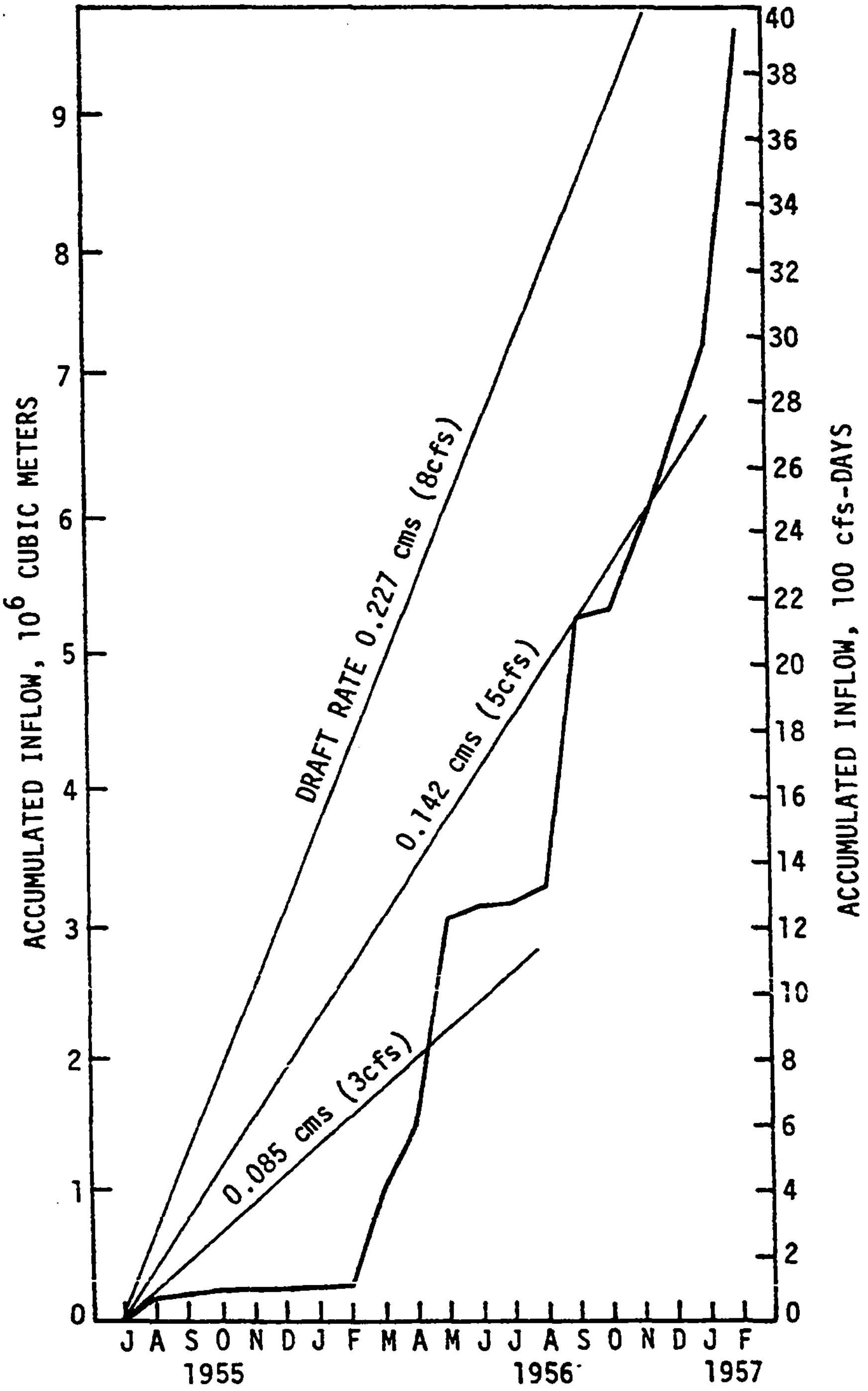


Figure 26. Rippl diagram, historic low flow analysis, South Skunk River near Ames

three draft rates of interest were obtained. To obtain these values, lines with slopes equal to the draft rates are drawn on the Rippl diagram from the point of tangency. The needed storage volume is the maximum distance between the draft rate line and the Rippl diagram line. Table 16 presents these values.

Frequency analysis

Frequency methods have been developed for providing both the magnitude and frequency of low flows in Iowa streams for selected durations of days. Using the methods outlined in the Iowa Natural Resources Council (INRC) Bulletin No. 10 (INRC, 1970) and the magnitude and frequency values for the 20-year recurrence interval for the South Skunk River near Ames from INRC Bulletin No. 13 (INRC, 1979), a 20-year frequency mass curve was constructed (Figure 27). Additional data for the 365-day duration were obtained from the United States Geological Survey (USGS) who prepared both of the INRC bulletins. The three draft rate lines were added to this curve to determine the amount of storage which is needed in order to meet these draft rates. The storage volume needed is again obtained by noting the point at which the two lines are farthest apart. Table 16 presents these volumes also.

Summary

The present volume of water at Hallett's Quarry is 2.43×10^6 cubic meters (1,972 acre-feet). This would be enough to supply at least a draft rate of 0.142 cms (5 cfs) for both the historical and 20-year recurrence interval low flow periods but not enough for the 0.227 cms (8 cfs) draft

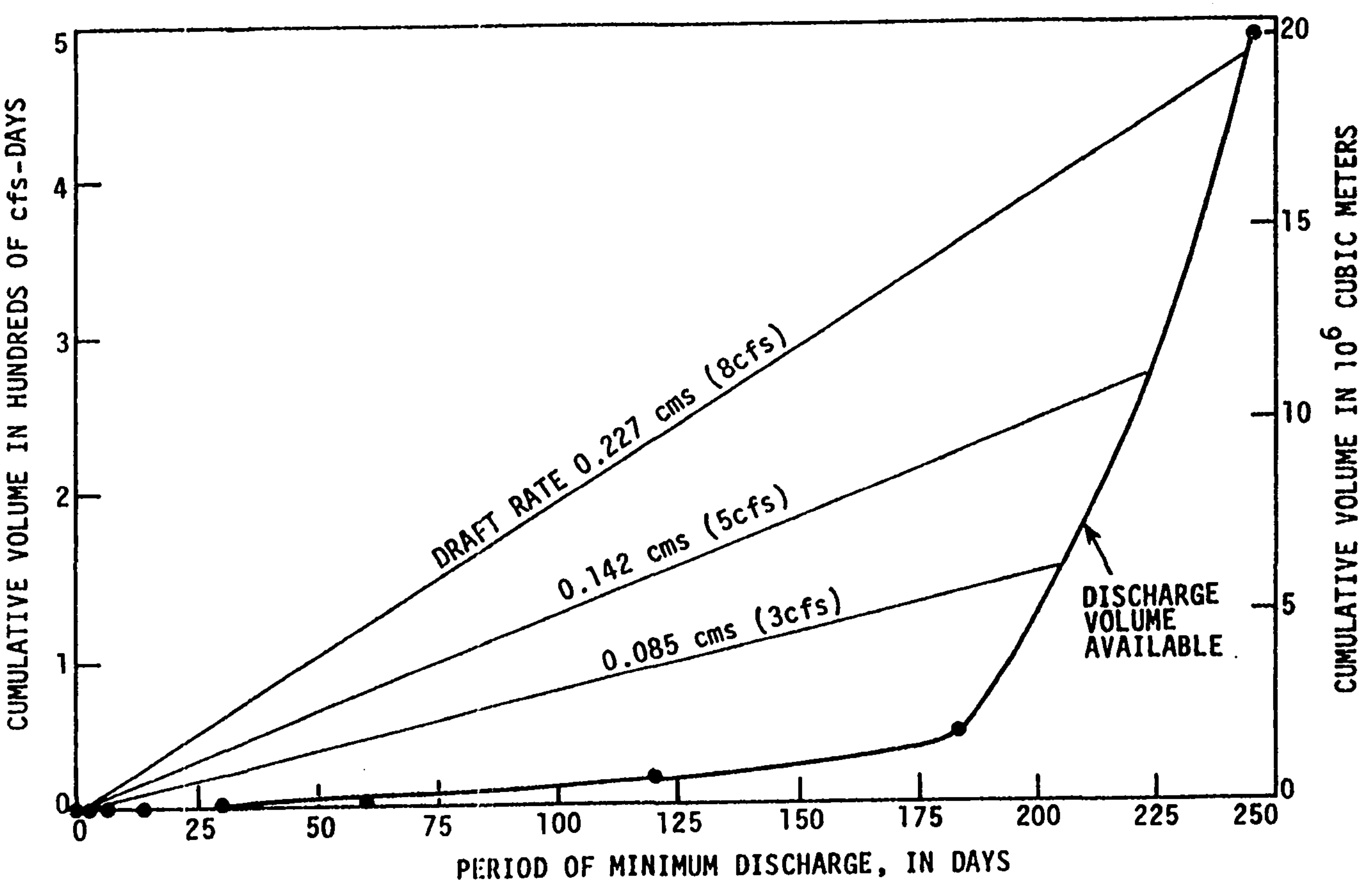


Figure 27. Frequency-mass curve and draft storage lines for 20-year recurrence interval low flows, South Skunk River near Ames

Table 16. Required storage volumes needed to meet draft rates in the historic and frequency analyses

	Draft rate	Volume of storage needed
Historical flow analysis (July, 1955 - January, 1957)	0.085 cms 3 cfs	1.33×10^6 m^3 1080 acre-ft
	0.142 cms 5 cfs	2.40×10^6 m^3 1940 acre-ft
	0.227 cms 8 cfs	4.48×10^6 m^3 3625 acre-ft
20-year recurrence interval low flow analysis	0.085 cms 3 cfs	0.93×10^6 m^3 750 acre-ft
	0.142 cms 5 cfs	1.81×10^6 m^3 1465 acre-ft
	0.227 cms 8 cfs	3.13×10^6 m^3 2535 acre-ft

rate. It is projected that the future volume of water at Hallett's Quarry will be 6.15 x 10^6 cubic meters (4,982 acre-feet) when the planned excavation is completed. This volume would be enough to supply the 0.227 cms (8 cfs) draft rate for both the historic and 20-year recurrence interval low flow periods. It is concluded from these analyses that the Hallett Quarry gravel-pit lake system has and will have sufficient storage volume to adequately serve as a supplemental water supply source for the City of Ames. Water from the gravel-pit lake system could be used to recharge the groundwater aquifer and well system or it could be piped directly from the gravel-pit lake system to the municipal water treatment plant. It is because of this that water quality protection remains the key issue.

Water Quality

Introduction

Several investigators have demonstrated that the total phosphorus concentration of natural lakes can be an important indicator of lake trophic state, chlorophyll *a* concentrations and water clarity (Dillon, 1975; Dillon and Rigler, 1975; Jones and Bachmann, 1976). Out of these relationships, simple empirical models to predict lake total phosphorus concentrations have been developed. The use of these input-output models requires only data on annual phosphorus loads, hydraulic flushing rates and lake morphometry. Since only a minimal amount of data is needed, lake managers have been using these models as decision aids for lake restoration. Uttormark and Hutchins (1980) evaluated three of these input-output models for their applicability of predicting changes in trophic state with changing nutrient inputs. They concluded that for at least 70 percent of their study lakes, accurate predictions of the general trophic state were made.

Canfield and Bachmann (1981), using data from 316 natural and artificial lakes, developed a relationship for the phosphorus sedimentation coefficient in the general Vollenweider model:

$$TP = \frac{L}{Z(\sigma + \rho)} \tag{4}$$

where

TP = total phosphorus concentration in the lake water, mg/m^3

L = annual phosphorus loading per unit of lake surface area, $mg/m^2/yr$

Z = mean depth of the lake, m

σ = phosphorus sedimentation coefficient, yr^{-1}

ρ = hydraulic flushing rate, yr^{-1}.

Their relationship is:

$$\sigma = 0.129\ (L/Z)^{0.549} \tag{5}$$

for all lakes, natural and artificial. This overall relationship can be divided into two distinct relationships, one for natural lakes and one for artificial lakes. These relationships are:

$$\sigma = 0.162\ (L/Z)^{0.458} \tag{6}$$

for natural lakes, and

$$\sigma = 0.114\ (L/Z)^{0.589} \tag{7}$$

for artificial lakes. They tested the abilities of these and other published empirical phosphorus loading models to predict measured in lake total phosphorus concentrations. The results of their investigation revealed that the models that they had developed had the smallest 95 percent confidence limits of all of the tested empirical input-output models.

The purpose of this part of the study was to apply the modified Vollenweider input-output model developed by Canfield and Bachmann to the Hallett Quarry watershed and gravel-pit lake system in order to determine the impact of various land use, drainage and lake configurations on future water quality. Two lake types, four drainage networks and three land use scenarios were investigated. This resulted in 24 predictions of the water quality.

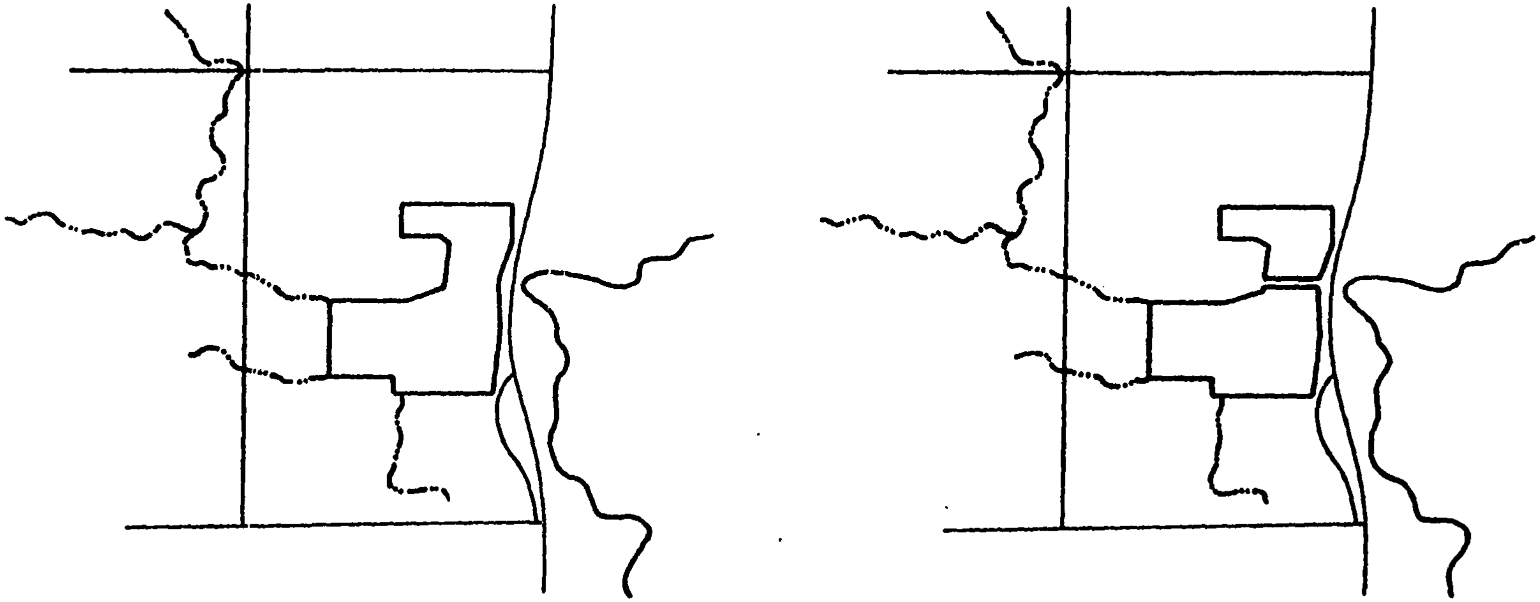
Description of scenarios

The two lake types investigated consisted of a single lake as proposed by the Hallett Construction Company and a two lake system as proposed by Dougal and Antosch (1980) in an earlier progress report to the City of Ames.

