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**WATER TABLE MANAGEMENT IMPACTS
ON WATER QUALITY**

By

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ABSTRACT

WATER TABLE MANAGEMENT IMPACTS ON WATER QUALITY

By

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There is tremendous concern for the impacts of agricultural drainage and, more recently, subirrigation on the water resources.

The objectives of this study are to: 1) review the effects of water and water table management on nitrogen, phosphorus, potassium, and atrazine within the soil profile and 2) investigate the water quality impacts of controlled drainage / subirrigation as compared to drainage only on Ziegenfuss clay soil in central Michigan.

Through field research and documentation of the literature it was confirmed that properly designed and managed controlled drainage and subirrigation systems have the potential to reduce the transport of accumulative plant nutrients and applied herbicides.

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I. INTRODUCTION

Although Midwestern states receive an ample amount of water as annual precipitation, irrigation in these areas is often economical. Most Midwestern states experience frequent periods of hot and dry weather during the growing season. When rainfall does occur, low permeability and flat topography of the heavy soils result in excessive water in the plant root zone. Therefore, artificial drainage systems are needed to ensure trafficable conditions for seedbed preparation, planting, harvesting, and other field operations. Drainage is also required to remove excess water from the root zone during heavy rainfall periods and to ensure a suitable environment for plant growth.

Controlled-drainage/subirrigation systems provide total water management for crop production in areas where both irrigation and drainage are needed. During wet periods, the system operates as a drainage system to remove excess water. During dry periods, water is supplied back through the system to the growing crop.

Release and migration of nutrients and pesticides from agricultural lands is a great loss of resources and a threat

to the quality of surface discharge waters. Adverse effects from drainage pollution have become increasingly evident in many locations. Examples of large-scale assessments include the San Luis Drainage in The San Joaquin Valley of California and the Grand Valley Drainage in the Upper Colorado River system. The water quality of these very large water drainage and distribution systems has experienced a severe impact due to agricultural runoff. Much of the effluent from these systems is unusable for agricultural or municipal purposes until it has been treated. These problems point out that many irrigated areas must learn to manage similar problems.

Surface and groundwater quality as effected by agricultural practices has been a concern for many years. In 1940, it was concluded that drinking waters with high nitrate concentrations often caused methemoglobinemia, a blood disorder that often causes death in infants (Maxey, K.F., 1950. Report on relation of nitrate nitrogen concentration in well waters to the occurrence of Methemoglobinemia in infants, Natl. Acad. Sci-Res Council Sanit. Eng. and Environmental Bull. 264). From investigations in Iowa, Minnesota, and Ohio, where the problem has been most acute, it has been concluded that nitrate content should be limited. The proposed Environmental Protection Agency drinking water regulations require that the nitrate concentration in terms of nitrogen not exceed 10 mg/l in

public water supplies. In the 1986 amendments to the Safe Drinking Water Act (SDWA), Congress required that maximum contaminant levels be promulgated for numerous highly water-soluble pesticides within three years of enactment. Among them were alachlor, atrazine, simazine and carbofuran. Maximum contaminant levels for alachlor, atrazine, and carbofuran have been proposed at 2, 3 and 40 g/L, respectively. Levels much greater than these are often experienced following a springtime application.

In Michigan, approximately 16,000 hectares of agricultural land is currently equipped with controlled-drainage/subirrigation systems. It is estimated there are over 1.2 million hectares of land with the potential to incorporate water table management systems. This enormous potential for utilizing water table management in Michigan has spurred concern as to the potential environmental impact of widespread incorporation of water table management systems.

Several field studies and modeling efforts have been conducted to gain a better understanding of the phenomena involved in overland and underground transport of nutrients and chemicals. The effects of tile drainage, tillage method and cropping practices have also been thoroughly studied. However, few field studies have been conducted to better discern the impacts of water table management systems on

surface and groundwater quality. It is the intent of this study to document through case studies and field research, the potential water quality impacts of water table management systems. This documentation is intended to help provide a data source that, despite differences in site conditions and geographical locations, will provide a better understanding of the water quality impacts of water table management.

The objectives of this study are to: 1) review the effects of water and water table management on nitrogen, phosphorus, potassium, and atrazine in tile drainage discharge and 2) investigate the water quality impacts of subirrigation. The specific objectives are:

1. To compare the nutrient and pesticide concentrations between a subirrigation plot and subsurface drainage only plot.
2. To use the water quality data to evaluate selected available water quality computer models that may have value in extrapolating subirrigation discharge water quality data to other soil, tillage, and crop conditions.
3. To use the knowledge gained to design and support funding requests for the additional research needed to develop a comprehensive understanding of the short and long term water quality effects of subirrigation.

II. LITERATURE REVIEW

A. Nitrogen

The efficient management of water and nitrogen is very important in areas of artificially drained soils; a deficiency of available N often limits yields while an excess can be an environmental concern. Inefficient management of nitrogen fertilizers can result in the loss of available N through denitrification and leaching, an economic loss to the farmer and potential for surface and groundwater pollution. Further, efficient fertilization is important to minimize energy input in crop production. Also, reduced forms of nitrogen are oxidized in natural waters, thereby affecting the dissolved oxygen resources (Kanwar, et al. 1984).

1. Nitrogen Cycle in the Soil

As stated by Watts and Hanks (1978) there are several potential nitrogen sinks within the soil environment. These include volatilization at the soil surface, denitrification, biological immobilization, nitrification and leaching.

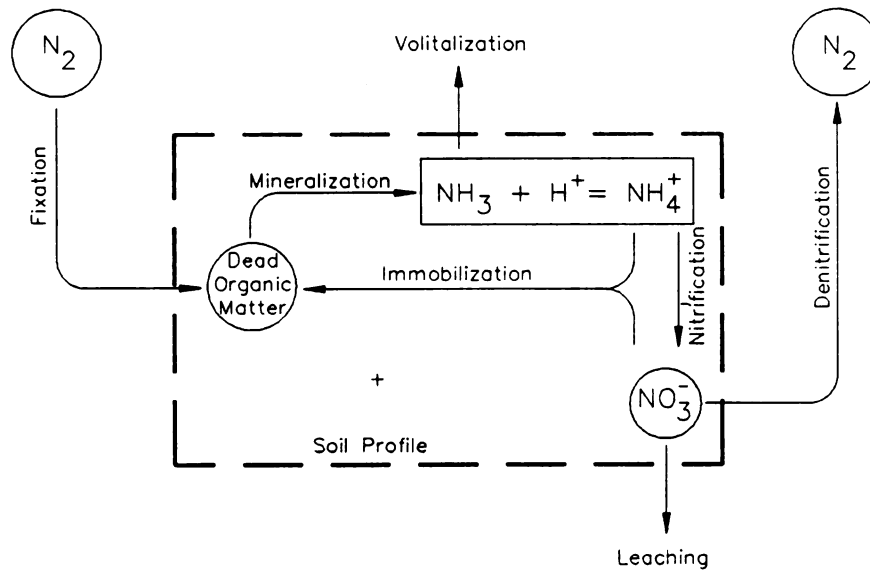


Figure 1. Nitrogen cycle in soils.

Transformation of nitrogen in the soil environment is very complex. Nitrogen can assume several oxidation states, and many of the changes in oxidation state are brought about by living organisms. The oxidation state wrought by bacteria can be either positive or negative, depending upon whether aerobic or anaerobic conditions prevail. Nitrogen can exist in seven oxidation states, NH_3 (-3), N_2 (0), N_2O (+1), NO (+2), N_2O_3 (+3), NO_2 (+4), N_2O_5 (+5). As far as is known, compounds of nitrogen in +1, +2 and +4 oxidation states have little if any significance in biological processes (Tisdale et.al. 1985).

Foth (1975) stated that plants absorb most of their nitrogen

in the NH_4 or NO_3 forms, and uptake of this nutrient is complicated since plants usually have access to both forms. Nitrate is often the dominant source of nitrogen since it generally occurs in higher concentrations than NH_4 , and it is free to move to the roots by mass flow and diffusion. Some NH_4 is always present and will influence plant growth and metabolism in ways that are not completely understood.

Soil water content effects many of these transformation processes in the nitrogen cycle (Tisdale et al. 1985). Trudgill et al. (1981) provides evidence supporting that during slow soil water flow, prolonged solid-solvent contact is allowed and the dissolution of soil chemical constituents is liable to approach chemical equilibrium. This also applies to static water in the soil which is displaced by incoming water after a long residence time. During rapid flow, only those chemical elements which are rapidly soluble will be able to maintain high concentrations. Rapid flow will therefore result in the preferential leaching of the most rapidly soluble chemical elements. Trudgill et al. (1981) also found that highly soluble nutrients such as nitrates and potassium loads are proportional to drainage discharge. Deciduous forests were used to provide a baseline which can be compared to agricultural situations where soluble nutrients are applied to the soil in excess quantities.

Kanwar, et al. (1983) developed a computer model to simulate the soil-plant-water-nitrogen system in a typical tile drained agricultural field. The model simulated the biophysiochemical transformation of various nitrogen forms in the soil, nitrogen uptake, nitrogen flow due to mass flow, dispersion, and diffusion. Water flow in the saturated and unsaturated soil zones and evapotranspiration were also simulated along with loss of water and nitrate from the root zone. The microbiological nitrogen transformations deemed to be important were; nitrification of NH_4 to NO_3 , mineralization of N to NH_4 , immobilization of NH_4 to NH_3 , and denitrification of NO_3 to gaseous forms.

The model was calibrated and its performance was evaluated using field data collected from 1970 to 1978. The measured and predicted nitrogen carried by subsurface drain flow over the data collection period was 30.84 kg/ha and 30.47 kg/ha respectively. The model provided satisfactory simulation results. Differences between measured and predicted values were attributed to a lack of a completely accurate hydrologic predictions. It was concluded the processes of nitrification, mineralization, nitrogen uptake, and denitrification are areas that require better investigation for better representation.

a. Mineralization and Nitrification

The mineralization of nitrogen compounds takes place in essentially three reactions: aminization, ammonification and nitrification.

Numerous groups of bacteria and fungi decompose organic matter. One of the final stages in the decomposition of nitrogenous materials is the decomposition of proteins and the release of amines and amino acids (aminization). The amines and amino acids are utilized by groups of heterotrophs with the release of ammoniacal compounds (ammonification). Some of the ammonium released by the ammonification process along with fertilizer applied ammonium are biologically oxidized to nitrate. This process is called nitrification. Factors affecting the nitrification pattern in soils are (1) supply of the ammonium ion, (2) population of nitrifying organisms, (3) soil reaction, (4) soil aeration, (5) soil moisture, and (6) temperature. The nitrobacteria are obligate autotrophic aerobes; they will not produce nitrates in the absence of molecular oxygen. When soils become waterlogged, oxygen is excluded and anaerobic decomposition takes place (Tisdale, et al. (1985)).

b. Denitrification

When soils become waterlogged, oxygen is excluded and anaerobic decomposition takes place. Some anaerobic organisms have the ability to obtain their oxygen from nitrates and nitrites with the accompanying release of nitrogen and nitrous oxide gases, this process is denitrification. The magnitude and rate of denitrification are strongly influenced by several environmental factors, the most important of which are amount and nature of organic matter present, moisture content, aeration, soil pH, soil temperature and level and form of inorganic nitrogen at hand (Bremner and Shaw (1958); Burford and Bremner (1975); Cooper and Smith (1963)).

Waterlogging of soils results in rapid denitrification by impeding the diffusion of oxygen to sites of microbiological activity (Bremner and Shaw (1958)). Denitrification of NO_3 and NO_2 proceeds only when the oxygen supply is too low to meet aerobic microbiological requirements. The denitrification process can operate in seemingly well-aerated soil, presumably in anaerobic microsites where biological oxygen demand exceeds the supply.

The process of denitrification is very sensitive to soil temperature and its rate increases rapidly in the 2 deg C to 25 deg C range. This rapid increase in denitrification at elevated soil temperature suggest that thermophilic

microorganisms have a major role in denitrification (Tisdale, et al. (1985)).

c. Immobilization

Immobilization of nitrogen is the reverse of mineralization - it occurs when large quantities of low-nitrogen crop residues begin decomposing in soil. The high amounts of carbohydrate in such residues cause the population of soil microflora to build up quickly. As new cells are formed, nitrogen is used to build protoplasm thus causing decreased levels of inorganic nitrogen. (Tisdale, et al. 1985 and Foth 1978).

B. Phosphorus

Experiments on small Canadian lakes demonstrate that adding carbon (as sucrose) and nitrogen (as nitrate) does not stimulate algal blooms without simultaneously adding phosphate (Schindler, 1974 cited by Ricklefs, 1984). It was concluded that phosphorus is the limiting factor in eutrophism.

Whereas naturally eutrophic systems are usually well balanced, the addition of artificial nutrients can upset the natural workings of the community and create devastating imbalances in the ecosystem (Likens, (1972) cited by Ricklefs, (1984)). Algal blooms are among the most

noticeable of these effects. The combination of high nutrient loads and favorable conditions of light, temperature, and carbon dioxide stimulate rapid algal growth. Algal blooms are a natural response of algae to their environment. But when the environment changes and can no longer support dense algal populations, the algae that accumulate during the bloom die and begin to decay. The ensuing rapid decomposition of organic detritus by bacteria robs the water of its oxygen, sometimes so thoroughly depleting the water of oxygen that fish and other aquatic animals suffocate. The nutrient imbalance in culturally eutrophic systems stems from the addition of nutrients at seasons when they are less available in naturally eutrophic waters, primarily during the summer peak of plant production during less productive seasons, phosphorus is readily absorbed by benthic bacteria and sediments at the bottoms of lakes, and its concentration in lake water is thus quickly reduced (Ricklefs, (1984)).

1. Phosphorus Cycle in Soils

In general, phosphorus applied to the soil remains at the point of application due to very rapid reaction with elements in the soil colloids (Merva, 1975). Dissolved phosphorus from fertilizer materials, in wastewater, and from indigenous soil sources reacts with soil constituents to create less soluble forms. Phosphorus thus removed from

the solution phase is said to be retained or fixed (See Figure 2). Many researchers view phosphorus retention as a continuous sequence of precipitation, chemisorption, and adsorption. With low phosphorus solution concentrations, adsorption seems to be the dominant mechanism (Tisdale, et al. (1985) and Foth (1975)).

a. Precipitated Phosphorus

There are many initial reaction products that might precipitate in the soil when common phosphatic fertilizers are applied. The chemical properties of fertilizer salts and their mixtures vary so widely that formation of a great variety of compounds in soil systems is to be expected (F.E. Khasawneh et al., 1980 cited by Tisdale et al., 1985). Many of these compounds are highly insoluble and are precipitated.

b. Adsorbed and Chemisorbed Phosphorus

When phosphorus is held at the surface of a solid it is said to be adsorbed. If the retained phosphorus penetrates more or less uniformly into the solid phase, it is considered to be absorbed or chemisorbed (Tisdale, et al. (1985)).

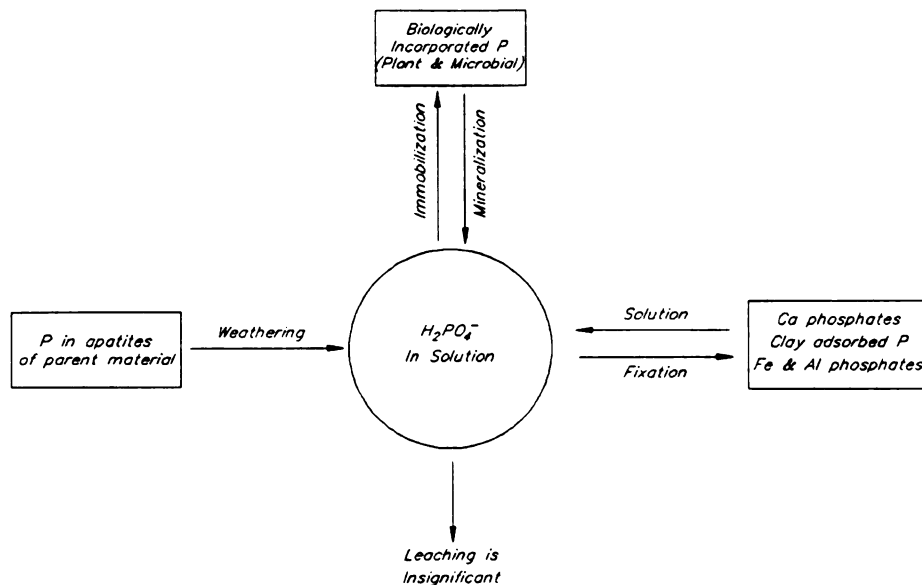


Figure 2. The phosphorus cycle in soils.

