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OAKWOOD LAKES - POINSETT

Rural Clean Water Program Comprehensive Monitoring and Evaluation Technical Report

Project 20

1988

SOUTH DAKOTA

May 1989

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COVER PHOTOGRAPHS

Upper left: An Oakwood Lakes fish survey (1988).
Center: Line drawings of common algae and zooplankton found in lakes.
Upper right: Measuring flow in Crazy Creek (March 1987).
Lower right: A typical field installation of shallow nested wells used for ground water sampling.
Lower left: A schematic diagram of the water quality sampling system in the soil above the water table.
Background: A typical field site drainage way after spring snow melt and run-off on agricultural land (April 1985).

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1.0 EXECUTIVE SUMMARY

The Comprehensive Monitoring and Evaluation (CM&E) of the Oakwood Lakes-Poinsett Rural Clean Water Program (RCWP) was initiated in 1982 in east central South Dakota. The CM&E is designed to describe the cause and effect relationship between the application of agricultural best management practices (BMPs) and the changes in the quality of the ground and surface water resources of the study area. Conservation tillage (BMP 9), fertilizer management (BMP 15), and pesticide management (BMP 16) have been implemented and cost shared on the study area. While the CM&E monitoring activities are site specific, the evaluation of the effectiveness of BMPs requires the effects on the quality of all the water resources in the project area to be evaluated. Making an evaluation requires the cause-effect relationships in the hydrologic system to be described quantitatively so that area-wide water quality impacts can be estimated from the site specific data. Each component adds a piece of evidence which contributes to the evaluation of the effects of land use practices on the quality of the water resources.

Nonpoint source pollution of water resources has always been a water quality concern in South Dakota, particularly problems that may be linked to production agriculture. Agriculture is the major income producing activity in South Dakota, and the chemical use to assure efficient production and profitability has the potential to contaminate water resources. Establishing cause and effect relationships and determining the potential for alleviating negative water quality impacts by the application of BMPs is a high priority for the state and the nation. The objectives of the Oakwood Lakes-Poinsett RCWP-CM&E reflect those priorities.

Before the Rural Clean Water Program was initiated, little quantitative data existed to characterize existing problems. Available knowledge was restricted to root zone/crop production relationships studied by agronomists, precipitation/water supply relationships studied by hydrologists, and aquifer quantity and quality characteristics studied by ground water geologists. Although it was generally understood that continuity would be maintained in the flow process between the separate components of the system, the details of the conservation equation,

$$U_{applied} = U_{transported} + U_{transformed} + U_{stored}$$

had not been explored in a systematic way. Development of the linkages between the separable components is necessary to estimate the impact of BMP on the ground water quality, surface water quality, and the transport of contaminants through the vadose zone.

The initial formulation of the project resulted in a site specific investigation of these relationships at several representative field sites located throughout the RCWP project area. Each site represented a particular hydrogeologic setting and was instrumented with nested wells to monitor water quality (nitrates and pesticides), and tensiometers and neutron access tubes to monitor the soil water characteristics, and agricultural practices on the surface were documented. A fertility and pesticide research master site was established to monitor root zone water balance and sample nitrate and pesticide leachate. Surface water quality was not addressed except for runoff at three field sites.

The initial project formulation generated data and an understanding of the hydrologic system sufficient to plan more intensive effort on each of the separable parts of the system that had been identified. An assessment of monitoring and evaluation progress and needs was conducted and reported in 1986. The importance of detailed knowledge of transport of contaminants through the vadose zone and the impact of production agriculture on the quality of lakes and streams was recognized in that assessment. Two comprehensive proposals were developed to address these concerns. The Oakwood Lakes System Study (OLSS) initiated in 1986, included monitoring of surface and ground water interaction, tributary and in-lake water quality monitoring, and hydrologic and material budgeting of the Oakwood Lakes. The Agricultural Chemical Leaching Study (ACLS), initiated in 1987, including monitoring the leaching of pesticides and nitrates through the vadose zone to the ground water on adjacent no-till and moldboard plow tillage treatments cropped in a corn/oats rotation. A unique monitoring design which addressed the importance of macropore flow was incorporated in the ACLS.

Each fall an assessment of progress has been made. A report of activities is made near the end of the field season in October, and the analysis of the data begins. Although the goal of the CM&E project requires the entire system to be analyzed as one entity, the monitoring has tended to focus in each separable area. In 1988, a formal plan was made for the comprehensive report in 1991. The major sections of the report will be,

.. FINDINGS AND RECOMMENDATIONS
.. IMPACT OF BMPs ON SURFACE WATER QUALITY
.. IMPACT OF BMPS ON CONTAMINANT MOVEMENT THROUGH THE VADOSE ZONE
.. IMPACT OF BMPS ON GROUND WATER QUALITY

The Findings and Recommendations will include a discussion of BMP effectiveness, options, conclusions on BMP impacts on water quality and recommendations for future water quality protection strategies. Understanding the processes and linkages between each of the components of the system as discussed in the last three sections is necessary before that plan can be accomplished.

The monitoring strategies, understanding of ground water quality relationships, and the characteristics of different tillage, fertilizer, and pesticide management systems used on this project are the basis for the State Water Quality Action Plan and much of what is known will become a part of the Nonpoint Source Pollution (NPS) Management Plan for South Dakota. The Oakwood Lakes-Poinsett will be the model for future NPS control projects. Knowledge generated by the project has already stimulated other research, information and education, and monitoring activities in the state, and an education program developed by the Extension Service has been initiated to train county agents and SCS personnel in water quality issues.

1.0.1 Summary of ground water monitoring and evaluation.

Above normal precipitation from 1984-1986, abnormally elevated the water levels in the project area. Below normal precipitation in 1987 and 1988, dramatically lowering the water levels. The drop in the water levels has resulted in fifteen monitoring wells going dry.

Nitrate data evaluation indicate the depth at which nitrate as N concentrations greater than 5 mg/l were found is less than 20 feet below the water table. Although there is evidence that higher concentrations of nitrates can enter the ground water and move to greater depths, the lack of nitrates at depth is attributed to denitrification. The median nitrate as N concentrations by year indicated that the two shallow geozones had an increase in media nitrate as N concentrations in 1986, and decreased in subsequent years. This increase corresponds with water levels which were highest in May 1986, and have been decreasing since that time. After over two years of declining water levels, the whole system is displaying decreasing nitrate as N concentrations, with a significant difference between 1987 and 1988, detected for the first year since monitoring began. As in previous years, there is a significant difference in nitrate as N concentrations between the unfarmed site and the farmed site, with higher concentrations of nitrate at the farmed sites.

To date, 845 ground water samples for pesticide analysis have been collected from 67 different wells. Eighty (80) positive detections from 27 different wells have been reported with pesticide detections in 9.5% of the samples and 40% of the wells. The most commonly detected pesticides were alachlor and 2,4-D. Eighty-five percent (85%) of the detections were one time events, indicating a rapid drop to below detection limits within four weeks. Most (78%) of pesticide detections occurred from May through September. Eight of the eleven geozones have had pesticide detections with most detections reported in the shallow weathered till. In 1988, a majority of the samples which detected pesticides were from the sand and gravel geozones. This year also constituted 44% of all pesticide detections since monitoring began. Detections of pesticides occurred in 18 wells in 1988, which was almost twice as many wells as in any previous year. It appears that the conditions in 1988 generally favored the delivery of pesticides to the ground water. The reason for this is unclear but seems likely to be a result of decreased precipitation.

1.0.2 Summary of surface water monitoring and evaluation

The winter of 1987-1988 was cold with less snow accumulation than in 1987 resulting in another below normal snowmelt for 1988. Rain intensities were higher than in 1987 but total rainfall was less and no significant runoff events occurred at any tributary after the snowmelt runoff had ceased.

Several water quality parameters indicate sources of organic pollution in most tributaries. Loomis Creek and Pony Creek appear to be the most severely affected by runoff from feedlots. Loomis Creek again exhibited the highest concentrations for most pollutants. Goose Creek again exhibited higher water quality than other tributaries. Most tributaries contributed significant loads of phosphorus and nitrogen to the Oakwood Lake system even though hydraulic loadings for all tributaries were less than in 1987 due to below normal snowpack and a summer drought.

There is some indication that one of the feedlot operators in Loomis Creek is interested in an animal waste management facility. SCS engineers have met with him and will be drawing up plans for the operators review in 1989. This is an excellent opportunity to document the water quality improvements possible through effective animal waste management. The current data base, consisting of three years of runoff data, would provide the basis for a before and after analysis as well as a paired watershed study with Goose Creek. The analysis will be made possible if the system is built and additional funds can be secured to collect water quality data during construction and for 2 or 3 years following. Samples were taken above and below the feedlot throughout the snowmelt period in 1989 to allow further documentation.

Lakes with phosphorus concentrations above .050 mg/l are considered hypertrophic. Every sample taken from interlake and in-lake sites in 1988 contained .050 mg/l or more total phosphorus. Mid summer maximum in-lake phosphorus concentrations ranged from .370 ppm at Turtle lake (L-5) to .210 ppm at East Oakwood Lake (L-7). These values indicate that substantial phosphorus reductions would be required to change the Oakwood Lakes from hypertrophic to eutrophic.

A partial winter kill during the early part of 1988 caused a large increase in the amount of available nutrients in the lake system early in 1988 and a change in the fish population. Following the spring season lower concentrations of available nutrients were observed during 1988 than in 1987. A slightly different pattern of nutrient limitation was also observed later in the year with increased phosphorus limitation. The relative concentrations of these available nutrients probably contributed to the shift from a system dominated by nuisance blue-green algae in 1987 to a more diverse population in 1988 that contained much fewer nuisance blue-green algae. The dramatic shift species composition which occurred may have been affected by any of these conditions or by other factors related to reduced runoff and less flushing of water through the lakes. Further analysis will be required to sort out all of these factors.

Since phytoplankton abundance is the major degrader of water clarity and quality in the Oakwood lakes system, phytoplankton abundance was evaluated to assess the effect of BMPs on water quality. Comparison of in-lake stations in 1988 indicates that algal biomass measured by both cell counts and chlorophyll a was significantly higher during the summer bloom in 1988 than in 1987. The lowest phytoplankton populations were again observed in East Oakwood Lake (L-7). The highest overall algal bloom density was again recorded at L-5 in Turtle lake.

Zooplankton graze on the phytoplankton. They were evaluated to estimate changes in phytoplankton attributable to zooplankton grazing. Overall zooplankton concentrations were highest in Turtle Lake in 1988 although differences between stations was much less evident than in 1987. There was no clear pattern in zooplankton abundance. They were least abundant at station L-2 in spring, L-7 during early summer and L-6 during late summer and fall.

The purpose of the fishery portion of the study was to monitor the relative abundance of fish in East and West Oakwood lakes and to monitor the diets of these fish. These data will help to determine the relationships between the biological community in the Oakwood lakes and water quality. Black bullhead dominated (84.7% of the total) the catch of 12 species in both East and West Oakwood lakes in 1988. Overall there were fewer yellow perch walleye and northern pike collected in 1988. There were 7.5 times more walleyes in West Oakwood than in East Oakwood. Relative abundance in 1987 was approximately the same. Populations of carp (benthivores) and fathead minnows (planktivores) and yellow perch were more abundant in East Oakwood than West Oakwood. Bullheads collected in West Oakwood were larger than those collected East Oakwood Lake but numbers were similar between lakes. The differences in fish populations observed in 1987 and 1988 will provide a basis for statistical analysis to determine the effect of fish on water quality.

1.0.3 Summary of vadose zone monitoring and evaluation.

Results of the monitoring of the vadose zone on different crops and different tillage systems to determine the flux of water and chemicals to the ground water at the "master site" is just getting into fully operational mode for data collection. The instrumentation set-up was not a cookbook procedure that needed to be implemented, but rather was very experimental and required much more development time than was anticipated two years ago.

No-till (NT) plots which had oats planted in 1988 are showing a faster response time to the flow of water through the soil profile compared to the moldboard plow treated plots as a result of an early rainfall received before the crop was planted in 1989. There appears to be more of a difference if the top foot of soil is dry rather than wet. This phenomena may relate to macropores on the NT system being larger and completely empty when there is less water in the top foot of soil, whereas the macropores tend to swell and "close down" and have not completely drained when the soil is wetter. The macropore system on the MP treatment has been disturbed so that the plow layer is acting more like a sponge and not allowing the movement of water beyond the top 6-8 inches before that layer is completely, or near, saturation. To extrapolate the limited data beyond this point in time would only be speculation.

With very limited data for 1988, there appears to be a positive (not statistically significant) relationship between the amount of nitrogen fertilizer applied to the soil surface and the concentration of nitrates detected in the ground water 15' below the land surface. The amounts of nitrogen applied in the spring were 100 lbs/Ac for oats and 200 lbs/Ac for corn. The samples were collected in the month of September. This occurred in a year when soil moisture was limiting in the months of June and July, when the crops were using water at the peak rate and yields were below normal.

With very limited data for 1988, there also appears to be a positive (not statistically significant) relationship between the amount of dicamba (Banvel) applied to the soil surface and the concentration of dicamba detected in the ground water 15' below the ground surface. Dicamba was sprayed on the ground surface in the spring as "label rates" to oats at 0.25 pts/Ac and to corn at 1.0 pts/Ac.

There does not appear at this time to be any differences between tillage systems either for oats or corn in the amount of nitrogen and dicamba applied and the amount detected in the ground water. The amount of data is limited presently and more can be determined as the water quality data from the unsaturated zone is collected.

1.2 Introduction

1.2.1 Project History

The Oakwood Lakes-Poinsett RCWP area, located in east-central South Dakota, was originally designated as two separate 208 Water Quality Study areas (WQSA) by the Department of Water and Natural Resources (DWNR) in 1976. As WQSA's, both were monitored to determine the extent of the surface water quality problems. Reports, including recommendations to alleviate the water quality degradation, were included in the original 208 South Dakota Statewide Water Quality Management Plan.

Meetings with local people to discuss the problems of the lakes and watersheds showed a considerable amount of public support for the initiation of a 208 Water Quality Implementation Project in the two watersheds. In response to this local support, DWNR contracted with the Brookings, Kingsbury, and Hamlin County Conservation Districts to hire a project coordinator and begin an intensive effort to apply BMPs in the two watersheds. This was to be accomplished through the use of special project and Agricultural Conservation Program (ACP) funds from the Agricultural Stabilization and Conservation Service (ASCS) of the U.S. Department of Agriculture (USDA). The contract was signed, and the project coordinator was hired in October, 1980.

As with other 208 projects in South Dakota, the Oakwood Lakes-Poinsett Project was a combined effort among various federal, state, and local agencies and groups. Included were: DWNR; Brookings, Kingsbury, and Hamlin County Conservation Districts; ASCS; Soil Conservation Service (SCS); the U.S. Environmental Protection Agency (EPA); Lake Poinsett and Oakwood Lakes Development Associations; East Dakota Conservancy Sub-District (EDCSD); First Planning and Development District (FPDD); and various others. Additional evidence of the combined support for the Oakwood Lakes-Poinsett Project was its inclusion in the State Water Plan.

About this time, interest was developing among applicable State and Federal government agencies to submit an application for funding through the National Rural Clean Water Program (RCWP). On January 15, 1981, a State RCWP coordinating committee meeting was held by the ASCS to make a decision on which project to submit for the RCWP application. The Oakwood Lakes-Poinsett WQSA was selected since both ground water and surface water quality problems were present. An application for approval for RCWP funding was submitted to the National Coordinating Committee (NCC) in February, 1981. The Oakwood Lakes-Poinsett WQSA was approved for RCWP funding in June, 1981, and the project plan of work was submitted to the NCC in October, 1981.

One of the major components of the RCWP is the water quality monitoring and evaluation of the BMPs effectiveness. The SCS has this responsibility according to the RCWP regulations. The state SCS developed an agreement with DWNR to administer this phase of the RCWP.

Prior to the completion of a monitoring strategy for the RCWP, the project was recommended by the NCC as a candidate for additional funds to develop a CM&E plan. A pre-proposal for three levels of funding, as requested, was submitted to the NCC in August, 1981. The South Dakota ASCS office was notified in December, 1981, that the Oakwood Lakes-Poinsett RCWP had been tentatively selected for CM&E funding and to submit a final CM&E plan of work. After many hours of coordinating with state and federal agencies for input, editing, and consultation, the final work plan was compiled and sent to the NCC. Funding for the CM&E was received after a cooperative agreement was signed between the DWNR and ASCS with concurrence by the SCS in October, 1982.

1.2.2 Water Quality Problems

A complex of lakes exists within the project area. The larger of these are: Lake Poinsett-7,868 acres/average depth of 10 feet; Oakwood Lakes--2,184 acres/average depth of 8 feet; and Lake Albert--2,400 acres/average depth of 4 feet. Smaller lakes partially within the project area are Lake St. John, Dry Lake, and Thisted Lake. Dry Lake drains directly into Lake Poinsett while Lake St. John and Thisted Lake drain to Lake Albert which drains into Lake Poinsett. Lake Poinsett has been hydraulically connected to the Big Sioux River through the Lake Poinsett diversion ditch. The Lake Poinsett drainage area (32,452 acres) is 83% cropland. The Oakwood Lakes drainage area (52,856 acres) is 50% cropland.

Lake Poinsett and Oakwood Lakes serve as the focal point for many recreational activities for eastern South Dakota cities and towns. These cities contribute significantly to an estimated 174,000 people living within a fifty mile distance of the lakes. The lakes and adjacent areas are used heavily for a variety of recreational activities including fishing, boating, swimming, water skiing, camping, picnicking, golfing, and hunting.

A national eutrophication study conducted by the EPA in 1977 ranked 31 lakes in South Dakota according to their eutrophic state. With one being the least eutrophic and thirty-one being the most eutrophic, Lake Poinsett ranked 19th, East Oakwood ranked 20th, and West Oakwood ranked 22nd. Water quality data generated by this study indicated that nutrient rich water (high nitrogen and phosphorus concentrations) was entering the lakes from several intermittent streams.

A 208 surface water quality study was conducted in the project area in 1977 and 1978. The SCS estimated 1.6 acre-feet/year of sediment was deposited in Lake Poinsett and 3.6 acre-feet/year in Oakwood Lakes; this is insignificant compared to the storage capacity of these lakes. Water quality data from the 208 study indicated (as did the eutrophication study) that high nutrient levels in the lake place it in an eutrophic to hypereutrophic state. According to the study the high levels of nutrients are being introduced by way of the intermittent streams and the Big Sioux diversion ditch.

Additional surface water sampling from 1982 through 1984 indicated that the lakes are phosphorus limited based on the typical 15:1 nitrogen to phosphorus ratio. A trophic state index (tsi) of greater than 50 has been calculated for Lake Poinsett (based only on total phosphorus) which would indicate that the lake is hypereutrophic (SD DWNR, 1985).

Non-bedrock aquifers in eastern South Dakota consist of glacial outwash deposits resulting from the Pleistocene Epoch glaciation. Within the project area surficial deposits are of the Wisconsin stage of glaciation, specifically the Cary and Iowan substage till, loess, and outwash. The outwash of greatest thickness is the Cary outwash. Morphology of the outwash is that of a valley train outwash which forms along the margin of a glacier as it melts and recedes. This results in long, relatively thin sinuous deposits of sand and gravel of variable thickness and aerial extent. There are three outwash aquifer systems in the area, referred to as the surficial, intermediate and basal aquifers. Connections between these aquifers occur but are not reliably known. The Big Sioux aquifer is the surficial aquifer associated with the Big Sioux River and its tributaries, and is of greatest importance in the project area because of its high quality water, accessibility, and thickness. The Oakwood Lakes-Poinsett project is not directly concerned with the other two aquifers of greater depth.

Thirty-two percent of the states population lives within the Big Sioux River basin. Within the basin, the Big Sioux aquifer supplies water to 94 percent of the total number of public wells. Domestic and stock use water needs are almost entirely supplied by ground water resources. Since the lakes are not suitable for drinking and the deeper underlying aquifers are of a poor water quality, the Big Sioux aquifer is the most extensively used source of water within the Big Sioux River basin.

The Big Sioux aquifer is found at a relatively shallow depth with the overlying soils being thin and/or highly permeable. The potential for aquifer contamination is great and from existing data, may already be underway. From the DWNR, Office of Water Quality files, water samples from 861 private wells in Brookings and Hamlin counties (wherein a portion of the project lies) showed 27 percent of the wells had nitrate levels in excess of the EPA's standard for drinking water of 10 milligrams per liter (mg/L) nitrate as nitrogen. Nitrate concentrations ranged from less than 0.1 to greater than 120 mg/L as nitrogen. Sampling of domestic wells during the Big Sioux Aquifer Water Quality Study showed excess nitrates in similar proportions as those reported by DWNR.

1.2.3 Overall Project Goals

The goal of the Oakwood Lakes-Poinsett RCWP project is to improve and protect the surface and ground water quality of the project area by the application of selected. The overall goals of the RCWP project are to:

a. Reduce the amount of total nitrogen and pesticides entering ground water and surface water by assisting with fertilizer and pesticide management on 70,000 and 65,000 critical acres, respectively (see 1986 Oakwood Lakes Poinsett annual progress Report for the definition and delineation of critical areas).

b. Reduce the amount of water and sediment borne pollutants entering waterways and lakes by applying or maintaining conservation tillage on 65,000 critical acres.

c. Reduce the amount of animal waste entering waterways, lakes and ground water by applying waste management systems on 10 livestock operations.

1.2.3.1 CM&E objectives

The objective of the CM&E program is to monitor the effect and to evaluate the impact on ground water and surface water quality of selected BMPs that have been implemented by the RCWP. Several investigations, each with its own set of objectives that relate to the main objective, are underway to describe the various parts of the system.

There are two levels of concerns: 1) are documented water quality problems due to farming operations? and 2) will the implementation of conservation tillage (BMP 9), fertilizer management (BMP 15), and pesticide management (BMP 16) have an effect on nitrogen and other nutrients, and pesticide levels in the hydrologic system?; if so, will the effect be positive or negative (i.e., will conservation tillage increase or decrease water related contaminant transport to the subsurface and directly or indirectly to the surface)?

Ground Water

Groundwater monitoring at field sites is being conducted to determine the effects of BMPs on field sites. The ground water problem is not straightforward. Concentrations of nitrate in the ground water are exceeding the recommended drinking water limit of 10 mg/L as nitrogen. The aquifer is quite susceptible to contamination and can be readily affected by land surface activities. Since the effects of BMPs 9, 15, and 16 on ground water have not been quantified, setting a goal of nitrate concentration reduction in the ground water is unreasonable. Currently, the monitoring objective is to test the idea (null hypothesis) that conservation tillage, fertilizer management, and pesticide management have no effect on ground water quality. Then, the goal of the project is to document changes in the water quality as a result of the BMP implementation in order to disprove this idea (null hypothesis).

Soil Profile (Master Site)

Any water reaching the ground water table (under natural conditions) must first pass through the soil profile. The master site will study the movement of, and quality of, the water within the soil profile. The objective is to determine the differences between land use effects on the annual vertical flux of the soil water solution between the soil surface and the ground water on soils typical of the RCWP area. An expansion of the current monitoring system is being implemented. It will gather data more often and at more depths than previous monitoring to determine if tillage, cropping or pesticide practices are affecting the soil water content, and nitrate or pesticide concentrations in the soil.

Surface Water

The goal of the OLSS project is to determine if the application of BMPs in agricultural watersheds will affect water quality in shallow, hypereutrophic prairie lakes. Documented surface water quality problems appear to be attributable to non-point source agricultural activities. Nutrient, sediment, and hydrologic budgets for the Oakwood Lakes in conjunction with the assessment of current trophic state and biological interations will be used to evaluate the effect of BMP implementation.

Edge of field runoff monitoring is being conducted to document the nutrients leaving the ground water field sites. This data will be used to account for water and nutrients on field sites. It will also be compared to the nutrient concentrations in the tributaries.

Agricultural Non-Point Source Model (AGNPS)

The objective of the AGNPS watershed modeling is to predict the effects of BMP implementation on excess nutrient loading to the surface waters within the CM&E project area. The model allows an examination of water quality under various management schemes over the entire project area or in sub-watersheds. The AGNPS model will be calibrated by comparing AGNPS output data with results from the OLSS watershed monitoring program.

Nitrogen Tillage Residue Management Model (NTRM)

The NTRM model simulates the soil-water-crop continuum based on climate, soil type, soil moisture, land use, management practices, vegatative cover, and fertilizer application. It outputs volumes and concentrations of leachate from the root zone entering the ground water. The objective of the NTRM modeling is to determine nitrogen solute transport to the ground water under various management conditions. Model outputs from the different conditions will be compared to estimate the effect of BMP implementation on nitrogen transport to the ground water over the entire CM&E project area.

Nutrient Budget Denitrification Study

There are many pathways for nitrogen to follow as it cycles through the environment. Two such avenues are the input of nitrogen through nitrogen fixation and mineralization and the output of nitrogen through denitrification. In that monitoring on the field sites would benefit from a complete accounting of the nitrogen budget, the objective of the denitrification study is to determine the nitrogen fixation and denitrification on the field sites. Another objective is to determine typical rates of denitrification under various croppings and tillages so that they can be applied project wide.

1.3 Project Methodology

1.3.1 Implementation

The RCWP is implementing land use management practices to improve surface water and ground water quality. Project assessment requires measurement of the effectiveness, first by applying a range of criteria which evaluates: 1) the surface and ground water quality improvement efficiency of selected BMPs; 2) the costs and viable cost share rates of applying a BMP or a set of BMPs; and 3) the implementation strategy which prioritized synthesis of project critical land areas and/or BMPs. Secondly, project assessment implies a information into an implementation strategy which would maximize water quality benefits while minimizing costs for planning and application under various land resource and climatic conditions. The second part of project assessment deals with the lessons to be learned from RCWP which will be valuable to the overall program assessment and future nonpoint source (NPS) control activities.

Given the range of questions to be answered by project assessment, the CM&E portion of this project requires several approaches which will be integrated to the extent possible. Statistical analysis of chemical and physical water quality and quantity data will yield information regarding the on-site effectiveness of BMP implementations and the status of the Oakwood Lake

System. Hydrologic modeling will relate the site specific information to the entire project area and the other lakes and aquifers which are affected by BMP implementation now and into the future. Economic modeling will evaluate the cost-effectiveness of an adopted implementation strategy. Given the limitations of climatic variation, project length, land use conditions and conservation treatment options in the project, modeling will allow the study of relative levels of effectiveness of BMPs and project plan alternatives.

1.3.2 Monitoring

To evaluate and discern the effects of BMPs, the system of water, nutrient, sediment, and pesticide cycling must be adequately described. This entails the monitoring of a physical and a chemical system. Six broad categories of monitoring arise from the pursuit of these objectives: ground water, surface water, soil profile, runoff, climate, and land use monitoring.

Ground Water

To accomplish the project objectives, the ground water monitoring approach is site specific. The site specific approach is desirable for two reasons: 1) the size of the project (106,000 acres) is too large to monitor as an entire unit; and 2) it increases the probability of detecting land use affected changes in water quality.

The specific sites are seven fields 10-80 acres in size. Six of the sites are farmed fields and one is unfarmed. Of the six farmed fields, one is a control site (i.e., farmed without the BMPs which are being evaluated). Originally, it was planned to monitor ten sites, but because of high precipitation, drilling was delayed for two years. At this point in the project, it is believed time and resources can best be spent on the seven established sites.

Ground water monitoring characterizes the physical setting of the system by drilling and installing monitoring wells and conducting in-situ aquifer testing. Well sampling defines the chemical setting and will continue as input to the evaluation of trends and comparisons throughout the project.

BMPs were implemented on the field sites prior to monitoring, so an experiment designed to compare with and without conditions is not possible. To discern effects attributable to BMPs, it is necessary to examine sites in terms of trends in water quality that may be developing due to the implementation of BMPs. The adopted analytical procedure makes comparisons between fields with BMPs, fields without BMPs, and fields that have never been farmed, in a pseudo paired watershed approach.

Surface Water

The OLSS study will meet project objectives of evaluating the water quality impacts of BMP implementation by determining hydrologic and nutrient budgets for the Oakwood lakes and assessing the current trophic state of the lake. Instrumentation to accomplish this includes gauging stations at all tributaries, and recording rain gauges to measure movement of surface water through the system. In addition to these inputs (and outputs) instrumentation is required to measure ground water movement using terrestrial wells, in-lake wells and lake bottom seepage meters.

To determine water quality, instrumentation sites and locations in the lake are sampled. Surveys of biological factors are performed to determine their effect on water quality and to describe the condition of the lake.

Runoff monitoring at applicable field sites utilizes stage recorders and flumes to measure flow volumes and automatic sampling devices to determine water quality. Topographic base maps of the field and control sites are being developed to determine contributing land areas.

Soil Profile

The expanded soil profile monitoring will include pesticide and nitrate soil water extractions and anlysis on a leaching-event-actuated automatic extraction system. By using more sensitive instruments which enable more timely data, a better correlation between tillage practices, soil water content, and soil water quality may be obtained. It is the ability to detect the contact time between soil and input water and the rate of movement of soil water to the ground water along with water quality parameters that provides information relative to the interaction of tillage, pesticides, and crops. The soil water monioring includes the use of transiometers (an electronic tensiometer), volumetric soil water monitoring, the use of infiltrometers to determine the rate of intake of water on the soil. Vadose zone water quality monitoring will detail the chemical setting in the soil profile and allow predictive evaluation of effects to the ground water. In an effort to make the predicitive evaluation more precise, the Master Site was established (and since has been re-evaluated) to facilitate the study under controlled conditions, of the interaction of pesticide applications, crops, and tillage practices.

Climatic

Monitoring of climatic conditions identify physical inputs to the system by measuring precipitation, solar radiation, soil and air temperature, and wind speed and direction. Sampling and analysis of precipitation will establish atmospheric chemical inputs.

Land Use

Land use monitoring describes the induced inputs and subsequent outputs due to farming activities on the sites. Land use histories will be collected and continuing operations will be tracked and recorded.

Denitrification Study

The soil nutrient budget study will calculate how much nitrogen is being lost in the gaseous form due to denitrification. This entails collecting soil cores in the field and returning them to the lab for incubation and analysis.

1.3.3 Evaluation

The comprehensive monitoring and evaluation of the Oakwood Lakes-Poinsett RCWP is designed to describe the cause and effect relationship between agricultural management practices and the quality of the ground and surface water resources of the study area. The conservation practices which are referred to as Best Management Practices (BMPs) have been applied to some of the farms in crop production. Conservation tillage (BMP 9), fertilizer management (BMP 15), and pesticide management (BMP 16) have been implemented and cost shared on the study area. While the CM&E monitoring activities are site specific, the evaluation of BMP requires the effects on the quality of all of the water resources to be evaluated. Making an evaluation requires the cause-effect relationships in the hydrologic system to be described quantitatively so that areal water quality impacts can be estimated from the site specific data. Each component adds a piece of evidence which contributes to the evaluation of the impacts of agricultural management on the quality of the water resources.

The data collected clearly documents differences in ground water quality between farmed and unfarmed sites; the same appears to be true from the runoff based on one year of paired watershed data. Measurements are made at each CM&E monitoring site to evaluate the critical parameters which control the transport of water and contaminants to the water resource. The quality of the surface or ground water resource results from the relatively amounts of water and contaminants which reach the resource in question. Evaluating the effects of the BMPs requires each part of the water and material balance at a monitoring site to be measured and related to each other part. The separable parts of the hydrologic system are illustrated in the conceptual diagram (Figure 1.1), and the processes are illustrated are illustrated by the arrows.

Each component of the CM&E project is reported in a separate section of this report. The sections describe the measurements which have been made on the physical characteristics of the hydrologic system, the processes of transport of water and contaminants from the source through the system to the water resource, and the quality of the water resource.

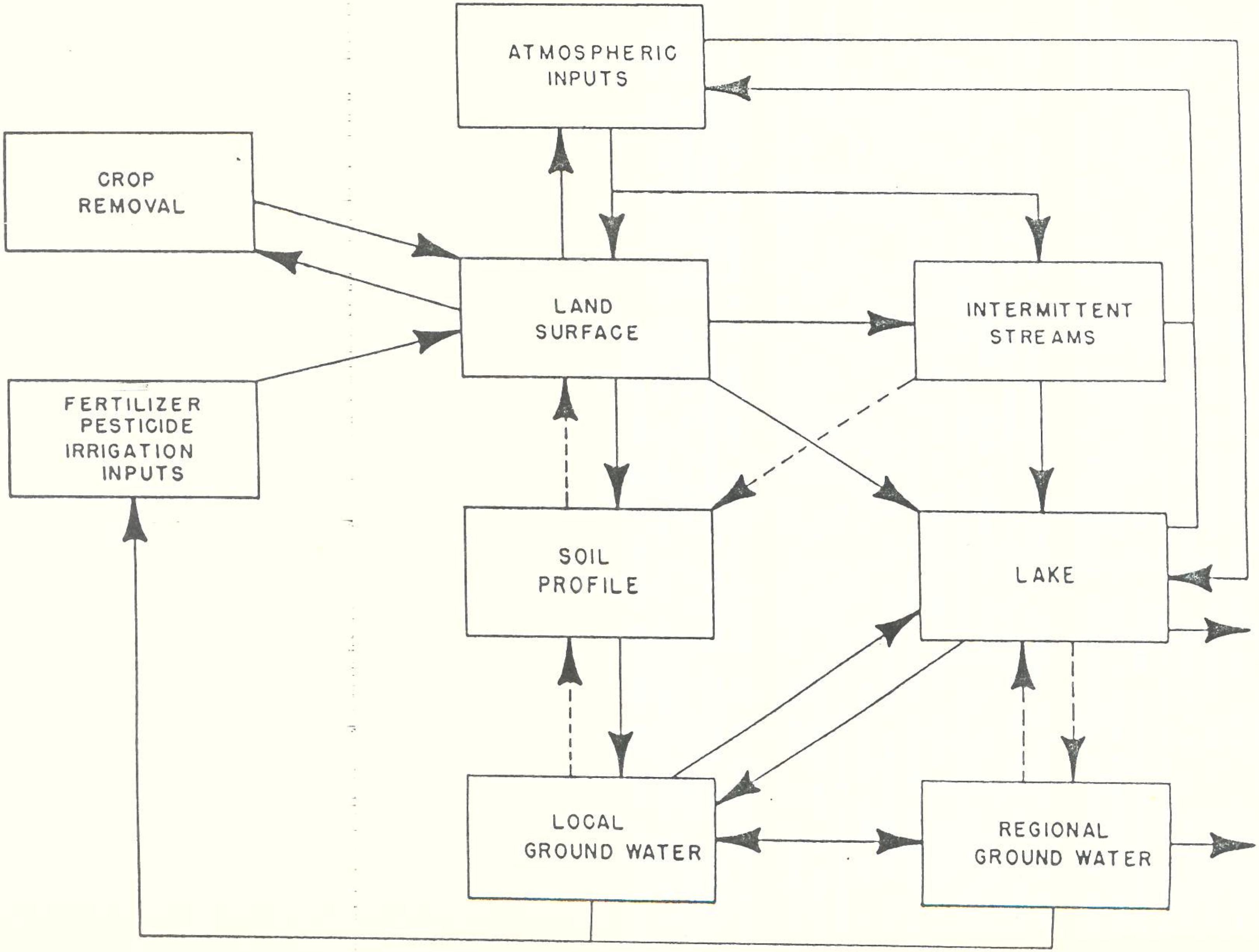

ATMOSPHERIC INPUTS
CROP REMOVAL
LAND SURFACE
INTERMITTENT STREAMS
FERTILIZER PESTICIDE IRRIGATION INPUTS
SOIL PROFILE
LAKE
LOCAL GROUND WATER
REGIONAL GROUND WATER

Figure 1-1

2.0 ANALYSIS AND EVALUATION OF FIELD SITE GROUND WATER MONITORING

Author: Clark Gregory Kimball
Contributing author: William Allen Best

2.1 Introduction

The CM&E ground water monitoring approach is site specific, given that: 1) the size of the project (106,000 acres) is too large to allow detailed monitoring as an entire study area; and 2) the selected sites increase the chances of detecting land use affected changes in water quality. The seven sites are fields 10-80 acres in size. Six of the sites are farmed fields and one is unfarmed (OP-Site). The unfarmed site was cropped until approximately 1970 to 1974. Of the six farmed fields, one (JW-site) is a control site (i.e., farmed without the BMPs which are being evaluated; BMP 9 conservation tillage, BMP 15 fertilizer management, BMP 16 pesticide management).

Monitoring began in 1984 and is continuing to date. Locations of the field sites and the Master site (see section 3.0 for the discussion of the Master site) are shown in Figure 2-1 (Oakwood Lakes-Poinsett Rural Clean Water Program Comprehensive Monitoring and Evaluation, project map). Field sites are labeled by the owners initials. Because of extremely wet conditions in the area, test hole drilling and monitoring well installation was not possible in the fall of 1985 or in 1986. Drilling and final ground water instrumentation was completed in the fall of 1987. CM&E ground water monitoring at the seven field sites utilizes 114 monitoring wells at 60 locations, 113 of which were installed for the project. One well was installed by the Department of Water and Natural Resources Division of Water Rights prior to the CM&E project.

2.2 Methodology

Monitoring at the sites includes land use, ground water, soil profile, runoff, and climatic monitoring. There are two main divisions to the monitoring, chemical and physical. The chemical monitoring is primarily water sample analysis and is designed to determine if water quality changes are occurring with time. Physical monitoring includes recording land use, water levels, flow volumes and other physical measurements. The physical monitoring will provide the foundation for explaining the mechanism of change and be the basis for extrapolations into the future, and aerial generalization.

2.2.1 Land Use

Land use monitoring is a major link in the monitoring system and an important information source for the final evaluation of the effects of BMPs. Land use histories at the field sites (section 2.5) have been tracked as far back as the farmer can recall. The farming operations during the year were documented at an annual interview with the land operator. Land use information will also be collected for as much of the project area as feasible.

Oakwood Lakes - Poinsett Project
Rural Clean Water Program
Comprehensive Monitoring & Evaluation

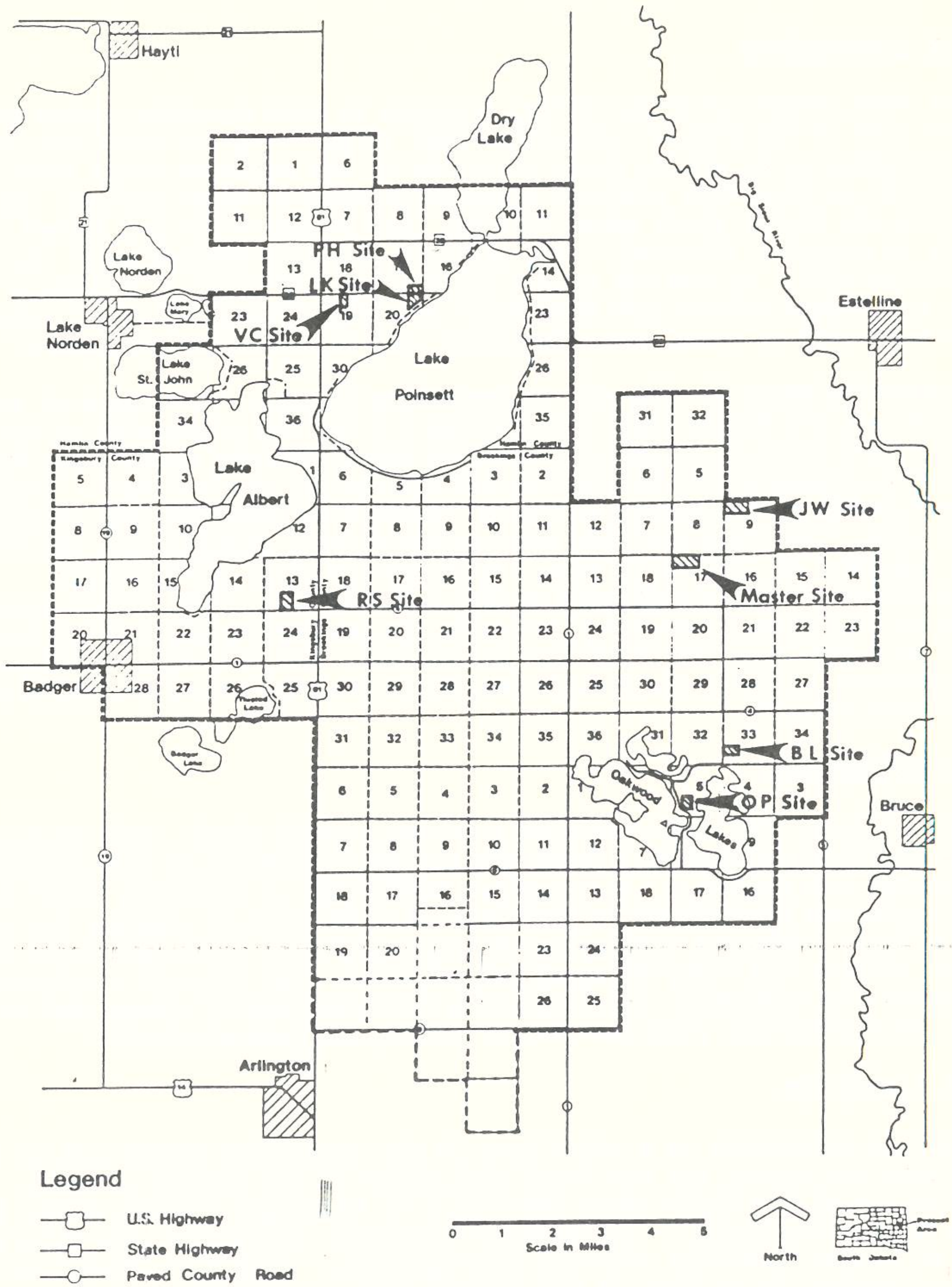


Figure 2.1 Oakwood Lakes - Poinsett Project area map.

2.2.2 Hydrogeology

Monitoring the ground water system is accomplished through monitoring wells. In any ground water monitoring project, well installation and construction procedures, and horizontal/vertical placement are crucial considerations. Improper installation, construction, or placement can yield data which is inaccurate, misleading or incapable of providing information needed to evaluate results. Once installed a monitoring well is a fixed sampling point.

Project monitoring wells were installed with a hollow flight auger drill rig so that: 1) no drilling fluid was used which could affect water chemistries; 2) semi-undisturbed split spoon samples could be obtained to document the geology; 3) accurate well placement was possible, especially in formations which tend to collapse or cave; and 4) sand/gravel pack and bentonite, to seal the annular space, could be placed in the proper interval.

The majority of the wells are two inch diameter polyvinyl chloride (PVC) pipe with three foot or five foot, # 18 slot, commercial PVC well screens joined to the pipe with threaded couplers. Five wells were constructed (installed November 1987) of fiberglass reinforced epoxy resin casing and three foot slotted intervals, for pesticide detection verification. Epoxy resin material has been found to adsorp less synthetic organic compounds than other materials, and not leach compounds into the water it is in contact with (Collins, A.G. and Johnson, A.I., 1988). Two inch diameter casing is favored because it is large enough to accept most sampling equipment and small enough to be relatively easy to purge of standing water prior to sampling. The length of well screen was chosen so discrete samples, as opposed to integrated samples across an entire aquifer thickness, would be collected. This is significant because chemistries in ground water can change vertically.

A sand/gravel pack was placed around the well screen to increase the efficiency of the intake and to retain particulates which would otherwise pass through the well screen. Natural sand/gravel pack was developed in unconsolidated sand and gravel formations when the materials collapsed around the well screen as the auger was removed. Above the well screen a seal (typically bentonite) was placed to isolate the screen from water outside the desired interval to be sampled. All wells were sealed from the ground surface to three feet below the ground surface. Wells finished in till or silty clay formations were sealed from 1 ft above the screen to the surface with bentonite. It was sealed because backfilling with drill cuttings could create an avenue for water movement that had a potential permeability orders of magnitude higher than the undisturbed soils.

Ground water environments are complicated three dimensional dynamic systems. Horizontal well placement at project sites, whenever possible, monitors for upgradient, on-site, and downgradient water quality and hydraulics of the site. Vertical placement of wells (well nests; groups of two or more wells at the same location screened at different depths) was coordinated with horizontal placement to document vertical variations of contaminants and vertical hydraulic gradients over the entire site. Vertical placement of wells was also directed in response to geologic stratigraphy.

2.2.3 Water Chemistry/Water Level Measurements

Ground water sampling, at all field site wells, was conducted quarterly. In addition, monthly samples were collected at selected wells on each site. Laboratory analysis of the water samples includes nitrate, nitrite, ammonia, organic nitrogen, total dissolved phosphorus, chloride, sulfate, total dissolved iron, total dissolved potassium, total hardness (occasionally), total alkalinity (occasionally), a scan for 26 pesticides (complete list of pesticides in section 2.3.5.3, Table 2-3), pH, electrical conductivity, and dissolved oxygen. The water level in each sampled well is measured prior to the well being purged.

The South Dakota Department of Water and Natural Resources (DWNR) has prepared a Quality Assurance (QA) plan according to the EPA recommendations and guidelines. The plan outlines QA activities and requirements for sampling procedures of all components including ground water, surface water, and soil samples, and for analytical procedures of all parameters. The QA plan also includes Quality Assurance/Quality Control documents prepared by the contractual laboratories.

Ground water sampling was conducted in a manner to assure a representative sample and to preserve the integrity of the sample prior to delivery to the laboratory. The sample was obtained with a pneumatic bladder pump, a variable capacity double check valve bailer or a peristaltic pump. The sample collection method depended on accessibility of the well, the weather sensitivity of the equipment, and the ability of the well to accept a sampling device. Before obtaining a well sample, the well was purged of standing water. Time for purging was determined at each pumpable well by pumping water through a cell until temperature and conductivity stabilized. In wells that must be bailed, the well was either bailed dry and sampled during recharge, or three to five well volumes were removed prior to sampling.

Pesticide samples were collected from five epoxy resin wells (installed in 1987), since April of 1988. The epoxy resin wells were installed at the same depth as existing shallow PVC wells. The epoxy resin and PVC wells are sampled at the same time but using different techniques. The epoxy resin wells are sampled with a polytetraflouro ethylene (PTFE) (Teflon-Teflon is a registered trademark) cleaned with acetone and distilled water. The epoxy resin well is purged using the "clean" Teflon bailer. The sample is collected in an acetone and sample rinsed glass bottle. Sample results will be compared to determine if the PVC materials and/or sampling techniques are a source of adsorption or desorption.

Sample containers were new or laboratory cleaned polyethylene bottles for most parameters, and glass with foil or teflon lids for the pesticides. Samples were kept cold until delivery to the laboratory and were always delivered within 24 hours of collection. A complete description of Standard Operating Procedures for ground water sampling is available upon request from DWNR.

Water level measurements in the wells were taken weekly during frost free seasons and alternate weeks after frost. From the water level measurements, at the shallow wells flow directions and horizontal gradients were determined.

Vertical gradients were calculated at well nests. Baildown and/or slug tests are being conducted at wells to determine hydraulic conductivity. Geologic cross-sections were constructed from drilling logs to determine stratigraphy and most probable routes of contaminant transport.

2.2.4 Geozones

Due to the variety of hydrogeologic environments that are being monitored, different sample populations were encountered. A classification method was devised to aggregate and help reduce the variability of the data. The method creates "Geozones" which characterize each monitoring well by the geologic stratum in which it is screened, depth of the well screen, and in the case of sand and gravel stratum, the thickness of overlying fine-grained material. The geozone classifications are project specific and not intended to encompass all possible geologic environments, but the methodology used and type of classifications produced may be applicable to other ground water investigations. Eleven geozones have been classified for the CM&E project.

Depth at which the well is screened is expressed in two ways: 1) depth below ground surface (depth b.g.s.) for wells screened in glacial till; and 2) depth below the water table (depth w.t.) for wells screened in sand and gravel.

Figure 2-2, (Geozones), shows the geozone abbreviations displayed on a diagrammatic cross section. The cross section is not a cross section based on the drilling information from a single site but represents a composite of several real stratigraphic scenarios found throughout the project area. The water table in the diagram is not intended to suggest flow directions, only the typical relative position or depth of the water table within the geozones. Following is an explanation of the geozone criteria, the number of project wells in each geozone, and the common abbreviation used throughout this report. (Till is glacial till; unsorted silty clay with a small percent of sand and gravel.)

Table 2-1. - Geozone Abbreviations and Definitions

WTLT15	Weathered till (brown color) or silty clay (reworked till) with the screened interval of the well at a depth b.g.s. of less than or equal to 15 ft. (19 wells)
WTGT15	Weathered till or transition zone (greenish brown zone interpreted as a transition zone between the weathered and the unweathered till), with the screened interval at a depth b.g.s. of greater than 15 ft. (11 wells)
UT	Unweathered till (gray color). (7 wells)
SC	Silty clay aquitard located between an upper and a lower aquifer system. (2 wells)
SS-A	Alternating layers of thinly bedded fine sand and silt. (4 wells)

NOTE: Overlying soil material refers to all silt and clay rich sediments overlying a sand and gravel layer. It includes silt and/or clay loams, and in some cases, glacial till.

SGLT5LT10 Sand and gravel with less than or equal to 5 ft of overlying soil material, with the screened interval at or less than or equal to 10 ft below the water table. (30 wells)

SGLT5GT10 Sand and gravel with less than or equal to 5 ft of overlying soil material, with the screened interval greater than 10 ft below water table. (15 wells)

SG5-15LT10 Sand and gravel with greater than 5 ft and less than or equal to 15 ft of overlying soil material, with the screened interval at or less than or equal to 10 ft below the water table. (2 wells)

SG5-15GT10 Sand and gravel with greater than 5 ft and less than or equal to 15 ft of overlying soil material, with the screened interval greater than 10 ft. below the water table. (3 wells)

SGGT15 Sand and gravel with greater than 15 ft of overlying soil material. (5 wells)

SG-UA Sand and gravel located under an aquitard as the lower unit of a two aquifer system. (16 wells)

The initial placement and subsequent distribution of wells within the geozones was targeted towards the shallower depths. The majority of the sand and gravel underlying aquifer geozone (SG-UA) wells penetrate saturated conditions ten feet or less. This bias was intentional from the outset and has proven to be advantageous since the highest concentrations of chemicals associated with agricultural activity have been observed at the shallower depths.

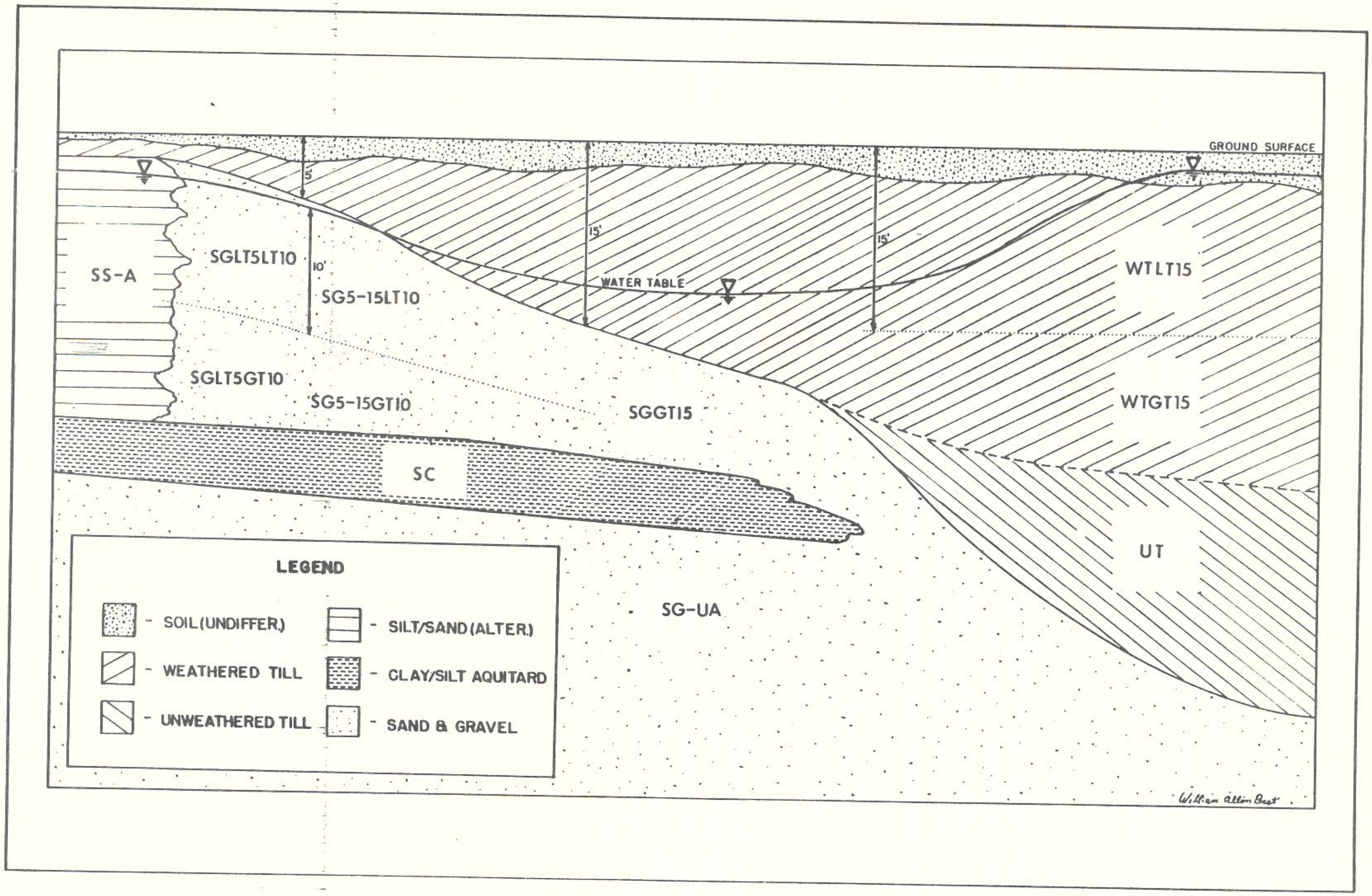


Figure 2-2. Geozone cross-section.

2.3 Results

2.3.1 Precipitation

Precipitation in the project area as a whole is best described by information from the U. S. Weather Bureau station in Castlewood (personal communication, Bill Lytle, State Climatologist). Lines of equal precipitation trend roughly in a southeast to northeast direction, and Castlewood is located just outside the project area to the northeast.

The intent of the following precipitation description is to indicate general trends during project monitoring. Different databases and techniques of computing estimated precipitation were employed in past years to describe site specific precipitation. Comparison of estimated versus actual precipitation at the Master Site indicates that below normal rainfall during the past two years has rendered the distance weighted mean method inaccurate.

Records of precipitation for Castlewood are complete from 1906 to present. Figure 2-3, (Annual Precipitation Castlewood Station) illustrates the total precipitation from 1906 through 1988.

For ten years prior to 1987 it has been above or near average; 1981 was just below average. This is the longest period of above average precipitation for Castlewood on record. Total annual precipitation for 1987 and 1988 was approximately 7% and 18% below normal, respectively. This is the second year in a row (1984-1988) that the project area has experienced below normal precipitation.

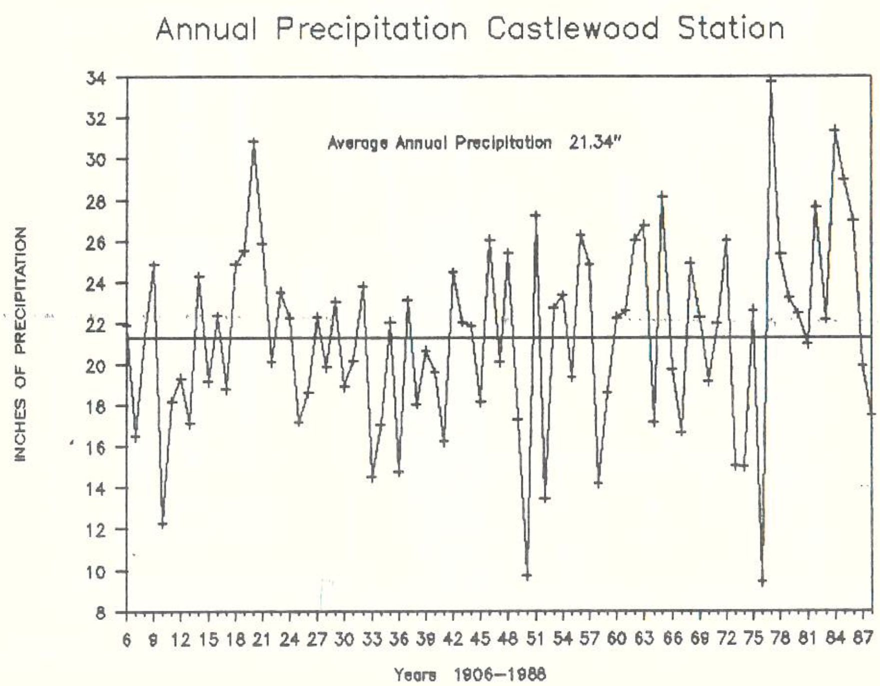


Figure 2-3. Annual precipitation for Castlewood Station.

2.3.2 Hydraulic Conductivities

Hydraulic conductivity (K) is defined as the capacity of a medium to transmit water. Single well hydraulic conductivity (slug and baildown) tests were conducted (1987) in the field. Hydraulic conductivity tests were conducted in the field because they are more representative of actual in-field hydraulic conductivities than laboratory testing. Water was instantaneously removed from a well and the rate at which the water in the well returned to its static level was recorded.

Single well hydraulic conductivity testing of wells screened in weathered and unweathered glacial till, and sand and gravel with slow recovery rates was performed using the baildown method. The procedure was to:

1. record pretest static water level (fiberglass tape)
2. remove water from the well using a PVC bailer
3. record changes in water level versus time until the water level reached static level.

Single well hydraulic conductivity testing of wells screened in rapidly recharging formations required the collection of water levels versus time more quickly than could be accomplished by hand. For these wells a pressure transducer and datalogger was utilized. The method of data collection used the following procedure:

1. record pretest static water level (fiberglass tape)
2. place pressure transducer on well bottom and program datalogger
3. displace a volume of water by inserting a slug
4. record changes in head with time until water levels equilibrate
5. remove slug, effectively removing a volume of water from the well
6. record changes in head with time until water levels equilibrate
7. numbers recalled and transcribed to coded forms.

The data was inputed on a spreadsheet which requests information about well construction, water table, and geology, and then manipulates and saves the data in ASCII format. These files are then submitted to a basic program which calculates hydraulic conductivities. Hydraulic conductivities are calculated using the technique and equations of Hvorslev (1951), a modified version of Hvorslev described by Cedergren (1967), and by a method developed by Luthin and Kirkham (1949).

Results of the single well hydraulic conductivity tests performed to date are presented in the following table. Tests were performed on 42 wells in 10 geozones.

Table 2-2. Hydraulic Conductivity Results.

WELL	K cm/sec	TYPE	NAME	DATE(s)	GEOZONE
BL-11M	6.2E-07	BAIL	BL-11M	06/08-12/87	WTLT15
BL-11S	1.0E-04	BAIL	BL-11S	06/09/87	WTLT15
BL-14S	6.5E-05	BAIL	BL-14S	06/08/87	WTLT15
BL-15S	8.9E-03	BAIL	BL-15S	09/30/87	WTLT15

JA-1M	1.0E-04	BAIL	JA-1M	06/09/87	WTLT15
JA-1S	3.3E-04	BAIL	JA-1S	06/09/87	WTLT15
JA-2S	2.2E-05	BAIL	JA-2S	06/09/87	WTLT15
JA-3M	1.6E-04	BAIL	JA-3M	9/21/87	WTLT15
JA-4M	6.9E-05	BAIL	JA-4M	06/09/87	WTLT15
OP-3S	4.3E-05	BAIL	OP-3S	06/08/87	WTLT15
OP-4S	1.4E-04	BAIL	OP-4S	06/08/87	WTLT15
OP-8S	2.4E-05	BAIL	OP-8S	06/08/87	WTLT15
BL-15D	5.3E-06	BAIL	BL-15D	06/08-09/87	WTGT15
BL-1D	6.0E-07	BAIL	BL-1D	06/08-11/87	WTGT15
BL-13D	4.0E-09	BAIL	BL-13D	06/08-15/87	WTGT15
BL-13M	6.1E-08	BAIL	BL-13M	06/08-15/87	WTGT15
BL-14D	1.0E-07	BAIL	BL-14D	06/08-15/87	WTGT15
BL-14M	1.3E-05	BAIL	BL-14M	06/08/87	WTGT15
JA-1D	2.2E-07	BAIL	JA-1D	06/09/87	WTGT15
JA-2D	1.0E-05	BAIL	JA-2D	06/09/87	WTGT15
JA-3D	3.2E-05	BAIL	JA-3D	06/09/87	WTGT15
RS-3S	1.1E-02	BAIL	RS-3S	06/09/87	WTGT15
BL-11D	4.0E-08	BAIL	BL-11D	06/08-12/87	UT
OP-3M	7.0E-08	BAIL	OP-3M	6/8-7/10/87	UT
OP-4M	7.5E-08	BAIL	OP-4M	06/08-25/87	UT
OP-8M	1.5E-08	BAIL	OP-8S	6/8-30/87	UT
RS-2	2.2E-07	BAIL	RS-2	6/9-9/30/87	UT
RS-3D	6.5E-07	BAIL	RS-3D	06/09/87	UT
LK-10D	5.6E-04	BAIL	LK-10D	6/11/87	SG-UA
BL-12S	4.17E-03	B/S	BL-12SA-C	08/14/87	SS-A
LK-14S	4.5E-04	BAIL	LK-14S-A	6/11&9/21/87	SS-A
PH-19	2.3E-04	BAIL	PH-19	09/21/87	SS-A
BL-13S	1.6E-04	BAIL	BL-13S	06/08/87	SGLT5LT10
LK-17S	2.1E-03	BAIL	LK-17S	06/11/87	SGLT5LT10
LK-18	3.4E-05	BAIL	LK-18	06/11/87	SGLT5LT10
OP-11	5.4E-05	BAIL	OP-11	06/08/87	SGLT5LT10
PH-8	5.2E-04	BAIL	PH-8	09/21/87	SGLT5LT10
BL-12D	7.3E-03	B/S	BL-12A-B	08/14/87	SGLT5GT10
OP-6S	1.1E-02	B/S	OP-6SB-F	08/21/87	SG5-15LT10
OP-6M	3.1E-03	B/S	OP-6MA-F	07/27/87	SG5-15GT10
OP-10	4.5E-03	B/S	OP-10A-F	08/14/87	SG5-15GT10
PH-21	2.2E-04	BAIL	PH-21	09/21/87	SC

* B/S - bail and slug test

2.3.4 Hydrogeology

Ground water level measurements are the basis from which hydrogeology interpretations begin. By relating the depth to water from each well to a common datum, a water table or potentiometric map can be drawn which indicates the direction of ground water flow. By examining water levels through time the occurrence of a significant recharge event may be determined. Recharge via infiltration from the surface is the avenue to ground water for land surface applied contaminants.

Though recharge to ground water can come from surface water sources, the primary source is precipitation. Precipitation may be lost to evapotranspiration prior to reaching the ground water table. As precipitation increases above normal, ground water levels rise. The degree of ground water rise is buffered by the degree of soil moisture deficit in the unsaturated zone above the water table.

Since December 1983, 12,687 water level measurements have been collected. Hydrographs (water levels versus time) have been plotted for each well. A representative well has been chosen from each site, and the hydrograph for that well is presented with the site fact sheet in section 2.5.

When the hydrographs are examined a familiar pattern is noted; water levels rose until May 1986 and have been declining since then. The smaller peaks are the result of spring and sometimes fall recharge events. These spring and fall events were greater on the ascending than on the descending limb.

The elevation side of the hydrographs (Y axis) is not at the same scale for all the graphs. Typically the rise and fall associated with recharge events has been of a higher magnitude in the wells completed in glacial till then in the wells completed in sand and gravel. Higher magnitude change has also been true for the decline in water levels since May 1986; glacial till wells have declined approximately 10 to 11 feet while sand and gravel wells have declined approximately 6 to 8 feet.

Water table maps are also presented with the fact sheet for each site in section 2.5. Data from May 1988 were chosen to be representative of the typical water table configuration. Shallow water table well data were used to construct the water table maps.

Water table maps were evaluated for changes through time during 1987 and 1988. Except for minor fluctuations the water table configurations were basically stable.

2.3.5 Ground Water Chemistry

2.3.5.1 Nitrates

Analysis of nitrate concentrations for all samples includes all data except data from wells known to be contaminated by activities not related to agricultural cropping practices. Two well nests, (4 wells) have had consistently elevated nitrate as nitrogen (NO_3-N) concentrations. Wells PH-23S and PH-23D have most likely been contaminated by the pumping of septic tank overflow into a dry well which is immediately upgradient of these wells. Wells RS-1S and RS-1D have had elevated NO_3-N concentrations due their position downgradient of an inactive barnyard, livestock holding area. Therefore, analysis of "all data" excludes data from these wells due to their point source nature of contamination.

From May 1984 through December 1988, 1,878 ground water samples were collected and analyzed for NO_3-N. This figure does not include the aforementioned samples or duplicate samples.

Water samples were analyzed for all the common nitrogen species; nitrate, nitrite, ammonia, and organic nitrogen. The evaluation in this report focuses only on nitrate, which is reported as NO_3-N. The reason for this focus is that 75% of the total nitrogen from all samples was NO_3-N. In the shallow geozones the average percent NO_3-N of the total nitrogen ranged from 78% to 91%. The average percent NO_3-N of the total nitrogen ranges from 8% to 73% in the deeper geozones. In general, the less total nitrogen the smaller the nitrate percentage. The dominant nitrogen species in samples with low nitrate percentages was either organic or ammonia nitrogen.

The results of NO_3-N analysis were plotted versus depth below water table of sample collection (Figure 2-4, NO3-N (ppm) vs. Depth Below Water). Depth below the water table where the sample was collected was used instead of depth below the ground surface. Depth below the water table results in an equilibration of depths which would otherwise be different because of differences in the depth to water. The plot includes 1,844 samples from 110 wells taken between May 1984 and December 1988. All of the 1,878 NO_3-N sample results could not be used because of missing water level data.

The plot indicates that NO_3-N concentrations greater than 5 ppm were found only at shallow depths of less than 20 ft below the water table. At depths greater than 20 feet nitrate values have not exceeded 4.1 ppm. At depths greater than 30 feet nitrate concentrations have not exceeded 0.2 ppm. Though the placement of wells is biased towards shallower depths, the data includes 150 points which exceed the 20 foot depth. In 1988, 33 samples were collected from a depth greater than 20 feet below the water table.

The median NO_3-N value and the number of samples comprising the median was plotted on a geozone cross section (figure 2-5). The total number of data points was 1,876 representing samples collected from May 1984 to December 1988. When a sample population is not normally distributed the median is a better measure of central tendency (than the mean) because it is not sensitive to extreme values (Crawford, C.G., 1984). All the geozone NO_3-N concentrations were analyzed for normality using the Statistical Analysis System (SAS release 5.18) and have nonnormal distributions (Shapiro-Wilk or Kolmogorov-Smirnov test for normality as appropriate). It is typical for ground water quality sample populations to not be normally distributed.

The cross section with median NO_3-N concentrations revealed that the highest median concentrations were in the shallow horizons. Specifically the shallow sand and gravel with thin topsoils (SGLT5LT10), the sand/silt alternating layers (SS-A), and the shallow weathered till (WTLT15). Samples from the silty clay (SC) were shallow with respect to the water table which was usually within ten feet of the sampling point. However, the median was based on 26 samples from only two wells. The two wells completed in it are probably more reflective of the immediately overlying shallow sand and gravel. The samples from deeper strata, sand and gravel especially but also the tills, display an almost four fold to twenty fold decrease in NO_3-N concentrations.

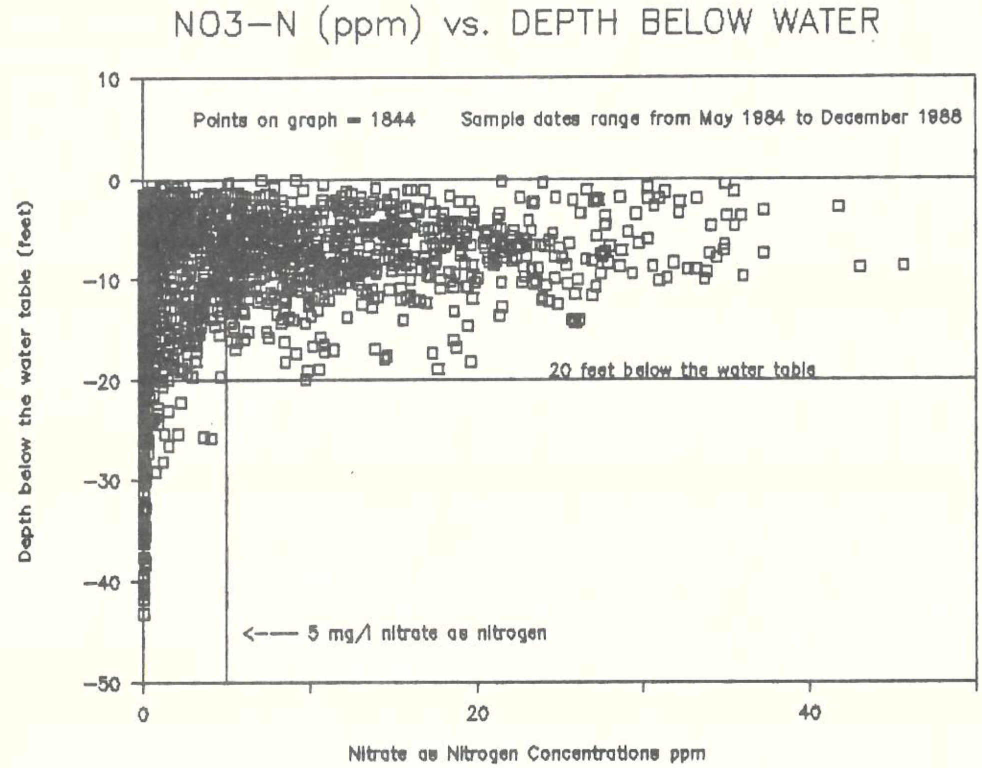


Figure 2-4. NO_3-N concentration (ppm) versus depth below water table.

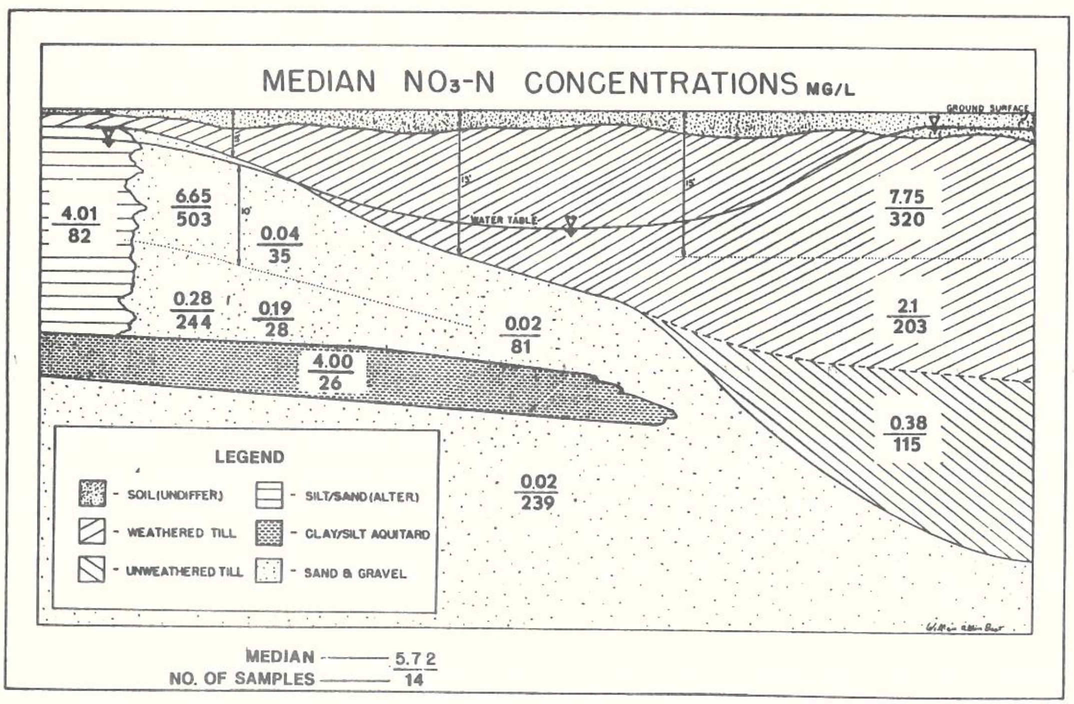


Figure 2-5. Median NO_3-N concentration by geozone.