The drainage networks considered were the ones which seemed the most realistic to the author. They consisted of:

A. all of the drainage discharges into the lake or lake system (Figure 28),

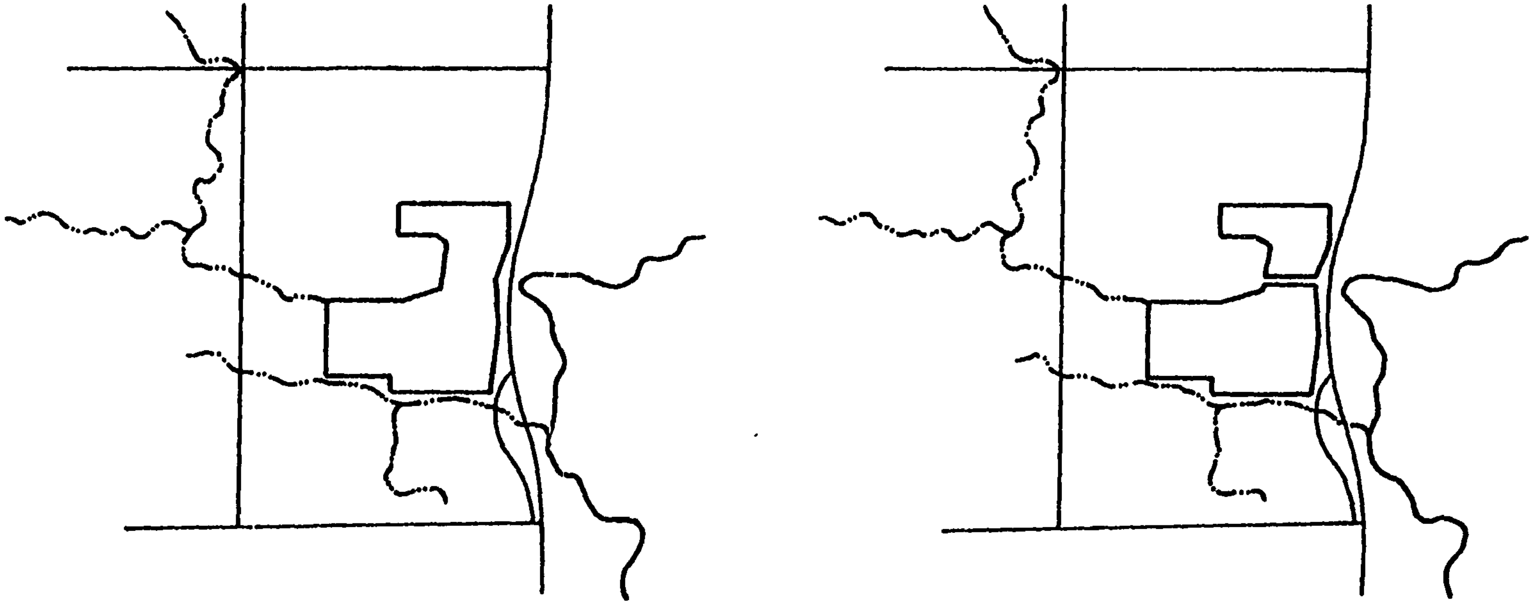
B. the discharge from the south is bypassed while the discharge from the north discharges into the lake or lake system (Figure 29),



A-1

A-2

Figure 28. Drainage scenario A, all drainage into single lake (A-1) and south lake (A-2)



B-1

B-2

Figure 29. Drainage scenario B, southern drainage bypasses single lake (B-1) and south lake (B-2)

C. the same as B except the discharge from the north is detained at Eisenhower Avenue before it discharges into the lake or lake system (Figure 30), and

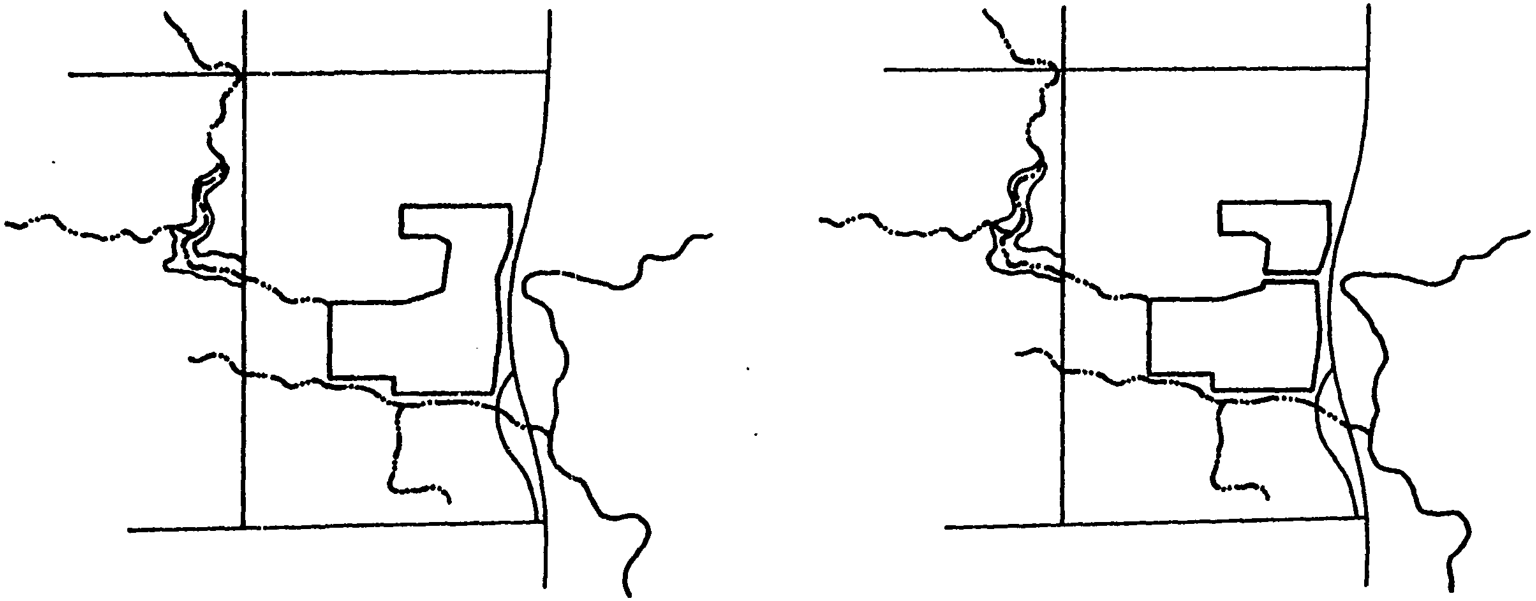
D. all of the drainage discharge is bypassed away from the lake or lake system (Figure 31).

The detention of the northern drainage at Eisenhower Avenue was included because it would reduce the sediment and nutrient load to the lake or lake system. From research conducted across the United States, it has been found that from 31 to 80 percent of the inflow stormwater total phosphorus is retained by small reservoirs (Gill et al., 1976; Schreiber and Rausch, 1979; Ahern et al., 1981; Rausch and Schreiber, 1981; Schreiber et al., 1981). For the purpose of this study, it has been assumed that the construction of a stormwater detention reservoir at Eisenhower Avenue will reduce the total phosphorus load from the northern drainage stream by 60 percent.

The three land use scenarios used were the present 1981 land use, the projected 2020 land use, based on personal communication with the City of Ames Planning and Zoning personnel, and an ultimate land use of total urbanization of the Hallett Quarry watershed. While total urbanization may not seem realistic, it was chosen here to represent the "worse" case in terms of impact on future water quality.

Sources and estimation of phosphorus loads

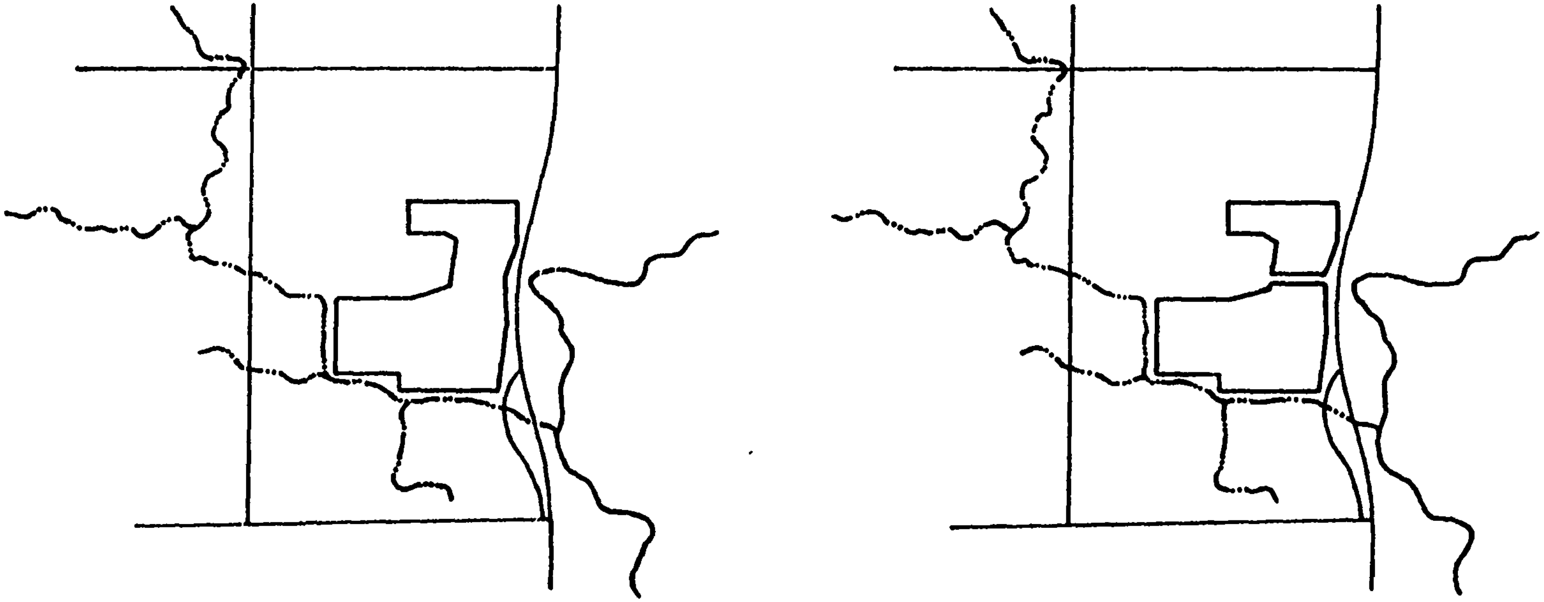
The sources of phosphorus to the Hallett Quarry gravel-pit lake system were assumed to be groundwater, direct precipitation and surface runoff. All other sources were assumed to be negligible. During the



C-1

C-2

Figure 30. Drainage scenario C, southern drainage bypasses while northern drainage is detained before entering single lake (C-1) and south lake (C-2)



D-1

D-2

Figure 31. Drainage scenario D, all drainage bypasses single lake (D-1) and south lake (D-2)

course of this study, groundwater quality samples were obtained from private wells north of the Hallett Quarry gravel-pit lake system. The total phosphorus concentration of the groundwater was found to be 0.156 mg P/l. In their study of the geology and geohydrology of the Ames Reservoir site, Sendlein and Dougal (1968) determined that the average annual groundwater flow through the buried channel aquifer is 1.098×10^9 liters (1.23 cfs). This volume multiplied by the observed phosphorus concentration provides an estimate of the groundwater contribution to the annual total phosphorus load.

The average annual precipitation for Ames, Iowa is 812.8 mm. Jones (1981), in his work on nonpoint source phosphorus loadings to Iowa rivers and lakes, used an average phosphorus concentration of 0.074 mg P/l for Iowa precipitation. An estimate of the precipitation contribution to the total phosphorus load can be made by multiplying the average annual amount of precipitation for Ames, Iowa by the surface area of the lake in question and then this value by the average phosphorus concentration of Iowa precipitation.

The below normal precipitation experienced during the course of this study provided few opportunities for direct measurement of stormwater phosphorus loading to the Hallett Quarry gravel-pit lake system. To overcome this problem, the watershed nutrient export coefficient approach for estimating phosphorus loads was used. The use of this approach requires knowledge of the types and percentages of major land uses within the watershed. Uttormark et al. (1974) concluded in their study that delineation of land usage beyond urban, forest, agricultural and wetlands can not be justified due to the observed variation of the data. An estimate of the total phosphorus load from surface runoff can be made by multiplying the watershed nutrient export coefficient by the area of the watershed under that land usage. Table 17 presents the watershed nutrient export coefficients used in this study. The area of the Hallett Quarry watershed under each type of land use for the three land use scenarios is presented in Table 18.

Table 17. Watershed nutrient export coefficients[a]

Watershed land use	Total phosphorus (g P/m^2/yr)
Urban	0.15
Agricultural	0.03
Forest	0.02

[a] After Uttormark et al., 1974.

Table 18. Area in square meters of Hallett Quarry watershed under each land use

	Present land use	2020 land use	Ultimate land use
North drainage system			
Urban	0	0	6,034,700
Agricultural	5,982,900	5,982,900	0
Forest	51,800	51,800	0
South drainage system			
Urban	1,295,000	2,331,000	3,108,000
Agricultural	1,813,000	777,000	0
Forest	0	0	0

The estimated total phosphorus load for each sceanrio is presented in Table 19. In the single lake scenarios, the total phosphorus load was obtained by summing the contributions from the groundwater, direct precipitation on the lake surface and surface runoff. The same procedure was used in the split lake system for the south lake. In the north lake however, only the contributions from groundwater and direct precipitation were used. This most likely gives a conservative estimate for the north lake since some surface runoff probably will enter this lake from the area to the west of the Oak's Golf Course.

Table 19. Estimated total phosphorus load (g P/yr) for the various lake type, land use and drainage scenarios

	Present land use	2020 land use	Ultimate land use
One lake			
A-1	639,426	763,746	1,581,668
B-1	390,786	390,786	1,115,468
C-1	282,472	282,472	572,345
D-1	210,263	210,263	210,263
Two lakes			
North	184,701	184,701	184,701
South			
A-2	626,013	750,333	1,568,255
B-2	377,373	377,373	1,102,055
C-2	269,059	269,059	558,932
D-2	196,850	196,850	196,850

Estimated morphological and hydrological features

The use of the Canfield and Bachmann modified Vollenweider input-output model requires knowledge of certain morphological and hydrological features of the water body to which it is to be applied. The needed information includes surface area, mean depth and hydraulic flushing rate. This information had to be estimated, based on the morphological and hydrological features of the present gravel-pit lakes, because the lake and lake system to which the model is to be applied are nonexistent at the present time. The estimated morphological and hydrological features for the future final lake and lake system are presented in Table 20.

Table 20. Estimated morphological and hydrological parameters of the future final lake and lake system at Hallett's Quarry

	One lake	Two lakes	
		South	North
Surface area	64.8 ha	42.5 ha	22.3 ha
Volume	$6.15 \times 10^6 m^3$ $2.17 \times 10^8 ft^3$	$4.19 \times 10^6 m^3$ $1.48 \times 10^8 ft^3$	$1.95 \times 10^6 m^3$ $0.69 \times 10^8 ft^3$
Mean depth	9.5 m 31 ft	9.9 m 32 ft	8.8 m 29 ft
Hydraulic flushing rate			
A	$0.47 yr^{-1}$	$0.63 yr^{-1}$	$0.71 yr^{-1}$
B	0.40	0.52	0.71
C	0.40	0.52	0.71
D	0.25	0.34	0.71

Input-output model application

The Canfield and Bachmann modified Vollenweider input-output model was applied to the Hallett Quarry gravel-pit lake system. This model is in the form:

$$TP = \frac{L}{Z\ (\sigma + \rho)} \qquad (4)$$

where

TP = total phosphorus concentration in the lake water, mg/m^3

L = annual phosphorus loading per unit of surface area, $mg/m^2/yr$

Z = mean depth of the lake, m

σ = phosphorus sedimentation coefficient, yr^{-1}

$$= 0.162\ (L/Z)^{0.458} \qquad (6)$$

ρ = hydraulic flushing rate, yr^{-1}.

Table 21 presents the values for L which were obtained by dividing the annual phosphorus load for each scenario by the surface area of the lake in question. The calculated values for σ are presented in Table 22 and the predicted values for TP from the model are presented in Table 23. It should be noted that the 95 percent confidence limits for this model are 31 to 288 percent of the predicted in lake total phosphorus concentration.

Table 21. L, annual phosphorus load per unit lake surface area, mg/m^2/yr

	Present land use	2020 land use	Ultimate land use
<u>One lake</u>			
A-1	987	1,179	2,440
B-1	603	603	1,721
C-1	436	436	883
D-1	325	325	325
<u>Two lakes</u>			
North	828	828	828
South			
A-2	1,473	1,765	3,690
B-2	888	888	2,593
C-2	633	633	1,315
D-2	463	463	463

Table 22. σ, phosphorus sedimentation coefficient, $\sigma = 0.162\ (L/Z)^{0.458}$

	Present land use	2020 land use	Ultimate land use
<u>One lake</u>			
A-1	1.36	1.48	2.04
B-1	1.09	1.09	1.75
C-1	0.93	0.93	1.29
D-1	0.82	0.82	0.82
<u>Two lakes</u>			
North	1.30	1.30	1.30
South			
A-2	1.60	1.74	2.44
B-2	1.27	1.27	2.08
C-2	1.09	1.09	1.52
D-2	0.94	0.94	0.94

Table 23. TP, predicted in lake total phosphorus concentration, mg/m^3

	Present land use	2020 land use	Ultimate land use
<u>One lake</u>			
A-1	56.8[a]	63.9	101.7
B-1	42.7	42.7	84.2
C-1	34.4	34.4	55.0
D-1	32.0	32.0	32.0
<u>Two lakes</u>			
North	46.8	46.8	46.8
South			
A-2	66.7	75.2	121.4
B-2	50.1	50.1	100.9
C-2	39.8	39.8	65.1
D-2	36.5	36.5	36.5

[a] Ninety-five percent confidence limits are 31 to 288 percent of the predicted in lake total phosphorus concentration.

Jones and Bachmann (1976), using data from 143 lakes covering a broad range of trophic states, demonstrated a high correlation ($r = 0.95$) between measured in lake total phosphorus concentrations and the average July-August chlorophyll a concentrations. Their relationship is presented in Figure 32. Using the regression line for this relationship,

$$\log (\text{chlorophyll } \underline{a}) = -1.09 + 1.46 \log (\text{total phosphorus}), \qquad (8)$$

the predicted values for in lake total phosphorus concentrations from the Canfield and Bachmann modified Vollenweider input-output model were used to generate predicted values of chlorophyll a concentrations. These values are presented in Table 24. The chlorophyll a concentrations observed during this study, while being for a different gravel-pit lake system than that to which the model was applied, fall within the 95 percent confidence range of the predicted chlorophyll a concentration. This indicates that the predicted total phosphorus and chlorophyll a concentrations are realistic. A management plan to optimize the future water quality (based on chlorophyll a concentrations) of the Hallett Quarry gravel-pit lake or lake system can now be developed by using the results of the application of the Canfield and Bachmann modified Vollenweider input-output model.