C. Potassium

As stated by Lyon, et al. (1950) most mineral soils, except those of a sandy nature, are comparatively high in total quantity of this element, yet, the quantity of potassium held in an easily exchangeable condition at any one time often is very small. Most of this element is held rigidly as part of the primary minerals or is fixed in forms that are at best only moderately available to plants.

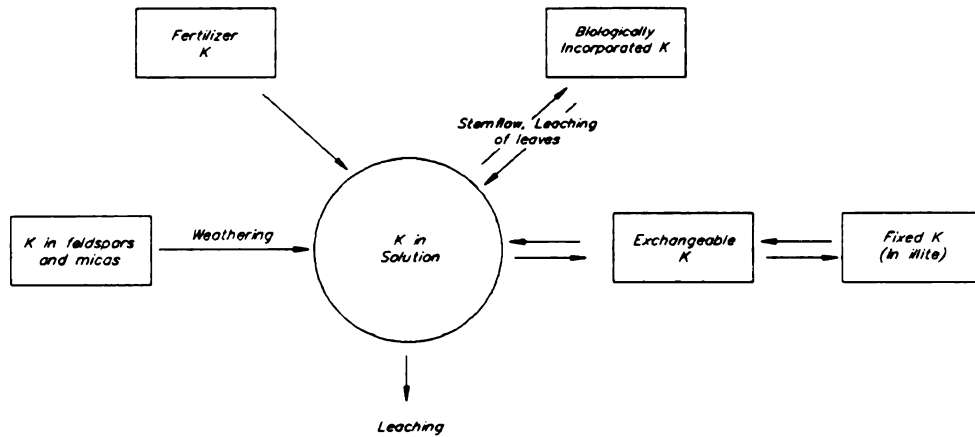


Figure 3. Potassium cycle in soils.

1. Potassium Cycle in Soils

a. Weathering

Potassium replenishment of the labile pool in soils is largely governed by the weathering of feldspars and micas. Potassium is liberated by feldspars by the destruction of the mineral. In micas, interlayer potassium can be released by exchange with other cations and by the destruction of the mineral (Tisdale et al. (1985)).

b. Exchangeable Potassium

Like other exchangeable cations, the K^+ ion is held around negatively charged soil colloids by electrostatic attraction. The cations are easily displaced when the soil is brought into contact with neutral salt solutions (Tisdale, 1985). An equilibrium exists between the solution potassium and the potassium which is held on exchange positions in the soil. For example, when the concentration of potassium in solution increases, more potassium is forced onto exchanged positions by mass action. When the concentration of potassium in soil solution decreases potassium is released from exchange sites by mass action (Foth, 1978).

c. Fixation

An equilibrium also exists between the exchangeable and fixed potassium. Fixation occurs by migration of K^+ into vacant positions of the mineral lattice from which a K^+ had been removed by weathering. Weathering begins at the edges of mineral particles and progresses inward. Along the edges, the potassium is weathered out leaving vacant spaces in the lattice, while the interior of the particle is still fresh and unweathered. Potassium fixation is the reverse of weathering out of potassium from the lattice.

Fixation and release is a reversible process dependent on the concentration of K^+ on the exchange sites which, in turn, is dependent on the concentration of K^+ in solution.

d. Leaching

Potassium is intermediate between nitrogen and phosphorus in regard to mobility in soils. Some potassium is leached from soils in humid regions, but the losses do not appear to have any environmental consequences (Foth, 1978). An examination of the drainage water from mineral soils on which rather liberal quantities of fertilizer have been applied will usually show considerable quantities of potash (Lyon et al., 1950).

In support of Lyon, et al. (1950), Bolton, et al. (1970) found that potassium losses through tile drains increased with increased fertilizer application. Similar results were witness by Bengtson, et al. (1984) and Logan and Schwab (1976).

D. Water Table Management

1. Effect on Field Runoff

a. Subsurface Drainage

The effects of subsurface drainage on field runoff, both subsurface and surface, has been widely studied and reported: Willard, et al. (1927); Schwab and Fouss (1967);

Schwab, et al. (1977); Schwab, et al. (1980); Bengtson, et al. (1988); Jacobs and Gilliam (1985); Bottcher, et al. (1981); Skaggs, et al. (1982); Natho-Jina, et al. (1987); Jackson, et al. (1973). These studies show subsurface drainage reduces overland flow from fields as compared to similar fields without subsurface drainage systems. However, the overall water that is lost from the fields is increased. The predominant contributing factor is the volume of flow from a field via subsurface drainage systems. It is also shown that subsurface drainage system design, climatological, geographical and soil conditions all influence the rate of flow from a field.

b. Controlled Drainage and Subirrigation

Research on the effects controlled drainage and subirrigation have on runoff and water quality is recent and the data is limited. This research does show that controlled drainage and subirrigation will reduce total subsurface drain flow over conventional subsurface drainage (Campbell, et al. (1985); Gilliam and Skaggs (1986); Deal, et al. (1986); Fouss, et al. (1987); Evans and Skaggs (1989) (ASAE Paper No. 89-2129); Evans, et al. (1989) (ASAE Paper No. 89-2695); and Evans et al. (1987) (Effects of agricultural water management on drainage water quality. Drainage Design and Management Proceedings of the Fifth

National Drainage Symposium, ASAE, Hyatt Regency Chicago in Illinois Center, Chicago, IL, December 14-15). Controlled drainage system design and management is concluded to have had a significant impact on the water flow from the field.

2. Effect on Water Quality

a. Nitrogen, Phosphorus and Potassium.

i. Subsurface Drainage

Subsurface drainage reduces erosion and sediment bound nutrient losses, mainly phosphorus and potassium, primarily by reducing overland flow. Nitrogen losses, particularly nitrate-nitrogen, are generally increased in both overland and subsurface drain flow of subsurface drained fields compared to non-drained fields (Schwab, et al. (1980); Bengtson, et al. (1988); Bottcher, et al. (1981); Jacobs and Gilliam (1985); Baker, et al. (1975)). System design and field characteristics greatly influence the fate of nitrate-nitrogen transport.

Pesticide losses have been reported to be decreased with subsurface drainage (Southwick, et al. (1989) (Effects of subsurface drainage on runoff losses of atrazine and metolochlor in Southern Louisiana. Submitted to Bulletin of Environmental Contamination and Toxicology). However, a lack of research in that area limits conclusions on the

effect subsurface drainage has on the fate and transport of pesticides.

ii. Controlled Drainage and Subirrigation

Data has not been reported on sediment transport in controlled drainage and subirrigation systems and little has been reported on the fate of potassium transport.

In general, soils which have a fine texture or a horizon which restricts water movement have lower quantities of nitrate below the surface horizons or leaving the field via water movement than do better drained soils (Devitt, et al., (1976); Gast et al., (1974); Gilliam et al.(1978)). The differences in the nitrate content of the soil water is believed to be a result of differences in denitrification. Data from North Carolina show that poorly drained soils with relatively high water tables (0.3-1.5 m below the surface) lose less nitrate to drainage waters than do well-drained soils because of denitrification in the subsoil of the poorly drained soil (Gambrell et al. (1976)). Gilliam, et al. (1979) compared the amount of nitrate-nitrogen lost from fields from conventional drainage and controlled drainage treatments. Controlled drainage was maintained by using flashboard riser-type water level control structures installed in drainage ditches at two locations representative of soil conditions of large areas of artificially drained soils of the North Carolina Coastal

Plain, moderately well and poorly drained. Each location had 2 fields, one which was under conventional drainage while the other was under controlled drainage. The treatments of each field were changed periodically. Controlling subsurface drainage in the moderately well drained soils reduced nitrate nitrogen in subsurface drain flow, during the growing season, from an average 32.5 kg/ha in the uncontrolled drainage fields to 4 kg/ha in the controlled drainage fields. However, the difference in nitrate nitrogen losses was due to less volume of water discharged and not due to differences in nitrate concentrations. Nitrate nitrogen concentrations averaged between 15-20 ppm throughout the year in both uncontrolled and controlled drainage discharge waters. In the poorly drained soils the average total nitrate-nitrogen lost from the uncontrolled drainage field was 25 to 30 kg/ha. The nitrate nitrogen losses from the controlled drainage treatment in poorly drained soils was approximately one-half that experienced in the uncontrolled fields. Based upon soil water sample results, this decrease is believed to represent a real decrease in the amount of nitrogen entering surface waters because of denitrification occurring in dense soil horizons below 1.5 m from the soil surface.

Campbell, et al. (1985) measured nitrogen and phosphorus losses from a sandy, high-water-table soil in Florida under two water management treatments. These were a furrow

irrigation system with surface drainage only and a subsurface drainage-irrigation system. The study was conducted for a one year period. Nitrate-nitrogen losses were the predominant nitrogen form detected from both systems, and orthophosphate was measured as well. The total nitrate-nitrogen carried in discharge waters in the water furrow system was 4.53 kg/ha. The total nitrate-nitrogen from the subirrigation system was 2.75 kg/ha, 0.83 kg/ha carried overland and 1.91 kg/ha carried in subsurface drain tile discharge. The total orthophosphate carried in discharge water from the furrow system was 1.10 kg/ha. Total orthophosphate discharged from the subirrigated field was 0.43 kg/ha , with 0.26 kg/ha carried in overland flow and 0.17 kg/ha carried in subsurface drain tile discharge. It was concluded nitrate-nitrogen and orthophosphate concentrations were both less in subsurface drain discharge than in surface runoff or water-furrow outflow. It was further concluded additional research is needed to explain the reduced nitrate concentrations in drain tile discharge.

Gilliam and Skaggs (1986) determined the effects of drainage system design and management upon water quality of drainage discharge through use of the DRAINMOD computer model on two experimental Atlantic Coastal Plain soils. Nitrate-nitrogen losses, both surface and subsurface, were compared between conventional drainage treatments and controlled drainage treatments. The average losses of nitrate-nitrogen for

several individual one year simulations from the conventional drainage treatments was 33.5 kg/ha. The nitrate-nitrogen losses from the controlled drainage treatments was 22.8 kg/ha. The simulated average phosphorus losses from the conventional drainage treatments was 0.12 kg/ha. Average phosphorus losses from the controlled drainage treatments was 0.22 kg/ha. Controlled drainage reduced the nitrate-nitrogen losses but increased the phosphorus losses. Gilliam and Skaggs (1986) stated there are many different management schemes that can be used in controlled drainage systems and drainage control has the potential to offset much of the environmental criticism of improved drainage systems, while providing adequate drainage protection for crop production.

Deal, et al. (1986) used the DRAINMOD computer simulation to predict nutrient losses under various drainage designs from 6 different soils over a 20-year period. Nitrate-nitrogen and total phosphorus losses to surface waters from conventional drainage treatments and controlled drainage treatments were compared. All soils simulated had poor to very poor natural drainage classifications. The simulations indicated that both drainage system design and management can have significant effects upon nitrogen and phosphorus losses in drainage water. Drainage systems designed to give good subsurface drainage lost 17 to 35 kg/ha per year more nitrate nitrogen than systems with poor subsurface drainage.

Good subsurface drainage decreased total phosphorus lost by 0.2 to 0.4 kg/ha per year on the mineral soils simulated. It was concluded the increase in nitrogen lost because of installing a good subsurface drainage system can partially be offset by utilizing controlled drainage. Under the conditions simulated, controlled drainage reduced the nitrate losses by as much as 34 percent, but the reduction varied with soil type and management conditions. Controlled drainage did result in a small increase in phosphorus losses under the conditions simulated.

Using the computer simulation model DRAINMOD, Skaggs and Gilliam (1981) showed considerable potential for reduction of nitrate nitrogen loss in subsurface drainage by use of controlled drainage in North Carolina. Conventional drainage, controlled drainage during applied only during the winter and controlled drainage utilized throughout the entire year were simulated for both good and poor surface drainage systems. Three parameters were calculated and tabulated for each year of simulation: (a) total nitrate nitrogen outflow (kg/ha); (b) number of working days during the one month period prior to planting (March 15 to April 15); and (c) SEW(30) which provides a measure of excessive soil water conditions during the growing season (Bouwer (1974)). Assuming an SEW(30) = 100 cm-days, more than 10 working days and poor surface drainage, the model predicted

nitrate-nitrogen losses from convention drainage of 38.9 kg/ha per year, 33.0 kg/ha for controlled drainage during the winter and 39.0 kg/ha for controlled drainage throughout the year. The study concluded: "The amount of nitrate nitrogen that leaves the field through drainage waters can be reduced by using controlled drainage during the winter months and during the growing season. Use of controlled drainage requires somewhat closer drain spacings than conventional drainage systems in order to meet trafficability requirements. Therefore, nitrate outflows will be increased over that of conventional drainage if outlet water levels are not controlled as planned in the system design."

Willardson, et al. (1972) studied the process of denitrification in an agricultural field by the submergence of drains in the San Joaquin Valley of California. The soil around the subsurface drains, groundwater from the center of the experimental field, and subsurface drainage flow were tested for nitrate-nitrogen concentrations. The highest nitrate-nitrogen readings, ranging from 330 to 364 ppm, were found in the soil around the bottom of the subsurface drains while the soil at the top of the drains had lower readings, ranging from 10 to 218 ppm. The highest concentrations found in all measurements were around the drains. While nitrate-nitrogen concentrations in the soil profile remained the same over the measured period of time, subsurface drain

flow concentrations decreased over the same period. Based upon this data it was concluded denitrification occurs in saturated soil where there is ample organic carbon for bacterial metabolism and a shortage of oxygen and that denitrification and dilution of high nitrate ground water were accomplished in the field.

Evans, et al. (1987) (Effects of agricultural water management. 1987, Drainage Design and Management Proc. of the Fifth Nat. Drainage Symp., Hyatt Regency Chicago in Illinois Center, Chicago, IL, December 14-15) studied the effects of water table management on drainage discharge. Surface drainage discharge was compared to subsurface drain water quality of conventional drainage and controlled drainage water table management systems.

The total nitrate-nitrogen losses from the conventional subsurface drain flow was 61.37 kg/ha as compared to 13.08 kg/ha for controlled subsurface drainage treatments. The total phosphorus losses from the conventional subsurface drain flow was 0.17 kg/ha as compared to 0.20 kg/ha for the controlled subsurface drainage treatment.

Doty, et al. (1986), ASAE Paper No. 86-2581) studied irrigation water supply and water quality from 1980 to 1985 along a substantial section of Mitchell Creek in North Carolina. The creek was supplying water for center pivot irrigation and high volume guns which irrigated a total of

79 ha. Nutrient concentrations and flow volumes were recorded with the creek flowing without restrictions and with a Fabridam in place to control stream water level for the irrigation supply for overhead and subirrigation. After comparing the 6 years of data it was concluded the stream water level control reduced the nitrate-nitrogen concentrations while little change was observed in potassium and phosphorus concentrations. Based on the lower flow volumes and the nutrient concentrations observed it can be seen there was a net increase in the water quality to the receiving waters.