The change in median NO_3-N concentrations since 1984 is presented in figure 2-6 Median Nitrate Concentrations by year. Five geozones were plotted; SGLT5LT10, SGLT5GT10, SG-UA, WTLT15, and WTGT15. These five geozones have the most wells completed in them, were the most frequently sampled (see figure 2-5) and displayed measurable change through time. They also follow a logical progression through the hydrogeologic system. Shallow sand and gravel (SGLT5LT10) to slightly deeper sand and gravel (SGLT5GT10) to sand and gravel separated from upper aquifers by an aquitard (SG-UA); likewise, a shallow weathered till (WTLT15) proceeds to a deeper weathered till (WTGT15).

Through the years, the medians for these geozones have, for the most part, maintained the same relative ranking. The exception was the deeper sand and gravel (SGLT5GT10) having a higher median than the deeper weathered till (WTGT15) in 1987, and the shallow sand and gravel (SGLT5LT10) having a higher median than the shallow weathered till (WTLT15) in 1988.

The two shallow geozone medians respond in a similar manner, but the shallow till response is of a higher magnitude. Response in the three deeper geozones is more subdued than the shallow geozones and apparently lags behind by approximately a year. The two shallow geozones displayed an increase in 1986 having decreased since monitoring began. The deeper geozones median concentrations did not display the increase until 1987.

Previous annual reports (1986 and 1987 Annual RCWP Progress Report - Project 20) have determined a statistically significant difference between the NO_3-N concentrations at the unfarmed OP-site and the other sites combined. A comparison analysis of all the data for these two data sets was performed for this report using the Mann Whitney U or equivalent Wilcoxan 2 sample test (Sokal, R. R., and F. J. Rohlf, 1969). These are nonparametric tests for comparing two populations. The tests are most appropriate, and more powerful than its parametric equivalents, (Crawford, C.G., 1984) when the population distribution is nonnormal.

The results of the analysis were that the NO_3-N concentrations for data from May 1984 through December 1988 at the unfarmed OP site (304 samples) were significantly lower (0.025 level of significance) than at the other sites (1574 samples) for the same time period. The 1988 data were also analyzed with the same results (78 samples from OP site, 467 samples from the other sites, 0.025 level of significance). The SGLT5LT10 geozone NO_3-N sample results from the OP (47 samples) and other sites (455 samples) for 1984 through 1988 were compared and the OP site was found to be significantly (0.025 level of significance) lower than the other sites. When the WTLT15 geozone NO_3-N sample results for the two sites were compared it was found that they were not significantly different until the 0.10 level of significance. In other words, the difference in NO_3-N concentrations in the WTLT15 geozone between the OP site and the other sites is not as great as the difference in the SGLT5LT10.

A distribution, by year, of the percent samples whose NO_3-N analysis results were within certain numerical categories was plotted. The categories were; 0-1 ppm, >1-3 ppm, >3-5 ppm, >5-10 ppm, >10-15 ppm, >15-20 ppm, >20-30 ppm, and >30 ppm. The distribution plot is presented in figure 2-7.

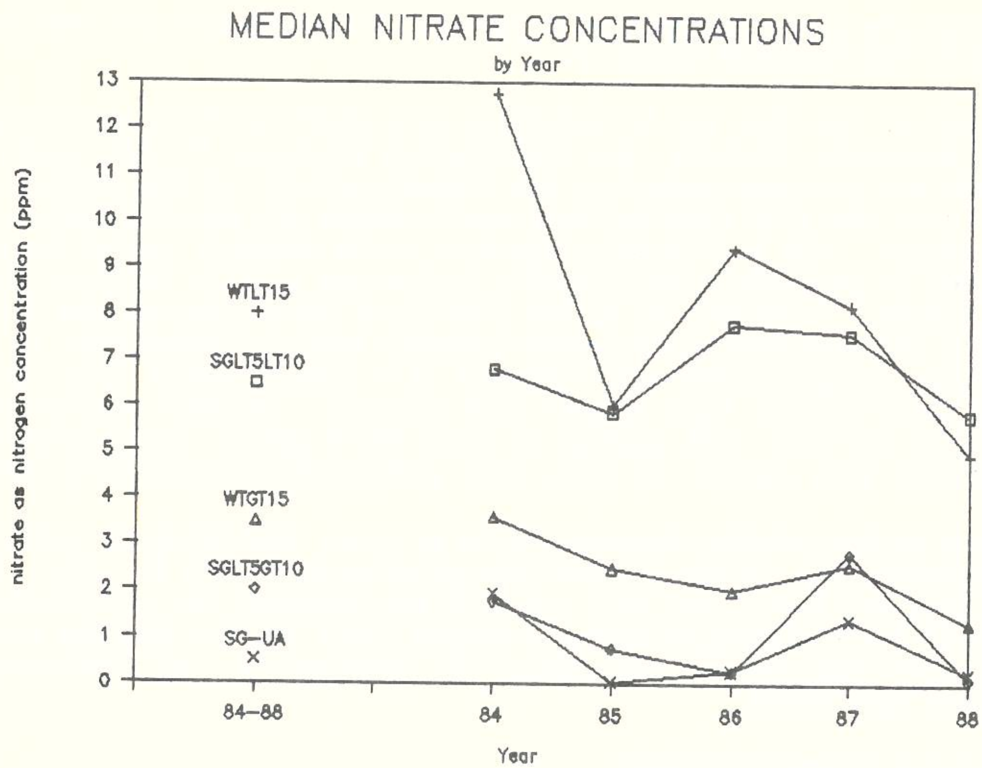


Figure 2-6. Median NO_3-N concentrations by year.

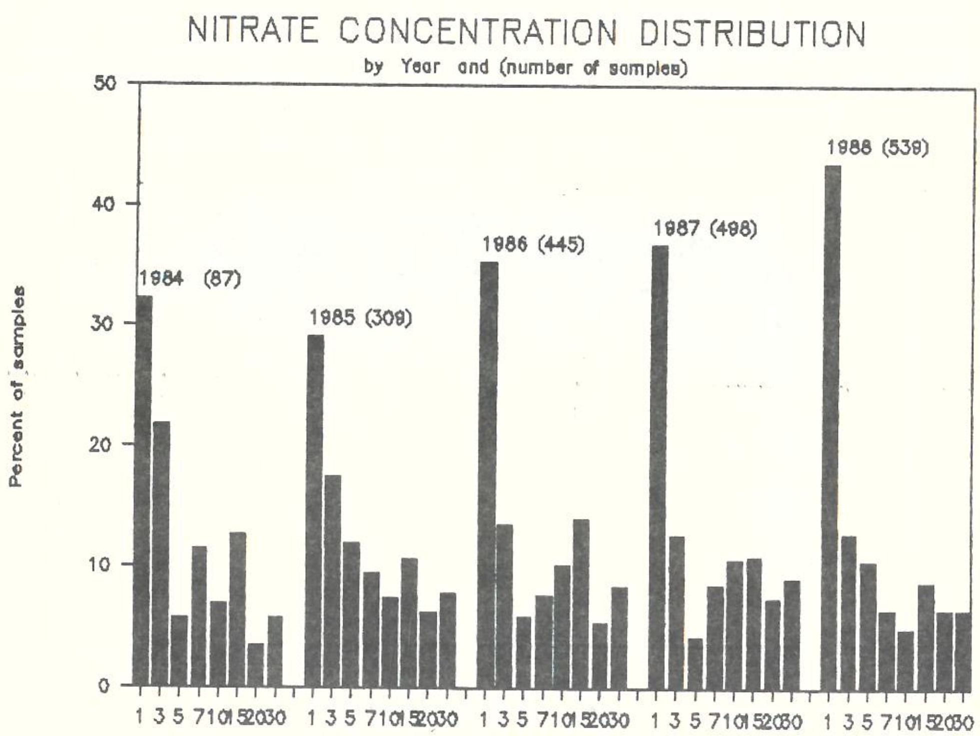


Figure 2-7. NO_3-N concentration distribution by year.

Each bar on the plot represents the percent of the samples for that year that were within the assigned category.

The purpose of the plot was to determine if a shift in NO_3-N concentrations could be observed. Overall, the distribution from year to year looks the same. The 0-1 category comprises the largest percent of the samples and for the most part the +1-3 (greater than one to three ppm NO_3-N) category is the second largest. The 0-1 category appeared to be somewhat larger in 1988 than it had been in previous years possibly indicating a shift to lower NO_3-N concentrations. A comparison of the 1988 NO_3-N concentration data to the 1987 data using the Mann Whitney/Wilcoxan 2 Sample Test indicated that in 1988, NO_3-N sample concentrations (539 samples) were significantly lower (0.025 level of significance) than in 1987 (498 samples). Further comparisons between 1987 and 1986 (445 samples in 1986) NO_3-N sample concentrations and 1986 and 1985 (309 samples in 1985) data indicated no significant difference.

Figure 2-6 Median Nitrate Concentrations by year, indicated an increase in the NO_3-N concentrations in the two shallow geozones from 1985 to 1986. The shallow sand and gravel for 1985 and 1986 was compared for statistical differences (Mann Whitney/Wilcoxan 2 Sample test) and the shallow weathered till for 1985 and 1986 was also tested for differences. No significant differences were found.

2.3.5.2 Dissolved Oxygen

Dissolved oxygen is measured in the monitoring well, with an in-situ probe, after purging and sampling. Dissolved oxygen was plotted versus depth below the water table and is presented in figure 2-8. The plot indicates that for the most part dissolved oxygen in the ground water decreases to less than one part per million as the 20 feet below water table depth is approached.

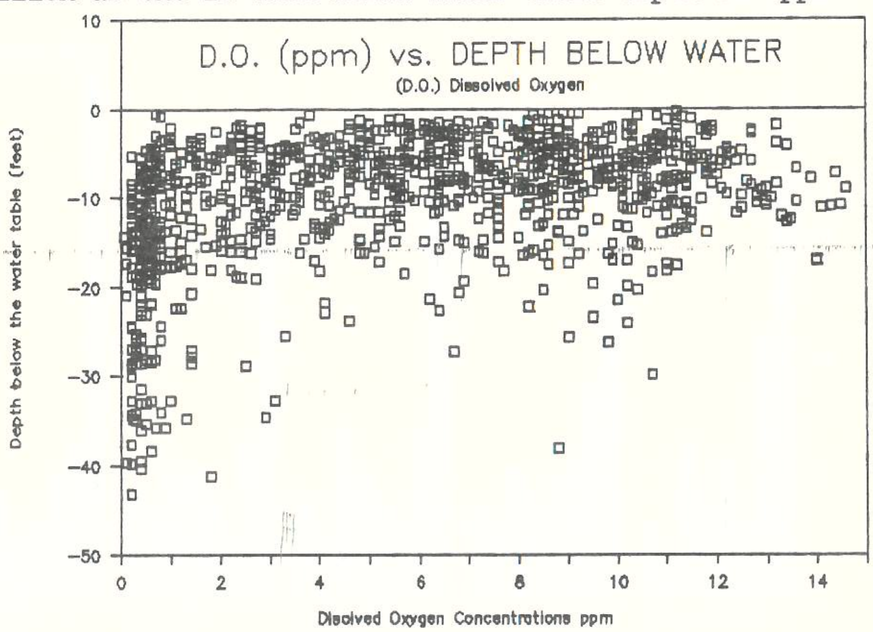


Figure 2-8. Dissolved Oxygen (D.O.) versus depth below water table.

2.3.5.3 Pesticides

Since May 1984 samples have been collected and analyzed for pesticides. With a few exceptions, samples have been collected for pesticide analysis on a monthly basis since 1985. In 1984 four sets of samples were collected; May, July, August and October. In 1985 samples were not collected in the months of January and February. In 1986 the months of September and October were missed. In 1987 and 1988 samples were collected every month.

The term pesticide includes both herbicides and insecticides. Samples are laboratory extracted (approximately 500 ml) and scanned for 22 pesticides with electron capture gas chromatography techniques. When the analysis detects a pesticide the sample is scanned a second time with a different column (thermionic nitrogen-phosphorus selective detector). Conservatively, detection limits are in the range of 0.10 - 0.01 parts per billion). The pesticide scan includes:

Table 2-3 - Pesticides Tested via Scan

Ambien (chloramben)	atrazine
Banvel (dicamba)	Bladex (cyanazne)
Counter (terbufos)	Dual (metolachlor)
Dyfonate (fonofos)	endrin
Eradicane (EPTC)	Furadan (carbofuran)
Ramrod (propachlor)	lindane
Sutan (butylate)	parathion
Tordon (picloram)	Sencor (metribuzin)
Treflan (trifluralin)	Thimet (phorate)
toxaphene	2,4-D
methoxychlor	
Lasso (alachlor)	

The pesticides used on the field sites are presented in Table 2-4. With the exception of Bassagrande and MCPA the pesticides in use on the field sites are included in the pesticide scan.

Table 2-4 - Pesticides Used On Field Sites

Banvel(dicamba)	Ramrod (propachlor)
Bassagrande	Sencor (metribuzin)
Furadan(carbofuran)	Treflan (trifluralin)
Lasso (alachlor)	2,4-D
MCPA	

In 1984 samples were collected from 33 different wells on approximately a quarterly basis. Starting in 1985 samples have been collected from 22 to 34 wells, (shallow, representative wells at each monitoring site), on a monthly basis.

To date, 845 samples have been collected from 67 different wells. Eighty positive detections from 27 different wells have been recorded. Pesticides have been detected in 9.5% of the samples and 40% of the wells.

There is reason to believe that two samples which tested positive for Lindane (sampled 1987) were contaminated by cattle. The cattle had been treated with an insecticide and were rubbing against the monitoring wells (knocking off the caps and in one case breaking the well).

The following table summarizes pesticide detections. All concentrations are in parts per billion.

Table 2-5. Pesticides Detected 1984-1988
(845 samples from 67 wells, 80 detections from 27 wells)

Pesticide	# of Detect	% of Detect	Median (ppb)	Range (ppb)
Alachlor (Lasso)	40	50.0	0.175	0.03 - 3.44
2,4-D	20	25.0	0.445	0.04 - 6.70
Metribuzin (Sencor)	6	7.5	0.08	0.02 - 0.124
Metolachlor (Dual)	5	6.25	0.35	0.28 - 0.96
Trifluralin (Treflan)	3	3.75	0.047	0.02 - 0.38
Dicamba (Banvel)	2	2.5	0.095	0.07 - 0.12
Lindane	2	2.5	0.05	0.04 - 0.06
Picloram (Tordon)	1	1.25	-	0.50
Atrazine	1	1.25	-	5.4

The majority of the pesticide detections are of low enough concentrations that detection limits of the techniques and equipment are being approached. Examining the data for continuity revealed that 85% of the detections were one time events with no detection in that well the following sample (typically four weeks later).

On a year by year basis the pesticides detected are presented in the following tables.

Table 2-6. Pesticide Detections by Year

Pesticides Detected 1984
(57 samples from 33 wells, 3 detections in 3 wells)

Pesticide	# of Detect	% of Detect	Median (ppb)	Range (ppb)
2,4-D	3	100	0.45	0.42 - 0.80

Pesticides Detected 1985
(126 samples from 22 wells, 23 detections in 9 wells)

Pesticide	# of Detect	% of Detect	Median (ppb)	Range (ppb)
Alachlor (Lasso)	20	87	0.315	0.03 - 3.09
Trifluralin (Treflan)	1	4.3	-	0.02
Atrizine	1	4.3	-	5.4
Metribuzin (Sencor)	1	4.3	-	0.02

Pesticides Detected in 1986
(168 samples from 24 wells, 14 detections in 10 wells)

Pesticide	# of Detect	% of Detect	Median (ppb)	Range (ppb)
Alachlor (Lasso)	6	43	0.17	0.07 - 0.43
2,4-D	7	50	0.43	0.13 - 6.7
Metribuzin (Sencor)	1	7	-	0.03

Pesticides Detected in 1987
(222 samples from 26 wells, 5 detections in 5 wells)

Pesticide	# of Detect	% of Detect	Median (ppb)	Range (ppb)
Alachlor (Lasso)	2	40	1.87	0.30 - 3.44
2,4-D	1	20	-	0.18
Lindane (suspected cattle contamination)	2	40	0.05	0.04 - 0.06

Pesticides Detected in 1988
(272 samples from 34 wells, 35 detections in 18 wells)

Pesticide	# of Detect	% of Detect	Median (ppb)	Range (ppb)
Alachlor (Lasso)	12	34	0.07	0.036 - 1.38
2,4-D	9	26	0.65	0.04 - 5.16
Metribuzin (Sencor)	4	11	0.085	0.08 - 0.124
Metolachlor (Dual)	5	14	0.35	0.28 - 0.96
Trifluralin (Treflan)	2	6	0.21	0.047 - 0.38
Dicamba (Banvel)	2	6	0.095	0.07 - 0.12
Picloram (Tordon)	1	3	-	0.5

Samples for pesticide analysis have been collected from wells ranging in depth below ground surface from 8.5 feet to 65.5 feet. Pesticide concentrations should be affected by transport through the soils, thus when referring to the depth of a well the depth below ground surface is used. This is in contrast to depth below the water table used during the discussion of nitrates. The average depth of the sampled wells was 19.9 feet. The average depth of wells in which pesticides have been detected was 17.9 feet.

Samples have been collected from every geozone. Figure 2-9 (Geozones Where Pesticides Were Sampled) presents this data as a pie diagram. The shallow sand and gravel with thin topsoil (SGLT5LT10) has been sampled more than the other geozones. The samples from the sand and gravel geozones as a group (stippled sections of the pie diagram) constitute approximately 61% of the total number of samples.

Eight of the eleven geozones have had pesticide detections (figure 2-10). The SC, SGGT15, and SG5-15GT10 geozones have not had any pesticide detections. The shallow weathered till (WTLT15) has had the most pesticide detections, 40% of all pesticide detections. The glacial tills as a group (non stippled sections of pie diagram) constitute approximately 54% of the samples which detected pesticides.

Figures 2-11A-D present geozones where pesticides have been detected, on a yearly basis, for the years 1985 through 1988. The percentage of detections in the sand and gravels stayed fairly stable at approximately 25% to 40% until 1988. In 1988, for the first time, a majority of the samples which detected pesticides were from the sand and gravel geozones.

Figure 2-12 presents the frequency of pesticide detections with time. With the exception of 1987, which had very few detections, it appears that the time when pesticides are most likely to be detected clusters around July. It is apparent that 1988 has had a large number of detections. This year is larger than any previous single year and constitutes 44 percent of all detections ever.

Figure 2-13 presents in a pie chart format, the months when pesticides were detected. The months May through August (stippled area) comprise the time when 68.8% of samples which detected pesticides were collected. The five month period of May through September represents the time when 78% of the samples which detected pesticides were collected.

Fiberglass reinforced epoxy resin (ER) monitoring wells were installed at five sites. The ER wells were installed alongside an existing PVC well, at the same depth, to determine if the PVC material was having an effect on pesticide concentrations. They were installed November 1987 at the OP (well OP-5E), VC (well VC-9E), RS (well JA-2E), BL (well BL-11E) and JW (well JW-7E) sites.

Since installation well JA-2E has been dry. One sample was collected from well BL-11E before water levels dropped so low that a samples could no longer be obtained. Well OP-5E was sampled five times before it went dry in November 1988. The remaining two wells VC-9E (sampled eight times) and JW-7E (sampled six times) continue to be sampled. In total 20 samples have been collected from the ER wells.

Three samples from the ER wells detected pesticides. Alachlor (LASSO) was detected in wells JW-7E and VC-9E, and trifluralin (Treflan) was detected in well OP-5E. The alachlor concentrations were the highest ever detected at the respective sites. The trifluralin had not been detected at the OP site previous to this and the only other detection at the OP-Site that year (1988) was alachlor.

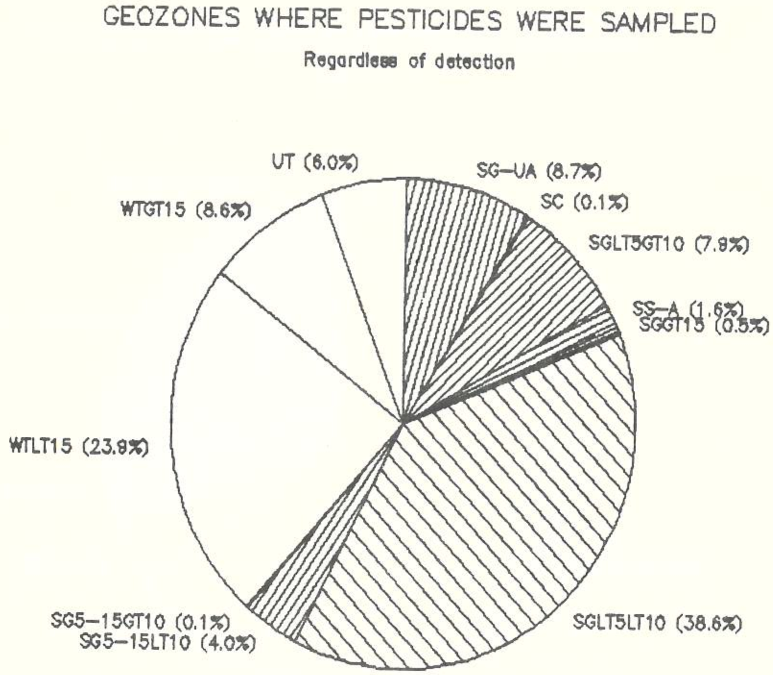


Figure 2-9. Geozones where pesticides were sampled.

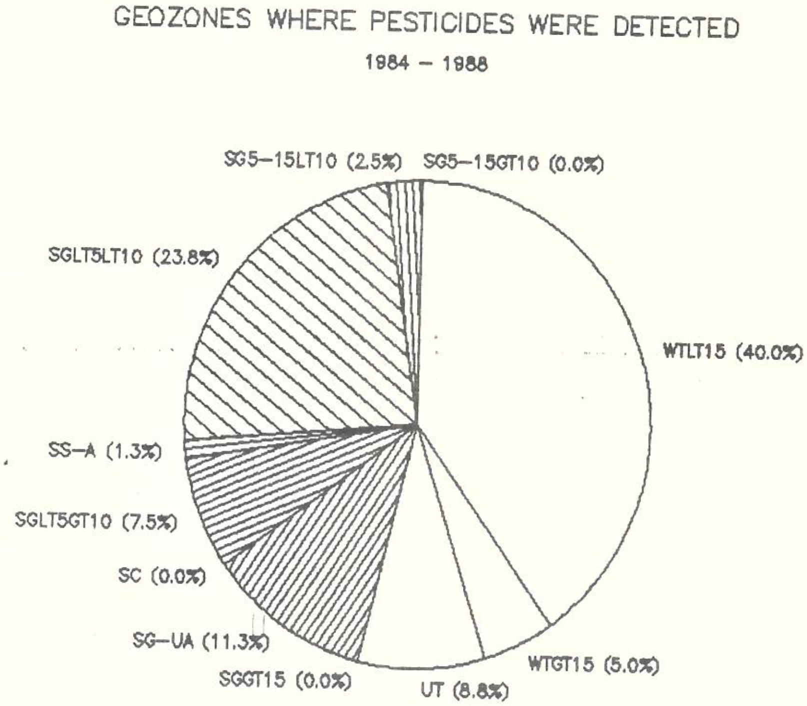


Figure 2-10. Geozones where pesticides were detected.

GEOZONES WHERE PESTICIDES WERE DETECTED

1985

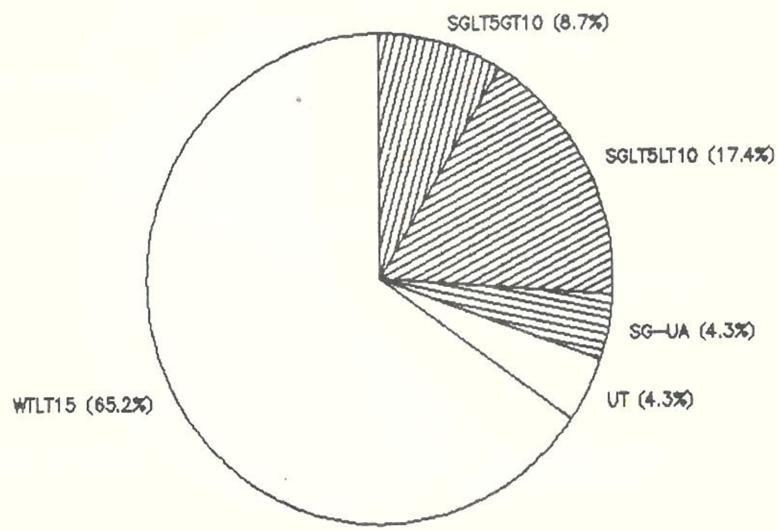


Figure 2-11A. Geozones where pesticides were detected - 1985.

GEOZONES WHERE PESTICIDES WERE SAMPLED

1986

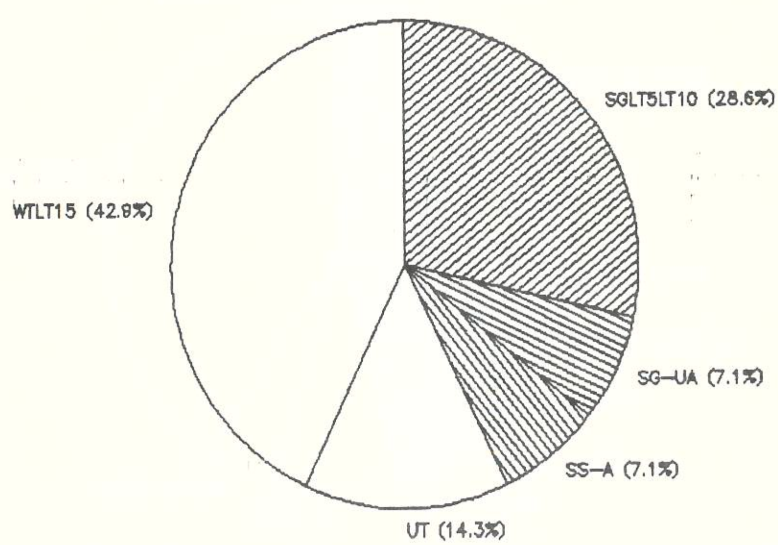


Figure 2-11B. Geozones where pesticides were detected - 1986.

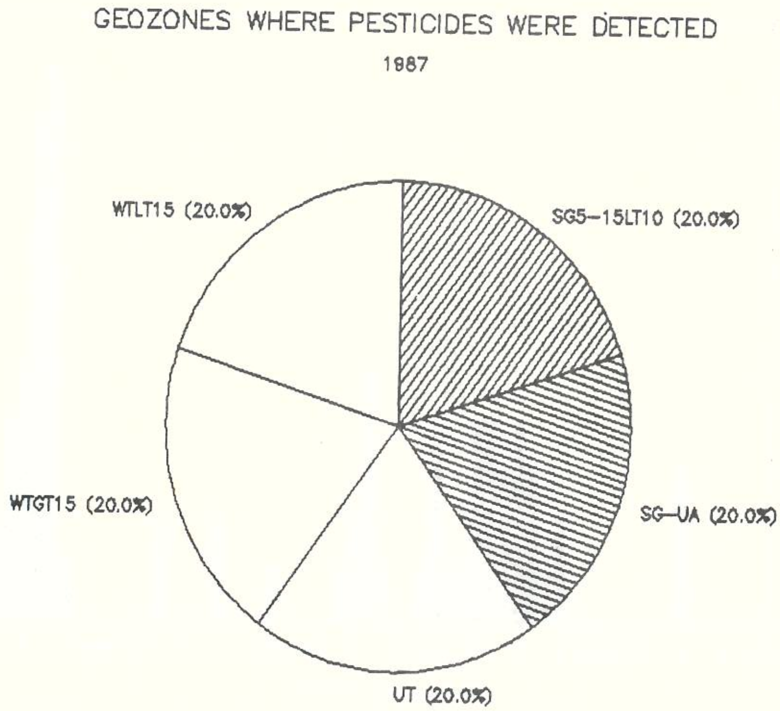


Figure 2-11C. Geozones where pesticides were detected - 1987.

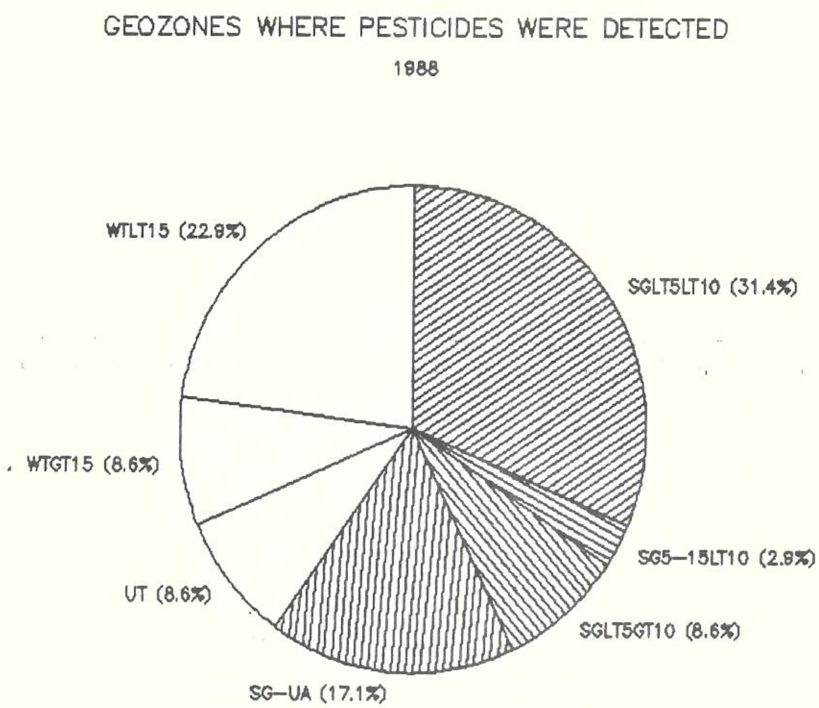


Figure 2-11D. Geozones where pesticides were detected - 1988.

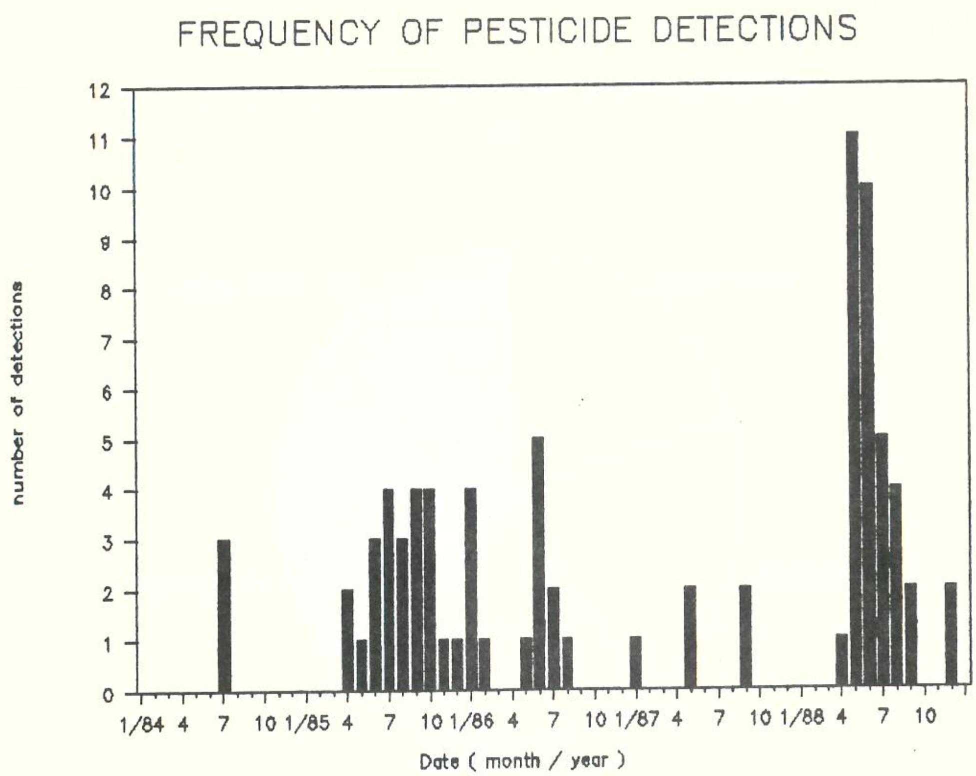


Figure 2-12. Frequency of Pesticide detections.

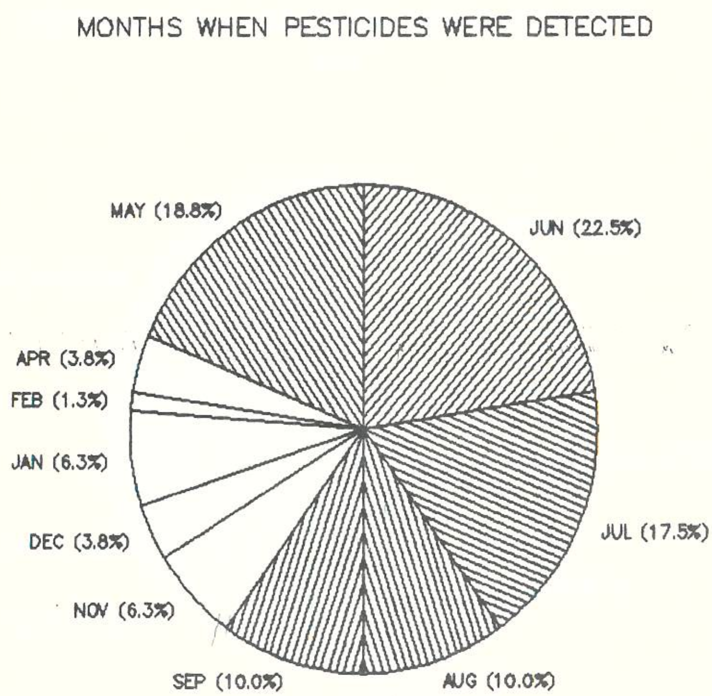


Figure 2-13. Months when pesticides were detected.

2.3.6 Surface Water Chemistry

Runoff samples were collected from the BL-site at a sharp-crested weir during the spring snowmelt of 1988. The water quality of field site runoff provides an indication of quality of the water that is available for infiltration to the ground water.

Samples were collected in 1-liter polyethylene or polypropylene bottles. Flows were determined using the sample procedures for tributaries (see section 5.2.2.1). Runoff samples were analyzed for the following parameters:

1. nitrate
2. nitrite
3. ammonia
4. organic nitrogen
5. chloride
6. sulfate
7. suspended solids
8. total solids
9. hardness
10. total phosphorus
11. orthophosphorus (soluble reactive P)

Table 2-7 is a summary of the water quality analyses of the runoff samples collected on the BL-site in 1988. Results were compared against ground water quality means of shallow wells to determine if any relationships exist. Ground water nitrate means for the shallow geozones (WTLT15, SS-A, and SGLT5LT10) are approximately 4 to 6 times greater than the surface waters, perhaps indicating that nitrates are dissolved in solution as infiltration occurs. Concentrations of organic nitrogen and ammonia in the surface water samples are greater than those in the ground water. The lower values in the ground water may be the result of leaching or conversion to nitrite or nitrate nitrogen. Surface water concentrations of total phosphorus is greater than those present in the ground water. This may be due to the adsorption of phosphorus to the soil with infiltration. Total dissolved solids are less in the surface water samples and is probably due to a shorter contact time of the surface water with the soils.

Table 2-7 Surface Water Quality Results - 1988 (in ppm)

Date	Suspended Solids	Total Dissolved Solids	Ortho PO4	Total PO4	%Ortho PO4	Nitrite as N	Nitrate as N	Ammonia as N	Organic Nitrogen as N	Total Nitrogen as N
2/29	141	259	0.36	0.51	70.58	0.15	1.57	0.18	3.31	5.21
3/01	34	182	0.21	0.22	95.45	0.11	1.66	0.21	2.00	3.98
3/01	323	161	0.25	0.62	40.32	0.05	1.66	0.19	2.06	3.96
3/03	3	285	0.20	0.24	83.33	0.15	1.35	0.13	1.38	3.01
3/10	23	181	0.16	0.23	69.56	0.09	2.60	0.17	2.09	4.95
3/24	15	571	0.30	0.40	75.00	0.07	8.69	0.05	1.97	10.7
Average:	90	272	0.30	0.37	66.67	0.11	2.92	0.16	2.14	5.35

Suspended solids and total dissolved solids (TDS) are plotted in figure 14. On the field sites suspended solids are an indication of soil erosion, crop residue or animal wastes. Flow through the sharp-crested weir during low flow on March 1st (< 0.1 cfs) was very low in suspended solids. As flows increased to 0.71 cfs later that day suspended solids increased (ten-fold) and total phosphorus (particulate matter) increased nearly forty times, indicating increased soil erosion. The small changes in the concentration in total dissolved solids (2/29 through 3/10) is because the source of the runoff was snow. As runoff decreased there was probably an increase in the soil-water contact time resulting in an increase in TDS, a decrease in suspended solids, and an increase in orthophosphorus (figures 14 and 15).

Organic nitrogen was the dominant form of nitrogen present on the Loomis field site (figure 16) until immediately after peak flow. The decrease in organic nitrogen is probably because the available organic nitrogen-rich matter had been flushed off the field site due to the higher flows. Concentrations of nitrate nitrogen begin to increase after the major runoff event (figure 16). Nitrates appear to be not related to flow but rather related to the water contact time with the soil.

Runoff samples collected from the BL-site and Loomis Creek (T-5) were compared. Water quality off the field site is lower in nutrients and higher in suspended solids due to erosion. See Section 3, Table 5-1 for Loomis Creek water quality results.

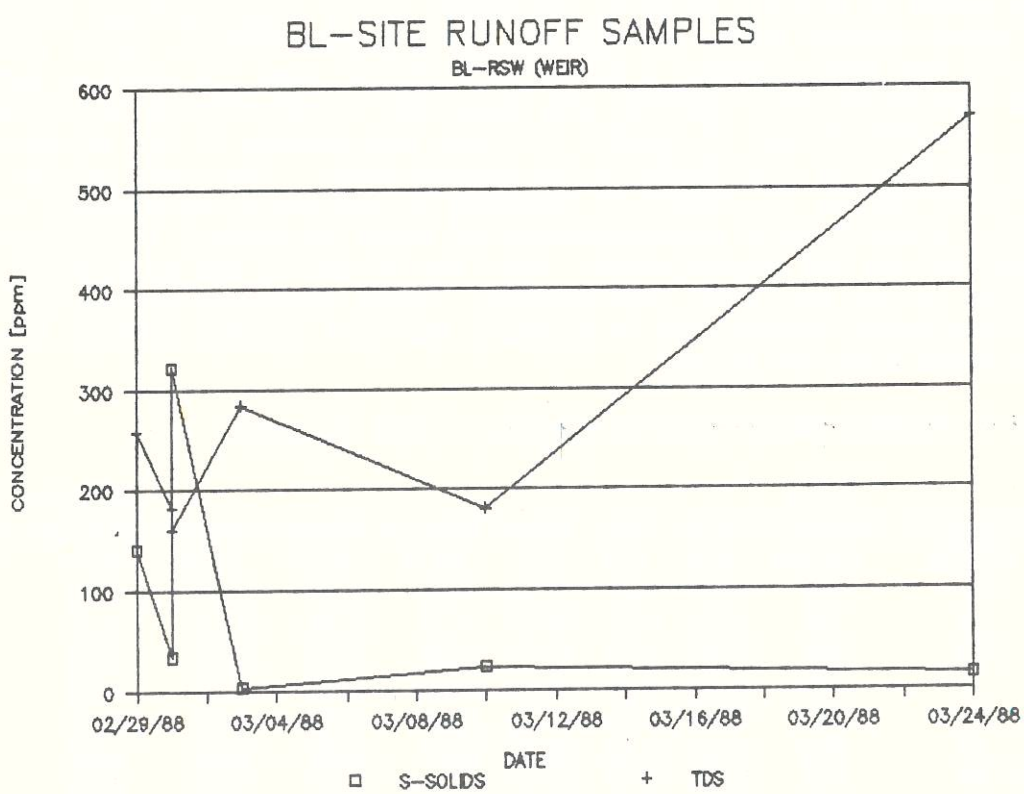


Figure 2-14. Suspended solids versus total dissolved solids (TDS).

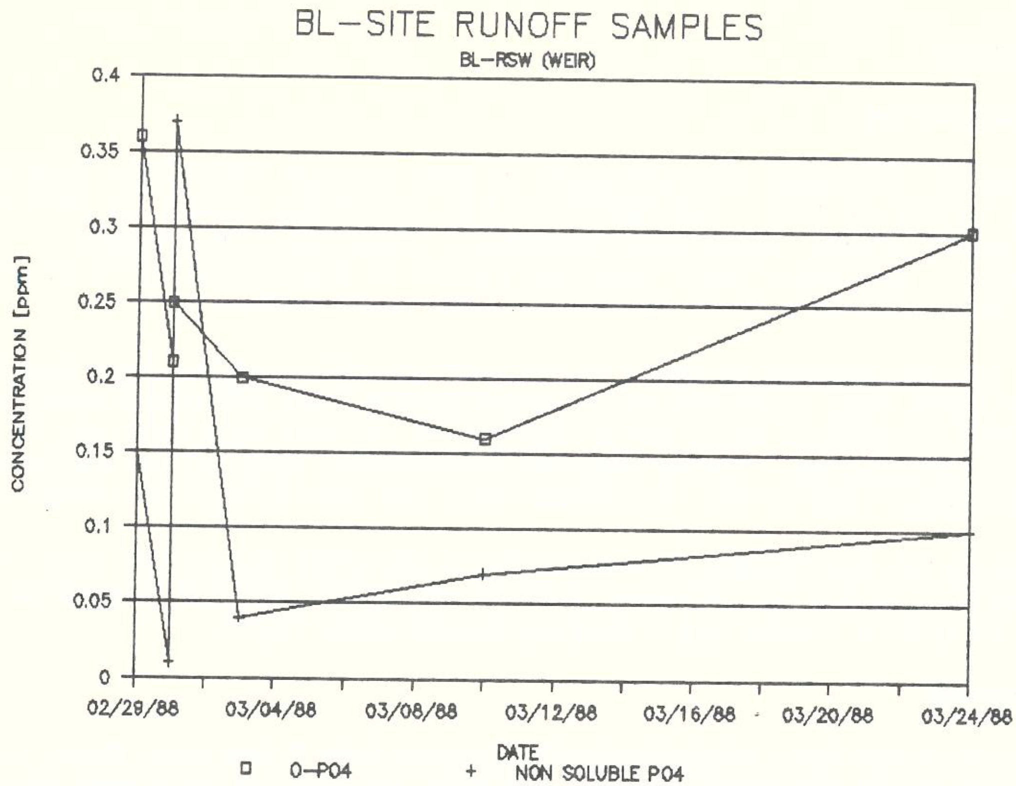


Figure 2-15. Total phosphorus versus orthophosphorus.

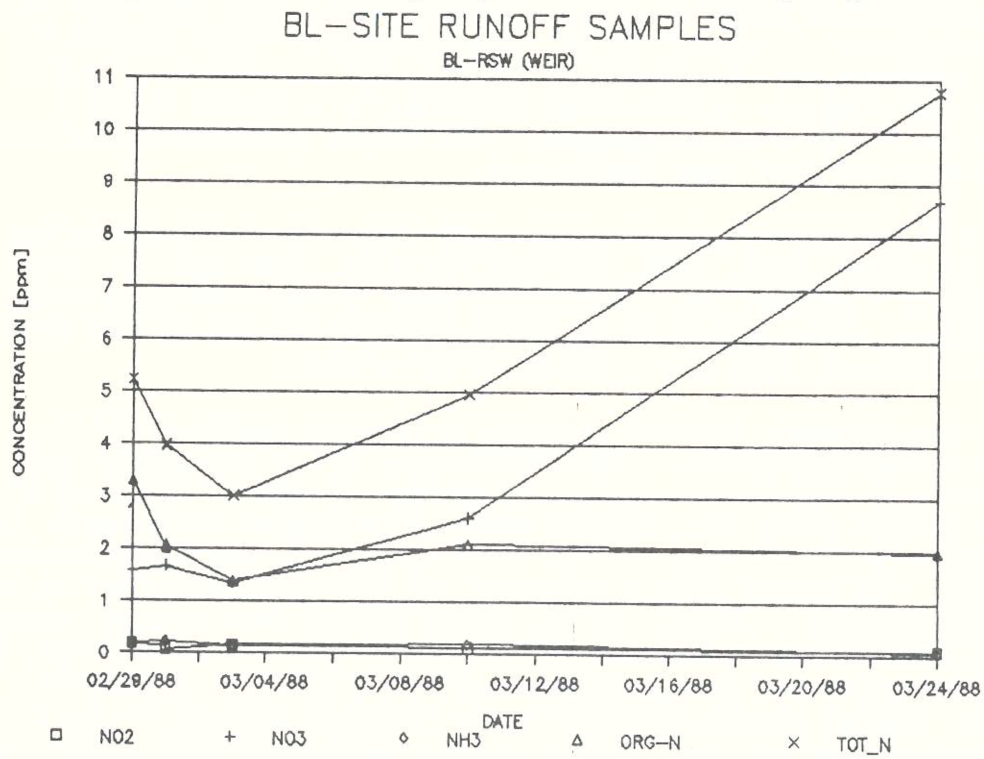


Figure 2-16. Nitrogen species.

2.4 Discussion

2.4.1 Hydrogeology

In response to increased precipitation in 1984 through 1986 water levels rose to a peak in May of 1986. Precipitation has been below normal in 1987 and 1988 and water levels, which were abnormally elevated, have dropped dramatically. The water level drop has caused 15 monitoring wells to go dry. Three of the wells were newly installed epoxy resin wells.

In order for the monitoring wells to collect discrete samples near the top of the water table they could not be screened deeply into saturated conditions. This results in shallow wells which may go dry if long term declines in water levels are experienced. Though this is unfortunate, many of the wells are nested and (what used to be) the deeper well can now be used for sampling.

The advantage of the changes in water levels recorded during the term of the project is the chance to evaluate nitrogen and other chemical parameter response to both a rising and a falling ground water table.

2.4.2 Nitrates

The depth at which NO_3-N concentrations greater than 5 ppm were found is less than 20 feet below the water table. The high (as high as 47.5 ppm) NO_3-N concentrations attest to how much nitrogen can enter the ground water. In the time since nitrogen has been applied in this area (approximately 20 to 30 years) it should have moved to greater depths than it has (see 1987 Annual RCWP Progress Report - Project 20 for calculations of travel distances). Additional evidence for the potential for nitrogen to move to a greater depth is found in the response of the deeper geozones to a change in NO_3-N concentrations in the shallow geozones. The deeper geozones lagged behind the shallow by only one year (see figure 2-6).

The plot of NO_3-N concentrations versus depth below the water table has been presented for three years, 1986, 1987 and now 1988 (1986 and 1987 Annual RCWP Progress Report - Project 20). Since 1986 when it was first presented over 1,100 additional water samples have been collected and the 20 feet below the water table critical depth for 5 ppm NO_3-N has endured.

The reason why nitrates have not traveled to greater depths could be attributed to denitrification. Denitrification is the biological reductive transformation of nitrate or nitrite to gaseous nitrogen. Denitrification has been shown to take place in a shallow sandy ground water environment (Trudell, M. R., Gillham, R. W., Cherry, J. A., 1986) similar to the sandy aquifers in South Dakota. The carbon source necessary for denitrification may be provided by infiltrating water. Trudell et al. (1986) states that "During recharge events when surface soil increases to near saturation, it is possible that organic carbon dissolved in the surface soil zone could be transported to the water table. Though denitrification is an anaerobic process it has been shown to take place in low (0.7 ppm) oxygen or even apparently well oxygenated conditions (Focht D.D., and Verstraete, W., 1977). As the plot of dissolved oxygen versus depth below the water table illustrates, (figure 2-8), oxygen decreased rapidly at about the same depth that nitrate reduction began. There seems to be no reason to preclude the possibility of denitrification limiting the depth to which nitrate can travel.

The median NO_3-N concentrations by year plot indicated that the two shallow geozones had an increase in median NO_3-N concentrations in 1986 and decreased thereafter. This increase corresponds quite well with water levels which were highest in May 1986 and have been decreasing since that time. The cause may simply be that water levels rise and fall in response to infiltration which is also the means by which nitrogen is delivered to the ground water. More infiltration throughout a year means more nitrogen transport to the subsurface. What remains to be answered is what the maximum leaching and transport capability may be.

The deeper geozones lag behind the shallow in their response to nitrogen changes. After two and a half years of water level declines the whole system is displaying decreasing NO_3-N concentrations and for the first time a significant difference between years has been detected.

The NO_3-N concentrations in the ground water above background concentrations appear to be attributable to agricultural cropping of the land. There is a significant increase in NO_3-N concentrations under the farmed sites as opposed to the unfarmed OP site. This significant difference has been detected during water level increases and declines. The WTLT15 geozone difference was not as significant as the SGLT5LT10 indicating that either the till has naturally higher nitrate or it still has residual nitrate remaining from when the OP site was farmed.

2.4.3 Pesticides

The most commonly detected pesticides were alachlor and 2,4-D. Together they account for 75% of the pesticide detections. These pesticides were also used the most frequently. Alachlor is used on corn and soybeans while 2,4-D is used only on corn. Many crop rotations include corn and soybeans so it adds to the probability that one of these two pesticides would be used.

Sampling for pesticides in ground water has taken place primarily in the shallow areas of the saturated strata. The analysis of geozones where pesticides were detected indicates that pesticides are most prevalent in the shallow zones. The shallow sand and gravels and the shallow glacial till constitute about 64 % of the samples which detected pesticides.

Pesticide samples have been collected primarily from the sand and gravel geozones. Conversely, the detection of pesticides has been mainly from samples collected in glacial tills. The presence of pesticides in the tills has been tentatively linked to the presence of cracks, joints and fractures known to exist in the tills (Connell, D. E., 1984). The fractures would allow rapid and direct access for infiltrating water to the ground water where samples were collected.

Detections of pesticides occurred in 18 wells in 1988, almost twice as many wells as in any previous year. Nine of these wells had never detected

pesticides before. Three of the wells were newly installed (the ER wells) and one well had not been sampled previously. The other five wells (LK-6, LK-15S, BL-14M, JW-3S, and VC-7) had been sampled in the past but had not detected pesticides.
Well LK-6 is located downgradient of the cropped portion of the LK site. Until 1988 the crop closest to the well was alfalfa which did not receive any application of pesticides. In 1988 the alfalfa was plowed under and a row crop was planted and pesticides applied. Well LK-6 had been sampled 35 times before first detecting pesticides in 1988. It would appear that prior to this, pesticides were unable to be transported to the well. It should be kept in mind that the LK site wells were sampled 69 times before 1988 with only two pesticides detections during that time. So it also appears that the conditions in 1988 generally favored the delivery of pesticides to the ground water.

Well VC-7 had been sampled 38 times prior to it's first detection of pesticides in the spring of 1988. In the years prior to 1987 little to no pesticides were used. In 1987 the land changed hands and the new operator began using more pesticides.

Wells BL-14M and JW-3S had been sampled 23 and 28 times, respectively, before their first detection in 1988. Well LK-15D had been sampled 5 times before it's first detection but there is some concern regarding the integrity of the well construction at this location.

The results of sampling in 1988 had proportions of detections in the sand and gravel that were roughly 50 % higher than they have been in the past. The sand and gravel was also, for the first time, the strata which produced the most detections. The reasons that sand and gravel samples detected more pesticides is not clear. The reason why more samples detected pesticides in 1988 than in any previous year is likewise unclear. The major change which seems likely to be a contributing factor in this increase of pesticide detections is the decreased precipitation. It may be speculated that the drier conditions caused more cracking in the upper topsoil and fine materials. When the precipitation events occurred, these cracks would be avenues to the lower sediments which bypass usual infiltration routes and the higher organic content of these upper sediments. With less organic content to bind the pesticides they could travel further. This reasoning offers an explanation for the overall increase in pesticides in 1988 but not for the increase in sand and gravel over tills.

The majority (78%) of the pesticide detections occur in a five month period of the year, May through September. Pesticide application takes place, in order of most frequent to least, in June, May, July, and April. This is the same order, from highest to lowest, as the top four months when pesticides were detected. It is reasonable that pesticides are detected in the same month in which they are applied.

The fact that 85% of the pesticide detections were one time events seems to indicate that the majority of the pesticides detected drop below detection limits within four weeks. The concentrations of the pesticides could be decreasing due to dilution, degradation, or transport away from the sampling point. We suspect that the first two processes are dominant due to the rapidity with which the concentrations drop.

2.4.4 Recommendations

An intensive analysis and evaluation of each site should be performed. The analysis would include horizontal and vertical aspects of ground water. Specific land use practices and nitrogen and pesticide response to those practices would be included. Special emphasis should be placed on those sites where different practices have recently begun (JW, LK and VC sites).
The other inorganic parameters collected as part of the ground water sampling, need to be examined with respect to possible changes attributable to climate, land use, geology and time (seasonal and or yearly). This data would be integrated with the nitrogen data and the responses of each compared.

The fate of the pesticide in ground water can not be evaluated with the present data. The pesticide must be detected more than once at a well. If one time detections are indicating a rapid loss of the pesticide than how many times were pesticides in the ground water at detectable levels but had degraded prior to sampling? We recommend that the sampling frequency be increased during the five months of most probable pesticide detection (May through September). Twice a month and weekly after application would substantially increase the probability of detecting pesticides. If necessary to maintain the present sampling budget, less sampling could be done during the other seven months.

Another analysis of pesticide detections versus a history (1987 Annual Progress Report - Project 20)) of use needs to be completed. In combination with the increased sampling frequency an understanding of when pesticides reach ground water after application may be gained.

The timing of storm events with respect to pesticide application and it's influence on the number of detections should be explored. This will require on-site rain gauges and frequent communications with the land owner (or operator).

In order to help eliminate false positives from the data analyzed by gas chromatography (GC), we recommend that samples which detect pesticides be verified using gas chromatography, mass spectrometry (GC/MS). A study in Massachusetts reported that positive detections of a herbicide by GC analysis, that was not used on the monitored field, was correctly identified as a nonagricultural compound by GC/MS analysis (Jenkins, J., Stone, C.T., and Bowes, J. 1988).

A few analyses should be performed which have not yet been attempted. An analysis of the detection of pesticides versus depth below the water table where the sample was collected. In a similar fashion the depth below the ground surface as an influence on pesticide detection. Lastly, whether the depth at which pesticides are detected is influenced by a decreasing or rising water table.

The initial indication from the epoxy resin wells was that concentrations of pesticides may be higher than in the PVC wells. If it were possible to install more of these wells it could increase the change of detecting pesticides which are at very low concentrations. The epoxy resin wells may also provide the most accurate concentrations due to their non-sorptive qualities.

2.5 Site Data Summaries

What follows are summaries of pertinent data for each site.

BL SITE Fact Sheet

Total area: 145 acres

Monitored: 40 acres

26	acres tilled
12	acres left in grass (hayed)
2	acres water (wetland)

General Geology: Two to three ft. of topsoil over 2 ft of clayey silt. Underlying the silt is usually 2 to 5 ft of poorly sorted sand and gravel which is absent in the northeast corner of the site and thickens to the west and south. Beneath the sand and gravel is 5 to 15 ft of brown weathered silty clay, little sand and gravel, glacial till overlying unweathered, gray glacial till. Varying thicknesses (0 ft to 30 ft) of a greenish brown transition till is found between the weathered and unweathered till. Under much of the site, at a depth of 40 to 45 ft is a sand and gravel unit 5 to 10 ft thick.

Precipitation (weighted mean calculation): Average 21.04" / year

1984	31.95"	52% over average
1985	25.37"	21% over average
1986	31.91"	52% over average
1987	21.64"	2% over average
1988	17.85"	15% under average

Monitoring Wells: 19 wells at 8 locations (21 wells, 9 locations when W.R. & OLSS wells are used)

Average well depth: 17.2 ft. Range: 8 ft. to 43 ft.

Average Depth to water (below ground surface): 7.25 ft.
Range: -1.11 ft. (negative number, water above ground) to +9.92 ft.

NO3-N concentrations: 347 samples average concentration 9.84 ppm

YEAR	# SAMPLES	MEAN	MIN	MAX
1984	22 samples	8.52 ppm	0.00 ppm	30.95 ppm
1985	70 samples	8.48 ppm	0.00 ppm	35.45 ppm
1986	83 samples	11.52 ppm	0.00 ppm	35.00 ppm
1987	89 samples	11.11 ppm	0.01 ppm	29.60 ppm
1988	83 samples	8.30 ppm	0.04 ppm	27.50 ppm

Geozones: Seven (7) geozone present on site.

WTLT15: Weathered till (brown color) or silty clay, reworked till with the screened interval of the well at a depth b.g.s. of less than or equal to 15 ft.

WTGT15: Weathered till or transition zone (greenish brown zone interpreted as a transition zone between the weathered and the unweathered till), with the screened interval at a depth b.g.s. of greater than 15 ft.

UT: Unweathered till (gray color).

SS-A: Alternating layers of thinly bedded fine sand and silt.

SGLT5LT10: Sand and gravel with less than or equal to 5 ft of overlying soil material, with the screened interval at a depth w.t. of less than or equal to 10 ft.

SGLT5GT10: Sand and gravel with less than or equal to 5 ft of overlying soil material, with the screened interval at a depth w.t. of greater than 10 ft.

SGGT15: Sand and gravel with greater than 15 ft of overlying soil material.

NO3-N Summary By Geozone:

			MEAN	MIN	MAX
WTLT15	5 wells	95 samples	18.19 ppm	3.33 ppm	35.42 ppm
WTGT15	6 wells	115 samples	9.43 ppm	0.19 ppm	28.00 ppm
UT	2 wells	50 samples	0.02 ppm	0.20 ppm	11.38 ppm
SS-A	1 wells	16 samples	11.79 ppm	6.90 ppm	19.00 ppm
SGLT5LT10	1 wells	16 samples	13.93 ppm	0.18 ppm	27.75 ppm
SGLT5GT10	2 wells	41 samples	3.88 ppm	0.03 ppm	19.75 ppm
SGGT15	1 wells	14 samples	0.05 ppm	0.00 ppm	00.14 ppm

Pesticides: 142 Samples taken from 14 Wells with 17 Detections

Pesticides Detected (in ppb)

Pest.	# Samp.	# Wells	Ave Conc.	Median	Range	Year
Lasso	5	3	0.27	0.160	0.030 - 0.820	1985,86,88
2,4-D	4	3	1.19	0.450	0.110 - 3.570	1986,88
Sencor	1	1	0.02	-	0.020	1985
Atrizine	1	1	5.40	-	5.400	1985
Lindane	2	2	0.05	0.050	0.050 - 0.050	1987
Tordon	1	1	0.50	-	0.500	1988
Banvel	2	2	0.09	0.095	0.095	1988

Note: # Samp. = the number of samples which detected the pesticide name;
Wells = the number of well in which the named pesticide was found, etc.

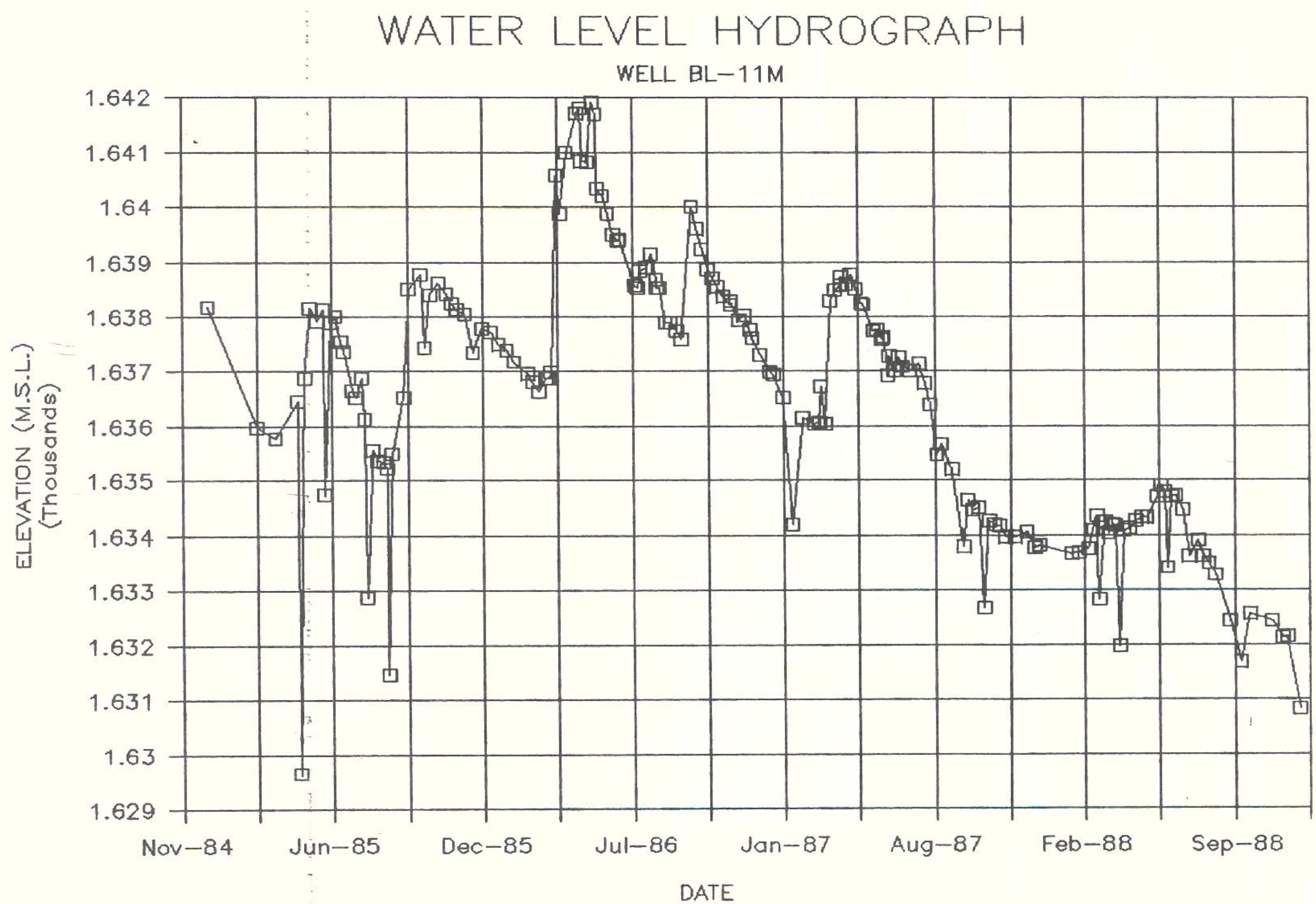
Land Use: Conservation Tillage

1983	Corn	60 lbs/ac 8-32-0 Spring	4.8 lbs./acre N
		3 qt./ac Lasso (alachlor)	
		1/4 pt./ac 2,4-D	
1984	Corn	70 lbs/ac 8-32-0 Spring	(total below)
		100 lbs/ac Anhyd. Summer	87.6 lbs./acre N
		7 lbs/ac Lasso (alachlor)	
		1/4 pt./ac 2,4-D	
		1/4 pt./ac Banvel (dicamba)	
1985	Oats	100 lbs/ac 30-12-0 Spring	30.0 lbs./acre N
		1/2 pt./ac MPCA	
	Corn just north of monitored area		
1986	Corn	75 lbs/ac 8-32-0 Spring	(total below)
		80 lbs/ac Anhyd. Summer	71.6 lbs./acre N
	Corn south of well nest BL-15; Soybeans north of BL-15		
		3 qt./ac Lasso (alachlor)	
		1/4 pt./ac 2,4-D	
		1/4 pt./ac Banvel (dicamba)	
	Soybeans		0.0 lbs./acre N
		3 qt./ac Lasso (alachlor)	
		1 qt./ac Bassagrande	

Fact Sheet continued

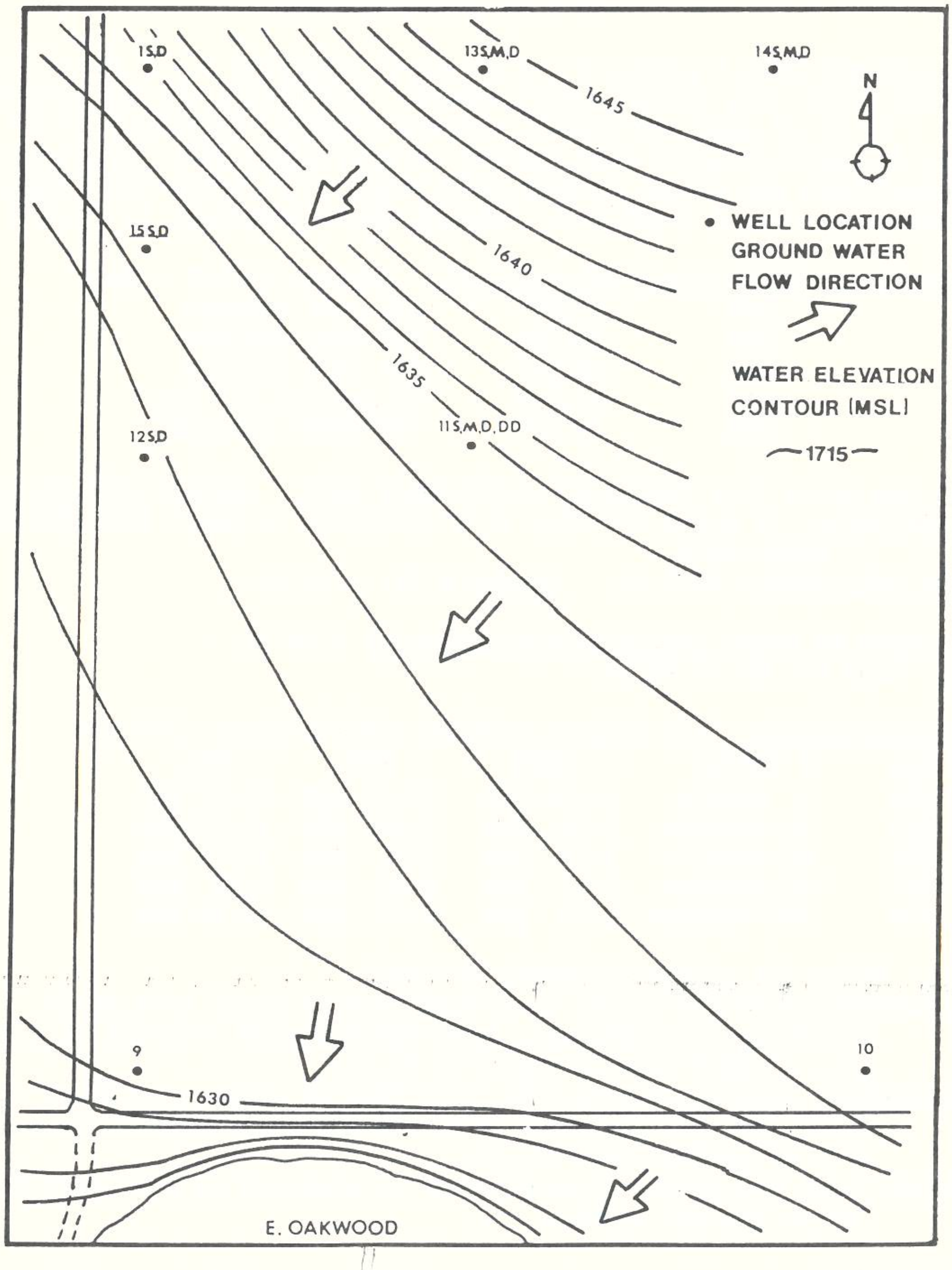
1987 Soybeans 0.0 lbs./acre N
Soybeans south of well nest BL-11; Corn north of BL-11
3 qt./ac Lasso (alachlor)
Corn 80 lbs/ac 8-32-0 Spring (total below)
80 lbs/ac Anhyd. Summer 72.0 lbs./acre N
3 qt./ac Lasso (alachlor)
1/4 pt./ac 2,4-D
1/4 pt./ac Banvel (dicamba)
Anhyd. = Anhydrous Ammonia

1988 Corn (drilled) 60 lb/ac 18-35-0 mid-May (total below)
80-90 lb/ac Anhyd. July 1 (side-dressed) 83.0 lbs./acre N
3/8 pint/ac Banvel mid-June
1/8 pint/ac 2,4-D mid-June
1/3 quart/ac LASSO banded at planting
South of E-W line Bl-15 well nest.
Soybeans 100 lb/ac 29-14-0 mid-April 29.0 lbs/acre N
M.C.P.A. 1/2 pint/ac Spring
North of E-W line BL-1 to BL-14 well nests. Chiseled (2) after harvest (fall).
Set Aside (remainder) Planted with rows of Sorghum. Sprayed mid-July with 1 pint/acre 2,4-D.



WATER LEVEL HYDROGRAPH
WELL BL-11M
ELEVATION (M.S.L.)
(Thousands)
1.642
1.641
1.64
1.639
1.638
1.637
1.636
1.635
1.634
1.633
1.632
1.631
1.63
1.629
Nov-84
Jun-85
Dec-85
Jul-86
Jan-87
Aug-87
Feb-88
Sep-88
DATE

BL-SITE WATER TABLE MAP



JW SITE Fact Sheet

Total area: 75 acres 75.0 acres tilled
Because of high precipitation in 1985, 86, & 87
35 - 25 acres tilled
40 - 50 acres too wet

General Geology: Thin topsoils 1 - 2 ft thick overlying 2 - 3 ft of light brown silty clay (occasionally absent). Underlying the top sediments is 10 - 17 ft of sand and gravel, glacial outwash, underlain by 9 - 17 ft (24 ft thick on south west corner) of gray silty clay, underlain by a second sand and gravel outwash unit about 40 ft thick (only penetrated completely at one location). Beneath above sequences is glacial till.

Precipitation (weighted mean calculation): Average 21.20" / year

1984	31.64"	49% over average
1985	26.55"	25% over average
1986	30.81"	45% over average
1987	21.30"	on average per year
1988	17.59"	17% under average

Thirteen new wells (13) installed in November 1987; sampled January 1988.
Monitoring Wells: 19 wells (13 new) at 9 locations (6 new); includes Epoxy Resin well.
Average well depth: 20.5 ft. Range: 8 ft. - 50 ft.

Average Depth to water (below ground surface): 7.64 ft.
Range: 0.06 ft. to 41.89 ft.

NO3-N Concentrations: 221 samples average concentration 2.74 ppm

YEAR	# SAMPLE	MEAN	MIN	MAX
1984	1 sample	10.24 ppm	10.24 ppm	10.24 ppm
1985	20 samples	4.84 ppm	0.30 ppm	11.85 ppm
1986	40 samples	3.11 ppm	0.00 ppm	12.85 ppm
1987	69 samples	2.57 ppm	0.01 ppm	9.88 ppm
1988	102 samples	2.24 ppm	0.00 ppm	11.59 ppm

Geozones: Three (3) geozones present on site.
SGLT5LT10: Sand and gravel with less than or equal to 5 ft of overlying soil material, with the screened interval at a depth w.t. of less than or equal to 10 ft.
SGLT5GT10: Sand and gravel with less than or equal to 5 ft of overlying soil material, with the screened interval at a depth w.t. of greater than 10 ft.
SG-UA: Sand and gravel located under an aquitard as the lower unit of a two aquifer system.