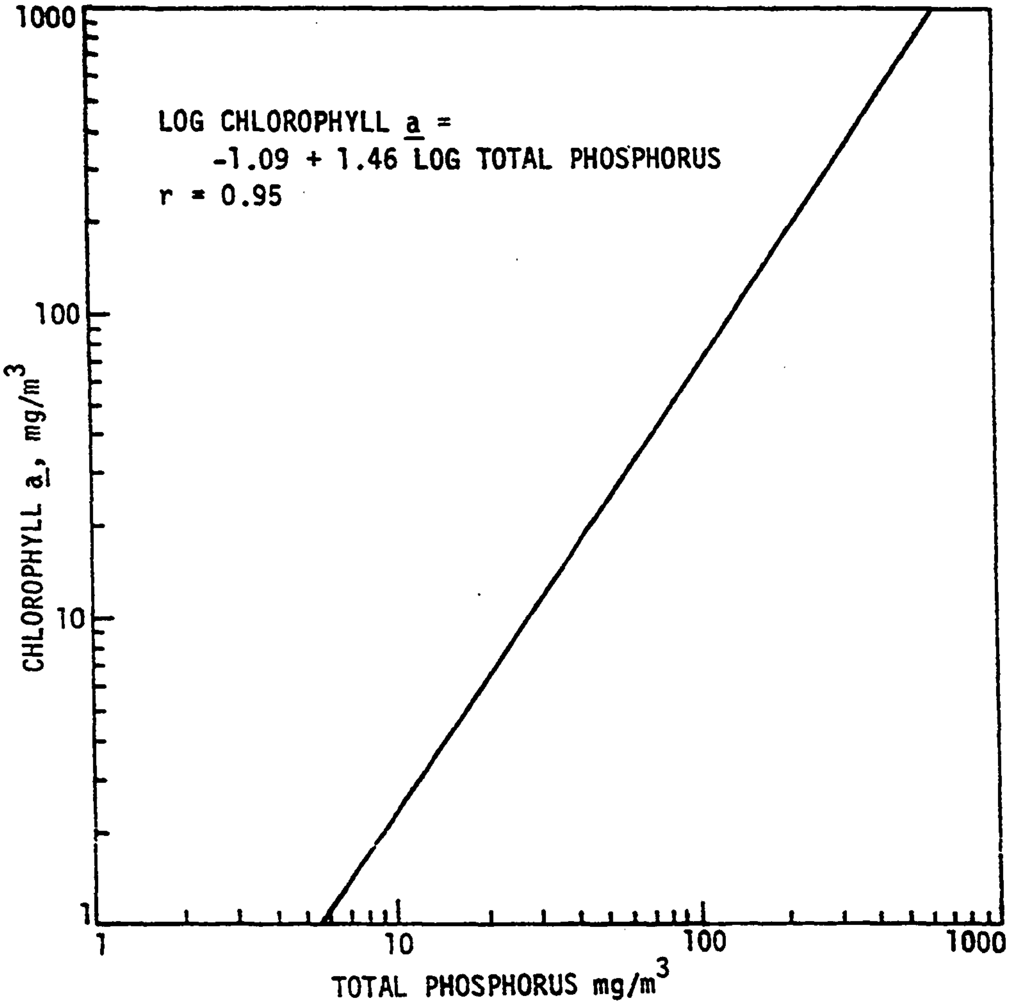


Figure 32. Relationship between summer chlorophyll a concentration and measured total phosphorus concentration (Redrawn from Jones and Bachmann, 1976)

Table 24. Predicted chlorophyll a concentrations (mg/m^3) based on predicted in lake total phosphorus concentrations

	Present land use	2020 land use	Ultimate land use
One lake			
A-1	29.6[a]	35.2	69.3
B-1	19.5	19.5	52.6
C-1	14.2	14.2	28.2
D-1	12.8	12.8	12.8
Two lakes			
North	22.3	22.3	22.3
South			
A-2	37.4	44.6	89.7
B-2	24.6	24.6	68.5
C-2	17.6	17.6	36.1
D-2	15.5	15.5	15.5

[a] Ninety-five percent confidence limits are 31 to 288 percent of the predicted chlorophyll a concentration.

Water quality management plan

The results of the application of the Canfield and Bachmann modified Vollenweider input-output model to the Hallett Quarry area (Table 24) indicate that changes in the watershed land use, drainage and lake configuration can have a large impact on the future water quality of the Hallett Quarry gravel-pit lake system. As the land use of the watershed changes from primarily agricultural to urban (present to ultimate land use), the chlorophyll a concentration in the gravel-pit lake system is predicted to increase up to 65 percent due to the increased phosphorus export from the watershed. Diversion of the drainage around the gravel-pit lake system would reduce the phosphorus load into the system. It is predicted that this reduction in phosphorus load would reduce the chlorophyll a concentration up to 83 percent depending upon how much drainage is diverted, the land use and lake configuration considered.

It is also predicted that the larger single lake would have chlorophyll a concentrations which are 17 to 23 percent lower than the smaller southern lake in the split lake system. The reduction in the aerial phosphorus load due to the larger surface area of the single lake seems to be the determining factor for this because it decreases at a faster rate than the mean depth, phosphorus sedimentation coefficient and hydraulic flushing rate as lake size increases. This means that as the size of the lake increases, the numerator in the input-output model relationship decreases at a faster rate than the denominator resulting in lower in lake total phosphorus and chlorophyll a concentrations.

It is concluded that the future water quality at Hallett's Quarry is dependent upon two factors, lake configuration and nutrient input. The size of the future final lake at Hallett's Quarry can have an influence on the water quality but it is only a minor influence when it is compared to the nutrient input. It appears at this time that the best management plan to implement in order to optimize the future water quality at Hallett's Quarry is to reduce the nutrient inflow into the system. This can be accomplished by either (1) bypassing as much of the drainage as possible around the gravel-pit lake system or (2) detaining the stormwater before it empties into the gravel-pit lake system to settle out sediment, phosphorus, fecal coliform bacteria, etc. In the opinion of the author, bypassing the drainage would be the better of the two alternatives because stormwater runoff contains heavy metals, hydrocarbons, herbicides, pesticides, road salt and many other pollutants which would not be desirable to have discharged into a supplemental municipal water supply source.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

The water quality of the three gravel-pit lakes at Hallett's Quarry and the west gravel-pit lake at Peterson's Quarry was monitored for a 16 month period starting in late June, 1980 and ending in late October, 1981. The four studied gravel-pit lakes were found to be eutrophic, exhibiting annual temperature and dissolved oxygen cycles which are characteristic of north temperate, cool, dimictic eutrophic lakes. The degree of eutrophication is different in each of the studied gravel-pit lakes and when ranked from least eutrophic to most eutrophic the following order is obtained: Hallett-North Pit, Hallett-South Pit, Peterson-West Pit, Hallett-West Pit. It is interesting to note at this time that while all four of the gravel-pit lakes are eutrophic, they are not as productive as other water bodies located on the Wisconsin glacial sheet in central Iowa.

Water quality differences were found to exist between the west gravel-pit lake at Peterson's Quarry and the three gravel-pit lakes at Hallett's Quarry. Of the 18 tested parameters, 8 were found to be significantly different at the 90 percent significance level. Total solids, plant nutrients and soluble silica concentrations are lower in the west gravel-pit lake at Peterson's Quarry while BOD, chloride and corrected chlorophyll _a_ concentrations are higher.

Differences were also found in the water quality of the three Hallett Quarry gravel-pit lakes. The north and south gravel-pit lakes have similar water quality and are different from the west gravel-pit lake. The west gravel-pit lake has significantly higher concentrations of BOD, COD, plant nutrients and fecal coliform bacteria than the north and south gravel-pit lakes.

The stormwater water quality portion of this study was reduced in magnitude due to the lack of runoff producing precipitation. During this study, the Hallett Quarry watershed received from 65 to 78 percent of normal precipitation, with little if any runoff being observed. Five storm runoff events were monitored for water quality in the late summer and fall of 1981. Three of these events were on the agricultural drainage stream and two were on the urban drainage stream. The sampling location on the agricultural drainage stream is directly downstream of a hog lot. The stormwater water quality samples which were collected during this study thus reflect the influence of this hog lot and are not representative of the stormwater water quality from other agricultural areas. The comparison of grand average time and flow weighted concentrations for all of the storms revealed that the values from the agricultural area were from 10 to 100 times greater than those from the urban area.

All of the stormwater runoff presently enters the west gravel-pit lake at Hallett's Quarry. A comparison was made between the three gravel-pit lakes at Hallett's Quarry to see what, if any, differences in water quality exist between them due to this input. Fecal coliform bacteria, turbidity and orthophosphate concentrations increase dramatically in the bottom waters of the west gravel-pit lake after periods of precipitation. This trend does not occur in the north and south gravel-pit lakes. The chemical oxygen demand and total nitrogen concentrations are higher in the west gravel-pit lake than in the north or south. These results indicate that the addition of stormwater to the west gravel-pit lake at Hallett's Quarry is having an effect on its water quality.

The stormwater runoff investigation revealed that large quantities of fecal coliform bacteria are being transported via stormwater runoff into the west gravel-pit lake at Hallett's Quarry. These inputs drastically elevate the in lake concentrations (Figure 21). Since one of the proposed future uses of the Hallett Quarry gravel-pit lake system is to serve as a supplemental water supply for the City of Ames, the sources of the fecal coliform bacteria should be reduced. Two possible solutions are bypassing the stormwater runoff around the gravel-pit lake system or controlling the land use of the watershed.

Water quantity analyses conducted for the period of record and 20-year recurrence interval low flow periods revealed that the present water volume of the Hallett's Quarry gravel-pit lake system could supply a draft rate of 0.142 cms (5 cfs). The projected future water volume when the planned extraction is completed could easily supply a draft rate of 0.227 cms (8 cfs). From these analyses, it is concluded that the Hallett Quarry gravel-pit lake system has sufficient storage volume to adequately serve as a supplemental water supply source for the City of Ames. It is because of this that water quality protection is the key issue for the future.

The Canfield and Bachmann modified Vollenweider input-output model was applied to the Hallett Quarry gravel-pit lake system in order to determine the impact of various land use, drainage and lake configurations on the future water quality. Two lake types, four drainage networks and three land use scenarios were investigated yielding 24 predictions of future water quality. From this investigation, it was determined that nutrient input has the greatest influence on the future water quality.

A management plan to optimize future water quality should then try to reduce the nutrient input into the Hallett Quarry gravel-pit lake system. This can be accomplished by one of two ways; detention of stormwater runoff before it enters the system or diversion of stormwater runoff around the system. Detention could remove 30 to 80 percent of the incoming nutrients due to stormwater runoff. The detention basins would have to be cleaned out periodically because they would fill up with the trapped sediments. On the other hand, diversion would remove 100 percent of the incoming nutrients and would probably not require further maintenance. It is the opinion of the author that diversion would be the better of the two alternatives since not only nutrients due to stormwater runoff but heavy metals, sediment, fecal coliform bacteria, hydrocarbons, road salt, herbicides, pesticides and other pollutants would not be discharged into a supplemental municipal water supply source and potential outdoor recreational use area.

Recommendations for Future Research

Two of the objectives of this research study were to collect baseline water quality data for the three gravel-pit lakes at Hallett's Quarry and west gravel-pit lake at Peterson's Quarry and to quantify the stormwater pollutant loads to the Hallett Quarry gravel-pit lake system. In meeting these objectives, it became apparent that a great deal of knowledge could be acquired in the future if more comprehensive research studies were carried out regarding the limnological characteristics of these gravel-pit lakes and the characterization of the stormwater from the Hallett Quarry watershed.

Future limnological studies of the four gravel-pit lakes should include:

1. primary production measurement to determine the production potential of the gravel-pit lakes,
2. algal assays to determine the factors which are limiting primary production in the gravel-pit lakes,
3. quantification of the zooplankton and phytoplankton communities and investigation of their relationships,
4. quantification of the fisheries and investigation of their interrelationships with the zooplankton and phytoplankton communities,
5. monitor the agricultural drainage stream upstream of the hog lot during storm runoff events to establish a data base for the agricultural part of the Hallett Quarry watershed which is not influenced by the hog lot and,
6. monitor both drainage streams for pollutants other than plant nutrients, sediments, bacteria, BOD and COD.

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ACKNOWLEDGMENTS

The work upon which this dissertation is based was funded by a research grant from the City of Ames, Iowa. Their financial assistance is gratefully acknowledged. I would especially like to thank Dr. Harris Seidel and Mr. Tom Neumann for their support.

I sincerely thank my major professor, Dr. Merwin D. Dougal, for his patience, help and guidance throughout the course of this study. He was always willing to share his expertise of water resources and because of this I have gained much. I would also like to thank the members of my committee, Dr. T. Al Austin, Dr. Roger W. Bachmann, Dr. E. Robert Baumann and Dr. James L. Baker, for their help and assistance.

Many individuals have provided assistance during this study and to them I am indebted. I would like to thank the Hallett Construction Company and the Story County Conservation Board for providing access to the gravel-pit lakes; my fellow graduate students, Robert Carr, Caesar Hall, Dennis Jermeland and Ed Ricci for their help and assistance in the field during data collection; Mr. and Mrs. Boss and Mr. and Mrs. Williams for their assistance in precipitation data collection and Ms. Diana Bosso for her excellent job of typing this manuscript.

I sincerely thank my parents, Peter and Rose Antosch. Their encouragement, understanding and confidence over the years has helped to keep me working toward this personal goal.

Finally, I would like to thank my loving wife, Karen, who has provided invaluable assistance in the laboratory and in the field during data collection, encouragement when I was down, an open ear to my ideas and data interpretation, and patience and understanding during the time I was involved with these studies.

APPENDIX A.

GRAVEL-PIT WATER QUALITY DATA

Table A.1. Temperature data in ^{o}C for Hallett Quarry-South Pit

Date	Depth meters						
	0M	2M	4M	6M	8M	10M	12M
06-25-80	28	24	21	19	17	15	9
07-09-80	29	28	22	20	18	18	15
07-23-80	26.8	26	25	21	17.8	17.8	16
08-06-80	25	25	25	20	19	17	*[a]
08-20-80	22	20	20	20	17	16	16
09-10-80	24.5	24	24	20	17	16	17
09-24-80	19	19	19	19	16	15	15
10-09-80	17.5	16.5	16	16	16	16	15
10-23-80	13	13	13	13	13	13	13
11-05-80	12	10.5	10	9.5	9	9	9
12-04-80	2.5	2.2	2.2	2.2	2.2	2.2	2.5
01-22-81	1.2	4	3.5	4	3.8	4.2	4.5
02-05-81	*	*	*	*	*	*	*
03-04-81	4.5	4.5	4.5	4.5	4.5	4.5	4.5
03-26-81	7	7	7	7	6.5	6.5	6.5
04-09-81	11.2	10.2	10.2	10.2	10.2	10.2	10.2

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[a] In this and all following tables, an asterisk indicates no data taken.