Kalita and Kanwar (1989), (ASAE Paper No. 89-2680) monitored the effects of water table management practices on corn yield and water quality for field experiments in Iowa. The authors concluded the lower the water table elevation is controlled, the higher the nitrate nitrogen concentration in the field.

b. Atrazine

It is known that atrazine is rendered nonphytotoxic or dissipates from soil by a variety of means (Jordan, et al. (1970); Sheets (1970)), the important processes being microbial decomposition, leaching, and chemical breakdown. It was noted the rate of dissipation by chemical and microbial means varies considerably between areas and is dependent on climatic as well as soil conditions.

Von Stryke and Bolton (1977) reported continuous corn treatment average annual atrazine losses of 0.007 kg/ha in the subsurface drainage discharge while rotation corn treatments had an annual average loss of 0.004 kg/ha carried to edge of field by subsurface drain flow, thus noting a carryover of atrazine from previous years.

Leaching as a factor in the removal of atrazine from soil is dependent on soil type and condition. Although the solubility of atrazine in water is low (33 ppm aqueous) and it is adsorbed to soil colloids by chemical forces, leaching does occur and has been documented by many workers (Burnside, et al. 1970; Rogers 1968).

Burnside, et al. (1971) stated that leaching was a major factor in removal of atrazine. Atrazine was found to have leached to a depth of 0.45 m within a 4 month period. It

was also observed the leaching process depended on the frequency and intensity of rainfall and was influenced by the type of soil and its organic content. Muir and Baker (1976) monitored residues of atrazine and other herbicides in tile-drain effluent under corn fields and found that atrazine residues were present in the ppb range.

Von Stryk and Bolton (1977) found atrazine losses were predominately dependent on the amount of water leaching through the soil at any given time. Bolton, et. al. (1970) reported corresponding results with losses of nutrients which increase with the amount of water passing through the soil.

Muir and Baker (1976) applied atrazine to test plots and collected water samples from tile outlets. The average residue concentration of atrazine present in drainage tile discharge was 1.2 g/liter, with an estimated residue loss from the field, which was managed in a drainage mode throughout the test period of April thru December, of 2.06 g/ha.

III. METHODOLOGY

A. Site Description

In August 1985, a combination subsurface drainage and subirrigation system was installed in a privately owned 16.2 ha field near Bannister in Gratiot County, Michigan (a part of the S.W. 1/4, of the N.W. 1/4, Section 34, T.9 N., R.1 W.). The Bannister site is relatively level with the predominant slope toward the northwest (See Figure 4). The soil is mapped as Lenawee series, however, on-site investigation and laboratory analysis by Soil Conservation Service and Michigan State University soil scientists resulted in revising the classification to Ziegenfuss for the entire 16.2 ha. The soil investigation results are given in Appendix A.

The Ziegenfuss series consists of deep, poorly drained soils formed in loamy and clayey calcareous glacial till on till plains and moraines. The surface layer is black silty clay loam 0.15 m deep. The subsoil is dark gray and gray mottled clay 1.15 m thick. The substratum is gray clay and extends to a very dense compacted clay layer at approximately 1.5 m below the surface.

Saturated lateral hydraulic conductivity, by the auger hole method, varied from 10 mm/h to 25 mm/h. The dominate saturated lateral hydraulic conductivity for the site was determined to be 17 mm/h. The auger holes used for hydraulic conductivity testing were 0.1 m diameter, 1.5 m depth and bottomed in the dense clay layer assumed to be the impermeable barrier.

The topography of the site allowed subdivision of the area into eight water table management zones in which the surface elevation variance within a zone did not exceed 0.30 m. The subsurface drainage/subirrigation system consists of 102 mm inside diameter (ID) corrugated plastic tubing laterals discharging into corrugated plastic submains and mains ranging in size from 127 mm through 305 mm ID. The system was installed August 5-9, 1985 by members of the Michigan Land Improvement Contractors Association. The submains and mains were installed by a trenching machine. The laterals were installed by drainage plows. The laterals are at 6, 12, and 18 m spacing as shown by Figure 4. The depths to the inverts of the laterals vary from 1.1 m to 1.4 m below the ground surface. The system, as installed, provides 8 water table management zones (A through H) and a maximum of 32 irregularly shaped treatment plots that vary in size. The surface elevation (from an arbitrary datum) of the water table management zones is from 29.75 m to 30.18 m for zone A, 29.87 m to 30.18 m for zone B, 30.18 m to 30.48 m for

zone C and D, 30.48 m to 30.78 m for zones E and H, and 30.78 m to 31.03 m for zones F and G.

The source of irrigation water for the system was the Maple River which is located approximately 500 m from the subirrigated field. A pump at the river supplies approximately 750 liters per minute via 152 mm inside diameter PVC pipe to four valved discharge lines on the West side of the field.

During the 1987 growing season corn and soybeans were grown and studied on the Bannister site. Both corn and soybeans were planted on zone A and zone B, the drainage only treatment and the high water table treatment respectively. As part of the companion projects a comprehensive yield analysis was conducted on the entire field. Crop yields from zones A and B are presented in Appendix D.

B. Water Table Management

The drainage only area (zone B) is part of the surrounding subirrigation system, and the drainage main serves the entire area. It was found that leakage from the main and lateral seepage from neighboring subirrigated zones resulted in a water table being maintained at the depth of the drains in the drainage only treatment. For the high water table treatment (zone A), the water table was maintained with an

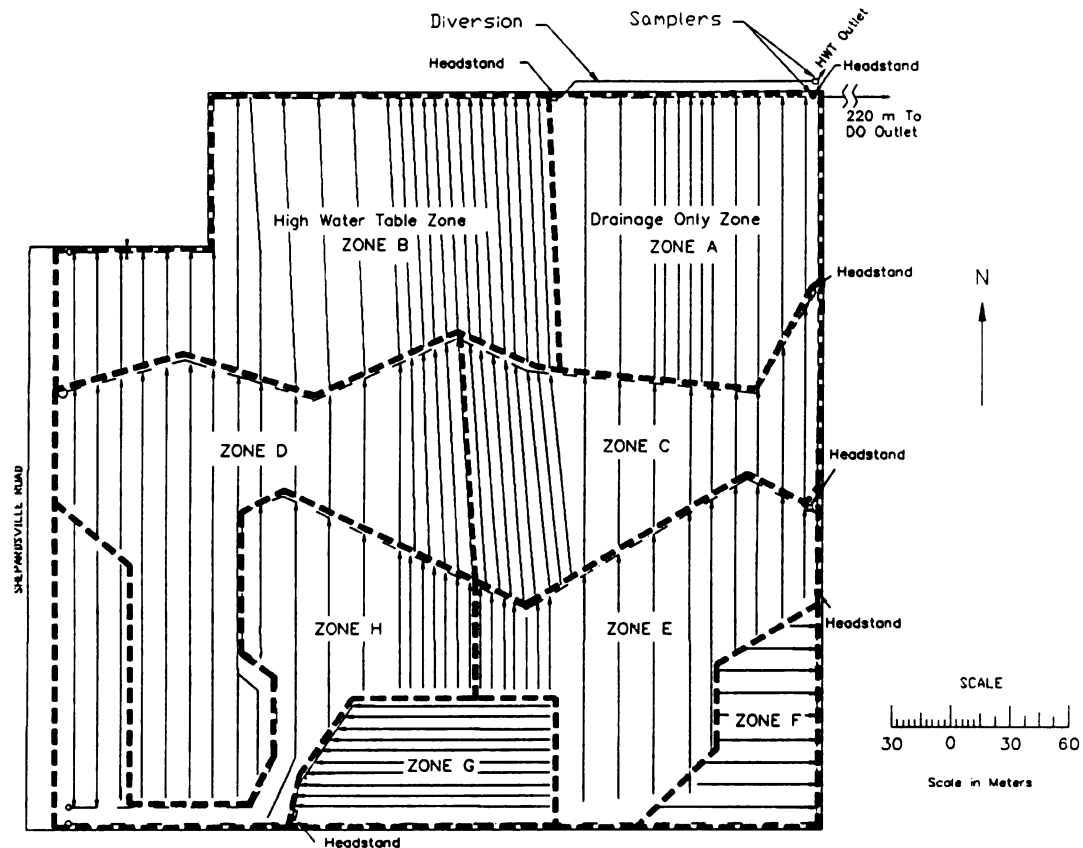


Figure 4. Bannister lateral spacing and water table management zone layout.

average weir depth of 0.3 m below the surface with a minimum of 0.15 m control depth, occurring in the lower part of the zone, and a maximum of 0.5 m control depth, occurring at the higher part of the zone, during the growing season.

The high water table treatment control stand was set on May 27, 1987 to provide a controlled drainage situation. The weir elevation was set to provide control of the drainage water to an average water table elevation of 0.30 m below

the surface. Subirrigation pumping began June 12 to bring the water tables up to the designed control depths in the various zones. Pumping continued until August 20 when the irrigation pump burned out because the pump motor was apparently damaged by lightning. It was decided to discontinue pumping for the year at this time. The high water table zone was continued in a controlled drainage mode until October 18 when the headstand weir was lowered by 0.3 m, to provide an average water table elevation of 0.6 m below the ground surface, to allow for harvest of the corn and soybeans. On November 19 the headstand in the high water table zone was raised from a water table control elevation of 0.6 m below the ground surface to 0.3 m below the surface. The water table control weir was left in the controlled drainage mode at 0.3 m average water table elevation throughout the winter.

In the spring of 1988, to prepare the high water table zone for field cultivation, the water table control weir was lowered to a 0.5 m control depth on March 28, 1988 and to a control depth of 0.7 m on April 1. The control depth was maintained at 0.7 m until May 15 when it was raised to table control depth of 0.3 m. Irrigation pumping began on May 27, 1988.

C. Fertilization and Herbicide Application

For the 1987 growing season the fertilization application was 55.2 kg/ha potash over the entire field in the fall of 1986 with an additional 36.8 kg/ha of 18:46:0 as a starter for corn applied at planting. The corn was also side dressed with 36.8 kg/ha of anhydrous ammonia applied when the corn, was approximately 0.3 m tall. The herbicides applied were: a) 1.9 L of Lasso over the entire field plus b) 0.68 kg. of atrazine, (Atrox 90) over the corn area.

For the 1988 growing season a fertilizer application of 55.2 kg/ha of potash and 12.3 L/ha of 28% nitrate was applied following the fall 1987 harvest.

D. Data Collection

The Bannister research site is utilized for many different research projects. As part of the water quality project presented here, drainage discharge volumes and water samples were collected from the drainage only treatment (zone A, Figure 4) and on the high water table treatment (zone B, Figure 5) at the rate of one sample per 19,000 liters of discharge. As part of companion projects, water table elevations meteorological and agronomic data was collected over the entire 16.2 ha site. (Belcher, H.W., 1990. Water table management to maximize the economic efficiency of

biomass production. Phd. Thesis, Michigan State University, E. Lansing). (See Appendix D)

Monitoring of the outflow was begun in April, 1987. Grab samples were taken from April 4 until August 5. In-line orifice meters (Protasiewicz, et al. 1987, ASAE Paper No. 87-2608) were designed, built, and calibrated prior to being installed early in the 1987 growing season (Appendix C). A tile flow diversion was designed and installed in the spring of 1987 (Figure 4) to separate the outflow from the drainage only site from that of the subirrigated high water table portion of the project. To correct outflow backup in the outlet main the outlet ditch was cleaned. This insured a free outfall which was necessary for flow measurement to proportionately monitor the outflow water. Prior to the time the diversion and flow measurement systems were operational, water samples were taken by hand (grab samples). After installation of the flow measurement system, flow data collection from orifice meters was carried out using the bubbler technique (Goebel, K.M. and G.E. Merva, 1985. Bubbler system for water table monitoring, ASAE Paper No. 85-2563 and Goebel (1986)) already in use for water table elevations. Tile flow was monitored thereafter and proportional samplers were used to obtain samples of tile outflow at the rate of one sample per 19,000 liters of discharge.

E. Sample Analysis

All samples were analyzed for nitrate, ammonia, total phosphorus and potassium by the soil testing lab in the Department of Crops and Soil Sciences, Michigan State University. The methods used for all analyses are accepted by the Environmental Protection Agency (EPA).

Nitrate nitrogen was analyzed using EPA Method 353.2, 1979, ammonia was analyzed using the salicylate method, phosphorus concentrations were obtained using the flow injection method (Murphy, et al. Flow Injection Method. Anal. Chem. Acta. 27:31-36.) and potassium was analyzed using the auto-analyzer method/exchangeable potassium procedure.

Analysis of atrazine was done using the Soxhlet extraction - gas chromatography method. The Michigan State University Pesticide Research Lab conducted the sample analysis.

IV. RESULTS

During July and August, no significant tile outflow occurred in either the drainage only or the high water table zones. Drain pipe discharge volumes for August through April are given in Table 1. Maximum discharge occurred in October and December of 1987, and in April of 1988 in the high water zone. In the drainage only zone, the maximum discharges occurred during March and April when significant drainage flows are to be expected from subsurface drained lands.

Table 1. Drainage Discharge Volumes - Bannister Water Quality Pilot Project.

	High Water Table		Drainage Only		Precipitation
	(m ³)	(mm)	(m ³)	(mm)	(mm)
1987					
April	NA	NA	NA	NA	15 ¹
May	NA	NA	NA	NA	31
June	NA	NA	NA	NA	58
July	NA	NA	NA	NA	73
August	0	0	0	0	69
September	406	13.7	360	17.8	>63 ²
October	2000	67.8	567	28.0	>159 ³
November	511	17.3	171	8.5	62
December	1870	63.4	360	17.8	54 ⁴
1988					
January	0	0.0	153	7.6	NA
February	38	1.3	340	16.8	NA
March	34	1.2	1740	85.8	NA
April	1320	44.9	1740	86.0	NA

NA = Data not available.

¹ For time period 4/16/87 to 4/30/87.

² Plus event of 9/11/85 that exceeded capacity of monit. equip.

³ Plus event of 10/12/87 that exceeded capacity of monit. equip.

⁴ For time period 12/1/87 to 12/22/87.

Table 2. Nutrients and Herbicide Concentrations in Outflow Waters -Bannister Water Quality Pilot Project.

	ppm						ppb	
	NO ₃ -N		P		K		ATRAZINE	
	HWT ¹	DO ²	HWT ¹	DO ²	HWT ¹	DO ²	HWT ¹	DO ²
1987								
Apr.	3.05	6.45	0.02	0.00	2.25	1.80	0.11	0.18
June	0.47	0.75	0.10	0.08	5.00	4.00	0.17	0.63
Aug.	1.66	0.47	0.06	0.08	4.34	5.65	----	----
Sep.	12.87	1.68	0.05	0.05	2.07	3.26	1.30	0.78
Oct.	6.16	2.29	0.12	0.04	2.43	2.69	0.38	0.29
Nov.	3.77	3.47	0.04	0.03	2.36	2.43	0.21	0.08
Dec.	6.40	5.63	0.06	0.08	6.98	2.09	2.31	1.63
1988								
Jan.	----	3.43	----	0.00	----	1.60	----	0.17
Feb.	0.00	5.87	0.09	0.10	5.23	1.00	----	0.67
Mar.	4.33	8.54	0.11	0.07	3.80	1.75	1.02	0.48
Apr.	3.91	12.31	0.15	0.00	6.19	1.50	1.80	0.24

---- Samples not taken due to insufficient drainage discharge.

¹ High Water Table Treatment

² Drainage Only Treatment

Table 3. Nutrients in Irrigation Supply Waters - Bannister Water Quality Pilot Project.