NO3-N By Geozone:

			MEAN	MIN	MAX
SGLT5LT10	9 wells	148 samples	4.02 ppm	0.00 ppm	12.85 ppm
SGLT5GT10	4 wells	45 samples	0.16 ppm	0.00 ppm	1.50 ppm
SG-UA	5 wells	28 samples	0.12 ppm	0.00 ppm	0.48 ppm

Pesticides: 96 Samples taken from 4 Wells with 5 Detections

Pesticides Detected (in ppb)

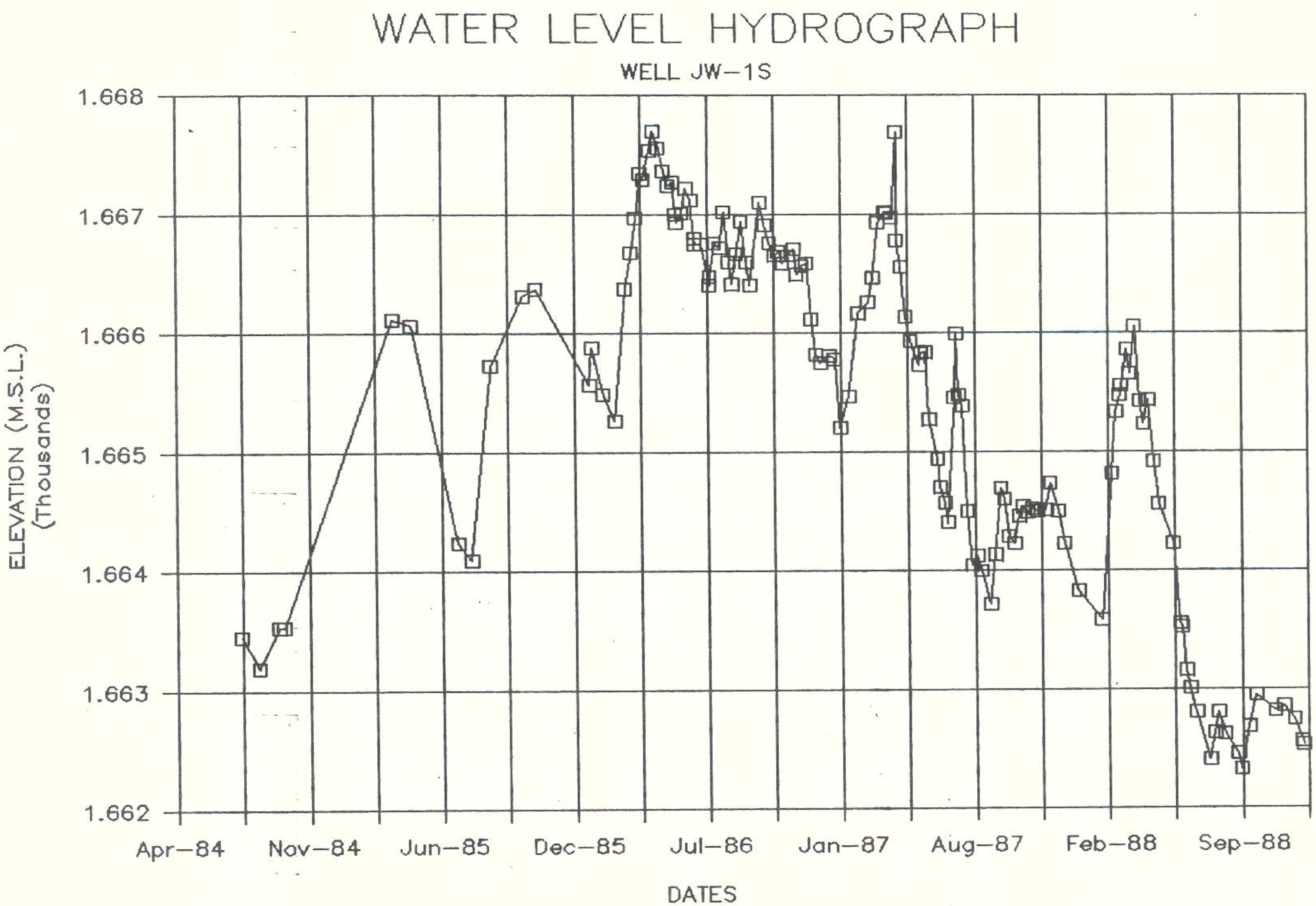
Pest.	# Samp.	# Wells	Ave Conc.	Median	Range	Year
Lasso	3	3	0.79	0.370	0.050 - 1.380	1985,88
2,4-D	1	1	0.95	-	0.95	1988
Treflan	1	1	0.38	-	0.38	1988

Note: # Samp. = the number of samples which detected the pesticide name;
Wells = the number of well in which the named pesticide was found, etc.

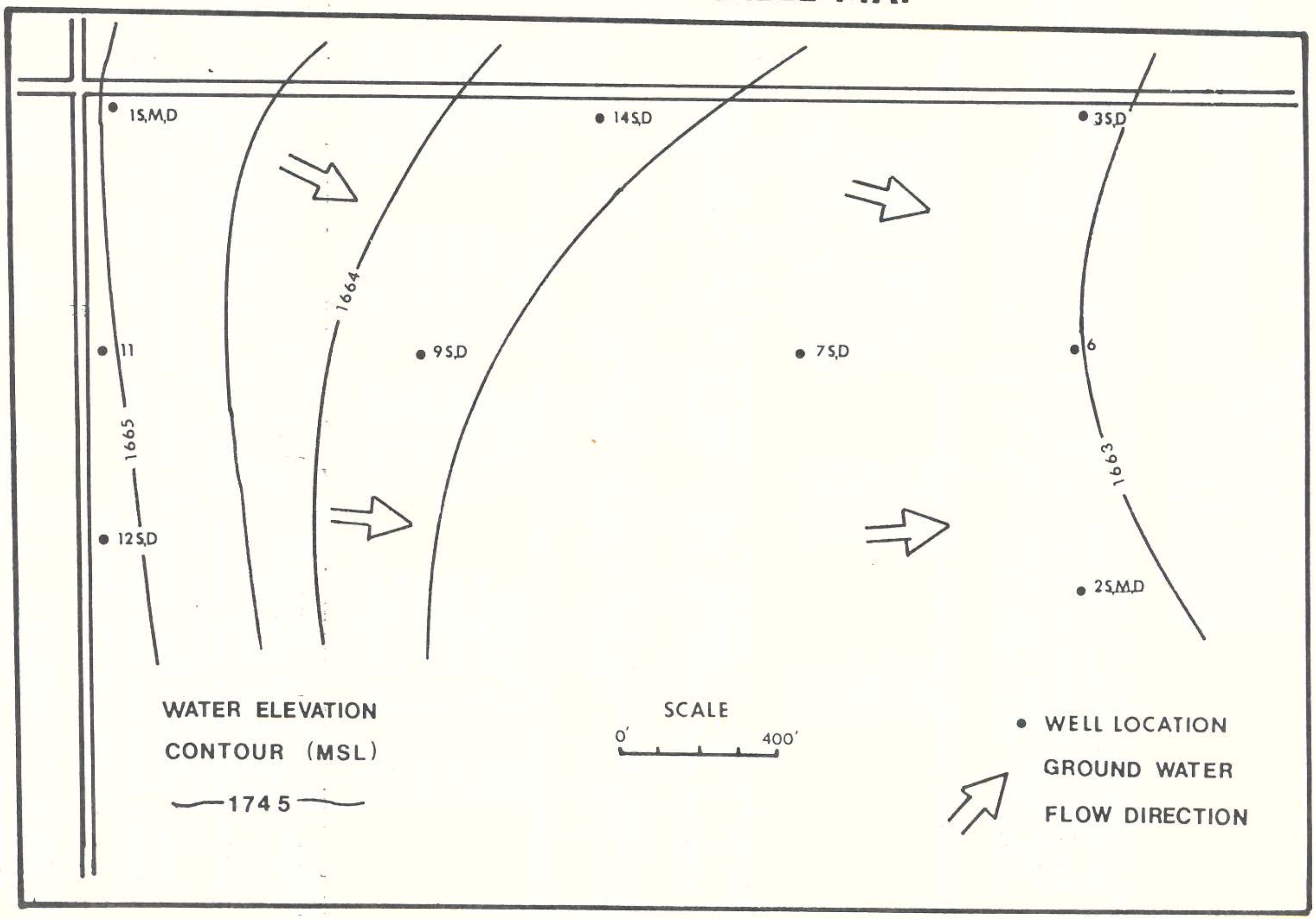
Land Use: Conventional Tillage

1983	Corn	100 lbs/ac 20-20-10 Summer	20.0 lbs./acre N
		7 lbs/ace Ramrod (propachlor)	
1984	Oats (north 2/3 of field)		(total below)
	Barley (south 1/3 of field)		0.00 lbs./acre N
		1/2 pt./ac 2,4-D	
1985	West half too wet; only east half tilled		
		6 tons/ac manure Winter	(total below)
	Corn	0 lbs/ac	12.0 lbs./acre N *
		1/2 pt./ac 2,4-D	
		1/8 pt./ac Banvel (dicamba)	
1986	West half too wet; only east half tilled		
		6 tons/ac manure Winter	(total below)
	Corn	0 lbs/ac	12.0 lbs./acre N *
		1/2 pt./ac 2,4-D	
		1/8 pt./ac Banvel (dicamba)	
1987	West half too wet; only east half tilled		
		6 tons/ac manure Winter	(total below)
	Corn	0 lbs/ac	12.0 lbs./acre N *
1988	Corn	? ton/ac cow manure Winter	??.? lbs./acre N*
	(2/3 of west 1/3 of field site)		
	Oats	? ton/ac cow manure Winter	??.? lbs./acre N*
	(east 2/3 of east half; 1/3 south 1/3; 1/3 of west 1/3; moldboard plow portion to wet past years)		
		1/4 pint/acre 2,4-D	
		1/8 pint/acre Banvel	

* Nitrogen content of manure determined from SCS handbook of average values, South Dakota Technical Guide, notice SD-142 pp. 633-634.


WATER LEVEL HYDROGRAPH
WELL JW-1S
ELEVATION (M.S.L.)
(Thousands)
1.668
1.667
1.666
1.665
1.664
1.663
1.662
Apr-84
Nov-84
Jun-85
Dec-85
Jul-86
Jan-87
Aug-87
Feb-88
Sep-88
DATES

JW-SITE WATER TABLE MAP



LK SITE Fact Sheet

Total area: 43 acres

18.5 acres tilled
8 acres grass (often too wet to plant)
16.5 acres alfalfa
Fall of 1987 land leased to Hamlin County Equipment; moldboard plowed wet acreage and alfalfa acreage. All 43 acres planted in 1988.

General Geology: One to three feet of silty clay topsoil over 6.5 - 15 ft. of sand and gravel outwash (upper aquifer). Upper sand and gravel aquifer separated by 3.5 - 10 ft. of silty clay (absent in some places) from lower sand and gravel aquifer 12 - 20 ft thick. Whole site is underlain at a depth of 42 - 46 ft by glacial till.

Precipitation (weighted mean calculation): Average 21.26" / year

1984	31.49"	47% over average
1985	28.03"	31% over average
1986	36.00"	68% over average
1987	20.98"	1.5% under average
1988	17.49"	18% under average

Monitoring Wells: 21 wells at 13 locations (3 wells in 2 locations on adjacent site, used in LK site analysis)
Average well depth: 18.7 ft. Range: 7 ft. - 29.5 ft.

Average Depth to water (below ground surface): 8.33 ft.
Range: -2.59 ft. (negative number, water above ground) to +17.88 ft.

NO3-N concentrations: 347 samples average concentration 6.69 ppm

YEAR	# SAMPLES	MEAN	MIN	MAX
1984	23 samples	5.24 ppm	0.00 ppm	15.00 ppm
1985	72 samples	8.92 ppm	0.00 ppm	35.50 ppm
1986	86 samples	7.68 ppm	0.00 ppm	27.00 ppm
1987	92 samples	6.04 ppm	0.00 ppm	23.38 ppm
1988	82 samples	4.79 ppm	0.00 ppm	24.77 ppm

Geozones: Four (4) geozones present at site.

SGLT5LT10: Sand and gravel less than 5 ft of overlying soil material screened less than 10 ft. below the water table
SGLT5GT10: Sand and gravel less than 5 ft of overlying soil material screened greater than 10 ft. below the water table
SS-A: Alternating layers of thinly bedded sand and silt
SG-UA: Sand and gravel located under an aquitard as the lower unit of a two aquifer system

NO3-N Summary By Geozone:

GEOZONE	# WELLS	# SAMPLES	MEAN	MIN	MAX
SGLT5LT10	6 wells	138 samples	9.38 ppm	0.34 ppm	35.50 ppm
SGLT5GT10	6 wells	84 samples	6.91 ppm	0.00 ppm	27.00 ppm
SS-A	2 wells	54 samples	6.94 ppm	0.02 ppm	26.20 ppm
SG-UA	4 wells	38 samples	1.11 ppm	0.00 ppm	0.00 ppm

LK-SITE

Pesticides: 104 Samples taken from 4 Wells with 7 Detections

Pesticides Detected (in ppb)

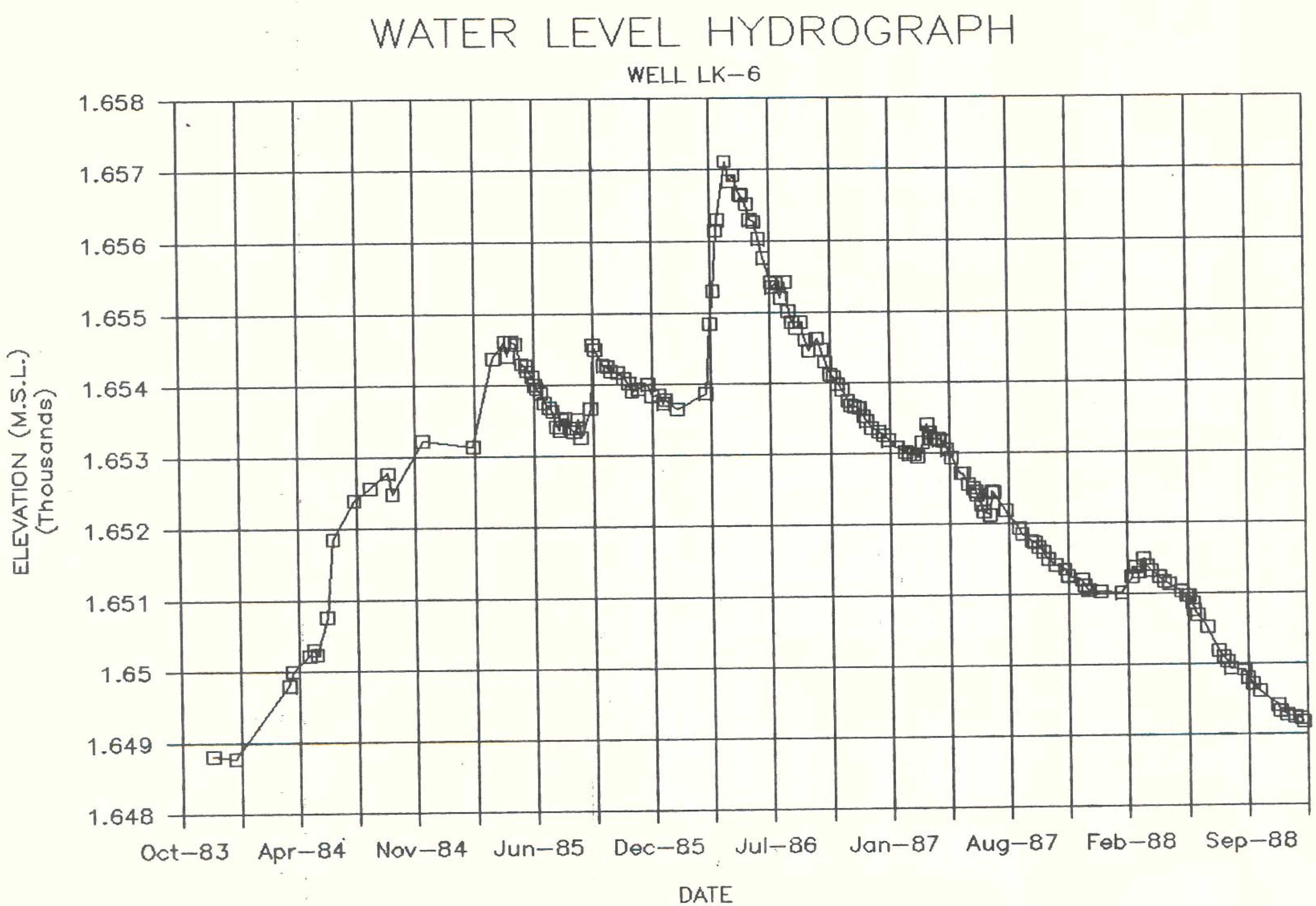
Pest.	# Samp.	# Wells	Ave Conc.	Median	Range	Year(s)
Lasso	2	2	0.10	0.100	0.050 - 0.150	1988
2,4-D	3	3	1.48	1.400	0.130 - 2.900	1986,88
Dual	2	2	0.65	0.655	0.350 - 0.960	1988

Note: # Samp. = the number of samples which detected the pesticide name;
Wells = the number of well in which the named pesticide was found, etc.

Land Use: Conservation Tillage

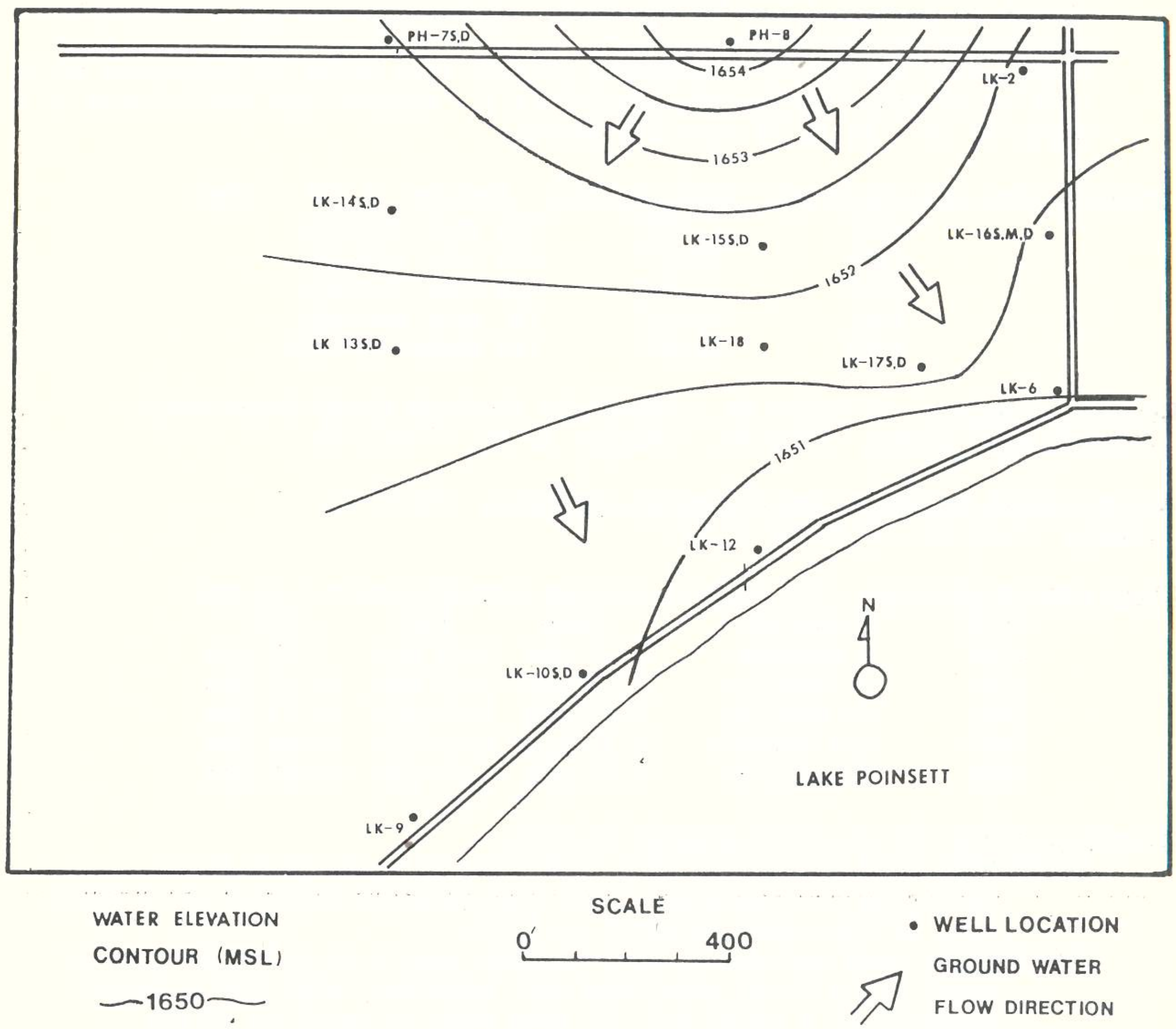
1983	Barley	80 lbs/ac 24-24-0 Spring	19.2 lbs./acre N
1984	Oats	80 lbs/ac 28-14-0 Spring	22.4 lbs./acre N
1985	Barley	80 lbs/ac 24-24-0 Spring	19.2 lbs./acre N
		1/8 pt./ac MCPA	
1986	Wheat	100 lbs/ac 28-14-0 Spring	28.0 lbs./acre N
		1/3 pt./ac Banvel (dicamba)	
		1/8 pt./ac MPCA	
1987	Wheat(n)	100 lbs/ac 20-20-0 Spring	20.0 lbs./acre N
		1/3 pt./ac Banvel (dicamba)	
	Soybeans(s)	100 lbs/ac 18-46-0 Spring	18.0 lbs./acre N
		1 1/2 pt./ac Treflan (trifluralin)	
1988	Soybeans(n)	???	
	Corn(s)	???	

(n):north half of field (s):south half of field



WATER LEVEL HYDROGRAPH
WELL LK-6
ELEVATION (M.S.L.)
(Thousands)
1.658
1.657
1.656
1.655
1.654
1.653
1.652
1.651
1.65
1.649
1.648
Oct-83
Apr-84
Nov-84
Jun-85
Dec-85
Jul-86
Jan-87
Aug-87
Feb-88
Sep-88
DATE

LK-SITE WATER TABLE MAP



OP SITE (State Park)   Fact Sheet

Total area: 40 acres
Monitored: 17 acres   0 acres tilled
17 acres grass (left natural)

General Geology: Topsoil 1 - 3 ft thick overlying 2 - 4 ft of clayey silt overlying 1 - 12 ft of sand and gravel. The silt and/or sand layers are absent in certain areas of the site. Underlying the upper sediments (which may or may not be present) is 10 - 15 ft of brown silty clay little sand and gravel, weathered glacial till which is underlain by 15 - 30 ft of gray unweathered glacial till. Beneath the entire site at a depth of 30 - 45 ft is sand and gravel.

Precipitation (weighted mean calculation): Average 21.04" / year

1984	31.95"	52% over average
1985	25.37"	21% over average
1986	31.91"	52% over average
1987	22.49"	7% over average
1988	18.64"	11% under average

Monitoring Wells: 17 wells at 7 locations (include Epoxy Resin well)
Average well depth: 23.9 ft. Range: 11 ft. - 48.5 ft.

Average Depth to water (below ground surface): 10.29 ft.
Range: 0.31 ft. to 26.62 ft.(?)

NO3-N concentrations: 304 samples average concentration 1.99 ppm

YEAR	# SAMPLES	MEAN	MIN	MAX
1984	4 samples	1.38 ppm	0.04 ppm	3.65 ppm
1985	39 samples	1.23 ppm	0.00 ppm	14.23 ppm
1986	80 samples	1.99 ppm	0.00 ppm	16.72 ppm
1987	104 samples	2.13 ppm	0.00 ppm	14.88 ppm
1988	78 samples	2.20 ppm	0.00 ppm	15.48 ppm

Geozones: Seven (7) geozones present on site.

SGLT5LT10: Sand and gravel with less than or equal to 5 ft of overlying soil material, with the screened interval at a depth w.t. of less than or equal to 10 ft.

SG5-15LT10: Sand and gravel with greater than 5 ft and less than or equal to 15 ft of overlying soil material, with the screened interval at a depth w.t. of less than or equal to 10 ft.

SG5-15GT10: Sand and gravel with greater than 5 ft and less than or equal to 15 ft of overlying soil material, with the screened interval at a depth w.t. of greater than 10 ft.

SGGT15: Sand and gravel with greater than 15 ft of overlying soil material.

SG-UA: Sand and gravel located under an aquitard as the lower unit of a two aquifer system.

WTLT15: Weathered till (brown color) or silty clay, reworked till with the screened interval of the well at a depth b.g.s. of less than or equal to 15 ft.

OP SITE (State Park) Fact Sheet Continued

UT: Unweathered till (gray color).

NO3-N Summary By Geozone:

			MEAN	MIN	MAX
SGLT5LT10	2 wells	47 samples	1.98 ppm	0.62 ppm	3.20 ppm
SG5-15LT10	1 well	35 samples	0.05 ppm	0.00 ppm	0.20 ppm
SG5-15GT10	2 wells	28 samples	0.48 ppm	0.00 ppm	2.00 ppm
SGGT15	3 wells	47 samples	0.41 ppm	0.00 ppm	4.07 ppm
SG-UA	2 wells	46 samples	0.03 ppm	0.00 ppm	0.16 ppm
WTLT15	3 wells	57 samples	8.15 ppm	0.01 ppm	16.72 ppm
UT	3 wells	42 samples	0.28 ppm	0.02 ppm	0.88 ppm

Pesticides: 125 Samples taken from 4 Wells with 7 Detections

Pesticides Detected (in ppb)

Pest.	# Samp.	# Wells	Ave Conc.	Median	Range	Year
Lasso	5	3	0.85	0.300	0.070 - 3.090	1985,86,87,88
2,4-D	1	1	0.41	-	0.410	1986
Treflan	1	1	0.047	-	0.047	1988

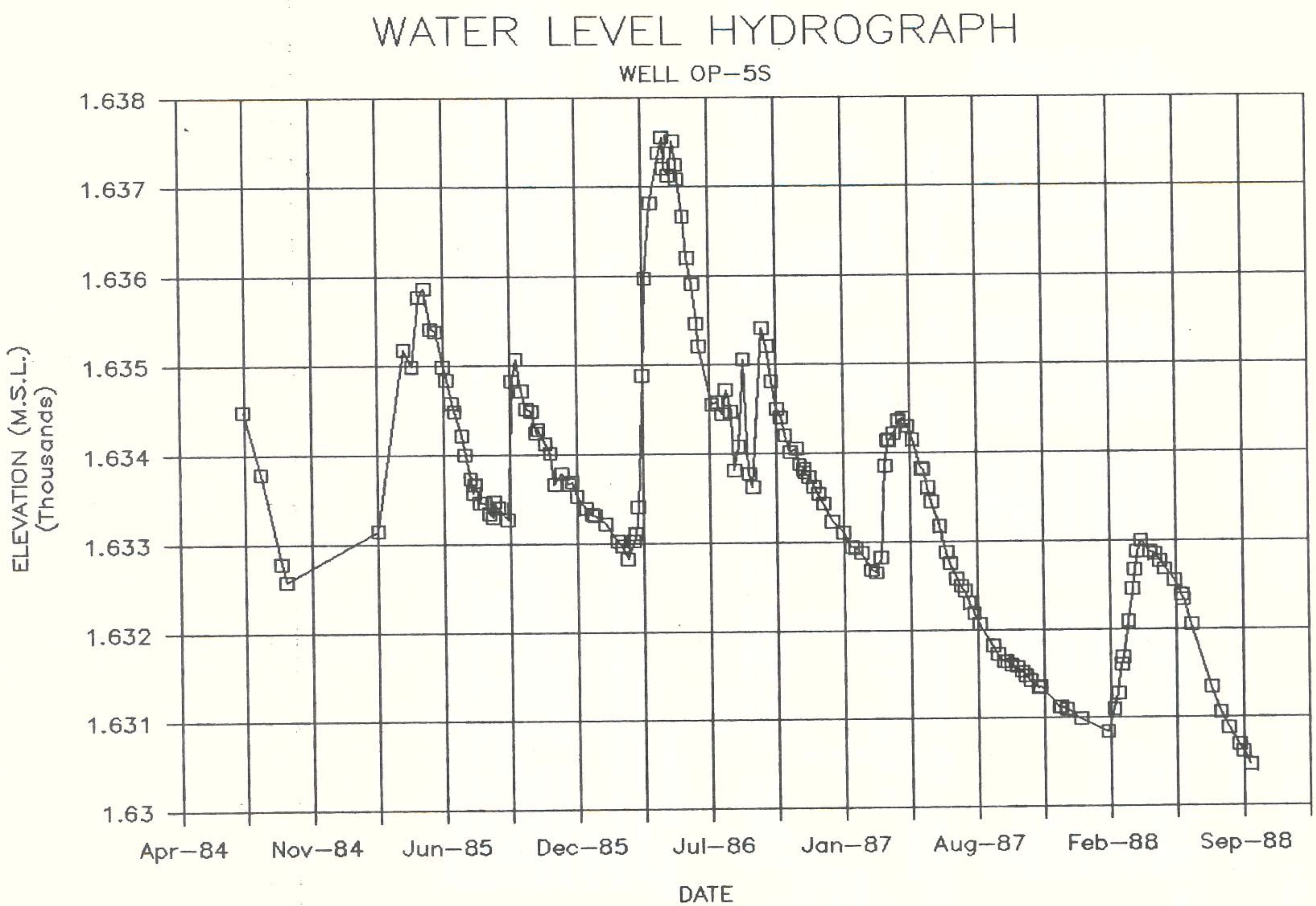
Note: # Samp. = the number of samples which detected the pesticide name;
Wells = the number of well in which the named pesticide was found, etc.

Land Use: Unfarmed

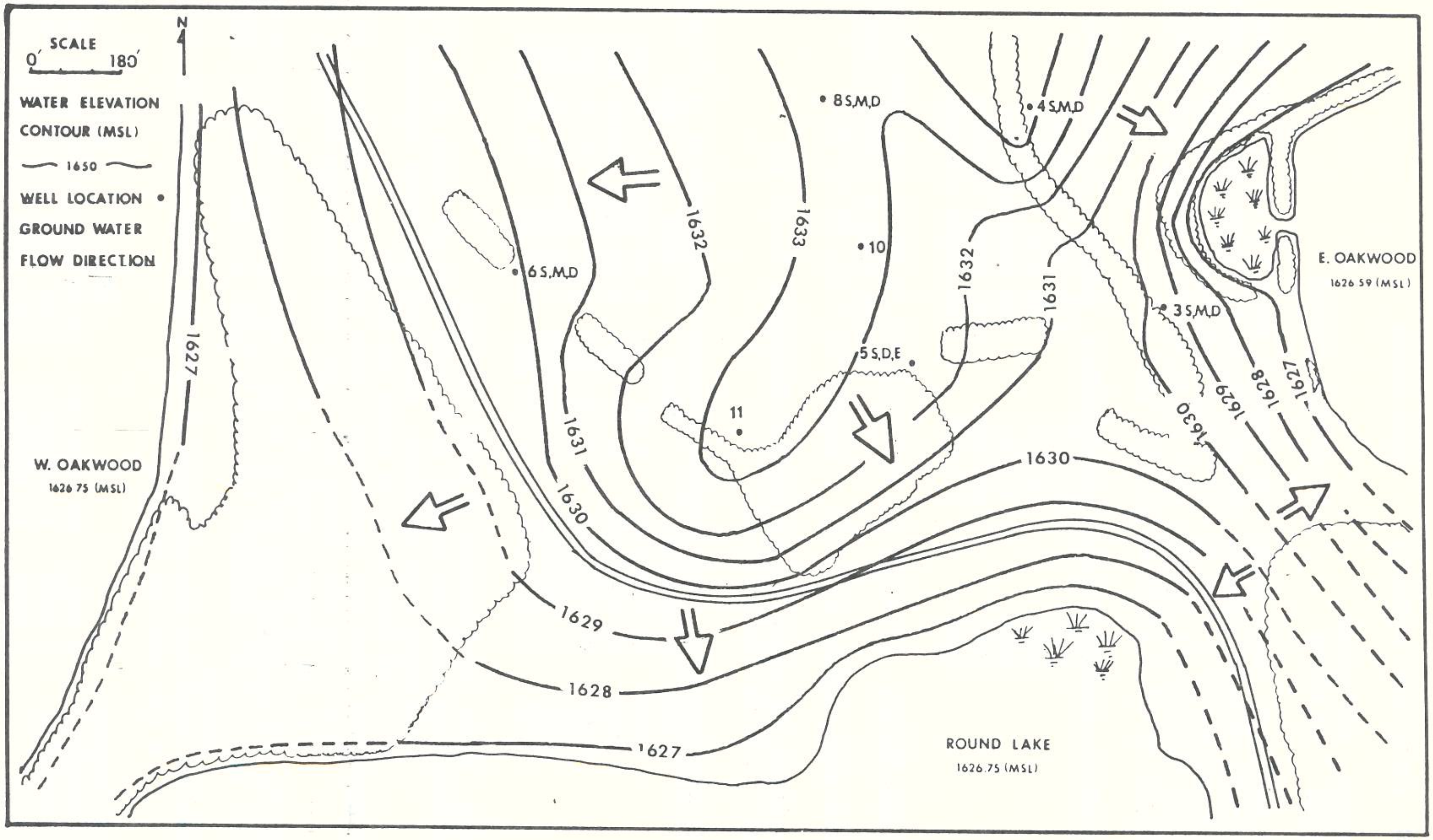
Farmed until 1974 (or 1976).

Planted with brome and other native grasses and left alone since then.

Pesticide Application - sprayed with Tordon 22-K and 2,4-D by both the Divisions of Wildlife/Parks and Recreation to control leafy spurge and canada thistle. Parks and Recreation Division applied 6 quarts/acre 2,4-D in late May/early June, 1988, and 3 pints/acre Tordon and 4 quarts/acre 2,4-D in October, 1988.


WATER LEVEL HYDROGRAPH
WELL OP-5S
ELEVATION (M.S.L.)
(Thousands)
1.638
1.637
1.636
1.635
1.634
1.633
1.632
1.631
1.63
Apr-84
Nov-84
Jun-85
Dec-85
Jul-86
Jan-87
Aug-87
Feb-88
Sep-88
DATE

OP-SITE WATER TABLE MAP



PH SITE (monitored portion) Fact Sheet

Total area: 160 acres
Monitored: 80 acres 80 acres tilled

General Geology: Thin silty clay topsoil over 8 - 13 ft. of sand and gravel glacial outwash (upper aquifer). Upper sand and gravel aquifer separated by 6 - 10 ft. of silty clay (absent in some places) from lower sand and gravel aquifer 12 - 20 ft thick. Whole site is underlain at a depth of 42 - 46 ft by glacial till.

Precipitation (weighted mean calculation): Average 21.26" / year

1984	31.49"	47% over average
1985	28.03"	31% over average
1986	36.00"	68% over average
1987	20.98"	<1% under average
1988	17.49"	18% under average

Monitoring Wells: 15 wells at 10 locations (2 wells not sampled due to point source contamination)
Average well depth: 22.8 ft. Range: 11.5 ft. to 32 ft.

Average Depth to water (below ground surface): 13.23 ft.
Range: 3.62 ft. to 26.87 ft.

NO3-N Concentrations: 263 samples average concentration 12.53 ppm

YEAR	# SAMPLES	MEAN	MIN	MAX
1984	16 samples	9.48 ppm	0.00 ppm	37.25 ppm
1985	39 samples	9.77 ppm	0.10 ppm	33.80 ppm
1986	65 samples	10.36 ppm	0.00 ppm	45.70 ppm
1987	72 samples	15.47 ppm	0.04 ppm	41.75 ppm
1988	71 samples	13.73 ppm	0.01 ppm	34.91 ppm

Geozones: Five (5) geozones present on site.

SGLT5LT10: Sand and gravel with less than or equal to 5 ft of overlying soil material, with the screened interval at a depth w.t. of less than or equal to 10 ft.

SGLT5GT10: Sand and gravel with less than or equal to 5 ft of overlying soil material, with the screened interval at a depth w.t. of greater than 10 ft.

SS-A: Alternating layers of thinly bedded fine sand and silt.

SC: Silty clay aquitard located between an upper and a lower aquifer system.

SG-UA: Sand and gravel located under an aquitard as the lower unit of a two aquifer system.

NO3-N By Geozone:

			MEAN	MIN	MAX
SGLT5LT10	4 wells	84 samples	19.48 ppm	0.56 ppm	45.70 ppm
SGLT5GT10	1 well	47 samples	3.88 ppm	0.03 ppm	19.75 ppm
SS-A	1 well	12 samples	5.27 ppm	1.37 ppm	12.88 ppm
SC	2 wells	27 samples	7.18 ppm	1.60 ppm	20.68 ppm
SG-UA	5 wells	93 samples	13.60 ppm	0.90 ppm	34.91 ppm

PH SITE (monitored portion) <u>Fact Sheet Continued</u>

<u>Pesticides:</u> 138 Samples taken from 3 Wells with 15 Detections

Pesticides Detected (in ppb)

Pest.	# Samp.	# Wells	Ave Conc.	Median	Range	Year
Lasso	7	3	0.09	0.070	0.040 - 0.220	1985,86,88
2,4-D	4	3	0.32	0.190	0.040 - 0.840	1986,87,88
Treflan	1	1	0.02	-	0.02	1985
Dual	3	3	0.31	0.280	0.280 - 0.360	1988

Note: # Samp. = the number of samples which detected the pesticide name;
Wells = the number of well in which the named pesticide was found, etc.

<u>Land Use:</u>

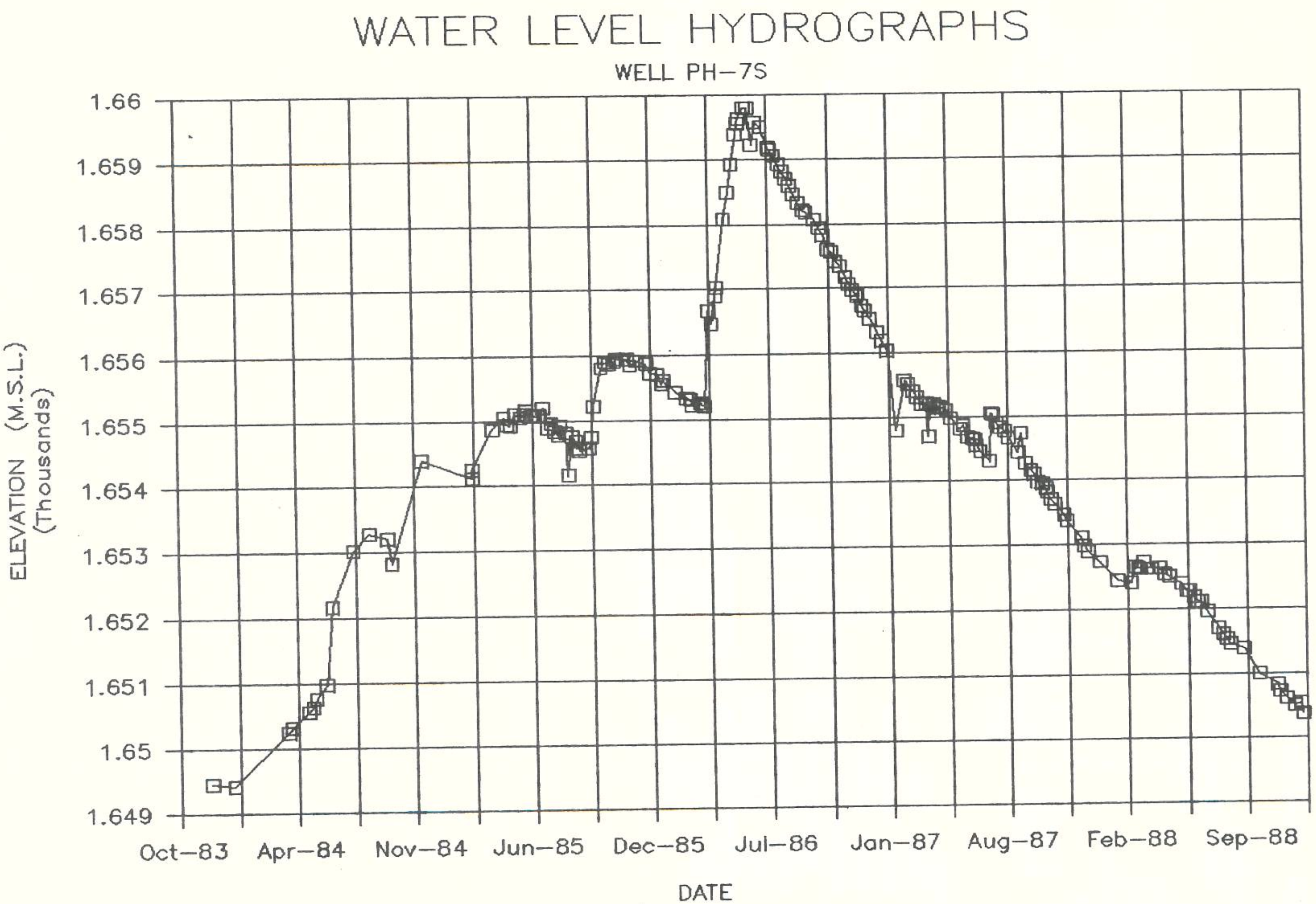
1983	PIK		0.0 lbs./acre N
1984	Soybeans		0.0 lbs./acre N
1985	Wheat	100 lbs/ac 18-36-0 Spring	18.0 lbs./acre N

NOTE: farmer no longer wishes to cooperate; land use based on past practices and observations.

1986	Wheat	100 lbs/ac 18-36-0 Spring	18.0 lbs./acre N
1987	Set aside		0.0 lbs./acre N

NOTE: farmer willing to cooperate.

1988	Wheat	100 lbs/ac 46-0-0 Spring	46.0 lbs./acre N
	Soybean	100 lbs/ac 46-0-0 Spring	46.0 lbs./acre N
		Treflan 1 pint/acre Spring	


WATER LEVEL HYDROGRAPHS
WELL PH-7S
ELEVATION (M.S.L.)
(Thousands)
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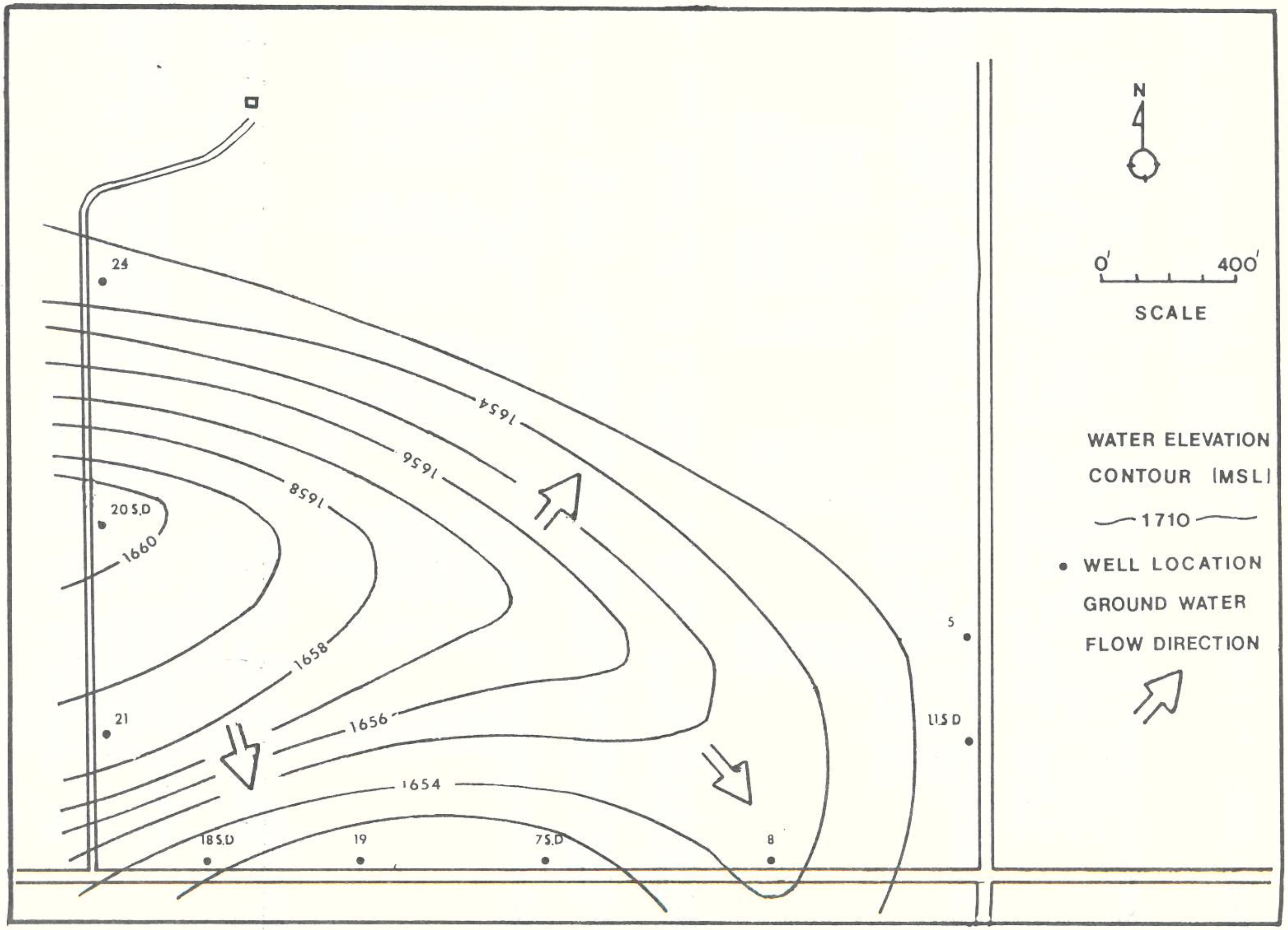
1.659
1.658
1.657
1.656
1.655
1.654
1.653
1.652
1.651
1.65
1.649
Oct-83
Apr-84
Nov-84
Jun-85
Dec-85
Jul-86
Jan-87
Aug-87
Feb-88
Sep-88
DATE

PH-SITE WATER TABLE MAP



RS SITE Fact Sheet

Total area: 47 acres

43.2 acres tilled
1.5 acres grass waterway until 1988
2.3 acres observed to be too wet to farm

General Geology: Two to three feet of silty clay topsoil over 8 - 10 ft of brown turning to gray very silty clay trace sand and gravel (ablation till?; loess?) reworked till. Underlying these sediments is 4 - 14 ft of brown weathered silty clay little sand and gravel glacial till, underlain by gray unweathered glacial till to depths exceeding 75 ft.

Precipitation: Average 21.41" / year @ Castlewood Station (insufficient record at other stations to calculate long term weighted mean average) (weighted mean calculation [yearly totals] versus Castlewood for average)

1984	36.04"	68% over average
1985	27.15"	27% over average
1986	32.52"	52% over average
1987	21.84"	1% under average
1988	18.07"	16% under average

Monitoring Wells: 17 wells at 7 locations (include Epoxy Resin well)
Average well depth: 15.7 ft. Range: 8 ft. to 29.5 ft.

Average Depth to water (below ground surface): 5.21 ft.
Range: -1.11 ft. (negative number, water above ground) to +13.81 ft.

NO3-N Concentrations: 284 samples average concentration 4.25 ppm

YEAR	# SAMPLES	MEAN	MIN	MAX
1984	13 samples	2.99 ppm	0.00 ppm	16.55 ppm
1985	54 samples	4.02 ppm	0.03 ppm	13.15 ppm
1986	74 samples	5.48 ppm	0.10 ppm	13.88 ppm
1987	73 samples	4.67 ppm	0.14 ppm	10.77 ppm
1988	70 samples	2.91 ppm	0.00 ppm	8.38 ppm

(no RSBY samples)

Geozones: Three (3) geozones present on site.

WTLT15: Weathered till (brown color) or silty clay, reworked till with the screened interval of the well at a depth b.g.s. of less than or equal to 15 ft.

WTGT15: Weathered till or transition zone (greenish brown zone interpreted as a transition zone between the weathered and the unweathered till), with the screened interval at a depth b.g.s. of greater than 15 ft.

UT: Unweathered till (gray color).

NO3-N By Geozone: No ER well.

			MEAN	MIN	MAX
WTLT15	9 wells	170 samples	5.99 ppm	0.003 ppm	16.55 ppm
WTGT15	5 wells	89 samples	2.01 ppm	0.010 ppm	10.63 ppm
UT	2 wells	25 samples	0.41 ppm	0.030 ppm	1.55 ppm

RS SITE Fact Sheet Continued

Pesticides: 164 Samples taken from 11 Wells with 28 Detections

Pesticides Detected (in ppb)

Pest.	# Samp.	# Wells	Ave Conc.	Median	Range	Year
Lasso	16	3	0.71	0.345	0.030 - 3.440	1985,86,87,88
2,4-D	6	4	2.27	0.610	0.230 - 6.700	1984,86,88
Sencor	5	1	0.08	0.080	0.030 - 0.124	1986,88

Note: # Samp. = the number of samples which detected the pesticide name;
Wells = the number of well in which the named pesticide was found, etc.

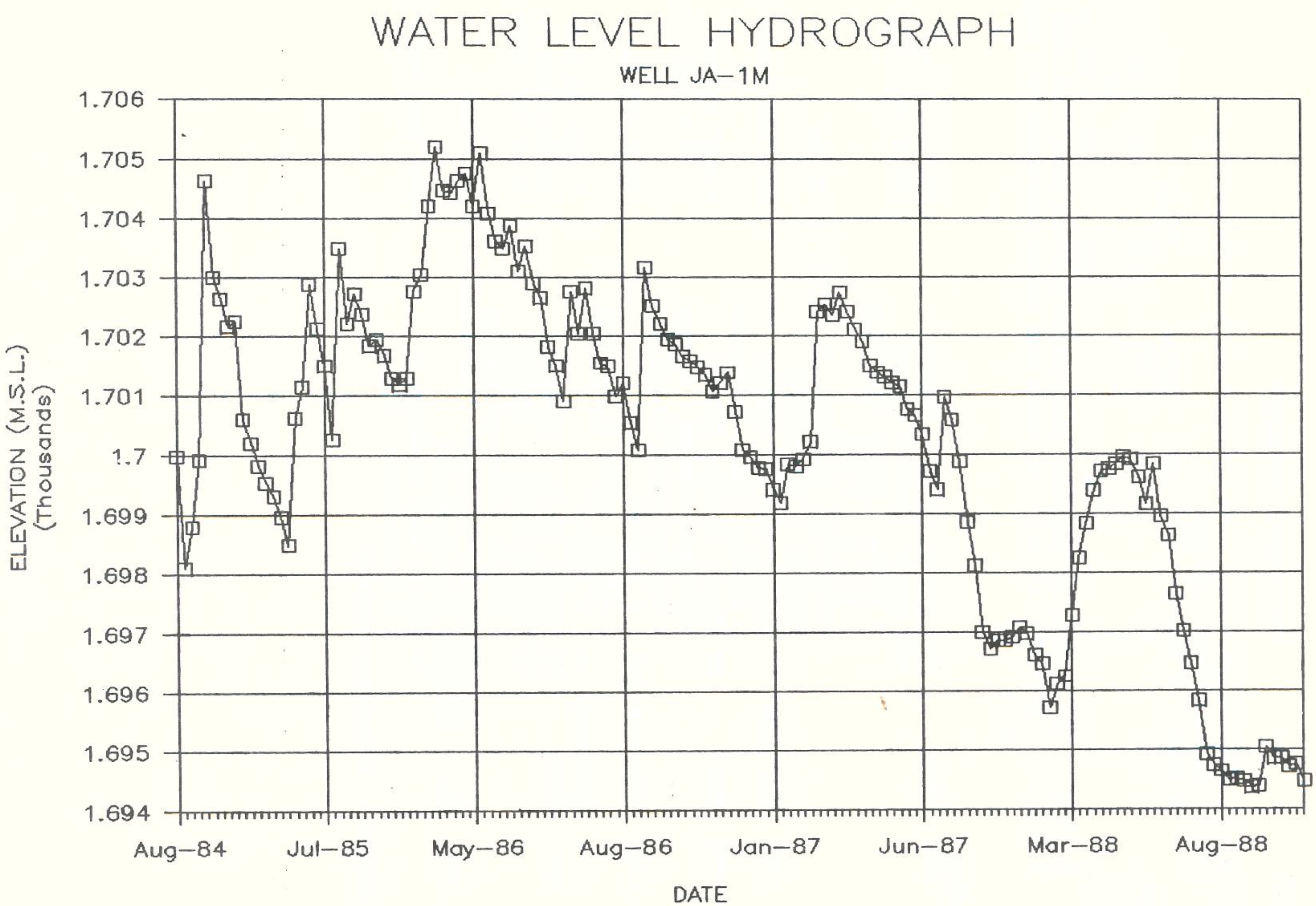
Land Use:

1983	Corn	100 lbs/ac Anhyd. Summer	(total below)
		100 lbs/ac 18-46-0 Summer	100.0 lbs./acre N
		8 lbs/ac Lasso (alachlor)	
		? pt./ac 2,4-D	
		Commercial application aerial spraying	
		Furadan (carbofuran)	
1984	Soybeans	80 lbs/ac 18-46-0 Summer	14.4 lbs./acre N
		8 lbs/ac Lasso (alachlor)	
1985	Corn	80 lbs/ac 18-46-0 Summer	(total below)
		100 lbs/ac Anhyd. Summer	96.4 lbs./acre N
		8 lbs/ac Lasso (alachlor)	
1986	Soybeans (s)	0 lbs/ac	(total below)
		8 lbs/ac Lasso (alachlor)	
	Buckwheat (n)	0 lbs/ac	0 lbs./acre N
1987	Corn	80 lbs/ac 18-46-0 Summer	(total below)
		100 lbs/ac Anhyd. Summer	96.4 lbs./acre N
		8 lbs/ac Lasso (alachlor)	

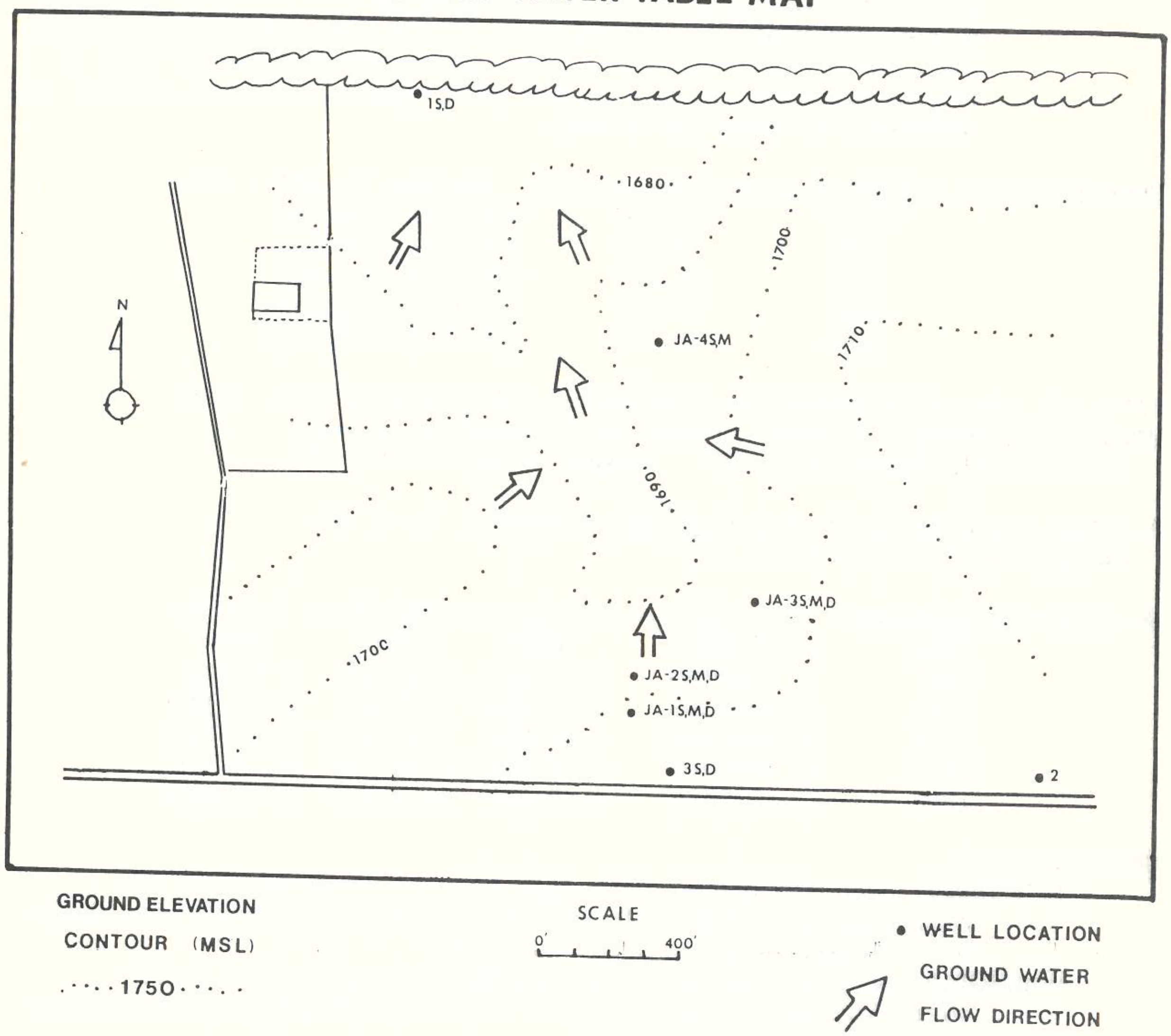
(n):north 2/3 of field (s):south 1/3 of field

1988	Wheat (planted in mid-April)		
		75 lbs/ac 46-0-0 Anhyd.?	34.5 lbs./acre N
		0.5 pint/acre M.C.P.A.	

*Anhyd. = Anhydrous Ammonia


WATER LEVEL HYDROGRAPH
WELL JA-1M
ELEVATION (M.S.L.)
(Thousands)
1.706
1.705
1.704
1.703
1.702
1.701
1.7
1.699
1.698
1.697
1.696
1.695
1.694
Aug-84
Jul-85
May-86
Aug-86
Jan-87
Jun-87
Mar-88
Aug-88
DATE

RS-SITE WATER TABLE MAP



VC SITE (monitored portion) <u>Fact Sheet</u>

Total area: 140 acres
Monitored: 10 acres 10 acres tilled

General Geology (of the 140 acres): Topsoil 1 - 2 ft thick overlying 0.5 - 2.5 ft of very silty clay. Under the upper sediments: in the north and northeast sides of the site is 6 - 50 ft of sand and gravel underlain by glacial till (silty clay with some to little sand and gravel); in the north west corner is glacial till to depths exceeding 50 ft; on the west side is 17 ft of glacial till underlain by sand and gravel.

Precipitation (weighted mean calculation): Average 21.26" / year

1984	31.49"	47% over average
1985	28.03"	31% over average
1986	36.00"	68% over average
1987	20.57"	<1% under average
1988	17.06"	20% under average

Five (5) new wells installed in November 1987; sampled Jan. 1988.
Monitoring Wells: 8 wells (5 new) at 5 locations (2 new)
Average well depth: 19.5 ft. Range: 12 ft. - 29.5 ft.

Average Depth to water (below ground surface): 10.63 ft.
Range: 4.37 ft. to 17.71 ft.

NO3-N Concentrations: 111 samples average concentration 3.77 ppm

YEAR	# SAMPLES	MEAN	MIN	MAX
1984	12 samples	0.87 ppm	0.00 ppm	3.76 ppm
1985	17 samples	3.62 ppm	0.01 ppm	11.73 ppm
1986	18 samples	3.83 ppm	0.00 ppm	11.65 ppm
1987	22 samples	4.04 ppm	0.00 ppm	12.38 ppm
1988	37 samples	4.49 ppm	0.01 ppm	15.65 ppm

Geozones: (3)

SGLT5LT10: Sand and gravel with less than or equal to 5 ft of overlying soil material, with the screened interval at a depth w.t. of less than or equal to 10 ft.

SGLT5GT10: Sand and gravel with less than or equal to 5 ft of overlying soil material, with the screened interval at a depth w.t. of greater than 10 ft.

SGGT15: Sand and gravel with greater than 15 ft of overlying soil material.

NO3-N By Geozone:

			MEAN	MIN	MAX
SGLT5LT10	3 wells	69 samples	6.05 ppm	0.00 ppm	15.65 ppm
SGLT5GT10	3 wells	23 samples	0.03 ppm	0.00 ppm	0.16 ppm
SGGT15	1 well	19 samples	0.04 ppm	0.00 ppm	0.20 ppm

VC SITE (monitored portion) Fact Sheet Continued

Pesticides: 76 Samples taken from 2 Wells with 2 Detections

Pesticides Detected (in ppb)

Pest.	# Samp.	# Wells	Ave Conc.	Median	Range	Year
Lasso	2	2	0.053	0.053	0.036 - 0.070	1988

Note: # Samp. = the number of samples which detected the pesticide name;
Wells = the number of well in which the named pesticide was found, etc.

Land Use:

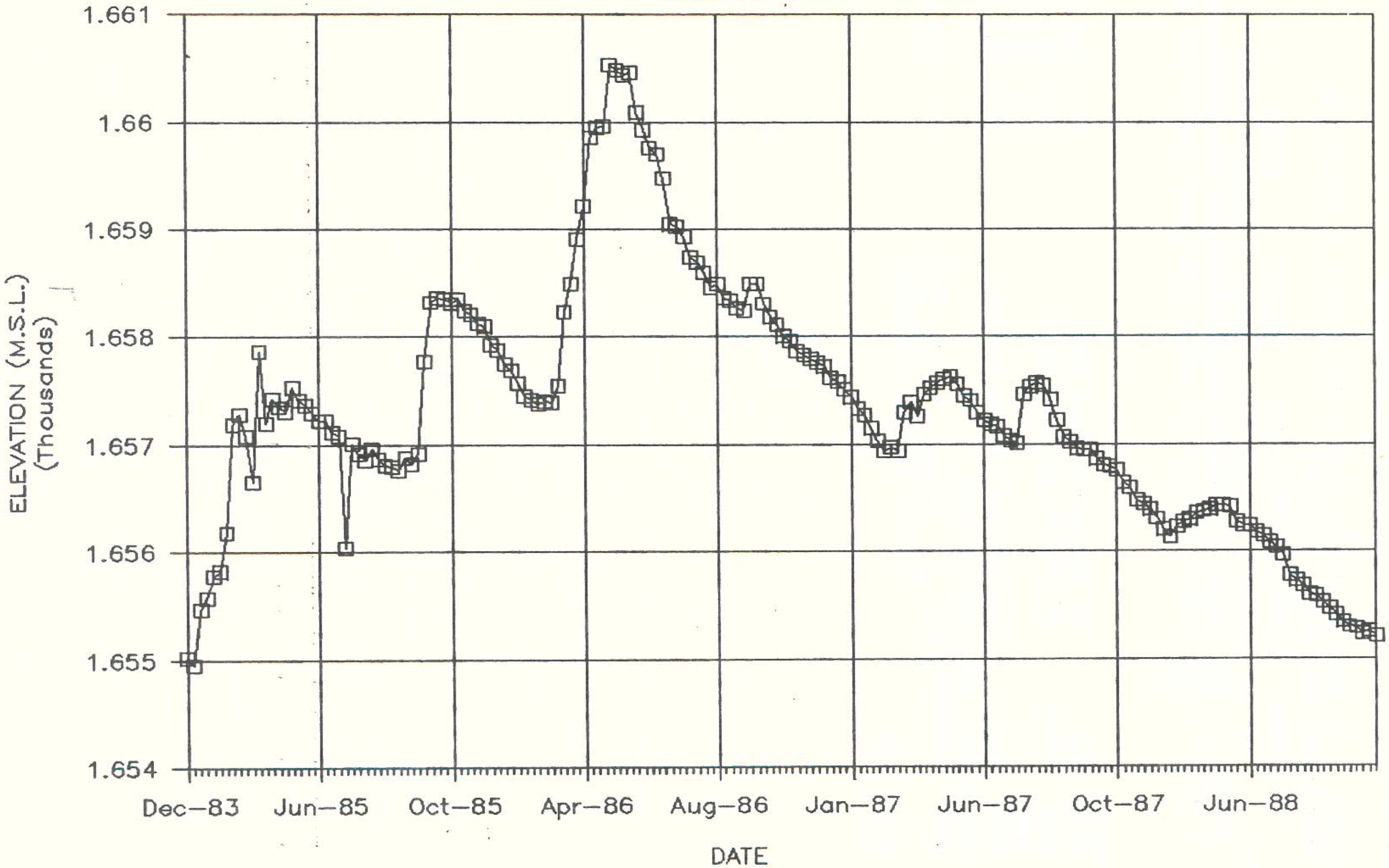
1983	Rye	70 lbs/ac 18-46-0 Fall	12.6 lbs./acre N
1984	Wheat	75 lbs/ac 18-46-0 Fall	13.5 lbs./acre N
1985			0.0 lbs./acre N
1986	Corn	100 lbs/ac 46-0-0 Spring	46.0 lbs./acre N

NOTE: new farmer starting in 1987

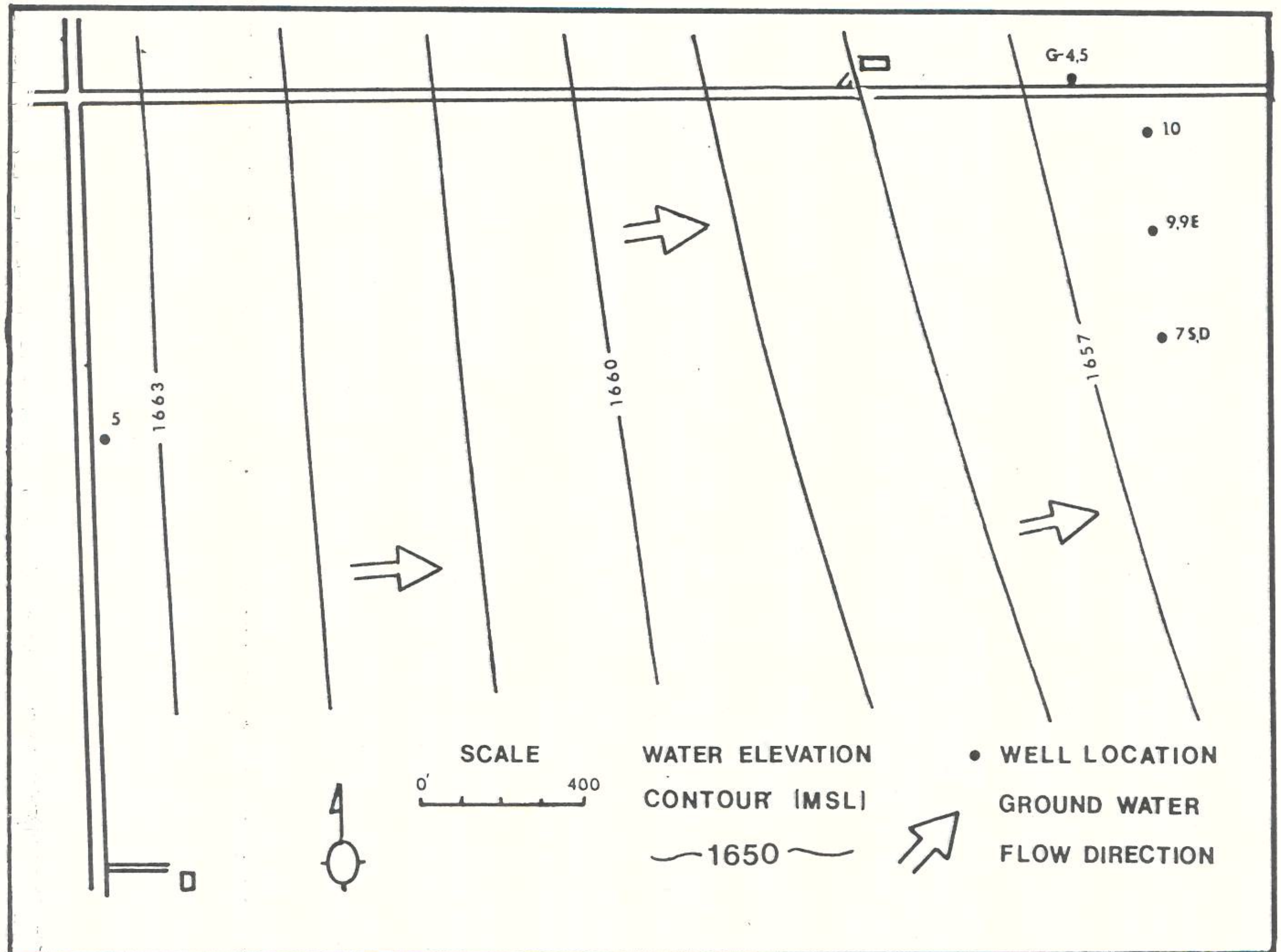
1987	Winter grain	? lbs/ac ..-..-. Fall	?... lbs./acre N
		???/ac Banvel (dicamba)	
1988	???		

WATER LEVELS HYDROGRAPHS

WELL VC-7



VC-SITE WATER TABLE MAP



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3.0. VADOSE ZONE MONITORING

3.1. Master Site

3.1.1. Introduction

The master site was originally set up in 1982 to monitor the differences in soil water contents and soil water energy levels between different tillage systems to determine if conservation tillage is a factor in changing the input of water to the ground water system. No water quality data was scheduled for collection. At the end of each growing season, soil samples were taken and analyzed for soil nitrates. Residual soil nitrates at the high rate of application were elevated over the treatment where no nitrogen was applied (check). Residual soil nitrates at the medium rate of application were slightly elevated over the check treatment (1986 Annual RCWP Technical Report - Project 20).

Interpretations of past volumetric soil water content data indicate that no-till (NT) treatments pick up water faster and deeper after a rain event and deplete water faster than the moldboard plow (MP) treatments in the 1-5' soil profile during the growing season. If water is penetrating deeper in the NT soil profile, it needs to be documented with hard data, and information is needed to determine the quality of that water and whether chemicals are moving with it and, if so, what are the concentrations.

In the original work plan, the master site was scheduled to terminate after 1986. The original objective of the master site, to provide a controlled intensive area with minimal soil variations to differentiate the effects of tillage systems and crops on soil water fluxes and water quality, has not been altered, but the approach to achieving this objective was. The new approach is intended to expand on the information which has been derived to date at the present RCWP CM&E master site. The information which will be developed from this segment of the project will help to definitively answer questions whether no-till systems affect ground water quality and if so, is it significant.

The changes that occurred as a result of the re-evaluation of the methodology included newly developed, more sensitive soil water sensors, and water quality monitoring on a continual basis in the vadose zone while maintaining the integrity of the plot. Differences between BMP's (tillage and pesticide) on soil water quality on one soil type, if they exist, should be able to be determined on an intensively monitored and controlled environment such as the master site.

The specific objectives of the re-evaluated methodology are aimed at monitoring and analyzing the low tension fracture/macropore flow water in the unsaturated soil in a typical RCWP soil profile.

The specific objectives for the continuation of the master site beyond 1986 are as follows:

1) To determine the differences in vertical fluxes of nitrates, organics, tracers, and water to specific depths between moldboard plow (MP) and no-till (NT) tillage systems for a corn-oats rotation.

2) To develop an event-actuated monitoring/control system for collecting low tension unsaturated soil water (characteristic of water held in macropores), during or after, precipitation/leaching events.

3) To determine the differences in response time of a given precipitation event to the change in matric potential at specific depths between NT and MP tillage systems on oats and corn.

3.1.2 Monitoring site and soil characteristics

The master site has Poinsett and Waubay silt loams which are the predominant soils for this area. The site is located in the NE 1/4 of the NW 1/4 of Section 17 T112N R51W in Brookings County, South Dakota directly four miles north and 1/2 mile west of East Oakwood Lake.