Table A.1. continued

Date	Depth meters						
	0M	2M	4M	6M	8M	10M	12M
04-23-81	11	*	*	*	*	*	*
05-07-81	14	14	14	14	14	13	13
05-21-81	15.5	15.5	14.5	14.5	14	14	14
06-04-81	21	21	19.5	18	17	17	16
06-25-81	22	21.5	21.5	20.5	20.5	19	17.5
07-09-81	26	26	26	24	23.5	21	19
07-23-81	25.4	25.2	25.2	24.6	23.2	20.8	20.5
08-13-81	25.7	25.7	25.7	24.5	22.9	22.1	20.0
08-31-81	24	24	24	24	23	21.5	20.5
09-14-81	23	23	23	23	22	21.5	21
09-28-81	18	18	19	18	18.5	18.5	18
10-12-81	15	15	15.5	15	15.5	15	15
10-26-81	10.5	10.5	10.5	10.5	11	11	11

Table A.2. Temperature data in °C for Hallett Quarry-North Pit

Date	Depth meters 0M	2M	4M	6M	8M	10M	12M
06-25-80	27	25	24	23	20	10	7
07-09-80	*	*	*	*	*	*	*
07-23-80	26	25	24	23.8	22.5	*	*
08-06-80	*	*	*	*	*	*	*
08-20-80	30	29.5	28	28	28	*	*
09-10-80	*	*	*	*	*	*	*
09-24-80	21	20.5	20	20	20	*	*
10-09-80	*	*	*	*	*	*	*
10-23-80	*	*	*	*	*	*	*
11-05-80	*	*	*	*	*	*	*
12-04-80	2.5	*	*	*	*	*	*
01-22-81	*	*	*	*	*	*	*
02-05-81	*	*	*	*	*	*	*
03-04-81	*	*	*	*	*	*	*
03-26-81	8	8	7	7	7	*	*
04-09-81	*	*	*	*	*	*	*

Table A.2. continued

Date	Depth meters						
	0M	2M	4M	6M	8M	10M	12M
04-23-81	11	*	*	*	*	*	*
05-07-81	*	*	*	*	*	*	*
05-21-81	17	16	15	14.5	14	*	*
06-04-81	*	*	*	*	*	*	*
06-25-81	23	23	22.5	22	18	*	*
07-09-81	*	*	*	*	*	*	*
07-23-81	26.2	26.0	25.4	24.9	23.8	*	*
08-13-81	*	*	*	*	*	*	*
08-31-81	24	24	24	24	23	*	*
09-14-81	*	*	*	*	*	*	*
09-28-81	18	18	18	18	18	*	*
10-12-81	*	*	*	*	*	*	*
10-26-81	*	*	*	*	*	*	*

Table A.3. Temperature data in °C for Hallett Quarry-West Pit

Date	Depth meters						
	0M	2M	4M	6M	8M	10M	12M
06-25-80	25	24	21	16	14	14	10
07-09-80	*	*	*	*	*	*	*
07-23-80	27	26	23	15.5	12.5	12	12
08-06-80	*	*	*	*	*	*	*
08-20-80	26	26	24	18	15	13	13
09-10-80	*	*	*	*	*	*	*
09-24-80	19	19	19	16	13	12	12
10-09-80	*	*	*	*	*	*	*
10-23-80	12	12	12	12	12	11.5	11
11-05-80	*	*	*	*	*	*	*
12-04-80	*	*	*	*	*	*	*
01-22-81	*	*	*	*	*	*	*
02-05-81	*	*	*	*	*	*	*
03-04-81	*	*	*	*	*	*	*
03-26-81	8	7.5	7.5	7	7	6	6
04-09-81	*	*	*	*	*	*	*

Table A.3. continued

Date	Depth meters						
	0M	2M	4M	6M	8M	10M	12M
04-23-81	11	*	*	*	*	*	*
05-07-81	*	*	*	*	*	*	*
05-21-81	16	15.5	14	14	13.5	13	12.5
06-04-81	*	*	*	*	*	*	*
06-25-81	23	22.5	22	21	18	14	14
07-09-81	*	*	*	*	*	*	*
07-23-81	26	26.5	25.4	22.5	16.1	15	14.6
08-13-81	*	*	*	*	*	*	*
08-31-81	24	24	24	23.5	19	16	15
09-14-81	*	*	*	*	*	*	*
09-28-81	17	17.5	18	17.5	18	14.5	13
10-12-81	*	*	*	*	*	*	*
10-26-81	*	*	*	*	*	*	*

Table A.4. Temperature data in °C for Peterson Quarry-West Pit

Date	Depth meters						
	0M	2M	4M	6M	8M	10M	12M
06-25-80	*	*	*	*	*	*	*
07-09-80	28	27	23	16	11	11	*
07-23-80	*	*	*	*	*	*	*
08-06-80	27	26	24	22	13	13	*
08-20-80	*	*	*	*	*	*	*
09-10-80	24	24	23	18.5	12	10.5	*
09-24-80	*	*	*	*	*	*	*
10-09-80	17.5	17	17	16.5	14	13	*
10-23-80	*	*	*	*	*	*	*
11-05-80	9	9	8.5	8	8	8	*
12-04-80	*	*	*	*	*	*	*
01-22-81	2.5	4.5	5	5.5	5	4.5	*
02-05-81	*	*	*	*	*	*	*
03-04-81	4	4	4	4	4	4	*
03-26-81	*	*	*	*	*	*	*
04-09-81	12.5	12.5	12	12	11.5	*	*

Table A.4. continued

Date	Depth meters 0M	2M	4M	6M	8M	10M	12M
04-23-81	*	*	*	*	*	*	*
05-07-81	15	14.5	14.5	14.5	12	12	*
05-21-81	*	*	*	*	*	*	*
06-04-81	23	23	19	16	14	14	*
06-25-81	*	*	*	*	*	*	*
07-09-81	27	27	25	20	14	14	*
07-23-81	*	*	*	*	*	*	*
08-13-81	27	26.4	25.4	23.3	17.0	16.8	*
08-31-81	*	*	*	*	*	*	*
09-14-81	22.5	23	22.5	21.5	18	15	*
09-28-81	*	*	*	*	*	*	*
10-12-81	14	14.5	14.5	14	14	14	*
10-26-81	*	*	*	*	*	*	*

Table A.5. Dissolved oxygen data in mg/l for Hallett Quarry-South Pit

Date	Depth meters						
	0M	2M	4M	6M	8M	10M	12M
06-25-80	8.7	9.2	8.0	5.7	4.7	4.7	2.9
07-09-80	8.4	10.0	6.7	4.6	1.6	2.1	0.6
07-23-80	8.3	8.3	8.3	5.5	0.4	1.2	0.5
08-06-80	8.1	8.1	7.9	0.8	0.5	0.4	*
08-20-80	8.0	7.7	7.3	1.1	0.4	0.2	0.6
09-10-80	7.7	8.5	7.8	0.8	0.6	0.8	0.5
09-24-80	8.5	7.9	7.9	7.4	0.9	0.9	0.6
10-09-80	7.7	9.0	9.1	7.0	7.8	4.4	0.8
10-23-80	8.2	9.5	8.5	8.6	8.6	8.8	8.0
11-05-80	9.2	8.8	8.4	9.4	9.3	9.5	8.9
12-04-80	12.3	12.4	12.4	12.1	12.3	11.8	12.2
01-22-81	14.5	15.4	15.5	15.6	13.9	11.3	9.4
02-05-81	17.7	17.6	17.4	17.1	14.1	11.3	8.5
03-04-81	11.3	11.6	11.4	11.6	11.6	11.4	11.9
03-26-81	12.4	12.4	12.3	12.2	12.0	11.8	11.9
04-09-81	10.6	10.5	10.9	10.8	10.8	10.7	10.6

Table A.5. continued

Date	Depth meters						
	0M	2M	4M	6M	8M	10M	12M
04-23-81	10.6	*	*	*	*	*	*
05-07-81	10.0	9.7	9.8	9.8	9.9	9.1	7.5
05-21-81	9.8	9.9	9.7	10.6	9.5	9.4	8.9
06-04-81	8.9	9.1	9.1	9.3	8.7	8.4	6.0
06-25-81	8.1	7.9	8.0	6.8	6.0	6.2	1.4
07-09-81	8.1	8.1	8.2	7.6	7.2	4.9	1.4
07-23-81	8.1	8.0	7.9	6.6	5.3	2.0	3.2
08-13-81	8.8	9.1	8.9	7.0	3.8	1.3	0.6
08-31-81	8.0	8.2	7.8	8.1	1.4	0.6	0.3
09-14-81	8.4	8.5	8.4	8.5	8.4	0.9	1.0
09-28-81	7.9	7.9	7.9	7.9	7.9	7.8	7.9
10-12-81	9.1	9.0	9.2	9.1	9.0	9.1	9.1
10-26-81	10.1	10.1	10.2	10.0	10.1	9.8	9.9

Table A.6. Dissolved oxygen data in mg/l for Hallett Quarry-North Pit

Date	Depth meters						
	0M	2M	4M	6M	8M	10M	12M
06-25-80	8.8	8.7	9.4	9.3	8.4	6.9	4.7
07-09-80	*	*	*	*	*	*	*
07-23-80	8.1	8.1	6.9	6.1	5.0	*	*
08-06-80	*	*	*	*	*	*	*
08-20-80	7.4	7.4	6.4	6.1	5.7	*	*
09-10-80	*	*	*	*	*	*	*
09-24-80	7.1	7.7	7.7	7.5	7.9	*	*
10-09-80	*	*	*	*	*	*	*
10-23-80	8.8	8.3	8.2	6.8	9.2	*	*
11-05-80	*	*	*	*	*	*	*
12-04-80	12.8	*	*	*	*	*	*
01-22-81	*	*	*	*	*	*	*
02-05-81	13.1	13.1	13.0	13.0	13.1	*	*
03-04-81	*	*	*	*	*	*	*
03-26-81	12.2	12.2	12.2	12.5	12.7	*	*
04-09-81	*	*	*	*	*	*	*

Table A.6. continued

Date	Depth meters 0M	2M	4M	6M	8M	10M	12M
04-23-81	11.2	*	*	*	*	*	*
05-07-81	*	*	*	*	*	*	*
05-21-81	11.5	11.4	10.8	10.0	9.9	*	*
06-04-81	*	*	*	*	*	*	*
06-25-81	8.3	8.4	7.9	7.7	5.3	*	*
07-09-81	*	*	*	*	*	*	*
07-23-81	8.0	8.0	7.7	8.3	6.0	*	*
08-13-81	*	*	*	*	*	*	*
08-31-81	7.9	8.0	8.0	7.8	4.3	*	*
09-14-81	*	*	*	*	*	*	*
09-28-81	8.2	8.2	8.3	8.4	8.1	*	*
10-12-81	*	*	*	*	*	*	*
10-26-81	10.2	10.3	10.3	10.2	10.2	*	*

Table A.7. Dissolved oxygen data in mg/l for Hallett Quarry-West Pit

Date	Depth meters						
	0M	2M	4M	6M	8M	10M	12M
06-25-80	10.2	13.1	8.4	1.8	0.6	0.5	3.2
07-09-80	*	*	*	*	*	*	*
07-23-80	8.2	8.4	5.3	1.5	2.2	1.7	0.8
08-06-80	*	*	*	*	*	*	*
08-20-80	10.4	10.0	5.6	1.2	0.5	0.8	0.0
09-10-80	*	*	*	*	*	*	*
09-24-80	9.0	7.2	8.3	1.0	0.6	1.0	1.2
10-09-80	*	*	*	*	*	*	*
10-23-80	8.1	6.6	8.3	7.8	8.0	7.5	2.0
11-05-80	*	*	*	*	*	*	*
12-04-80	11.9	*	*	*	*	*	*
01-22-81	*	*	*	*	*	*	*
02-05-81	20.1	20.8	20.5	17.1	14.6	11.1	6.1
03-04-81	*	*	*	*	*	*	*
03-26-81	12.3	12.4	12.2	12.3	11.7	11.8	11.4
04-09-81	*	*	*	*	*	*	*

Table A.7. continued

Date	Depth meters						
	0M	2M	4M	6M	8M	10M	12M
04-23-81	12.0	*	*	*	*	*	*
05-07-81	*	*	*	*	*	*	*
05-21-81	10.6	10.3	11.0	10.7	9.0	5.1	2.3
06-04-81	*	*	*	*	*	*	*
06-25-81	8.4	8.0	7.4	6.1	4.2	0.9	0.5
07-09-81	*	*	*	*	*	*	*
07-23-81	10.4	10.4	10.4	8.6	0.5	0.4	0.5
08-13-81	*	*	*	*	*	*	*
08-31-81	8.9	8.9	9.1	5.0	0.6	0.1	0.0
09-14-81	*	*	*	*	*	*	*
09-28-81	9.2	9.2	9.4	9.5	9.1	0.5	0.0
10-12-81	*	*	*	*	*	*	*
10-26-81	7.2	7.0	7.0	7.1	7.0	7.1	7.1

Table A.8. Dissolved oxygen data in mg/l for Peterson Quarry-West Pit

	Depth meters						
Date	0M	2M	4M	6M	8M	10M	12M
06-25-80	*	*	*	*	*	*	*
07-09-80	8.7	8.6	7.9	0.8	0.5	0.3	*
07-23-80	*	*	*	*	*	*	*
08-06-80	8.7	8.6	3.9	2.8	0.2	0.0	*
08-20-80	*	*	*	*	*	*	*
09-10-80	6.6	6.5	5.4	0.9	0.1	0.0	*
09-24-80	*	*	*	*	*	*	*
10-09-80	10.2	7.8	7.9	6.4	0.2	0.1	*
10-23-80	*	*	*	*	*	*	*
11-05-80	11.5	10.9	10.8	10.7	10.7	10.6	*
12-04-80	*	*	*	*	*	*	*
01-22-81	13.9	15.1	13.8	13.9	12.4	12.1	*
02-05-81	*	*	*	*	*	*	*
03-04-81	12.0	11.8	11.6	11.6	11.6	11.7	*
03-26-81	*	*	*	*	*	*	*
04-09-81	11.3	11.4	10.7	10.3	9.3	*	*

Table A.8. continued

Date	Depth meters						
	0M	2M	4M	6M	8M	10M	12M
04-23-81	*	*	*	*	*	*	*
05-07-81	10.6	10.4	10.4	7.2	2.4	0.9	*
05-21-81	*	*	*	*	*	*	*
06-04-81	8.9	8.8	7.1	3.7	1.3	0.1	*
06-25-81	*	*	*	*	*	*	*
07-09-81	7.5	7.5	3.8	4.9	0.3	0.1	*
07-23-81	*	*	*	*	*	*	*
08-13-81	9.1	9.1	5.6	1.1	0.5	0.0	*
08-31-81	*	*	*	*	*	*	*
09-14-81	8.2	8.2	6.5	2.6	0.8	0.3	*
09-28-81	*	*	*	*	*	*	*
10-12-81	8.0	7.9	7.7	7.0	6.4	4.7	*
10-26-81	*	*	*	*	*	*	*

Table A.9. pH data for the four studied gravel-pit lakes

Date	Hallett's South			Hallett's North			Hallett's West			Peterson's West		
	S[a]	M	B	S	M	B	S	M	B	S	M	B
06-25-80	8.2	7.8	7.6	8.3	8.1	7.8	8.2	7.6	7.5	*	*	*
07-09-80	8.0	7.8	7.4	*	*	*	*	*	*	8.2	7.5	7.4
07-23-80	8.1	7.6	7.7	8.3	8.1	7.9	8.2	7.7	7.6	*	*	*
08-06-80	8.0	7.5	7.5	*	*	*	*	*	*	8.3	7.5	7.6
08-20-80	7.9	7.1	7.1	7.9	7.8	7.7	8.2	7.3	7.2	*	*	*
09-10-80	7.9	7.1	7.2	*	*	*	*	*	*	8.0	7.4	7.3
09-24-80	7.4	7.5	7.4	8.1	8.0	8.0	8.1	7.3	7.3	*	*	*
10-09-80	8.1	8.0	7.3	*	*	*	*	*	*	8.3	8.1	7.5
10-23-80	8.1	8.0	8.0	8.2	8.2	8.2	7.9	7.9	7.4	*	*	*
11-05-80	8.0	8.0	7.9	*	*	*	*	*	*	8.2	8.2	8.2
12-04-80	8.0	8.1	8.1	8.2	*	*	8.1	*	*	*	*	*
01-22-81	8.2	8.1	7.7	*	*	*	*	*	*	8.4	8.2	8.2
02-05-81	8.0	7.9	7.4	7.8	7.7	7.7	8.2	7.9	7.3	*	*	*
03-04-81	7.5	7.5	7.7	*	*	*	*	*	*	7.5	7.3	7.8
03-26-81	7.8	7.7	7.7	7.7	7.7	7.7	7.8	7.8	7.7	*	*	*
04-09-81	7.9	7.9	7.9	*	*	*	*	*	*	7.9	7.7	7.8

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[a] In this and all following tables, S = surface, M = middle and B = bottom.