DATE	ppm			
	NO ₃ -N	NH ₄	P	K
6/23/87	0.43	0.11	0.11	5.00
8/5/87	0.35	0.14	0.04	5.38

Table 4. Nutrients and Herbicides Loadings From Drainage Discharge Waters - Bannister Water Quality Pilot Project.

kg/ha								
	NO ₃ -N		P		K		ATRAZINE	
	HWT ¹	DO ²	HWT ¹	DO ²	HWT ¹	DO ²	HWT ¹	DO ²
1987								
Sep.	1.76	0.30	0.00	0.00	0.28	0.58	.00018	.00014
Oct.	4.18	0.64	0.08	0.01	1.65	0.75	.00026	.00008
Nov.	0.65	0.29	0.00	0.00	0.41	0.21	.00004	.00001
Dec.	4.06	1.00	0.04	0.01	4.43	0.37	.00147	.00029
1988								
Jan.	----	0.26	----	0.00	----	0.12	-----	.00001
Feb.	0.00	0.99	0.00	0.02	0.07	0.17	.00000	.00011
Mar.	0.05	7.33	0.00	0.06	0.05	1.50	.00001	.00041
Apr.	1.76	10.60	0.07	0.00	2.78	1.29	.00081	.00021
TOTALS				kg/ha				
	12.41	21.40	0.19	0.10	9.67	4.99	.00277	.00126

---- Samples not taken due to insufficient drainage discharge.

¹ High Water Table Treatment

² Drainage Only Treatment

Nutrient and herbicide data are presented in Tables 2, 3 and 4. All field samples were analyzed for nitrate nitrogen, ammonia, total phosphorus, potassium and atrazine. Water supply samples from the Maple River were analyzed for nitrogen, ammonia, phosphorus and potassium only. Ammonia concentrations were negligible and are therefore not reported.

Nitrate nitrogen concentrations were consistently higher in the high water table discharge zone from August through

December of 1987. Beginning in January of 1988 however, higher concentrations of nitrates were found in the drainage only discharge. The only discharge concentration exceeding the 10 ppm drinking water standard occurred in September of 1987.

Potassium concentrations and loading comparisons (Figures 9 & 10) show little distinguishable differences until December of 1987. In the high water table zone, 91.7 % of the total potassium in the outflow water for the study period occurred during October and December of 1987, and April of 1988.

Except for the data of September of 1987 when atrazine concentrations were less than 1 part per billion (ppb), the relative magnitudes of the concentrations were comparable in the discharges from the high water table and the drainage only zone. However, after the late fall tillage and application of potassium and nitrogen fertilizer, an increase in the concentration of atrazine in the high water table zone to in excess of 1 ppb was observed. A corresponding increase occurred in the drainage only zone but the concentration exceeded 1 ppb in this zone only during December of 1987.

The irrigation water source for the high water table treatment is the Maple River. The concentration (ppm) of nutrients in the source water is given in Table 3.

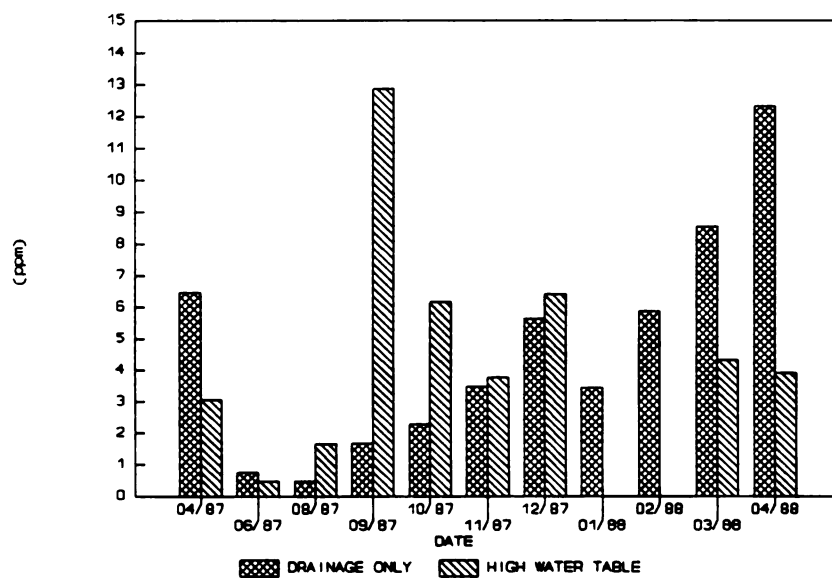


Figure 5. Average nitrate concentrations.

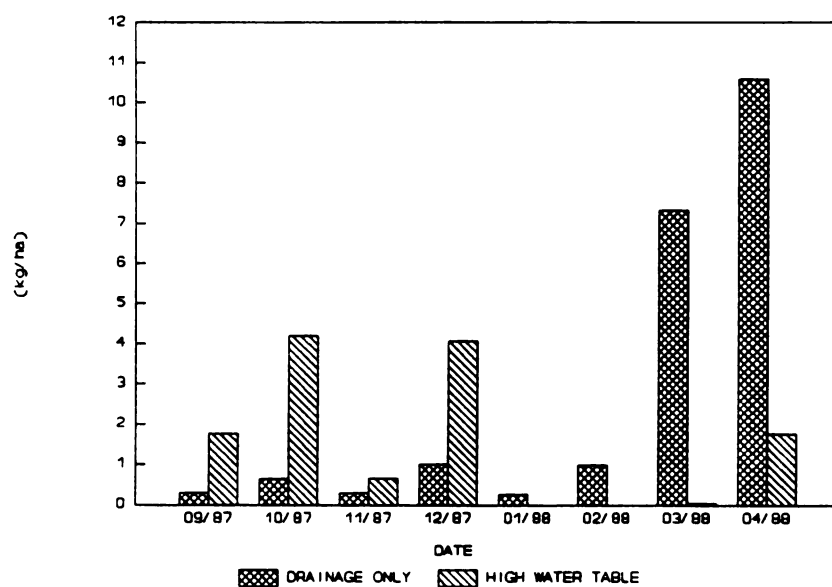


Figure 6. Average nitrate loads, kg/ha.

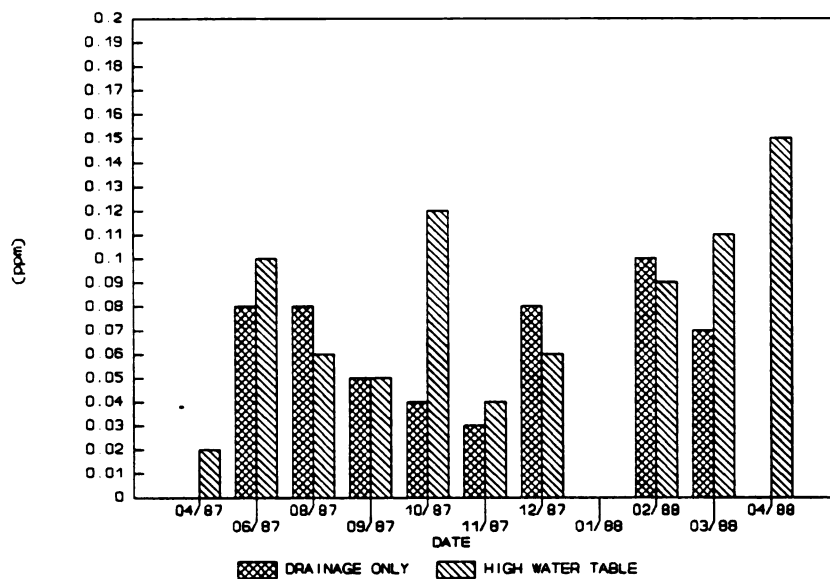


Figure 7. Average phosphorus concentrations.

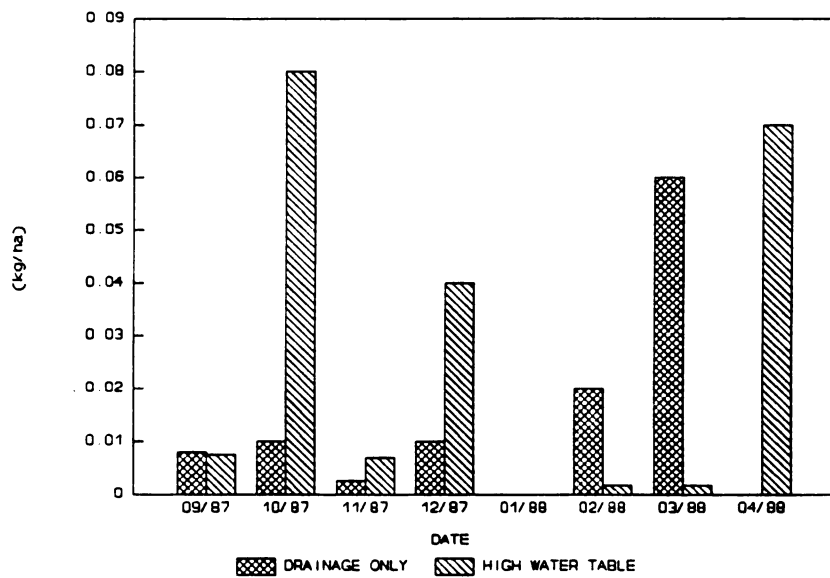


Figure 8. Monthly phosphorus loads, kg/ha.

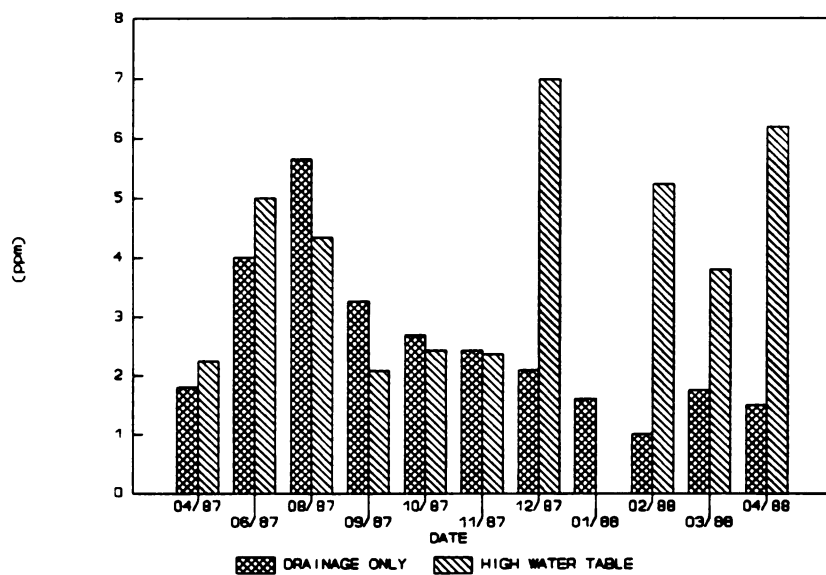


Figure 9. Average potassium concentrations.

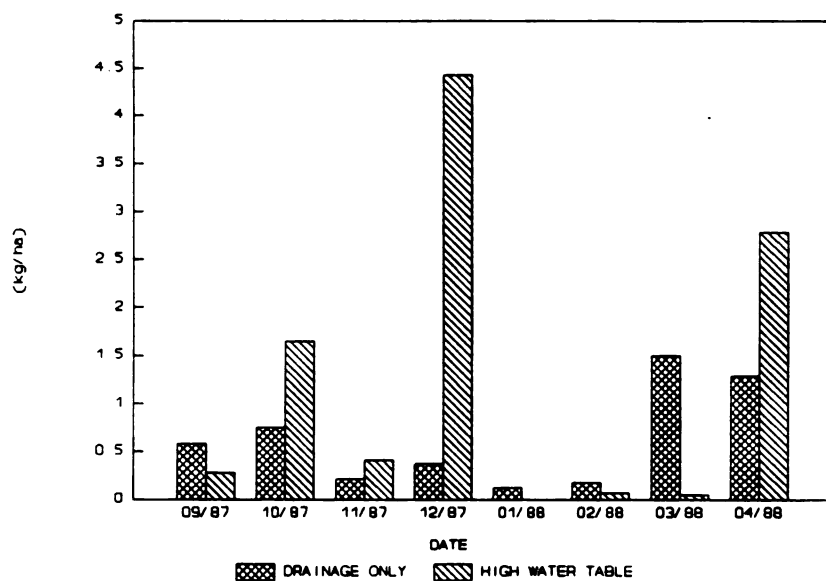


Figure 10. Monthly potassium loads, kg/ha.

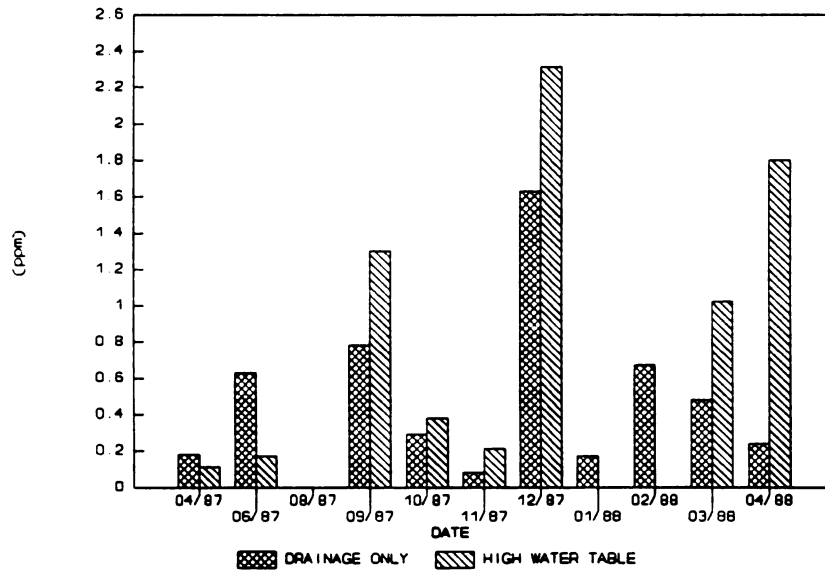


Figure 11. Average atrazine concentrations.

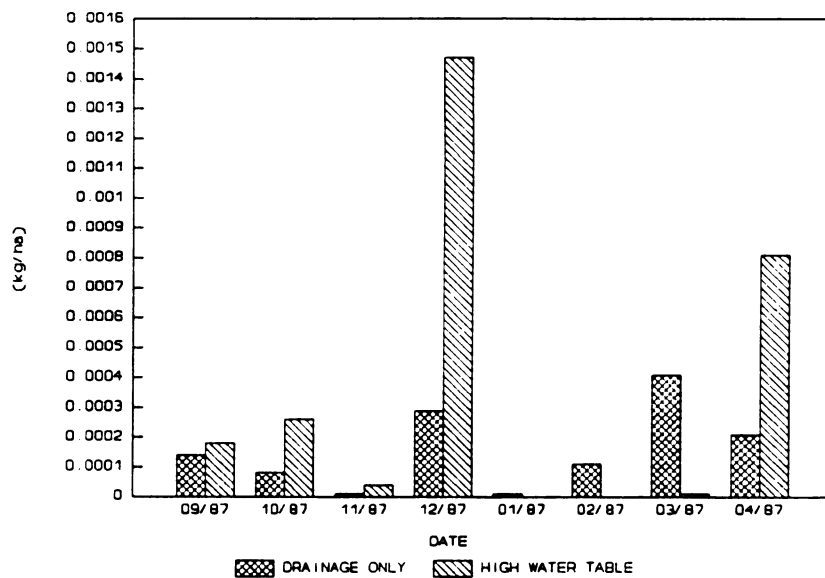


Figure 12. Monthly atrazine loads, kg/ha.

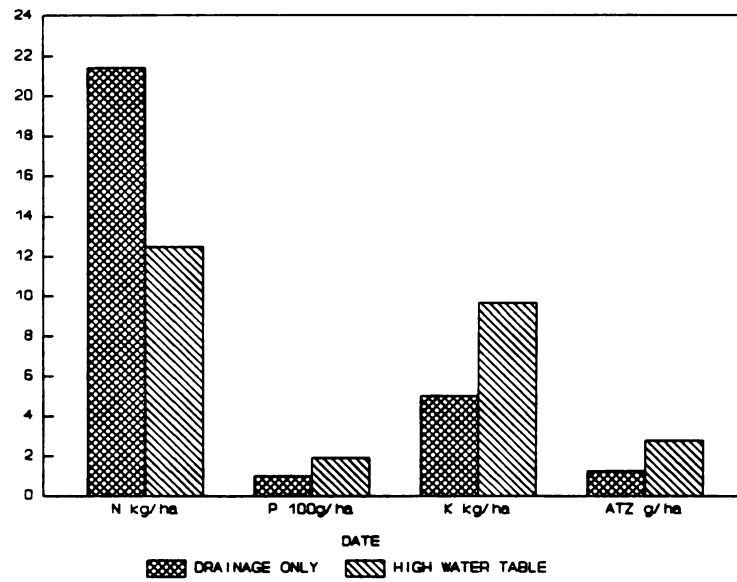


Figure 13. Summary of nutrient and atrazine loadings 4/87 to 4/88.