The Poinsett soil, gently undulating, is a well-drained Chernozem soil developed in stratified silty glacial drift of late Wisconsin Age (Cary substage). It has varying stratified lenses of clay, clay loam, sand, and sandy loam at depths usually between 40"-72" depending on the topography of the ground surface. These stratified lenses are usually directly on top of the glacial till clay loam material (lodgement till) and range in thickness between 10"-24". The top of the underlying lodgement till follows the ground surface contours but not necessarily at the same depth. This accounts for the varying depths to the glacial material below ground level. Soil profile descriptions for each of the manholes monitored were mapped and an analysis of the texture and other chemical parameters is presently underway.

The glacial till material begins between 4 and 5 1/2 ft below ground surface. It is at this point where the ratio of large cylindrical pores relative to the smaller pores begins to increase from 1-2% of the cross-sectional area to 4-7%. This may indicate that larger roots are more capable of penetrating the heavier glacial till material. The average bulk density measurement by 10 cm increments from the ground surface to a depth of 115 cm ranges from 1.22 to 1.54 g/cm3.

The following table lists the average saturated hydraulic conductivity of the top 6 1/2 ft. of soil derived from 3-7 replications of small laboratory cores:

AVG. DEPTH, (ft)	AVERAGE K_{sat} (cm/hr)	STANDARD DEV.
(0.5)	2.5	3.3
(1.5)	5.7	5.1
(2.5)	6.8	5.8
(3.5)	5.8	4.2
(4.5)	0.9	1.0
(5.5)	0.3	0.2
(6.5)	0.2	0.2

The drainable porosity of the subsurface (glacial till) material at the master site ranges from 2.3-4.4% with a mean of 3.3%. In situ determinations of saturated hydraulic conductivity were made using transiometers and a neutron moisture probe. The hydraulic conductivity of the subsurface glacial till at

RCWP master site ranges from a low of 0.0028 iph to 0.0128 iph for the 8-20 ft below ground surface material.

3.1.3 Monitoring design and instrument system

Macropore flow and the concerns that have arisen regarding the flux of waters through unquantified continuous porous system prompted the monitoring to change from one crop to three. The crop or cropping pattern may be a major factor in affecting the response of subsurface ground water to precipitation events. Transiometers (electronic tensiometers) indicate the rate of response of soils to precipitation at specific depths, and stainless steel soil water samplers determine qualitatively and quantitatively the impact that different cropping and tillage systems have on soil water quality through the use of tracers and, of course, pesticides applied.

A corn-oats rotation is practiced on two tillage systems, MP and NT, with three replications of each crop/tillage management system, plus three replications of an alfalfa treatment which makes for a total of 15 plots (Figure 3-1). The fertilizer level is the same for each tillage system. Ammonium nitrate fertilizer is broadcast at a rate of 200 # of actual N for corn and 100 # of actual N for oats, and no fertilizer for the alfalfa (100#/A nitrogen as ammonium nitrate was applied to one replication of the alfalfa treatment in 1988. Refer to Table 3-4). The pesticides of alachlor (Lasso), dicamba (Banvel), metolalchlor (Dual), terbufos (Counter), 2-4,D ester, MCPA, carbofuran (Furadan), and glyphosate (Roundup) are all applied as "label rates". Except for Roundup, the same chemicals are applied at the same rate for each tillage system. This may not be a common practice in "normal" farm operations, but it is necessary in this study to eliminate the variable of amount applied between tillage systems within a crop treatment.

The monitoring and control system consists of electronic tensiometers (transiometers) that sense matric potential, porous stainless steel cylinders for collecting unsaturated water samples at 2', 4', and 6' below the soil surface, soil temperature thermistors, and a datalogger for monitoring the water energy and controlling the pump to start sample collection. This system is designed to collect water as it moves through the soil <u>when</u> it moves through (Figure 3-2). Fifteen 4' diameter manholes were installed to a depth of 7 1/2' on plots at the master site in November of 1987 to allow for the installation of the sensors and to provide a place for the automated water collection system and samples. At each of three depths a 500 ml Erlenmeyer flask was mounted on a tipping mechanism counter-balanced by a weight equal to 250 ml of water (Figure 3-3). When the bottle was empty and water was sensed moving through the soil profile, a pump is started and a low tension (180 cm H_2O) vacuum is applied to the porous sampler to extract low tension "macropore" water. Each tipping mechanism is connected in parallel to the pump suction plumbing. Beneath the tipping mechanism is a mercury switch that closes a valve in the plumbing once the flask reaches 250 ml. When the last flask is filled, the mercury switch turns off the pump.

A special lateral drilling rig was designed to install the transiometers and soil water samplers 6' away from the edge of the manhole (Figures 3-4 and 3-5). Designing a device to bore a hole 6 feet laterally from inside a 4 foot diameter culvert was a continual challenge with many trial and error designs.

Master site plots established
for monitoring 1988 and 1989

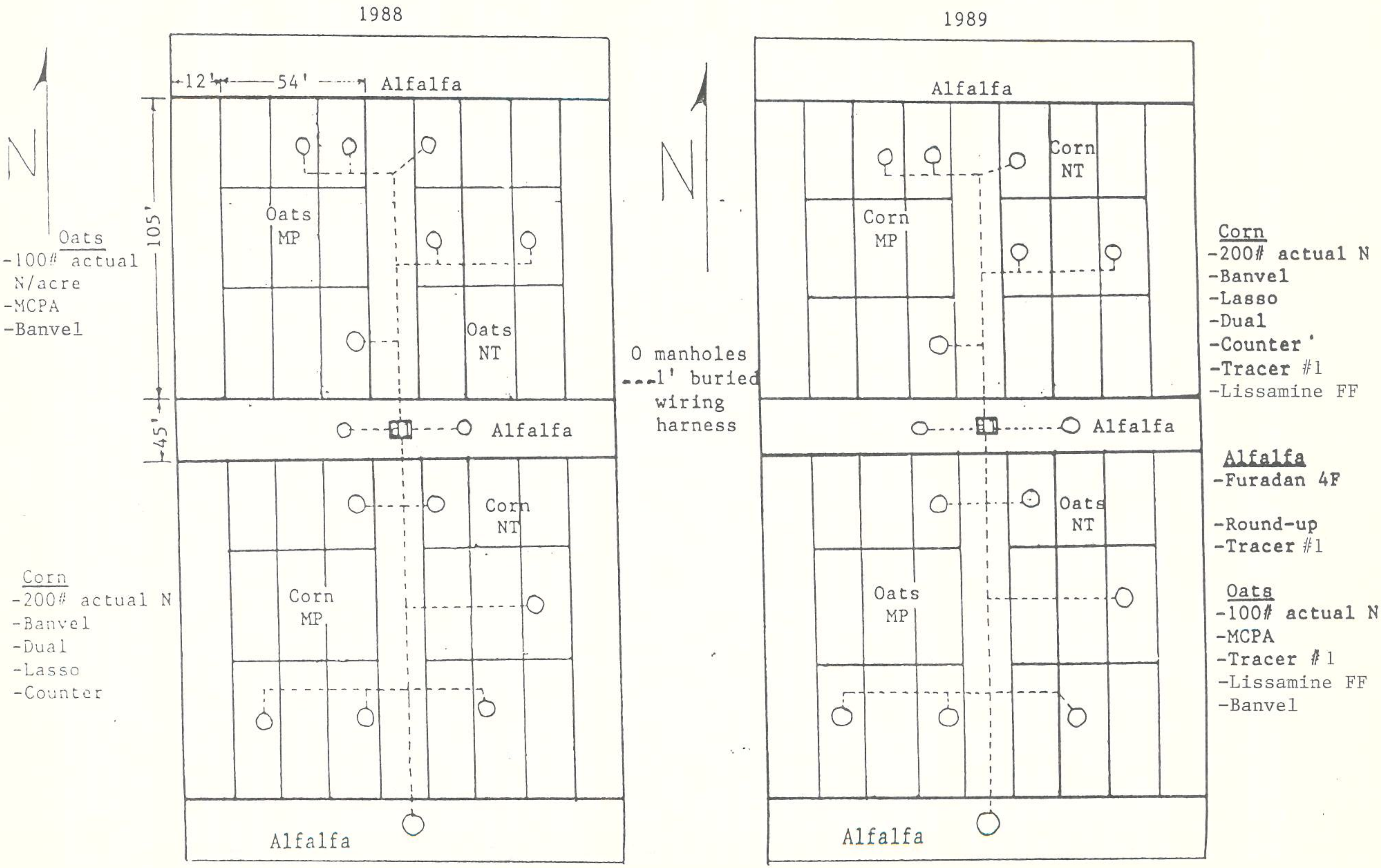


Figure 3-1. The Revised RCWP Master Site practices and treatments for 1988 and 1989.

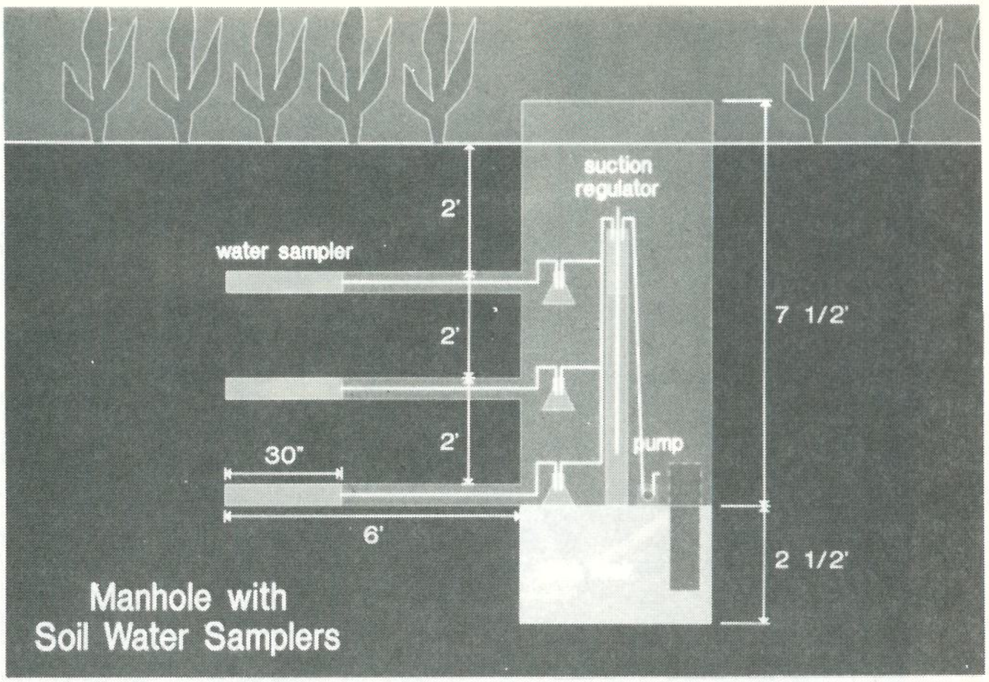


Figure 3-2. A simple schematic diagram of the installation of soil water samplers with regulator and collection flasks.

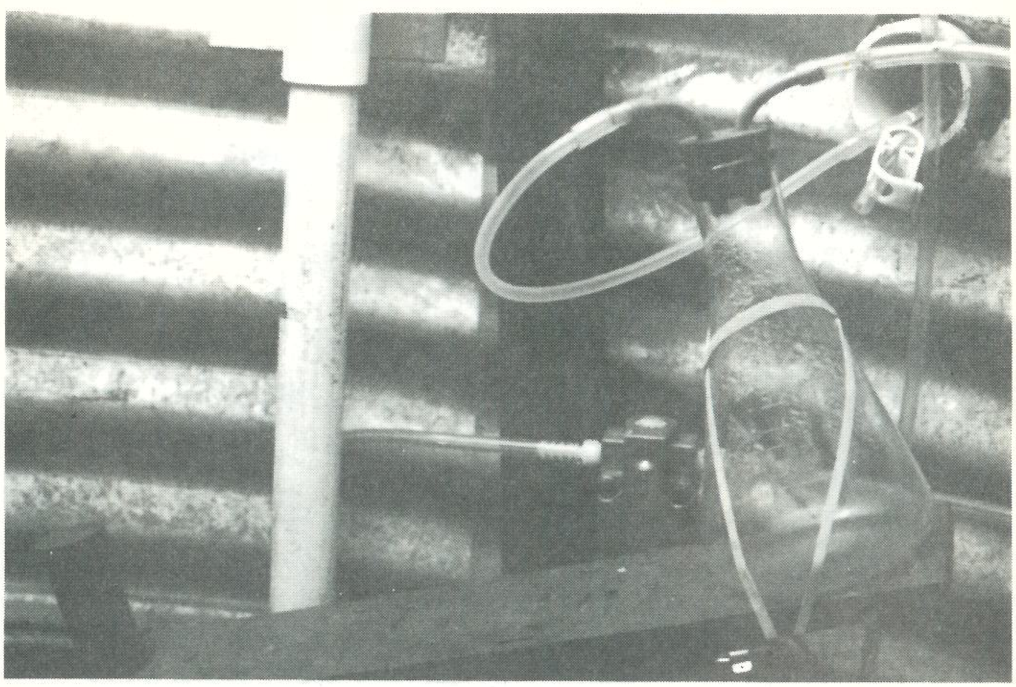


Figure 3-3. A view of the inside wall of a manhole with the water collection flask attached to a tipping mechanism and the soil water sampler.

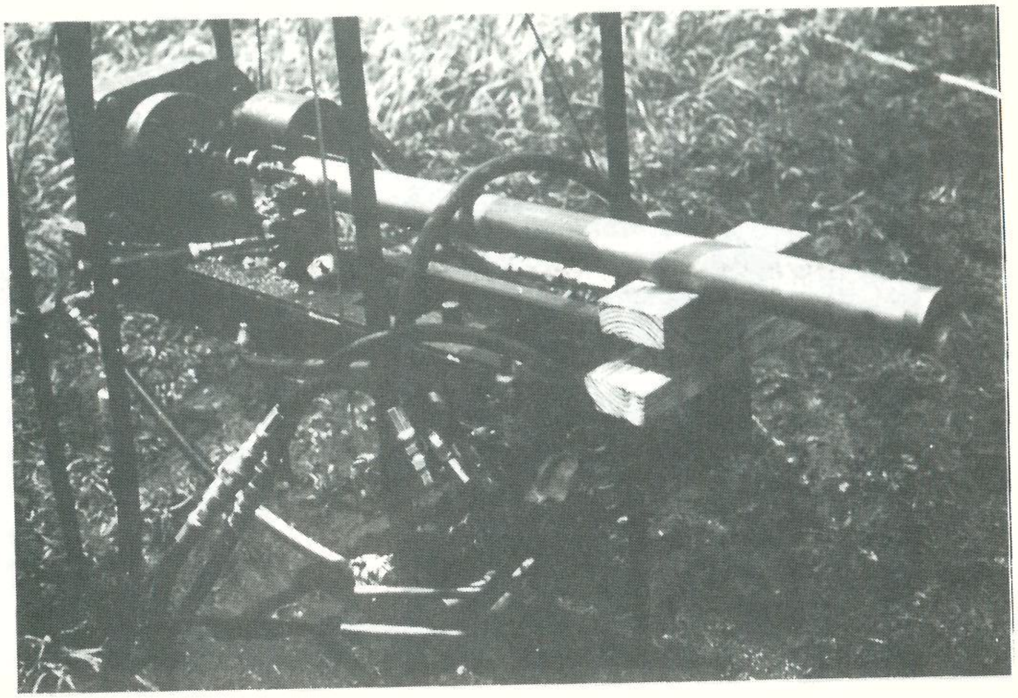


Figure 3-4. The lateral hydraulically-operated soil drilling/coring machine designed to fit in a 4' manhole and drill 6' laterally.

Figure 3-5. Using the lateral drilling machine to make a hole 6' away from the manhole wall for installation of the porous stainless steel cylinder.

Since an auger, when used alone, would cause sidewall smearing on wet soils, and using a coring tube alone would compact the soil, a 2 inch auger inside a 2.5 inch diameter coring tube was designed to solve the problem. The auger and flared tip were designed to pull the soil from the hole as the coring tube, which did not rotate, cut the soil (Figure 3-6).

The process of installing the water samplers and transiometers was very time consuming. Boring the two holes at three different depths took approximately 6 hours when things worked well. Since the equipment was designed with absolutely no field experience, there were many alterations and design changes, as well as breakdowns in the field. The months of July and August were spent installing water samplers and transiometers, connecting instruments to the datalogger, and programing the datalogger. Figure 3-7 is an example of an installed water sampler.

Soil matric potential monitoring provides a complete and accurate hourly record by depth on each of the 15 plots which has been designed for data-logging. The automatic matric potential monitoring is the basis for triggering a mechanism for soil water sampling. When a significant increase in soil water content is sensed two feet below the ground surface, a trigger relay board actuates a vacuum pump to withdraw a 250 ml sample of water from the vadose zone through stainless steel porous filters installed in the soil (Figures 3-8 and 3-9). The filters are capable of intercepting a portion of the soil at a given depth and will theoretically intercept more macropore flow than vertically installed units.

3.1.4 Climate and land use

The Oakwood-Poinsett Lakes area is in a climate where an average of 22.5 inches of precipitation falls annually. The normal growing season precipitation is 17 inches per year. 1988 was dry in the months of June and July. Total precipitation at the Castlewood site was 17.5 inches (5 inches below normal). The majority of the rain fell after crops needed it (Figure 3-10). Over 40% of the rain for the year came in a 17 day period after August 6th. Air temperatures were well above normal for 1988. Limited rain in June and July coupled with hot temperatures drew heavily on the reserves of the soil and lowered the water table, if roots could penetrate and grow to that depth.

At the beginning of the growing season visual observations indicated that the water table was within 4.5 to 6' of the soil surface over all treatments. There was little difference in soil water content and depth to the water table in the spring of 1988 (visual observations). The depth to water table did not vary substantially between treatments like it did at the end of the growing season in 1989. Corn and alfalfa have an extensive root system that is capable of extending deeper to obtain water when the upper soil profile is depleted. Both of these crops use substantially more water than small grain crops. The average annual water usage for three cuttings of alfalfa is 30". Corn uses approximately 22-24" per year and small grains use 10-13".

There were several small rains the latter part of May and the first part of June. Beginning on May 19, 1988 there were five consecutive rain events on five consecutive days, each of about 0.25", which totaled 1.22". These rains

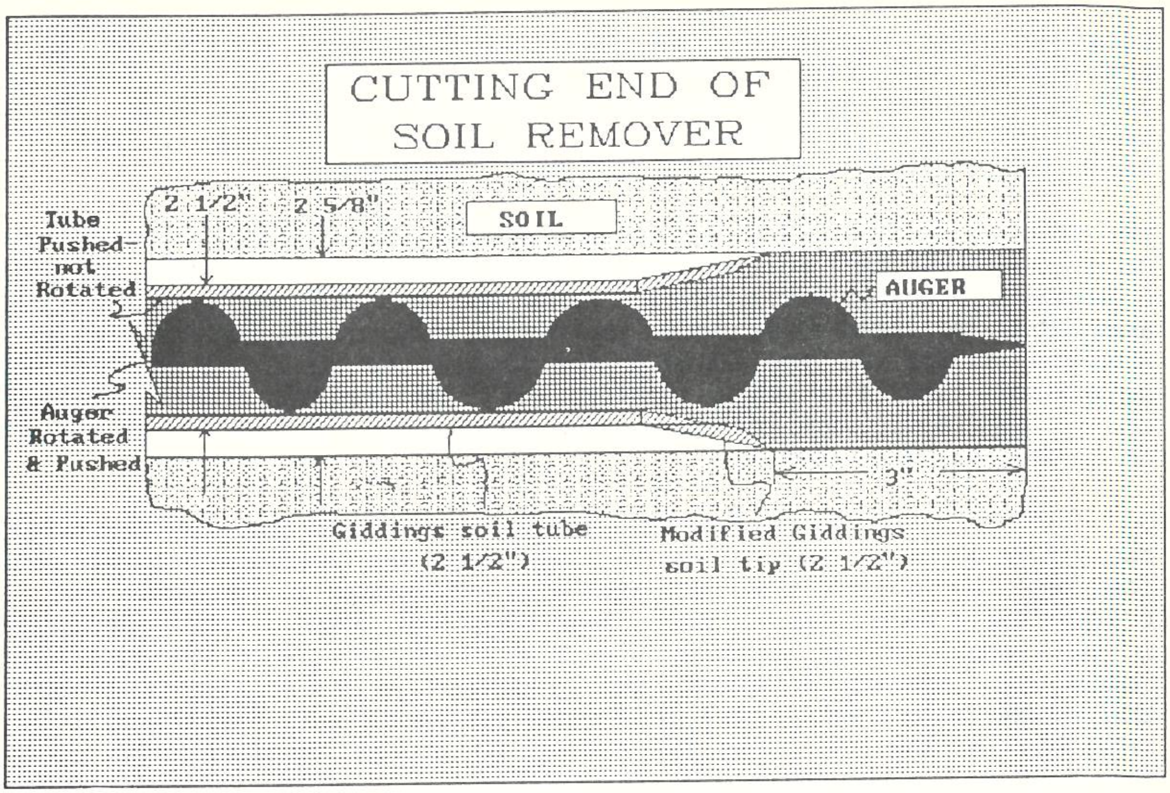


Figure 3-6. A schematic depiction of the method of soil removal using the lateral soil drilling machine. The auger and tube were pushed at a constant velocity. The auger pulled the soil back as the flared cutting edge prevented soil smearing.

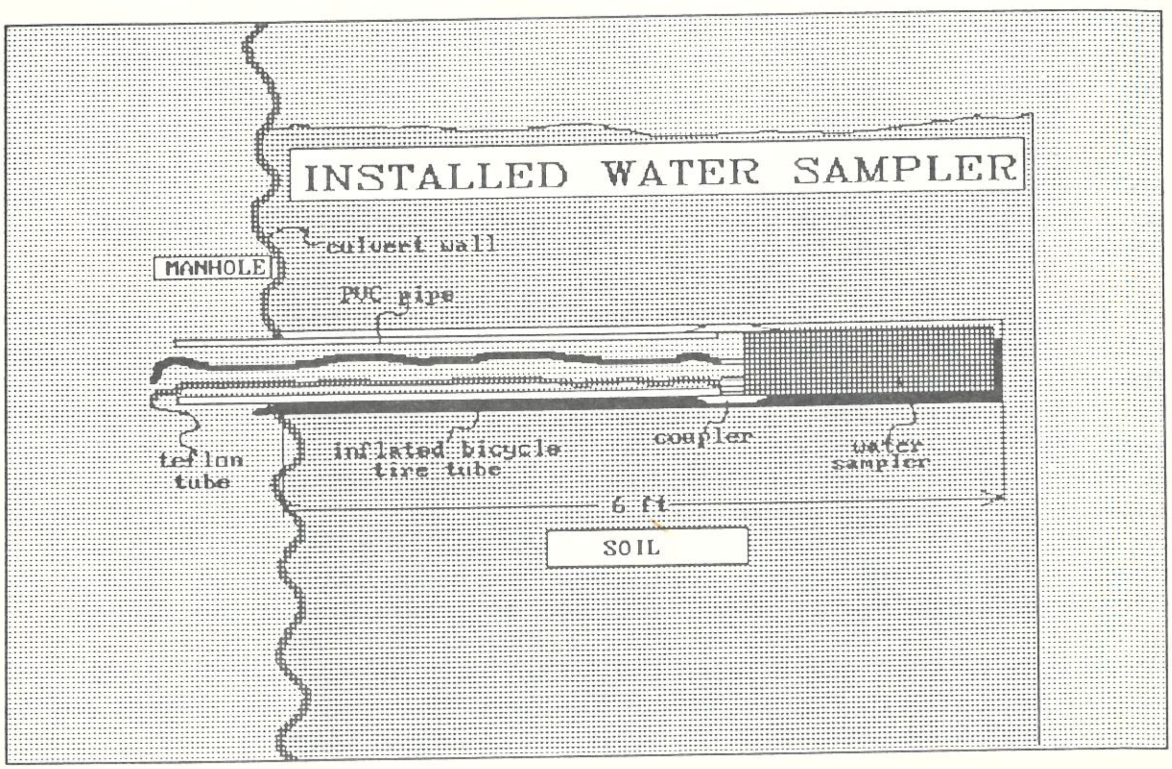


Figure 3-7. A schematic diagram showing what an installed soil water sampler would look like in the soil.

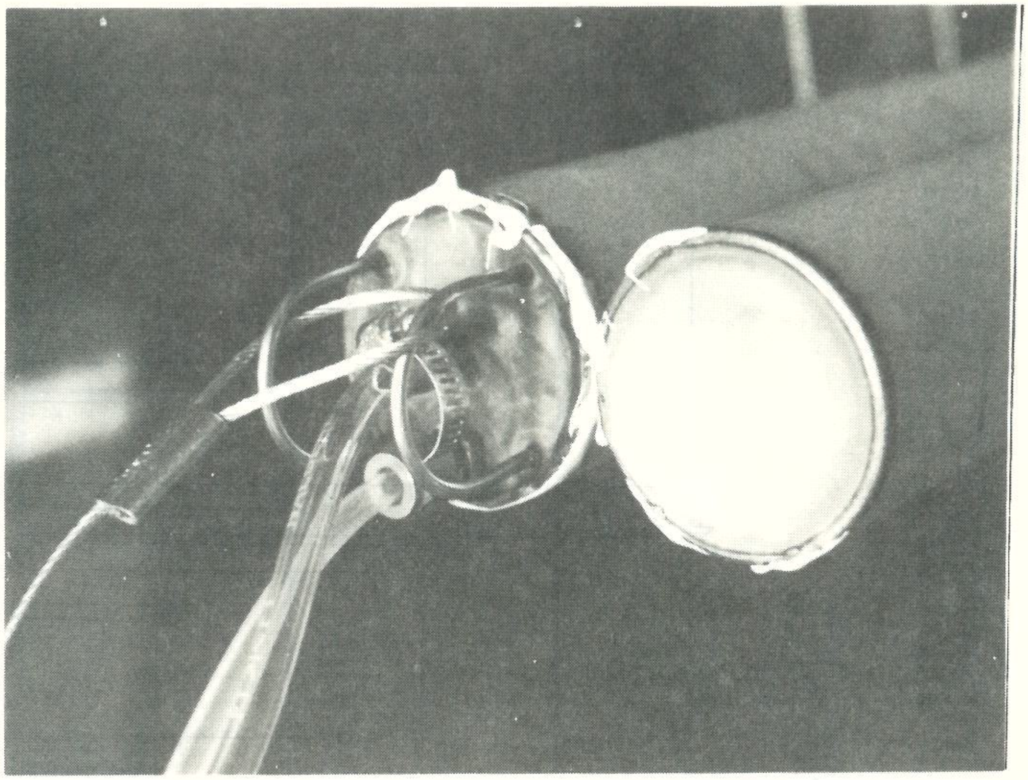


Figure 3-8. Close-up view of each end of a porous sintered stainless steel water sampling device for use in unsaturated soils.

Figure 3-9. A stainless steel porous water sampler with a rubber tube located beneath to force the unit to contact the soil after lateral insertion.

RCWP 1988 DAILY PRECIP. SUMMARY

MASTER SITE

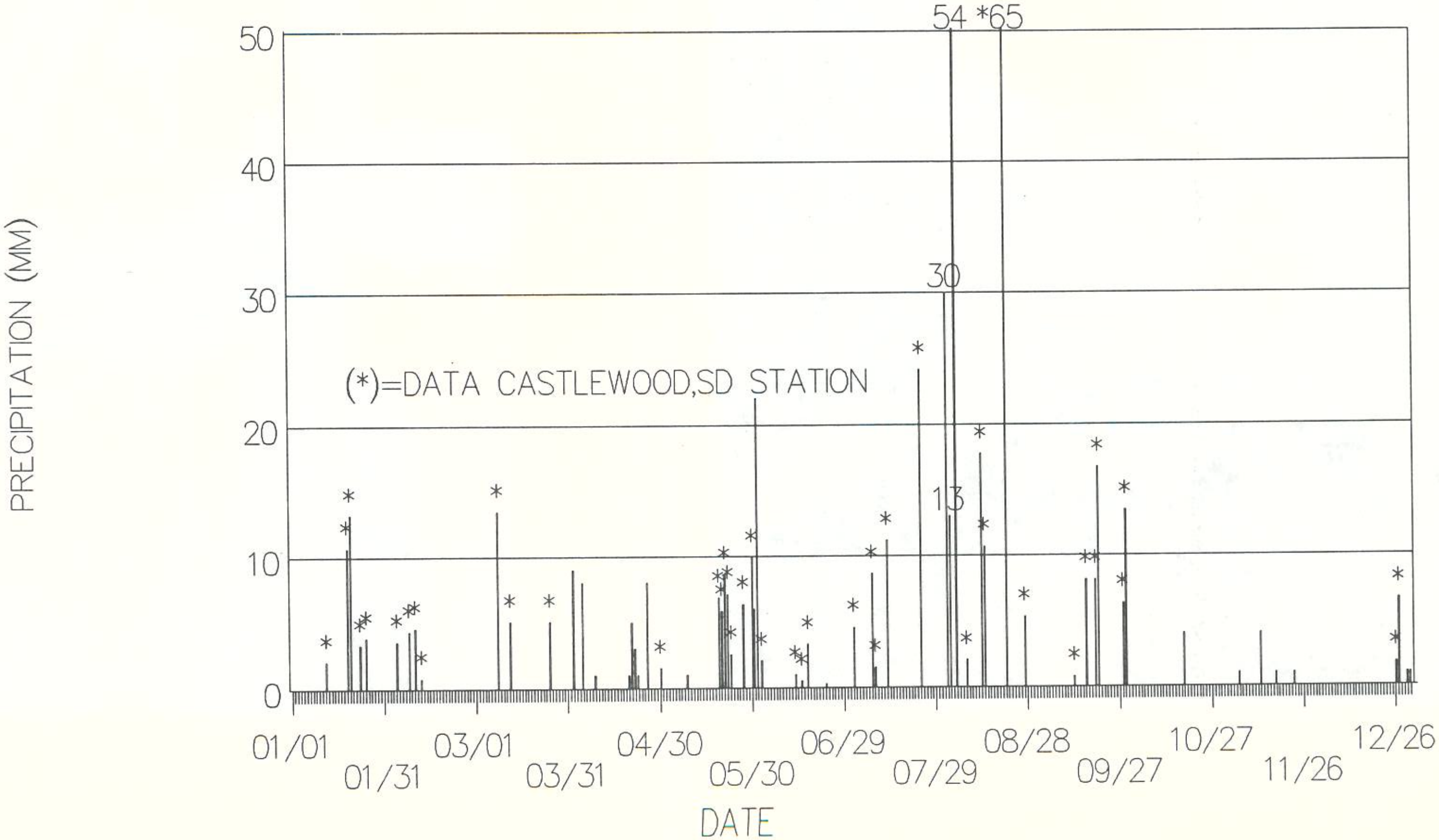


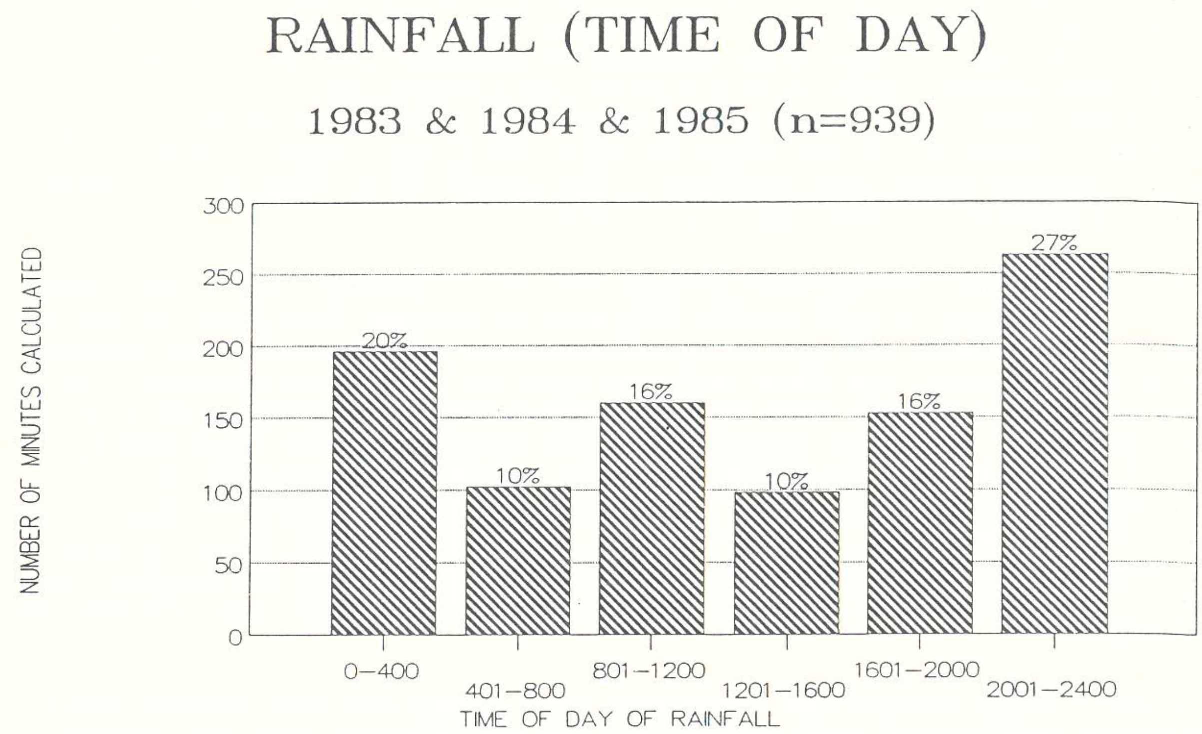
Figure 3-10

fell 9 days after Banvel and MCPA was sprayed on the oats. The corn treatment was sprayed with Banvel and 2,4-D the day after this 1.22" of rain fell. Within the next 10 days after application another 1.30" of rain fell in 5 different events. Some of these rains had intensities of 11.8 and 5 inches per hour (iph) rates. The timing of the application and rainfall along with the early maturity of the crops may have led to the leaching of Banvel and some nitrates which were detected in the ground water sampled in September (data presented in water quality section).

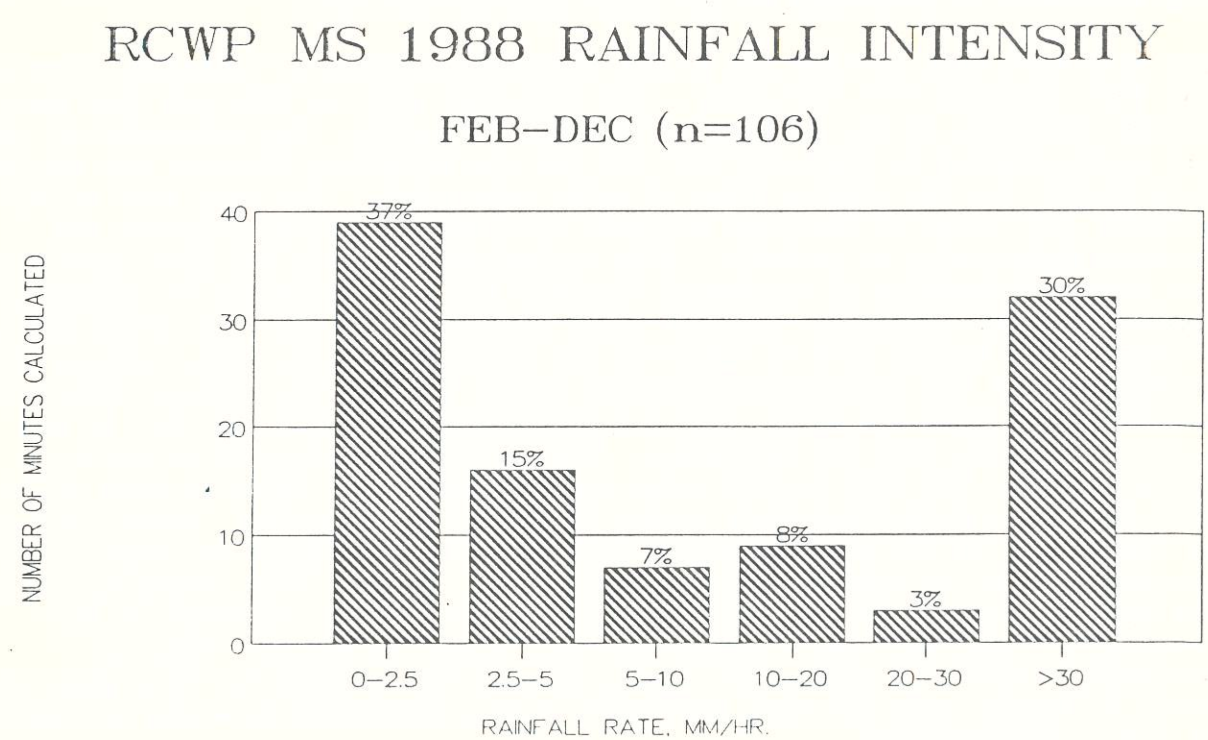
Little rain fell in the next 30 days (<0.35"). Between July 2 and August 2nd 1.91 inches fell in rain events that were no greater that 0.95" at any one time. The alfalfa and corn crop and extremely warm temperatures consumed all that fell in this time frame and drew upon the soil water reserves. In August large rainfall amounts with high intensities fell (intensities as high as 24 and 10 iph). By visual inspection of the saturated water level and by drilling in the soil following the rains, these rains elevated the water table on the oats plots (indicating leaching), but did not appear to cause water to move to the saturated zone on the corn or alfalfa. Water from the rain in August went to replenishing the soil profile in the corn and alfalfa, but since the oats soil profile was wetter, more of the water went through the profile.

It isn't clear whether the rains that came in May and June shortly after chemical application were responsible for the chemical that was detected in the ground water in September, or whether it was the heavy rains with high intensities in August that fell on dry cracked soil. (Detections of chemicals and nutrients is presented in the water quality section.)

The rain that fell in 1988 had a very different pattern of intensity from 1986 and 1987 (Figures 3-11 and 3-12). The rain that fell in 1986 and 1987 were almost identical in the pattern of rainfall intensity. The intensity in 1988 was quite similar to 1986 and 1987 for the low intensity rainfall but was more than double for the greater than 30 mm/hr rate range. The rain fell on dry cracked soil later in the year as crops utilized soil water reserves and created essentially no run-off. This drying and cracking may have increased the size and quantity of macropore channels for water movement to subsurface depths. Higher intensity rainfall would contribute to the flow mechanism by maintaining a higher rate of water to any given macropore, thus, keeping the macropore full and allowing penetration deeper through the channel before the matric forces pull the water into the micropores and swell the soil to the point of closing down the macropore. The pesticide monitoring of wells on field sites in the RCWP project area reported more than twice as many wells with pesticide detections than in any other year of sampling. These hits may be the result of the same mechanism that caused the movement of chemicals on the master site to appear in the ground water. Larger, high intensity rains falling on parched, cracked soil may have been the right combination for leaching of chemicals and nitrates on small grain in August. However, movement of water to subsurface depths on corn and alfalfa for this same time frame in August does not seem realistic, unless macropore flow was undetected by visual observations.



RAINFALL (TIME OF DAY)
1983 & 1984 & 1985 (n=939)
NUMBER OF MINUTES CALCULATED
300
250
200
150
100
50
0
20%
10%
16%
10%
16%
27%
0-400
401-800
801-1200
1201-1600
1601-2000
2001-2400
TIME OF DAY OF RAINFALL

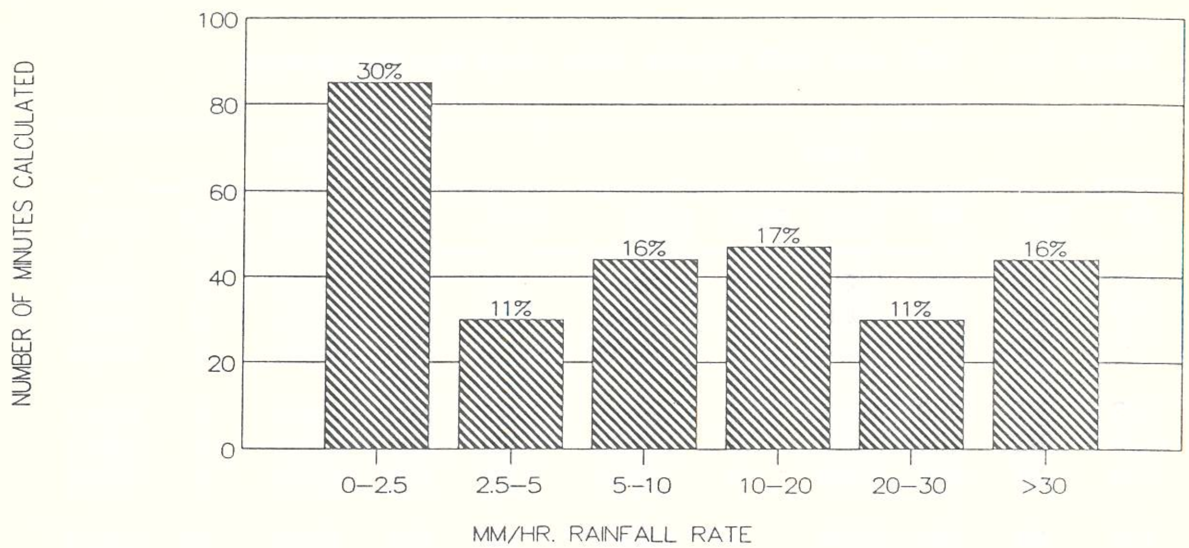


RCWP MS 1988 RAINFALL INTENSITY
FEB-DEC (n=106)
NUMBER OF MINUTES CALCULATED
40
30
20
10
0
37%
15%
7%
8%
3%
30%
0-2.5
2.5-5
5-10
10-20
20-30
>30
RAINFALL RATE, MM/HR.

Figure 3-11.

RCWP MS 1987 RAINFALL INTENSITY

MAY 29 – SEPT. 22 (n=280)



RCWP MS 1986 RAINFALL INTENSITY

MAY 20 – SEPT. 17 (n=262)

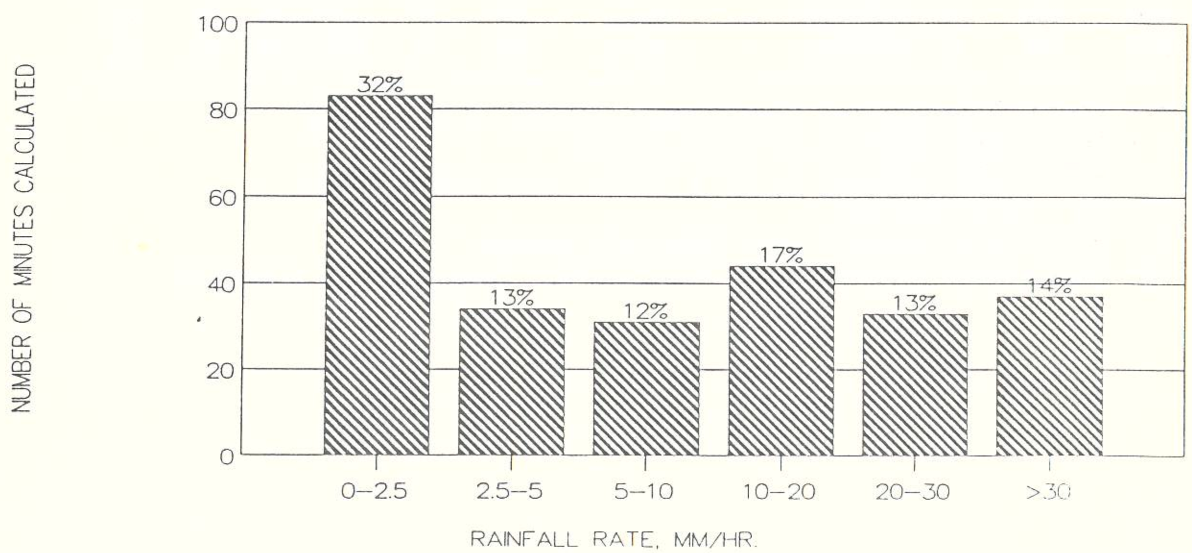


Figure 3-12.

Land Use Activities

The following tables are documented historical agronomic, chemical, and fertilizer land use practices that were applied either in 1987 or 1988. These activities are presented to help the reader clearly examine the facts.

Table 3-1. 1987 and 1988 master site land use management.

Site	1987					1988				
ID	Till	#N	Crop	Pest	Rate	Till	#N	Crop	Pest	Rate
503	MP	200	CORN	*	Label+	MP	100	OATS	@	Label
507	MP	200	CORN	*	Label	MP	100	OATS	@	Label
508	MP	250	CORN	*	40%>#	MP	100	OATS	@	Label
522	NT	200	CORN	*	Label	NT	100	OATS	@	Label
525	NT	200	CORN	*	Label	NT	100	OATS	@	Label
526	NT	250	CORN	*	40%>	NT	100	OATS	@	Label
703	MP	200	CORN	*	Label	MP	200	CORN	##	Label
704	MP	250	CORN	*	40%>	MP	200	CORN	##	Label
707	MP	200	CORN	*	Label	MP	200	CORN	##	Label
721	NT	200	CORN	*	None	NT	200	CORN	##	Label
722	NT	250	CORN	*	40%>	NT	200	CORN	##	Label
725	NT	200	CORN	*	Label	NT	200	CORN	##	Label
901	NA**	0	ALFALFA	-	None	NA	100	ALFALFA	NA	NA
902	NA	0	ALFALFA	-	None	NA	0	ALFALFA	NA	NA
903	NA	0	ALFALFA	-	None	NA	0	ALFALFA	NA	NA

* - Pesticides applied were Lasso, Banvel, 2-4,D ester
\+ - Pesticides applied as label rates
\# - Pesticides applied as 40 % higher than label rates
**- NA - None Applied
@ - Pesticides applied were MCPA and Banvel
\#\#- Pesticides applied were 2-4,D ester, Lasso, Dual, & Banvel

Table 3-2. 1988 master site chemical applications.

Activity	Date	Treatments MP-OATS	NT-OATS	MP-CORN	NT-CORN	ALFALFA
Sprayed Eptam 6E at 8 qts/Ac	4/20/88					XX
Sprayed 1.7 pts/Ac glyphosate (Roundup)	5/05/88				XX	
In-furrow granular Counter 12 lb/Ac (with seed)	5/06/88			XX	XX	
Sprayed 1 pt/Ac MCPA & 0.25 pt/Ac Banvel	5/10/88	XX	XX			
Sprayed 3 qt/Ac Lasso & 2.5 pt/Ac Dual	5/10/88			XX	XX	
Sprayed 1 pt/Ac Banvel & 0.5 pt/Ac 2,4-D ester	5/24/88			XX	XX	
Spot sprayed Canadian thistles w/glyphosate (Roundup)	5/24/88					XX
Sprayed 0.25 pt/Ac Banvel & 0.5 pt/Ac MCPA (+)	5/24/88		South 1/3 of plots			
Sprayed 1.5 pt/Ac glyphosate (Roundup)	8/29/88		XX			

\+ - to control broadleaf weed problem in this area

Table 3-3. 1988 master site agronomic land use activities.

Activity	Date	Treatments MP-OATS	NT-OATS	MP-CORN	NT-CORN	ALFALFA
Plowed 7-8" deep; no disk or chisel	4/15/88	XX				
Seeded "Hytest" oats with double disc drill 3 bu/Ac rate	4/15/88	XX	XX			
Seeded "Hytest" oats with K. Kirby's no-till drill 3 bu/Ac rate (was used to penetrate soil on no-till plots)	4/19/88		XX			
Harrowed plots to incorporate fertilizer	4/19/88	XX				
Rototilled to a depth of 4-6" w/ 51" wide tractor-powered rototiller	4/20/88					XX
Spike-tooth harrowed area to incorporate herbicide and seed	4/20/88					XX
Seeded 5 lb Vernal alfalfa	4/20/89					XX
Disked twice with 6' wide tandem disk (5-7")	5/06/88			XX		
Planted Agripro seed corn 24,500 seeds/Ac w/ JD 7000 planter	5/06/88			XX	XX	
Diked plots & set out flumes & stage recorders for monitoring run-off	5/12/88	XX	XX	XX	XX	
Harvest oats - straight combine	7/16/88	XX	XX			
No corn cultivations this year						
Plowed 7-8" deep with moldboard plow	7/29/88	XX				
Harvested corn 5-6pm New Holland TR70	10/25/88			XX	XX	
Chopped corn stalks 6" high	10/25/88			XX	XX	
Plowed 6-7" deep with moldboard plow	11/14/88			XX		

Table 3-4. 1988 master site fertilizer applications.

Activity	Date	Treatments MP-OATS	NT-OATS	MP-CORN	NT-CORN	ALFALFA
Surface applied granular Diammonium Phosphate (18-46-0) with drop spreader; 50 lb actual P/Ac (one pass)	4/19/88	XX	XX			
Surface applied granular Ammonium Nitrate (34-0-0); 100 lb actual N/Ac(includes N in above fertilizer) (second pass)	4/19/88	XX	XX			
Surface applied Ammonium Nitrate (34-0-0) 100 lb of actual N/Ac	4/20/88					Middle tier only
Surface applied Ammonium Nitrate (34-0-0) = 200 lb of actual N/Ac	5/06/88			XX	XX	

3.1.5 Water balance

In order to determine if all the precipitation which is received goes into the soil, dikes were made around all the plots of oats and corn. A calibrated v-notch flume with a stage recorder in each downstream corner of the plot was installed to determine the amount of run-off which may occur. The intensity of the rainfall is recorded by a tipping bucket raingauge which also records the total amount received. One run-off event occurred in 1988 (June 3) which recorded runoff on 6 plots. The intensity of the rain was about 2 iph and a total of 0.35" of precipitation was received. There was no correlation between the number of plots that had runoff and the type of tillage or the type of crop used. Figures 3-13 and 3-14 show the differences in the amount of surface water remaining immediately after the rain event between MP and NT tillage treatments on corn. These pictures were taken directly after the rain stopped. There was more surface water visible on the moldboard corn treatment than on the no-till corn treatments. There was no standing water on the alfalfa treatments and the oats plots had enough vegetation cover to prevent visual inspection.

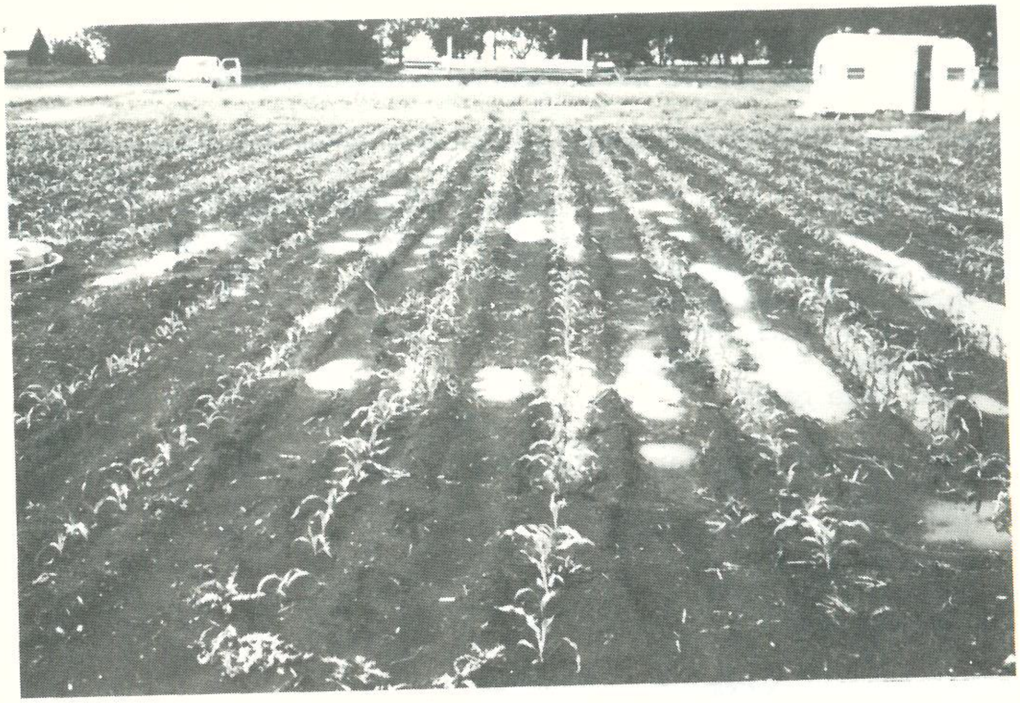


Figure 3-13. Water ponded at the surface on MP tillage treatments after 0.37" of rain fell in 15 minutes. Contrast this to the NP treatment below.

Figure 3-14. Very little water ponded on NT corn treatments immediately after a 0.37" rain fell in 15 minutes. Contrast this with the MP treatment above.

Volumetric water content

Volumetric soil profile water contents (from the ground surface to 6' below ground surface) were initiated on December 6, 1988. The data which quantifies the amount of water in the soil profile and the changes which occurred over the winter and into the spring will be presented in next year's annual report. This data along with the run-off data will be used together to determine the differences between tillage and crop treatments on the amount of water that reaches a certain depth after a precipitation event.

3.1.6. Water Quality

Introduction

The results of the chemical analysis of nitrates, pesticides, and background fluorescent yellow dye presented in this section are all determined on water which was extracted from the saturated zone. The unsaturated water samplers were not ready for sample extraction before the onset of winter.

The depth below ground surface of the saturated zone varied between treatments with time. The earliest comparison of water levels between treatments was obtained in January of 1989. The last deep transiometers were installed at that time. The approximate water table positions at one point in time are given in Table 3-5.

Table 3-5. Depth (feet) below ground surface of the saturated zone for the various treatments.

		Treatments				
Date	Replication	MP-OATS	NT-OATS	MP-CORN	NT-CORN	ALFALFA
2/15/89	1	8.5	8.5	11.5	11.5	10
	2	10.0	--	11.5	--	17
	3	7.9	--	--	--	--

There is a wide range in the water table position as a result of the type of crop grown above the measurement point. Generally, the crop that used the most water during the growing season in 1988 had used the most water from the saturated zone, thus lowering water levels in the soil. The shortage of rainfall, particularly in June and July, contributed to this water level decline. Past rainfall (1984-1987) provided a sufficient quantity of water to balance that used by the crop while maintaining fairly stable water levels. The position of the water table will have an impact on the results of the quality of water removed from the deep samplers. From past monitoring of the nitrate concentration in wells at different depths on the RCWP field sites, there is a trend that exists between depth below water table and nitrate concentration. As the depth below water table decreased, the nitrate concentration increased. This phenomenon is evident particularly in the ground water monitoring geozone classification of "weathered till with a screen interval less than or equal to 15 ft below ground surface". This is the geozone classification that fits the deep samplers installed at the master site.

All stainless steel water samplers were installed with the top of the sampler approximately 15' below the ground surface. Since each sampler is 30" long, the water level would have to drop to greater than 17.5' below the soil surface before a "saturated" water sample could not be obtained. Because of the difference in water levels, the water samples that were obtained from the deep samplers varied in depth "below water level". The range in the depth below water table from which water samples were obtained varied from 7 feet to 0.5 feet. The drainable porosity of the glacial till material has been determined to be approximately 3%. This translates to a range of 2.5" to 0.2" depth of free water. Whether this range is significant in affecting the concentration of pesticides or nitrates present in the sample is questionable. When the unsaturated samplers at the 2', 4', and 6' are functioning properly, the water quality taken from these instruments may definitively answer these questions. Some samples have been collected at these depths and the results will be reported in subsequent reports.

The first samples which were obtained for water quality determination at the master site were from the deep samplers (15' below ground surface). This sampling was initiated on September 1, 1988 and continued on a two-week interval sampling schedule for two months. This schedule was used to clean out any contamination that may have been introduced to the system when the samplers were installed and to determine reliable background information on dyes, nitrates, and organics. As the following data indicate, there appear to be some surface contamination from installation, but most was cleaned out after the first sampling.

Nitrates

Preliminary nitrate data taken from the deep samplers show a particular trend (Figure 3-15) by treatment. The nitrate concentration in the water samples tend to decrease with time (Sept. 1 through Feb. 16, 1989). This may be the result of replacing the existing water at that depth with lower concentration water from above as the water is purged for sample collection, since the drainable porosity of the glacial till material is very low (3%). Anywhere from 0.5 to 1.0 gallons of water are purged from the samplers before collection of about 0.5 quart. The samplers, when completely full, hold approximately 0.6 gallons.

An analysis was used to determine if there is a relationship between the amount of nitrogen applied at the soil surface and the amount detected in the water from the saturated zone (deep samplers). A weak trend developed that indicates that the nitrate concentration detected in the ground water increases as the amount of nitrogen applied at the soil surface increases. One analysis relates the amount of nitrogen applied in the "most recent year" (Figure 3-16) to ground water nitrate concentration and another analysis relates the total amount of nitrogen applied within the "last two years" (Figure 3-17) to ground water nitrate concentration. For each analysis a linear regression model was used for all tillage treatments, NT treatments alone, and MP treatments alone. The linear regression models, for any of the analyses, have weak coefficients of multiple determination ($R^2 \leq 0.31$).

NITRATES DETECTED IN WATER

15' BELOW GROUND SURFACE 1988

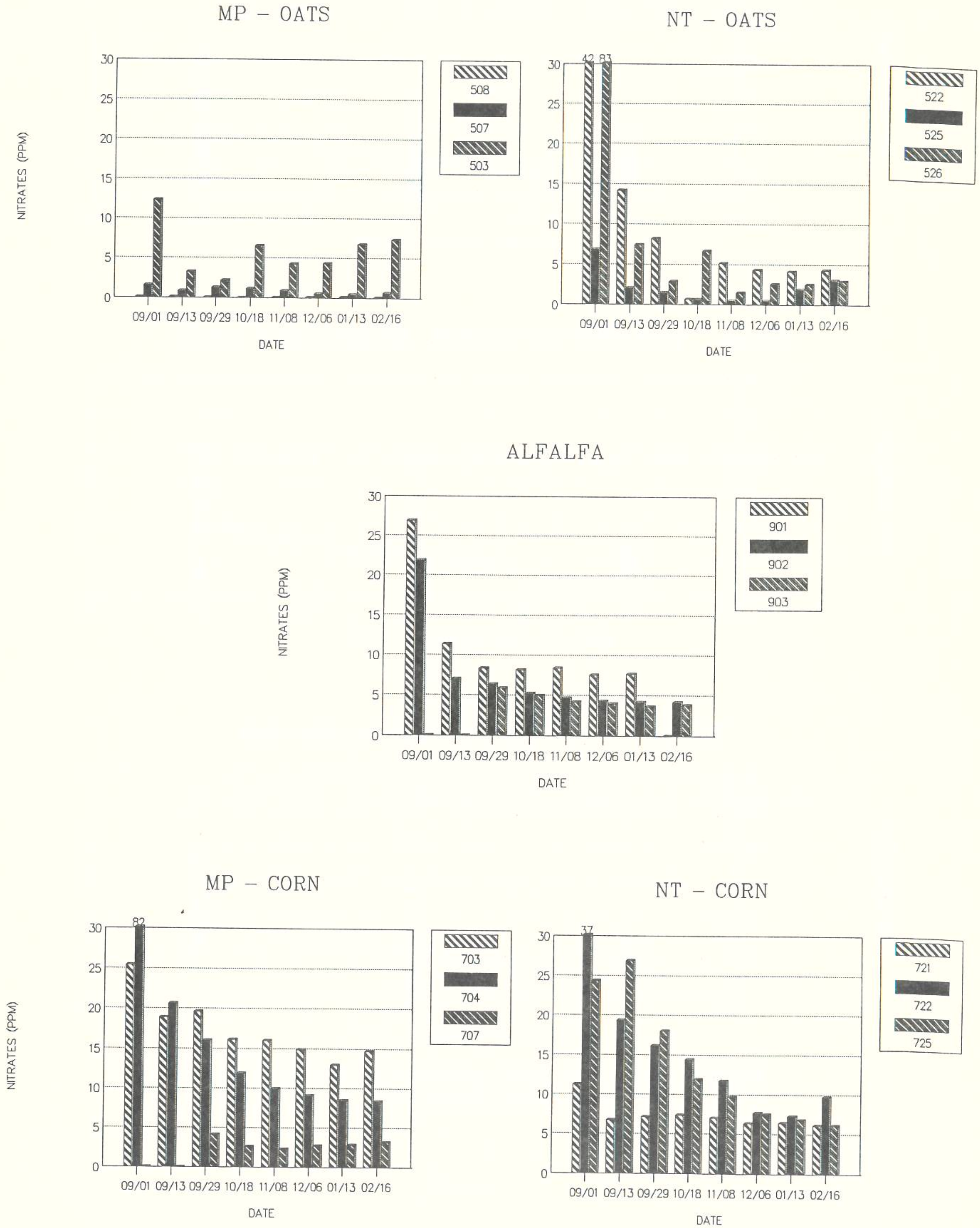
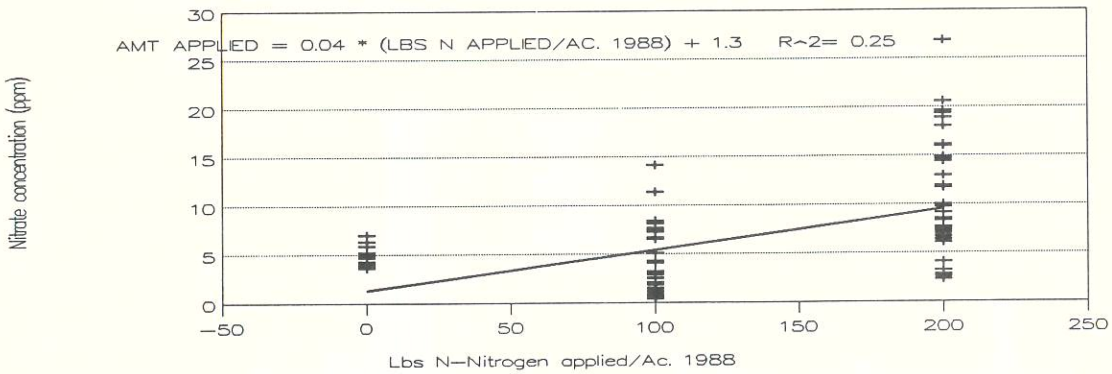


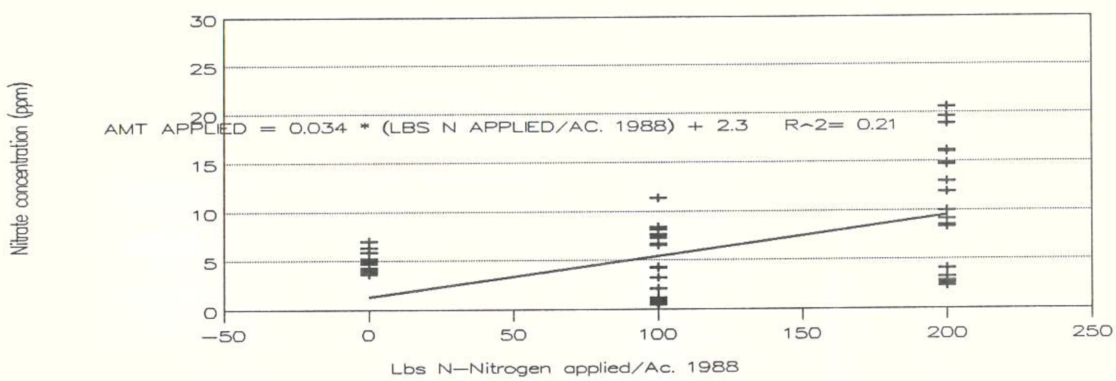
Figure 3-15

Nitrogen Applied Vs. Nitrates Detected

Deep; 9/1/88-2/16/89; All Treatments



Deep; 9/1/88-2/16/89; Moldboard Plow



Deep; 9/1/88-2/16/89; No-till

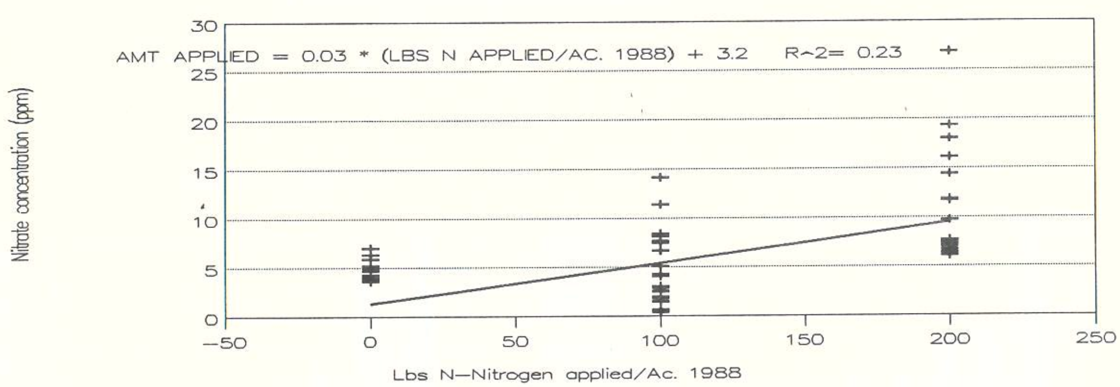
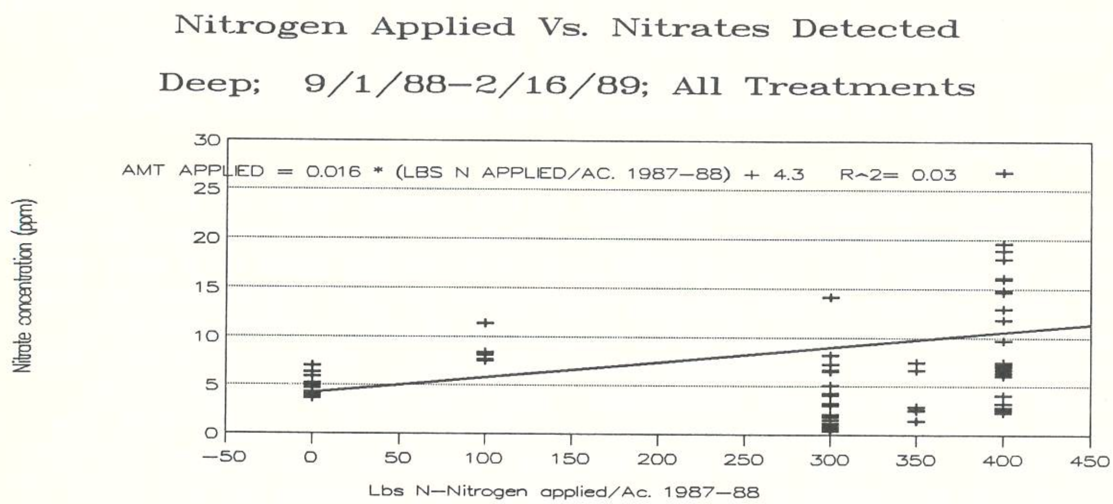
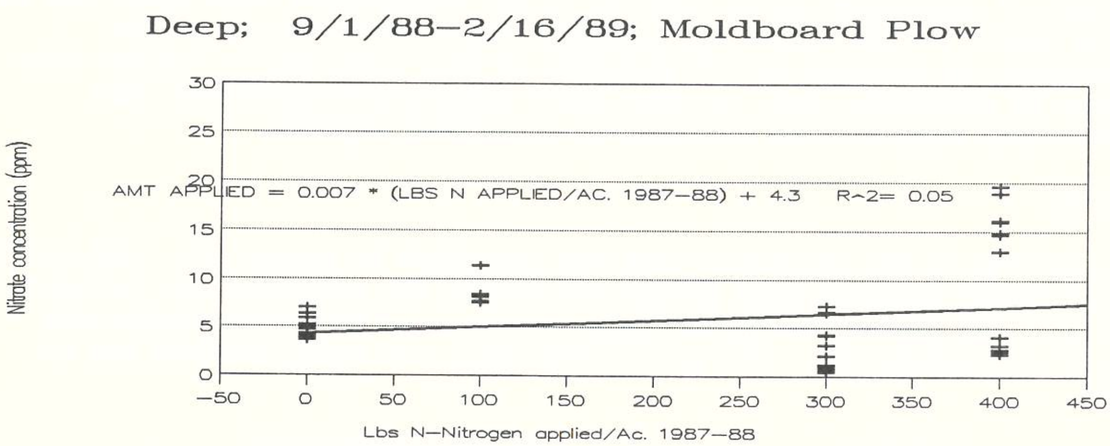


Figure 3-16. One year analyses of nitrogen applied vs. nitrates detected.





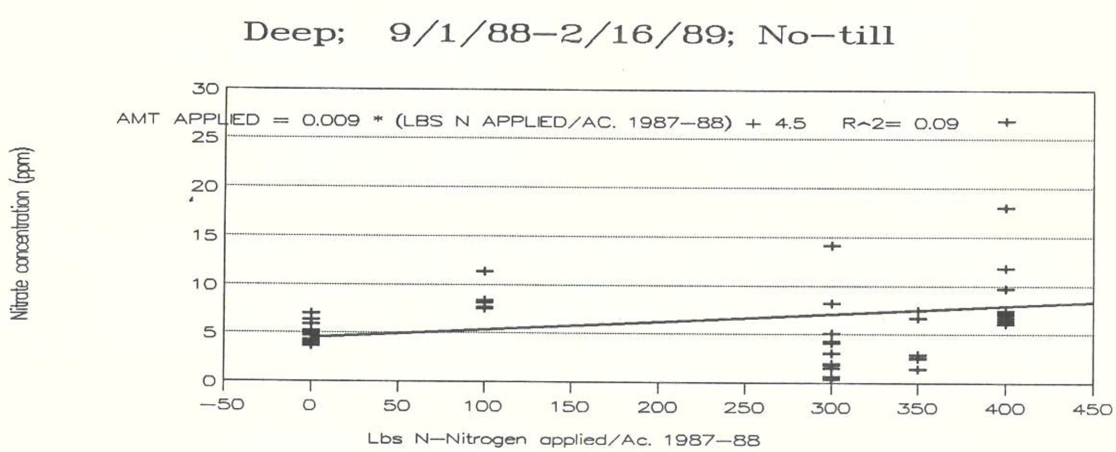


Figure 3-17. Two year analyses of nitrogen applied vs. nitrogen detected.

Clearly the "most recent year" analysis indicates that the most recently applied nitrogen correlates better ($R^2 = 0.31$) with the nitrate concentration of the water 15' below ground surface than the "last two years" analysis ($R^2 = 0.09$). There is no distinction between NT and MP tillage treatments affecting the level of nitrates found in the subsurface ground water based on this limited data.

The mean nitrate concentration detected in the ground water of the corn treatment (10.4 ppm) which had 200#/Ac. Nitrogen applied as ammonium nitrate fertilizer is about four times higher than that of the oats (2.8 ppm) and twice as high as that of the alfalfa treatments (6 ppm) (disregarding the first sampling date because of water suspected of being contaminated by surface water when the instruments were installed). With the limited data, statistical analysis was not performed. Past fertilizer and pesticide applications to various plots may have an effect on the results that are presented here. The data thus far, however, indicate that higher nitrogen applications at the surface in 1988 generate more nitrates in the water 15' below ground surface.

The effect of antecedent water content in the unsaturated zone above the water sampling point, or the effect of the depth below water table, on the concentration of nitrates is not possible at this time due to limited data. This data is available, and, as more water samples are collected, the composite data base will be analyzed in subsequent reports.

Pesticides

Water sampling in the saturated zone was initiated on August 30, 1988 and the stainless steel samplers were purged and tested for nitrates, pH, background yellow dye, and pesticides on two week intervals to determine background levels of all parameters. The pesticides which are being scanned are as follows:

2,4-D
Alachlor (Lasso)
Atrazine
Butylate (Sutan)
Carbofuran (Furadan)
Chloramben (Ambien)
Cyanazine (Bladex)
Dicamba (Banvel)
EPTC (Eradicane)
Fonofos (Dyfonate)
Glyphosate (Roundup)
MCPA
Metolachlor (Dual)
Pendimethalin (Prowl 4E)
Pichloram (Tordon)
Propochlor (Ramrod)
Terbufos (Counter)
Trifluralin (Treflan)

Most of these parameters have not been applied within the past two years, however, background levels of pesticides which have been used in past management practices need to be determined to see if they are present in the ground water since the cost of analysis is the same. The following is a list of the pesticides which are scheduled to be applied in 1989:

2,4-D
Alachlor (Lasso)
Carbofuran (Furadan)
Dicamba (Banvel)
Glyphosate (Roundup)
MCPA
Metolachlor (Dual)
Terbufos (Counter)

Figure 3-18 shows the number of detections of various pesticides by treatment for the first three samplings 15' below ground surface in 1988. 2,4-D and Banvel were, by far, the most frequently detected pesticide. Forty-two samples were analyzed for pesticides in the three samplings. Twenty-seven of those samples (64%) had, at least, one detection of a pesticide. Thirteen water samples (30%) had more than one pesticide detection, and three samples (7%) had more than two pesticide detections. Forty (81%) of 49 pesticide detections in the first three samplings came from pesticides which were applied in 1988. The highest concentration of any of these 40 detections was 2.99 parts per billion (ppb) of 2,4-D.