Table A.9. continued

Date	Hallett's South			Hallett's North			Hallett's West			Peterson's West		
	S	M	B	S	M	B	S	M	B	S	M	B
04-23-81	8.0	*	*	7.9	*	*	8.0	*	*	*	*	*
05-07-81	7.4	7.9	7.6	*	*	*	*	*	*	8.0	6.9	7.4
05-21-81	7.7	7.5	7.5	7.8	7.6	7.4	7.8	7.7	7.1	*	*	*
06-04-81	7.6	7.4	7.1	*	*	*	*	*	*	7.7	7.1	7.0
06-25-81	7.9	7.5	7.4	8.1	7.9	7.5	7.8	7.6	7.5	*	*	*
07-09-81	7.7	7.5	7.1	*	*	*	*	*	*	7.8	7.7	7.1
07-23-81	8.0	7.7	7.3	8.1	8.1	7.7	8.2	7.8	7.3	*	*	*
08-13-81	8.0	7.7	7.2	*	*	*	*	*	*	8.2	7.3	7.2
08-31-81	7.9	7.9	7.0	8.0	8.0	7.5	8.5	7.7	7.2	*	*	*
09-14-81	8.0	8.0	7.2	*	*	*	*	*	*	8.1	7.5	7.2
09-28-81	8.0	7.9	8.0	8.0	8.1	7.9	8.5	8.5	7.5	*	*	*
10-12-81	8.3	8.3	8.2	*	*	*	*	*	*	8.1	8.0	7.9
10-26-81	8.3	8.3	7.3	8.2	8.2	8.2	7.9	7.9	7.9	*	*	*

Table A.10. Total alkalinity data in mg/l as $CaCO_3$ for the four studied gravel-pit lakes

Date	Hallett's South			Hallett's North			Hallett's West			Peterson's West		
	S	M	B	S	M	B	S	M	B	S	M	B
06-25-80	203	236	261	162	163	197	226	274	295	*	*	*
07-09-80	167	178	257	*	*	*	*	*	*	156	220	254
07-23-80	154	210	235	144	148	158	178	251	293	*	*	*
08-06-80	145	207	223	*	*	*	*	*	*	154	199	271
08-20-80	139	208	258	143	144	145	142	175	200	*	*	*
09-10-80	162	227	272	*	*	*	*	*	*	166	251	305
09-24-80	180	177	277	156	155	156	172	279	284	*	*	*
10-09-80	203	202	260	*	*	*	*	*	*	195	198	317
10-23-80	215	216	216	162	164	163	237	235	284	*	*	*
11-05-80	219	219	217	*	*	*	*	*	*	209	209	210
12-04-80	229	239	240	180	*	*	263	*	*	*	*	*
01-22-81	246	255	279	*	*	*	*	*	*	233	244	248
02-05-81	244	254	272	189	196	193	253	264	291	*	*	*
03-04-81	264	262	248	*	*	*	*	*	*	276	247	233
03-26-81	259	256	258	202	202	201	273	273	275	*	*	*
04-09-81	246	247	245	*	*	*	*	*	*	239	233	237

Table A.10. continued

Date	Hallett's South			Hallett's North			Hallett's West			Peterson's West		
	S	M	B	S	M	B	S	M	B	S	M	B
04-23-81	238	*	*	189	*	*	250	*	*	*	*	*
05-07-81	217	229	238	*	*	*	*	*	*	215	190	239
05-21-81	171	227	226	171	174	174	245	239	264	*	*	*
06-04-81	207	216	228	*	*	*	*	*	*	207	219	264
06-25-81	209	211	233	170	167	182	196	199	282	*	*	*
07-09-81	179	201	224	*	*	*	*	*	*	191	198	283
07-23-81	174	201	213	154	153	175	153	189	296	*	*	*
08-13-81	165	175	228	*	*	*	*	*	*	189	212	323
08-31-81	160	160	221	149	148	169	132	148	313	*	*	*
09-14-81	167	166	210	*	*	*	*	*	*	194	205	343
09-28-81	184	185	185	166	164	165	157	156	318	*	*	*
10-12-81	185	187	186	*	*	*	*	*	*	225	223	235
10-26-81	186	186	184	171	172	172	200	199	199	*	*	*

Table A.11. Total hardness data in mg/l as $CaCO_3$ for the four studied gravel-pit lakes

Date	Hallett's South			Hallett's North			Hallett's West			Peterson's West		
	S	M	B	S	M	B	S	M	B	S	M	B
06-25-80	300	322	340	274	282	310	324	342	356	*	*	*
07-09-80	288	292	332	*	*	*	*	*	*	244	306	326
07-23-80	273	316	320	274	278	286	293	342	364	*	*	*
08-06-80	258	316	324	*	*	*	*	*	*	246	292	360
08-20-80	260	322	340	271	278	283	273	336	384	*	*	*
09-10-80	274	320	334	*	*	*	*	*	*	254	316	331
09-24-80	266	290	328	282	280	278	258	335	344	*	*	*
10-09-80	314	308	331	*	*	*	*	*	*	270	274	300
10-23-80	314	264	312	288	292	291	309	308	340	*	*	*
11-05-80	311	314	320	*	*	*	*	*	*	200	270	200
12-04-80	331	327	328	301	*	*	318	*	*	*	*	*
01-22-81	335	344	363	*	*	*	*	*	*	292	304	310
02-05-81	339	342	363	314	324	322	312	322	357	*	*	*
03-04-81	333	332	326	*	*	*	*	*	*	288	290	288
03-26-81	342	322	338	324	320	318	318	324	326	*	*	*
04-09-81	330	324	329	*	*	*	*	*	*	294	285	292

Table A.11. continued

Date	Hallett's South			Hallett's North			Hallett's West			Peterson's West		
	S	M	B	S	M	B	S	M	B	S	M	B
04-23-81	324	*	*	310	*	*	301	*	*	*	*	*
05-07-81	326	320	328	*	*	*	*	*	*	271	278	284
05-21-81	322	320	324	292	298	284	288	292	314	*	*	*
06-04-81	316	276	322	*	*	*	*	*	*	272	278	304
06-25-81	308	310	318	286	292	296	260	268	350	*	*	*
07-09-81	288	306	328	*	*	*	*	*	*	256	258	320
07-23-81	288	304	312	284	279	292	214	252	324	*	*	*
08-13-81	276	294	316	*	*	*	*	*	*	249	274	364
08-31-81	272	272	314	276	276	294	180	192	320	*	*	*
09-14-81	280	279	306	*	*	*	*	*	*	254	262	340
09-28-81	290	286	288	288	286	288	194	194	318	*	*	*
10-12-81	290	292	290	*	*	*	*	*	*	272	270	276
10-26-81	294	294	294	296	296	296	232	232	240	*	*	*

Table A.12. Total solids data in mg/l for the four studied gravel-pit lakes

Date	Hallett's South			Hallett's North			Hallett's West			Peterson's West		
	S	M	B	S	M	B	S	M	B	S	M	B
06-25-80	436	423	447	481	426	409	387	422	452	*	*	*
07-09-80	410	435	452	*	*	*	*	*	*	385	420	457
07-23-80	400	439	434	394	397	432	348	432	464	*	*	*
08-06-80	425	437	520	*	*	*	*	*	*	411	396	469
08-20-80	394	436	456	423	428	464	337	428	477	*	*	*
09-10-80	347	431	410	*	*	*	*	*	*	338	398	433
09-24-80	396	386	420	403	390	612	328	422	430	*	*	*
10-09-80	400	403	410	*	*	*	*	*	*	380	359	435
10-23-80	430	431	416	404	403	420	392	372	428	*	*	*
11-05-80	422	439	430	*	*	*	*	*	*	382	370	380
12-04-80	432	402	404	426	*	*	411	*	*	*	*	*
01-22-81	379	456	460	*	*	*	*	*	*	346	361	362
02-05-81	412	417	432	427	424	429	368	398	419	*	*	*
03-04-81	442	435	424	*	*	*	*	*	*	358	372	368
03-26-81	436	435	445	433	444	440	345	396	391	*	*	*
04-09-81	426	424	438	*	*	*	*	*	*	380	379	403

Table A.12. continued

Date	Hallett's South			Hallett's North			Hallett's West			Peterson's West		
	S	M	B	S	M	B	S	M	B	S	M	B
04-23-81	387	*	*	546	*	*	396	*	*	*	*	*
05-07-81	398	404	396	*	*	*	*	*	*	376	372	388
05-21-81	412	418	412	418	414	416	361	357	396	*	*	*
06-04-81	429	436	452	*	*	*	*	*	*	388	380	408
06-25-81	413	422	423	420	436	450	341	368	425	*	*	*
07-09-81	402	414	425	*	*	*	*	*	*	353	398	424
07-23-81	404	412	438	400	402	412	304	332	382	*	*	*
08-13-81	416	424	520	*	*	*	*	*	*	352	358	558
08-31-81	395	382	424	393	410	418	233	258	384	*	*	*
09-14-81	384	388	396	*	*	*	*	*	*	364	388	422
09-28-81	402	388	398	400	404	394	297	320	439	*	*	*
10-12-81	421	408	414	*	*	*	*	*	*	374	374	380
10-26-81	395	409	400	403	411	412	293	296	306	*	*	*

Table A.13. Suspended solids data in mg/l for the four studied gravel-pit lakes

Date	Hallett's South			Hallett's North			Hallett's West			Peterson's West		
	S	M	B	S	M	B	S	M	B	S	M	B
06-25-80	14.0	18.0	5.4	2.4	7.3	11.6	19.0	2.6	4.0	*	*	*
07-09-80	6.7	8.4	13.0	*	*	*	*	*	*	4.1	12.0	20.0
07-23-80	4.6	8.0	6.8	7.2	12.2	39.8	4.0	3.8	7.2	*	*	*
08-06-80	7.8	8.8	3.8	*	*	*	*	*	*	5.0	7.2	21.4
08-20-80	9.4	7.1	8.1	9.6	14.0	20.5	4.0	4.5	7.1	*	*	*
09-10-80	8.0	8.2	19.0	*	*	*	*	*	*	7.1	9.1	21.0
09-24-80	2.6	4.4	5.6	13.0	13.0	23.5	7.0	6.0	14.5	*	*	*
10-09-80	3.4	3.9	6.1	*	*	*	*	*	*	5.9	4.1	21.0
10-23-80	4.5	3.8	5.5	17.0	22.0	20.0	14.0	14.0	20.0	*	*	*
11-05-80	5.2	7.8	8.2	*	*	*	*	*	*	8.2	9.5	10.0
12-04-80	7.2	12.0	12.0	27.0	*	*	4.5	*	*	*	*	*
01-22-81	6.4	5.4	12.0	*	*	*	*	*	*	7.0	6.8	8.2
02-05-81	5.5	3.0	3.0	3.0	3.2	3.5	2.8	3.0	2.5	*	*	*
03-04-81	19.0	18.0	23.0	*	*	*	*	*	*	6.8	6.2	6.8
03-26-81	6.0	5.6	9.4	4.6	6.2	5.4	3.0	4.6	4.2	*	*	*
04-09-81	30.0	33.0	36.0	*	*	*	*	*	*	13.0	16.0	23.0

Table A.13. continued

Date	Hallett's South			Hallett's North			Hallett's West			Peterson's West		
	S	M	B	S	M	B	S	M	B	S	M	B
04-23-81	48.8	*	*	15.3	*	*	20.0	*	*	*	*	*
05-07-81	22.0	23.0	34.0	*	*	*	*	*	*	10.0	12.0	13.0
05-21-81	9.0	13.0	13.0	8.8	7.8	10.0	2.8	2.8	3.8	*	*	*
06-04-81	4.2	7.0	12.0	*	*	*	*	*	*	5.5	7.8	14.0
06-25-81	4.8	8.2	6.5	4.8	5.2	1.8	11.2	21.0	15.5	*	*	*
07-09-81	3.2	5.5	4.2	*	*	*	*	*	*	4.5	5.2	7.0
07-23-81	3.0	5.0	19.8	4.2	4.2	9.0	3.4	21.2	10.4	*	*	*
08-13-81	5.1	5.1	6.1	*	*	*	*	*	*	5.9	6.5	6.9
08-31-81	2.8	2.2	6.4	3.4	4.0	6.4	5.2	6.4	9.4	*	*	*
09-14-81	4.8	5.8	5.6	*	*	*	*	*	*	7.8	5.6	9.5
09-28-81	6.2	6.9	7.4	6.4	6.4	11.6	7.0	7.4	8.6	*	*	*
10-12-81	5.5	4.6	6.6	*	*	*	*	*	*	8.0	8.3	8.2
10-26-81	5.0	4.5	8.0	6.8	6.2	5.5	4.5	4.0	4.2	*	*	*

Table A.14. Specific conductance data in μ mho/cm for the four studied gravel-pit lakes

Date	Hallett's South			Hallett's North			Hallett's West			Peterson's West		
	S	M	B	S	M	B	S	M	B	S	M	B
06-25-80	581	611	641	560	581	622	651	671	671	*	*	*
07-09-80	571	593	659	*	*	*	*	*	*	549	637	681
07-23-80	535	620	642	562	572	578	576	642	699	*	*	*
08-06-80	541	626	658	*	*	*	*	*	*	584	584	690
08-20-80	554	611	686	580	588	588	567	694	738	*	*	*
09-10-80	551	623	621	*	*	*	*	*	*	551	628	695
09-24-80	590	585	695	583	587	587	562	686	693	*	*	*
10-09-80	626	616	626	*	*	*	*	*	*	591	580	690
10-23-80	609	617	619	596	597	599	609	608	659	*	*	*
11-05-80	603	592	607	*	*	*	*	*	*	593	592	590
12-04-80	592	573	597	573	*	*	573	*	*	*	*	*
01-22-81	655	655	698	*	*	*	*	*	*	623	658	655
02-05-81	645	655	686	634	645	655	598	615	655	*	*	*
03-04-81	635	646	623	*	*	*	*	*	*	614	614	624
03-26-81	624	614	573	614	624	614	604	583	593	*	*	*
04-09-81	618	645	629	*	*	*	*	*	*	613	623	628

Table A.14. continued

Date	Hallett's South			Hallett's North			Hallett's West			Peterson's West		
	S	M	B	S	M	B	S	M	B	S	M	B
04-23-81	613	*	*	624	*	*	597	*	*	*	*	*
05-07-81	592	590	590	*	*	*	*	*	*	590	581	601
05-21-81	585	590	609	580	591	590	561	554	561	*	*	*
06-04-81	620	626	645	*	*	*	*	*	*	604	613	660
06-25-81	629	638	657	610	614	624	530	526	636	*	*	*
07-09-81	610	628	632	*	*	*	*	*	*	581	629	700
07-23-81	586	619	665	597	619	608	456	543	643	*	*	*
08-13-81	556	577	663	*	*	*	*	*	*	556	598	748
08-31-81	564	553	628	574	574	607	325	328	639	*	*	*
09-14-81	567	566	622	*	*	*	*	*	*	567	590	698
09-28-81	606	595	596	617	628	595	347	347	641	*	*	*
10-12-81	767	797	783	*	*	*	*	*	*	797	797	954
10-26-81	573	572	583	593	603	587	460	452	465	*	*	*

Table A.15. Turbidity data in NTUs for the four studied gravel-pit lakes

Date	Hallett's South			Hallett's North			Hallett's West			Peterson's West		
	S	M	B	S	M	B	S	M	B	S	M	B
06-25-80	*	*	*	*	*	*	*	*	*	*	*	*
07-09-80	*	*	*	*	*	*	*	*	*	*	*	*
07-23-80	3.2	6.5	14.0	5.0	5.9	26.0	3.2	1.9	6.0	*	*	*
08-06-80	4.0	3.0	3.4	*	*	*	*	*	*	4.0	4.1	1.7
08-20-80	9.5	5.4	18.0	8.3	12.0	23.0	3.0	3.6	18.0	*	*	*
09-10-80	7.3	4.4	9.5	*	*	*	*	*	*	5.4	4.7	18.0
09-24-80	3.9	4.5	6.4	13.0	14.0	14.0	4.4	4.0	15.0	*	*	*
10-09-80	17.0	15.0	16.0	*	*	*	*	*	*	16.0	13.0	28.0
10-23-80	4.4	6.0	5.5	14.0	15.0	16.0	9.8	11.0	14.0	*	*	*
11-05-80	12.0	13.0	13.0	*	*	*	*	*	*	12.0	13.0	14.0
12-04-80	5.5	5.6	4.1	18.0	*	*	3.4	*	*	*	*	*
01-22-81	3.1	2.0	5.0	*	*	*	*	*	*	4.0	6.2	5.5
02-05-81	1.2	1.4	2.8	2.0	2.2	5.5	3.0	1.6	1.7	*	*	*
03-04-81	3.5	2.7	3.0	*	*	*	*	*	*	2.7	2.9	2.9
03-26-81	1.9	2.0	3.8	2.5	2.7	2.6	1.6	1.0	2.5	*	*	*
04-09-81	3.1	4.9	4.5	*	*	*	*	*	*	6.3	5.6	7.6

Table A.15. continued

Date	Hallett's South			Hallett's North			Hallett's West			Peterson's West		
	S	M	B	S	M	B	S	M	B	S	M	B
04-23-81	*	*	*	*	*	*	*	*	*	*	*	*
05-07-81	4.0	3.2	7.9	*	*	*	*	*	*	4.2	4.3	6.1
05-21-81	2.6	5.7	4.8	4.4	4.5	6.0	1.1	1.6	2.4	*	*	*
06-04-81	2.3	3.4	2.9	*	*	*	*	*	*	2.5	1.9	7.7
06-25-81	2.4	5.9	4.0	2.2	3.5	7.0	4.0	11.0	7.0	*	*	*
07-09-81	2.7	3.5	3.2	*	*	*	*	*	*	3.5	3.7	6.5
07-23-81	1.3	1.0	4.6	1.7	1.6	4.1	1.7	4.1	6.4	*	*	*
08-13-81	4.3	2.3	3.9	*	*	*	*	*	*	2.4	3.0	14.0
08-31-81	1.2	1.6	3.4	1.5	1.6	3.6	2.0	2.8	9.4	*	*	*
09-14-81	2.5	1.9	2.0	*	*	*	*	*	*	2.4	1.5	11.0
09-28-81	2.1	2.4	2.4	2.8	2.8	3.9	2.5	2.8	14.0	*	*	*
10-12-81	3.7	3.3	3.5	*	*	*	*	*	*	3.8	3.6	3.7
10-26-81	2.8	3.2	3.6	3.4	3.5	3.4	2.3	2.5	2.1	*	*	*

Table A.16. Ortho PO_4 data in mg/l as PO_4 for the four studied gravel-pit lakes