V. DISCUSSION

The maximum drainage discharges which occurred from the high water table zone were closely related to the practices necessary for successful farming operations on subirrigated soils. The high water table treatment flow in October resulted from the lowering of the water table in the high water table zone from 0.3 m below the ground surface to 0.6 m below the ground surface so that harvesting could be performed. This was aggravated by the over 159 mm of precipitation that occurred during that month. Lowering the water table 0.3 m yielded about 68 mm of water. This value compares favorably with the commonly accepted 61 mm per 0.3 m water holding capacity of the B horizon of Ziegenfuss soil. The large flow of water in December resulted from approximately 76 mm of precipitation which exceeded the long term average by about 23 mm. In April, the water table in the high water table zone was lowered to 0.7 m to facilitate tillage operations and again, a significant flow of water was observed from the area.

Considerably higher concentrations of nitrates were found in the high water table effluent during September and in October. The higher concentrations in October were found as the water table was lowered to facilitate harvest. The high September concentrations appeared to result from the fact that during much of the 1987 growing season very little drainage flow from the high water table treatment occurred due to limited rainfall (see Table 1) and because the high water table treatment was maintained in a subirrigation mode until September. The first measurable discharge from the high water table zone occurred in September. This discharge was caused by over 63 mm of rainfall leaching through the soil profile. Thus, any nitrate left in the soil unsaturated soil profile was leached into the soil water and then out of the system. The water table rose sufficiently that flow over the retaining weirs occurred. At this time, the nitrates leached out and the resulting concentration exceeded the drinking water standard. The high concentration of nitrates observed in September (12.9 ppm) was therefore probably due to the nitrate being held in the plot in the groundwater during the summer.

It is possible that such high concentrations may indicate a need for a more gradual lowering of the water table in a high water table management zone. A

gradual lowering, even if the total volume of nitrate remained the same, would spread the total over a longer interval, thus lessening the concentrations over a single short span of time. This is apparent from a comparison of nitrate concentrations for November and December. The outflow for October, November and December resulted from precipitation rather than from a sudden lowering of the water table resulting from a lowering of the retaining weirs. For November and December, the nitrate concentrations were relatively the same.

A much higher concentration and loading of nitrate nitrogen was observed in the drainage only zone during the spring drainage (Figures 5 & 6). It is hypothesized that the high concentration resulted from nitrate which was in solution in the soil water and which was flushed out in the drainage flows which normally accompany the spring thaw and rains. Also, denitrification of nitrogen nitrate in the high water table zone may have been encouraged by holding the water table high (0.3 m) during the winter months.

The control of high concentrations of nitrate in drainage water in climates such as are experienced in the North Central regions of the United States probably require controlling outflow from the drainage lines.

If the water table were lowered gradually during periods when flushing of nitrate from the soil could be expected to occur, the total amount of nitrate leaving the area would again be spread over a longer interval, thus lowering concentrations. Likewise, in the high water table zone, when it is necessary to lower the water table to facilitate harvest, it would appear advantageous to lower the water table gradually beginning late in the growing season and continuing until the desired level is reached. In the spring, during periods of intense drainage flows, control of the drainage may again be necessary since only in April, during the spring drainage flush, did the nitrate levels in the drainage only zone exceed the drinking water standard of 10 ppm.

It is interesting to compare the total mass of nitrate discharge from the high water table treatment with the drainage only treatment. The total mass of nitrate discharged for the period September 1987 through April 1988 from the drainage only zone was 72% greater than from the high water table zone. This difference may be the result of: a) the maintenance of the high water table during the growing season causing a relative high root density in the top 0.3 m of the soil profile which could result in more efficient plant uptake of the available nitrogen; b) the high water table zone yield

being greater than the drainage only zone yield (See Appendix D), thus utilizing more of the nitrogen available; c) increased denitrification in the high water table zone as previously discussed, and/or; d) maintenance of a high water table resulting in more runoff from the high water table zone as compared to the drainage only zone which would likely cause an increase in nitrate loss as well as the other nutrients and pesticides. Because totals for P and K for the high water table treatment as compared to the drainage only treatment are lower, this suggests that sediment movement by runoff off the site is not significant. Obviously, more study is needed to develop a complete understanding of the fate of the nutrients and pesticides in a system that establishes the water table near the soil surface for extended lengths of time.

Phosphorus is a difficult mineral to manage in the soil. According to Lyons (1950), although the amount of total phosphorus in an average mineral soil compares favorably with that of nitrogen, most of the phosphorus present is unavailable to the green growing plant. Thus, it is necessary to apply considerably more phosphorus to the soil than the plant will remove. Much of the phosphorus becomes tied up in the soil, either in inorganic or organic compounds, or by the active clay fraction of the soil. It appears that

rapidly decomposing organic matter and a high microbial population in the soil results in a temporary tying up of the inorganic phosphorus. In a soil such as the Ziegenfuss, which is high in clay content, several factors may be working together to make phosphorus available to be leached out of the soil profile. In the summer when plants are growing and are in need of the mineral, both organic decomposition and microbial activity are at high levels, thus, the phosphorus is temporarily unavailable. When the growing season ends, however, soil temperatures begin to drop resulting in a decrease in both organic decomposition and microbial activity so that some of the phosphorus that has been inactivated may then become available. However, this occurs when the crop is no longer growing and therefore the phosphorus is removed by leaching or through runoff and erosion.

The highest concentrations of phosphorus occurred in drainage from the high water table zone in October (0.12 ppm) and in March and April (0.11 and 0.15 ppm). In the drainage only zone, in December and February somewhat higher concentrations (0.08 and 0.10 ppm) appeared. Again, the higher flows from the high water table zone carried a flush of phosphorus which became available, probably due to reduced microbial activity and/or reduced organic decomposition. The increased

concentrations in December from the drainage only zone probably resulted from the same cause. Also, the absence of flow during January and the increased concentration during February from the drainage only zone appear to be related with the February flow carrying that phosphorus which did not leach out during the January interval.

The lesser total phosphorus volume in the drainage only treatment is not surprising. The deeper water table condition allows for more of the phosphorus to be tied up in the soil and thus to be less available for discharge in the tile waters.

It appears, then, that the higher phosphorus concentrations which appeared in the drainage water during the periods of higher flow are indicative of the propensity of phosphorus to move through the soil and be discharged from the drainage system during periods of excess soil water. This may be especially true if the higher flows occur following a release of phosphorus due to a lessening of microbial activity or organic decomposition.

According to Lyon, et al., (1952) potassium behaves similarly to phosphorus with regard to being tied up by microbial activity. However, unlike phosphorus, potassium is readily lost by leaching, even to the

amount leached may equal that used by the crop. Under saturated conditions, potassium will move through the soil in large quantities. Thus, the high potassium discharge which occurred following the fall application of potash (6.98 ppm in December, 1987 and 5.23 ppm in February, 1988) was to be expected. No explanation is immediately obvious for the June and September concentrations of 4.00 and 5.65 ppm which occurred in the drainage only plots except that the June data came from a grab sample rather than from proportional sampling. At any rate, the results of this study dramatically indicate that, at least under poorly drained conditions, fall application of potassium fertilizers should be avoided.

We note that along with the potassium lost through tile effluent, it is probable that large quantities were lost due to surface runoff from the high water table zone. Standing surface water was observed in the high water table zones during most of the period from December, 1987 to April, 1988.

The higher atrazine concentrations of 1.30 ppb in September, 1987, 2.31 ppm in December 1987, and 1.02 and 1.80 ppm in March and April of 1988 that were observed following fall application of the potash and nitrogen are probably unrelated to the addition of

fertilizers, but instead, may be due to the breaking up of the aggregates and consequent exposure of previously undisturbed pesticide compounds due to freezing and thawing. There is no indication in the literature that the application of potash and nitrogen in the fall should affect the atrazine holding capability of the soil. During the spring, atrazine concentrations were distinctively higher in effluent from the high water table zone. This again was probably due to atrazine that came into solution in the winter months before being flushed from the soil profile.

VI. CONCLUSIONS

1. Careful water table management during fall and spring can decrease environmental nitrate nitrogen concentrations in drainage discharge water.
2. Total nitrate nitrogen loading from drainage effluent may be decreased by a high water table management scheme.
3. Environmental phosphorus loading from drainage effluent may be substantially increased by a high water table management scheme.
4. Under saturated and poorly drained conditions, large quantities of potassium will leach through the soil profile and enter the drainage water.
5. Saturated and poorly drained conditions may increase the removal of atrazine by drainage in clay type soils.

RECOMMENDATIONS

Improved subsurface drainage lowers water tables and, thereby, allows increased potential for infiltration. This in turn reduces soil erosion and loss of nutrients associated with surface runoff, such as potassium, phosphorus and organic nitrogen. Improved subsurface drainage also influences the nutrient concentrations and loadings of highly water soluble nutrients such as nitrate nitrogen. It is not clear which of the situations causes the greatest detrimental impact on the receiving waters, surface discharges of nutrients and chemicals associated with surface runoff or subsurface discharge of those nutrients and chemicals associated with subsurface drainage. In situations where controlled drainage and subirrigation are applicable, there are usually several different water table management alternatives that will provide the cropping requirements for the producer. It then becomes a management decision to select the water table management alternative which provides the least overall adverse water quality impacts on the receiving waters.

Controlled drainage will reduce flow during periods when the water table is being raised; however, maintaining high water table levels by either controlled drainage or subirrigation will reduce potential storage and infiltration as the growing season progresses, thus increasing the potential for higher peak flows from surface runoff, similar to those which now occur for surface drainage only systems. A critical management decision will be to select the water management strategy which restricts drainage during periods when receiving waters are most sensitive, especially if this is not entirely compatible with production requirements.

Properly designed and managed, controlled drainage and subirrigation systems have the potential to reduce the transport of accumulative plant nutrients and applied herbicides. In addition to design and management factors, site characteristics influence the fate of transport of nutrients and applied herbicides.

Research on controlled drainage and subirrigation systems is beginning to show that nutrient and sediment losses to surface waters can be controlled and reduced. But further studies have to be made to establish the impacts of such systems on the environment. The research supports the need to classify drainage systems

as a conservation measure and should be implemented as a best management practice. Further investigations must be made to optimize the potential water table management systems have as a conservation measure.

APPENDIX A

Site Soil Data

APPENDIX A

CLASSIFICATION: ZIERHUPFS; FINE-LOAMY, MIXED, NOMACID, MESIC MOLLIC HAPLAQUEPT

SAMPLE NO	DEPTH (CM)	HORIZON	(- - -TOTAL- - -)			(- CLAY -)		(- -SILT- -)		(- - - - -SAND- - - - -)				(- COARSE FRACTIONS(MM) -)					(>2MM) WT PCT OF WHOLE SOIL	
			CLAY	SILT	SAND	FINE	CO3	FINE	COARSE	VF	F	M	C	VC	-----WEIGHT-----					
			LT	.002	.05	LT	LT	.002	.02	.05	.10	.25	.5	1	2	5	20	.1-		
			.002	-.05	-2	.0002	.002	-.02	-.05	-.10	-.25	-.50	-1	-2	-5	-20	-75	75		
			(- - - - - PCT OF (2MM) (3ml) - - - - -)										(- PCT OF <75MM(3B1) -)							
85P3482S	0- 23	AP	24.3	47.9	27.8			29.3	18.6	5.7	12.5	7.4	1.6	0.6	2	--	--	24	2	
85P3483S	23- 38	BG1	30.3	39.4	30.3			27.5	11.9	6.1	14.3	7.4	1.7	0.8	1	1	--	26	2	
85P3484S	38- 61	BG2	28.0	33.6	38.4			22.1	11.5	7.4	17.9	9.7	2.3	1.1	5	--	--	34	5	
85P3485S	61- 92	BG3	33.0	36.3	30.7			25.7	10.6	6.0	14.6	7.8	1.6	1.3	2	2	--	28	4	
85P3486S	92-112	CG1	31.6	36.8	31.6			25.6	11.2	6.4	14.5	7.8	1.6	1.3	2	2	--	28	4	
85P3487S	112-160	CG2	29.7	39.1	31.2			26.7	12.5	6.1	13.6	7.5	2.4	1.6	2	3	1	30	6	

DEPTH (CM)	ORGM C	(-RATIO/CLAY-)		(BULK DENSITY)			COLR		(-WATER CONTENT-)				WRD		(- - - CLAY/MINERALOGY - RELATIVE AMOUNTS - - -)			
		15	1/3	OVEN	WHOLE		1/10	1/3	15	WHOLE								
		CBC	BAR	BAR	DRY	SOIL	BAR	BAR	BAR	SOIL								
		PCT			(- G/CC- -)	CM/CM				(- PCT OF <2MM -)	CM/CM				(<.002MM)			
0- 23	1.90	0.61	0.44	1.62	1.76	0.028	23.3	22.2	10.6	0.19		KK 3	HI 3	VH 2	VR 1			
23- 38	0.78	0.44	0.40	1.65	1.79	0.027	21.3	20.3	12.2	0.13		KK 3	HI 3	VH 2	VR 1			
38- 61	0.42	0.41	0.39	1.68	1.84	0.030	21.5	20.4	10.9	0.15		KK 3	HI 3	VH 3	GR 1			
61- 92	0.38	0.35	0.40	1.68	1.85	0.032	21.3	20.6	13.3	0.12		HI 3	KK 3	VH 2	GR 1			
92-112	0.32	0.34	0.42	1.69	1.84	0.028	19.8	19.1	13.3	0.10		HI 3	KK 3	VH 2	GR 1			
112-160	0.41	0.34	0.42	1.63	1.81	0.034	21.4	21.0	12.5	0.13		HI 3	KK 3	VH 2	GR 1			

AVERAGES, DEPTH 25-100: PCT CLAY 31 PCT .1-75MM 29

ANALYSIS: S= ALL ON SIEVED <2MM BASIS

MINERALOGY: KIND OF MINERAL KK KAOLINITE HI MICA VH VERM-MICA VR VERMICULITE GR GORTHITE
 RELATIVE AMOUNT 6 INDETERMINATE 5 DOMINATE 4 ABUNDANT 3 MODERATE 2 SMALL 1 TRACE

NOTE: THIS PEDON IS A TAILJUNCT TO THE ZIERHUPFS SERIES. IT HAS LESS THAN 35% CLAY IN THE CONTROL SECTION

APPENDIX B

PAPER - Orifice Flow Meter To Measure Drain Pipe Discharge

A FLOW METER TO MEASURE DRAIN PIPE DISCHARGE

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SUMMARY:

Orifice flow meters were designed, built, calibrated and installed to measure the flow in two corrugated tubing mains. The flow meters were designed to enable flow to take place through the meters while flow in the lines would not be adversely affected.

KEY WORDS:

drainage, water quality, subirrigation, sampler, flow meters, flow.

ORIFICE FLOW METER

ABSTRACT

Orifice flow meters were designed, built, calibrated and installed to measure the flow in two corrugated tubing mains, one a subsurface drainage main and the second used for both drainage and subsurface irrigation. It was necessary to measure flow rates in the system so that water samples, proportionally based on drainage discharge, could be taken. The flow meters were designed to enable flow to take place through the meters while flow in the lines would not be adversely affected. The orifice meters were calibrated using an automated hydraulic flume. The calibration curves were compared to the theoretical curves using the appropriate orifice flow meter equations. From this comparison it was concluded that, even in the absence of facilities to perform a calibration, careful attention to construction procedures will yield an instrument which will reliably measure flow using the orifice meter technique.