Figure 3-19 represents the number of detections of pesticides by treatment and date from water located 15' below ground surface. The first samples appear to be clearly following the same pattern of the nitrates. That pattern is that possible surface contamination from water closer to the surface resulted when the instruments were first installed. No clear distinction between concentrations, or frequency of occurrence, of pesticide detections is evident between MP and NT for either corn or oats at this time.

The most frequently detected pesticides were 2,4-D and Banvel. Thirty- four (69%) of the 49 detections were represented by 2,4-D and Banvel. Banvel accounted for 43% of all detections. 2,4-D accounted for 34% of all detections. In 1987 Banvel and 2,4-D were applied to the corn treatments on both the north and south plots. There was no oats treatment in 1987 (refer to Table 3-1). In 1988 Banvel was applied to both the oats and corn treatments, but at different rates. The oats treatment in 1988 received only MCPA and no 2,4-D. The concentrations for each of the replications of the three different sample dates is given by treatment and date for Banvel (Figure 3-20) and for 2,4-D (Figure 3-21). There were only two plots which had successive detections of the same pesticide for all three samplings. These were MP-Oats with three detections of 2,4-D (from 1-2 ppb) and NT-Corn with three detections of Banvel (from 1.36-0.8 ppb).

Banvel concentrations in the ground water were related to the amount applied at the soil surface, just as the nitrates were. There is a "most recent year" analysis (top graph of Figure 3-22) and a "last two years" analysis (bottom graph of Figure 3-22). The "most recent year" analysis uses a least squares fit of the Banvel concentration in the water collected 15' below ground surface to the amount applied (pints/Ac) in the year the samples were collected. The same analysis was used for the "last two years", where the concentrations were compared to the total amount applied in the last two years (pints/Ac). In both analyses the regression line was forced through zero since there should be no pesticide detected where none is applied. Considering the tremendously high variability of results in the ppb range for most pesticides, one would expect the Banvel results to behave like the 2,4-D results, where there is no clear trend or pattern (Figure 3-21) based on tillage or rate of application. However, the trend does indicate that Banvel is detected in the ground water in proportion to the rate that it is applied at the soil surface. Banvel is highly soluble (4500 ppm @25 degrees C) and weakly adsorbed to soil exchange sites, whereas, other pesticides in this

Pesticide Detections (Sep.1—29, 1988)

15' BELOW GROUND SURFACE

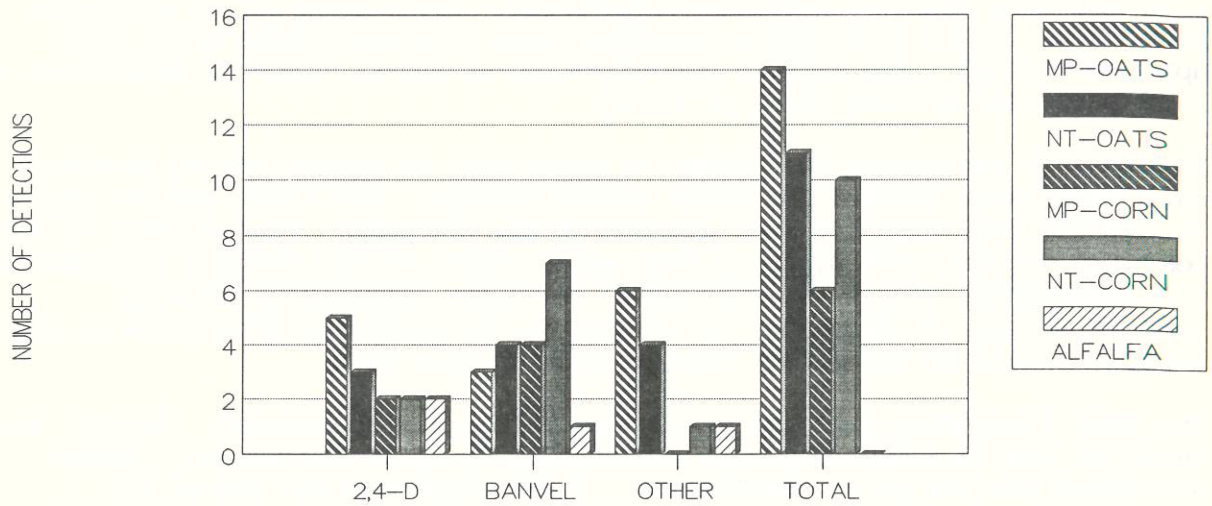


Figure 3-18

Pesticide Detections By Date

& Treatment — 15' Below Ground Surface

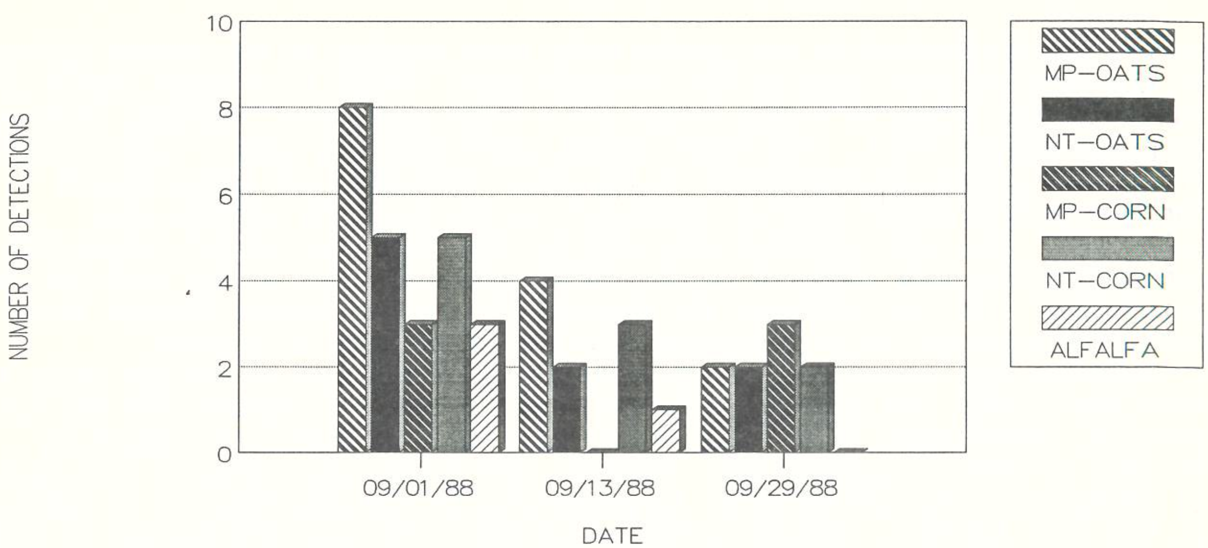


Figure 3-19

BANVEL DETECTED IN WATER

15' BELOW GROUND SURFACE 1988

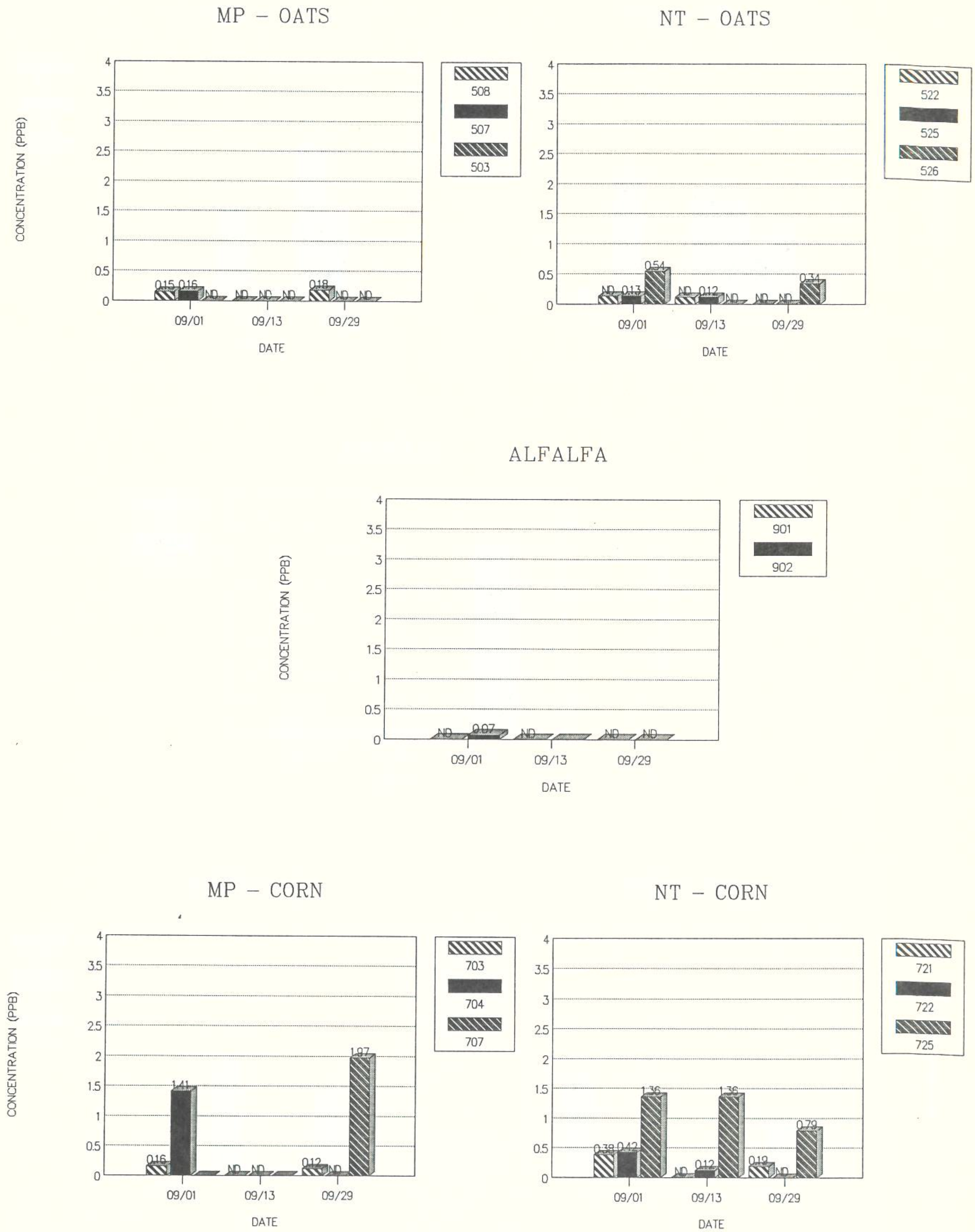
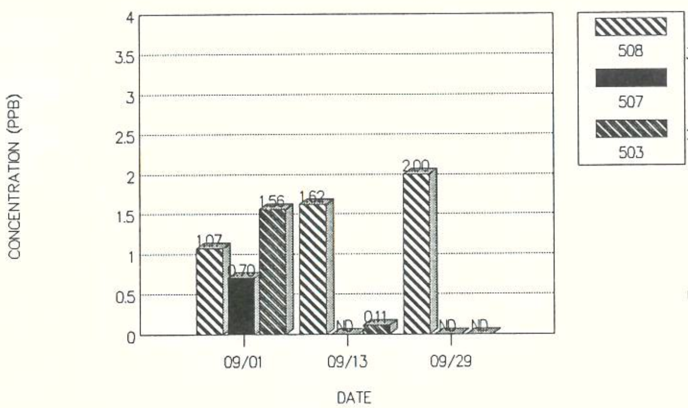


Figure 3-20

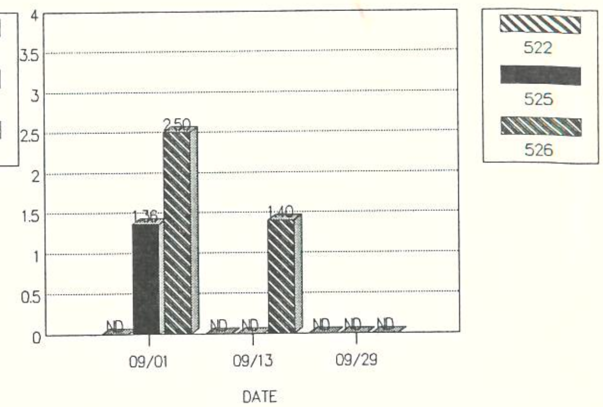
2,4-D DETECTED IN WATER

15' BELOW GROUND SURFACE 1988

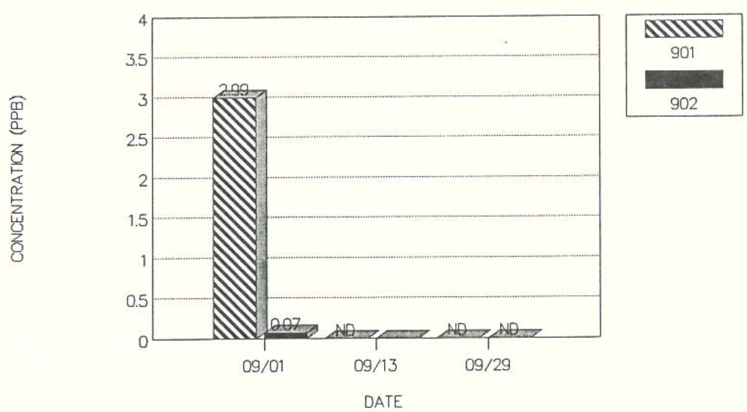
MP - OATS



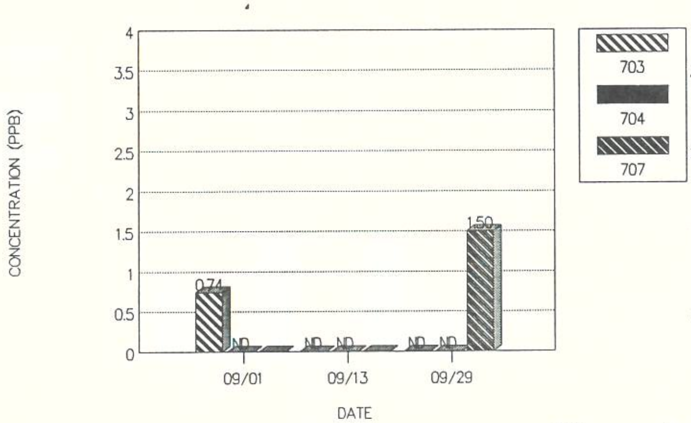
NT - OATS



ALFALFA



MP - CORN



NT - CORN

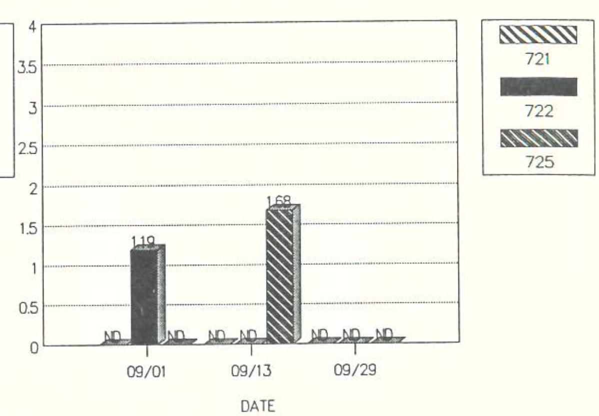
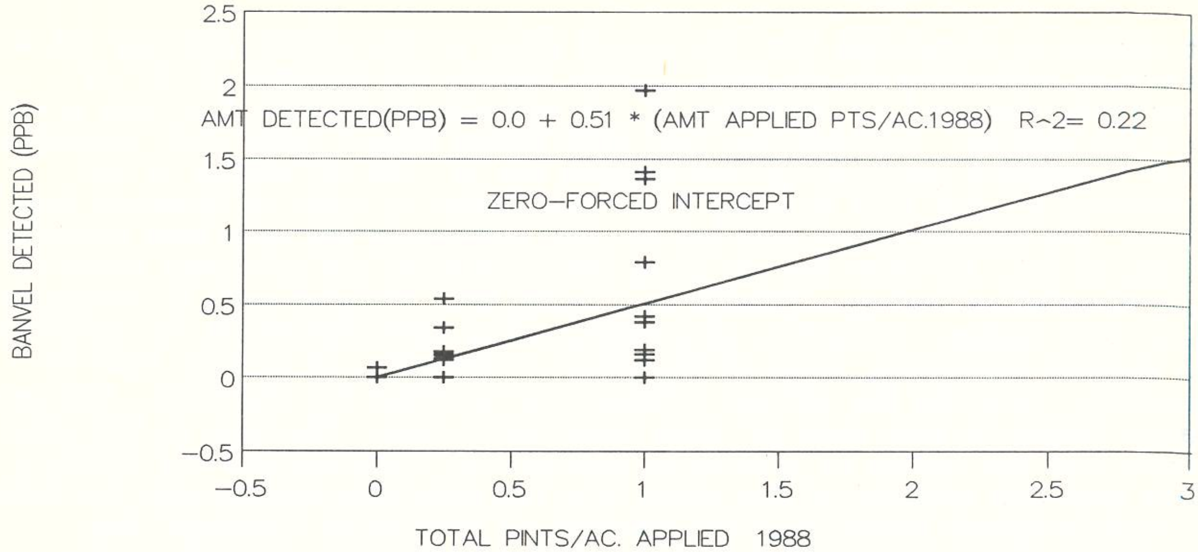


Figure 3-21

Banvel Applied Vs. Banvel Detected

Deep; 9/1/88–9/29/88; All Treatments



Banvel Applied Vs. Banvel Detected

Deep; 9/1/88–9/29/88; All Treatments

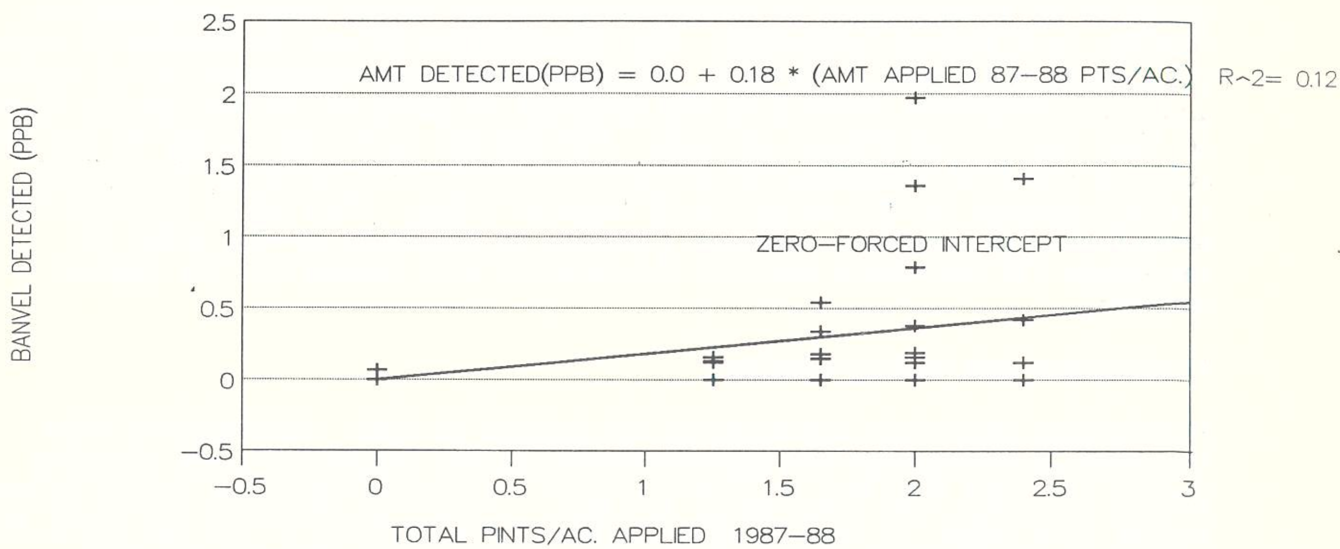


Figure 3-22

study are not nearly as water soluble. 2,4-D is the second most water soluble pesticide in this study at 600 ppm @ 25 degrees C. The coefficients of multiple determination ($R^2 = 0.22$) are very low, and, are not statistically significant, although a trend does exist. Preliminary Banvel data (first run lab results) extending beyond Sept. 30, 1988 (data not verified at this time) indicates that Banvel is still being detected in 32 (71%) of 45 samples submitted for analyses.

It should be recognized that the ground water at the master site may not be leaching vertically to any major aquifer due to the presence of 20' of weathered glacial till overlying 25' of unweathered glacial till over a water-bearing aquifer. Although the 1985 RCWP Annual Report (page 105) indicates that a downward gradient existed between the 12' and 20' depths in the weathered glacial till that may have contributed to 0.42" of downward flux of water, the circumstances that led to that conclusion may have been misleading. First of all, the area for the study was in alfalfa for two years prior to instrumentation set-up. Alfalfa is a heavy user of water with an extensive, deep root system. Secondly, immediately after instrumentation was installed to measure the energy level of the water in the soil, 6" of rain came in October. This was the wettest October ever recorded for the area. The water table jumped by more than 12' when these rains came. The drop in the water table over the winter of 1984-85 as measured by transiometers may actually have been the movement of the water from the macropore system into the dense micropore system rather than the movement of this water "through" the weathered till. In addition to this, the measurements were made in the more fractured, less dense weathered till above the unweathered till.

The water that appeared to have moved through the weathered till may actually have done so by sqeezing more air from the once-unsaturated zone as the elevation potential of the water above it increased. There is a decreasing flux rate of water through the glacial till material with depth.

The potential for movement of small concentrations of Banvel to ground water needs to be investigated on different geologies rather than extrapolating results to different geologies. The continuation of the monitoring of water quality at the master site will, however, enable the determination of tillage and crop management effects on the movement of chemicals to the ground water on this type of geological setting. The glacial till geology may be the ideal setting for this determination because of the minimal dilution from water already present in the formation of outwash sites. This would increase the sensitivity of chemical analysis (because of dilution) by one order of magnitude (3% drainable porosity for glacial till versus 30% for typical outwash).

Fluorescent Dye Tracer Studies

Fluorescent dyes were scheduled to be applied in 1988. Development time involved in the design and implementation of the automatic water sampling system extended into the fall of the year. Since the dyes are unique to the master site area, it is desirable to keep the area free of the dye until the system is operational to detect the dyes as they move through the soil profile. In the spring of 1989, a yellow fluorescent dye (Lissamine FF) will be applied soon after the crop is planted so that simulations can be made with the fertilizers and pesticides applied.

Figure 3-23 shows the background readings of the yellow fluorescent dye naturally occurring in the soil. As can be seen from the analyses, the readings (15-30 ppb) are very stable from sampling to sampling. Any movement of the dye through the soil to the sampling depths should be able to be detected.

3.1.7 Summary and preview of 1989 activities

Ultimately, how does conservation tillage affect subsurface water quality? With this <u>very</u> limited water quality data, there is no evidence to differentiate between NT and MP tillage treatments on the basis of concentrations of nitrates or pesticides found in ground water at this point in time. There does appear to be a positive relationship between Banvel and nitrates applied and Banvel and nitrates detected in the ground water.

The potential for leaching of water through a soil profile on the basis of what type crop is grown above it was demonstrated this year. Oats is known to use less water from the soil profile possessing a shallower root system and shorter maturity date than corn or alfalfa, and, consequently, would leave more water in the soil at the end of the growing season. When high intensity rain fell in August, water leached through the soil on the oats plots to the water table, but none appeared to reach the water table in the corn and alfalfa treatments. Even though no instruments were installed to monitor the soil water content in August, visual inspections verified that the water table increased on the oats and did not visibly wet the soil beyond 3 1/2' on the alfalfa and corn (we were laterally drilling in the soil at these depths to install the samplers). If a chemical or nitrate source was available for leaching on the oats treatment, it could have moved with the water that moved through in August. The question that needs answering is "When did Banvel and nitrates that was detected in the ground water, move through the soil profile"? Was it shortly after the chemicals were applied in May and June when a higher percent of water was in the soil profile, in August after heavy, high intensity rainfall fell on cracked, dry soil, in 1987, or combinations of all three?

1989 Activities

The soil water samplers installed in 1988 did not function and perform to "air entry" specifications, or the way that the one in the laboratory functioned. They were installed differently, however. The final conclusion on the problem is believed to be poor soil contact between the sampler and the soil itself (after eliminating several other possible sources). The problem is minimized when the soil profile is quite wet (<100 cm water tension), but the soil profile will not be this wet throughout the growing season. In an attempt to solve the problem, "silica flour" will either be coated on the surface of each sampler before insertion into the hole from which it is withdrawn, or pumped in as a slurry between the sampler and soil insitu, to provide a media between the sampler and the soil.

BACKGROUND FLUORESCENT YELLOW DYE

15' BELOW GROUND SURFACE 1988

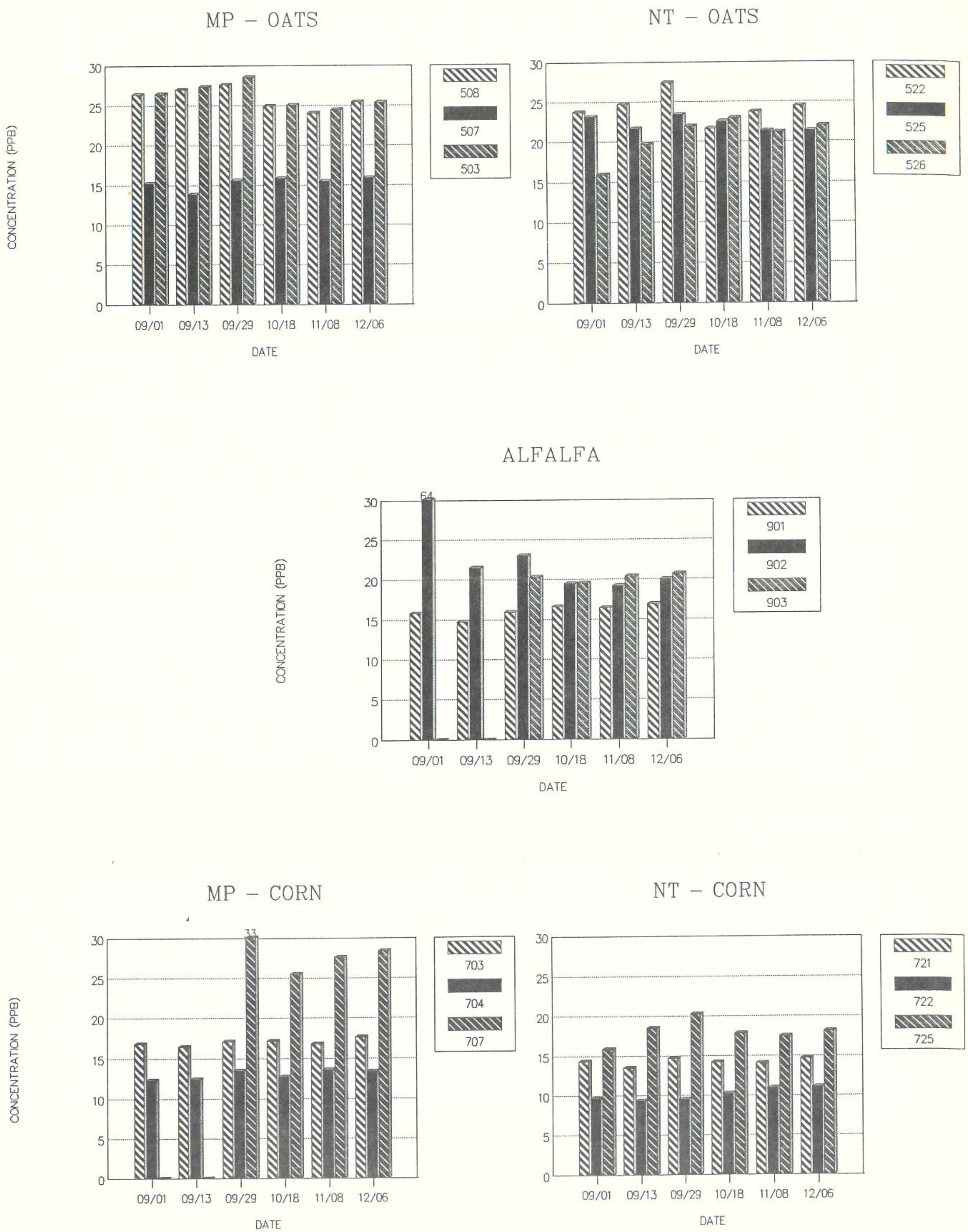


Figure 3-23.

Samples have been extracted (16) from the unsaturated soil from various depths and treatments, but a complete set from all depths for all treatments has not been collected as of April 30th, 1989.

The "transiometers" (electronic soil matric potential sensors) are functioning quite well. A recent rainfall event that occurred (April 26th, 1989) indicated that the response time for water to reach a particular depth was quite different between NT-Oats and MP-Oats (Figure 3-24 shows the response at 2' and 4'). Objective 3 of this study was to compare the response times of water reaching a given depth on the basis of tillage or crop. This latest data is very exciting in explaining that water penetrates to a given depth on NT much faster than for MP when the soil water content is fairly dry at the surface. The graphs show two rainfall events that take place within 3 days. The first event shows an exaggerated difference in the time that it takes for water to reach 2' on the NT versus MP whereas, the second rainfall event one day later (after the soil was wetter) did not demonstrate the same differences occurring. This could be attributed to the rainfall swelling the pores so that they are smaller, or more of the macropore is "full" during the second rain event, or probably a combination of both. There are three replications of each treatment at each of three different depths (2', 4', and 6'). At the six foot depth (Figure 3-25), three replications of the NT-Oats follows the same slope whereas, the MP-Oats is not responding as quickly to water movement through the soil above it. The lag time for the event happening at the surface and when a change in water content occurs at 4' and 6' is about one and a half days.

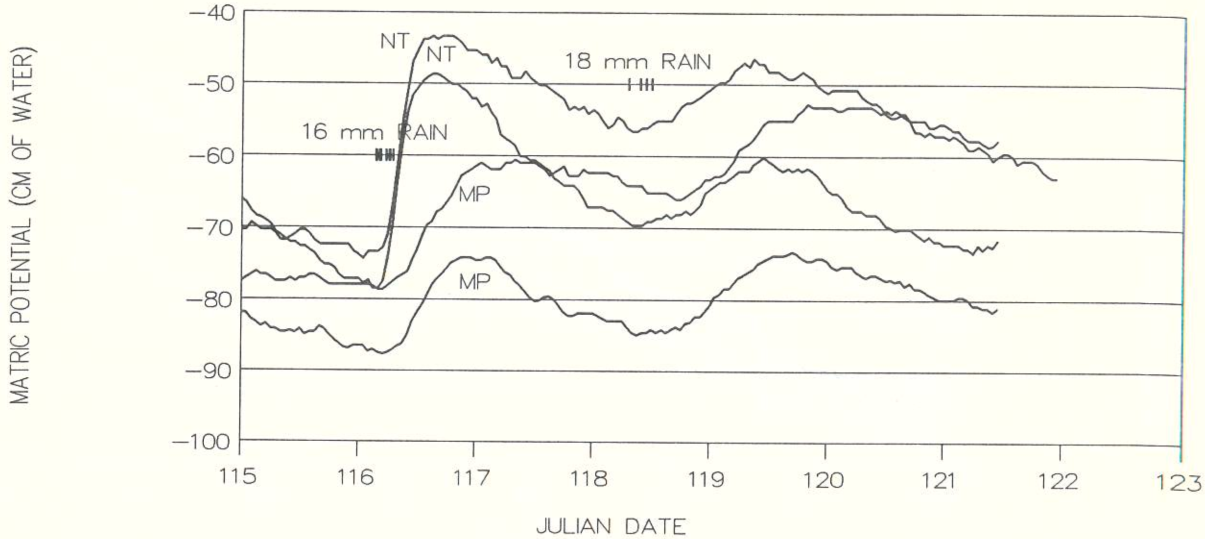
What does this difference in matric potential between the two tillage systems mean in terms of contaminant transport? It is clear that water has less contact time on the surfaces of soil particles for the NT treatment. If there are no highly soluble contaminants at the surface of the soil to be dissolved and carried with the water as it penetrates the NT treatment, the water quality is probably better than through the MP treatment. If however, a rainfall event occurs shortly after the application of nitrogen sources and chemicals, the rainfall that dissolves the contaminants would be carried to subsurface depths faster than on the MP treatment. This would, in turn, cause more probability for contaminant movement through the NT system. In order to manage or control this movement of chemicals with the water, some type of tillage would have to be implemented to incorporate, or mix, the chemical or fertilizer into the soil to "dilute" the substance.

The NT system seems to be much more dynamic in terms of water movement through the soil profile. The water quality curve over time may parallel the matric potential curves. At times, perhaps, the water that moves through from rainfall may be much better quality than the MP system. Other times, after the application of chemicals, the water quality may be much worse than the MP treatments. The MP system may have a more stable water quality moving through it over time.

Once the samplers are functioning properly, and all other monitoring components are operating correctly, the chemicals, fertilizers and dyes will be applied to set the stage for a leaching event. If the rain does not fall within seven days of application, water will begin to be applied with an irrigation system.

WATER PENTRATION BETWEEN TILLAGE SYSTEM

OATS – APRIL 1989 (2 FT.)



MASTER SITE 4 FT TRANSIOMETER DATA

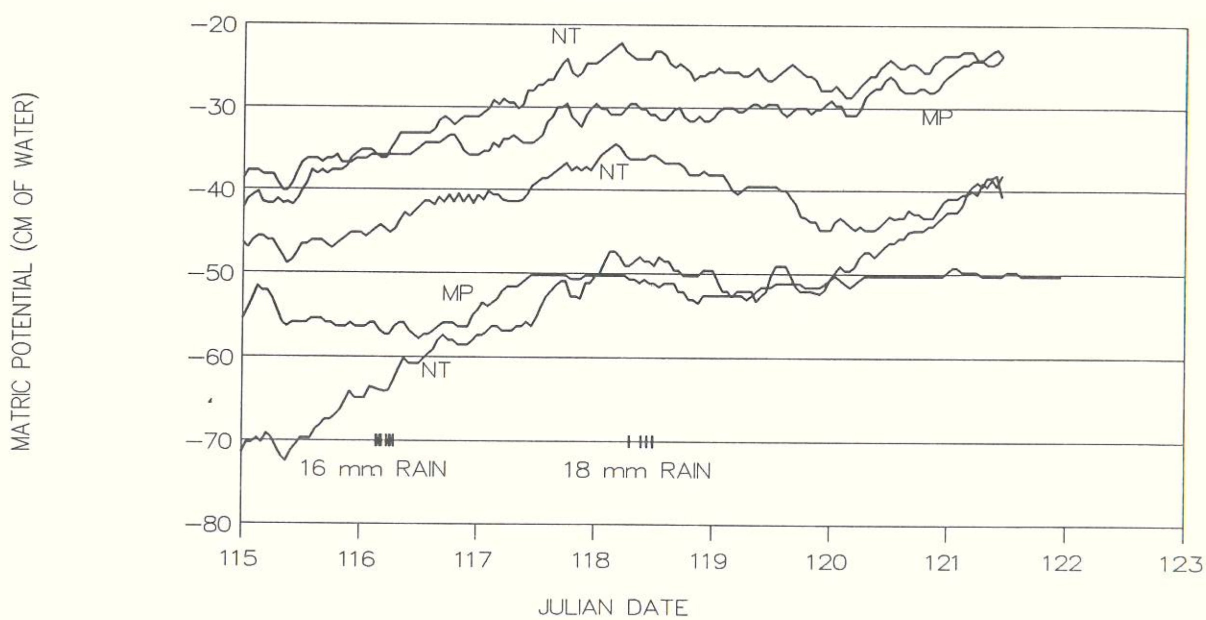


Figure 3-24

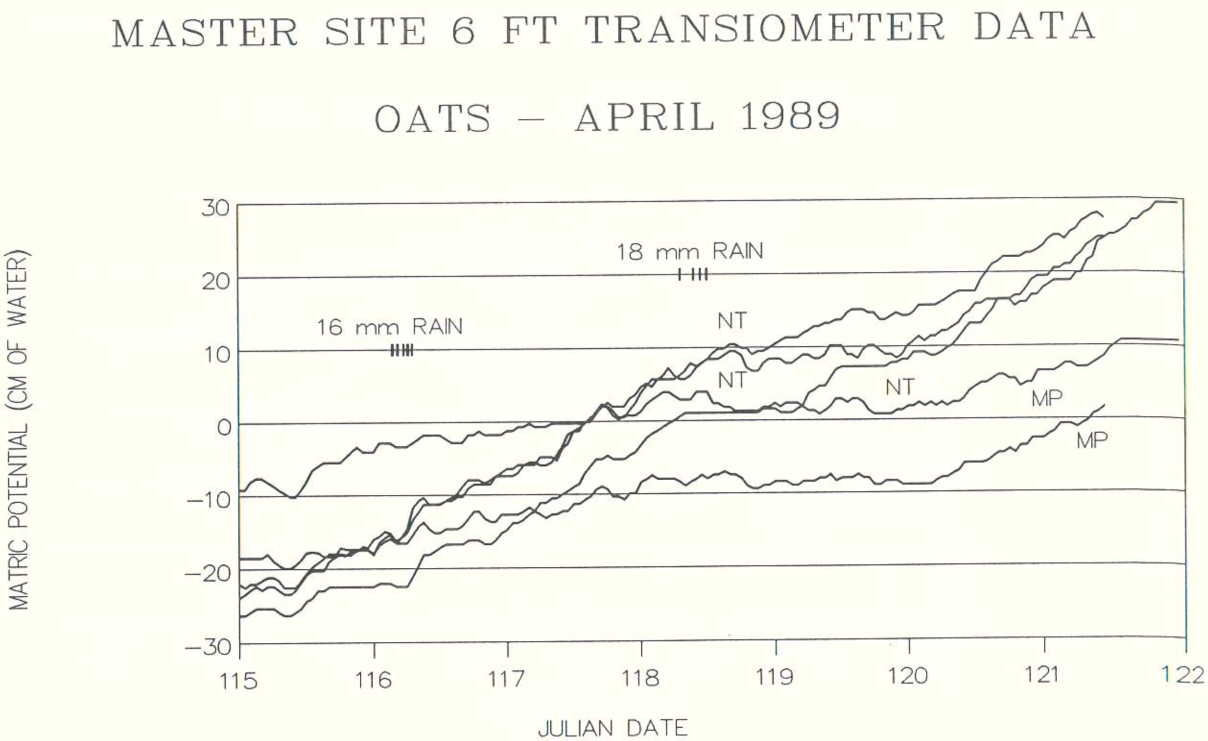

MASTER SITE 6 FT TRANSIOMETER DATA
OATS – APRIL 1989
MATRIC POTENTIAL (CM OF WATER)
18 mm RAIN
16 mm RAIN
NT
NT
NT
MP
MP
30
20
10
0
−10
−20
−30
115
116
117
118
119
120
121
122
JULIAN DATE

Figure 3-25

4.0 PROCESS MODELING

Authors Alan R. Bender and C.G. Carlson

Process modeling has been an important part of this project and will become even more important as the focus of analysis changes from interpreting the monitoring data for significant differences and describing correlation to the description of cause and effect. The AGNPS Model has been reported in previous RCWP-CM&E reports. The results of the resource allocation model performed on the Oakwood Lakes-Poinsett Study area were published in a paper that was presented at the North American Lakes Management Conference in St. Louis. This study identified optimum fertilizer management as a very effective tool for controlling nutrient loading of the lake. Indications were that adjustments would have to be made in fertilizer applications to account for the savings that an optimum strategy would provide, otherwise more nitrates would be available for leaching. Some questions were raised about the changes in runoff estimates that should occur when conservation tillage is applied on the land. New runs are being made to adjust the model for this and a revised report will be published later in the year. The model study also identified Conservation Reserve as a very effective BMP for water quality improvement, although the costs were very high.

Field verification of the model on the Oakwood Lakes System could not be performed during 1988. No runoff except a limited snow melt runoff event has been recorded since the monitoring instrumentation has been installed. A decision has been made to monitor in 1989 because continued monitoring of the OLSS is expected. This may provide an opportunity for the model verification to take place.

Very little has been done in modeling of flow processes in the vadose zone since the inadequacies of the NTRM and all other process models for handling both matix as well as macropore flow was identified last year. Monitoring data from the master site can be fit to models based upon Richard's equation during recharge events, but the model parameters are unstable over a large moisture content conditions. The preliminary data presented from the ACLS master site (Figure 4-1) demonstrates that the experimental system can capture the rapid flow of water through the soil profile and capture differences between tillage treatments. Analysis of water quality data collected during this event will help explain water quality impacts; the positive or negative of these different flow regime is conjectural until measured. This preliminary data demonstrates what is possible with the ACLS measurement instrumentation; exploitation of the system to collect appropriate date will give insight into fate and transport questions.

Additional work needs to be done here and several research projects at SDSU and on other campuses are addressing this very important problem. Testing of theoretical developments in this area is not likely to be available for a while yet, although a great deal of interest has been shown by ARS and CSRS researchers. The inability to use existing models to simulate continuous processes of infiltration and transport of water through the root and unsaturated zones to the ground water has stimulated a reevaluation of options available for system analysis. The model inadequacies do not completely eliminate the model for evaluation but it must be applied judiciously to situations where monitoring data is sufficient to get good fit.

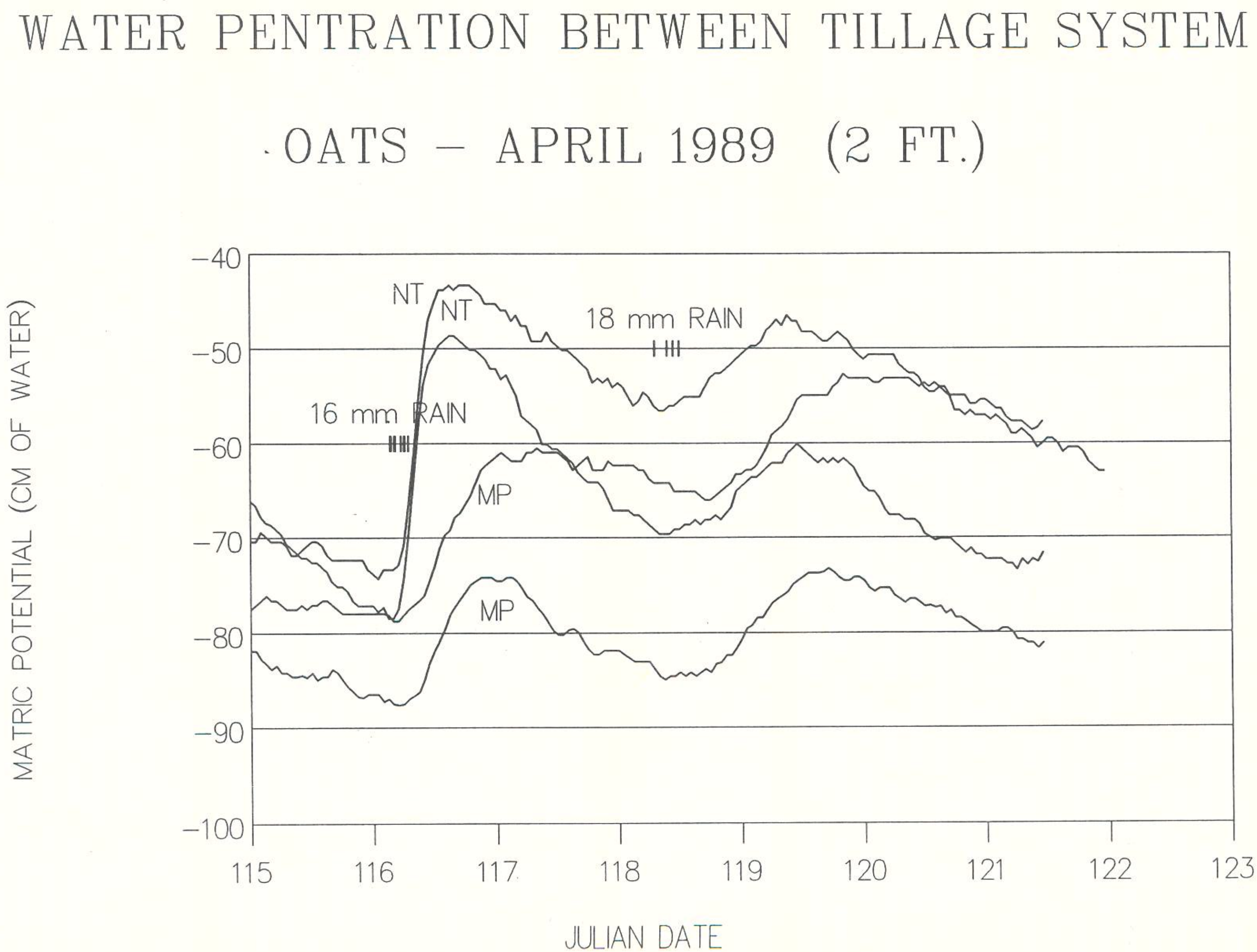


Figure 4-1. Soil moisture potential comparison between no-till and moldboard plow tillage.

Targeting of resources is one justification of modeling such as AGNPS. AGNPS, as used on the project, was used to estimate runoff and surface water transport of nutrients. Based on the knowledge gained by project experience, the knowledge that both runoff and leaching must be considered in designing appropriate resource management strategies. The hydrologic system in a glacial topography and semi-arid climate has a great deal of storage, and delivery of contaminants to lakes and streams is sporadic. Thus knowledge of the recharge potential of a landscape is a very important factor to consider. Evaluation of the effects of BMP on ground water will need to consider the vulnerability of the aquifer, ie. the recharge potential of a landscape to the aquifer, the paths by which the water mobile contaminants reach the recharge sites, and the water and mass contaminant loading at a recharge site.

Maps have been constructed of the depth to aquifer and the runoff potential as estimated by RKLS factors in the universal soil loss equation. Examples of the maps for the RCWP area are presented in Figures 4-2 and 4-3. These maps are based on existing data and will need some verification to determine the reliability of estimates made from the isopleths. Identifying the recharge sites in the landscapes and estimating the water balance at these sites will be the next task. This data can then be linked with the chemical applications and the transport of the chemicals to the recharge sites where water either moves to the aquifer or to a stream or lake. The kinds of analysis suggested here are the kinds performed by Geographical Information Systems. Tools to integrate data from several different sources are needed to perform these analyses in an effective and timely manner for prescription of land treatment practices to meet water quality objectives.

In terms of evaluation of the RCWP project implementation, new procedures which are developed can be used to evaluate the fertilizer and pesticide management decisions made on preproject knowledge versus the understanding that now exists. It may turn out that applying BMP to keep the precipitation where it falls is the best strategy, but several other options present themselves when the water quantity needed for crop growth, rural water system wells, and water fowl production areas is not adequate to provide for all the uses. Modeling products will provide quantitative estimates of runoff and leaching and the the contaminant concentrations thereof to be used in system analysis protocols.

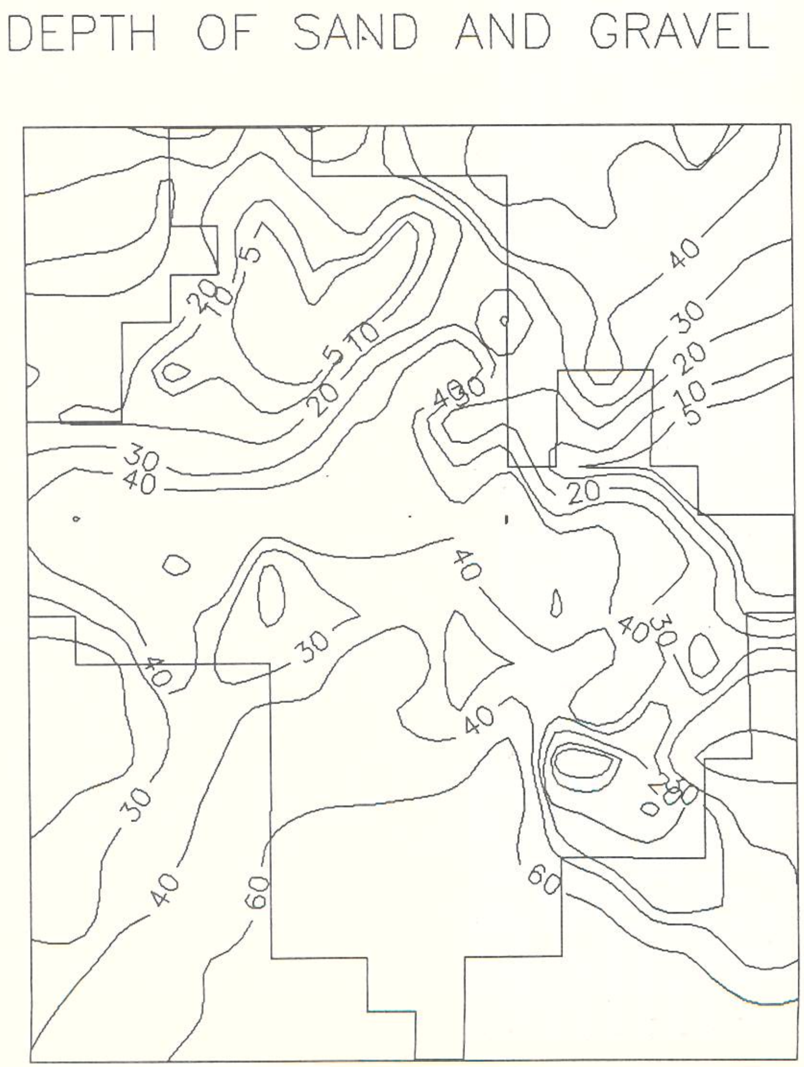


Figure 4-2. Depth to aquifer map of Oakwood Lakes-Poinsett study area.

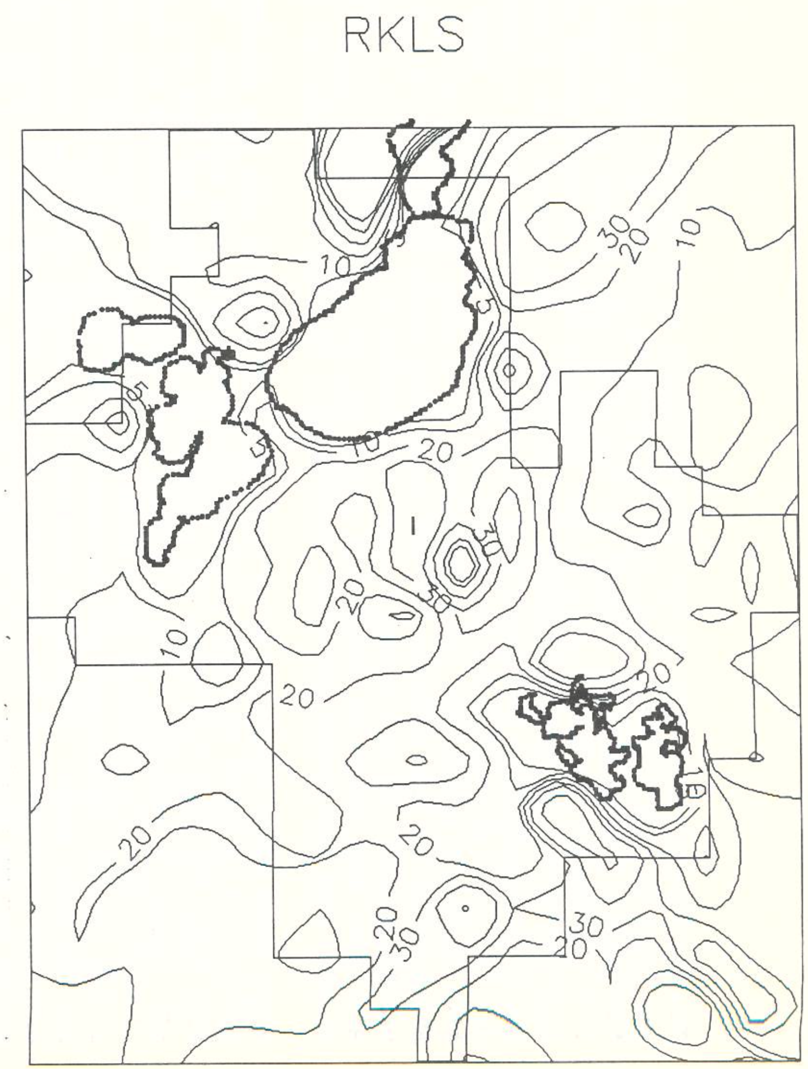


Figure 4-3. Runoff potential (RKLS) map of Oakwood Lakes-Poinsett study area.

5.0 ANALYSIS AND EVALUATION OF THE OAKWOOD LAKES SYSTEM

5.1 Introduction

The Oakwood Lakes System Study (OLSS) began as an expansion of the Comprehensive Monitoring and Evaluation (CM&E) project. The CM&E was initiated to study the water quality impacts of the Oakwood Lakes-Poinsett Rural Clean Water Program (RCWP). The goal of the OLSS project is to determine if the application of BMPs in agricultural watersheds will affect water quality in shallow, hypereutrophic prairie lakes. In order to meet this goal it was necessary to collect data on the current trophic state of the lake system, the flux of water and nutrients through the system and various chemical, biological and physical interactions that affect in-lake water quality. Development of annual material budgets for the Oakwood Lakes system and monitoring of in-lake water quality, algae, zooplankton and fish populations was implemented to meet this goal.

Organization of this section follows the divisions of the original OLSS project proposal. Data is presented separately for each area of investigation as they relate to major objectives. This report represents the current state of data analysis for each area. Comprehensive analysis and modeling to describe the system as a whole is scheduled for 1989 with a comprehensive report in December 1989.

5.1.1 OLSS Monitoring Strategy

Monitoring before and after BMP implementation to determine water quality effects was inappropriate for OLSS since monitoring was scheduled for only two years and RCWP installation of BMPs preceded the OLSS by several years. A strategy was developed which incorporated monitoring of water quality and quantity, biological surveys, land use modeling and, lake modeling to evaluate BMP impacts. The strategy relies upon the development of nutrient, sediment and hydrologic budgets for the Oakwood lakes system. These budgets were to be compared with reductions in loadings estimated by watershed models following verification of the AGNPS model. Evaluation of factors that predict in lake water quality and the use of input-output lake models to estimate the potential for BMPs to improve trophic state completes the strategy. This strategy requires an integrated monitoring design with several parts that contribute data on different parts of the system. Monitoring designs are included in the appropriate sections.

5.1.2 Study Area

The Oakwood Lakes are a complex of 5 small, interconnected, shallow, hypereutrophic lakes in eastern South Dakota. The lakes have a mean depth of 2 meters, a maximum depth of approximately 3 meters, a combined surface area of 971 ha and a total watershed area of 12,793 ha. The lakes are fed by several intermittent streams which drain a predominantly agricultural watershed which is estimated to be 50 % cropland. The lake system has a single outflow from East Oakwood to the Big Sioux River through Mill Creek (SDDWNR 1985).

Non-bedrock aquifers in eastern South Dakota consist of glacial outwash deposits resulting from the Pleistocene Epoch glaciation. Within the project area surficial deposits are of the Wisconsin stage of glaciation, specifically the Cary and Iowan substage till, loess, and outwash. The outwash of greatest thickness is the Cary outwash. Morphology of the outwash is that of a valley train outwash which forms along the margin of a glacier as it melts and recedes. This results in long, relatively thin sinuous deposits of sand and gravel of variable thickness and aerial extent. There are three outwash aquifer systems in the area, referred to as the surficial, intermediate and basal aquifers. Connections between these aquifers occur but are not reliably known. The Big Sioux aquifer is the surficial aquifer associated with the Big Sioux River and it's tributaries and is of greatest importance in the project area. The Oakwood Lakes-Poinsett project is not directly concerned with the other two aquifers of greater depth.

5.2 Material Budgeting and Water Quality

Author: David R. German.
Coauthors: Mary B. Price and C. Greg Kimball

5.2.1 Introduction

In order to assess the effects of BMP implementation on in-lake water quality it is necessary to document the current trophic state of the lake and account for external nutrient and sediment loadings from surface water, ground water and atmospheric sources. These material budgets can be used in conjunction with physical characteristics of a lake (surface area and volume), to develop a mass balance equation which can be expressed as:

(accumulation) = (inputs) - (outputs) + (reactions in the lake + or -)

Residence times can also be calculated. These can indicate the potential for changes in the lake's trophic state, the degree to which the lake is acting as a nutrient sink (or possible source) and the potential for improving water quality through BMP implementation. And the time that may be required to pass before changes are measurable.

5.2.2 Monitoring Design

The monitoring design includes components for surface water, ground water, and atmospheric deposition. Each of these components has a unique monitoring methodology.

5.2.2.1 Surface Water

Instrumentation for surface water movement through the Oakwood Lakes system consisted of 13 stage recorders (Leupold and Stevens model F) and stilling wells located at ten sites; six at tributaries entering the lake system (T-1 through T-6), three at sites between the lake basins (IL-1 through IL-3) and one (T-0) at the lake outlet (Figure 5-1). Converting the continuous record of stage into discharge volume for each station involved several steps. First in-field measurements of flow velocity were measured with a portable flow meter (Montedoro Whitney model PVM-2A) and combined with channel (or culvert) area to determine discharge for discreet points on the stage record. The result was an empirical stage to discharge relationship. The empirical stage to discharge relationship is simply a listing of stage heights and their corresponding discharges for various dates and times. To adequately describe the relationship they should represent the full range of stage heights observed for each tributary. These pairs of stage and discharge values are then described by a discharge equation which allows the calculation of discharge for any stage, whether measured manually or with the stage recorder. OLSS stage recorders produced an analog record of stage which was digitized into two hour segments. The discharge equations were used to convert the digital stage record to a digital record of discharges. In the final step stream discharge is combined with water quality data to determine material loadings for various periods of time the stream was flowing.

At sites with a stable control (where discharge is only a function of channel shape or culvert size) a logarithmic equation was developed to describe each empirical stage to discharge relationship. The equations that best described the curve as a whole did not always give accurate results near zero flow. They often produced slightly negative discharges. When this occurred a table of discharge versus stage heights was constructed with points from the low end of the empirical stage to discharge plot. This table or the appropriate equation (depending on the stage) was then used within a spreadsheet program to select appropriate discharge values for each stage reading.

At three sites between the lake basins (IL-1,2,3) (Figure 5-1) water passes through corrugated steel pipe-arch culverts which were partially submerged by the lakes at either end. This situation requires the development of a complex equation to account for the effects of backwater on the down stream end of the culverts. The manning formula can be used when the culvert is flowing partially full. The formula relates the average flow velocity V, the channel slope S, the channel roughness n and the hydraulic Rh of the channel cross section (Olson 1967).

$$V = (1.49/n)\ Rh^{2/3}\ S^{1/2}$$

and since discharge = velocity * area or $Q = VA$

$$Q = 1.49/n\ Rh^{2/3}\ S^{1/2}\ A$$

With the exception of the roughness coefficient (n), the information required to calculate discharge with the formula can be determined from stage records. Channel slope S is represented by slope of the water surface in partially submerged culverts. Wetted cross sectional area and hydraulic radius were derived from stage height record and a survey of the culvert.

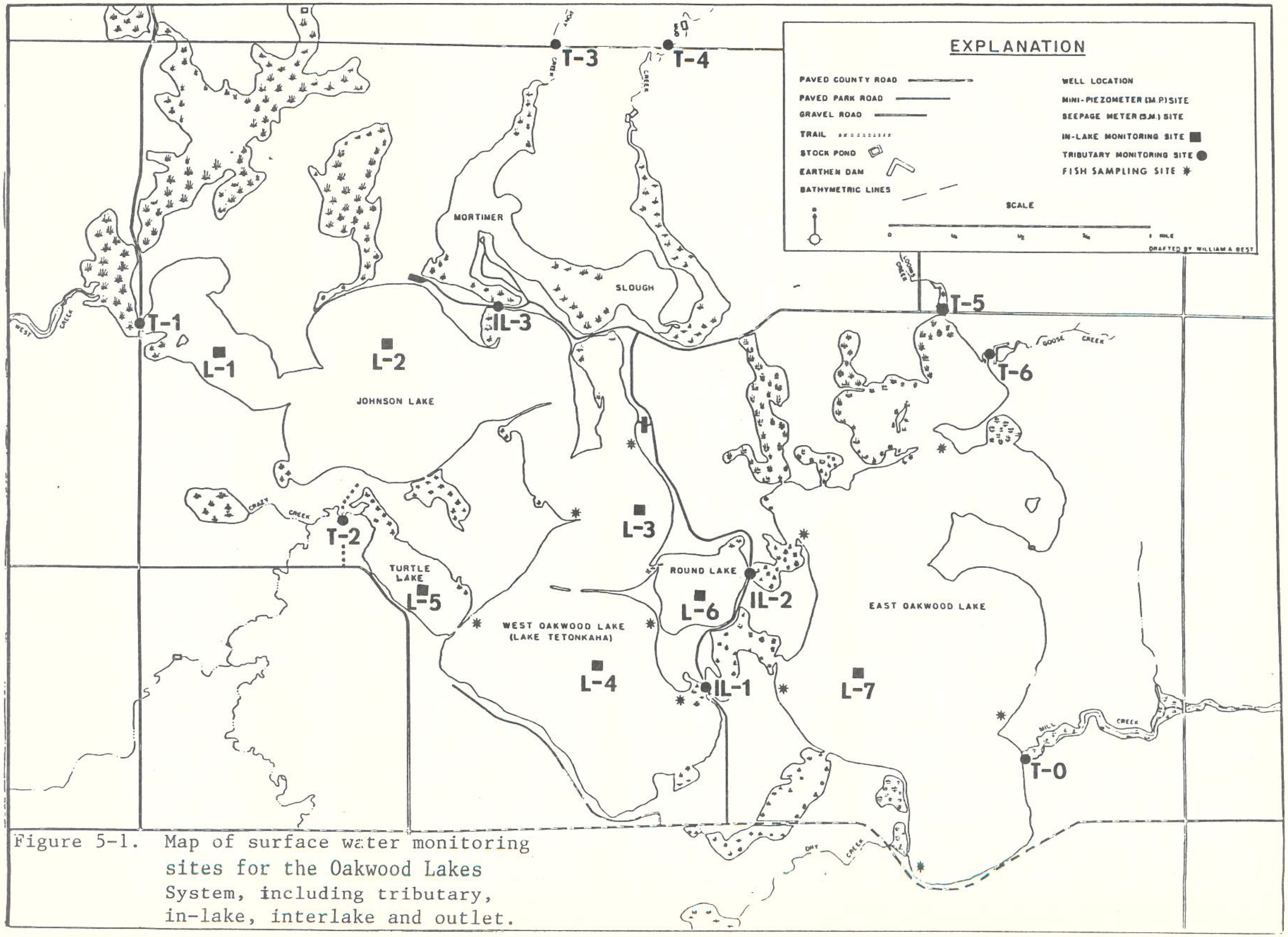


Figure 5-1. Map of surface water monitoring sites for the Oakwood Lakes System, including tributary, in-lake, interlake and outlet.

Solving the formula for n, using known values for Q, indicated that n was not a constant but varied depending on depth of water in the culvert. Although the culverts were all constructed of corrugated steel each had mud, sand and gravel or small stones lining the bottom. These factors caused n to vary depending on the amount of wetted perimeter affected. Regression analysis was used to develop an empirical relationship between n and other factors in the manning formula. Manning's n in most culverts was found to have an inverse relationship with A or $Rh^{2/3}$. To calculate discharge, at the interlake sites, n was predicted for each point on the digital stage record and used in the manning equation with the other parameters determined from the stage record.

To determine the hydraulic, nutrient and suspended sediment loading for each tributary the digital discharge record was divided into time intervals determined by the date and time when a sample had been taken. The water quality sample was located at the midpoint of the time interval. This method is patterned after the "trapezoidal rule" proposed by Huber, et.al.(1979) for the calculation of event mean concentrations. The material load (kg of each constituent) was calculated by multiplying the volume of water (liters) by the sample concentration (ppm), for each interval and summing over the period of interest (kg/year, kg/month, etc.).

Frequency of sample collection varied and was determined by hydrologic activity. During periods of base flow collection was weekly for all inlet tributaries and three times a week for the interlake sites and the outlet. During periods of active snowmelt all sites were sampled once to twice daily. All samples collected during snowmelt and base flow were grab samples. Flow actuated automatic samplers (ISCO) were kept in a state of readiness throughout the ice free seasons in 1988 at all tributaries to collect rain induced runoff although none occurred.

All samples were collected in polyethylene bottles and transported from the field on ice, in a cooler and refrigerated upon arrival at the laboratory. Analysis of most parameters was conducted within 24 hours of collection following EPA approved methods. Parameters analyzed on tributary and interlake samples were:

1. total phosphorus
2. ortho phosphorus (soluble reactive P)
3. nitrate
4. nitrite
5. ammonia
6. total kjeldahl nitrogen
7. suspended solids

In lake monitoring was designed to determine current trophic state. Monitoring of zooplankton and fish populations, nutrient parameters and weather produced data for use in a regression analysis to determine factors that best explain variability in dependent variables such as chlorophyll a, total phosphorus, algal biomass and Secchi disc transparency. This empirical lake model will be used to determine the role of nutrients and other factors in controlling in-lake water quality.

In-lake water quality samples were collected at seven sites (Figure 5-1). Samples were collected with a project designed, integrated sampler rather then a point source sampler such as a Van Dorn sampler. The sampler collected a column of water from the lake surface to within one foot of the bottom. The sample was poured into a clean plastic bucket to ensure complete mixing of the water column from which subsamples for water quality and biological analysis were taken. For reasons of statistical analysis a second (independent) cast of the integrated sampler and a second set of subsamples were taken at each location. Secchi disc depths were determined at all sampling locations using a standard black/white 25 cm Secchi disc suspended on a 0.01 foot interval calibrated line. In-situ measurements of dissolved oxygen (DO) and temperature were taken using a dissolved oxygen probe calibrated by the Winkler DO method. Measurements were taken six inches below the water surface and six inches above the lake bottom. If a difference greater than 1 ppm of DO existed between the surface and the bottom a vertical DO/temperature profile was conducted at 3 ft. intervals or less.

Samples were placed in 1 liter polyethylene bottles, kept in a cooler until delivery to the laboratory and refrigerated thereafter. Chemical analysis of unstable parameters was conducted within 24 hours of collection. Chlorophyll analysis was begun immediately upon arrival in the laboratory. In-lake water quality samples were collected every two weeks from May through October and monthly from November through April. The following parameters were analyzed:

1. total phosphorus
2. ortho phosphorus (soluble reactive)
3. nitrate
4. nitrite
5. ammonia
6. total Kjeldahl nitrogen
7. pH
8. chlorophyll "a"
9. algal density (cell counts)
10. suspended solids
11. alkalinity
12. total solids

5.2.2.2 Atmospheric Deposition

Material inputs from atmospheric sources were measured with two Belfort recording rain gauges installed near the lake basins. Combined wetfall and dryfall samples were collected following rainfall events to measure bulk deposition and rainwater. Supplemental rain data was collected by volunteer observers who recorded daily rainfall at 3 sites. Atmospheric samples were analyzed for the following parameters:

1. total phosphorus
2. nitrate
3. nitrite
4. ammonia
5. total Kjeldahl nitrogen
6. pH
7. total dissolved solids

5.2.2.3 Ground Water

Instrumentation for ground water inputs consisted of 29 terrestrial wells (as opposed to in-lake wells to be discussed later) installed in November 1987. The wells were installed through an 8 inch inside diameter hollow stem auger. Two and a half foot split spoon samples at 5 ft intervals were taken and logging was done by a geologist during drilling to determine the geology. Wells were installed at a depth of approximately 5 to 10 ft below the water table when the water bearing strata was sand and gravel. At many well locations (Figure 5-2) more than one well was installed (referred to as a well nest). The second well, or in some cases the second and third well, at a well nest is installed at a different depth then the first, to allow the calculation of vertical gradients, and the sampling of water quality at different depths. The wells were constructed of 2" diameter polyvinyl chloride (PVC) pipe coupled (not glued) to 0.018 inch manufactured well screen. Sand and gravel was allowed to cave in around the well screen during withdrawal of the auger to form a natural gravel pack. When caving did not occur pea gravel was installed as a gravel pack. If the borehole penetrated a confining layer then 2 to 3 ft of bentonite was placed in this interval during auger withdrawal to create a seal between the well screen and upper saturated layers. A 3 ft bentonite seal was always placed in the last three feet of hole around the well.

Wells were sampled every two months and water levels were recorded weekly throughout 1988. Sampling techniques were the same as those used for the field site ground water investigation (see section 2.0). The parameters analyzed on ground water samples were:

1. total dissolved phosphorus
2. ortho phosphorus (soluble reactive)
3. nitrate
4. nitrite
5. ammonia
6. total Kjeldahl nitrogen
7. total dissolved solids
8. chloride
9. sulfate

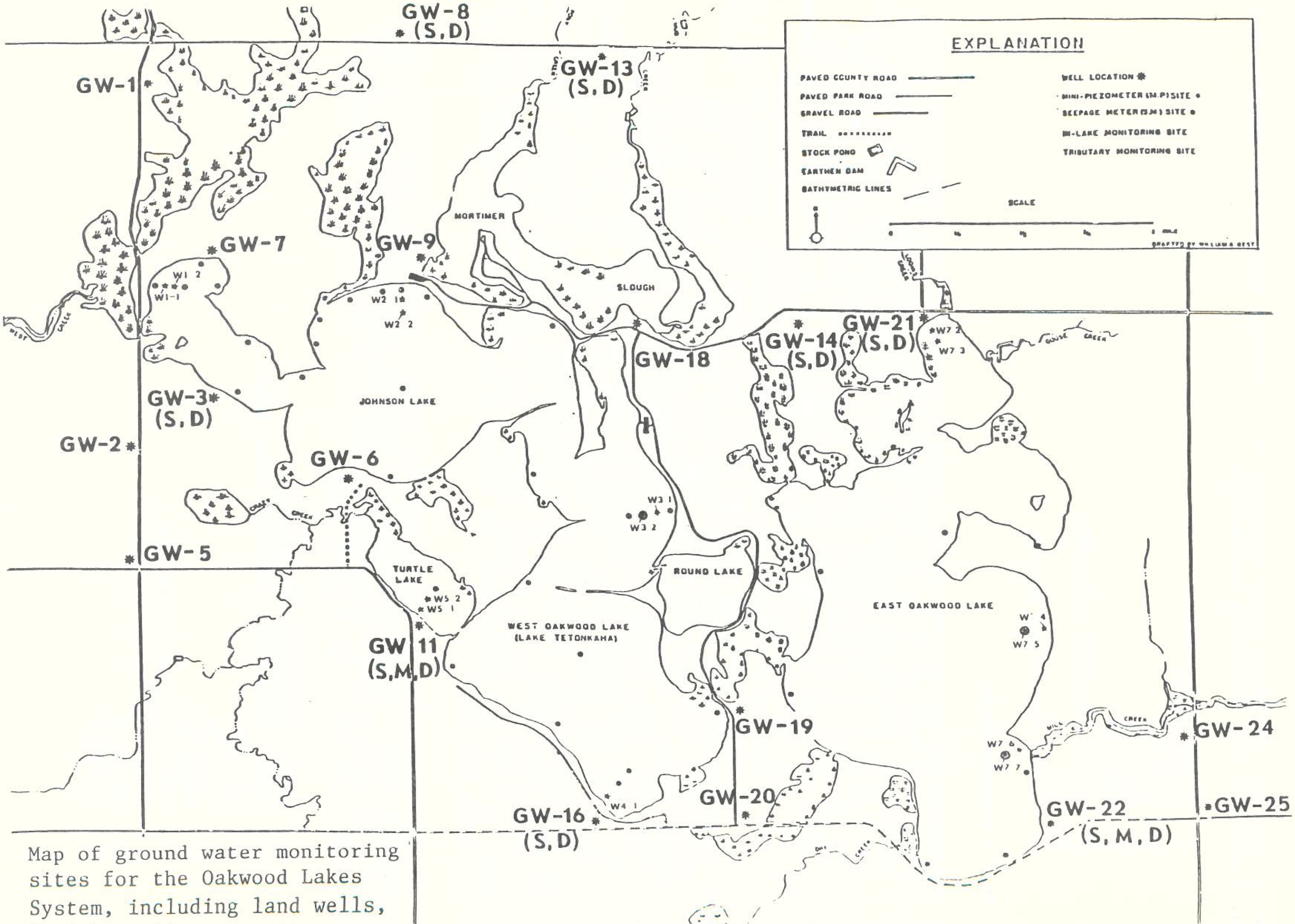


Figure 5-2. Map of ground water monitoring sites for the Oakwood Lakes System, including land wells, in-lake wells, seepage meters and sediment core sites.