Date	Hallett's South			Hallett's North			Hallett's West			Peterson's West		
	S	M	B	S	M	B	S	M	B	S	M	B
06-25-80	0.20	0.42	0.24	0.17	0.15	0.17	0.19	0.26	0.47	*	*	*
07-09-80	0.12	0.09	0.15	*	*	*	*	*	*	0.03	0.06	0.09
07-23-80	0.10	0.12	0.12	0.10	0.08	0.09	0.08	0.19	0.34	*	*	*
08-06-80	0.15	0.13	0.13	*	*	*	*	*	*	0.03	0.04	0.13
08-20-80	0.07	0.07	0.11	0.09	0.06	0.06	0.06	0.11	0.57	*	*	*
09-10-80	0.19	0.20	0.24	*	*	*	*	*	*	0.09	0.24	0.36
09-24-80	0.20	0.16	0.23	0.12	0.16	0.20	0.14	0.21	0.63	*	*	*
10-09-80	0.28	0.17	0.17	*	*	*	*	*	*	0.05	0.06	0.34
10-23-80	0.07	0.07	0.07	0.05	0.05	0.05	0.07	0.08	0.40	*	*	*
11-05-80	0.15	0.15	0.15	*	*	*	*	*	*	0.04	0.03	0.03
12-04-80	0.11	0.11	0.11	0.10	*	*	0.19	*	*	*	*	*
01-22-81	0.12	0.12	0.13	*	*	*	*	*	*	0.05	0.05	0.29
02-05-81	0.09	0.09	0.10	0.08	0.08	0.07	0.10	0.10	0.10	*	*	*
03-04-81	0.13	0.13	0.13	*	*	*	*	*	*	0.03	0.02	0.02
03-26-81	0.15	0.13	0.16	0.11	0.12	0.12	0.15	0.16	0.16	*	*	*
04-09-81	0.07	0.07	0.09	*	*	*	*	*	*	0.03	0.03	0.05

Table A.16. continued

Date	Hallett's South			Hallett's North			Hallett's West			Peterson's West		
	S	M	B	S	M	B	S	M	B	S	M	B
04-23-81	0.13	*	*	0.10	*	*	0.12	*	*	*	*	*
05-07-81	0.09	0.09	0.10	*	*	*	*	*	*	0.02	0.02	0.04
05-21-81	0.14	0.14	0.14	0.13	0.11	0.11	0.13	0.13	0.15	*	*	*
06-04-81	0.10	0.10	0.10	*	*	*	*	*	*	0.00	0.01	0.27
06-25-81	0.11	0.10	0.10	0.08	0.07	0.08	0.10	0.11	0.55	*	*	*
07-09-81	0.08	0.09	0.09	*	*	*	*	*	*	<0.005	0.01	0.53
07-23-81	0.08	0.07	0.08	0.05	0.06	0.06	0.06	0.08	0.71	*	*	*
08-13-81	0.10	0.08	0.14	*	*	*	*	*	*	0.02	0.02	1.17
08-31-81	0.08	0.09	0.11	0.05	0.19	0.05	0.19	0.06	0.67	*	*	*
09-14-81	0.08	0.10	0.10	*	*	*	*	*	*	0.01	0.03	1.46
09-28-81	0.08	0.06	0.06	0.04	0.05	0.04	0.04	0.04	0.99	*	*	*
10-12-81	0.10	0.13	0.11	*	*	*	*	*	*	0.06	0.08	0.12
10-26-81	0.07	0.07	0.07	0.06	0.07	0.06	0.28	0.28	0.28	*	*	*

Table A.17. Total PO_4 data in mg/l as PO_4 for the four studied gravel-pit lakes

Date	Hallett's South			Hallett's North			Hallett's West			Peterson's West		
	S	M	B	S	M	B	S	M	B	S	M	B
06-25-80	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	*	*	*
07-09-80	<0.2	<0.2	<0.2	*	*	*	*	*	*	<0.2	<0.2	<0.2
07-23-80	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	*	*	*
08-06-80	<0.2	<0.2	<0.2	*	*	*	*	*	*	<0.2	<0.2	0.96
08-20-80	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	1.61	*	*	*
09-10-80	<0.2	<0.2	<0.2	*	*	*	*	*	*	<0.2	0.21	1.66
09-24-80	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	0.41	*	*	*
10-09-80	<0.2	<0.2	<0.2	*	*	*	*	*	*	<0.2	<0.2	1.10
10-23-80	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	0.62	*	*	*
11-05-80	0.46	<0.2	<0.2	*	*	*	*	*	*	<0.2	<0.2	<0.2
12-04-80	<0.2	<0.2	<0.2	<0.2	*	*	<0.2	*	*	*	*	*
01-22-81	<0.2	<0.2	<0.2	*	*	*	*	*	*	<0.2	<0.2	0.37
02-05-81	<0.2	<0.2	<0.2	<0.2	<0.2	0.70	<0.2	<0.2	<0.2	*	*	*
03-04-81	<0.2	<0.2	<0.2	*	*	*	*	*	*	<0.2	<0.2	<0.2
03-26-81	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	*	*	*
04-09-81	<0.2	<0.2	<0.2	*	*	*	*	*	*	<0.2	<0.2	<0.2

Table A.17. continued

Date	Hallett's South			Hallett's North			Hallett's West			Peterson's West		
	S	M	B	S	M	B	S	M	B	S	M	B
04-23-81	<0.2	*	*	0.34	*	*	<0.2	*	*	*	*	*
05-07-81	<0.2	<0.2	<0.2	*	*	*	*	*	*	<0.2	<0.2	<0.2
05-21-81	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	*	*	*
06-04-81	<0.2	<0.2	<0.2	*	*	*	*	*	*	<0.2	<0.2	<0.2
06-25-81	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	0.47	*	*	*
07-09-81	<0.2	<0.2	<0.2	*	*	*	*	*	*	<0.2	<0.2	0.95
07-23-81	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	0.93	*	*	*
08-13-81	<0.2	<0.2	<0.2	*	*	*	*	*	*	<0.2	<0.2	1.72
08-31-81	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	0.88	*	*	*
09-14-81	<0.2	<0.2	<0.2	*	*	*	*	*	*	<0.2	<0.2	2.25
09-28-81	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	1.29	*	*	*
10-12-81	<0.2	<0.2	<0.2	*	*	*	*	*	*	<0.2	<0.2	<0.2
10-26-81	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	0.24	0.24	0.25	*	*	*

Table A.18. NO_2+NO_3-N data in mg/l as N for the four studied gravel-pit lakes

	Hallett's South			Hallett's North			Hallett's West			Peterson's West		
Date	S	M	B	S	M	B	S	M	B	S	M	B
06-25-80	2.33	1.07	0.68	2.24	0.15	0.14	10.73	4.03	5.34	*	*	*
07-09-80	1.64	1.69	0.76	*	*	*	*	*	*	0.03	0.02	0.03
07-23-80	1.43	1.46	1.00	0.08	0.08	0.09	9.40	3.31	0.25	*	*	*
08-06-80	1.10	1.27	0.98	*	*	*	*	*	*	0.03	0.03	0.03
08-20-80	1.03	1.10	0.10	0.11	0.11	0.12	3.21	3.08	0.21	*	*	*
09-10-80	0.97	0.91	0.19	*	*	*	*	*	*	0.09	0.09	0.09
09-24-80	0.76	0.77	0.06	0.11	0.11	0.10	4.35	2.50	2.46	*	*	*
10-09-80	0.72	0.72	0.26	*	*	*	*	*	*	0.08	0.06	0.06
10-23-80	0.50	0.54	0.55	0.18	0.15	0.15	2.29	2.53	1.61	*	*	*
11-05-80	0.56	0.57	0.56	*	*	*	*	*	*	0.11	0.09	0.12
12-04-80	0.52	0.52	0.52	0.23	*	*	2.17	*	*	*	*	*
01-22-81	0.43	0.42	0.33	*	*	*	*	*	*	0.08	0.09	0.09
02-05-81	0.43	0.47	0.34	0.26	0.23	0.26	1.86	2.00	1.36	*	*	*
03-04-81	0.35	0.36	0.37	*	*	*	*	*	*	0.11	0.11	0.09
03-26-81	0.35	0.35	0.34	0.26	0.23	0.23	1.55	1.56	1.55	*	*	*
04-09-81	0.37	0.37	0.37	*	*	*	*	*	*	0.16	0.16	0.16

Table A.18. continued

Date	Hallett's South			Hallett's North			Hallett's West			Peterson's West		
	S	M	B	S	M	B	S	M	B	S	M	B
04-23-81	0.38	*	*	0.20	*	*	2.94	*	*	*	*	*
05-07-81	0.36	0.37	0.36	*	*	*	*	*	*	0.08	0.06	0.08
05-21-81	0.33	0.31	0.30	0.06	0.09	0.16	1.31	1.31	1.03	*	*	*
06-04-81	0.30	0.31	0.36	*	*	*	*	*	*	0.01	0.01	0.01
06-25-81	0.41	0.43	0.50	0.06	0.05	0.08	1.27	1.13	0.31	*	*	*
07-09-81	0.38	0.42	0.48	*	*	*	*	*	*	0.03	0.01	0.02
07-23-81	0.36	0.44	0.28	0.01	0.01	0.06	0.90	1.14	0.03	*	*	*
08-13-81	0.25	0.32	0.22	*	*	*	*	*	*	0.02	0.02	0.01
08-31-81	0.20	0.21	0.19	0.01	0.01	0.02	0.47	0.56	0.03	*	*	*
09-14-81	0.18	0.20	0.12	*	*	*	*	*	*	0.01	0.01	0.01
09-28-81	0.16	0.16	0.16	<0.005	<0.005	0.01	0.16	0.16	0.01	*	*	*
10-12-81	0.16	0.16	0.16	*	*	*	*	*	*	0.02	0.02	0.01
10-26-81	0.19	0.23	0.22	0.05	0.10	0.05	0.15	0.13	0.17	*	*	*

Table A.19. NH_4-N data in mg/l as N for the four studied gravel-pit lakes

Date	Hallett's South			Hallett's North			Hallett's West			Peterson's West		
	S	M	B	S	M	B	S	M	B	S	M	B
06-25-80	0.35	0.12	0.83	0.22	0.05	0.22	0.12	0.23	0.58	*	*	*
07-09-80	0.04	0.04	0.73	*	*	*	*	*	*	0.03	0.40	1.65
07-23-80	0.10	0.03	0.32	0.05	0.07	0.09	0.12	0.20	2.15	*	*	*
08-06-80	0.06	0.04	0.15	*	*	*	*	*	*	0.04	0.08	1.81
08-20-80	0.08	0.10	1.39	0.07	0.04	0.09	0.08	0.32	2.67	*	*	*
09-10-80	0.14	0.36	1.15	*	*	*	*	*	*	0.06	0.25	4.63
09-24-80	0.07	0.06	1.10	0.03	0.02	0.08	0.10	0.44	1.03	*	*	*
10-09-80	0.20	0.24	1.02	*	*	*	*	*	*	0.20	0.24	3.44
10-23-80	0.32	0.31	0.30	0.08	0.08	0.08	0.54	0.54	1.49	*	*	*
11-05-80	0.68	0.65	0.68	*	*	*	*	*	*	0.55	0.57	0.57
12-04-80	0.36	0.36	0.35	0.09	*	*	0.83	*	*	*	*	*
01-22-81	0.34	0.29	0.52	*	*	*	*	*	*	0.30	0.19	0.24
02-05-81	0.43	0.32	0.59	0.15	0.10	0.11	0.29	0.29	0.85	*	*	*
03-04-81	0.34	0.33	0.33	*	*	*	*	*	*	0.15	0.14	0.17
03-26-81	0.38	0.35	0.37	0.39	0.15	0.08	0.52	0.36	0.61	*	*	*
04-09-81	0.28	0.28	0.30	*	*	*	*	*	*	0.09	0.09	0.14

Table A.19. continued

Date	Hallett's South			Hallett's North			Hallett's West			Peterson's West		
	S	M	B	S	M	B	S	M	B	S	M	B
04-23-81	0.30	*	*	0.08	*	*	0.22	*	*	*	*	*
05-07-81	0.29	0.25	0.32	*	*	*	*	*	*	0.13	0.11	0.61
05-21-81	0.23	0.24	0.24	0.18	0.14	0.49	0.16	0.11	0.73	*	*	*
06-04-81	0.25	0.25	0.22	*	*	*	*	*	*	0.11	0.22	1.54
06-25-81	0.17	0.14	0.16	0.35	0.19	0.21	0.19	0.35	1.71	*	*	*
07-09-81	0.07	0.09	0.13	*	*	*	*	*	*	0.07	0.07	1.75
07-23-81	0.09	0.12	0.32	0.08	0.10	0.12	0.16	0.17	2.50	*	*	*
08-13-81	0.11	0.13	0.36	*	*	*	*	*	*	0.16	0.14	3.08
08-31-81	0.15	0.14	0.35	0.19	0.16	0.18	0.14	0.22	2.23	*	*	*
09-14-81	0.07	0.10	0.31	*	*	*	*	*	*	0.07	0.18	3.50
09-28-81	0.16	0.15	0.17	0.08	0.05	0.06	0.08	0.05	2.09	*	*	*
10-12-81	0.07	0.07	0.06	*	*	*	*	*	*	0.33	0.30	0.47
10-26-81	0.06	0.05	0.07	0.12	0.12	0.08	0.67	0.67	0.68	*	*	*

Table A.20. Kjeldahl-N data in mg/l as N for the four studied gravel-pit lakes

Date	Hallett's South			Hallett's North			Hallett's West			Peterson's West		
	S	M	B	S	M	B	S	M	B	S	M	B
06-25-80	0.52	0.68	1.00	0.34	0.27	0.34	0.68	0.76	1.09	*	*	*
07-09-80	0.46	0.47	1.13	*	*	*	*	*	*	0.49	0.90	1.96
07-23-80	0.41	0.54	0.68	0.27	0.28	0.39	0.68	0.68	2.52	*	*	*
08-06-80	0.47	0.45	0.45	*	*	*	*	*	*	0.65	0.66	2.26
08-20-80	0.42	0.37	1.50	0.29	0.27	0.26	0.78	0.80	2.63	*	*	*
09-10-80	0.26	0.36	1.36	*	*	*	*	*	*	0.53	0.94	2.99
09-24-80	0.27	0.27	1.28	0.19	0.19	0.22	0.66	0.85	1.63	*	*	*
10-09-80	0.52	0.51	1.08	*	*	*	*	*	*	0.83	0.68	3.33
10-23-80	0.98	0.55	0.57	0.25	0.21	0.19	1.06	1.08	1.85	*	*	*
11-05-80	0.52	0.77	0.63	*	*	*	*	*	*	0.75	0.81	0.78
12-04-80	0.61	0.55	0.59	0.37	*	*	0.97	*	*	*	*	*
01-22-81	0.48	0.47	0.57	*	*	*	*	*	*	0.60	0.81	0.72
02-05-81	0.69	0.60	0.88	0.35	0.39	0.35	0.97	1.01	1.44	*	*	*
03-04-81	0.73	0.65	0.51	*	*	*	*	*	*	0.64	0.71	0.63
03-26-81	0.77	0.80	0.74	0.66	0.57	0.58	0.96	1.10	0.96	*	*	*
04-09-81	0.46	0.43	0.48	*	*	*	*	*	*	0.48	0.50	0.53

Table A.20. continued

Date	Hallett's South			Hallett's North			Hallett's West			Peterson's West		
	S	M	B	S	M	B	S	M	B	S	M	B
04-23-81	0.38	*	*	0.27	*	*	0.83	*	*	*	*	*
05-07-81	0.51	0.38	0.47	*	*	*	*	*	*	0.65	0.54	1.07
05-21-81	0.51	0.47	0.45	0.55	0.25	0.34	0.62	0.69	1.20	*	*	*
06-04-81	0.43	0.71	0.59	*	*	*	*	*	*	0.48	0.82	1.87
06-25-81	0.22	0.41	0.89	0.48	0.30	0.43	0.53	0.70	1.74	*	*	*
07-09-81	0.80	0.83	0.80	*	*	*	*	*	*	0.35	0.42	2.03
07-23-81	0.49	0.43	0.50	0.39	0.37	0.33	0.52	1.18	2.26	*	*	*
08-13-81	0.42	0.35	0.61	*	*	*	*	*	*	0.56	0.58	3.20
08-31-81	0.25	0.18	0.45	0.23	0.19	0.17	0.39	0.53	2.11	*	*	*
09-14-81	0.37	0.30	0.51	*	*	*	*	*	*	0.66	0.73	3.97
09-28-81	0.26	0.35	0.37	0.27	0.21	0.24	0.59	0.59	3.08	*	*	*
10-12-81	0.40	0.37	0.34	*	*	*	*	*	*	0.93	0.90	1.08
10-26-81	0.33	0.24	0.27	0.29	0.28	0.27	0.90	0.94	0.91	*	*	*

Table A.21. Chloride data in mg/l for the four studied gravel-pit lakes

Date	Hallett's South			Hallett's North			Hallett's West			Peterson's West		
	S	M	B	S	M	B	S	M	B	S	M	B
06-25-80	19.6	20.1	17.3	17.5	19.1	15.1	26.1	22.9	16.4	*	*	*
07-09-80	18.6	11.7	14.7	*	*	*	*	*	*	29.4	28.9	29.6
07-23-80	18.7	17.2	18.7	21.7	20.7	20.2	26.4	22.2	21.2	*	*	*
08-06-80	18.3	17.1	36.4	*	*	*	*	*	*	30.6	30.2	30.4
08-20-80	18.3	19.7	15.5	20.3	20.4	20.7	20.6	20.3	19.7	*	*	*
09-10-80	17.9	17.4	14.9	*	*	*	*	*	*	29.8	27.5	29.8
09-24-80	18.2	18.1	15.0	21.0	21.2	20.9	24.5	21.4	20.7	*	*	*
10-09-80	17.9	17.7	16.4	*	*	*	*	*	*	30.6	30.6	29.4
10-23-80	18.0	17.5	17.5	21.4	20.9	20.9	22.4	22.4	21.4	*	*	*
11-05-80	18.3	18.4	18.2	*	*	*	*	*	*	30.9	30.9	30.9
12-04-80	18.0	18.0	18.0	21.0	*	*	22.0	*	*	*	*	*
01-22-81	18.0	18.0	17.0	*	*	*	*	*	*	31.0	32.0	33.0
02-05-81	19.0	19.0	20.0	24.0	24.0	24.0	24.0	24.0	22.0	*	*	*
03-04-81	18.0	18.0	18.0	*	*	*	*	*	*	32.0	32.0	32.0
03-26-81	17.8	17.7	17.9	23.4	23.0	22.7	21.9	22.0	21.9	*	*	*
04-09-81	18.0	18.0	17.7	*	*	*	*	*	*	30.6	30.8	30.3