INTRODUCTION

For several years there has been growing concern about the quality of drainage line discharge water. In

recent years, subsurface irrigation, an innovative method of improving the soil water environment for crop production in areas which require subsurface drainage, has emerged. The practice is generating much interest throughout the midwest and southeast. It is being actively promoted by manufacturers of subsurface drainage materials and by drainage contractors. The increasing interest in the use of subsurface irrigation systems has exacerbated concern over the quality of water discharged from these systems.

To effectively evaluate the impacts that subsurface drainage and subsurface irrigation may have on the environment, flow rates, discharge volumes, and water quality from these systems must be monitored. Continuous monitoring of the discharge is necessary for such sampling to take place.

A major problem in monitoring subsurface drainage and subirrigation discharge is that the lines rarely operate at full flow. Because of this characteristic, special problems are faced by the investigator in evaluation flow through these systems. In order to solve the problems, for the subirrigation study being carried out by the Department of Agricultural Engineering at Michigan State University, a special flow meter was designed. The instrument was based on

orifice flow principles. It allowed partially full flow to occur in the lines in which the measurements were being made, and, through the use of an innovative system of measuring pressure differentials, enabled continuous monitoring of the discharge with data being collected in such a fashion that immediate computer analysis was possible. This paper presents the design and implementation of the flow meter.

DESIGN

Many commercially available flow measuring devices were examined, but none would perform as required. The requirements of being able to measure partially full flows, unattended, with data collection suitable for computer analysis, all at a cost that was feasible, make it necessary to design an instrument. The nitrogen bubbler system of water table measurement implemented by Goebel and Merva (1985) was already in use and appeared to offer, differentially, the best possibility of success. A venturi or an orifice meter both seemed feasible. For simplicities sake, it was decided to design and construct an orifice flow meter that could be instrumented with the nitrogen bubbler tube system.

Stearns (1951) gives the equation modeling flow through an in-line orifice under full pipe flow as:

$$W = 125.14 (d_2)^2 a K Y (pH)^{1/2} \quad [1]$$

Where:

- W = Weight rate of flow (kg/hr)
- d_2 = Diameter of orifice (cm)
- a = Area multiplier expansion factor (dimensionless)
- K = Orifice Discharge Coefficient (dimensionless)
- Y = Expansion Factor (dimensionless)
- p = Density of fluid (gm/cm³)
- H = Differential pressure (cm of water)
- d_1 = Line diameter (cm)

The area multiplier expansion factor a is a temperature dependent parameter. It is used to compensate for expansion of the orifice diameter due to the temperature of the fluid and is a function of the orifice plate material. The expansion factor Y is a fluid pressure function. It includes dependence on flow pressure, differential pressure, diameter ratio, flow temperature and the nature of the fluid, and is used to account for density variations under gas flows such as steam. For conditions where water is the fluid which is at the reasonably constant temperature of the soil, the parameters a and Y can be ignored. The parameter $p=1$ gm/cm³ for water. After conversion to SI dimensions of liters/minute and making the appropriate substitutions, the equation reduces to:

$$W = 2.086 (d_2)^2 K (pH)^{1/2} \quad [2]$$

where K is dependent on $d_2/d_1=B$ and the Reynolds number.

Table 1C gives K factors corresponding to the range of $d_o/d_i=B$ values. Flow conditions to be expected in the subirrigation experiment at Michigan State dictated a main diameter of 152 mm. This condition could be satisfied by a wide variety of orifice to pipe ratios. To facilitate selection, a spreadsheet was used to generate a table of flows which could be measured with various diameter orifices (Table 2C). For ease of selection of the appropriate orifice diameter, the data thus produced were then graphed (Fig. 1C). For our situation, orifice diameters of 38.1 mm, 50.8 mm and 63.5 mm were chosen. These gave ratios of 0.25, 0.333 and 0.42. For normal drainage pipe flows, K, from Table 1, was found to be 0.598, 0.602, and 0.614. This allowed the measurement of flows as small as 9.12 liters/min and as large as 380 liters/min.

After the range of flows under which the meter would operate was selected, the instrumentation was specified. A 7.1 kPa (1 psig) pressure transducer was available and was used to monitor pressure differentials, therefore, the head on the upstream side of the orifice was restricted to 680 mm. The orifice size was also critical. Too small an orifice would create back pressure in the line, severely altering the operation of the drainage system. Once the orifice size was chosen and an acceptable pressure loss across

the orifice plate was found, a length of smooth, straight pipe was selected to direct flow into the orifice. The straight, smooth pipe was required on both the upstream and downstream side of the orifice plate to eliminate turbulence and obtain laminar flow through the orifice plate. The length of pipe was calculated using Figure 2C (Stearns, 1951, pg 110). For the meter which was installed in the experimental area, the ratio of orifice diameter to approach pipe diameter was 0.33. According to Figure 2C, the minimum length of pipe for the upstream side was 9 pipe diameters while the downstream was 3 pipe diameters. To attain maximum accuracy, it was decided for our purpose to use 12 inside pipe diameters of straight pipe upstream, and 6 inside pipe diameters downstream.

The general shape of the flow meter can be seen in Figure 3C. Because an orifice flow meter requires full flow for operation, it was decided to depress the length of tubing in which the orifice is located. The meter was designed to be installed so that the top of the pipe in which the orifice is located is immediately below the invert elevation of the existing tile line elevation (See Figure 3C). This was done through the use of PVC elbows and sections of straight PVC pipe.

The location of the taps where the pressure differential is read on each side of the orifice plate was determined according to Stearns (1951). The upstream tap is located one inside pipe diameter from the orifice plate. For the orifice diameter ratio of 0.33 as indicated above, the downstream tap location was determined using Figure 4C (Stearns, pg 116) at 0.8 pipe diameters downstream of the orifice plate.

CONSTRUCTION

As mentioned above, PVC (poly vinyl chloride) tubing was used for the upstream and downstream straightening pipes. The orifice plate was constructed from plexiglass. It was positioned in the PVC tubing using the clamp assembly detailed in Figures 5C and 6C. A rubber gasket on both sides of the orifice plate butted against the upstream and downstream sections of PVC pipe and the sections were aligned with the clamp assembly.

INSTRUMENTATION

Instrumentation to monitor and record the flow based upon the head difference across the orifice plate was assembled as follows. The materials used for the design represented here are shown on Figure 7C. The components used to monitor and calculate flow include a

manometer assembly to measure pressure, a pressure transducer to sense the pressure, a data logger to record the output of the pressure transducer, and a communication device. The communication device enables communication between the pressure measuring system and the computer.

To measure the pressure, nitrogen gas is bubbled into the manometer tubes which are placed at the pressure taps on the flow meter. The nitrogen is bubbled at a rate of approximately one bubble per second. At this rate of nitrogen flow, an accurate pressure reading could be determined from the nitrogen pressure required to force water from the manometer tubes. This pressure is read by a pressure transducer which converts the pressure to a voltage corresponding to the head pressure. The voltage is then converted to a digital signal and stored by a datalogger. The digital number can then be used by a computer, in the flow equation, to calculate the flow rate.

CALIBRATION AND RESULTS

Calibration of the flow meters was performed on a hydraulic flume which simulated drainage main line flow. The design presented here was calibrated using the modern hydraulic flume at the University of Illinois Department of Agricultural Engineering.

To determine calibration curves for the flow meters, six different average flow rates were maintained for a duration of five minutes each. The output of the calibration, the pressure differential, was recorded a minimum of six times during measurement interval and later converted to flow rates using equation [2]. The flow that was calculated by the instrumentation on the flume was recorded every 15 seconds giving 60 data points for each calibration curve. This process was performed with two orifice plates for three different orifice diameters, 38.1 mm, 50.8 mm and 63.5 mm.

Calibration of the orifices was done by obtaining points from the calibration data and comparing this with the flow calculated from equation [2]. Figures 8C, 9C, and 10C are graphs of the observed head differential graphed versus the flow from the hydraulic flume as calculated by the flume instrumentation along with the theoretical orifice curve as calculated from equation [2]. Figure 8C presents the results of the first set of calibrations which were performed on the 38.1 mm diameter orifice. The values given were obtained by plotting observed flow differentials versus actual values read from the flume instrumentation as indicated above. In Figures 9C and 10C, the values given again are actual values but they are averaged to

remove fluctuations. The fluctuations were removed because it was uncertain as to how accurate the flume flow actually was. The uncertainty occurred because it was realized that the flow from the flume had to travel the length of the flume and return through a conduit before a value was given by the instrumentation. Thus, values read from the flume instrumentation lagged behind the head differential values read from the manometer tubes. If the flow through the flume were to have been perfectly steady state, the lag would not have had to be considered. However, as was normal, fluctuation existed in the flow. The result was that the values given in Figure 8C are "instantaneous" values which incorporated fluctuations due to the lag mentioned above. In Figures 9C and 10C however, during a particular level of flow, averaging was performed on the flume flow values. The averaging was done only on flume flow values for which the head differential was constant.

As seen in Figure 8C, the measured values generally were less than the predicted values over the entire range of measurement. In Figure 9C, for the 50.8 mm diameter orifice, the predicted values fell virtually on the measured values while in Figure 10C, of the 63.5 mm orifice, scatter occurred with the values for the first orifice causing a considerably lower head

differential than that for the second orifice. At 250 liters per minute and 300 liters per minute, the head differentials predicted less flow than would be expected from equation [2].

DISCUSSION

The flow meter presented here is being used in calculating flow from two variations of a subirrigation experiment. The first, subsurface irrigation in a high water table mode required a design which was tolerable to large head losses across the orifice plate. For this case, the limiting design feature became the size of the pressure transducer. For the second case, a drainage only mode, the limiting design feature was not to create a back pressure head in the line larger than the size of the inlet pipe. If the head were to have been larger than the inlet pipe, obstruction of flow into the pipe from the laterals would have occurred. Therefore the orifice and line size was such that, for the expected flow conditions, the head was limited to the diameter of the pipe entering into the upstream pipe on the flow meter (See Figure 5C).

For the design application discussed here a 51 mm (2.0 in.) diameter orifice and a 152 mm (6.0 in.) diameter pipe met the design criteria. Since the orifice plates are rather inexpensive and easy to build, 38 mm (1.5

in.) and 64 mm (2.5 in.) diameter orifices were also built and calibrated. The calibration of the entire set of orifice plates enabled us to judge whether or not the orifice flow model (equation [2]) was unduly influenced by the orifice diameter.

As can be seen by examination of Figures 8C, 9C, and 10C, some dependence of predicted flow as a function of orifice diameter might be inferred. However, since the flow fluctuations were averaged out for the two larger orifices while they were not for the smallest orifice (Figure 8C), it is not possible to definitively state that the above occurred. Careful examination of the results indicates that the error incurred in using the flow model (equation [2]) to predict flows based directly on measured head differentials would result in an error of less than 10% in most cases. In the range of flows between 140 to 200 liters per minute, the error is larger with selected points, namely those obtained from the second orifice, being obviously in error. It is not known why the discrepancy occurred. No conclusions can be inferred regarding the 38.1 mm orifice since the data obtained in this case were not averaged to remove flow fluctuations. It is felt that the results from the 50.8 mm orifice describe the flow sufficiently well that no further correction is needed to predict flow rates based on observed differentials.

For this case, equation [2] was used directly.

The system as installed at Michigan State University research project is currently performing completely satisfactorily. The only problems of significance encountered to this writing occurred when meters were installed. When the soil was backfilled around the meters to hold them into place, backfilling began in the middle of the meter and then proceeded outward to the elbows. This sequence of backfilling created a pressure outward from the orifice plate towards the elbows and caused one of the meters to separate. It is felt that the problem can be avoided by careful attention to the backfilling procedure, probably backfilling from the ends toward the middle of the meters.

The clamp system used to hold the orifice plate meter and join the inflow and outflow pipe has several advantages. It allows the orifice plates to be easily changed so that a wide range of flows can be monitored. The technique of offsetting the orifice below the invert of the main pipe allows drainage pipe flows to be determined even when the drainage flow is not pipe full. It should be noted that the diameter of the inlet PVC pipe need not be the same as that of the drainage pipe. If a smaller diameter is to be used it

is suggested the straight lengths of pipe before and after the orifice plate be lengthened to eliminate convergence and divergence effects on the monitored pressure differentials.

CONCLUSIONS

1. Orifice meters can be used to measure tile line discharge within the normal range of tile line discharge without disturbing natural flow conditions.
2. While calibration is always desirable, in the absence of facilities to perform adequate calibration, careful attention to design and construction procedures will yield an instrument which, with a high degree of confidence, will reliably measure flow using the orifice flow equation in its applicable form.

REFERENCES

- Goebel, K.M. and G.E. Merva, 1985. Bubbler system for water table monitoring, ASAE paper 85-2563.
- Stearns, R.F. et al., 1951. Flow Measurement With Orifice Meters. New York: Van Nostrand Company

Table 1C. Values of K vs Beta (d_2/d_1) where d_2 is the orifice diameter and d_1 is the line diameter

BETA (d_2/d_1)	K	BETA (d_2/d_1)	K
0.250	0.598	0.525	0.632
0.275	0.599	0.550	0.639
0.300	0.601	0.575	0.647
0.325	0.603	0.600	0.655
0.350	0.605	0.625	0.666
0.375	0.607	0.650	0.674
0.400	0.610	0.675	0.691
0.425	0.614	0.700	0.707
0.450	0.618	0.725	0.725
0.475	0.622	0.750	0.748
0.500	0.627		

Table 2C. Spreadsheet generated data used for finding the mininum and maximum measurable flow rate with different xiz orifices, using a 152 mm (6 in.)diameter pipe.

ORIFICE DIA (cm)	BETA	K	Q (lpm) .25 cm	Q(lpm) .50 cm
3.81	0.250	0.598	9.05	128.04
4.19	0.275	0.599	10.97	155.19
4.57	0.300	0.601	13.10	185.30
4.95	0.325	0.603	15.43	218.20
5.33	0.350	0.605	17.95	253.90
5.72	0.375	0.607	20.68	292.43
6.10	0.400	0.610	23.64	334.36
6.48	0.425	0.614	26.87	379.94
6.86	0.450	0.618	30.32	428.73
7.24	0.475	0.622	34.00	480.78
7.62	0.500	0.627	37.97	537.00
8.00	0.525	0.632	42.20	596.77
8.38	0.550	0.639	46.83	662.21
8.76	0.575	0.647	51.82	732.84
9.14	0.600	0.655	57.12	807.82
9.53	0.625	0.666	63.02	891.26
9.91	0.650	0.674	68.98	975.56
10.29	0.675	0.691	76.27	1,078.59
10.67	0.700	0.707	83.92	1,186.82
11.05	0.725	0.725	92.31	1,305.52
11.43	0.750	0.748	101.92	1,441.43

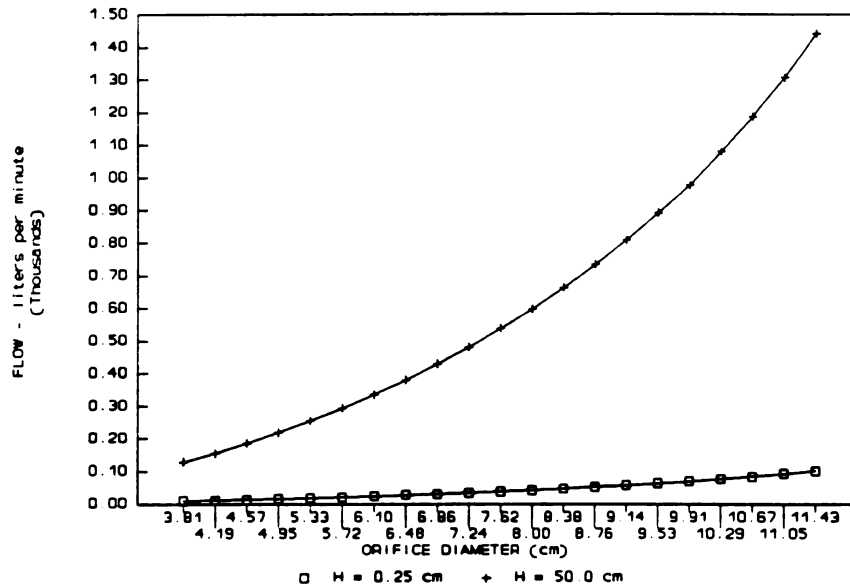


Figure 1C. Plot of maximum and minimum measurable flow rates vs orifice diameter, using 152 mm (6 in.) diam. PVC pipe.