Seepage meters installed in 1987 were not operated during the winter following ice over in November 1987. Of the 38 seepage meters installed in 1987 11 had been lost or damaged and had to be repaired or replaced. All meters were checked for leaks and resealed with bentonite. Fourteen new seepage meters were added in 1988 for more complete coverage of the lake basins (Figure 5-2). Of those four were removed or destroyed by the public.

Seepage meters were constructed by cutting the top, or bottom, portion off of a 55 gallon drum and attaching a hospital IV bag to it. Seepage meters were placed on the lake bottom, driven into the sediments and then sealed around the edge with bentonite. In areas subject to wave action truck tire tubes were used to protect the bentonite from the wave action. In areas with soft deep mud whole barrels were converted into seepage meters to allow contact with firm sediment before the meter was completely covered by mud. Bags partially filled with water were attached to seepage meters. If ground water is moving into the lake then the bag gains water, if ground water is moving out of the lake then the bag loses water. Seepage meters allow the direct determination of the volume of ground water moving into and/or out of a lake by periodically removing the old bag, measuring the volume of water and attaching a new bag. Under certain conditions ground water chemistry can be analyzed with samples from seepage meters.

In lake wells were placed into the lake bottom in 1987 to allow ground water level readings beneath the lake. The OLSS in-lake wells were constructed of one inch diameter polyvinyl chloride pipe with 6 inches of slots at the bottom, wrapped with fiberglass cloth (epoxied in place), for a screen. Installation was accomplished by pounding a steel tube, with a drive point on the end, into the lake bottom, to the desired depth. The in-lake well was inserted into the tube and the tube was withdrawn, leaving the in-lake wells and drive point in place. Bentonite and a collar were placed around the base of the well, at the lake bottom, to seal the well, to give the well strength and to help keep the bentonite in place. The collar was weighted to the bottom with large cobble size rocks.

Only one in-lake well (of 21 installed in 1987) was broken during ice break up in 1988 however all were partially lifted by the ice. This condition caused the wells to list because the support base was held off the bottom by the well making water level readings impossible. Wells in soft sediment could be driven deeper and resealed with bentonite to allow them to again be supported in an upright position. Wells in harder sediments had to have a collar removed that had been cemented in place before installation to allow the support base to rest on the bottom again. The collar was designed to prevent the well from pulling through the support base but it did not allow for adjustment. After the collar was replaced, with an adjustable model, the wells were resealed with bentonite. This maintenance required work underwater and prevented the early use of the in-lake wells in 1988.

Seepage meters were installed adjacent to each in-lake well and at several transects beginning near shore and extending out into the lake. Frequency of seepage meter readings was determined by seepage rate. Seepage bags were checked within 1 to 24 hours of being attached so that pressure due to a full seepage bag did not inhibit seepage. No readings were taken during the winter on seepage meters or in lake wells. In lake wells were sampled with a peristaltic pump. Water quality analysis was conducted on seepage meter samples and samples obtained from in lake wells. Parameters analyzed were the same as for terrestrial wells.

Groundwater Data Analysis Design

The goal of analysis and evaluation of ground water data was to determine the quantity and quality of ground water entering and exiting the Oakwood Lakes system. Seepage rates to lake beds can be estimated without using seepage meters. By knowing the hydraulic conductivity and effective porosity of the aquifer and lake bottom, and the gradient between ground water and lake level, a velocity for the ground water can be calculated. The equation for the average linear ground water velocity (Freeze and Cherry 1985) is:

$$A.L.V. = K * I / n$$

A.L.V. = average linear velocity
K = hydraulic conductivity
I = gradient
n = effective porosity

Flow velocity multiplied by the area yields a quantity of water.

$$Q = A * (K * I / n)$$

It is difficult to determine the effective porosity, (usually estimated from references based on particle distribution of the material), especially on the lake bottom. Hydraulic conductivity of the aquifer can be determined by pump tests or single well slug or bail down procedures. In-lake monitoring wells may allow similar tests. The key hydraulic conductivity needed for accurate quantity calculations is the limiting hydraulic conductivity. This is probably located within the strata that comprises the lake bottom sediments. The hydraulic conductivity of the in-lake well may not be located in this limiting layer.

With the use of seepage meters direct measurements of seepage rates are possible. Seepage rates are combined with chemical concentrations to calculate the total ground water loading to the lake. In it's simplest form the following steps are followed:

1.) Seepage rates are calculated at every available measuring point.

2.) Areas of lake bottom with similar seepage rates for selected time intervals are delineated. The area is multiplied by the seepage rate and the time interval to obtain a volume.

3.) Each volume is multiplied by a concentration determined by available water quality data from in-lake or land wells to obtain a loading for each area.

4.) The loadings are summed to obtain a total loading for the entire lake bottom for the selected time interval.

Seepage rates can be obtained from direct measurement or by establishing a predictive relationship with wells and hydraulic properties of the aquifer and lake bottom. Establishing a predictive relationship is not only desirable as a way of determining seepage when the seepage meter is no longer present but also because measurements at seepage meters are difficult when the lake is frozen. Once the relationship is derived, seepage can be calculated from the gradient between wells and lake elevation because effective porosity and hydraulic conductivity become a constant and are combined into one term.

Following a completion of well elevation surveys in 1989, ground water flow maps around the Oakwood Lakes will be compiled based on water elevations in land wells and lake well elevations. Equipotential maps (vertical expressions of ground water flow contours) will be drawn through the land well and in-lake well transects.

5.2.3 <u>Results and Discussion</u>

5.2.3.1 Tributary Water Quality

The primary purpose for collecting tributary water quality data is to calculate the surface water component of nutrient, sediment, and hydrologic budgets for the Oakwood Lakes (section 5.2.3.3). The data may also be used to identify water quality problems in watersheds. Tributary water quality is described by evaluating several significant parameters that indicate possible pollution sources in the watershed that impacts on the receiving water. Variations in these parameters for each tributary are due to watershed characteristics, weather conditions and time of year.

Since weather is such a large factor in determining both quality and quantity of runoff, a brief discussion of weather conditions in 1988 is appropriate. The winter of 1987-1988 was colder and drier than normal with little snow accumulation (Lytle, personal communication). Snow pack just prior to the snowmelt in 1988 was lower than in 1987. Rain quantities were measured with instruments at Castlewood SD. Rain intensities and quantities were also measured at the Master Site and near Oakwood Lake with two Belfort recording rain gages. Rain intensities as measured at the Master Site (section 3.0) and by the Belfort rain gages were higher in 1988 than in 1987. Significant rain fell on several occasions during 1988 (Figure 5-3), but no significant runoff events occurred at any tributary after the snowmelt runoff had ceased.

Minimum, maximum and mean values for several parameters are presented for each tributary in Table 5-1. The values presented may be atypical since they represent a second year of below normal snow pack and the lack of runoff during the remainder of the year. The data does provide a basis for comparisons between tributaries since the tributaries were subject to similar hydrologic conditions. South Dakota water quality standards are cited when appropriate.

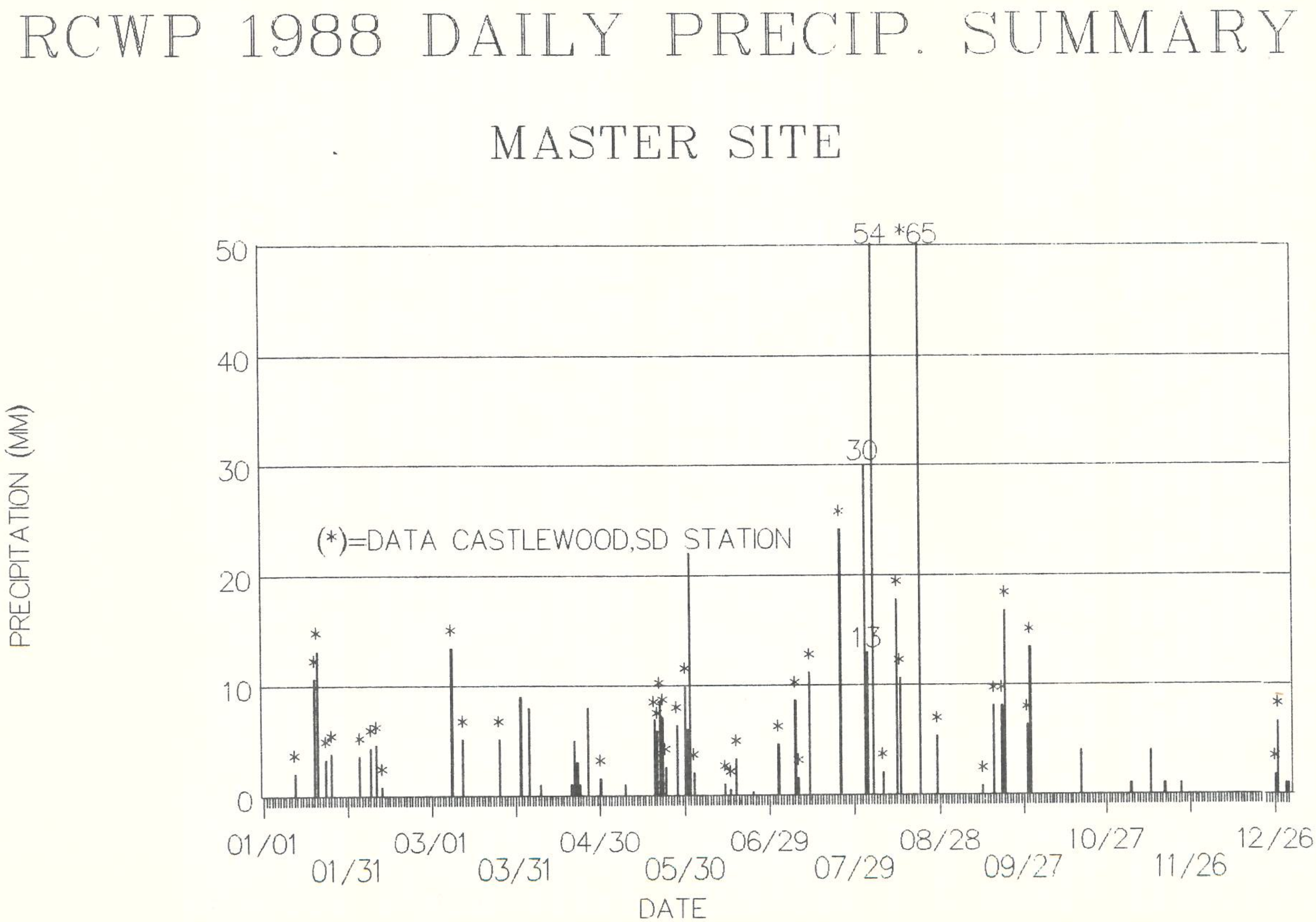


Figure 5-3. Graph of 1988 daily precipitation at the master site.

Table 5-1 Minimum, Maximum, and Mean Values of Selected Water Quality Parameters for Oakwood Lake System Tributaries for 1988.

		Suspended Solids (ppm)	Dissolved Solids (ppm)	Total Solids (ppm)	Nitrite as N (ppm)	Nitrate as N (ppm)	Ammonia as N (ppm)	Organic Nitrogen as N (ppm)	Total Nitrogen as N (ppm)	Total Phosphorus as P (ppm)	Ortho PO_4 as P (ppm)	% Ortho PO_4
West	min	1	30	32	0.000	0.03	0.00	0.12	0.30	0.040	0.010	6.4%
Creek	max	50	1438	1468	0.190	1.18	2.00	4.61	5.68	1.290	1.140	88.4%
(T-1)	mean	15	919	934	0.024	0.26	0.31	1.49	2.06	0.264	0.131	42.8%
Crazy	min	2	377	436	0.001	0.01	0.00	0.40	1.02	0.160	0.100	48.4%
Creek	max	59	2212	2232	0.067	3.34	0.66	1.92	4.83	0.710	0.690	97.2%
(T-2)	mean	15	1212	1227	0.018	0.54	0.15	1.22	1.93	0.375	0.292	76.5%
Pony	min	4	176	180	0.001	0.07	0.04	0.57	0.73	0.360	0.270	45.2%
Creek	max	64	1306	1332	0.230	0.84	12.30	9.00	21.93	2.860	2.650	93.9%
(T-3)	mean	20	765	786	0.039	0.23	2.17	3.12	5.63	1.050	0.866	72.4%
Mud	min	1	128	152	0.000	0.02	0.02	0.61	0.83	0.230	0.180	57.6%
Creek	max	73	1055	1116	0.039	1.27	0.60	3.69	3.92	0.950	0.750	95.2%
(T-4)	mean	11	557	568	0.009	0.25	0.12	1.47	1.80	0.464	0.361	78.0%
Loomis	min	1	276	284	0.002	0.06	0.07	1.68	2.35	0.460	0.450	39.2%
Creek	max	118	1131	1192	0.114	1.07	7.49	8.52	18.24	4.400	3.350	97.8%
(T-5)	mean	31	812	842	0.020	0.24	1.98	3.94	6.79	1.912	1.102	63.5%
Goose	min	5	231	236	0.017	0.09	0.00	0.99	1.15	0.030	0.010	3.1%
Creek	max	51	601	652	0.044	2.46	0.26	2.36	3.98	0.650	0.250	96.2%
(T-6)	mean	23	458	481	0.030	1.19	0.12	1.65	2.97	0.210	0.082	37.0%

Suspended Solids

Suspended solids concentrations can be an indication of how much sediment is carried by a stream although it does not include a measure of larger particles that are carried along the stream bed as bed load during higher flows. High concentrations of suspended solids can result from excessive soil erosion or contamination by human or animal wastes. Excessive suspended solids can have detrimental effects on stream and lake fisheries and speed up the aging of lakes by filling in the basin and providing a future source of nutrients for plant growth.

Mean suspended solids ranged from 11.0 ppm at Mud Creek to 31.0 ppm at Loomis Creek (Table 5-1). The state standard for maintaining a warm water marginal fishery is 150 ppm. This level was never exceeded in 1988 but was approached at Loomis Creek where a suspended solids concentration of 118.0 ppm was reached.

Ammonia as N

Ammonia nitrogen is an inorganic form of nitrogen derived from the decay of organic material and is present in human and animal wastes and commercial fertilizers. It is directly available to plants as a nutrient for growth. Significant levels of ammonia may indicate organic pollution or fertilizer leaching. In high concentrations it can be toxic to fish if present as unionized ammonia. Ammonia concentrations ranged from a maximum of 12.30 ppm at Pony Creek to below detection limits at West, Crazy and Goose Creeks. Pony Creek also had the highest mean ammonia concentration of 2.17 ppm. Although concentrations were lower in Loomis Creek a mean concentration of 1.98 ppm and a maximum of 7.49 ppm indicate it is a substantial ammonia source to Oakwood Lake. Ammonia concentrations observed in Pony and Loomis Creek indicate a source of organic pollution in the watersheds. Several small feedlots located on or near these creeks are contributing organic wastes. Several other parameters that indicate contamination by organic wastes are also elevated in Loomis Creek and Pony Creek. All other tributaries had lower mean ammonia concentrations ranging between 0.12 ppm and 0.31 ppm.

Nitrate and Nitrite Nitrogen as N

Nitrate and nitrite are important and readily absorbed sources of inorganic nitrogen for plant growth. High levels in lakes can cause excessive algal growth. Nitrite levels are generally low (0 to 0.01 ppm) in natural surface waters. Nitrate nitrogen concentrations generally range from below detection limits to 10.0 ppm in unpolluted fresh water (Wetzel, 1983).

Oakwood Lake tributary concentrations of nitrite ranged from below detection limits at West and Mud Creeks to a maximum of 0.230 ppm at Pony Creek. Mud Creek also had the lowest mean nitrite concentration (0.009 ppm) and Pony Creek showed the highest mean nitrite concentration (0.039 ppm).

The maximum and minimum nitrate concentrations for 1988 both occurred at Crazy Creek and ranged from 0.01 ppm to 3.34 ppm. The highest 1988 mean nitrate concentration of 1.19 ppm occurred at Goose Creek. All other tributaries had much lower means (Table 1). All tributaries except Goose creek exhibited a decline in nitrate concentrations from 1987 to 1988. In 1987 means ranged from .51 ppm to 1.00 ppm in 1987 with most above .70 ppm. Mean concentrations of nitrates for all tributaries in 1988 were higher than concentrations observed for in-lake samples. Since the lake exhibited less nitrogen limitation early in 1988 than in 1987 ,it is likely that inorganic nitrogen (ammonia, nitrite and nitrate) from tributaries had less impact on algal growth early in 1988.

Organic Nitrogen as N

Organic nitrogen is a measure of organic material both living and non-living contained in the water. High levels can be an indication of pollution by human or animal wastes. When oxidized, it becomes a source of nitrogen for plant growth. Organic nitrogen was the dominant form of nitrogen in most tributary samples collected in 1988. Concentrations ranged from 0.12 ppm at West Creek to 9.00 ppm at Pony Creek. Pony and Loomis Creeks were similar showing high concentrations of organic nitrogen indicating their watersheds contain sources of organic pollution. Pony Creek had a mean concentration of 3.12 ppm and Loomis Creek had a mean of 3.94 ppm with a maximum concentration of 8.52 ppm at Loomis Creek (Table 1). Other tributaries also exhibit possible sources of organic pollution but to a lesser degree.

Total Nitrogen as N

Total nitrogen is the sum of the three inorganic forms plus organic nitrogen. It is a useful parameter for calculating nitrogen loads to a lake. Loomis and Pony Creeks again were the largest contributors with mean concentrations of 6.79 ppm and 5.63 ppm respectively. The lowest mean concentration (1.80 ppm) was observed at Mud Creek. All of the Oakwood Lake tributaries supply significant amounts of nitrogen to the lake system. Reductions in the amount of total nitrogen could probably be achieved through better management of animal wastes and better incorporation of fertilizers.

Total Phosphorus as P

Phosphorus is an essential nutrient for algal growth and is frequently the most limiting nutrient in lakes. However only the orthophosphate form measured in this parameter is immediately available for algal productivity. Many of the unavailable forms of phosphorus carried by streams, such as dissolved organics, particulate suspensoids and scoured sediment deposits can be made available by chemical, physical and biological processes after reaching the lake (Wetzel, 1983). This is especially true for a shallow system like the Oakwood Lakes. The concentration of total phosphorus in tributaries is an important indicator of the potential impact they will have on the receiving water.

Phosphorus concentrations above 0.025 ppm entering a lake would be considered a dangerous load (ie. would lead to rapid eutrophication) according to Vollenweider and Kerekes (1980) (from Wetzel 1983). Lakes with phosphorus concentrations above 0.050 ppm would be considered hypereutrophic according to a classification proposed by Reckhow, et al. (1980). Based on these standards there is little hope that a lake will improve from a hypereutrophic to eutrophic state as long as it continues to receive substantial quantities of water with phosphorus concentrations above 0.050 ppm. Although phosphorus is probably the single most important nutrient involved with degradation of lakes, the State of South Dakota does not currently have a phosphorus standard for waters discharging to lakes.

For discussion a phosphorus concentration level of 0.050 ppm will be used as a reference. The majority of samples taken from tributary, and interlake sites in 1988 had concentrations above .050 ppm total phosphorus. All tributaries are contributing an excessive load of phosphorus to the Oakwood Lake system. The highest maximum and mean total phosphorus concentrations of 4.40 ppm and 1.91 ppm respectively were found at Loomis Creek (Table 5-1). This concentration indicates a severe case of pollution in the Loomis Creek watershed. Pony Creek was also substantially higher in phosphorus concentration than the other creeks with a maximum concentration of 2.860 ppm and a mean concentration of 1.050 ppm. At all tributaries the mean concentrations of total phosphorus was higher in 1988 than in 1987.

Goose Creek is the smallest monitored tributary entering the Oakwood Lakes. It continued to have the lowest mean phosphorus when compared to other tributaries although it increased from .12 ppm in 1987 to .21 ppm in 1988. The watershed drains an area dominated by cropland and pasture with no concentrated animal feeding operations. Water from the entire drainage passes through a small dam built by the Soil Conservation Service. These factors probably combine to produce more moderate levels of phosphorus in Goose Creek than other tributaries.

Orthophosphorus as P

Orthophosphate (or soluble reactive phosphorus) is a measure of bioavailable phosphorus in a sample. Concentrations of orthophosphorus in a tributary can indicate the short term impact that tributary will have on a water body that is or will become limited by phosphorus. Orthophosphorus was measured on all tributary samples where the hold time before analysis was less than 24 hours.

Loomis Creek and Pony Creek carried the highest mean levels of orthophosphate with 1.102 ppm and 0.866 ppm, respectively. Goose Creek had substantially lower levels of orthophosphate (mean of 0.082 ppm) as well as the lowest percentage (37%) of the total phosphorus (Table 5-1). For all tributaries orthophosphorus represented a high percentage of the total phosphorus (37% - 78%).

5.2.3.2 In-Lake Water Quality

Minimum, maximum and mean values for selected parameters at in-lake, interlake and the outlet sites are presented in Table 5-2. In-lake water quality is described by evaluating several parameters that provide information about the trophic state of the lake, the ability to support a fishery, the nutrients that are available for algal growth and aesthetic factors. Interlake sites and the outlet are included in Table 5-3 since they represent lake water flowing between basins or leaving the system. This data is used primarily to calculate mass transfer between basins but provides some insight into in-lake water quality. Mortimer's crossing at Station IL-3 does not have a corresponding in-lake monitoring site and is the only source of water quality data for that basin. IL-3 tends to have high mean values for most parameters when compared with other sites. Station T-0, the outlet at Mill Creek, generally exhibits the lowest mean concentrations for sediment and nutrient parameters which is a reflection of the higher quality water in East Oakwood Lake.

The Oakwood Lakes have been assigned the following beneficial uses:

1. warm water marginal fish propagation
2. immersion recreation
3. limited contact recreation
4. wildlife propagation and stock watering.

A discussion of water quality standards set by the State of South Dakota to meet these beneficial uses will be included where appropriate. Figures are presented in this section which show seasonal trends for several parameters. They indicate the distribution of each station about the mean for all stations. Stations L-1, L-2 are presented on the same graph in each figure. Stations are presented in the order of flow through the system with stations L-3 and L-4 in the center of each page and stations L-6 and L-7 at the bottom.

Table 5-2. Minimum, Maximum, and Mean Values of Selected Water Quality Parameters for In-Lake and Interlake Sites and the Outlet for 1988.

		Suspended Solids (ppm)	Dissolved Solids (ppm)	Total Solids (ppm)	Nitrite as N (ppm)	Nitrate as N (ppm)	Ammonia as N (ppm)	Organic Nitrogen as N (ppm)	Total Nitrogen as N (ppm)	Total Phosphorus as P (ppm)	Ortho PO_4 as P (ppm)	% Ortho PO_4
Johnson	min	6	966	1036	0.001	0.01	0.00	1.26	1.35	0.100	0.010	2.6%
Lake	max	114	1332	1344	0.015	0.19	1.79	6.69	6.92	0.390	0.110	45.8%
(L-1)	mean	49	1093	1142	0.005	0.10	0.36	3.12	3.59	0.207	0.024	13.0%
Johnson	min	9	971	1008	0.001	0.02	0.00	1.22	1.30	0.080	0.000	0.0%
Lake	max	80	1355	1366	0.012	0.18	1.78	6.43	6.64	0.320	0.090	47.4%
(L-2)	mean	41	1087	1128	0.004	0.09	0.33	3.07	3.50	0.167	0.021	15.3%
West	min	6	896	928	0.001	0.01	0.00	1.28	1.37	0.090	0.000	0.0%
Oakwood	max	80	1257	1268	0.010	0.18	2.63	7.50	7.72	0.240	0.160	71.4%
(L-3)	mean	38	1044	1083	0.003	0.08	0.50	3.27	3.77	0.164	0.023	13.3%
West	min	9	864	896	0.000	0.01	0.00	1.25	1.49	0.050	0.000	0.0%
Oakwood	max	70	1097	1148	0.009	0.17	2.59	6.69	6.88	0.230	0.170	94.4%
(L-4)	mean	32	1001	1033	0.003	0.08	0.50	2.90	3.44	0.145	0.025	17.7%
Turtle	min	10	881	892	0.000	0.04	0.00	1.25	1.69	0.120	0.000	0.0%
Lake	max	104	1283	1296	0.016	0.54	2.67	6.81	7.03	0.370	0.160	68.2%
(L-5)	mean	45	1050	1096	0.004	0.13	0.38	3.48	3.88	0.205	0.028	15.0%
Round	min	6	893	924	0.000	0.02	0.01	1.58	2.04	0.080	0.000	0.0%
Lake	max	79	1200	1224	0.019	0.17	3.71	6.51	6.66	0.230	0.130	60.0%
(L-6)	mean	37	1061	1099	0.004	0.07	0.90	3.23	4.17	0.153	0.020	12.3%
East	min	4	752	776	0.000	0.01	0.00	0.95	1.11	0.050	0.000	0.0%
Oakwood	max	69	1010	1016	0.010	0.16	3.08	6.29	6.52	0.210	0.070	66.7%
(L-7)	mean	29	896	925	0.003	0.06	0.52	2.64	3.16	0.110	0.016	18.3%
Kimball's	min	2	654	672	0.000	0.01	0.00	0.71	1.38	0.130	0.010	4.3%
Crossing	max	45	1299	1308	0.035	0.18	3.58	2.99	5.19	0.880	0.880	100.0%
(IL-1)	mean	20	985	1005	0.007	0.10	0.71	2.09	2.91	0.252	0.101	32.2%
Round	min	4	668	684	0.000	0.02	0.02	0.76	1.38	0.080	0.010	5.0%
Crossing	max	132	4241	4262	0.027	0.14	1.71	4.21	5.59	0.340	0.040	33.3%
(IL-2)	mean	27	1002	1029	0.006	0.06	0.67	2.28	2.94	0.146	0.020	14.4%
Mortimer's	min	5	168	174	0.002	0.03	0.06	1.12	2.26	0.160	0.020	2.2%
Crossing	max	67	1021	1040	0.049	0.17	1.79	5.68	6.40	0.900	0.300	79.3%
(IL-3)	mean	25	562	586	0.009	0.09	0.58	3.42	3.88	0.312	0.063	20.9%
Mill	min	5	471	484	0.000	0.00	0.00	0.63	0.75	0.050	0.010	8.3%
Creek	max	69	954	1016	0.014	0.42	0.28	2.46	2.68	0.230	0.050	50.0%
(T-0)	mean	19	819	838	0.002	0.05	0.08	1.51	1.64	0.119	0.022	20.5%

IN-LAKE SUSPENDED SOLIDS

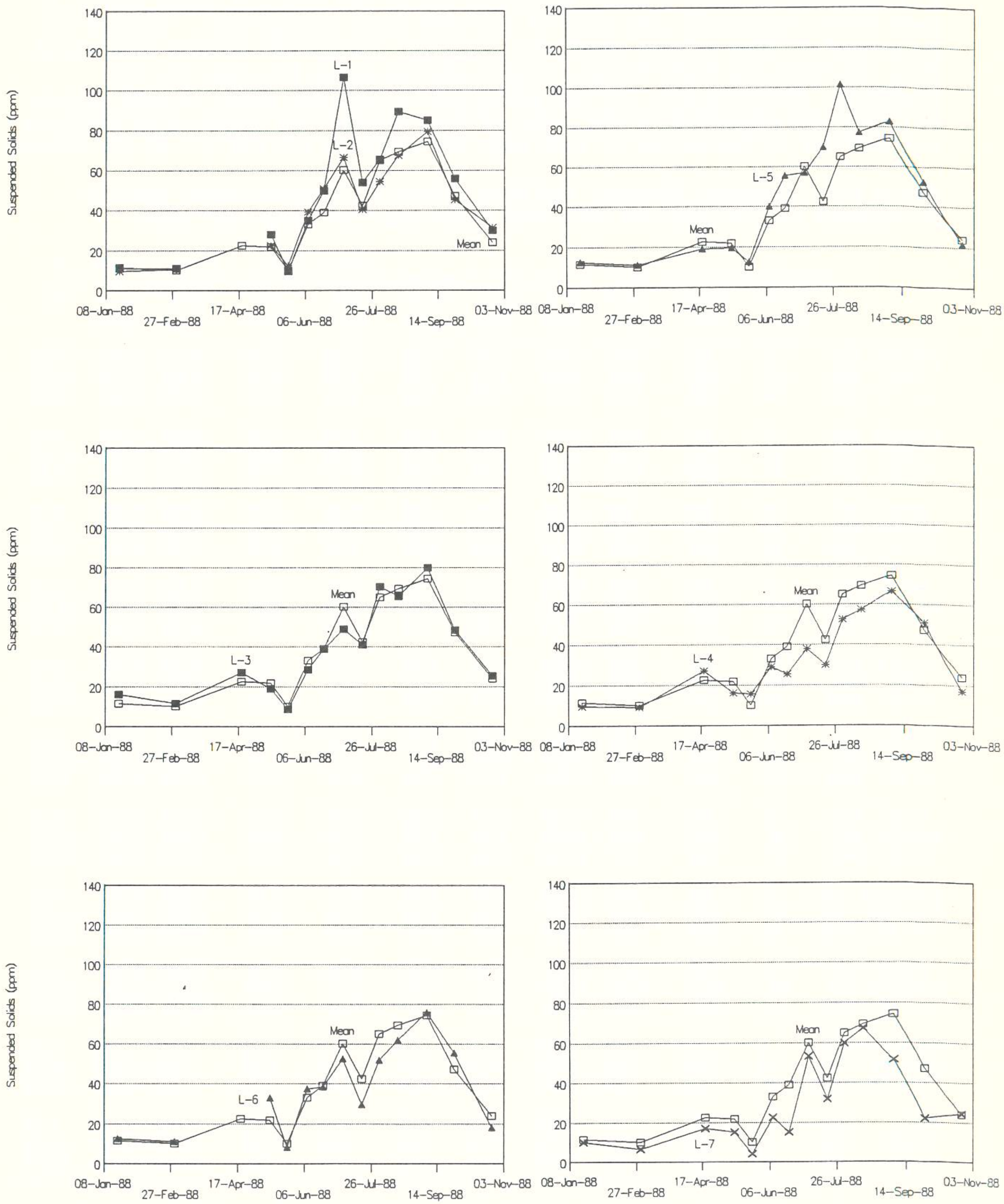


Figure 5-4. Suspended solids concentrations for in-lake stations in 1988.

IN-LAKE INORGANIC NITROGEN

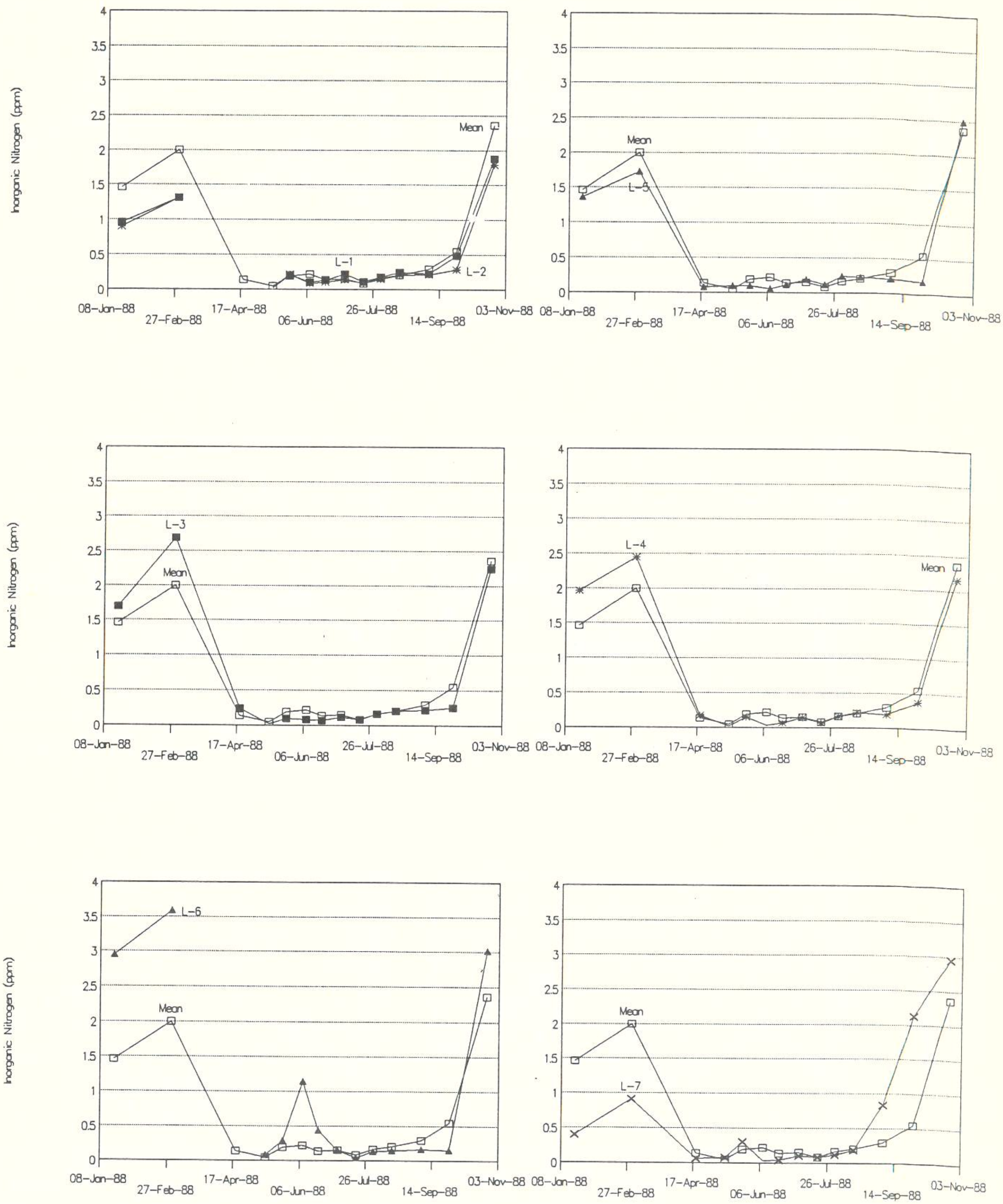


Figure 5-5. Inorganic nitrogen concentrations for in-lake stations in 1988.

IN-LAKE TOTAL PHOSPHORUS

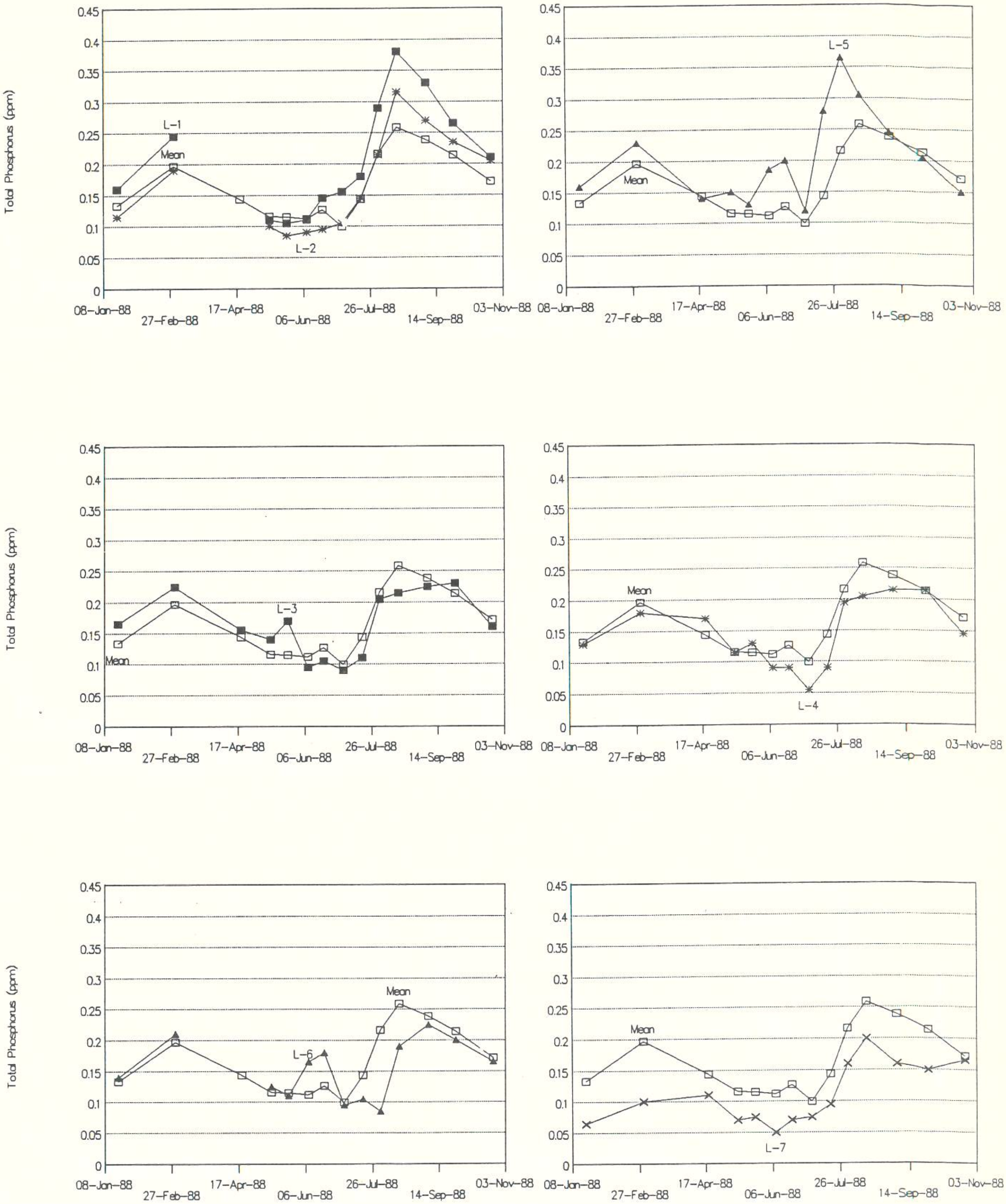


Figure 5-6. Total phosphorus concentrations for in-lake stations in 1988.

IN-LAKE ORTHO PHOSPHORUS

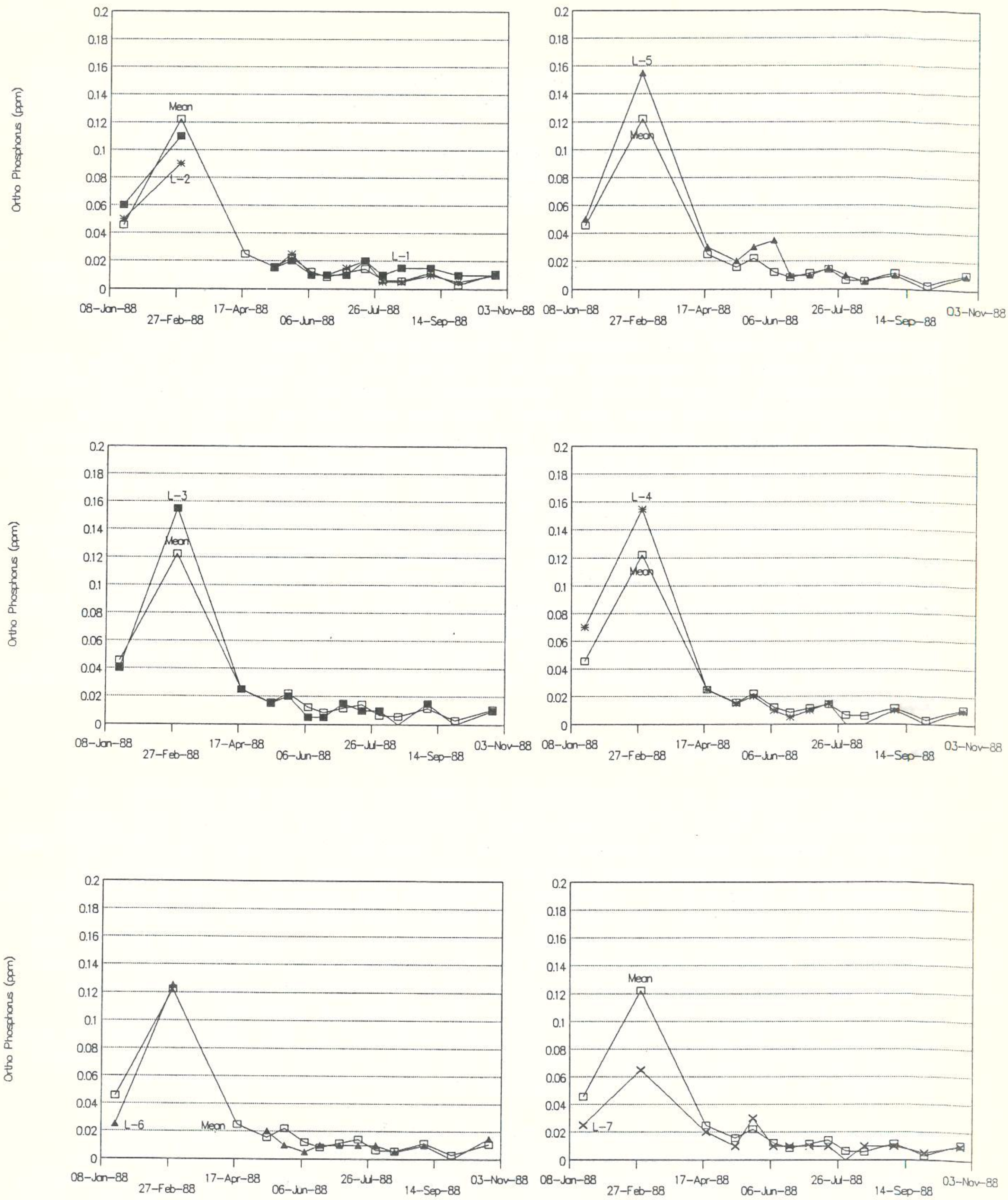


Figure 5-7. Orthophosphorus concentrations for in-lake stations in 1988.

Suspended solids

Low suspended solids concentrations are desirable both for aesthetic reasons and for maintenance of a healthy fishery. Fish populations can be affected by high suspended solids in several ways. Fish can be killed directly or their growth resistance to disease and reproduction success may be reduced. Migrations can also be affected (EPA, 1976). High suspended solids concentrations result in reduced aesthetic value of a lake and often limits recreational use.

The state standard for maintaining a warm water marginal fishery is 150 ppm. The standard was not exceeded at any in-lake sites in 1988 or 1987. In the Oakwood Lakes suspended solids is primarily a reflection of the plankton population and does not represent large amounts of suspended sediment. Seasonal trends for suspended solids (Figure 5-4) are similar to trends shown for chlorophyll (Figure 5-10). Suspension of sediment probably occurs during high winds in shallow area but water quality monitoring is not conducted during high winds. Two stations, L-1 in West Johnson Lake and L-5 in Turtle Lake, had the highest levels of suspended solids with mean concentrations of 49 ppm and 45 ppm, respectively (Table 5-2). Both stations receive direct discharge from major tributaries (Figure 1), are shallow and exhibit high algal populations. Station L-4 and L-7 had the lowest mean suspended solids concentrations with 32 and 29 ppm, respectively. Although Station L-7 was consistently below the mean for all sites in 1988, station L-4 had lower concentrations during the summer period (Figure 5-4). Suspended solids tend to decline at deeper stations and as water moves through the system. Mean suspended solids concentrations for interlake sites tended to be lower than for in-lake stations because flow between basins had ceased before large algal populations had developed.

Inorganic Nitrogen as N

Inorganic nitrogen is a combination of ammonia, nitrite and nitrate. It represents the forms of nitrogen that are immediately available for algal growth. Ammonia was the dominant form of inorganic nitrogen in 1987 and 1988. A distribution of individual stations about the mean for all stations is presented in Figure 5-5. Inorganic nitrogen was generally low at all stations through the first half of 1987 but in 1988 high levels were observed during January and February at all stations and at L-3, L-4, and L-5 in April. The high levels observed during this time are probably due to the decay of dead plant and animal remains that resulted from the partial winter kill that occurred throughout the system during the winter of 1987-88. Inorganic nitrogen, dominated by ammonia, increased sharply in the fall of 1988 as the summer algal bloom declined. Station L-6 had a sharp increase in inorganic nitrogen in June that was not observed at other stations (Figure 5-5).

Ammonia nitrogen is an inorganic form of nitrogen in lakes derived from excretion products or the decay of organic material. Unionized ammonia (NH_4OH) is highly toxic to many aquatic organisms, especially fish (Trussell, 1972). The ratio of NH4+ to NH_4OH is determined by pH and temperature. High pH and high temperatures produce high amounts of unionized ammonia. Toxic ammonia conditions existed at L-6 on both dates in June. The unionized form was not a widespread problem at other stations in 1988 since concentrations were relatively low during mid summer when high temperature and high pH were observed. Ammonia levels in the Oakwood Lakes ranged from below detectable limits at all stations except L-6, to a maximum of 3.71 ppm at L-6 which also had the highest mean concentration for 1988 at .90 ppm (Table 5-2).

Nitrite concentrations were generally insignificant at all stations in 1988 (Table 5-2). Nitrate concentrations ranged from .01 ppm at several stations to .54 ppm at L-5. Mean concentrations ranged from .06 ppm at station L-7 to .13 ppm at station L-5. Nitrate levels tended to decline as water moved downstream through the system but not as dramatically as other parameters. Nitrate concentrations were similar at interlake sites. The outlet at Mill Creek had a lower mean nitrate concentrations (.05 ppm) than any other surface water site.

Organic Nitrogen as N

Organic nitrogen ranged from .95 ppm at station L-7 to 7.50 ppm at station L-3. Means were higher in 1988 than 1987 and ranged from 2.64 ppm at L-7 to 3.48 ppm at L-5. Lakes with mean concentrations of organic nitrogen above 1.2 ppm are classified as hypereutrophic (Wetzel, 1983). Mortimer's Crossing had a mean concentration of 3.88 ppm organic nitrogen even though flow ceased before peak algal growth. Mortimer's Slough is probably the most eutrophic basin in the system although there is no in-lake monitoring station to document the trophic level. Mean values for organic nitrogen in 1987 and 1988 indicate that all of the Oakwood Lakes are well into the hypereutrophic classification.

Total Phosphorus as P

Phosphorus is frequently a limiting nutrient in freshwater lakes. Numerous investigators have found a strong correlation between total phosphorus concentrations and a lake's tropic state (Wetzel, 1983). A tropic state index based on phosphorus put forth by Reckhow, et al (1980), would classify lakes with between .020 and .050 ppm as eutrophic and would classify lakes with phosphorus concentrations greater than .050 ppm as hypertrophic. According to this classification, the Oakwood lakes system has several times more phosphorus than would be required to place it in the hypereutrophic classification. The State of South Dakota has no standard for phosphorus, therefore Reckhow's definition of hypereutrophic (.050 ppm) will be used for discussion.

In 1988 in-lake total phosphorus ranged from .050 ppm at stations L-4 and L-7 to .390 ppm at station L-1. Mean concentrations were lower in 1988 than 1987 and ranged from .110 ppm at station L-7 to .207 ppm at station L-1. Phosphorus concentrations for interlake and outlet sites were similar to in-lake stations above them except IL-1 had a larger mean than L-4 (Table 5-2). Water draining from Mortimer's slough at IL-3 had the highest mean phosphorus concentrations in the system at .312 ppm.

A decline in total phosphorus was observed as water moved through the system. Upstream stations (L-1 and L-5) had consistently higher concentrations than downstream stations. A distribution of individual stations about the mean for all stations is presented in Figure 5-6. All of the stations followed a similar seasonal trend in phosphorus concentrations during 1988. A minor peak in phosphorus was observed in June at stations L-5 and L-6. In 1988 station L-7 had consistently less total phosphorus than other stations throughout the year (Figure 5-6). There was no phosphorus peak in May 1988 as was observed in 1987. Lowest phosphorus levels were observed in mid summer in 1988. Phosphorus concentrations increased steadily following the July 5th sampling date and then fell steadily in September and October. Since no significant runoff occurred during the last half of the year, the increase in phosphorus observed was probably derived from in-lake sources. Temporary periods of low dissolved oxygen near the bottom may have contributed to the released of phosphorus from sediments.

Total Orthophosphorus as P

Total orthophosphorus (or soluble reactive phosphorus) is a measure of the phosphorus that is immediately available for uptake by phytoplankton. A distribution of individual stations about the mean for all stations in 1988 is presented in Figure 5-7. The seasonal trend shows a decline of concentrations throughout the year. Very high levels were present during the winter. Orthophosphorus was below .02 ppm at most stations after the April sampling date. Starting in May all of the stations had similar trends and varied little from the overall mean (Figure 5-7). These concentrations are much lower than those observed through most of 1987 except for the winter period. Orthophosphorus fell below detectable limits (.01 ppm) at times at all stations in the June to September period. Orthophosphorus concentration ranged from below detection limits at all stations to .170 ppm at station L-5. Mean concentrations for each station ranged from .016 ppm at station L-7 to .028 ppm at L-5 (Table 5-1).

Dissolved Oxygen

Dissolved oxygen concentrations in the Oakwood Lakes exhibited strong seasonal variations but on most sampling dates oxygen was fairly uniform throughout the water column (Table 5-3). Oxygen stratification was observed only on June 20th in 1988. Several stratification events were observed in 1987. Stratification in both years occurred during periods of no wind, warm weather and high algal biomass. Dissolved oxygen and temperature profiles for in lake stations on June 20th 1988 are presented in Figure 5-8. Station L-1 is not included in the figure but was similar to T-5. Oxygen concentrations were near zero on the bottom at L-3 and L-4. The pattern of stratification varied among stations. Station L-4 maintained over 8 ppm dissolved oxygen through most depths while other stations exhibited a decline in concentration at about three feet. Temperature stratification was weak at all stations (Figure 5-8).

Oxygen depletion was observed in March at stations L-3, L-4 and L-6 which resulted in a partial winter kill (Table 5-3). A measurement at L-7 was not taken on March 1st due to fouling of the probe by high levels of hydrogen sulfide gas at L-6. Anoxic conditions at the sediment water interface probably facilitated the release of phosphorus from the sediments. Lack of sufficient oxygen caused the death of significant numbers of fish but did not result in a complete kill. The more hardy species of fish such as bullheads are likely to be favored by these conditions. The decay of fish and other aquatic organisms from the partial winter kill affected many of the chemical parameters early in 1988.

Table 5-3 Surface and Bottom Dissolved Oxygen Concentrations at Seven Oakwood Lakes Stations in 1988.

	L-1A		L-2A		L-3A		L-4A		L-5A		L-6A		L-7A	
Date	Depth (ft)	O_2 (ppm)	Depth (ft)	O_2 (ppm)	Depth (ft)	O_2 (ppm)	Depth (ft)	O_2 (ppm)	Depth (ft)	O_2 (ppm)	Depth (ft)	O_2 (ppm)	Depth (ft)	O_2 (ppm)
18-Jan-88	0.5	2.5	0.5	4.6	0.5	11.2	0.5	6.4	0.5	7.3	0.5	3.8	0.5	8.2
	5.5	1.4	7.5	3.7	6.3	4.2	9.6	3.1	4.6	4.0	6.0	1.8	8.3	4.0
01-Mar-88	0.5	2.7	0.5	2.8	0.5	1.8	0.5	1.2	0.5	3.2	0.5	0.2		
	5.6	5.1	7.5	3.8	6.3	0.5	9.6	0.6	4.7	4.0	6.0	0.0		
19-Apr-88					0.5	14.6	0.5	14.2	0.5	12.3			0.5	11.7
					6.7	14.5	10.3	13.3	5.2	11.8			8.7	11.6
11-May-88	0.5	7.8	0.5	8.2	0.5	8.4	0.5	8.2	0.5	9.6	0.5	8.3	0.5	9.2
	5.9	7.3	7.7	7.5	6.5	8.4	10.0	7.5	5.0	9.6	6.1	8.0	8.4	8.8
24-May-88	0.5	7.9	0.5	7.3	0.5	8.9	0.5	9.2	0.5	10.8	0.5	6.9	0.5	7.4
	5.9	7.3	7.8	5.7	6.7	7.5	10.1	6.0	5.0	6.8	6.7	3.5	8.2	7.7
08-Jun-88	0.5	7.7	0.5	9.2	0.5	9.6	0.5	8.0	0.5	7.7	0.5	10.2	0.5	8.8
	5.9	7.5	7.6	8.4	6.5	8.0	9.8	10.0	4.9	7.5	7.4	10.0	8.2	8.6
20-Jun-88	0.5	8.4	0.5	10.3	0.5	8.4	0.5	8.2	0.5	10.3	0.5	9.6	0.5	7.2
	4.6	7.9	7.4	3.0	6.2	0.7	9.6	0.6	4.7	10.1	6.2	2.2	8.9	4.1
05-Jul-88	0.5	8.6	0.5	9.8	0.5	9.3	0.5	9.3	0.5	9.0	0.5	9.1	0.5	9.2
	5.4	8.8	7.1	9.6	6.0	9.3	9.3	9.2	4.3	8.9	5.8	9.0	7.8	9.2
19-Jul-88	0.5	9.6	0.5	9.1	0.5	11.3	0.5	11.7	0.5	10.2	0.5	8.4	0.5	14.4
	4.9	9.4	6.7	9.0	5.7	11.1	9.0	11.4	4.3	10.4	5.6	8.2	7.4	13.2
01-Aug-88	0.5	7.0	0.5	7.3	0.5	8.3	0.5	8.2	0.5	9.9	0.5	11.0	0.5	10.0
	4.7	6.7	6.5	7.2	5.5	8.2	8.7	7.7	4.0	9.6	5.3	10.9	7.1	9.8
27-Sep-88	0.5	8.1	0.5	9.2	0.5	9.7	0.5	9.6	0.5	10.2	0.5	8.3	0.5	9.4
	4.4	8.1	6.1	9.0	5.2	9.0	8.6	9.2	3.4	9.9	4.5	7.9	6.9	9.1

Chlorophyll a

Because of their importance in primary production, measurements of photosynthetic pigments have been widely used to quantify phytoplankton standing crops and as a measure of in-lake water quality. Chlorophyll a is the pigment of choice since it is normally the most important pigment in living material and has been studied extensively. Chlorophyll in the Oakwood Lakes system is measured primarily to permit modeling of the lake system. The most direct result of increased nutrient enrichment to lakes is an increase in algal biomass in the summer which can be estimated by measurement of chlorophyll. It represents a trophic variable that characterizes the response of the lake system to other variables such as phosphorus loadings which are subject to management. This response to external forces that impact in-lake water quality allow a linkage between activities in the watershed with in-lake water quality. Chlorophyll and other trophic state variables will be used to predict the lake response to reduced nutrient loadings that have resulted from RCWP efforts.

Mean chlorophyll a concentrations at seven in-lake stations in 1988 are presented in Figure 5-9. In first half of 1988 chlorophyll concentrations were generally below 50 mg/m^3. On May 24th minimum values were observed at most stations. Following the May sampling date a steady increase in chlorophyll concentrations were observed at all stations until peak concentrations were reached in August. Station L-5 in Turtle Lake had the earliest growth of large algal populations and the highest concentrations (near 400 mg/m^3 in early August). The down stream stations L-6 in Round Lake and L-7 in East Oakwood Lake had the lowest concentrations of chlorophyll in 1988. This is a reflection of the removal of nutrients by the lake basins as water passes through the system. Algal biomass as indicated by chlorophyll concentrations was lower in 1987 than 1988.

Carlson (1977) proposed a Trophic State Index that allows lakes to be placed on a scale of 0 to 100 based on their trophic state with 0 being the least productive. Each change of ten in the scale represents approximately a doubling of the algal biomass for the index based on summer chlorophyll levels. This represents a TSI of 80-90 for the Oakwood lakes which is well into the hypertrophic classification.

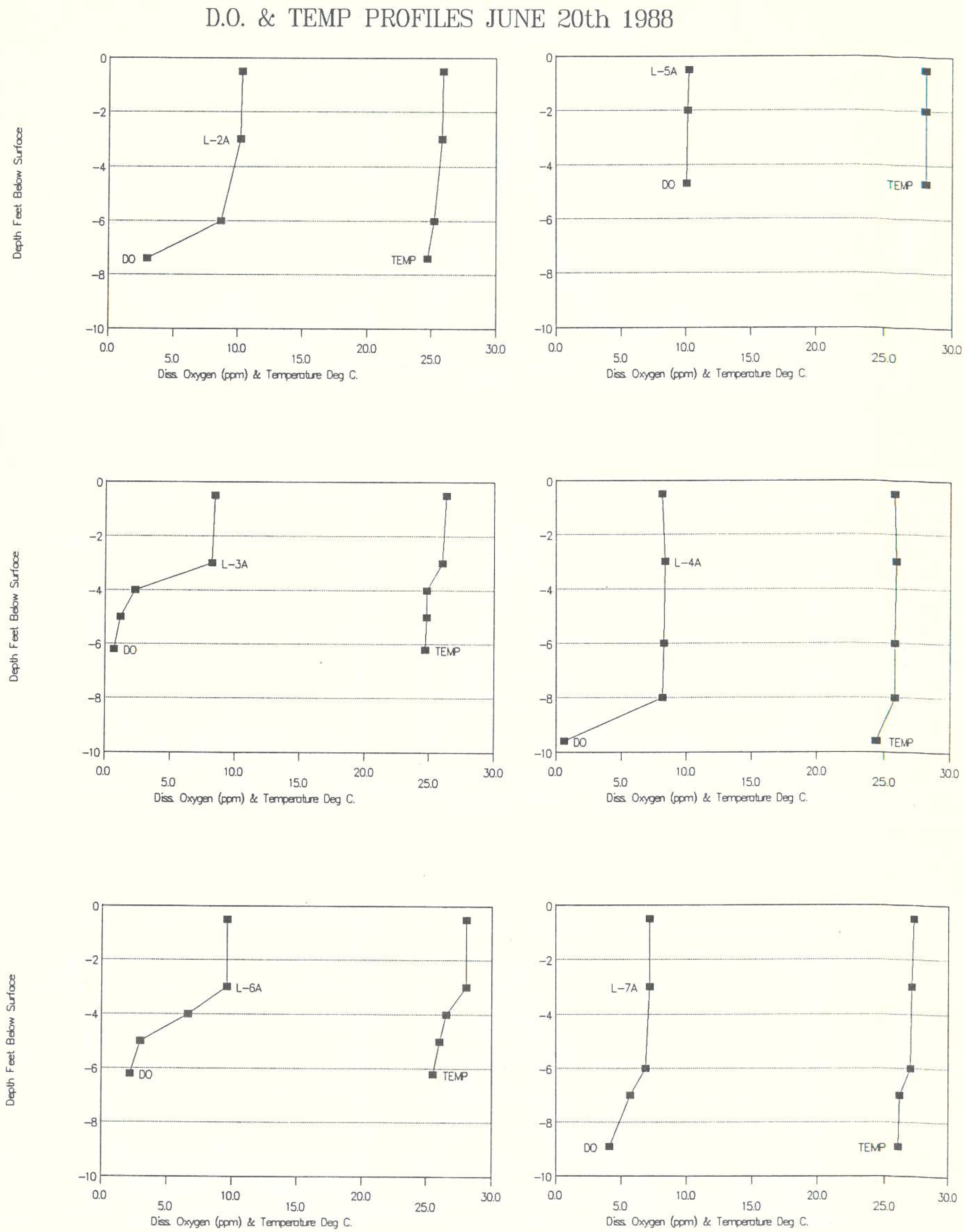


Figure 5-8. Dissolved oxygen profiles for in-lake stations on June 20 in 1988.

IN-LAKE CHLOROPHYLL

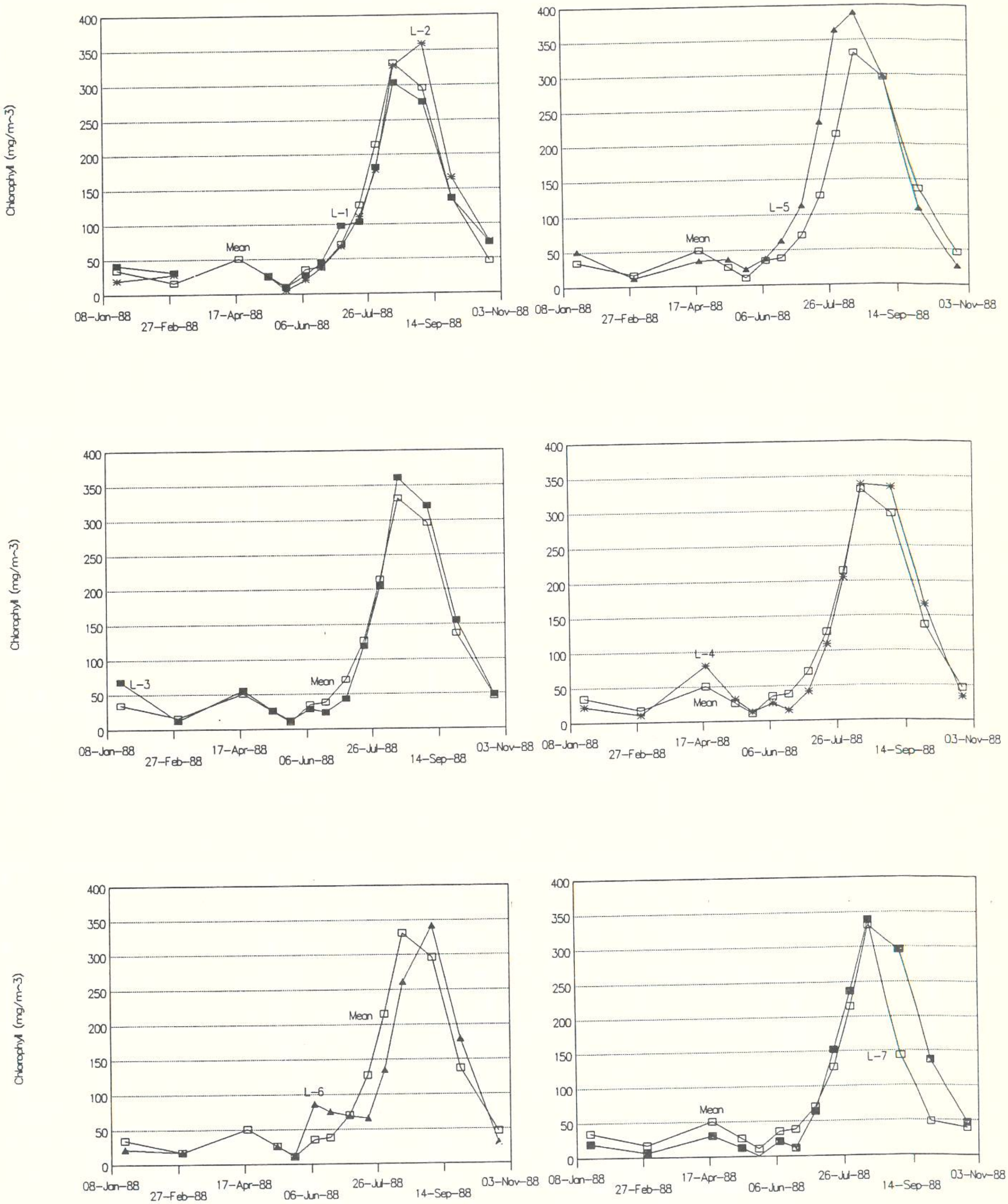


Figure 5-9. Chlorophyll concentrations for in-lake stations in 1988 in mg/m^3.

Limiting Nutrients

The ratio of nitrogen to phosphorus can determine which nutrient controls or limits the maximum biomass developed during the summer period. The evaluation of limiting nutrients during rapid growth periods is based on the available forms (inorganic nitrogen and orthophosphorus). N:P ratios of less than 10 (10 parts nitrogen to one part phosphorus) suggest nitrogen limitation. Ratios of N:P greater than 17 suggest phosphorus limitation. Ratios between 10 and 17 indicate either nutrient could be limiting. To be considered limiting the concentrations of available nutrients have to be close to zero (Forsberg, 1980). Nitrogen:Phosphorus ratios for 7 in-lake stations are presented in Table 5-4.

Ratios of available N:P were calculated for all Oakwood Lake stations for each date during 1987 and 1988 but they were included in Table 5-4 only if available phosphorus and nitrogen were less than .012 ppm or .18 ppm respectively. These concentrations are relatively low for the Oakwood Lakes and are approaching levels that can be reliably determined in the lab.

High levels of available phosphorus (Figure 5-7) and available nitrogen (Figure 5-5) were observed early in 1988. This represents the period when ice cover was present and all stations were suffering from oxygen depletion. During this period nutrients were not limiting algal biomass in the system.

The most apparent period of nitrogen limitation in 1988 occurred in April and early May at most stations. This may have contributed to the minimum in algal biomass that was observed on May 24th (Figure 5-8). Round Lake (L-6) was phosphorus limited earlier in the year than other stations (Table 5-4). During the period from June 20th to August 5th, when the most rapid accumulation of algal biomass was observed, inorganic nitrogen concentrations were low at all stations (Figure 5-5). Nitrogen may have been limiting at some stations during this time. Phosphorus and nitrogen were both at low concentration on July 19th and nitrogen was limiting at all stations including Round Lake. This date appears to mark the point at which the lakes switched from nitrogen to phosphorus limitation.

In general the lakes exhibited more nitrogen limitation in 1987 than 1988 (Table 5-4). Nutrients did not appear to be limiting algal growth in August 1987 during the peak of the algal bloom. In 1988 the lake was phosphorus limited during this period. Conversely the lakes were nitrogen limited in January of 1987 but had extremely high concentrations of nitrogen in January 1988. These differences may have contributed to the shift in algal species composition that was observed in 1988 (see section 5.3.0).

Table 5-4. Inorganic Nitrogen to Inorganic Phosphorus Ratios for Oakwood Lake Stations 1988.

	Johnson Lake (L-1)		Johnson Lake (L-2)		West Oakwood Lake (L-3)		West Oakwood Lake (L-4)		Turtle Lake (L-5)		Round Lake (L-6)		East Oakwood Lake (L-7)	
22-Jan-87	6	N	4	N	2	N	3	N	2	N	3	N	2	N
12-Apr-87	57	P	22	P	8	N	10	N or P	6	N	27	P	23	P
28-Apr-87	14	N or P	13	N or P	21	P	5	N	2	N	8	N	37	P
14-May-87	3	N	3	N	2	N	1	N	1	N	2	N	6	N
27-May-87					3	N					7	N	4	N
09-Jun-87	2	N	1	N	3	N	4	N	5	N	5	N	4	N
23-Jun-87	4	N	3	N	14	N or P	21	P	4	N	19	P	5	N
06-Jul-87			56	P	162	P	206	P	84	P	39	P	276	P
20-Jul-87			32	P	21	P	30	P			31	P	18	P
04-Aug-87							4	N						
17-Aug-87														
09-Sep-87	20	P	61	P	147	P	255	P	72	P	27	P	135	P
23-Sep-87	2	N	3	N	2	N	3	N	3	N				
21-Oct-87														
18-Nov-87														
18-Jan-88														
01-Mar-88														
19-Apr-88	no data		no data		no data		7	N	3	N	no data		3	N
11-May-88	1	N	1	N	1	N	1	N	5	N	4	N	7	N
24-May-88					5	N	7	N	3	N	29	P		
08-Jun-88	10	N or P	8	N	14	N or P	3	N	2	N	208	P	3	N
20-Jun-88	13	N or P	10	N or P	13	N or P	12	N or P	10	N or P	44	P	4	N
05-Jul-88	22	P	9	N	8	N	14	N or P	19	P	15	N or P	10	N or P
19-Jul-88	5	N	4	N	8	N	5	N	8	N	3	N	8	N
01-Aug-88	18	P	26	P	16	N or P	166	P	24	P	13	N or P	116	P
15-Aug-88			37	P	206	P	216	P	41	P	26	P	19	P
06-Sep-88	15	N	21	P			19	P	21	P	17	P	84	P
27-Sep-88	48	P	52	P	254	P	373	P	177	P	152	P	387	P
25-Oct-88	188	P	179	P	225	P	217	P	249	P			295	P

5.2.3.3 OLSS Groundwater Quality

The primary purpose of collecting ground water quality data for the OLSS is to calculate ground water contributions to the hydraulic, nutrient, and sediment budgets for the Oakwood Lakes (section 5.2.3.4). The data is also useful to determine the extent of similarities between ground water surrounding the lake and ground water collected from in-lake wells and seepage meters.

Prior to the initiation of the OLSS a sand and gravel isopach map (contour of the thickness of sand and gravel) was developed of the area surrounding the Oakwood lakes to help determine key locations in the lake-ground water flow system. The sand and gravel isopach map was prepared from approximately 55 test borings done in the Oakwood Lakes area. The early isopach map indicated that almost the entire lake was surrounded by sand and gravel. Areas to the north, south and southeast had large areas of sand and gravel which could potentially impart water to the lake. The northeast was predominantly glacial till material and not likely to be major contributor. The sand and gravel isopach map was combined with the water elevations to delineate potential inflow, outflow and flow-through areas around the lake. Flow was from northwest to southeast with most areas contributing except for the area east of the lake outlet.

OLSS drilling provided more detailed information on the geology of the area which will improve estimates of the contributing ground water areas. A new isopach map was prepared which indicates current knowledge of the thickness of sand and gravel areas surrounding the lake (Figure 5-12). The areas of greatest thickness of sand and gravel are located along the southwest sides of Turtle, West Oakwood and East Oakwood Lakes. These same areas have tended to produce the largest rates of seepage into the lake during both 1987 and 1988. CM&E field site monitoring indicated elevated concentrations of nitrate as nitrogen (NO_3-N) in shallow ground water that were attributed to agricultural practices. Mean NO_3-N concentrations in the upper 3.05 meters (10 ft) of the shallow sand and gravel aquifer was 7.82 ppm (428 samples). Mean phosphorus levels in the upper 3.05 meter (10 ft) of shallow sand and gravel was 0.038 ppm (174 samples). The source of the phosphorus may be partially related to agricultural practices. The aquifers surrounding the Oakwood Lakes were assumed to have similar NO_3-N and phosphorus levels creating the potential for ground water to comprise a significant portion of the hydrologic and nutrient budgets.

There were 18 existing monitoring wells (15 on CM&E Field sites) applicable to OLSS projects goals. To complete the coverage of the lakes, 26 additional ground water monitoring wells were installed. This brought to 44 the total number of wells available for analysis of flow and ground water chemistries. Wells were located in the sand and gravel areas surrounding the lakes. in positions to determine horizontal and vertical gradients and chemical stratification (Figure 5-2). Only those wells drilled for OLSS monitoring purposes will be included in the discussion at this time.