Table A.21. continued

Date	Hallett's South			Hallett's North			Hallett's West			Peterson's West		
	S	M	B	S	M	B	S	M	B	S	M	B
04-23-81	18.2	*	*	23.5	*	*	21.2	*	*	*	*	*
05-07-81	18.2	18.2	18.1	*	*	*	*	*	*	30.8	31.0	30.8
05-21-81	18.4	18.1	18.1	24.3	24.3	24.6	21.8	21.6	20.8	*	*	*
06-04-81	18.1	18.1	18.0	*	*	*	*	*	*	31.8	31.5	30.1
06-25-81	18.7	18.2	17.7	24.6	25.1	24.1	20.7	19.7	20.7	*	*	*
07-09-81	18.7	17.5	16.0	*	*	*	*	*	*	32.3	18.5	29.6
07-23-81	19.4	16.9	17.4	25.9	25.9	22.4	20.4	19.4	20.4	*	*	*
08-13-81	19.3	19.3	18.1	*	*	*	*	*	*	32.2	31.8	29.3
08-31-81	19.1	18.7	18.5	25.7	25.9	25.1	16.8	17.0	20.4	*	*	*
09-14-81	19.0	16.8	15.9	*	*	*	*	*	*	31.6	31.1	28.1
09-28-81	18.4	23.2	18.5	25.4	27.1	25.7	17.1	16.9	19.2	*	*	*
10-12-81	20.4	20.6	20.9	*	*	*	*	*	*	33.5	32.7	34.3
10-26-81	18.7	18.7	18.5	25.2	25.7	25.7	17.2	17.2	17.2	*	*	*

Table A.22. Soluble silica data in mg/l as SiO_2 for the four studied gravel-pit lakes

Date	Hallett's South			Hallett's North			Hallett's West			Peterson's West		
	S	M	B	S	M	B	S	M	B	S	M	B
06-25-80	14.7	17.2	17.3	12.9	12.5	13.0	4.3	17.2	21.1	*	*	*
07-09-80	15.3	15.9	18.4	*	*	*	*	*	*	1.6	4.5	10.0
07-23-80	15.6	17.0	18.4	12.6	12.8	13.9	10.4	20.1	23.7	*	*	*
08-06-80	15.1	16.4	17.9	*	*	*	*	*	*	1.2	2.5	12.8
08-20-80	14.5	16.4	20.7	13.0	13.1	13.1	11.9	20.8	24.8	*	*	*
09-10-80	14.7	17.6	20.6	*	*	*	*	*	*	2.0	7.8	15.1
09-24-80	16.0	15.7	21.2	13.3	12.8	12.8	13.2	21.4	22.9	*	*	*
10-09-80	16.8	17.0	19.3	*	*	*	*	*	*	2.2	3.1	15.9
10-23-80	17.9	17.9	18.1	13.4	13.4	13.4	18.2	18.2	21.4	*	*	*
11-05-80	17.2	17.2	17.2	*	*	*	*	*	*	0.9	1.0	1.0
12-04-80	18.2	18.2	18.2	12.6	*	*	18.6	*	*	*	*	*
01-22-81	17.8	18.1	20.3	*	*	*	*	*	*	0.9	1.0	1.1
02-05-81	17.5	18.0	20.2	13.2	13.5	13.4	18.5	19.0	19.6	*	*	*
03-04-81	17.7	17.8	17.7	*	*	*	*	*	*	2.1	2.1	2.1
03-26-81	17.7	17.7	17.8	12.9	14.4	12.8	17.4	17.4	17.5	*	*	*
04-09-81	17.4	17.3	17.4	*	*	*	*	*	*	2.3	2.3	2.4

Table A.22. continued

Date	Hallett's South			Hallett's North			Hallett's West			Peterson's West		
	S	M	B	S	M	B	S	M	B	S	M	B
04-23-81	16.8	*	*	12.2	*	*	15.5	*	*	*	*	*
05-07-81	17.1	17.0	17.0	*	*	*	*	*	*	1.5	1.9	4.6
05-21-81	16.5	16.6	16.6	12.7	12.6	12.5	14.8	14.8	16.7	*	*	*
06-04-81	16.3	16.4	16.7	*	*	*	*	*	*	0.2	1.0	1.9
06-25-81	15.3	15.6	16.3	11.8	11.8	12.1	13.0	12.8	13.0	*	*	*
07-09-81	15.9	16.1	17.0	*	*	*	*	*	*	1.4	3.1	10.7
07-23-81	16.0	16.0	17.4	12.7	12.1	12.4	13.2	14.1	19.4	*	*	*
08-13-81	15.8	16.1	18.9	*	*	*	*	*	*	1.2	3.0	14.2
08-31-81	15.2	15.2	18.2	12.5	12.5	12.9	11.2	11.8	20.2	*	*	*
09-14-81	15.4	15.5	17.9	*	*	*	*	*	*	1.8	3.0	15.9
09-28-81	16.0	16.0	16.0	13.0	13.0	13.0	12.0	12.0	21.5	*	*	*
10-12-81	15.6	15.8	15.6	*	*	*	*	*	*	4.1	4.2	5.1
10-26-81	15.6	15.6	15.8	13.3	13.3	13.5	14.3	14.2	14.2	*	*	*

Table A.23. Fecal coliform data in organisms/100 mls for the four studied gravel-pit lakes

Date	Hallett's South			Hallett's North			Hallett's West			Peterson's West		
	S	M	B	S	M	B	S	M	B	S	M	B
06-25-80	2	2	1	0	8	5	5	2	110	*	*	*
07-09-80	0	2	1	*	*	*	*	*	*	2	1	5
07-23-80	0	0	1	0	1	1	4	1	39	*	*	*
08-06-80	1	1	0	*	*	*	*	*	*	0	1	5
08-20-80	0	0	4	0	0	0	1	220	160	*	*	*
09-10-80	0	0	1	*	*	*	*	*	*	0	0	8
09-24-80	1	2	1	0	1	0	4	38	100	*	*	*
10-09-80	7	1	0	*	*	*	*	*	*	0	0	2
10-23-80	0	0	0	4	1	3	12	11	54	*	*	*
11-05-80	0	0	0	*	*	*	*	*	*	0	0	0
12-04-80	0	0	0	0	*	*	0	*	*	*	*	*
01-22-81	0	0	0	*	*	*	*	*	*	0	0	0
02-05-81	0	0	0	0	0	0	0	0	0	*	*	*
03-04-81	0	0	0	*	*	*	*	*	*	0	0	0
03-26-81	0	0	0	0	0	0	0	0	0	*	*	*
04-09-81	1	2	13	*	*	*	*	*	*	0	6	35

Table A.23. continued

Date	Hallett's South			Hallett's North			Hallett's West			Peterson's West		
	S	M	B	S	M	B	S	M	B	S	M	B
04-23-81	0	*	*	0	*	*	120	*	*	*	*	*
05-07-81	0	0	0	*	*	*	*	*	*	0	0	83
05-21-81	0	0	0	0	0	0	6	0	4	*	*	*
06-04-81	0	0	0	*	*	*	*	*	*	1	1	1
06-25-81	6	5	3	7	2	0	260	230	430	*	*	*
07-09-81	1	1	1	*	*	*	*	*	*	2	1	0
07-23-81	0	0	1	1	4	2	1	0	200	*	*	*
08-13-81	0	1	8	*	*	*	*	*	*	3	12	22
08-31-81	43	4	0	1	5	1	280	200	1500	*	*	*
09-14-81	4	7	3	*	*	*	*	*	*	0	0	7
09-28-81	3	10	4	3	4	1	70	83	1400	*	*	*
10-12-81	4	1	0	*	*	*	*	*	*	0	0	0
10-26-81	0	0	0	0	0	0	2	7	2	*	*	*

Table A.24. BOD data in mg/l for the four studied gravel-pit lakes

Date	Hallett's South			Hallett's North			Hallett's West			Peterson's West		
	S	M	B	S	M	B	S	M	B	S	M	B
06-25-80	1.2	3.1	4.6	1.8	0.9	1.4	1.8	1.2	1.9	*	*	*
07-09-80	1.9	2.0	5.0	*	*	*	*	*	*	2.5	1.7	2.1
07-23-80	1.4	1.3	0.8	0.8	1.6	0.6	1.5	1.1	1.8	*	*	*
08-06-80	0.9	1.2	0.8	*	*	*	*	*	*	1.7	1.7	1.2
08-20-80	*	*	*	*	*	*	*	*	*	*	*	*
09-10-80	1.5	<0.3	0.4	*	*	*	*	*	*	1.1	1.0	0.6
09-24-80	1.4	1.1	0.8	1.0	1.1	0.9	2.0	1.4	3.1	*	*	*
10-09-80	7.3	1.1	1.2	*	*	*	*	*	*	2.2	1.2	1.2
10-23-80	0.8	1.0	0.5	0.5	0.6	0.6	1.6	1.4	2.2	*	*	*
11-05-80	0.7	0.4	0.3	*	*	*	*	*	*	2.3	1.7	2.0
12-04-80	0.7	0.7	0.8	0.8	*	*	0.8	*	*	*	*	*
01-22-81	1.7	1.7	1.1	*	*	*	*	*	*	1.1	2.6	2.1
02-05-81	0.9	1.0	1.8	<0.8	<0.8	<0.8	1.3	1.8	1.3	*	*	*
03-04-81	0.8	1.2	0.8	*	*	*	*	*	*	2.7	2.8	2.5
03-26-81	0.8	0.8	<0.8	0.8	0.8	0.9	1.2	1.3	0.8	*	*	*
04-09-81	<0.8	<0.8	<0.8	*	*	*	*	*	*	3.0	2.9	2.1

Table A.24. continued

Date	Hallett's South			Hallett's North			Hallett's West			Peterson's West		
	S	M	B	S	M	B	S	M	B	S	M	B
04-23-81	1.4	*	*	1.2	*	*	2.5	*	*	*	*	*
05-07-81	0.8	0.9	0.8	*	*	*	*	*	*	3.5	2.3	1.2
05-21-81	1.0	0.8	<0.75	3.2	1.1	1.0	1.1	1.4	1.1	*	*	*
06-04-81	0.8	1.0	1.7	*	*	*	*	*	*	1.8	2.2	1.6
06-25-81	*	*	*	*	*	*	*	*	*	*	*	*
07-09-81	0.8	0.8	1.0	*	*	*	*	*	*	2.3	1.5	1.3
07-23-81	0.8	0.9	1.1	0.8	1.1	1.4	2.2	2.4	0.9	*	*	*
08-13-81	1.0	0.8	1.0	*	*	*	*	*	*	2.6	2.5	2.1
08-31-81	1.0	0.8	1.0	0.9	0.8	0.8	2.0	1.8	<0.8	*	*	*
09-14-81	1.4	1.2	<0.75	*	*	*	*	*	*	2.2	3.0	1.2
09-28-81	0.8	0.8	<0.8	<0.8	<0.8	<0.8	1.3	1.3	1.0	*	*	*
10-12-81	1.1	0.9	0.8	*	*	*	*	*	*	1.8	1.2	1.2
10-26-81	<0.8	<0.8	0.8	0.9	0.9	0.8	1.0	1.1	1.1	*	*	*

Table A.25. COD data in mg/l for the four studied gravel-pit lakes

Date	Hallett's South			Hallett's North			Hallett's West			Peterson's West		
	S	M	B	S	M	B	S	M	B	S	M	B
06-25-80	*	*	*	*	*	*	*	*	*	*	*	*
07-09-80	*	*	*	*	*	*	*	*	*	*	*	*
07-23-80	13.0	12.2	14.2	10.8	11.6	12.1	13.2	13.8	17.2	*	*	*
08-06-80	8.4	8.4	10.8	*	*	*	*	*	*	18.4	14.5	14.1
08-20-80	10.5	9.3	4.9	7.3	3.0	8.9	20.7	5.6	5.8	*	*	*
09-10-80	9.6	6.4	7.8	*	*	*	*	*	*	13.0	13.0	12.0
09-24-80	5.9	6.0	5.9	5.9	7.1	14.2	14.9	10.7	16.2	*	*	*
10-09-80	7.0	7.5	8.3	*	*	*	*	*	*	14.0	14.0	16.8
10-23-80	11.1	7.1	8.0	7.1	6.4	5.2	15.8	15.3	18.0	*	*	*
11-05-80	7.0	7.1	7.5	*	*	*	*	*	*	16.0	14.8	14.9
12-04-80	7.2	7.4	7.4	6.0	*	*	10.6	*	*	*	*	*
01-22-81	6.2	5.8	5.0	*	*	*	*	*	*	9.3	10.9	11.5
02-05-81	7.1	7.3	5.3	4.0	5.0	4.9	13.1	14.5	11.0	*	*	*
03-04-81	10.6	11.1	13.1	*	*	*	*	*	*	11.7	10.4	12.1
03-26-81	8.0	7.8	8.0	6.4	1.8	2.8	10.6	8.0	10.0	*	*	*
04-09-81	6.0	6.0	5.0	*	*	*	*	*	*	13.9	13.9	14.1

Table A.25. continued

Date	Hallett's South			Hallett's North			Hallett's West			Peterson's West		
	S	M	B	S	M	B	S	M	B	S	M	B
04-23-81	11.0	*	*	13.0	*	*	15.0	*	*	*	*	*
05-07-81	9.6	9.1	8.3	*	*	*	*	*	*	38.7	37.0	15.2
05-21-81	9.3	9.7	9.5	16.3	9.9	9.9	12.0	14.0	12.4	*	*	*
06-04-81	6.3	8.1	6.9	*	*	*	*	*	*	13.6	13.3	14.4
06-25-81	4.0	4.0	4.0	6.0	5.0	6.0	11.0	14.0	13.0	*	*	*
07-09-81	6.1	5.5	5.0	*	*	*	*	*	*	13.4	14.8	13.6
07-23-81	3.2	4.4	5.2	5.4	4.2	7.0	14.0	20.0	13.0	*	*	*
08-13-81	6.4	4.4	5.0	*	*	*	*	*	*	12.2	11.2	18.2
08-31-81	7.0	6.4	7.0	7.2	7.0	6.6	15.2	14.0	19.2	*	*	*
09-14-81	6.9	5.9	5.5	*	*	*	*	*	*	13.0	11.6	16.9
09-28-81	6.2	5.8	7.2	7.4	7.4	6.8	14.6	14.8	15.8	*	*	*
10-12-81	6.8	7.6	7.4	*	*	*	*	*	*	11.4	14.2	13.6
10-26-81	3.9	4.5	3.9	5.1	4.3	4.3	8.6	10.3	10.2	*	*	*

Table A.26. Corrected chl a data in mg/m^3 for the four studied gravel-pit lakes

Date	Hallett's South			Hallett's North			Hallett's West			Peterson's West		
	S	1M	2M	S	1M	2M	S	1M	2M	S	1M	2M
06-25-80	2	2	2	1	1	1	1	0	0	*	*	*
07-09-80	3	4	5	*	*	*	*	*	*	5	5	5
07-23-80	3	2	2	2	1	2	2	2	2	*	*	*
08-06-80	5	6	5	*	*	*	*	*	*	12	12	13
08-20-80	1	7	6	3	3	3	19	18	14	*	*	*
09-10-80	3	7	22	*	*	*	*	*	*	8	10	16
09-24-80	4	5	2	4	4	3	9	8	8	*	*	*
10-09-80	5	5	5	*	*	*	*	*	*	28	28	26
10-23-80	4	4	4	5	5	5	14	12	14	*	*	*
11-05-80	2	4	4	*	*	*	*	*	*	31	38	35
12-04-80	6	5	6	5	*	*	5	*	*	*	*	*
01-22-81	13	14	16	*	*	*	*	*	*	5	27	33
02-05-81	8	10	12	1	1	1	6	14	15	*	*	*
03-04-81	4	4	3	*	*	*	*	*	*	15	15	15
03-26-81	4	4	4	2	2	2	3	4	4	*	*	*
04-09-81	3	3	4	*	*	*	*	*	*	29	30	30

Table A.26. continued

Date	Hallett's South			Hallett's North			Hallett's West			Peterson's West		
	S	1M	2M	S	1M	2M	S	1M	2M	S	1M	2M
04-23-81	3	*	*	6	*	*	9	*	*	*	*	*
05-07-81	4	4	3	*	*	*	*	*	*	24	24	24
05-21-81	2	1	1	49	41	47	2	2	2	*	*	*
06-04-81	0	0	0	*	*	*	*	*	*	4	4	4
06-25-81	1	1	1	2	2	2	4	4	4	*	*	*
07-09-81	2	1	1	*	*	*	*	*	*	7	6	6
07-23-81	2	2	2	2	2	2	6	7	7	*	*	*
08-13-81	3	3	3	*	*	*	*	*	*	10	8	8
08-31-81	2	2	2	1	2	2	8	6	8	*	*	*
09-14-81	3	4	4	*	*	*	*	*	*	12	12	12
09-28-81	2	2	2	2	2	2	20	21	19	*	*	*
10-12-81	4	5	5	*	*	*	*	*	*	17	16	16
10-26-81	4	4	4	2	2	2	2	2	2	*	*	*

Table A.27. Secchi depth data in meters for the four studied gravel-pit lakes

Date	Hallett's South	Hallett's North	Hallett's West	Peterson's West
06-25-80	1.0	2.5	3.5	*
07-09-80	1.7	*	*	2.2
07-23-80	1.8	1.3	2.6	*
08-06-80	1.0	*	*	1.0
08-20-80	0.75	0.6	2.0	*
09-10-80	1.0	*	*	1.1
09-24-80	1.7	0.6	1.4	*
10-09-80	2.0	*	*	1.0
10-23-80	2.0	0.5	0.6	*
11-05-80	1.3	*	*	0.8
12-04-80	1.1	0.4	1.5	*
01-22-81	2.25	*	*	1.2
02-05-81	1.8	1.5	1.6	*
03-04-81	1.2	*	*	1.1
03-26-81	1.4	1.2	3.0	*
04-09-81	1.2	*	*	0.6

Table A.27. continued

Date	Hallett's South	Hallett's North	Hallett's West	Peterson's West
04-23-81	*	*	*	*
05-07-81	1.2	*	*	0.85
05-21-81	1.5	0.75	3.2	*
06-04-81	2.2	*	*	1.2
06-25-81	2.0	1.5	0.65	*
07-09-81	1.1	*	*	1.3
07-23-81	3.0	2.1	2.2	*
08-13-81	1.5	*	*	1.6
08-31-81	2.5	1.95	1.5	*
09-14-81	1.6	*	*	1.2
09-28-81	1.6	1.1	1.0	*
10-12-81	1.5	*	*	1.1
10-26-81	1.7	1.4	2.4	*

APPENDIX B.