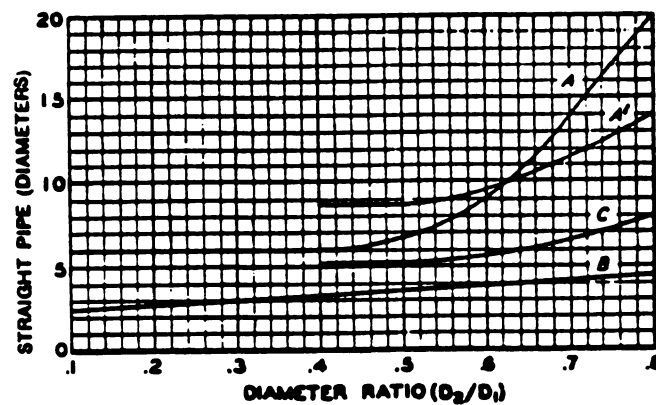
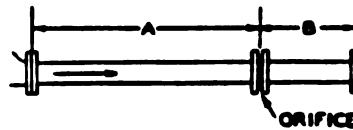


Figure 2C. Minimum straight runs of pipe.

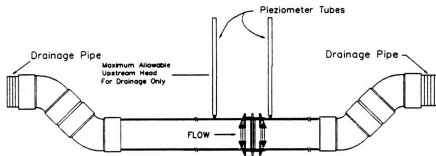


Figure 3C. Orifice flow meter.

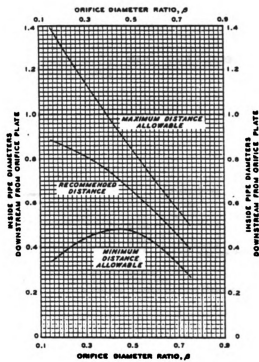


Figure 4C. Location of downstream vena contracta pressure tap.

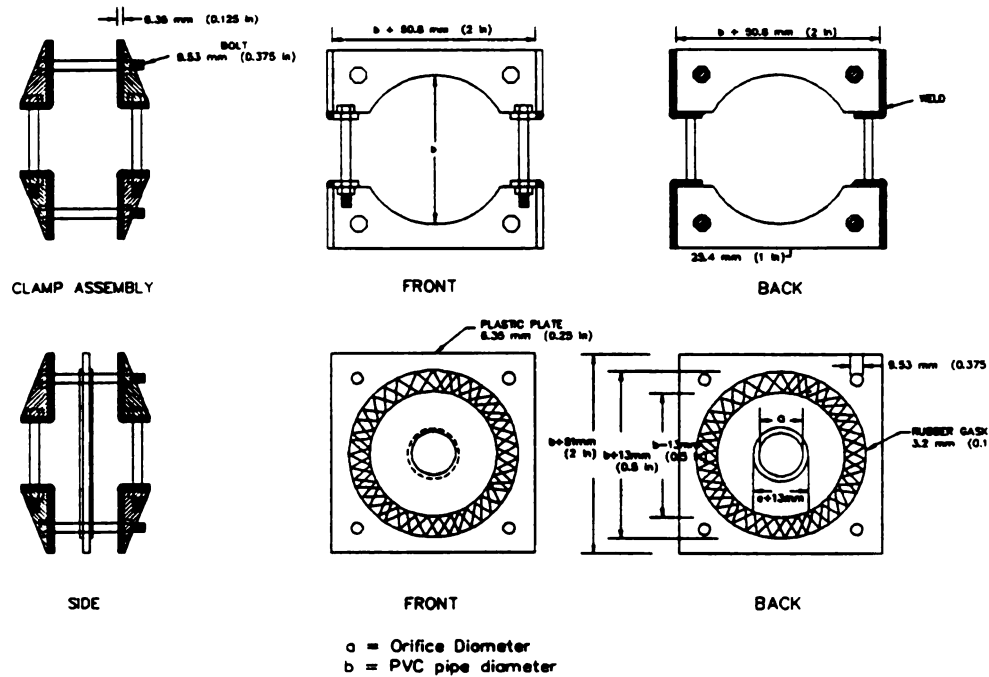


Figure 5C. Clamp assembly and orifice plate specifications

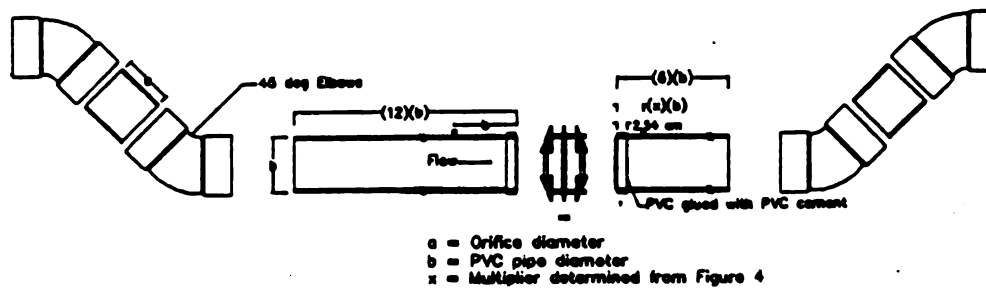


Figure 6C. Flow meter materials and assembly specifications.

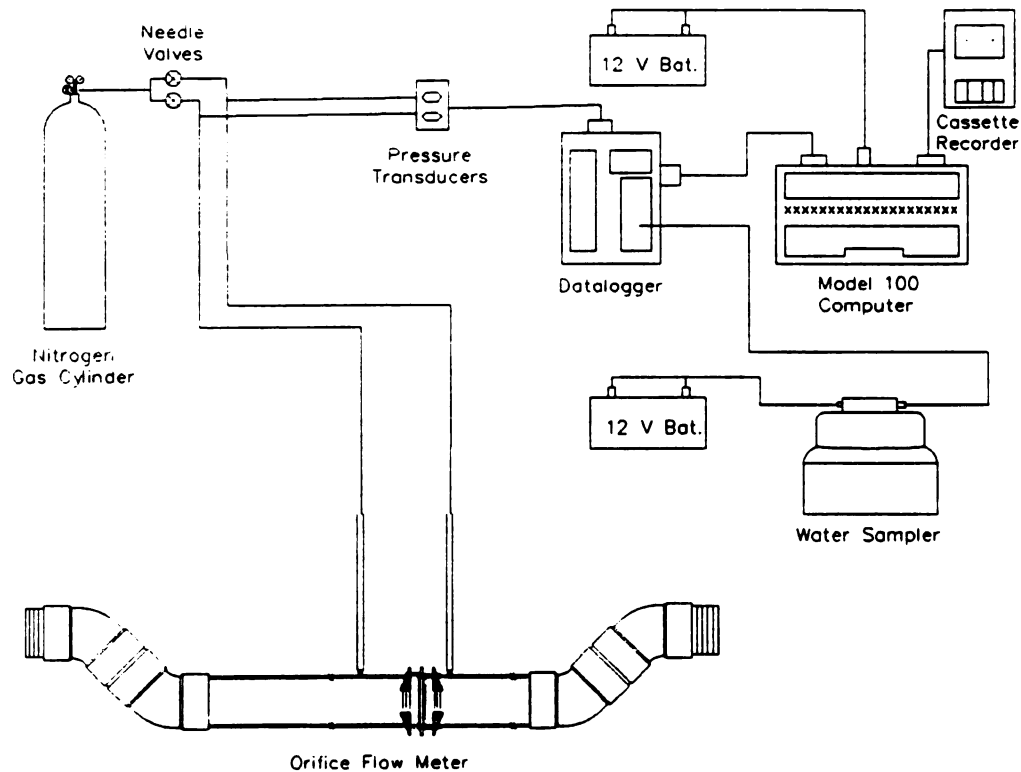


Figure 7C. Instrumentation used to determine drainage pipe discharge and trigger water sampler.

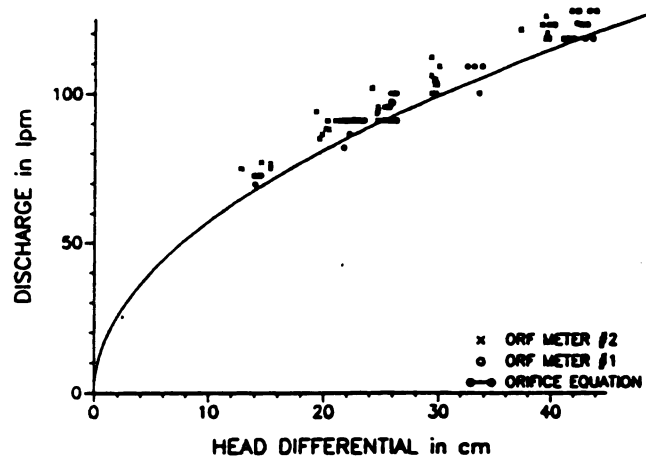


Figure 8C. Calibration data plotted with orifice equation curve for 38.1 mm orifice and a 152 mm line.

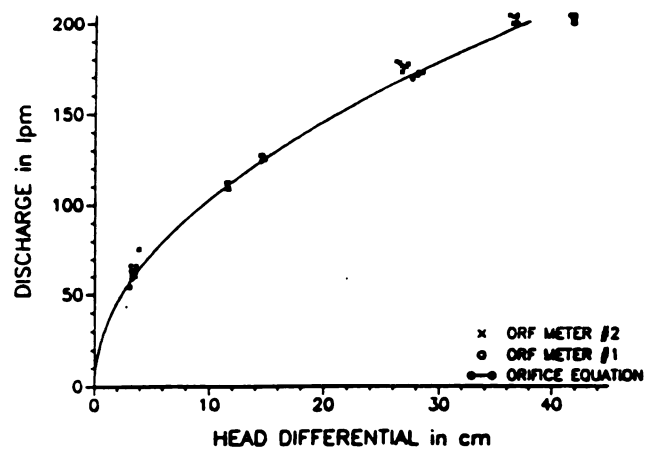


Figure 9C. Calibration data plotted with orifice equation curve for 50.8 mm orifice and a 152 mm line.

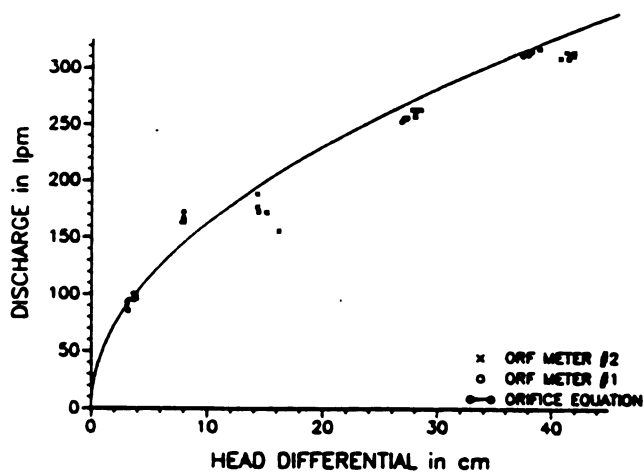


Figure 10C. Calibration data plotted with orifice equation curve for 63.5 mm orifice and a 152 mm line.

APPENDIX C

Corn and Soybean Yields, 1987 Growing Season

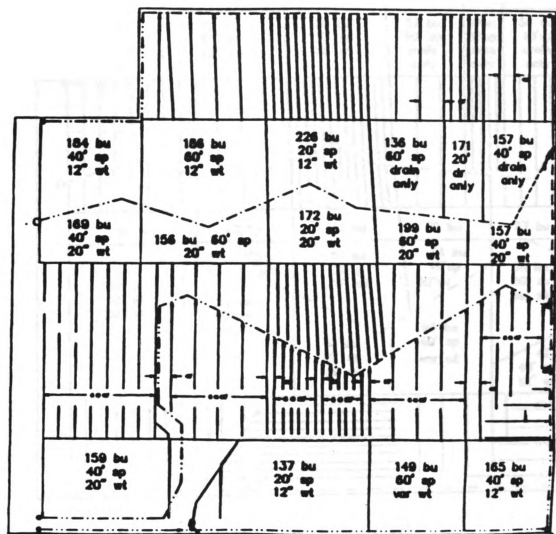


Figure 14. Layout of corn irrigation water table treatments at the Bannister Water Management for Crop Production Site. Yields are given along with the drain spacings and water tables which correspond to each treatment.

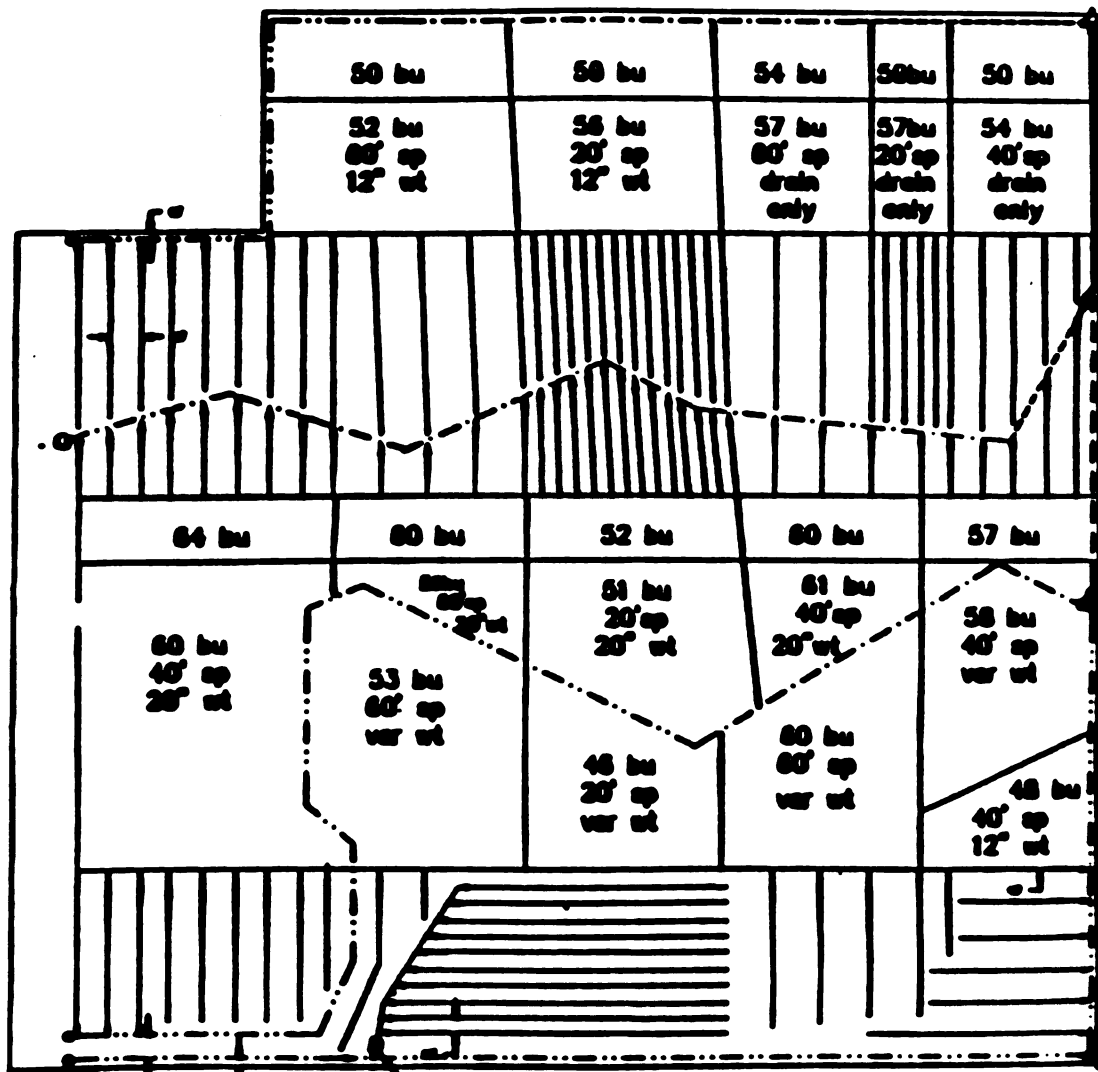


Figure 15. Layout of soybean irrigation water table treatments at the Bannister Water Management for Crop Production Site. Yields are given along with the drain spacings and water tables which correspond to each treatment. The narrow plots are the Hoyt variety while the larger blocks are Great Lakes variety. The indicated water tables and spacings apply to both varieties.