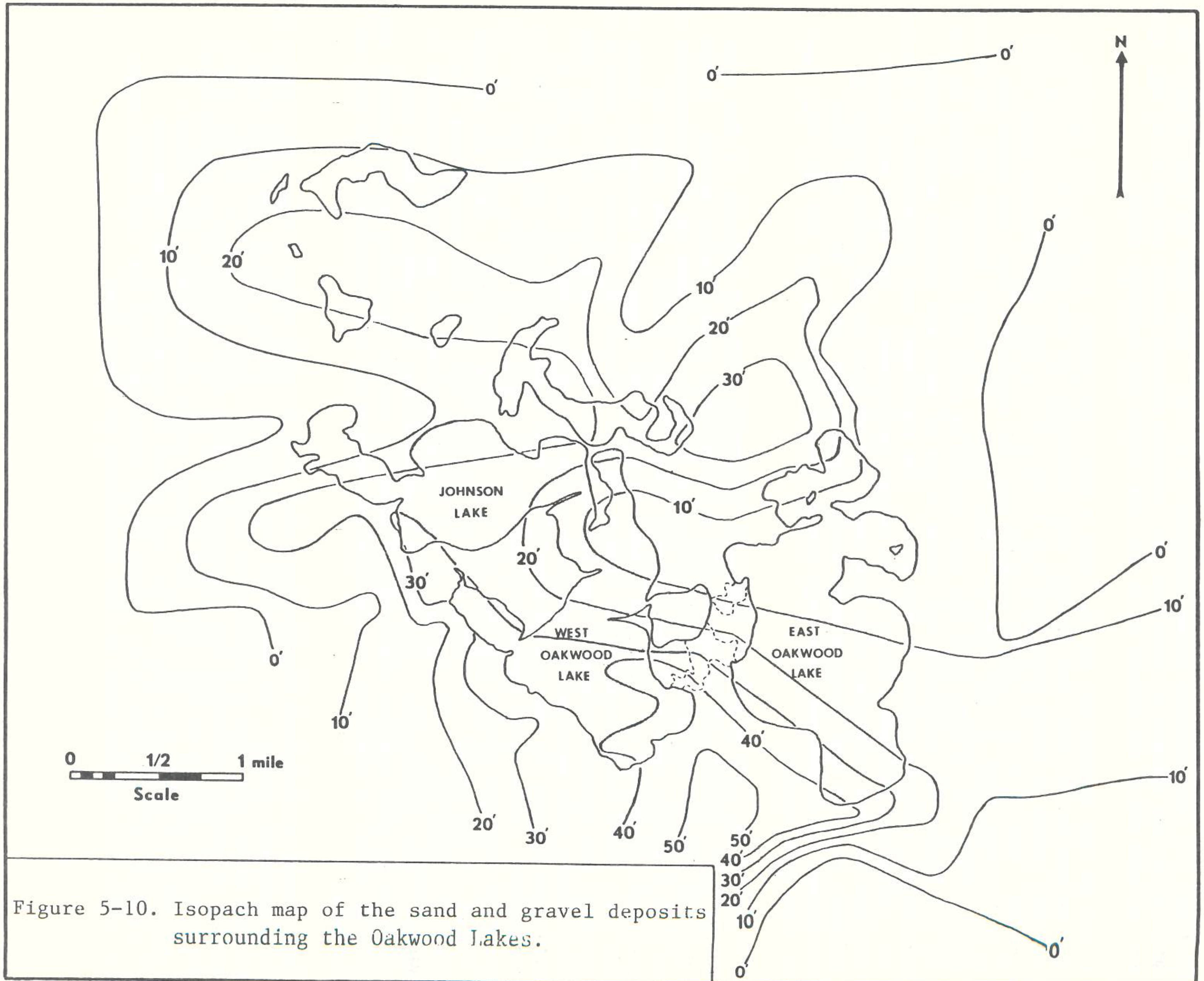


Figure 5-10. Isopach map of the sand and gravel deposits surrounding the Oakwood Lakes.

Minimum maximum and mean values for selected parameters land and in lake wells are presented in Table 5-5. Locations of wells can be found on Figure 5-2. Land wells have a "GW" prefix and in-lake wells have a "W" prefix. Wells positioned in well nests are indicated by (S) shallow, (M) mid depth or (D) deepest well.

Table 5-5 Minimum, Maximum, and Mean Values of Selected Water Quality Parameters for in-lake and land wells

Well ID		Total Dissolved Solids (ppm)	Chloride (ppm)	Sulfate (ppm)	Nitrite as N (ppm)	Nitrate as N (ppm)	Ammonia as N (ppm)	Organic Nitrogen as N (ppm)	Total Nitrogen as N (ppm)	Dissolved PO_4 as P (ppm)
GW-1	min	1280	7	488	0.001	0.04	0.00	0.01	0.241	0.00
	max	1940	128	724	0.018	2.73	0.08	0.25	2.982	0.02
	mean	1477	71	598	0.009	0.92	0.03	0.17	1.302	0.01
GW-2	min	370	2	72	0.001	0.43	0.00	0.00	0.539	0.02
	max	528	3	81	0.029	1.06	0.08	0.19	1.173	0.07
	mean	436	2	76	0.014	0.80	0.04	0.09	0.944	0.03
GW-3 (S)	min	404	3	88	0.001	0.41	0.00	0.04	0.520	0.01
	max	540	8	108	0.013	0.77	0.10	0.17	0.941	0.07
	mean	464	5	96	0.008	0.58	0.04	0.10	0.732	0.02
GW-3 (D)	min	1584	6	680	0.000	0.01	0.72	0.00	0.862	0.01
	max	1780	11	970	0.009	0.23	1.03	0.12	1.130	0.10
	mean	1678	8	851	0.003	0.05	0.86	0.08	0.990	0.03
GW-5	min	1740	1	912	0.000	0.00	0.24	0.00	0.249	0.02
	max	2260	4	1182	0.009	0.03	0.31	0.27	0.561	0.04
	mean	2047	3	1038	0.004	0.01	0.28	0.10	0.392	0.03
GW-6	min	1680	4	506	0.001	0.00	1.67	0.00	1.674	0.02
	max	1848	11	1075	0.077	0.06	2.05	0.11	2.160	0.06
	mean	1754	7	888	0.020	0.03	1.89	0.07	2.000	0.04
GW-7	min	1408	4	820	0.000	0.00	0.93	0.00	0.945	0.01
	max	1892	8	874	0.064	0.04	1.32	0.13	1.497	0.04
	mean	1627	6	838	0.012	0.02	1.11	0.08	1.215	0.02
GW-8 (S)	min	868	1	285	0.001	0.00	0.42	0.00	0.572	0.01
	max	1156	3	410	0.018	0.12	0.62	0.11	0.711	0.03
	mean	1023	2	376	0.006	0.03	0.53	0.07	0.636	0.01
GW-8 (D)	min	1004	1	400	0.000	0.00	0.41	0.00	0.443	0.02
	max	1228	3	460	0.007	0.03	0.64	0.12	0.780	0.03
	mean	1096	2	420	0.003	0.01	0.57	0.05	0.636	0.03
GW-9	min	400	6	64	0.000	7.09	0.00	0.23	7.504	0.08
	max	508	10	86	0.021	8.18	0.05	0.41	8.560	0.14
	mean	441	8	75	0.005	7.76	0.01	0.33	8.099	0.11
GW-11 (S)	min	484	2	63	0.000	12.35	0.00	0.28	12.738	0.00
	max	780	9	80	0.028	20.88	0.08	0.70	21.467	0.10
	mean	623	6	71	0.006	16.99	0.02	0.53	17.539	0.04
GW-11 (M)	min	412	1	49	0.000	3.02	0.00	0.12	3.202	0.00
	max	576	5	160	0.020	6.61	0.08	0.29	6.901	0.08
	mean	481	3	70	0.008	4.59	0.02	0.22	4.838	0.02
GW-11 (D)	min	380	0	50	0.000	0.00	0.00	0.00	0.044	0.00
	max	648	3	182	0.007	0.04	0.08	0.08	0.102	0.06
	mean	536	2	149	0.002	0.02	0.02	0.04	0.081	0.02
GW-13 (S)	min	496	3	64	0.001	4.08	0.00	0.29	4.402	0.01
	max	644	8	70	0.008	6.93	0.16	0.44	7.384	0.03
	mean	596	6	67	0.003	5.26	0.04	0.36	5.661	0.01
GW-13 (D)	min	660	2	224	0.000	0.00	0.07	0.00	0.122	0.00
	max	822	3	281	0.008	0.16	0.44	0.16	0.738	0.02
	mean	746	2	249	0.003	0.04	0.23	0.07	0.346	0.01

Table 5-5 continued

Well ID		Total Dissolved Solids (ppm)	Chloride (ppm)	Sulfate (ppm)	Nitrite as N (ppm)	Nitrate as N (ppm)	Ammonia as N (ppm)	Organic Nitrogen as N (ppm)	Total Nitrogen as N (ppm)	Dissolved PO_4 as P (ppm)
GW-14	min	444	1	136	0.000	0.00	0.00	0.03	0.073	0.00
(S)	max	572	4	181	0.009	0.04	0.09	0.12	0.184	0.03
	mean	523	3	156	0.002	0.02	0.03	0.07	0.115	0.02
GW-14	min	564	2	200	0.000	0.00	0.00	0.03	0.073	0.00
(D)	max	676	6	228	0.006	0.03	0.13	0.14	0.276	0.06
	mean	618	3	215	0.002	0.01	0.09	0.09	0.188	0.03
GW-16	min	720	2	195	0.000	0.00	0.04	0.01	0.125	0.00
(S)	max	936	7	248	0.020	0.38	0.11	0.23	0.650	0.08
	mean	795	4	211	0.005	0.06	0.08	0.11	0.257	0.04
GW-16	min	844	15	300	0.000	0.00	0.02	0.05	0.122	0.00
(D)	max	1080	24	381	0.033	0.04	0.11	0.36	0.433	0.07
	mean	941	19	348	0.005	0.01	0.06	0.14	0.215	0.03
GW-18	min	832	1	337	0.000	0.00	0.14	0.06	0.264	0.00
	max	1048	4	380	0.013	0.16	0.30	0.32	0.693	0.10
	mean	914	2	360	0.004	0.03	0.25	0.16	0.448	0.03
GW-19	min	584	1	200	0.000	0.00	0.16	0.11	0.342	0.00
	max	804	6	278	0.008	0.07	0.41	0.24	0.676	0.06
	mean	701	3	235	0.003	0.04	0.25	0.18	0.470	0.03
GW-20	min	436	3	135	0.000	0.00	0.13	0.13	0.282	0.00
	max	580	8	214	0.007	0.04	0.30	0.18	0.515	0.05
	mean	506	5	167	0.003	0.02	0.20	0.16	0.378	0.03
GW-21	min	500	1	172	0.000	0.00	0.12	0.03	0.203	0.00
(S)	max	684	4	188	0.006	0.05	0.25	0.13	0.366	0.06
	mean	608	2	180	0.002	0.02	0.22	0.06	0.296	0.02
GW-21	min	464	1	178	0.000	0.00	0.14	0.02	0.183	0.00
(D)	max	680	4	212	0.006	0.03	0.26	0.20	0.416	0.03
	mean	622	2	191	0.002	0.01	0.22	0.06	0.290	0.02
GW-22	min	484	4	76	0.000	2.32	0.02	0.09	2.776	0.00
(S)	max	748	9	222	0.016	4.28	0.16	0.45	4.830	0.10
	mean	575	6	130	0.006	3.25	0.09	0.27	3.603	0.04
GW-22	min	540	1	192	0.002	0.00	0.72	0.11	1.042	0.05
(M)	max	668	3	222	0.007	0.34	1.03	0.30	1.316	0.15
	mean	635	2	202	0.004	0.10	0.88	0.16	1.137	0.10
GW-22	min	572	1	222	0.000	0.02	0.74	0.06	0.984	0.00
(D)	max	756	6	314	0.010	0.24	0.96	0.16	1.130	0.12
	mean	693	3	253	0.005	0.06	0.88	0.13	1.071	0.05
GW-24	min	1084	8	490	0.000	0.08	0.00	0.18	0.320	0.00
	max	1316	17	538	0.008	1.82	0.11	0.35	2.094	0.06
	mean	1182	12	514	0.004	0.98	0.04	0.24	1.256	0.02
GW-25	min	456	2	272	0.001	0.01	0.38	0.10	0.572	0.00
	max	924	6	360	0.012	0.04	0.62	0.39	0.882	0.04
	mean	788	4	315	0.004	0.03	0.50	0.20	0.733	0.02
W1-1	min	3940	4	2300	0.003	0.06	0.69	0.98	1.876	0.02
(S)	max	5060	8	2856	0.017	0.35	1.56	1.87	3.493	0.02
	mean	4372	6	2612	0.007	0.17	1.11	1.32	2.605	0.02
W1-2	min	3936	5	2240	0.005	0.04	1.69	1.01	3.964	0.00
(S)	max	4744	6	2335	0.024	0.18	3.17	2.36	4.477	0.02
	mean	4276	5	2295	0.010	0.10	2.64	1.40	4.153	0.01
W2-1	min	520	2	355	0.001	0.00	0.05	0.13	0.191	0.01
(S)	max	1164	5	372	0.005	0.00	0.17	0.35	0.505	0.02
	mean	864	4	362	0.003	0.00	0.11	0.19	0.308	0.01

Table 5-5 continued

Well ID		Total Dissolved Solids (ppm)	Chloride (ppm)	Sulfate (ppm)	Nitrite as N (ppm)	Nitrate as N (ppm)	Ammonia as N (ppm)	Organic Nitrogen as N (ppm)	Total Nitrogen as N (ppm)	Dissolved PO_4 as P (ppm)
W2-2	min	952	1	385	0.002	0.00	0.53	0.09	0.706	0.01
(D)	max	1156	3	400	0.008	0.04	0.66	0.34	1.028	0.02
	mean	1009	2	393	0.005	0.03	0.58	0.24	0.850	0.01
W2-2	min	888	1	360	0.003	0.03	0.52	0.15	0.733	0.02
(S)	max	1148	3	365	0.022	0.07	0.61	0.25	0.862	0.03
	mean	983	2	363	0.009	0.04	0.55	0.19	0.796	0.02
W3-1	min	3288	4	1560	0.009	0.18	4.57	0.82	5.597	0.01
(S)	max	3296	6	1775	0.027	0.29	6.50	0.85	7.649	0.03
	mean	3292	5	1668	0.018	0.24	5.54	0.84	6.623	0.02
W3-2	min	4282	2	2130	0.005	0.10	16.80	0.60	17.955	0.20
(S)	max	4812	15	2150	0.014	0.16	17.25	2.26	19.234	0.21
	mean	4547	8	2140	0.010	0.13	17.03	1.43	18.595	0.21
W4-1	min	908	14	371	0.001	0.03	0.00	0.09	0.145	0.01
(D)	max	1120	16	385	0.005	0.15	0.56	0.29	1.005	0.36
	mean	1027	15	378	0.004	0.07	0.23	0.16	0.464	0.13
W4-1	min	892	11	385	0.001	0.03	0.08	0.14	0.262	0.01
(S)	max	1004	11	385	0.012	0.04	0.21	0.69	0.941	0.54
	mean	948	11	385	0.006	0.04	0.15	0.42	0.602	0.28
W5-1	min	852	1	420	0.001	0.00	0.12	0.05	0.261	0.01
(D)	max	1012	2	450	0.016	0.04	0.38	0.14	0.486	0.03
	mean	942	2	437	0.006	0.01	0.28	0.09	0.388	0.02
W5-1	min	924	1	466	0.001	0.00	0.36	0.13	0.491	0.01
(S)	max	1116	45	500	0.078	0.04	0.71	0.29	0.923	0.05
	mean	1037	16	485	0.022	0.02	0.52	0.19	0.747	0.04
W5-2	min	2472	1	1128	0.002	0.02	3.04	0.69	3.774	0.01
(S)	max	2980	2	1172	0.010	0.06	6.40	1.24	7.332	0.04
	mean	2768	1	1144	0.006	0.04	3.94	0.98	4.961	0.02
W7-2	min	2668	8	1528	0.001	0.00	0.76	0.67	1.536	0.00
(D)	max	2988	11	1625	0.026	0.18	1.04	0.80	2.036	0.02
	mean	2794	10	1571	0.013	0.07	0.90	0.74	1.730	0.01
W7-2	min	2044	10	1049	0.000	0.00	0.13	0.52	0.006	0.00
(S)	max	4224	408	1100	0.006	0.08	0.38	0.75	1.193	0.07
	mean	2867	143	1075	0.003	0.05	0.25	0.64	0.633	0.02
W7-3	min	4348	5	2320	0.001	0.04	0.66	1.40	2.551	0.00
(D)	max	4956	6	2325	0.005	0.06	1.32	1.85	2.862	0.03
	mean	4611	6	2323	0.003	0.05	1.05	1.63	2.733	0.01
W7-3	min	3384	3	1688	0.007	0.10	4.78	1.93	7.726	0.00
(S)	max	4368	4	1975	0.044	0.22	13.60	2.83	15.766	0.04
	mean	3999	3	1809	0.021	0.17	10.62	2.32	13.133	0.02
W7-4	min	924	2	328	0.001	0.00	1.39	0.36	1.961	0.00
(S)	max	3384	52	1688	0.007	0.16	11.50	2.09	13.757	0.12
	mean	1494	15	677	0.003	0.05	3.60	0.81	4.463	0.05
W7-5	min	1672	3	610	0.002	0.03	11.30	0.73	12.136	0.00
(S)	max	2716	113	720	0.006	0.10	14.80	1.83	16.462	1.14
	mean	2012	40	673	0.005	0.07	13.43	1.10	14.598	0.46
W7-6	min	1250	6	520	0.002	0.00	2.30	0.75	3.092	0.00
(D)	max	1256	8	569	0.007	0.22	3.07	0.93	4.024	0.17
	mean	1253	7	545	0.004	0.09	2.76	0.86	3.708	0.06
W7-6	min	916	6	296	0.001	0.03	1.72	0.68	2.513	0.00
(S)	max	1268	8	415	0.019	0.10	2.88	0.91	3.896	0.23
	mean	1108	7	356	0.007	0.07	2.47	0.79	3.335	0.09
W7-7	min	1184	3	410	0.002	0.03	3.53	0.67	4.262	0.00
(S)	max	1848	4	426	0.011	0.06	5.17	3.42	8.622	0.47
	mean	1409	4	418	0.005	0.04	4.16	1.64	5.848	0.28

Total Nitrogen as N

Total nitrogen concentrations observed in wells surrounding the Oakwood Lakes will be used to calculate the ground water contributions to the nitrogen budget for the Oakwood Lakes. Land wells that exhibited the highest total N concentrations are plotted at a larger scale in Figure 5-11A. Wells with less than 3 ppm total N are presented in Figure 5-11B. Wells north and south of Johnson Lake and south of Turtle Lake appear to have the greatest potential for contributing significant quantities of nitrogen to the lake system.

Mean total N concentrations found in land wells ranged from .115 ppm at GW-14S to 17.5 ppm at GW-11S. Concentrations at in-lake wells were generally higher and ranged from .388 ppm at W5-1D to 18.59.3 ppm at W3-2S (Table 5-5). Note that two land wells with high nitrogen, GW-11S and GW-11M (4.84 ppm), are only 75 feet from in-lake wells W5-1S and W5-1D (Figure 5-2) with .388 ppm and .747 ppm respectively. They are all four screened in the same layer of sand and gravel and GW-11M and W5-1D are screened at the same elevation. W5-1S is screened at an elevation between GW-11S and GW-11M. Lower nitrogen observed at W5-1D may indicate that the origin of water at W5-1D is deeper in the profile than where GW-11M is screened or that nitrogen is being lost as it moves toward the lake.

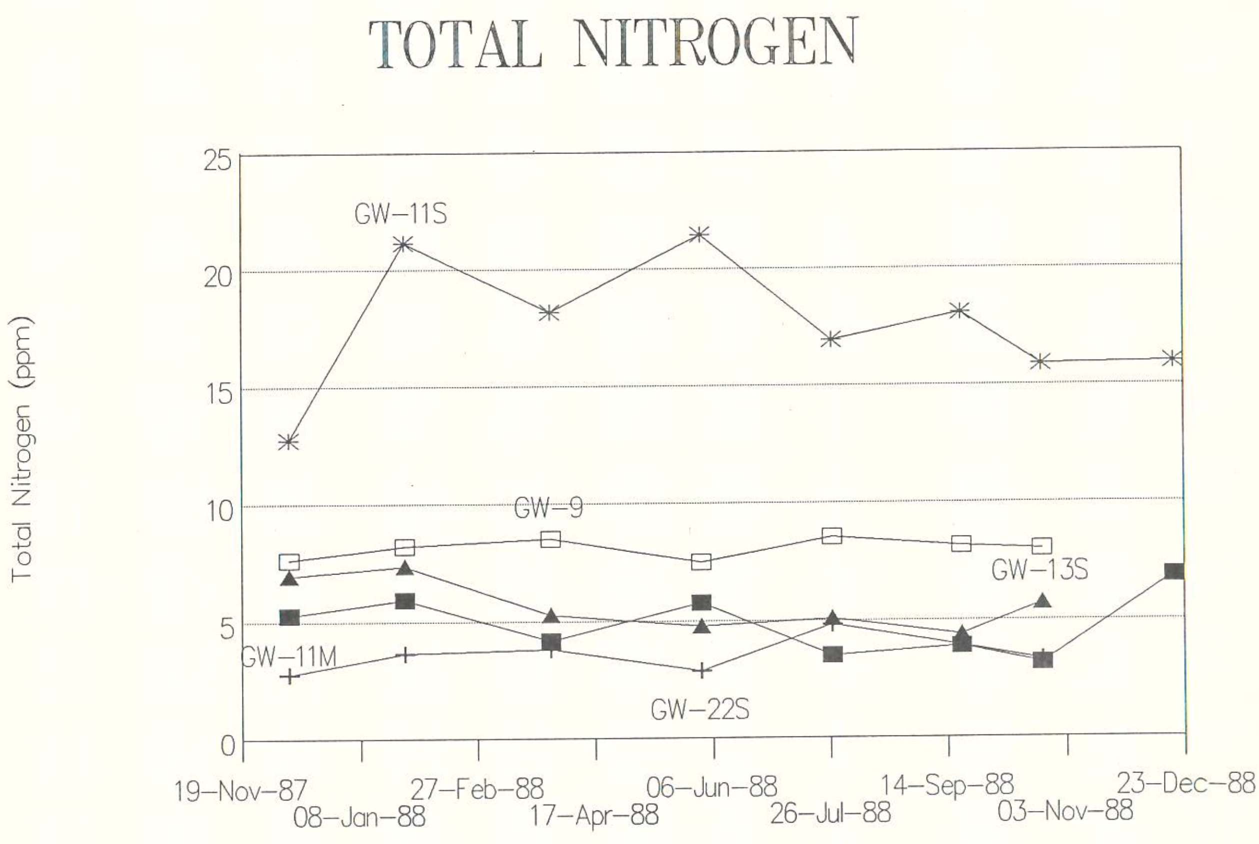


Figure 5-11A. Total nitrogen concentrations in Oakwood Lake land wells.

TOTAL NITROGEN in OLSS WELLS in 1988

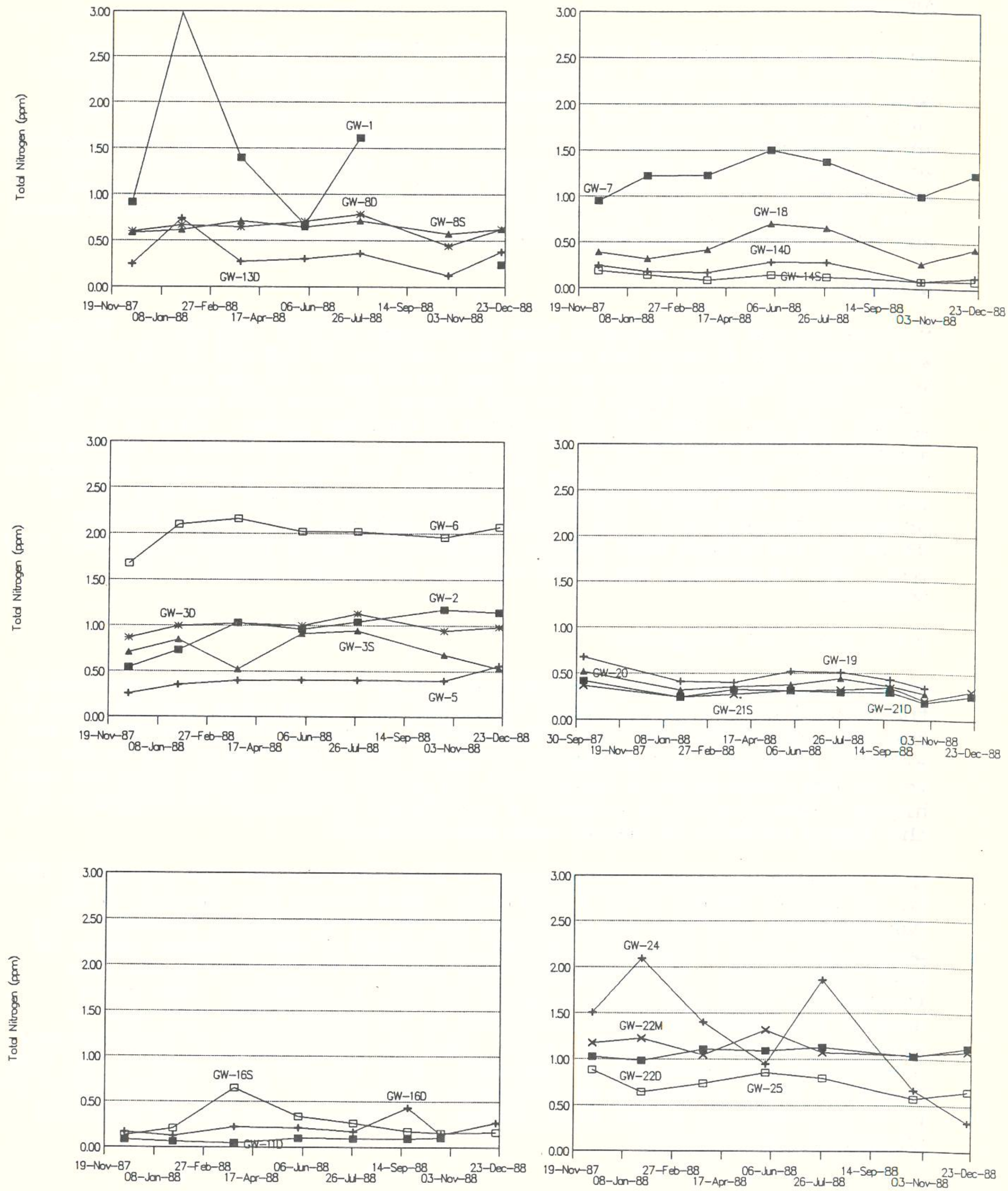


Figure 5-11B. Total nitrogen concentrations in Oakwood Lake land wells.

Ammonia

Ammonia was the dominant form of nitrogen in some OLSS land wells in 1988. Wells GW-6 and GW-7 with 1.89 ppm and 1.11 ppm respectively had the highest mean concentrations of ammonia among land wells. Several in-lake wells, (W3-2S, W7-3S and W7-5S) had very high ammonia concentrations (Table 5-5). These wells are all shallow (3 ft.) and screened in mud although other shallow wells screened in the similar materials do not exhibit high ammonia levels. In-lake wells W2-1S and W4-1S had the lowest concentrations of ammonia of in-lake wells with .11 ppm and .15 ppm respectively. Both are screened in gravel and are adjacent to land wells that are also low in ammonia.

Nitrate

Nitrate was the other dominant form of nitrogen in OLSS land wells. Nitrate was above 1 ppm in only four wells, GW-9, GW-11S, GW-11M and GW-13S which had mean nitrate concentrations of 7.76 ppm, 16.99 ppm, 4.59 ppm and 5.26 ppm respectively. All of these wells are located in areas with pasture or trees as the land use. They are all screened in sand and gravel. GW-9 is located approximately 75 feet from a pit privy near the swimming beach at the Oakwood State Park. There has been some speculation that this may account for some of the nitrates even though the privy is between the lake and the well and is probably down gradient. The in-lake wells were all quite low in nitrate. W3-1S had the highest mean nitrate concentration among in-lake wells with 0.24 ppm. This is probably due to the reducing environment common to lake sediments.

Total Dissolved Phosphorus

Total dissolved phosphorus concentrations observed in land wells surrounding the Oakwood Lakes will be used to calculate the ground water contributions to the phosphorus budget for the Oakwood Lakes. Trends in total phosphorus for all OLSS land wells are presented in Figure 5-13. Most wells fall in the .02 to .06 ppm range which is significant for ground water. Other wells are much higher. Ground water is probably a significant contributor of Phosphorus to the system although it has not been quantified yet.

Mean phosphorus concentrations found in land wells ranged from .11 ppm at GW-9 to .01 ppm at several wells (Table 5-5). GW-9 is the well located in the Oakwood State Park near the pit privy and may be affected by leachate. The second well with a high mean, GW-22M, is located at the southeast corner of East Oakwood Lake. It is possible that water is flowing out of the lake through the thick sand layer in which the well is screened. This could account for higher levels of phosphorus in the medium depth well than in either the shallow or the deep well. This may be confirmed or rejected when analysis of flow gradients is completed. Most in-lake wells were in the same range for total phosphorus as land wells (Table 5-5). W3-2S, W7-5S, W4-1S and W7-7S were somewhat higher with .21 ppm, .46 ppm, .28 ppm and .28 ppm total phosphorus respectively.

TOTAL DISSOLVED PHOSPHORUS

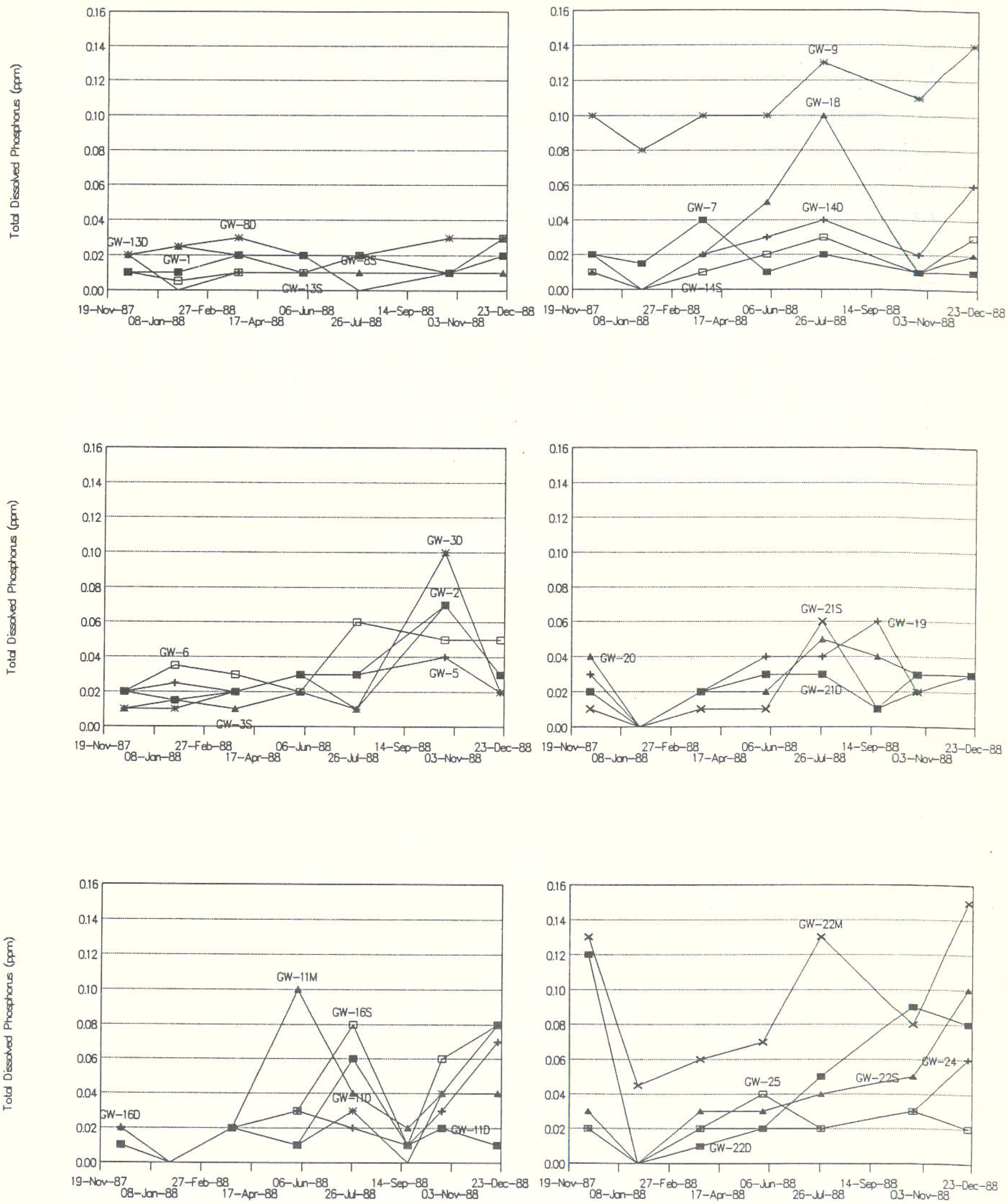


Figure 5-12 Total phosphorus concentrations in Oakwood Lake land wells.

Chloride

Chloride is a conservative parameter that was included in the set of parameters to be analyzed for in OLSS ground water samples to determine similarities between ground water taken from land wells and water collected in in-lake wells and seepage meters. This information may help confirm connections that are suspected from drilling information and analysis of flow gradients. In order for this information to be useful, differences in chloride concentrations between individual wells in the same area would be desirable. Wells GW-1, GW-16D and GW-24 had higher concentrations than other wells and are plotted in a larger scale in (Figure 5-13A). GW-1 and GW-24 are some distance from the lake and will not be very useful for drawing connections with in-lake wells. GW-16D is significantly different than GW-16S and may be useful in drawing comparisons. In-lake wells W4-1S and W4-1D that are located near the GW-16 land wells are intermediate with 11 ppm and 15 ppm mean chloride respectively (Table 5-5). Most land wells are below 10 ppm chloride and may not be very useful in making comparisons to in-lake wells. A few in-lake wells had very high concentrations of chloride which may have been due to contamination. Note that GW-9 had chloride concentrations between 5 and 10 ppm which is not consistent with the theory that it is contaminated by leachate from the pit privy.

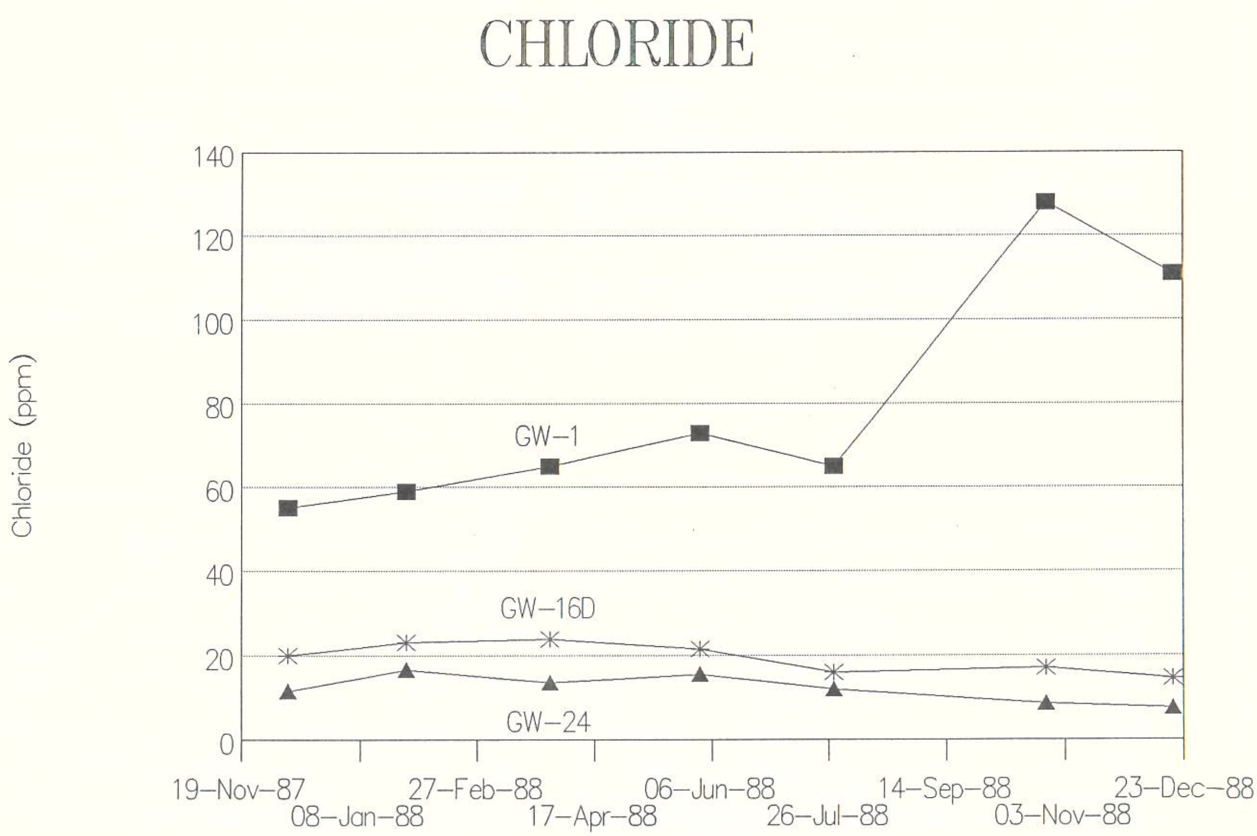


Figure 5-13A. Chloride Concentrations in Oakwood Lake land wells in 1988.

CHLORIDE in OLSS WELLS 1988

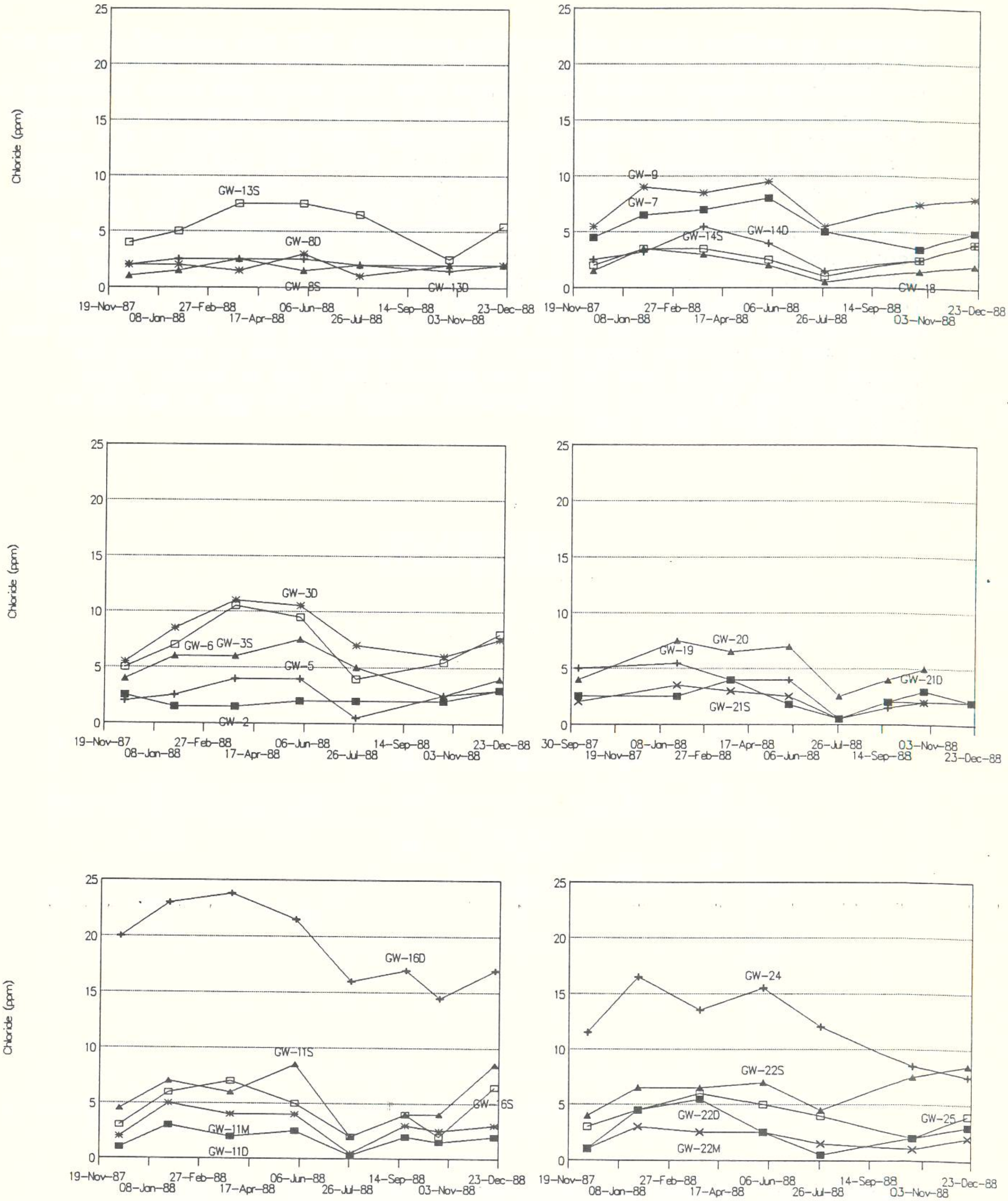


Figure 5-13B. Chloride concentrations in Oakwood Lake land wells.

Sulfate

Sulfate is another fairly conservative parameter that was included in the set of parameters to be analyzed for in OLSS ground water samples to determine similarities between ground water taken from land wells and water collected in in-lake wells and seepage meters. In order for this information to be useful, differences in sulfate concentrations between individual wells in the same area would be desirable. Wells GW-1, GW-3D, GW-5, GW-6 and GW-7 had higher concentrations than other wells and are plotted in a larger scale in (Figure 5-14A). These wells are located south of Johnson Lake except for GW-1 (Figure 5-2). There are significant differences between concentrations in other land wells (Figure 5-14B) but comparisons with in-lake wells may not be valid due to high concentrations of sulfate in some in-lake wells that may be influenced by sediment chemistry (Table 5-5). For example the GW-11 well nest had mean sulfate from 71 to 149 ppm but adjacent W5-1 in-lake wells had 437 to 485 ppm sulfate (Table 5-5). Mean concentrations of sulfate for in-lake wells ranged from 362 ppm at W2-1S to 2612 ppm at W1-1S. Mean concentrations of sulfate for land wells ranged from 67 ppm at GW-13S to 1038 ppm at GW-5 (Table 5-5).

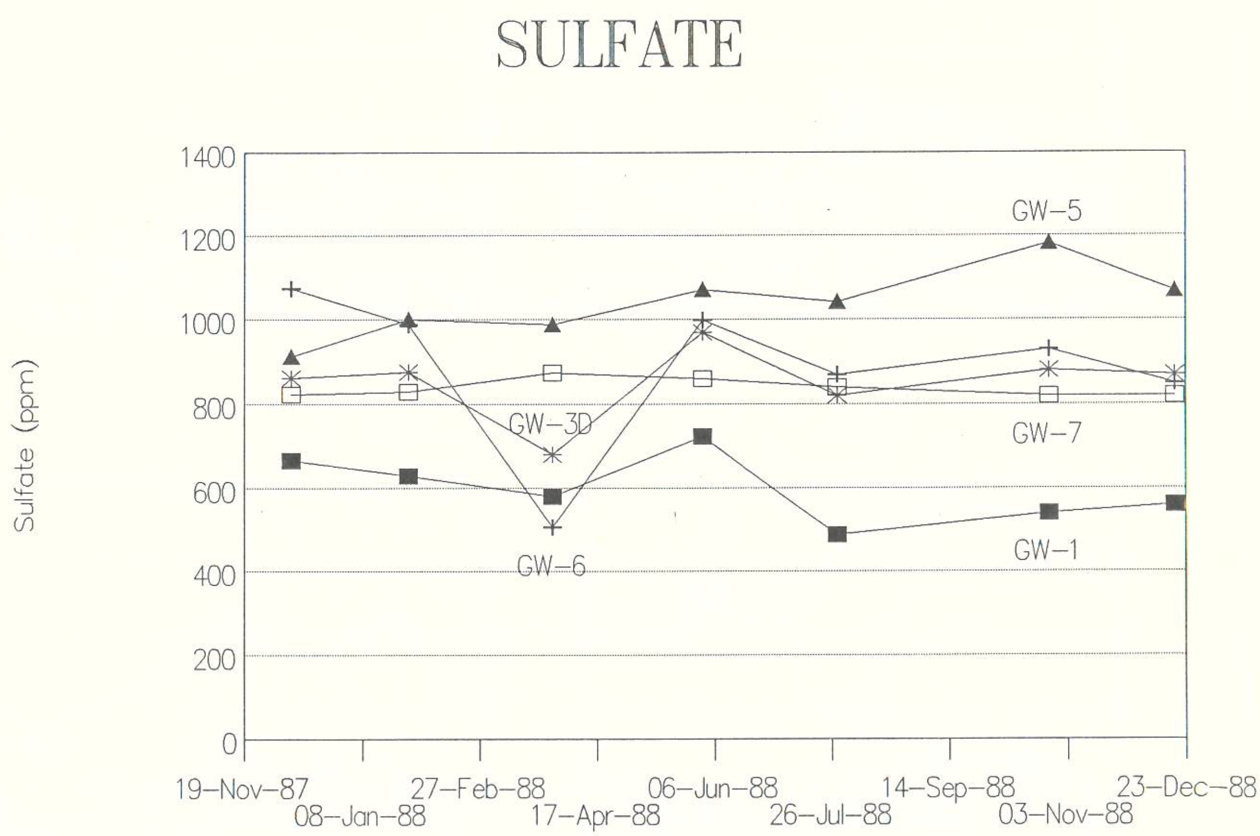


Figure 5-14A. Sulfate concentrations in Oakwood Lake land wells.

SULFATE in OLSS WELLS 1988

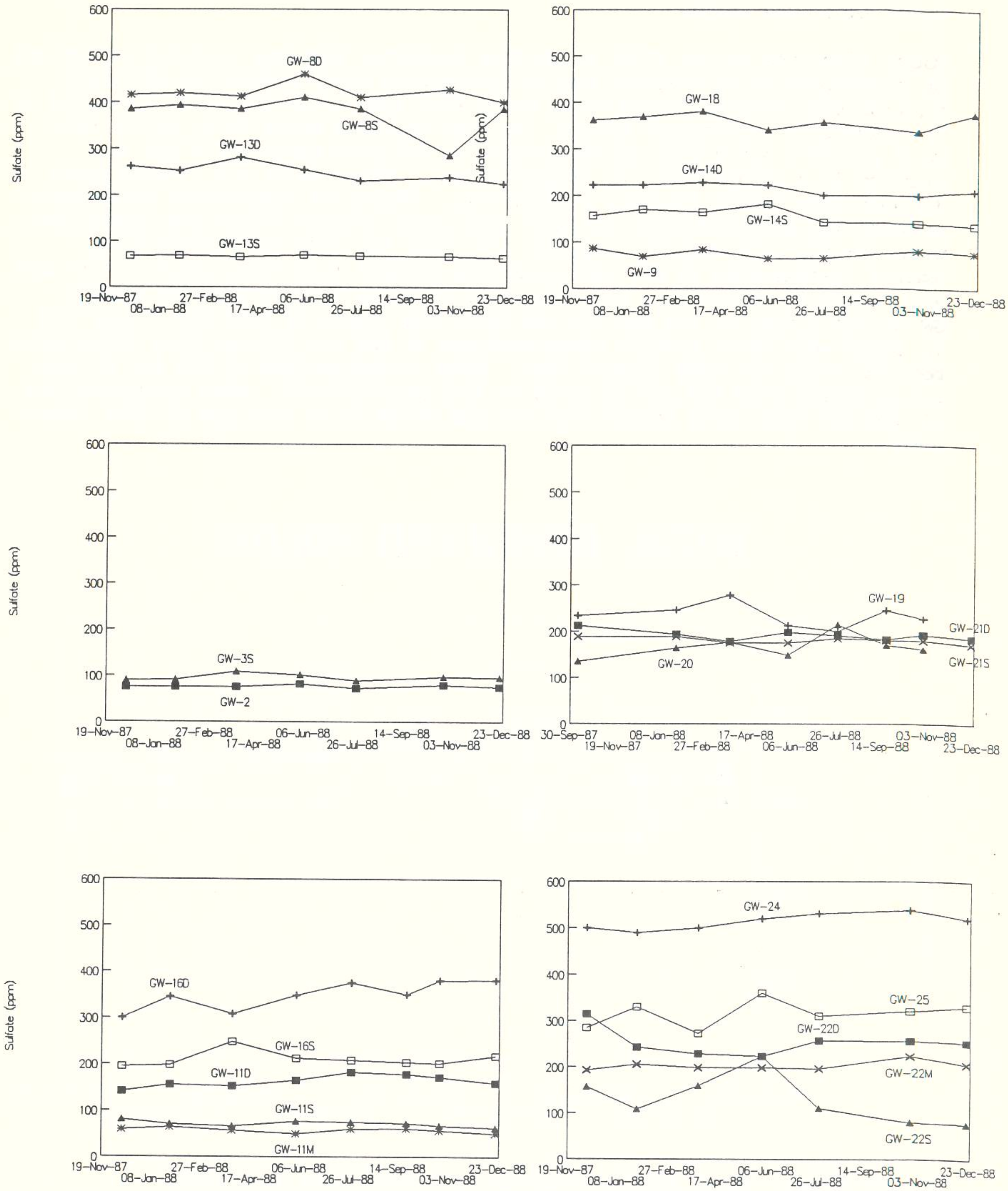


Figure 5-14B. Sulfate concentrations in Oakwood Lake land wells.

Total Dissolved Solids

Total dissolved solids (TDS) is another parameter that was included in the set of parameters to be analyzed for in OLSS ground water samples to determine similarities between ground water taken from land wells and water collected at in-lake wells and seepage meters. As with sulfates wells GW-1, GW-3D, GW-5, GW-6 and GW-7 had higher concentrations of TDS than other wells and are plotted in a larger scale in (Figure 5-15A). These wells are located south of Johnson Lake except for GW-1 (Figure 5-2). There are significant differences between TDS concentrations in other land wells (Figure 5-14B) and comparisons with in-lake wells may be possible. In order for this information to be useful, differences in TDS concentrations between individual wells in the same area would be desirable. For some nests of wells this is true for example GW-3S has a mean of 464 ppm TDS and GW-3D has a mean of 1678 ppm (Table 5-5). In other well nests however concentrations of TDS are similar when comparisons between wells are made (Figure 15B). Mean concentrations of TDS for in-lake wells ranged from 864 ppm at W2-1S to 4611 ppm at W7-3D. Mean concentrations of TDS for land wells ranged from 464 ppm at GW-3S to 1678 ppm at GW-5 (Table 5-5).

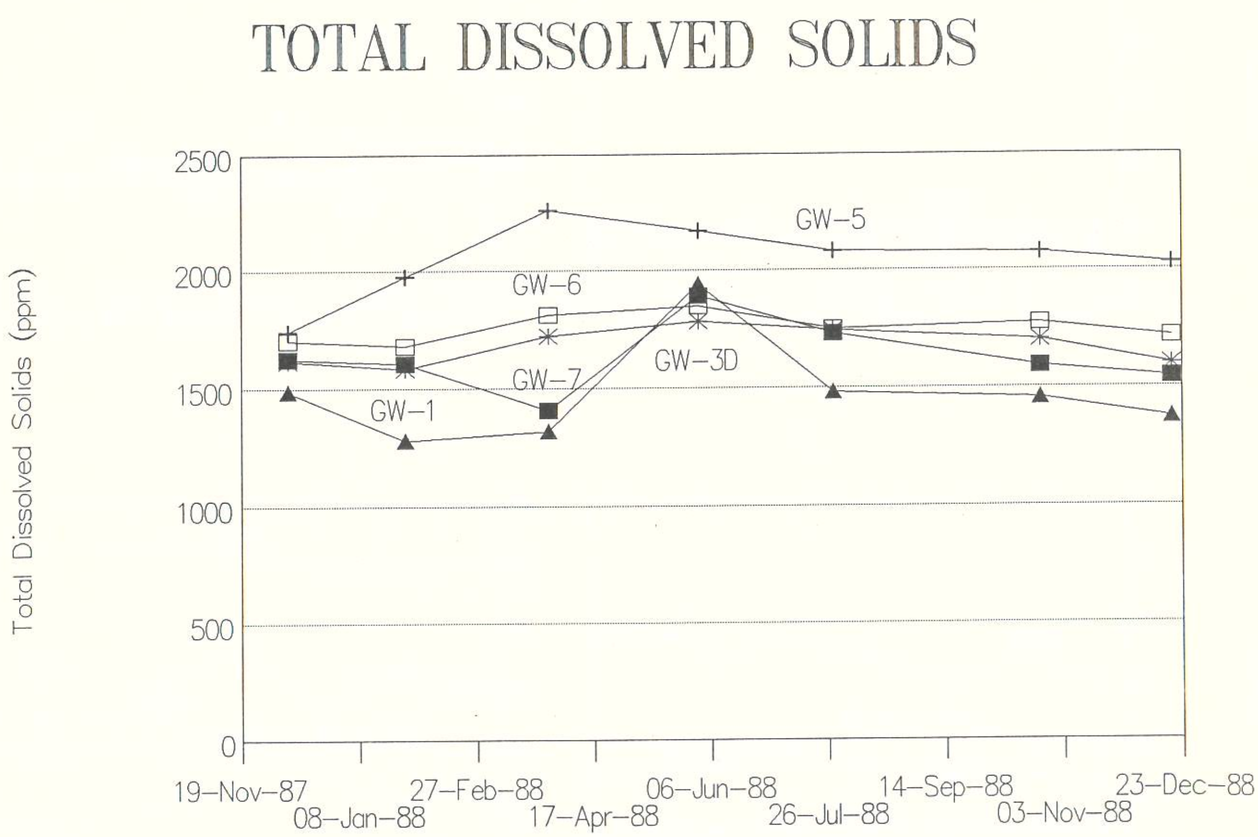


Figure 5-15A. Total dissolved solids in Oakwood Lake land wells.

TOTAL DISSOLVED SOLIDS in OLSS WELLS

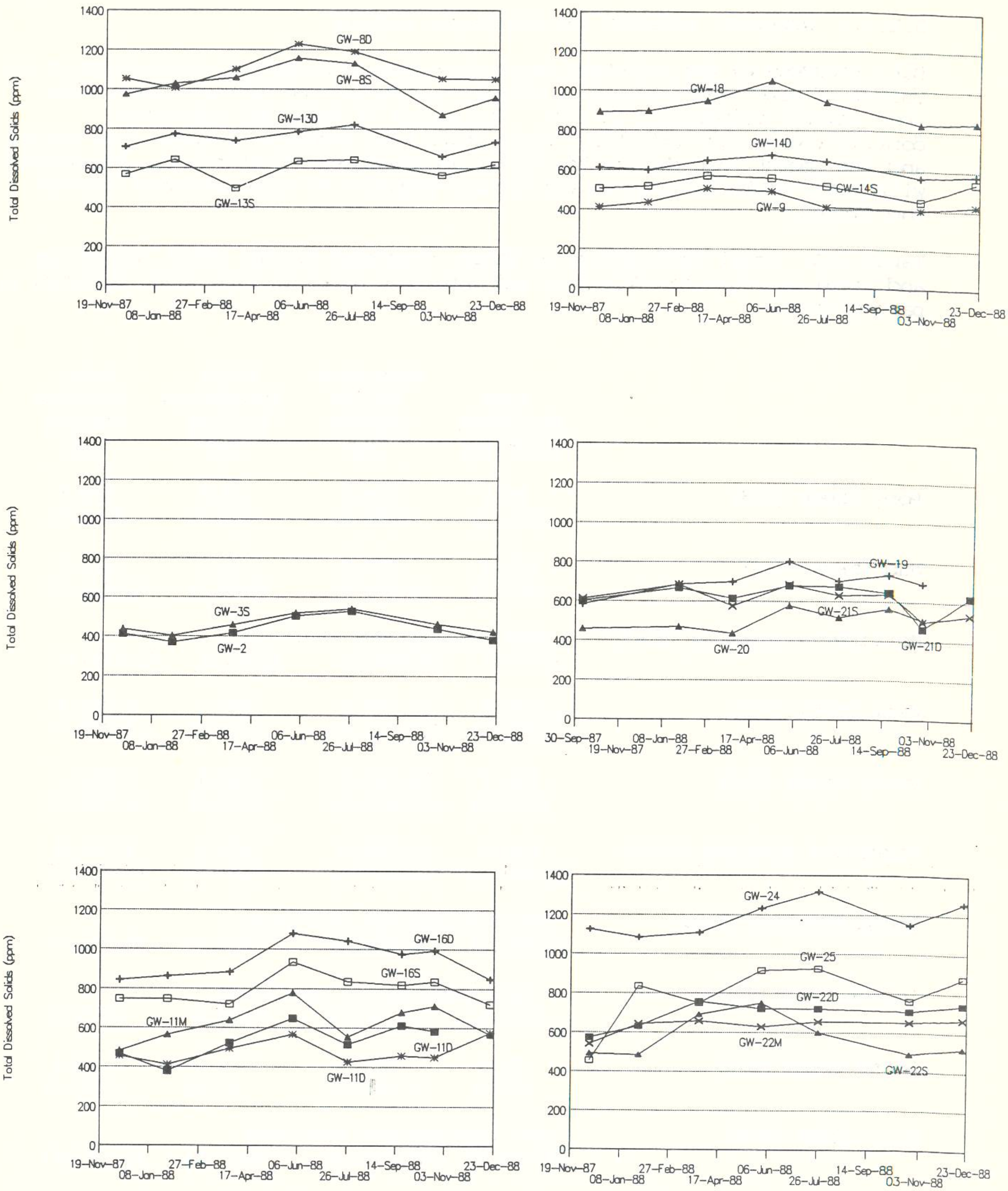


Figure 5-15B. Total dissolved solids in Oakwood Lake land wells.

5.2.3.4 Nutrient, Sediment and Hydrologic Budgets

Data produced by the tributary monitoring program permitted calculation of the volume of water and the mass of nutrients entering the Oakwood Lake System from several tributaries in 1988. The amount of water and nutrients contributed by each tributary, those which were exchanged between lake basins and the amount lost through the outlet is presented in Table 5-6. Arrangement within the table is based on the natural sequence of water movement through the system.

Table 5-6. Total Contribution of Water, Suspended Solids, Total Phosphorus and Total Nitrogen for Tributary and Interlake Sites in 1988 (1987 loadings in parenthesis).

	1988 Discharge (acre ft)	Suspended Solids Loading (kg)	Total Phosphorus Loading (kg)	Total Nitrogen Loading (kg)
Pony Creek (T-3)	39.4 (133.1)	746.3 (950.4)	32.6 (96.7)	110.6 (453.9)
Mud Creek (T-4)	121.2 (493.2)	371.9 (8,026.0)	71.1 (263.1)	283.6 (2,204.8)
Mortimer's Crossing (IL-3)	1988 loadings not available (512.4)	(9,684.1)	(106.0)	(1,197.1)
West Creek (T-1)	1,089.9 (2,200.3)	33,165.4 (43,301.2)	403.1 (553.5)	3,056.6 (6,898.3)
Crazy Creek (T-2)	565.7 (866.5)	10,840.1 (41,675.1)	306.4 (339.4)	1,533.1 (3,590.2)
Kimball's Crossing (IL-1)	874.3 (3,445.1)	24,994.3 (66,887.4)	263.1 (517.1)	3,231.8 (6,607.5)
Round Crossing (IL-2)	1988 loadings not available (1,127.5)	(24,798.0)	(172.3)	(2,261.6)
Loomis Creek (T-5)	1988 loadings not available (104.4)	(2,105.7)	(158.6)	(676.8)
Goose Creek (T-6)	15.8 (53.0)	327.6 (1,509.4)	4.6 (7.8)	66.2 (192.4)
Mill Creek (T-0)	1988 loadings not available (4,319.5)	(55,581.3)	(427.9)	(7,560.9)

The total tributary load was not calculated in 1988 because loadings for some sites were not available in time for inclusion in this report. A spring snow storm caused disruption in some stage records and shifts in the stage to discharge relationship for other portions of the record. Further analysis will be required to make optimal use of this stage data for calculating loadings. Direct measurement of flow and integration between flow points was used to calculate portions of the loadings . The loadings presented in Table 5-6 are provisional and may change slightly when analysis is complete. The loadings that were contributed by each tributary in 1987 are included in parenthesis.

Additional work is also needed to estimate ground water flux, direct runoff from unmonitored watershed areas, loss and gain due to lake level changes and the effect of precipitation and evaporation. Data was collected to make these calculations and estimates but it will not be interpreted until additional survey work and mapping is completed.

Hydraulic Budget

Hydraulic loadings for most tributaries were far lower in 1988 than in 1987. These loadings represent a year with very little snow pack and extreme drought during summer. West Creek contributed the greatest volume of water (1089.9 acre feet) to the system in 1988. Goose Creek contributed the least with 15.8 acre feet. There was much less transfer between basins in 1988 for two reasons. Lake levels were lower at the beginning of 1988 so more water was needed to fill the basins before out flow could begin. Second local people partially blocked the culverts at Kimball's Crossing for most of the summer so water flowed more slowly into East Oakwood Lake in 1988. Transfer of water through Round Crossing was also reduced. Reduced hydraulic loadings and the blockage between basins produced reduced flushing rates which probably impacted the way plankton populations developed in 1988. The basins were more isolated and would be expected to behave more as individual lakes. Reduced connections between the lakes also affected fish migration. Reduced migration following the partial winter kill early in 1988 combined to produce greater differences in fish populations between East and West Oakwood lakes. This should enhance the statistical analysis which will be carried out in 1989 to sort out the water quality impacts of fish populations.

Suspended Solids Budget

All tributaries and interlake sites contributed less suspended sediment to the Oakwood Lakes in 1988. The largest reduction in suspended solids occurred at Mud Creek, from 8,026 kg in 1987 to only 371.9 kg in 1988. Crazy Creek also contributed much less suspended solids in 1988. In 1987 it produced nearly as much suspended sediment as West Creek (Table 5-6). The output of suspended solids by West Creek is probably reduced somewhat by the large wetland complex that much of the watershed drains through before entering the lake system. Much of the 24,994 kg of suspended solids that passed through Kimball's Crossing was probably in the form of organic material produced within the lake basin.

Phosphorus Budget

Tributary loads of phosphorus were also reduced at all tributaries in 1988 although not as much as some of the other parameters (Table 5-6). West Creek and Crazy Creek contributed 403.1 kg and 306.4 kg respectively to the system in 1988. This represents nearly as much phosphorus contributed in 1987 by these tributaries. A substantial amount of phosphorus (263.3 kg) was also transferred through Kimball's Crossing into East Oakwood lake. Goose Creek again produced the least phosphorus with only 4.6 kg. The reduced amount of phosphorus loading in 1988 may have had some impact on the growth of algae in the lake. Although nitrogen was probably limiting in the early summer there was more evidence of phosphorus limitation in late summer and much lower levels of available phosphorus.

Nitrogen Budget

Tributaries contributed less nitrogen to the system in 1988 than in 1987. West Creek and Crazy Creek were the largest contributors with 3,056 kg and 1,533 kg respectively. A large amount (3,231.8) also passed through Kimball's Crossing. The smallest tributary Goose Creek produced the least amount of total nitrogen (66.2 kg).

5.3.0 Phytoplankton and Zooplankton Dynamics

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5.3.1 Introduction

The purpose of this part of the study was to monitor the water clarity and the abundance of phytoplankton and zooplankton species at all of the seven in-lake stations. Since excess phytoplankton are a major degrader of water quality in the Oakwood lakes system, phytoplankton abundance needs to be known in order to evaluate the success of any management plan. Zooplankton graze on the phytoplankton and lower their abundance, increasing the clarity of the water. Zooplankton abundance needs to be monitored in order to estimate what fraction of the changes in phytoplankton numbers can be attributable to zooplankton grazing as opposed to changes in nutrient loading.

5.3.2 Monitoring Design

Replicate phytoplankton and zooplankton samples were collected from all seven stations on 15 dates during 1987 and on 14 dates during 1988. Phytoplankton samples were taken from the same bottle cast as the samples for chemical analysis. Zooplankton were sampled by both vertical net tows (0.3m diameter), and horizontal tows with a larger net (1m diameter). In the laboratory, samples were counted by species and values represented by numbers and biomass (gm) or biovolume (ml) estimates. Water clarity was measured by replicate secchi disc measurements taken at the same time and location as the plankton samples.

5.3.3 Results

5.3.3.1 Comparison of Phytoplankton Density, Water Clarity, Nutrient levels, and Zooplankton Density.

In both 1987 and 1988, the lowest phytoplankton densities were found in station 7 (East Oakwood Lake), the most downstream location in the lake system, and the highest densities were recorded in station 5 (Turtle Lake), one of the upstream locations in the system (Table 5-7). Station 1, the other upstream location in the system, did not show as high an algal density as station 5, possibly indicating either lower nutrient loading or increased zooplankton grazing at station 1 relative to station 5. Densities were higher at all stations and for all seasons in 1988 than they were in 1987, despite the fact that nutrient loadings were not higher in 1988. This could have reflected either less grazing pressure in 1988, or a response to different weather conditions. Rainfall was lower in 1988, and temperatures and evaporation rates were higher. This would be expected to result in less dilution of phytoplankton by runoff and more concentration by evaporation in 1988 than in 1987.

Table 5-7. Comparison of 1987 and 1988 Phytoplankton Density Means by Season (ml Biovolume /m^3).

1987	L-1	L-2	L-3	L-4	L-5	L-6	L-7	Avg
Winter	4	4	4	1	3	1	2	3
Spring	64	86	68	71	95	71	32	68
Early Summer	24	20	48	25	31	54	48	38
Late Summer	99	97	94	76	158	75	45	84
Fall	9	9	7	12	19	13	3	13
Open Water Avg	49	53	54	46	76	53	32	51
1988								
Winter	15	15	28	7	24	48	27	23
Spring	112	116	169	136	293	186	132	173
Early Summer	235	223	219	168	251	173	107	189
Late Summer	187	176	200	241	190	201	270	212
Fall	115	111	103	135	80	98	67	101
Open Water Avg	162	157	173	170	204	165	144	169

Water clarity showed an inverse pattern of distribution to phytoplankton density (Table 5-8). This indicated that the phytoplankton were a major factor degrading water clarity. Water clarity was greatest at station 7 where phytoplankton were least abundant, and lowest at station 5, where phytoplankton was most abundant. This relationship was present both years. Seasonal water clarity was greatest in the spring of 1988 following the partial winterkill in East Oakwood Lake (station 7). 1988 values for water clarity were, on the average, lower than 1987 values reflecting the greater quantity of algae present in the lake in 1988.

Table 5-8. Comparison of 1987 and 1988 Water Clarity Means by Season (Secchi disc, ft.)

1987	L-1	L-2	L-3	L-4	L-5	L-6	L-7	Avg
Winter				NOT TAKEN				
Spring	1.4	1.7	1.7	1.8	1.3	1.4	2.4	1.7
Early Summer	0.9	1.7	1.7	1.8	0.8	1.3	1.8	1.4
Late Summer	0.7	0.7	0.6	0.6	0.6	0.7	0.7	0.7
Fall	1.4	2.0	2.4	1.0	1.0	1.7	2.1	1.8
Open Water Avg	1.1	1.5	1.6	1.5	0.9	1.3	1.8	1.4

1988								
Winter	2.3	3.2	1.9	3.2	2.5	3.1	6.1	3.5
Spring	1.9	2.1	1.8	1.7	1.4	1.6	3.7	2.2
Early Summer	0.9	1.4	1.4	1.5	0.7	1.0	2.0	1.3
Late Summer	0.3	0.4	0.3	0.4	0.3	0.3	0.5	0.4
Fall	0.7	0.8	1.1	1.1	1.1	1.7	1.2	1.1
Open Water Avg	1.0	1.2	1.2	1.2	0.9	1.2	1.9	1.3

Combined nitrite and nitrate nitrogen showed the same pattern of distribution between stations as phytoplankton abundance. Values were highest at station 5 and lowest at station 7, during both 1987 and 1988. However, the nutrient differences between years did not reflect differences in biovolume and water clarity between years. Phytoplankton density was higher in 1988 but nitrate and nitrite levels were lower. This could indicate several possibilities. A switch to phytoplankton species having lower nitrate needs in 1988 could result in equal density but different species present. This did happen, Anacystis in 1987 was replaced as the most abundant species by Aphanizomenon in 1988. Aphanizomenon can only use ammonia as a nitrogen source, not nitrate. There may also have been greater zooplankton removal rates of algae in 1987. It is also possible that the phytoplankton never were nitrogen limited, but is not likely. The simultaneous downstream depletion of algae as nitrogen levels are depleted indicates nitrogen limitation as does the 1987 multiple regression analysis (Section 5.3.3.2)

Table 5-9. Comparison of 1987 and 1988 Nitrate and Nitrite Means by Season (ppm).

1987	L-1	L-2	L-3	L-4	L-5	L-6	L-7	Avg
Winter	.03	.03	.03	.04	.04	.05	.05	.04
Spring	.07	.05	.05	.04	.07	.05	.03	.05
Early Summer	.11	.07	.06	.06	.11	.06	.05	.07
Late Summer	.11	.10	.10	.10	.13	.08	.09	.10
Fall	.22	.17	.09	.08	.18	.06	.16	.14
Open Water Avg	.13	.10	.08	.07	.12	.06	.08	.09
1988								
Winter	.10	.10	.09	.09	.34	.03	.04	.11
Spring	.04	.03	.03	.05	.06	.05	.03	.04
Early Summer	.09	.07	.05	.05	.09	.07	.06	.07
Late Summer	.15	.14	.14	.13	.16	.12	.10	.13
Fall	.12	.08	.07	.07	.08	.07	.08	.08
Open Water Avg	.10	.08	.07	.08	.10	.08	.07	.08

Ammonia nitrogen levels showed a different pattern of distribution between stations than all previously discussed variables (Table 5-10). In 1987, ammonia levels were highest in late summer and fall in station 6, after the experimental fishkill of that lake in late May. Ammonia remained high at station 6 during the winter of 1988. In 1988, ammonia levels were highest at station 7, showing a sharp peak during the late summer season, after station 7 experienced partial winterkill of fish in 1988. The correlation of high ammonia levels and fishkill is expected, as decomposition of dead organisms releases ammonia. During late summer 1988, station 7 was highest and not lowest in algal density even though its average values were lowest. The major algal species present at station 7 at that time was Aphanizomenon, which uses ammonia as its nitrogen source. Ammonia levels were higher in 1988 than in 1987, and may have been part of the reason that algal density measurements were also higher in 1988.

Table 5-10. Comparison of 1987 and 1988 Ammonia Means by Season (ppm).

1987	L-1	L-2	L-3	L-4	L-5	L-6	L-7	Avg
Winter	.10	.07	.01	.06	.02	.06	.03	.05
Spring	.00	.01	.00	.00	.03	.03	.01	.01
Early Summer	.12	.09	.06	.10	.10	.09	.08	.09
Late Summer	.09	.16	.14	.09	.10	.29	.17	.15
Fall	.88	1.04	1.42	1.38	1.41	1.40	.41	1.13
Open Water Avg	.28	.33	.41	.39	.41	.45	.17	.35

1988								
Winter	1.03	1.00	2.10	2.12	1.20	3.24	0.62	1.61
Spring	.07	.09	.09	.07	.04	.10	.10	.08
Early Summer	.04	.04	.03	.03	.03	.37	.01	.08
Late Summer	.13	.08	.07	.11	.05	.03	.72	.17
Fall	1.77	1.72	2.18	2.10	2.42	2.95	2.87	2.28
Open Water Avg	.50	.48	.59	.58	.64	.86	.93	.65

Orthophosphate levels showed the same pattern of distribution as nitrate levels and phytoplankton abundance when stations were compared within years (Tables 5-11 and 5-12). They were highest at station 5 and lowest at station 7. Phosphate levels, like nitrate levels, were highest in 1987 when algal levels were lower. This indicates either less removal of algae by zooplankton in 1988, or the possibility that the algae were not often limited by phosphate. Multiple regression analysis (Section 5.3.3.3) indicates much less evidence of phosphorous limitation than nitrogen limitation.

Table 5-11. Comparison of 1987 and 1988 Orthophosphate Levels Means by Season (ppm).