STAGE-DISCHARGE CURVES FOR LOW FLOW MEASURING WEIRS

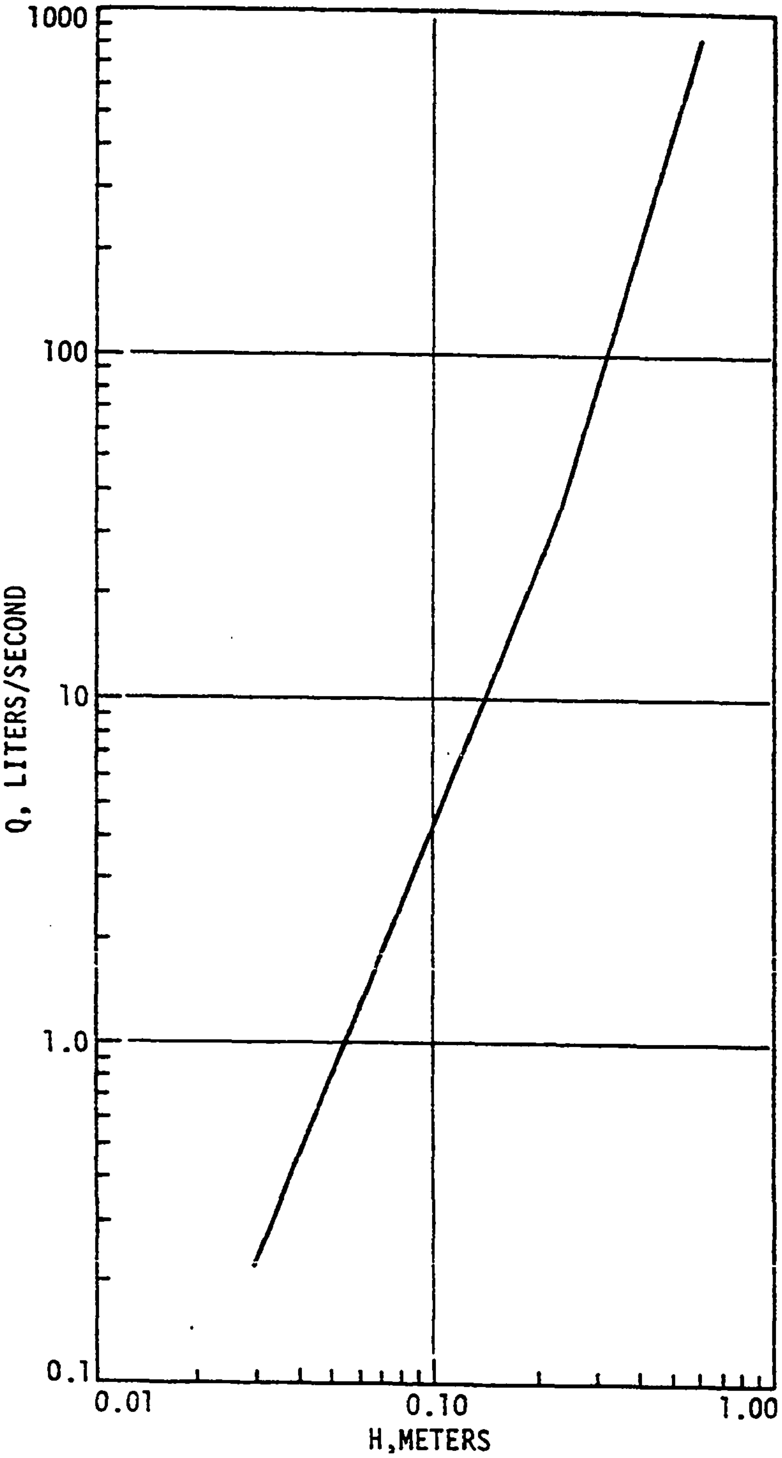

Figure B.1. Stage-discharge curve for agricultural weir

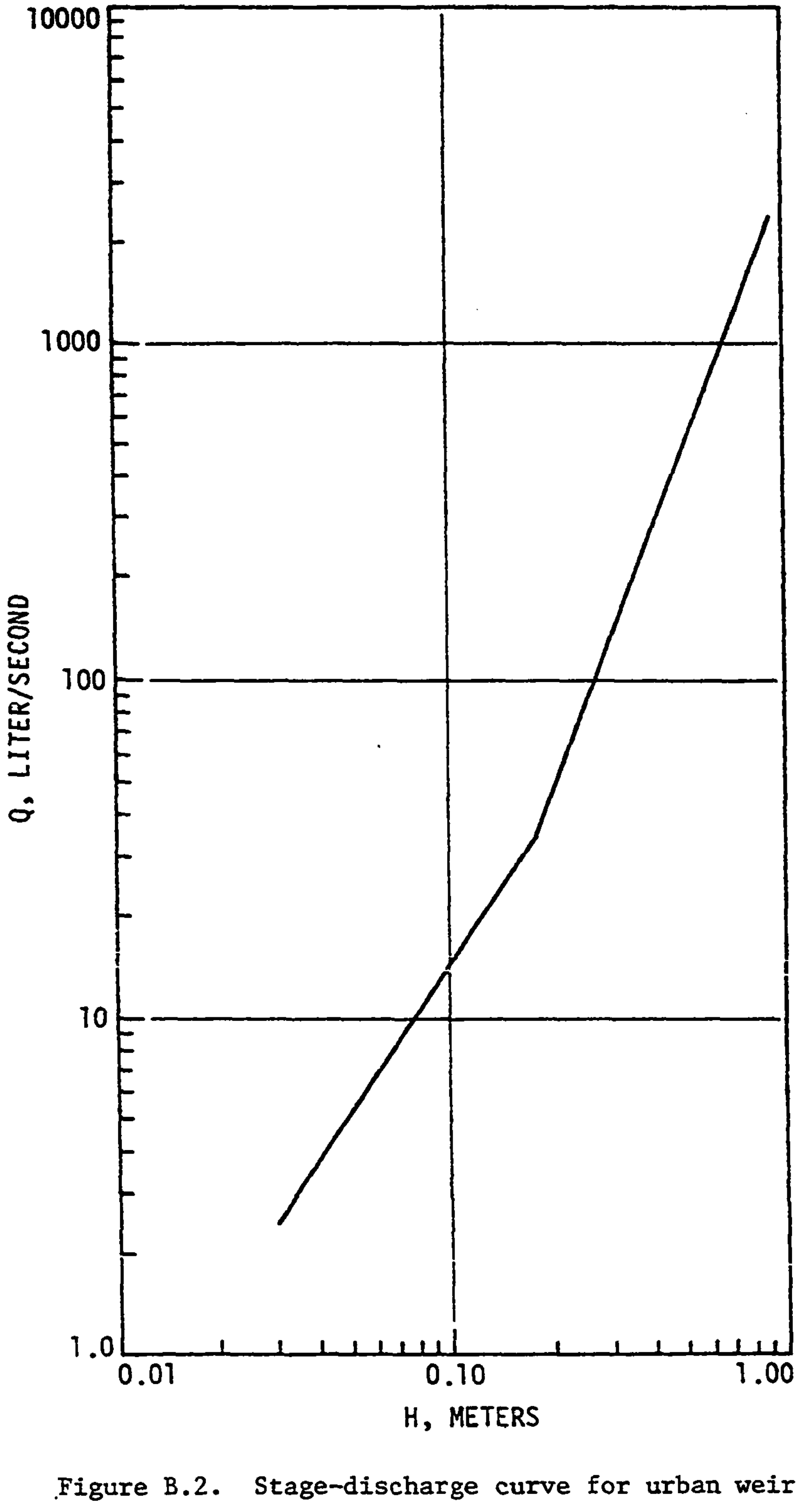

Figure B.2. Stage-discharge curve for urban weir

APPENDIX C.

STORMWATER RUNOFF WATER QUALITY DATA

Table C.1. Stream flow at time of sample collection for all agricultural drainage storm runoff events

Agricultural drainage	Sample number							
	1	2	3	4	5	6	7	8
07-27-81								
Time of sample	3:03	3:33	3:48	4:03	4:18	4:33	4:48	*
Flow (1/sec)	0.00	0.001	0.001	0.039	0.371	0.499	0.095	*
08-14-81								
Time of sample	23:12	23:14	23:20	23:22	23:30	23:45	24:00	01:15
Flow (1/sec)	12.11	24.22	66.55	75.33	110.45	35.55	59.47	47.44
08-28-81								
Time of sample	12:40	12:55	1:10	1:25	1:40	1:55	*	*
Flow (1/sec)	2.440	0.340	0.128	0.095	0.023	0.008	*	*

Table C.2. Stream flow at time of sample collection for all urban drainage storm runoff events

Urban drainage	Sample number							
	1	2	3	4	5	6	7	8
09-24-81								
Time of sample	20:05	20:15	20:25	20:35	20:50	21:05	21:20	21:35
Flow (l/sec)	455.95	785.88	1069.08	1033.68	283.20	111.44	47.58	38.52
11-03-81								
Time of sample	7:43	7:53	8:03	8:13	8:23	8:43	9:03	9:33
Flow (l/sec)	21.71	118.21	260.83	279.09	257.71	180.40	130.41	42.92

Table C.3. Water quality data, agricultural drainage stream, 7-27-81 storm

	Sample number							
	1	2	3	4	5	6	7	8
BOD mg/1	9.9	20	>21	>20	>18	>15	>13	*
COD mg/1	193	213	215	271	382	584	909	*
Total Solids mg/1	2930	2016	1420	1299	2154	2010	2270	*
Suspended Solids mg/1	2775	1665	940	820	1725	1430	1655	*
Total PO_4 mg/1 PO_4	14.1	22.0	22.9	31.5	35.5	41.9	56.5	*
Ortho PO_4 mg/1 PO_4	1.85	5.00	6.41	5.44	8.96	10.0	13.6	*
NO_2 + NO_3-N mg/1 N	11.56	10.63	10.58	9.84	8.17	6.81	5.96	*
NH_4-N mg/1 N	0.79	1.40	1.40	2.29	3.17	5.71	14.60	*
Kjel-N mg/1 N	13.4	12.0	12.6	17.0	22.9	33.4	52.0	*
Fecal Coliform org/100 ml	1.3E5	TNTC[a]	TNTC	TNTC	TNTC	TNTC	TNTC	*
Fecal Strep org/100 ml	*	*	*	*	*	*	*	*

[a] Too numerous to count.

Table C.4. Water quality data, agricultural drainage stream, 8-14-81 storm

	Sample number							
	1	2	3	4	5	6	7	8
BOD mg/l	16.7	46.3	>212	>215	>183	>116	67.5	33.5
COD mg/l	713	3700	4960	5250	4980	1130	607	321
Total Solids mg/l	16060	24970	22400	19240	14520	4305	3699	2348
Suspended Solids mg/l	15240	24600	18200	14980	10120	3630	3240	2060
Total PO_4 mg/l PO_4	42.5	176	408	506	444	92.6	39.5	27.4
Ortho PO_4 mg/l PO_4	3.27	11.9	72.8	98.6	121	36.2	6.31	4.30
NO_2 + NO_3-N mg/l N	0.98	3.80	2.91	2.76	2.38	2.55	1.11	0.72
NH_4-N mg/l N	0.67	3.33	38.8	60.5	59.8	13.3	3.06	1.38
Kjel-N mg/l N	40.0	163	345	491	394	84.4	47.0	42.3
Fecal Coliform org/100 ml	2.6E5	>2E6	>2E6	>2E6	>2E6	>2E6	>2E6	>2E6
Fecal Strep org/100 ml	*	*	*	*	*	*	*	*

Table C.5. Water quality data, agricultural drainage stream, 8-28-81 storm

	Sample number							
	1	2	3	4	5	6	7	8
BOD mg/l	207	192	70.5	31.5	21.0	25.0	*	*
COD mg/l	903	798	324	193	138	115	*	*
Total Solids mg/l	3158	1956	1261	1073	926	924	*	*
Suspended Solids mg/l	2760	1510	836	232	312	533	*	*
Total PO_4 mg/l PO_4	73.4	61.1	25.2	17.5	15.0	14.7	*	*
Ortho PO_4 mg/l PO_4	18.6	19.8	9.20	8.50	9.45	8.83	*	*
NO_2 + NO_3-N mg/l N	3.04	3.83	1.51	0.88	0.73	0.39	*	*
NH_4-N mg/l N	4.20	9.40	2.91	2.09	2.23	2.16	*	*
Kjel-N mg/l N	55.3	52.5	19.6	14.0	11.5	8.24	*	*
Fecal Coliforms org/100ml	>2E6	>2E6	>2E6	1.5E6	7.0E5	6.7E5	*	*
Fecal Strep org/100 ml	*	*	*	*	*	*	*	*

Table C.6. Water quality data, urban drainage stream, 9-24-81 storm

	Sample number							
	1	2	3	4	5	6	7	8
BOD mg/l	16.5	33.5	9.9	6.3	6.3	6.7	6.3	6.1
COD mg/l	131	316	79.9	49.9	25.1	22.7	22.7	24.0
Total Solids mg/l	968	1744	442	394	237	218	218	194
Suspended Solids mg/l	640	1470	367	248	151	116	88	72
Total PO_4 mg/l PO_4	2.52	6.37	1.76	1.13	0.85	0.82	0.76	0.78
Ortho PO_4 mg/l PO_4	0.71	1.25	0.43	0.37	0.36	0.39	0.42	0.48
NO_2 + NO_3-N mg/l N	0.63	1.55	0.20	0.20	0.33	0.50	0.59	0.67
NH_4-N mg/l N	0.45	1.58	0.35	0.35	0.41	0.45	0.46	0.47
Kjel-N mg/l N	3.58	10.00	2.30	1.65	0.69	0.68	0.99	0.96
Fecal Coliform org/100 ml	4.3E4	>2E6	1.6E5	4.7E4	2.6E4	3E4	3.5E4	2.6E4
Fecal Strep org/100 ml	1.9E5	>1E6	>4E5	1.5E5	9.8E4	>6.7E4	>4E4	>4E4

Table C.7. Water quality data, urban drainage stream, 11-3-81 storm

	Sample number							
	1	2	3	4	5	6	7	8
BOD mg/l	4.0	5.2	8.5	7.8	9.9	7.2	4.8	3.6
COD mg/l	21.2	26.7	54.9	74.5	65.1	35.3	25.9	20.5
Total Solids mg/l	272	326	250	441	265	141	144	133
Suspended Solids mg/l	15	63.8	140	285	185	83.3	59.8	41.2
Total PO_4 mg/l PO_4	0.28	0.66	0.81	1.18	0.97	0.67	0.72	0.76
Ortho PO_4 mg/l PO_4	0.22	0.47	0.22	0.29	0.19	0.29	0.42	0.54
NO_2 + NO_3-N mg/l N	2.17	2.39	1.27	1.43	0.90	0.52	0.46	0.54
NH_4-N mg/l N	0.35	0.55	0.40	0.28	0.36	0.38	0.33	0.28
Kjel-N mg/l N	0.73	1.38	1.74	2.04	1.79	1.06	0.86	0.95
Fecal Coliform org/100 ml	38,000	20,000	52,000	26,000	27,000	18,000	39,000	22,000
Fecal Strep org/100 ml	*	*	*	*	*	*	*	*