1987	L-1	L-2	L-3	L-4	L-5	L-6	L-7	Avg
Winter	.02	.03	.02	.04	.04	.04	.03	.03
Spring	.01	.01	.01	.01	.06	.02	.00	.02
Early Summer	.05	.04	.01	.02	.03	.01	.01	.02
Late Summer	.04	.04	.03	.03	.05	.04	.03	.04
Fall	.08	.05	.05	.06	.08	.06	.06	.06
Open Water Avg	.05	.04	.03	.03	.06	.03	.04	.04

1988								
Winter	.09	.07	.10	.11	.10	.08	.05	.08
Spring	.02	.02	.02	.02	.03	.02	.02	.02
Early Summer	.01	.01	.01	.01	.02	.01	.01	.01
Late Summer	.01	.01	.01	.00	.01	.01	.01	.01
Fall	.01	.01	.01	.01	.01	.01	.01	.01
Open Water Avg	.01	.01	.01	.01	.02	.01	.01	.01

Total phosphate levels showed the same pattern of distribution as orthophosphate, nitrate, and algal density with the highest levels at station 5 and the lowest levels at station 7, when stations were compared within years. Total phosphate , like orthophosphate, was lower in 1988 when algal levels were higher.

Table 5-12. Comparison of 1987 and 1988 Total Phosphate Levels Means by Season (ppm).

1987	L-1	L-2	L-3	L-4	L-5	L-6	L-7	Avg
Winter	.07	.10	.14	.12	.09	.09	.07	.10
Spring	.16	.13	.15	.14	.23	.17	.10	.15
Early Summer	.24	.17	.15	.13	.25	.13	.14	.17
Late Summer	.24	.24	.22	.21	.28	.14	.19	.22
Fall	.20	.20	.19	.18	.22	.11	.14	.18
Open Water Avg	.21	.19	.18	.17	.25	.13	.12	.18
1988								
Winter	.20	.15	.20	.16	.20	.18	.08	.17
Spring	.11	.09	.16	.14	.14	.12	.09	.12
Early Summer	.15	.11	.10	.08	.20	.14	.07	.12
Late Summer	.15	.14	.14	.13	.16	.12	.10	.13
Fall	.12	.08	.07	.07	.08	.07	.08	.08
Open Water Avg	.13	.11	.12	.11	.15	.12	.09	.11

Zooplankton abundance was greatest at stations with high water clarity and low levels of phytoplankton in 1987 (Table 5-13). Zooplankton were least abundant at station 5 where phytoplankton levels were greatest, and most

Table 5-13. Comparison of 1987 and 1988 Zooplankton Numbers Means by Season (#/1).

1987	L-1	L-2	L-3	L-4	L-5	L-6	L-7	Avg
Winter	162	128	85	73	57	154	167	118
Spring	255	360	304	411	156	215	334	296
Early Summer	569	653	474	693	307	519	970	612
Late Summer	917	1389	805	1813	526	187	1171	977
Fall	826	733	551	1451	243	284	689	696
Open Water Avg	642	784	534	1092	308	301	791	645
1988								
Winter	273	233	227	201	426	346	419	304
Spring	1020	721	2311	1753	2219	1098	1404	1966
Early Summer	1267	944	1437	1503	1609	2282	938	1423
Late Summer	1490	1627	948	678	2031	761	792	1189
Fall	725	334	212	429	366	311	891	467
Open Water Avg	1126	907	1227	1091	1556	1113	1006	1261

abundant at stations 4 and 7, where phytoplankton levels were lowest. This distribution is expected as high levels of zooplankton should remove phytoplankton from the water and increase water clarity. During 1988, however, there was no clear pattern shown in zooplankton abundance. Zooplankton were least abundant at station 2 in spring, at station 7 during early summer, and at station 6 during late summer and fall. This might indicate several possibilities. Firstly, zooplankton may have been less affected by downstream transport in 1988 than in 1987 because of lower runoff in 1988. In 1987, zooplankton were clearly most abundant at the stations with the largest basins and thus the longest water retention times (Stations 2, 4, and 7). In 1988, runoff was less and retention time was higher in all basins, allowing zooplankton to develop large populations in locations such as station 5 which have small basin sizes. Secondly, zooplankton may have been less effective at removing the algae present in 1988 because of the algal species changes that occurred. Finally, stations of high zooplankton grazing pressure may also have been stations of heavy predation on zooplankton by fish and therefore may not have developed high zooplankton numbers. Since the larger 1m diameter net used to sample zooplankton in 1988 also samples small zooplanktivorous fish, the latter possibility will be investigated when the counting of those samples is completed.

A major change in composition of the different types of algae present occurred between the 1987 and 1988 seasons (Table 5-14). During 1987, almost 100% of the biomass of algae present was composed of nuisance bluegreen bloom formers, and more than 90% was one species, Anacystis cyanea. In 1988, however, a definite switch was seen, with less than 60% of the biomass composed of nuisance bluegreens, and a switch in the most abundant species to the bluegreens Aphanizomenon and Gomphosphaeria. In 1987 only 4 species comprised more that 1% of the total biomass. In 1988, 19 different species comprised more than 1% of the total biomass, and substantial quantities of the more desirable greens, diatoms, and flagellates were present.

Table 5-14. Percent Composition of Major Algal Genera (by volume) in 1987 vs. 1988

		1987	1988
Bluegreens:	Non heterocystous		
	Anacystis cyanea	90%	1%
	A. incerta	5%	
	Coccochloris	1%	
	Gomphosphaeria	10%	
	Agmenellum		1%
	Oscillatoria		3%
	Lyngbya		1%
	Heterocystous:		
	Aphanizomenon	1%	36%
	Cylindrospernum	1%	2%
	Anabaena		5%
Greens:			
	Pediastrum		7%
	Ankistrodesmus		6%
	Closteriopsis		2%
	Schroederia		1%
Diatoms:			
	Melosira		6%
	Synedra		5%
	Pinnularia		4%
	Stephanodiscus		2%
Flagellates:			
	Chlamydomonas		6%
	Cryptomonas		2%
	Chroomonas		1%

5.3.3.2 Results of initial statistical analyses of 1987 data.

The multiple regression results shown are part of the Masters Thesis in preparation by Mr. Mark Lesinski and will be presented in more detail in the completion report. Multiple regression has been completed for spring, early summer, and late summer populations of all major algal species present in 1987. Sufficient replicates are not available from the fall sampling period of either year to perform meaningful multiple regression analysis on the data from that season. In the regression analysis shown in Table 5-15, the following dependent variables were used to predict the abundance of the algal species listed: nitrate+nitrite levels, ammonia levels, orthophosphate levels, the station at which the sample was taken (as a dummy variable) and all major zooplankton species present during the season being tested. Results will be shown for the three major species mentioned above, Anacystis cyanea, Aphanizomenon holsatica, and Gomphosphaeria wichurae. The partial correlation coefficient (r^2) shown is the percent variation of the algal species significantly predicted by the independent variable.

Table 5-15. Fraction of variation significantly predicted (.05) by multiple regression for three species of phytoplankton during 1987.

Dependent variable	Total R^2	Partial correlation coefficients (r^2 for each independent variable found to be significant)
Spring:		
Anacystis	.53	+ NO_3 (.26) +DSi (.23) + S-5 (.04)
Early summer:		
Anacystis	.50	- Dih (.13) - (Brc, S-1,S-2, S-3, S-4, S-5) (.31) + PO_4 (.04)
Aphanizomenon	.81	- Bos (.48) + Brc (.08) + DSi (.08) + CVe (.04) + S-4 (.04) - Asp (.04) + NH_3 (.03) - S-1 (.01) - S-5 (.02)
Gomphosphaeria	.38	+ NH_3 (.17) (- DPr - Brc + Asp) (.21)
Late Summer:		
Anacystis	.27	+ NO_3 (.15) + S-5 (.06) - PO_4 (.06)
Aphanizomenon	.72	- NO_3 (.19) - S-6 (.14) - Bos (.12) - Brc (.07) - S-3 (.06) - DCt (.03) - Asp (.02) - S-2 (.03) - S-5 (.03) - S-1 (.03)
Gomphosphaeria	.43	+ NO_3 (.39) - S-5 (.04)

S-1 = station 1 etc., DSi = Diaptomus siciloides, CVe = Cyclops vernalis (both copepods), Dih = Diaphanosoma leuchtenbergianum, DPr = Daphnia parvula, DCt = Daphnia catawba, Bos = Bosmina coregoni (cladocerans), Ker = Keratella, Brc = Brachionus, Asp = Asplanchna (rotifers), NO_3 = nitrate + nitrite, NH_3 = ammonia, PO_4 = orthophosphate.

All regressions shown are using station 7, the most downstream station as a control. If other stations show up as an independent variable, it means that those stations were significantly different from the relationship predicted for station 7.

Regression results indicate that nitrogen levels (as either nitrate or ammonia) were far more important as predictors of algal abundance than phosphate levels in 1987. Anacystis cyanea represented 90% of the total biomass in 1987, and 26% of its increases in spring, and 15% of its increases in late summer, were predicted by increases in nitrate levels, alone. Anacystis declined during early summer, and 13% of its decrease during that season was predicted by increases in the grazing zooplankter Diaphanosoma. In all three seasons, station 5 (highest concentrations of algae) was significantly different from the relationship predicted for station 7 (lowest concentrations of algae). In the early summer season, stations 1-4 were also different from station 7.

Aphanizomenon increases were associated with decreases in the grazing zooplankter Bosmina, during both early summer (48%) and late summer (12%) seasons. Aphanizomenon increases were also associated with increases with the predatory copepod Cyclops vernalis, which is known to prey on Bosmina. Aphanizomenon was negatively correlated with nitrate (which is known to inhibit its growth), and positively correlated with ammonia. Increases in ammonia and decreases in nitrate seen in the system in 1988 might have helped to trigger the change from Anacystis as the major species in 1987 to Aphanizomenon as the major species in 1988. In both seasons tested, stations 1 and 5 were significantly different from the relationship predicted for station 7. Stations 4 was also different in early summer, and stations 2, 3 and 6 were also different in late summer.

Gomphosphaeria increases were associated with increases in ammonia (17%, early summer) and nitrate (39%, late summer.) Gomphosphaeria decreases were associated with increased concentrations of the grazing zooplankters Daphnia parvula and Brachionus, and decreased concentrations of the predatory zooplankter Asplanchna. Station 5 was significantly different from station 7 only during the late summer season.

5.4.0 Fisheries Study

Author: Dr. Charles R. Berry Jr.

5.4.1 Introduction

The purpose of this phase of the study was to monitor the relative abundance of fish in East and West Oakwood Lakes and to monitor fish diet. These data will show the possible relation between the biological community in the Oakwood lakes and the water quality. i.e. consumer control of lake productivity (Carpenter and Kitchell 1988). During the second year, we continued to monitor the relative abundance of fish species in Oakwood lakes and to determine their diets.

5.4.2 Methods

Relative abundance and size-class distribution of fish in East and West Oakwood Lakes were estimated through assessment netting using four gears. Gear consisted of a 0.9 X 1.8 m frame fyke net (1.3 cm mesh) with a 13.7 m lead, a 0.9 X 1.2 m frame fyke net (1.9 cm mesh) with a 25.0 m lead, a 61.0 X 1.8 m multifilament, experimental gill net composed of 5-12.2 m sections of 1.3, 2.5, 3.8, 5.1, and 6.4 mm mesh (sample periods 1 and 2 only), a 38.1 X 1.8 m multifilament, experimental gill net composed of 5-7.6 m sections of the same mesh sizes above (sample periods 3, 4, and 5), and a 13.7 X 1.5 m bag seine with 3.2 mm mesh.

Five stations were selected on both lakes to represent similar habitat types (i.e. rock shoreline, point, vegetation) (Figure 1). Five 20-24 hour sets were made at each station using fyke nets and gill nets. A 30 meter section of shoreline at each station was used for seining. Sampling was initiated on June 1 and continued every three weeks until August 10. All stations were again sampled on October 15. Total number and weights for each species collected from each gear were recorded according to the size groups in Table 5-16.

5.4.3 Results and Discussion

5.4.3.1 Relative Abundance of Fish Populations

We collected 97,274 fish representing 12 species (Table 5-17). Bullheads (mostly Ictalurus melas and to a lesser degree I. natalis) dominated the catch in total number (88.5%) and weight (81.4%) (Tables 5-17 and 5-18). Northern pike (Esox lucius), yellow perch (Perca flavescens), and walleye (Stizostedion vitreum) accounted for 2.7% and 6.7% of the total number and weight, respectively. Carp (Cyprinus carpio), bigmouth buffalo (Ictiobus cyprinellus), and white sucker (Catostomus commersoni) accounted for 3.9% of the total number and 11.9% of the total weight. Fathead minnows (Pimephales promelas) accounted for the remaining 4.9% of the total number of fish collected. Darters (Etheostoma sp.), green sunfish (Lepomis cyanellus), and shiners (Notropis sp.) were also collected, but were not abundant.

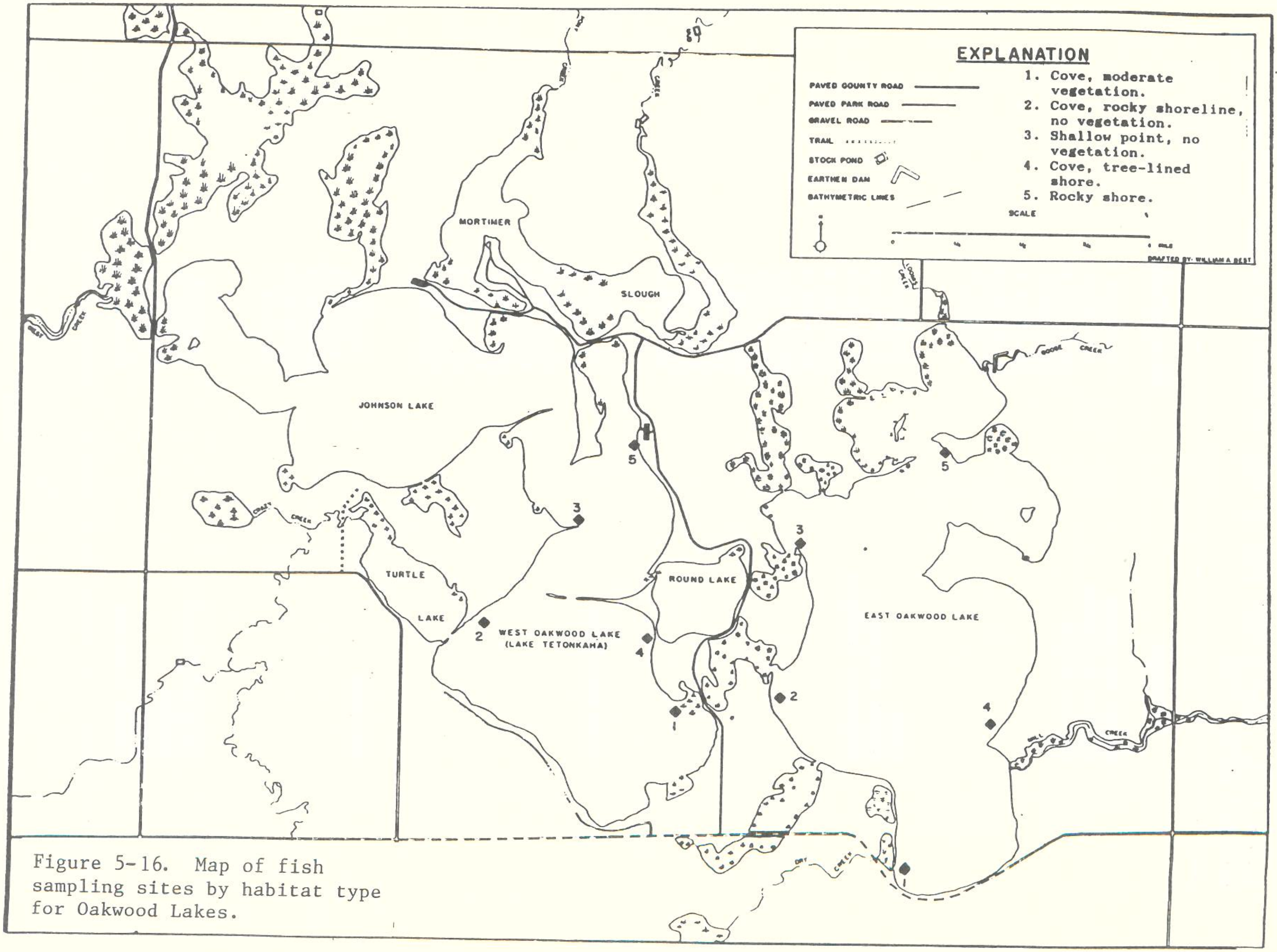

Figure 5-16. Map of fish sampling sites by habitat type for Oakwood Lakes.

Table 5-16. Size groups (cm) of fish collected from East and West Oakwood Lakes, 1988.

Species	Size groups
Black Bullhead Yellow Bullhead Yellow Perch	0.0-5.0 5.1-10.1 10.2-15.2 15.3-20.3 20.4-25.4 25.5-30.5 30.6-35.6
Carp White Sucker Bigmouth Buffalo	0.0-7.6 7.7-15.2 15.3-22.9 23.0-30.5 30.6-38.1 38.2-45.7 45.8-53.3 53.4-61.0 61.1-68.6 68.7-76.3 76.4-84.0
Northern Pike	0.0-5.0 5.1-10.1 10.2-15.2 15.3-30.5 30.6-45.7 45.8-61.0 61.1-76.2 76.3-91.4
Walleye	0.0-5.0 5.1-10.1 10.2-15.2 15.3-30.5 30.6-45.7
Fathead Minnow Darter Shiner Green Sunfish	0.0-3.8 3.9-7.6 7.7-11.5 11.6-15.3

Table 5-17. Relative abundance of fish in East and West Oakwood Lakes, 1988.

Species	East Oakwood No.	East Oakwood %	West Oakwood No.	West Oakwood %	Total No.	Total %
Black Bullhead	41,721	(77.1)	40,594	(94.0)	82,315	(84.7)
Fathead Minnow	4,118	(7.6)	626	(1.5)	4,744	(4.9)
Carp	3,173	(5.9)	149	(0.3)	3,322	(3.4)
Yellow Bullhead	2,887	(5.3)	796	(1.8)	3,683	(3.8)
Yellow Perch	1,717	(3.1)	108	(0.3)	1,825	(1.9)
Northern Pike	237	(0.4)	334	(0.8)	571	(0.6)
White Sucker	135	(0.3)	150	(0.3)	285	(0.3)
Darter	85	(0.2)	9	(--)	94	(--)
Bigmouth Buffalo	42	(0.1)	155	(0.4)	197	(0.2)
Walleye	27	(--)	203	(0.5)	230	(0.2)
Shiner	2	(--)	0	(--)	2	(--)
Green Sunfish	1	(--)	5	(--)	6	(--)
Total	54,145		43,129		97,274	

Table 5-18. Biomass (Kg) of fish collected from East and West Oakwood Lakes, 1988.

Species	East Oakwood Wt.	East Oakwood %	West Oakwood Wt.	West Oakwood %	Total Wt.	Total %
Black Bullhead	3,368.6	(73.6)	4,373.1	(79.5)	7,741.7	(76.8)
Yellow Bullhead	364.9	(8.0)	93.4	(1.7)	458.3	(4.6)
Northern Pike	204.5	(4.5)	208.4	(3.8)	412.9	(4.1)
Carp	186.3	(4.1)	167.8	(3.1)	354.1	(3.5)
Bigmouth Buffalo	170.6	(3.7)	413.5	(7.5)	584.1	(5.8)
White Sucker	139.0	(3.0)	116.7	(2.1)	255.7	(2.6)
Yellow Perch	115.8	(2.5)	9.4	(0.2)	125.2	(1.2)
Walleye	25.9	(0.6)	115.0	(2.1)	140.9	(1.4)
Fathead Minnow	2.4	(0.1)	0.8	(--)	3.2	(--)
Shiner	0.2	(--)	0	0	0.2	(--)
Darter	---	(--)	---	(--)	---	(--)
Green Sunfish	---	(--)	---	(--)	---	(--)
Total	4,578.2		5,498.1		10,076.1	

Black bullheads accounted for 84.7% of the total number (Table 5-17) and 76.8% of the total weight (Table 5-18) of all fish collected in East and West Oakwood Lakes. Generally, the number of black bullheads collected was similar between the two lakes (Table 5-17) however, weight differed. The 40,594 black bullheads in West Oakwood weighed 1,004.6 Kg more than the 41,721 black bullheads in East Oakwood (Table 5-18). This difference in weight can be attributed to the difference in the population structures between lakes. All size-classes of black bullheads were represented in both lakes (Figure 1), but in West Oakwood, fish > 15.3 cm accounted for 95% of the catch compared to 47% in East Oakwood (Figure 1). Young-of-the-year black bullheads (< 10.1 cm) were more abundant in the catch from East Oakwood, accounting for 14% of the number collected compared to 1% in West Oakwood (Figure 1).

Yellow bullheads accounted for 3.8% of the total number (Table 5-17) and 4.6% of the total weight (Table 5-18) of all fish collected. There were about 3.6X more yellow bullheads collected in East than West Oakwood (Table 5-17). Five of the seven size-classes were represented in both lakes, and adult yellow bullheads between 15.3-25.4 cm accounted for 99% of the number collected in both lakes. Young-of-the-year yellow bullheads (< 10.1 cm) were absent in the catch from East Oakwood, but accounted for 0.3% in West Oakwood.

Walleyes accounted for 0.2% of the total number (Table 5-17) and 1.4% of the total weight (Table 5-18) of all fish collected in both lakes. Approximately 7.5X more walleyes were collected in West than East Oakwood (Table 5-17). In East Oakwood, three of the six size-classes were represented, where as five size-classes of walleyes were represented in West Oakwood. Adult walleyes in the 30.6-45.7 cm size-class dominated the catch in both lakes, accounting for 78% and 88% of the number of walleyes collected in East and West Oakwood Lakes, respectively. Young-of-the-year walleyes (< 10.1 cm) were more abundant in the catch from West Oakwood, accounting for 9%, compared to 3% in East Oakwood.

Yellow Perch accounted for 1.9% of the total number (Table 5-17) and 1.2% of the total weight (Table 5-18) of all fish collected. Approximately 16X more yellow perch were collected in East than West Oakwood (Table 5-17). All seven size-classes of yellow perch were represented in East Oakwood and six in West Oakwood. Adult yellow perch, mostly in the 20.4-30.5 cm size-classes, accounted for 27% of the number collected in East Oakwood and 30% in West Oakwood. Young-of-the-year yellow perch (< 10.1 cm) were abundant in the catch from both lakes, accounting for 73% in East Oakwood and 65% in West Oakwood.

Northern pike accounted for 0.6% of the total number (Table 5-17) and 4.1% of the total weight (Table 5-18) of all fish collected. There were 97 more northern pike collected in West Oakwood. Four of the eight size-classes were represented in both lakes. Adult northern pike in the 45.8-61.0 size-class were most abundant in the catch from both lakes, accounting for 73% and 58% in East and West Oakwood Lakes, respectively. Young-of-the-year northern pike were absent in the catch from both lakes.

White suckers accounted for 0.3% of the total number (Table 5-17) and 2.6% of the total weight (Table 5-18) of all fish collected. Fifteen more white suckers were collected in West Oakwood. Four size-classes of white suckers were represented in East Oakwood and six in West Oakwood. Adult white suckers in the 38.2-45.7 cm size-class dominated the catch in East Oakwood, accounting for 76% of the fish collected, while adult white suckers in the 30.6-38.1 cm size-class were more abundant in West Oakwood and accounted for 43% of the catch. No young-of-the-year white suckers (< 15.2 cm) were collected from East Oakwood, but in West Oakwood, young-of-the-year fish accounted for 3% of the catch.

Bigmouth buffalo accounted for 0.2% of the total number (Table 5-17) and 5.8% of the total weight (Table 5-18) of all fish collected. There were 3.7X more bigmouth buffalo collected in West than East Oakwood (Table 5-17). Six of the eleven size-classes were represented in East Oakwood and eight in West Oakwood. Adult bigmouth buffalo in the 38.2-45.7 cm size-class were most abundant in the catch from West Oakwood, accounting for 38% of the number collected, where as adult fish in the 61.1-68.8 cm size-class were most abundant in East Oakwood, accounting for 48% of those collected. No young-of-the-year bigmouth buffalo (< 22.9 cm) were collected from either lake.

Carp accounted for 3.4% of the total number (Table 5-17) and 3.5% of the total weight (Table 5-18) of all fish collected in East and West Oakwood Lakes. Seven size-classes were represented in West Oakwood and 10 in East Oakwood. Adult carp in the 45.8-53.3 cm size-class dominated the catch in West Oakwood, where as in East Oakwood, adult carp in the four size-classes from 38.2-68.8 cm were about equally abundant. Young-of-the-year carp (< 22.9 cm) accounted for 98% of the number collected in East Oakwood and 36% in West Oakwood.

Although fathead minnows accounted for 4.9% of the total number of fish collected (Table 5-17), they did not contribute to the total weight. The two smallest size-classes of fathead minnows (see Table 5-16) were represented in both lakes. In East Oakwood, 2,111 (0-3.8 cm size-class) and 2,007 (3.9-7.6 cm size-class) fish were collected, where as in West Oakwood 306 fish in the first size-class and 320 in the second were collected. No fish over 7.6 cm were collected from either lake.

Darters, green sunfish, and shiners were least abundant and did not contribute to the total number or weight of fish collected (Tables 5-17 and 5-18). Darters were represented by the two smaller size-classes, while green sunfish and shiners were collected in the two larger size-classes (see Table 5-16).

The four gear types used to collect fish in East and West Oakwood Lakes were selective. The seine collected all size-classes of fathead minnows and darters, and most of the green sunfish (Table 5-19). Black bullheads, carp, yellow perch, walleye, and white suckers collected with the seine were mostly young-of-the-year fish, while the northern pike were adults (Table 5-19). Large and small mesh fyke nets were most effective on adult black bullheads, yellow bullheads, and bigmouth buffalo, while gill nets were most effective on adult walleye, yellow perch, and carp (Table 5-19).

Table 5-19. Numbers of fish collected from 4 gear types in East and West Oakwood Lakes, 1988.

Species	Large mesh fyke net		Small mesh fyke net		Gill net		Seine	
	East	West	East	West	East	West	East	West
Black Bullhead	24,551	23,972	12,713	13,674	1,586	2,537	2,871	411
Fathead Minnow	0	0	0	0	0	0	4,118	626
Carp	20	11	33	25	62	63	3,058	50
Yellow Bullhead	1,377	365	1,447	426	62	4	1	1
Yellow Perch	100	8	24	5	355	22	1,238	73
Northern Pike	100	141	40	72	92	110	5	11
White Sucker	50	43	31	54	54	49	0	4
Darter	0	0	0	0	0	0	85	9
Bigmouth Buffalo	20	81	17	66	5	8	0	0
Walleye	5	44	2	37	19	102	1	20
Shiner	1	0	0	0	1	0	0	0
Green Sunfish	0	0	0	0	1	0	0	0

The numbers of fish collected in East and West Oakwood Lakes varied by sampling period. The greatest number of northern pike, walleye, bigmouth buffalo, white sucker, and adult carp collected in 1988 occurred during the August 3 sampling period; yellow bullheads were the least abundant of all five periods (Table 5-20). Yellow perch numbers were highest from the June 1 period and generally decreased through October. Black bullheads were most abundant in the catch from June 22 and October 15. Fathead minnows were most abundant in the catches from August 3 and October 15, while darters were most abundant from July 13.

Table 5-20. Numbers of fish collected from East and West Oakwood Lakes from each of 5 sampling periods, 1988.

Species	June 1		June 22		July 13		August 3		October 15	
	East	West	East	West	East	West	East	West	East	West
Black Bullhead	3,776	10,984	11,064	11,939	9,876	4,521	5,894	4,123	11,111	9,027
Fathead Minnow	11	783	59	56	77	124	1,248	61	2,723	1
Carp	75	38	2,812	41	100	35	150	29	36	6
Yellow Bullhead	523	385	835	63	677	77	221	50	631	221
Yellow Perch	809	15	481	26	114	27	218	34	95	6
Northern Pike	19	70	37	73	53	64	88	113	40	14
White Sucker	11	12	18	11	32	30	48	82	26	15
Darter	0	1	19	5	47	3	18	0	1	0
Bigmouth Buffalo	2	17	8	38	18	21	9	44	5	35
Walleye	0	23	5	16	3	35	14	86	5	43
Shiner	0	0	1	0	0	0	1	0	0	0
Green Sunfish	0	0	0	0	1	3	0	1	0	1

5.4.3.2 Fish Food Habits

The fish species collected during this survey can be placed into four general groups, based on dominant prey items in the adult diet. The dominant or codominant items include 1) plankton, 2) plankton and benthic invertebrates, 3) benthic invertebrates, and 4) fish. Based on the adult diets, fathead minnow and bigmouth buffalo would be considered specialists feeding on plankton, while walleye and northern pike would be specialists feeding on fish. The remainder of the species are considered generalists feeding on a variety of planktonic and benthic invertebrate prey (Table).

Major Prey Groups

Plankton

Bigmouth buffalo

Bigmouth buffalo adults are considered nonselective planktivores, where adults and sub-adults in Lake Poinsett, South Dakota consumed zooplankton species in the same relative proportion as their abundance except for calanoid copepods. Larvae and young (12.5 - 21.0 mm) consumed Tendipedidae larvae (midge) and Leydigia (a benthic cladoceran), Daphnia pulex, and copepods (Starostka and Applegate 1970). In Lewis and Clark Lake and the Missouri River, small fish (16 - 47 mm) fed on cladocerans, copepods, and rotifers (McComish 1967). Cladocerans, copepods, and blue-green algae and insets have been reported in adults in Iowa Lakes (Moen 1953). In Lake Poinsett, Daphnia pulex, Chydorus spaericus, Diaphanosoma brachyurum, cyclopoid copepods, and blue-green algae were found in fish 236 - 833 mm in length (Starostka and Applegate 1970). Cyclops and Diaptomus were the major copepod species, and Bosmina and Daphnia were the major cladoceran species in adult bigmouth buffalo in Lewis and Clark lake and the Missouri River (McComish 1967).

Fathead minnow

The diet of fathead minnows (> 20 mm) in North Dakota lakes is comprised primarily of cladocerans, both by volume and by number (Held and Peterka 1974). Fish this size also consumed copepods and amphipods, while fish less than 19 mm consumed rotifers, cladocerans, and copepods. Ostracods, dipteran larvae and pupae were also consumed by larger individuals. Cladocerans and dipterans dominated the diet of early summer and copepods in the fall. Amphipods were important in the diet in late summer. Larvae have been reported to feed on diatoms and benthic algae (Coyle 1930; Isaak 1961).

Predation by fathead minnows in small experimental ponds in Michigan has been intense enough to reduce numbers of both small and large zooplankton species. Decreased abundance of herbivorous zooplankters resulted in a shift of algal composition to inedible blue-greens (Helfrich 1977; Spencer and King 1984). Introduction of largemouth bass into different experimental ponds containing fathead minnows reduced the minnow population, and both zooplankton populations and water clarity increased (Spencer and King 1984). Intense walleye predation on fathead minnows in a South Dakota prairie pothole was also followed by an increase in zooplankton numbers and water clarity (Walker and Applegate 1976).

Plankton and Benthic Invertebrates

Black bullhead

Crustaceans, immature insects, clams, snails, leeches, fishes, and plant material have been reported as components of the black bullhead diet. However, a great deal of seasonal and geographic variability exists (Scott and Crossman 1973). Campbell and Branson (1978) found larval feeding to be more selective than that of adults. In Kentucky, larvae and juveniles consumed amphipods, ostracods, and adult copepods, apparently selected by their abundance. In Michigan, juvenile black bullheads (10 - 60 mm) consumed primarily Entomostracha (ostracods and copepods) and insects. Large fish (206 - 224 mm) also consumed amphipods, snails, and clams (Williams 1970).

In Buckeye Lake, Ohio, small bullheads (36 - 76 mm) fed on amphipods, Entomostraca, and insect larvae (Ewers 1931), whereas Forney (1955) reported primarily Entomostraca in Clear Lake, Iowa in 15 - 53 mm individuals. In Lake Poinsett, South Dakota, young bullheads (37 - 87 mm TL) were selective feeders, with diets comprised of two species of cladocerans, Diaphanosoma leuchtenbergianum, and Leptodora kinditii, comprising 35.3 and 51.2% of the diet respectively. Copepods and chironomids were also consumed. Sub-adult and adult black bullheads fed on Leptodora, chironomid pupae, and fish (crappies, yellow perch, spottail shiner). Although Daphnia pulex accounted for 59.6% of the total number of organisms consumed, it accounted for only 8.8% of the total volume of organisms from March to November. Daphnia was the sole food item in March and was dominant in May. Leptodora was dominant from August through October, while chironomids predominated in June and July stomachs (Repsys et al. 1976). All age groups appeared to be selective for the largest available cladocerans in Lake Poinsett, feeding in limnetic, littoral and benthic habitats (Repsys et al. 1976).

Differences in time of feeding among age classes of black bullheads has been described (Darnell and Meierotto 1965) and would eliminate potential intraspecific competition. Feeding on aquatic vegetation prior to spawning has been reported in Cayuga Lake, New York (Raney and Webster 1940) and Clear Lake, Iowa (Forney 1955), but was not seen in Kentucky (Campbell and Branson 1978).

Yellow perch

The general pattern of yellow perch feeding is initially exclusively on zooplankton as limnetic larvae, then incorporating chironomids and insects into their diet as they grow and change to a littoral habitat, and then adding fish to their diet when reaching a size of 150 mm. Juveniles also consume leeches, odonates, clams, and trichopterans. Thorpe (1977) has suggested that switching from plankton to benthos is a response to increased mouth size utilizing larger prey.

Habitat shifts along with concomitant morphological features (vertical pigment bars) enable foraging in the vegetated littoral area where numerous benthic invertebrates and large zooplankton occur. In Ontario and Minnesota, larvae (7 - 10 mm) consumed Cyclops (Siefert 1972; Keast 1980), and incorporated Bosmina at 17 mm and Polyphemus and Ceriodaphnia between 18 and 23 mm (Keast 1980). The relative proportion of zooplankton species in the diet of yellow perch is related to the zooplankton community present and may vary geographically and seasonally, as well as annually. Yellow perch diet changes with age (size) and involves gradual shifts in proportions of major foods eaten (Keast 1978). Young perch in Canada fed on cladocerans, ostracods, and chironomids and at the end of the first year fed on odonates, mayflies, and fish. Adults consume crayfish, fish, and odonates (Scott and Crossman 1973). In an angler survey of adult yellow perch (> 228 mm) in Wisconsin, dipterans were the most abundant prey numerically from May to July, cladocerans were most abundant in August and September (Serns and Hoff 1984). Yellow perch are well known for their selectivity of large daphnids even when smaller species are more abundant (Galbraith 1967). In Minnesota, intermediate size yellow perch diets consisted primarily of zooplankton prior to white sucker removal after which mayflies became the dominant food item (Johnson 1977).

Benthic Invertebrates

White sucker

White sucker larvae (12 mm) feed on zooplankton until they reach 18 mm, when their mouth shifts from terminal to ventral with concomitant shift to benthic prey organisms. Food items change with age and season (Bigelow 1923). Rotifers, copepod nauplii, Cyclops, cladocerans, algae, and chironomids were consumed by 13 - 26.5 mm white suckers (Siefert 1972). As the fish grew larger, cladocerans (Daphnia, Bosmina, Polyphemus, Acroperus, and Camptocerus) were included in the diet. Chironomid larvae, trichopteran larvae, mollusca, Entomostraca, amphipods, and detritus as well as terrestrial insects were also eaten (Eder and Carlson 1977). In northeastern Minnesota, white suckers (400 mm) fed almost exclusively on invertebrates, primarily insects (chironomids and mayflies), amphipods, and cladocerans (Johnson 1977).

Carp

Larval carp feed on zooplankton such as Bosmina and Alona but will consume phytoplankton when zooplankton are unavailable (Bulkley et al. 1976; Edwards and Twomey 1982). As carp grow their diet expands to include littoral and benthic fauna such as chironomids and other insects as well as seeds, algae, and detritus (Edwards and Twomey 1982). Adult carp consume chironomid larvae, diptera pupae, trichopteran larvae, terrestrial insects, fish, seeds, aquatic plants, detritus, and sand as well as crayfish, entomostrachans, and odonates. Crayfish and dragonfly nymphs were consumed by fish greater than 300 mm (Eder and Carlson 1977). Chironomids were a dominant food in young and adult carp from rivers and from a pond in Colorado (Eder and Carlson 1977), in lakes in northwestern Iowa (Moen 1954), and in central Iowa (Effendie 1968). Carp will utilize allochthonous food. Large amounts of detritus in carp intestines have been found in fish from lakes with depauperate benthic fauna. The presence of aquatic plants has been suggested to reflect intense food searching rather than deliberate consumption since these species are unable to digest cellulose (Eder and Carlson 1977). The adults are highly opportunistic and will utilize any food source.

Fish

Northern pike

Northern pike initially feed on zooplankton, then insects, and at approximately 50 - 60 mm, fish (Hunt and Carbine 1951; Inskip 1982). Young pike have also been reported to be cannibalistic at 21 mm. As adults, northern pike have been characterized as opportunistic predators, exploiting seasonally abundant fishes (Inskip 1982), as well as mice, muskrats, and ducklings (Lagler 1965). In Wisconsin, pike preyed on bluegills, yellow perch, minnows, and crappies in that order (Johnson 1969). In many food habit studies of top aquatic carnivores, a high proportion of empty stomachs are reported, ranging from 29 to 76% empty (Seaburg and Moyle 1964; Johnson 1969; Hill 12974; Diana 1979). Yellow perch was the dominant prey species in Lac Ste. Anne, Ontario, while carp and buffalo alternated with crappies and crayfish as the dominant prey species in Brown's Lake, Iowa (Hill 1974; Diana 1979). Johnson (1969) reported size of prey appeared to be a function of abundance, with pike taking smaller, more abundant prey.

Walleye

The adult walleye has been characterized as a highly piscivorous opportunist which tends to feed on the abundant forage species in a variety of habitats (Regier et al. 1969; Ryder and Kerr 1978). Walleye larvae feed on zooplankton with Daphnia comprising 88% of the diet of larvae greater than 12 mm in Spirit Lake, Iowa. Diaptomus and Cyclops are also consumed. Predation by larvae 9.5 - 10 mm on yellow perch larvae has been reported (McWilliams 1976; Bulkley et al. 1976). Several investigators have found Cyclops to be preferred over Diaptomus in Wisconsin and New York (Priegel 1970). The general trend in feeding is from smaller zooplankters followed by large species (Daphnia, Bosmina, Chydorus) as the fish gets larger (28 mm) (Pycha and Smith 1954; Siefert 1973). In general, walleye tend to select for the largest species available. Diaptomus was the largest zooplankter present in a South Dakota prairie pothole and was positively selected for (Walker and Applegate 1976). Diaptomus was negatively selected for in Lake Winnebago, Wisconsin and Oneida Lake, New York where larger prey species were available (Priegel 1970). Rotifers were consumed by 6 - 9 mm walleye in rearing ponds (Smith and Moyle 1945) and in Lake Erie (Hohn 1966), however, Mathias and Li (1982) felt that rotifers are normally too small. Walleye are usually piscivorous by a size of 50 mm (Forney 1966). In South Dakota, walleyes stocked in a prairie pothole included fathead minnows in their diet when they reached a length of 62 mm.

Priegel (1970) found chironomids important in the diet after 35 mm, along with larvae of yellow perch, white sucker, quillback, and trout-perch. Cladocerans were important until 75 mm, when fish became dominant. Fish have been reported as a major component of the diet at 30 mm (Dobie 1966) and even as early as 15 - 20 mm (Smith and Moyle 1945). Although cannibalism has been reported, the abundance of yellow perch and its availability as forage is suggested to regulate the future year class of walleye through a negative feedback mechanism (Forney 1974).

Juvenile and adult walleyes consume primarily fish, aquatic insects, and invertebrates. Generally, in the northern and central portion of its range, age 0+ and 1+ yellow perch account for a large portion of the diet, while in the southern parts of the range clupeids, cyprinids, and centrarchids dominate the diet (Kelso and Ward 1977; Ryder and Kerr 1977). Although yellow perch predominate, if unavailable other species such as cyprinids, suckers, and sticklebacks are consumed in the north (Colby et al. 1979). In many lakes, insects and invertebrates are major diet components in late spring and early summer, being replaced by fish as these pelagic forms become available and insects have emerged (Colby et al. 1979). Walleye have been found to be size selective predators with the length of perch generally consumed being 40% of the predators size (Nielson 1980). The relative proportion of a prey species in a diet, as a reflection of prey availability, is seen in a study of Wilson Lake, Minnesota, following removal of white sucker. Following sucker removal, numbers of microcrustaceans in the diet of young walleye increased eight-fold (Johnson 1977). Where forage species are scarce, walleye adults utilize invertebrates such as mayflies, chironomids, amphipods, and leeches (Colby et al. 1979).

Table 5-21 Feeding guilds of adult fishes from the Oakwood Lakes system. Preliminary guild assignment based on a literature review. Guild assignment may be adjusted later depending on results of diet analysis.

Plankton	Plankton and Benthic Macro-invertebrates	Benthic Macro-invertebrates and Fish	Fish
Fathead minnow	Black bullheads	Yellow perch	Walleye
Bigmouth buffalo	Yellow bullheads	White sucker	Northern pike
Darter		Carp	
Shiner			

5.5.0 Work Remaining

Hydrologic Nutrient and Sediment Budgeting

Calculation of tributary loadings will be completed and incorporated into the overall budget. A survey of land wells will be completed to allow horizontal gradients to be determined and flow lines constructed. Calculation of seepage rates will be completed. The data will be combined with land and in-lake well gradients to determine the ground water contribution to the budget.

Tributary Water Quality

Loomis Creek tends to have the poor water qualiy which can be attributed in part to animals confined and fed along the stream channel a short distance upstream from the monitoring site. There is some indication that one of the feedlot operators in Loomis Creek is interested in an animal waste management facility. SCS engineers have met with him and will be drawing up plans for the operators review in 1989. This will provide an excellent opportunity to document the water quality improvements possible through effective animal waste management. The current tributary data base, consisting of three years of runoff data, would provide the basis for a before and after analysis of water quality in Loomis Creek if a waste management system were built. Samples were collectd above and below the feedlot throughout the snowmelt period in 1989 to better document the feedlot as the source of the water quality problem in Loomis Creek. Preliminary analysis of the data indicates that significant water quality degradation occurs at the feedlot site.

The current data base would also permit a paired watershed study with Goose Creek. A three year water quality data base exists for both creeks and if Goose Creek were monitored following construction at Loomis Creek it could serve as a control watershed. Documentation of water quality benefits will be made possible only if the system is built and additional funds can be secured to collect water quality and discharge data from both creeks during the construction period and for 2 or 3 years following.

In-lake Monitoring

Zooplankton numbers will be converted to biomass estimates and the counting and calculation of zooplankton and fish density from the meter net tows will be completed. 1988 data will be tested by statistical analysis of variance and multiple regression analysis of major phytoplankton species. 1988 multiple regressions will be run using the density of zooplanktivorous fish captured in the meter net tows as an additional independent variable to predict the abundance of the algae species present.

Fish diet analysis for 1988 will be completed to determine grouping of fish based on diets. The information will be used to quantify the relative effect of various fish groups on zooplankton populations. The data will also help determine groupings of benthivorous fish to assess impact on recycling of nutrients by bottom feeders.

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6.0 SYSTEM ANALYSIS

Authors Alan R. Bender and C. Gregg Carlson

System analysis of the processes in the hydrologic system which affect the quality of the water resource is an iterative exercise. This activity is the one which pulls all the interactive pieces together into one conceptual framework. A hypothesis is constructed about the processes, controlling parameters are identified and values established, measurable variables identified. A model is selected and tested against reality. Models are always a simplification of reality and based on hypotheses of parametric relationships. If the test against reality confirms the validity of the hypothesis, measured variables can be used to calibrate the model. Calibration means choosing appropriate values for the parameters which describe the processes under consideration. Calibration instability generally indicate weakness in the hypothesis characterized by parametric relationship.

Hypothesis refinement, i.e. modeling the processes in a hydrologic system, takes place when the best tools available are chosen, mesaurements are carefully made, and hypotheses are tested and found to be inadequate to simulate reality. Failure is not often apparent. Rejection of a hypothesis which has been validated by other experiments can not be rejected easily. Our refined hypothesis of flow processes in glacial till systems violate the parametric relationships which have been used to explain the processes characterizing other systems and used as the basis of mechanistic models available. Formulation of the problem to conform to the refined hypothesis must now take place.

Many of the concepts which relate to a refined hypothesis of hydrologic system in the Oakwood Lakes-Poinsett RCWP are presented in a paper prepared for presentation at the ASAE Winter Meeting, Chicago, Illinois. The main conclusion of this paper is that the flow process which is heavily dependent on macropore flow in glacial till soils must be understood before strategies for controlling transport of contaminants can be designed. Macropores alter the time scale of water mobile contaminant contact with the soil because the pore velocity of the water is much higher than would be calculated for mass flux through the entire soil profile. This paper is an appendix to this report.

6.1 Preparation of FY91 Comprehensive Report

Discussion in this and previous annual reports have documented the work which has been completed to date. The work conducted during the last year has been focused on reviewing the data collected by various components of the project and formulating the new knowledge into a consistent and workable set of hypotheses. These hypotheses will result in a more detailed conceptual model that can be used to guide the development of the 1991 Comprehensive CM&E Report document.

The technical committee allocated a significant amount of effort during the past year to planning the contents of the 1991 Comprehensive CM&E Report. This plan has been reviewed by the State Coordinating Committee (SCC) and several external reviewers. A Report Management Team has been organized, RCWP CM&E Report Management Team

Name	Organization
Alan Bender	Water Resources Institute, SDSU
John Bischoff	Water Resources Institute, SDSU
David German	Water Resources Institute, SDSU
C. Gregg Carlson	SDSU Extension Service
Mike Kuck	Soil Conservation Service
Jeanne Goodman	South Dakota DWNR

and the major sections of the report are,

1.0 EXECUTIVE SUMMARY

2.0 INTRODUCTION

- 2.1 Project goals and objectives
- 2.2 Historical review
- 2.3 Identified water quality problems
- 2.4 Geologic and hydrologic setting
- 2.5 Climatic setting
- 2.6 Monitoring and evaluation approach
- 2.7 Project components
- 2.8 Literature review
- 2.9 Land use patterns and changes
- 2.10 Report format

3.0 FINDINGS AND RECOMMENDATIONS

- 3.1 BMP implementation summary
- 3.2 BMP impacts on water quality
- 3.3 BMP impacts on water balance
- 3.4 BMP impacts on nutrient movement
- 3.5 BMP impacts on pesticide movement
- 3.6 Effectiveness of applied BMPs
- 3.7 Other BMP options
- 3.8 Conclusions
- 3.9 Recommendations

4.0 IMPACT OF BMPs ON SURFACE WATER QUALITY

4.1 Introduction
4.2 Study area
4.3 OLSS monitoring strategy and design
4.4 In-lake water quality
4.5 In-lake biological surveys
4.6 Tributary water quality
4.7 Ground water quality surrounding the Oakwood Lakes
4.8 Mechanistic modeling to evaluate BMP effectiveness
4.9 AGNPS verification
4.10 Water quality of field site runoff
4.11 AGNPS modeling of RCWP watersheds
4.12 Conclusions and recommendations
4.13 References and publications

5.0 IMPACT OF BMPS ON CONTAMINANT MOVEMENT THROUGH THE VADOSE ZONE

5.1 Introduction
5.2 Physical and chemical characteristics of the experimental master site
5.3 Experimental procedure
5.4 Soil water balance and the distribution of water within the vadose zone of water under different crops and tillage treatments
5.5 Pesticide movement under different crops and tillage treatments
5.6 Nutrient balance under different crops and tillage treatments
5.7 Modelling the movement of pesticides, nutrients, and water through the vadose zone
5.8 Conclusions and recommendations
5.9 References and publications

6.0 IMPACT OF BMPS ON GROUND WATER QUALITY

6.1 Introduction
6.2 Monitoring strategy and design
6.3 Geozone characteristics
6.4 Field sites
6.5 Nutrient movement
6.6 Pesticide occurrence
6.7 Water balance
6.8 Land use data and water quality analysis
6.9 Conclusions and recommendations
6.10 References and publications

The complete planning document is published as an internal project report. As a result of interim analysis conducted for the report planning, a proposal was prepared for the SCC which outlined what activities should be conducted to complete the monitoring and evaluation program which is underway.

6.2 Evaluation of Fertilizer and Pesticide Management

The importance of the CM&E program can not be overemphasized. The data and knowledge of monitoring of ground water systems for BMP effects did not exist when the project started. Initial hypotheses have been shown to be inadequate, new knowledge is contributing to revised hypotheses, and this information is being used to support programs such as the cooperative agreement between SCS and the Extension Service. Model builders are using data to revise models. The state water management agency, DWNR, is using the project as a basis for Nonpoint Source Pollution planning and project formulation.

In many cases, the experience gained by this project has helped to document inadequacies in our understanding which were known to exist. In other cases, new problems and basis for understanding the impact of BMPs on water quality has been developed. For example, the scouting program collected data from each of the farms under contract for fertilizer and pesticide management during the 1982-1988 project years (Tables 6-1 and 6-2). The BMP cost share was paid to farmers if they took soil samples and followed recommendations. Recommendations were followed if fertilizer was applied, although fertilizer may not have been applied when field conditions prevented application or recommended rates were so low that it was not worth doing. Thus, the rates in the table are lower than actual application rates but are an indication of how important soil tests are to prevent overfertilization. The residual nutrients available are substantial and fertilizer applications based on yield expectations alone would generally be in excess of actual needs. In the case of nitrogen, the residuals may be a concern for leaching. Aquifer vulnerability data is underdevelopment which will permit this analysis to be done. Similar analyses can be made of the pesticide data.

Pesticide application rates are somewhat different from fertilizer in that the need for application is determined by the field scouts. The scouts look at pest populations and informed the farmer of problems. Application of chemicals is controlled by label rates or other criteria.

6.3 Field Application of New Management Information

When the RCWP project was initiated, leachability and aquifer vulnerability were not used because neither the knowledge or the data was available. These kinds of data are under development at present and will be used to support Extension/SCS information and education programs. Analysis of the BMP modifications necessary to achieve highest potential benefit from management will be conducted based on the scouting data and the leachability, runoff, and depth to ground water. These efforts are part of a growing need to raise the technical competency of resource planners and managers who are responsible for working with farmers to develop farm level conservation plans. Formulation of techniques and methodologies for control of agricultural nonpoint pollution will require rational approaches to problem identification and resolution. Prevention and forward planning will become the rule rather than correcting problems after they occur. The justification for this approach will be based on findings of this project or monitoring and research stimulated by this project.

The following sections present a prescription process for determining appropriate land treatment for water quality preservation. This process represents a composite of what has been learned by system analysis of the Oakwood Lakes-Poinsett RCWP about the application of BMPs for reducing the negative impacts on ground and surface water. Monitoring and evaluation of the impacts of BMPs must be a part of any implementation plan. The data collected by monitoring enables the refinement of the prescription process and provides the basis for quantitative assessment of land treatment effects on water quality. The goal of the RCWP-CM&E is to determine the cause and effect of specific practices so that quantitative water quality objectives can be set and land treatment can be prescribed to achieve these goals. One unifying effect is not possible at this point, but the data being collected contributes to that goal by examining each part of the system which must be considered in determining vulnerability, i.e. the tillage effects on leaching and runoff, the structure of the unsaturated profile, the water quality changes occurring from hydrologic processes, ground water surface water interactions, tributary and in-lake processes, land treatment effects on water balance. The extension specialist combines this knowledge with fertilizer and pesticide requirements and characteristics for different cropping systems to derive an appropriate plan to achieve agriculture production goals and environmental preservation goals. This knowledge becomes the basis for an educational program which can be delivered to extension agents and conservation district specialists and technicians.

The following report is in a draft from and will receive modification and revision before publication; however it does represent the methodlogies which have been derived from the CM&E activities on the project.

6.4 The Prescription Process for Surface and Ground Water Protection

by

C. G. Carlson and Roger Dean

Over the last several years, EPA and other environmentally minded organizations and the United States Department of Agriculture, have released the results of studies documenting the detection of both pesticides and excessive amounts of nutrients in our ground and surface water systems underlying and in close proximity of intensively cultivated agricultural fields. There is no doubt that the intensive agriculture that we practice today has resulted in some degradation of surface and ground waters. The 1984 "Report to Congress, Nonpoint Pollution in the U.S." attributes over 60% of the nonpoint pollution in the United States to agricultural sources. We in agriculture hold the smoking gun. No one else is applying pesticides and nutrients in the concentrations that we are and in close proximity to our water supplies. It should also be noted that we in agriculture are the first and closest group exposed to risk and related health effects.

It is imperative that the real issue be well defined and understood as the complex problem that it is. The real question is, how do we balance intensive agronomic productivity (which has been a significant factor in creating the high standard of living that all of us in America enjoy) against the maintenance of quality ground and surface water. Both are important natural resources and both must be maintained.

How can or should we in agriculture work toward protecting the quality of our own farm and rural water systems while simultaneously maintaining agronomic productivity? The answer to this question lies in increasing management intensity. There are two aspects of this process that need to be considered. First is the political question; how will farmers be encouraged to intensify their management to include consideration of the environmental risk and fate of compounds applied. The political process will determine if that which we discuss in this paper will be a voluntary one or if it will be compulsory. It is neither our desire nor intent to discuss this political part of the question.

Regulation can result in reduced productivity. However, the level of management in ways we are suggest can increase productivity. The prescription process requires consultation with trained agronomists and enhances our ability to protect the environment but also farmer productivity.

Laying the political questions aside, it is our intent to focus on the second component of the question, the technical management process. Our experience for the development of this process comes from lessons that we have learned over the last eight years working on the Oakwood Lakes-Poinsett Rural Clean Water Program (RCWP) in South Dakota.

Each participating farmer was required to conduct a yearly farming program review with the Cooperative Extension Service and the Soil Conservation Service and to receive cost share from the RCWP. The RCWP has shown us that the focus of best management practices must revolve around a Resource Management plan developed with the objective of balancing water quality and agronomic productivity resources. This is the basic premise of the prescription process and the following outline details each step of the process.

<u>Outline of the prescription process</u>

1) Determine the value of resources that need to be protected, and prioritize those resources.

    a) Ground water.
    b) Surface water.
    c) Agricultural production resources.

2) Determine vulnerability of resources.

    a) Ground water, compare field in question against predetermined vulnerability criteria.
    b) Surface water, compare field in question against the predetermined vulnerability criteria.
    c) Tillage zone interaction with surface and ground water
    d) Accurately delineate zones of contribution.

3) Develop and refine a cropping system plan for each field that meets the farmers production needs. Consider best management practices that maximize productivity while minimizing environmental impact.

4) Evaluate nutrient needs.

   a) Collect the history of soil tests, fertilizer applications, cropping practices and yields.
   b) Evaluate current soil test information and analysis it by including historical information.
   c) From cropping system plan which includes cultural practices (fertilization, tillage, pesticide applications, etc.), the yield goals (which imply nutrient needs), and vulnerability of surface and ground water analysis, determine the potential impact of the planned farming practices upon the delineated priority resources.
   d) If (using figures 1, 2, and 3) there exists a unresolvable conflict with a priority water resource, go back to step 3).

5) Evaluate pest problems.

   a) Review historical scouting reports to identify field specific pest problems.
      1) Evaluate the anticipated cultural practices and cropping systems to maximize pest control and minimize environmental impact.
      2) Using the cropping system plan already developed, select cultural the anticipated practices and/or compounds which will be needed.
   c) In fields that need priority protection, determine if the combined vulnerability of field physical factors, runoff and leaching potential, and chemical's runoff or leaching potential pose greater than acceptable risk.
   d) If (using figures 1, 2, and 3) there exists a unresolvable conflict with a priority water resource, go back to step 3).

<u>How is the process implemented?</u>

..Plan the work.

At the initial planning session, the farmer and agronomist develop a plan by following the prescription process. Farming is dynamic, and because weather conditions and spring commodity prices drive farming operations, flexibility is necessary. The plan will contain all of the various acceptable alternatives for each farm field and the alternatives are rated according to production goals and environmental vulnerability.

..Work the plan.

After the plan has been developed, it is implemented by choosing an acceptable alternative for each field from the pre-season plan. Throughout the growing season there must be continual dialogue between the farmer and the agronomist to assure production and environmental protection objectives are met. The farmer scouts his fields (or hires a scouting service) to assure that pest and nutrient problems are detected early and that they are accurately diagnosed.

A timely, agronomically sound, and environmentally acceptable solution to each specific nutrient or pest problem results from these in-season consultations.

Each part of the prescription process is based upon things which have been learned by CM&E monitoring and evaluation of BMP effects on water quality. Let us look at each piece of prescription process and discuss how to integrate each into the balanced environmentally sound agronomic recommendation, "the prescription".

<u>The vulnerability and value of the resources in the area.</u>

Remember that our underlying objective is to balance short term and long term surface and ground water quality preservation against the preservation (and improvement of) short and long term agronomic productivity. We must balance our short term needs against the needs of future generations. To adequately accomplish this objective, we must define those natural resources for which we need to target our protection efforts. What must and should we be protecting? Which water resources within our geographical area of concern (some would call this the hydrologic unit) are vulnerable to degradation by farming practices? Are our environmental concerns surface water, ground water or both? Our final task is to very specifically (draw lines on a 1 to 24,000 map) identify those land resources within the zone of contribution of the water resources that have been identified as needing priority protection. These are political and engineering questions that must be accomplished locally, by the city, county, and state officials.

<u>The discussion with the vulnerability ground water.</u>

As a specific water supply is evaluated, its present and future value to society, its physical vulnerability, and its responsiveness to clean up must be considered.

Examples of the considerations which must be made to determine the value of a water source are: Is the aquifer being used as a public water supply for a water distribution system; what is the zone of contribution for a well that must be protected? Does it supply water to a surface water resource? Are there rural families that are dependent upon the aquifer? Each situation will be different. Political leaders must be coerced into prioritizing. Criteria to determine worth or value is much more a political question than their local area's water and agricultural production resources.

Well head protection is an important part of this process.

a) Delineation of the zone of contribution to the well of concern must be accomplished. Overly simplified calculations can add greatly to our understanding. As an example, assume that all of the water entering a surficial aquifer comes from percolation through the soil profile.

   Theoretically how many acres are providing the recharge for a municipal water system (about 5000 people) that pumps on the average 250 gal/min, 24 hours/day, 7 days a week, 365 days/year? Assume for a surficial aquifer in east central

South Dakota that the average percolation rate through the soil that lies over the aquifer is 4 inch/year. How many acres of land are in need of protection as the primary zone of contribution?

$$\frac{\left[\dfrac{250\ \text{gal}}{\text{minute}} * \dfrac{1\ \text{ft3}}{7.481\ \text{gal}} * \dfrac{525600\ \text{min}}{\text{year}}\right]}{\left[\dfrac{4\ \text{inch} * 1\ \text{acre}}{1\ \text{acre year}} * \dfrac{\text{ft}}{12\ \text{inch}} * \dfrac{43560\ \text{ft2}}{\text{acre}}\right]} = 1210\ \text{acres}$$

We should note that this is a crude simplification and that flow within the aquifer can be important. However, it will not be discussed here.

Next we will look at the physical vulnerability of the aquifer. Below are the criteria that we use to characterize the four physical vulnerability categories for the glacial surficial aquifer region of Eastern South Dakota. Also included are soils information that may influence our categorization methodology. Note that this categorization must be site specific (there are many areas within our State for which different criteria are more appropriate).

b) Most vulnerable
From 0-5 feet of soil over more than 10 to 15 feet of sand and gravel aquifer material.

c) Second level of vulnerability
From 5-20 feet of soil over more than 10 to 15 feet of sand and gravel aquifer material.

d) Third level of vulnerability
From 20-60 feet of soil over more than 10 to 15 feet of sand and gravel aquifer material.

e) Least vulnerable
Greater then 60 feet of soil over more than 10 to 15 feet of sand and gravel aquifer material. It is very unlikely that profiles in this vulnerability class can contribute to the degradation of an aquifer system.

f) Soils data is considered when the second and third vulnerability classes are found and can result in the reevaluation (if the soil is course or has extensive macropores and the vulnerability class is "b" above, we may want to consider this profile to be the same as "a" above or if the vulnerability is "b" above and the soil profile is fine, clay, then we might want to consider the profile the same as the "c" above.) water vulnerability classification. The discussion and inclusion in the decision process of the effect from macropore flow is also critical. For many of our soil profiles, macropores are perhaps the most important and yet least understood physical attribute. Some data indicates that macro pores in native vegetation (without nutrients or pesticides applied at the surface) may act as a piping system allowing precipitation to bypass the soil solution and move into the aquifer much more pure than expected. Under conditions of notill, surface applied nutrients and/or pesticides not incorporated are vulnerable to easily mix with precipitation falling on the surface. This solution is vulnerable to flowing into the macro pores and rapidly move deep into the soil profile. This process can reduce the potential for these compounds to sorb to the soil as flow of the soil water solution to depths is accomplished.

Next we must characterize the vulnerability of the surface waters of the area

Again, the very first step is the political and engineering process of categorizing each water body by its relative value and importance as a water supply, (fishery, recreational use, etc.) and identifying those areas that are the zones of contribution for the priority surface water resources.

For the technical evaluation of resource vulnerability, our strategy starts by using the Universal Soil Loss equation and removing those factors that are determined by cultural practice. Using the R K L S factors gives us an adequate characterization of the inherent capacity of the soil to erode. We are implying that this is highly correlated with surface runoff.

As an initial approximation we are suggesting the following classification scheme.

RKLS < 10 tons/acre = least vulnerable surface runoff potential.
RKLS is 10 to 25 tons/acre = intermediate surface vulnerability.
RKLS > 25 tons/acre = most vulnerable to surface runoff.

An additional factor that needs to be considered is the potential for surface water to move to a portion of the watershed where it is likely to infiltrate into the ground water system. The justification for this approach was discussed earlier in this report.

The nutrient needs of the crop to be grown

The nutrient planning process is begun with a thorough review of soil tests from the previous 4 or 5 years (used to determine trends along with a detailed and to identify possible anomalies in the most recent soil tests) review of crops grown and their yield on each field in question. The NO_3-N recommendation is the most difficult nutrient question. To put it into perspective, let us first review the basis of fertilizer management. To grow 80 bu/acre of corn most agronomist will conclude that we need in excess of 100 lb of NO_3-N. If we assume that 50 lb of this 100 lb is added as fertilizer and is initially in the top 6 inches of soil profile and if there is 40% soil water by volume in the top 6 inches of profile there is:

$$\frac{50 \text{ lb NO3-N}}{\text{Acre 6 inch}} * \frac{12 \text{ inch}}{\text{ft}} * \frac{1 \text{ Acre}}{43560 \text{ ft2}} * \frac{1 \text{ ft3 soil}}{.40 \text{ ft3 H2O}} * \frac{1 \text{ ft3 H2O}}{62.4 \text{ lb}} * \frac{106}{106}$$

= 91 ppm NO3-N in the top 6 inch of soil solution.

Certainly this is a gross simplification, yet it points to the fact that water flowing through the soil profile to an aquifer can pick up high concentrations of nitrates. This result is not necessarily the after effect of poor farm management. It does point to the need for intensive management. Thus, to minimize the applied nitrogen's exposure to potential leaching, apply nitrogen to vulnerable lands closest to its time of need. The management plan may call for multiple nitrogen applications that are designed to match plant demand with nutrient application in a timely way. Additionally, nitrification inhibitors may need to be used with ammonia applications.

The specific pest to be controlled

Integrated pest management, IPM, provides us with the management hub. Practitioners of IPM have traditionally held the philosophy that pesticides should be applied to a crop only when needed, ie., when pest counts indicate that the economic threshold for the application of the pesticide in consideration has been exceeded. With the knowledge of the specific pest, a cultural practice, a pesticide or a group of pesticides can be selected that maximize the potential of eliminating or at least reducing to an economically acceptable level the pest in question. If there are multiple possible agronomic solutions that neutralize the pest in question, the compound or cultural practice that minimizes the acute and chronic environmental impact will be chosen. This management philosophy represents a significant change in farming practice. Much of the pesticide being applied today is put on for it's prophylactic potential. Although on some fields, IPM will increase the amount of pesticide used, the USDA estimates that most intensively cultivated fields will experience a 10% to 50% reduction in pesticide usage when IPM practices are introduced.

The toxicity of the compound

The most difficult evaluation step in the prescription recommendation process is asked as follows. What is the threat, what is the acute and chronic toxicity of each compound in question? ??To is the compound toxic. Is it toxic??
To answer this question we must first accurately define to whom or what to humans, mammals, plants, insects, fish, aquatic plants, bacteria, virus, and the list could go on. Certainly the compound is toxic to some life form, the target pest. What about its acute and chronic toxicity to the life forms other than the target, those life forms with which it will certainly come into contact with. Our discussion will be limited to human toxicity but it would be presumptuous to assume that other life forms are not significant. The question of to which species or group of species we will direct the toxicity question should be addressed while vulnerability and value are being determined.

After we have been able to conclude to what/whom the compound is toxic, (we will assume humans to be our concern), the next question is the type of toxicity. Is the toxicity an acute or chronic problem? From the perspective of a ground and surface water scientist, the effect of consuming low concentrations over long periods of time, the chronic toxicity of a compound, is a more significant problem. Chronic toxicity must first address the type of problem that is most likely to be found at the lowest possible concentration. Is the compound a carcinogen, does it cause birth defects, or does it cause some other long term negative health effect? These problems need to be evaluated according to their carcinogen index, their MCL, or if the MCL is not available, the MCLG or life time health advisory. Because of the complexity of the issue, there is a reluctance to include the toxicity issue in evaluation of the potential for contamination. New compounds are entering the market that are both far safer (from a human toxicity perspective) than their predecessors, and applied at active ingredient rates of fractions of pounds/acre. Both of these factors must be integrated into our decision making process.

<u>The leaching and runoff potential of the compound</u>

Every compound has unique physical and thermodynamic properties that dictate its surface and/or profile (the soil--vadose layer--geological system) movement potential. The objective in determining the leaching or surface runoff potential of a compound is to estimate the concentration, (parts per million), total amount of runoff water, and total flux to the ground water (cm^3 of soil water--compound/cm^2 of surface area) of the compound that will end up in the receiving ground water aquifer or surface water system. This estimate is probably best made by the use of a complex leaching or runoff model. A comment on the use of models for this purpose needs to be made. Models are at best inaccurate estimates. They seldom reflect either the actual runoff, flux or concentration that will flow through a given profile or off a given field even when the important input parameters (the rate of rain fall or evaporation and the depth to a water table) for the flow event being considered are correctly defined. Nevertheless, (and after all of these apologies) they are the best estimates that we have and their prediction capability is improving as the models themselves are improved to better mimic the reality of the dynamic behavior of the field profile being considered.

As a method of simplifying leaching and runoff potential, Goss, 1988, USDA Water Quality Initiative Handbook, has taken the physical and thermodynamic chemical properties of a number of compounds and run USDA GLEAMS and CREAMS models. He then used regression analysis to develop prediction equations. With this process, he classified compounds into large, medium, and small runoff and leaching potential.

<u>Special consideration for surface runoff potential of a compound</u>

There are two modes of surface runoff that pose a problem. Not considered in the above mentioned model analysis is runoff that occurs as the result of a precipitation event occurring shortly after application of a pesticide (and there was no incorporation into the soil of the compound). In this case the pesticide has not had the time to sorb to a plant, surface organic matter, or the surface soil. It is vulnerable to movement into the runoff solution. The obvious resolution of this problem is to avoid the application of pesticides during periods when there is a high potential for a precipitation event to occur.

The soil profile

The potential for the sorbtion of pesticides as they flow through the soil profile is extremely variable from one soil to another. Parameters listed below are usually needed by complex models used to estimated the leaching potential for specific sites.

a. The texture (CEC and rate of flow)
   The more important question is the nature of the matric potential (psi) vs the volumetric moisture content (theta) curve and the hydraulic conductivity (K) vs theta curve. These are the parameters that describe the velocity and quantity of flow through the soil profile. The cation exchange capacity (CEC) of the soil profile indicates the ability of the soil to sorb charged compounds. For a given geographical area, CEC will closely parallel the texture changes.
b. Organic matter content (sorbtivity)
   Organic matter is an important parameter on the soil surface and within the soil profile because it is significant in determining the amount of organic pesticide that is sorbed by the soil profile as the soil water solution moves down. High organic matter content correlates well with high concentrations of microbes which tend to increase the breakdown capability of the soil profile.
c. Structure
   Macropores were discussed earlier.
d. Surface topography
   Surface topography is important in partitioning between infiltration and runoff. The surface loss potential of a compound is largely dependent upon it's ability to remain at the surface of a soil profile and upon the susceptibility of water to runoff of the field in question. The universal soil loss equation modified to eliminate cultural practices and surface cover can be used to estimate the susceptibility of a particular field.

Cultural practices

The cropping system and tillage practices that are conducted as farming practices have significant impact upon the surface and ground water resources of a hydrologic unit. When conservation practices (no till, conservation tillage, terraces, strip cropping, grass waterways, and filter strips) are conducted, sediment runoff is minimized and total runoff flow is usually reduced.

Comparing a conventionally tilled field with a native prairie provides us with some insight.

The terminal infiltration capacity (greater than 6 inch/hour) of a native prairie (Houdek loam) will exhibit infiltration that is as much as an order of magnitude greater than the terminal infiltration capacity (less than .5 inch/hour) of the same soil in an adjacent field that had been conventionally farmed for 40 years. The textures of both profiles were identical but there existed significant structural differences between the two profiles. This discussion provides management practices that are relevant to our earlier discussion of macropore flow.

Integration of the above into a recommendation

The last and most crucial part of the prescription process is the integration of all of the above facts, and factors into a recommendation that maximizes productivity while minimizing environmental impact. This process is a balancing act that identifies the most significant factors affecting production and the environment. Figures 1, 2, and 3 are decision matrixes that are designed to assist in this process. All pertinent constraints have been identified. A best management plan is developed for each of the fields on the farm. The plan is modified based upon identified growing season problems.

At this point the decision criteria are qualitative and cannot be linked to quantitative changes in water quality. Monitoring of the effects provides the data to define what the quantitative rankings mean in terms of water quality effects. Further quantifying the effects is necessary for determining what the critical decision points are in the prescriptive process. Without quantitative data documenting the effects, differences, between prescriptive plans is conjectural and is dependent solely upon the skill of the practioner. Thus system analysis is necessary before water quality goals for a specific water resource can be established and the reasons for attainment can be reasonably assured. Preliminary implementation must be based upon good judgement because the current knowledge is insufficient to document the effectiveness of each BMP; however, documentation of the value of the prescriptive process is dependent upon quantitative measures used in the CM&E. The measurements made by monitoring specific parts of the hydrologic system provide the basic data for the evaluation of BMP effectiveness.

Surface Runoff Potential Soil \ Compound Surface Runoff Potential	High	Medium	Low
High	High	High	Medium
Medium	High	Medium	Medium
Low	Medium	Medium	Low

Figure 6-1. Degree of concern from surface runoff

Geology Leaching Potential \ Compound Leaching Potential	High	Medium	Low
Most Vulnerable	High	High	Medium
2nd	High	Medium	Medium
3rd	Medium	Medium	Low
Least Vulnerable	Low	Low	Low

Figure 6-2. Leaching degree of concern for ground water contamination.

Runoff or Leaching Degree of Concern \ Value of the Resource to Society	High*	Low*
High	Do Not Use	Question
Medium	Do Not Use	Use
Low	Question	Use

Figure 6-3. Decision matrix to use or not use a compound.

Question means that more analysis must be conducted. What is the toxicity to species of concern. At what rates is the compound being applied.

* Note: In the analysis of a large number of problems, the value of the resource was either high or low. It had beneficial use or it did not. Thus, we have no intermediate to these.