APPENDIX D
WATER QUALITY LAB RESULTS

N.D. - None Detected.
N.S. - No analysis conducted on sample.
DO - Drainage only sample.
HWT - High water table sample.

DATE	LOCATION	NO3	NH4	P	K
04/16/87	Head Stand ZONE A	6.45	N.D.	N.D.	1.8
06/23/87	Head Stand ZONE A	0.75	N.D.	0.08	4
08/05/87	Head Stand ZONE A	0.53	0.13	0.08	5
08/05/87	Head Stand ZONE A	0.41	0.1	0.07	6.3
09/11/87	STEELOUTLET	2.73	N.D.	N.D.	3.26
09/18/87	DO 1	2.78	N.D.	N.D.	4.23
09/18/87	DO 10	N.D.	N.D.	0.02	3.13
09/18/87	DO 11	0.33	N.D.	N.D.	3.12
09/18/87	DO 12	0.04	N.D.	N.D.	2.77
09/18/87	DO 13	2.75	N.D.	0.45	3.01
09/18/87	DO 14	2.56	N.D.	N.D.	2.93
09/18/87	DO 15	1.12	N.D.	N.D.	3.01
09/18/87	DO 16	1.71	N.D.	0.06	3.09
09/18/87	DO 17	2.69	1.16	0.07	3.43
09/18/87	DO 18	N.D.	N.D.	0.08	3.2
09/18/87	DO 19	2.07	N.D.	N.D.	3.13
09/18/87	DO 2	2.72	N.D.	N.D.	3.73
09/18/87	DO 20	1.81	N.D.	0.02	4.4
09/18/87	DO 21	N.D.	N.D.	N.D.	3.16
09/18/87	DO 22	N.D.	N.D.	N.D.	3.1
09/18/87	DO 23	N.D.	N.D.	N.D.	3.26
09/18/87	DO 24	N.D.	N.D.	N.D.	3.24
09/18/87	DO 25	N.D.	N.D.	N.D.	
09/18/87	DO 26	1.67	N.D.	0.18	3.34
09/18/87	DO 27	N.D.	N.D.	N.D.	3.13
09/18/87	DO 28	N.D.	N.D.	0.26	3.25
09/18/87	DO 3	3.19	N.D.	N.D.	3.66
09/18/87	DO 4	2.94	N.D.	N.D.	3.66
09/18/87	DO 5	N.D.	0.04	1.09	4.62
09/18/87	DO 6	0.06	N.D.	N.D.	3.75
09/18/87	DO 7	0.5	N.D.	0.01	3.21
09/18/87	DO 8	3.03	N.D.	N.D.	3.09
09/18/87	DO 9	2.85	N.D.	N.D.	3.25
09/21/87	DO 1	1.04	N.D.	N.D.	3.07
09/21/87	DO 10	0.77	N.D.	N.D.	3
09/21/87	DO 11	0.82	N.D.	N.S.	2.97
09/21/87	DO 2	0.83	N.D.	N.D.	2.37
09/21/87	DO 25	N.S.	N.S.	N.S.	3.76
09/21/87	DO 3	1.01	N.D.	N.D.	3.05

09/21/87	DO 4	1.04	N.D.	N.D.	3.07
09/21/87	DO 5	0.97	N.D.	N.D.	3.07
09/21/87	DO 6	0.93	N.D.	N.D.	3.05
09/21/87	DO 7	0.82	N.D.	N.D.	3.12
09/21/87	DO 8	0.98	N.D.	0.01	3.15
09/21/87	DO 9	0.32	N.D.	N.D.	2.89
10/06/87	DO 10	1.13	N.D.	N.D.	2.11
10/06/87	DO 11	2.19	N.D.	0.01	3.15
10/06/87	DO 12	1.66	N.D.	N.D.	2.29
10/06/87	DO 2	1.56	0.05	N.D.	2.37
10/06/87	DO 3	1.43	N.D.	N.D.	2.39
10/06/87	DO 4	1.46	N.D.	N.D.	2.35
10/06/87	DO 5	1.39	N.D.	N.D.	2.08
10/06/87	DO 6	1.31	N.D.	N.D.	2.38
10/06/87	DO 7	1.02	N.D.	0.01	2.42
10/06/87	DO 8	1.17	0.05	N.D.	2.33
10/06/87	DO 9	1.17	N.D.	0.01	2.34
10/09/87	DO 1	1.28	N.D.	0.04	2.74
10/20/87	DO 1	2.21	N.D.	0.05	3.05
10/20/87	DO 2	1.65	N.D.	0.04	3.56
10/20/87	DO 3	1.7	N.D.	0.05	3.41
10/20/87	DO 4	1.76	N.D.	0.02	3.4
10/20/87	DO 5	1.91	N.D.	N.D.	3.38
10/20/87	DO 6	1.68	N.D.	0.12	3.5
10/20/87	DO 7	1.49	N.D.	0.04	3.62
10/20/87	DO 8	1.23	N.D.	0.04	2.88
10/23/87	DO 1	3.85	N.D.	0.03	2.35
10/27/87	DO 1	3.89	N.D.	0.06	2.78
10/27/87	DO 2	4.34	N.D.	0.03	2.4
10/31/87	DO 1	4.52	N.D.	0.06	2.38
10/31/87	DO 2	4.32	N.D.	0.02	2.35
10/31/87	DO 3	3.5	N.D.	0.03	2.42
10/31/87	DO 4	3.05	N.D.	0.13	2.42
10/31/87	DO 5	3.76	N.D.	0.04	2.56
10/31/87	DO 6	3.5	N.D.	N.S.	N.S.
10/31/87	DO 7	3.5	N.D.	N.S.	N.S.
11/10/87	DO 1	3.08	0.2	0.02	2.42
11/10/87	DO 2	3.37	0.12	N.P.	2.4
11/10/87	DO 3	2.92	N.P.	0.04	2.53
11/10/87	DO 4	2.87	N.P.	0.03	2.46
11/10/87	DO 5	3.13	0.29	0.02	2.42
11/13/87	DO 1	4.09	0.03	0.05	2.37
11/19/87	DO 1	3.92	0.08	0.04	2.47
11/19/87	DO 2	4.36	0.06	0.01	2.38
12/01/87	DO	9.97	0.19	0.02	2.3
SNOW					
12/04/87	DO 1	9.74	8.28	N.P.	1.15
12/04/87	DO 2	9.22	7.34	N.P.	1.1
12/04/87	DO 3	9	N.D.	N.P.	1.1
12/04/87	DO 4	8.66	3.75	N.P.	1.1
12/04/87	DO 5	7.39	N.D.	N.P.	1.1
12/04/87	DO 6	8.78	7.71	N.P.	1.1
12/10/87	DO 1	4.58	N.D.	N.P.	0.25

12/10/87	DO 2	1.1	N.D.	N.P.	0.7
12/10/87	DO 3	2.63	N.D.	0.01	1.2
12/10/87	DO 4	3.56	1.21	N.D.	1.1
12/10/87	DO 5	2.2	N.D.	N.D.	0.7
12/10/87	DO 6	2.72	1.56	N.D.	0.2
12/14/87	DO GRB	N.D.	N.D.	COND.	
12/14/87	DOgrb	N.S.	N.S.	N.D.	5
12/23/87	DO 1	9.81	N.D.	0.01	
12/28/87	DO 1	2.26	N.D.	N.D.	0.3
12/28/87	DO 2	2.49	N.D.	N.D.	0.7
01/18/88	DO 1	6.36	N.D.	N.D.	1.23
01/18/88	DO 2	N.D.	N.D.	N.D.	1.4
01/18/88	DO 3	4.74	N.D.	N.D.	1.6
01/18/88	DO 4	N.D.	1.47	N.D.	1.44
01/18/88	DOgrb	2.5	7.98	N.D.	2.95
01/18/88	DOgrb	3.46	8.72	N.D.	1
01/18/88	DOgrb	2.5	8.04	N.D.	1.1
01/18/88	DOgrbaft 4	N.D.	7.94	N.D.	1
01/18/88	DOgrbaft 4	5.26	7.42	N.D.	2.1
02/01/88	DO 1	7.87	N.D.	0.11	2.35
02/01/88	DO 10	5.67	N.D.	0.08	3.83
02/01/88	DO 11	5.48	N.D.	0.08	3.25
02/01/88	DO 12	6.48	N.D.	0.1	2.8
02/01/88	DO 13	4.45	N.D.	0.09	2.75
02/01/88	DO 2	0.83	N.D.	0.09	2.35
02/01/88	DO 3	6.48	N.D.	0.1	2.5
02/01/88	DO 4	7.22	N.D.	0.1	2.85
02/01/88	DO 5	4.6	N.D.	0.09	2.8
02/01/88	DO 6	6.93	N.D.	0.08	3.8
02/01/88	DO 7	6.32	N.D.	0.09	3.8
02/01/88	DO 8	6.32	N.D.	0.09	12
02/01/88	DO 9	6.33	N.D.	0.11	3.83
02/03/88	DO 1	7.25	N.D.	0.08	1.65
02/03/88	DO 2	7.87	N.D.	0.08	1.65
02/03/88	DO 3	7.67	N.D.	0.08	1.6
02/03/88	DO 4	7.37	N.D.	0.08	1.1
02/03/88	DO 5	7.37	N.D.	0.08	1.1
02/19/88	DO	N.S.	N.D.	N.S.	0.9
GRAB					
02/19/88	DO	4.37	N.D.	0.11	N.S.
OVERFLOW					
03/02/88	DO	2.29	N.D.	N.S.	3.25
GRAB					
03/04/88	DO 1	2.49	N.D.	0.08	3.75
03/07/88	DO 1	3.53	N.D.	0.09	2.5
03/07/88	DO 10	5.8	N.D.	0.1	1.5
03/07/88	DO 11	3.63	N.D.	0.07	1.5
03/07/88	DO 2	0.87	N.D.	0.07	1.75
03/07/88	DO 3	0.87	N.D.	0.07	1.75
03/07/88	DO 4	3.38	N.D.	0.09	1.9
03/07/88	DO 5	5.05	N.D.	0.1	1.5
03/07/88	DO 6	5.05	N.D.	0.1	1.5
03/07/88	DO 7	3.57	N.D.	0.08	1.7

03/07/88	DO 8	3.76	N.D.	0.07	2.1
03/07/88	DO 9	4.46	N.D.	0.09	2
03/10/88	DO 1	4.63	N.D.	0.1	2.25
03/10/88	DO 10	8.77	N.D.	N.S.	2
03/10/88	DO 11	9.68	N.D.	0.07	1.5
03/10/88	DO 12	8.47	N.D.	0.11	1.5
03/10/88	DO 13	9.45	N.D.	0.09	1.5
03/10/88	DO 14	9.39	N.D.	0.09	1.5
03/10/88	DO 15	8.09	N.D.	0.09	1.5
03/10/88	DO 16	8.3	N.D.	0.09	1.5
03/10/88	DO 17	9.02	N.D.	0.09	1.4
03/10/88	DO 18	8.99	N.D.	0.09	1.2
03/10/88	DO 19	9.09	N.D.	0.08	1.3
03/10/88	DO 20	9.13	N.D.	0.08	1.2
03/10/88	DO 3	4.49	N.D.	0.08	1.75
03/10/88	DO 4	6.35	N.D.	0.08	1.45
03/10/88	DO 5	7.3	N.D.	0.09	1.25
03/10/88	DO 6	7.12	N.D.	0.08	1.45
03/10/88	DO 7	5.01	N.D.	0.08	1.4
03/10/88	DO 8	7.59	N.D.	0.08	1.4
03/10/88	DO 9	8.22	N.D.	0.08	1.5
03/10/88	DO 2	4.8	N.D.	0.08	1.95
03/15/88	DO 1	10.44	0.1	0.19	1.21
03/15/88	DO 10	12.7	0.12	0.23	2.53
03/15/88	DO 11	11.97	0.1	0.1	3.07
03/15/88	DO 12	12.73	N.D.	N.D.	2.51
03/15/88	DO 13	11.76	0.14	0.21	2.65
03/15/88	DO 14	11.62	0.1	N.D.	2.43
03/15/88	DO 15	12.86	0.33	0.1	2.29
03/15/88	DO 16	12.53	0.1	N.D.	2.94
03/15/88	DO 17	11.49	0.11	N.D.	2.74
03/15/88	DO 18	13.37	0.1	N.D.	2.51
03/15/88	DO 19	12.81	0.09	N.D.	2.15
03/15/88	DO 2	10.34	0.04	0.22	1.02
03/15/88	DO 20	11.57	0.12	N.D.	1.99
03/15/88	DO 21	12.18	0.12	N.D.	1.62
03/15/88	DO 22	12.34	0.1	N.D.	1.12
03/15/88	DO 23	11.13	0.11	N.D.	1.22
03/15/88	DO 24	12.51	0.6	N.D.	1.4
03/15/88	DO 25	10.89	0.17	N.D.	1.1
03/15/88	DO 26	10.59	0.23	0.21	1.12
03/15/88	DO 3	11.6	0.11	N.D.	1.09
03/15/88	DO 4	10.67	0.14	N.D.	1.1
03/15/88	DO 5	10.86	0.2	0.2	0.99
03/15/88	DO 6	9.88	0.13	N.D.	1.14
03/15/88	DO 7	12.13	0.11	0.16	1.1
03/15/88	DO 8	12.27	0.11	N.D.	1.33
03/15/88	DO 9	12	0.11	N.D.	1.66
04/01/88	DO 1	8.38	0.62	N.D.	2.18
04/01/88	DO 10	12.16	0.41	N.D.	1.28
04/01/88	DO 11	10.5	0.26	N.D.	1.28
04/01/88	DO 12	11.9	0.15	N.D.	0.88
04/01/88	DO 13	11.11	0.15	N.D.	0.9

04/01/88	DO 14	11.36	0.2	N.D.	0.92
04/01/88	DO 15	10.84	0.13	N.D.	0.82
04/01/88	DO 16	11.04	0.13	N.D.	0.84
04/01/88	DO 2	11.52	0.39	N.D.	2.19
04/01/88	DO 3	13.21	0.23	N.D.	2.1
04/01/88	DO 4	13.02	0.26	N.D.	2.01
04/01/88	DO 5	13.29	0.15	N.D.	1.6
04/01/88	DO 6	12.83	0.24	N.D.	1.45
04/01/88	DO 7	13.02	0.23	N.D.	1.1
04/01/88	DO 8	12.75	0.3	N.D.	1.22
04/01/88	DO 9	12.31	0.27	N.D.	1.86
04/08/88	DO 1	13.83	0.28	N.D.	4.65
04/08/88	DO 10	15.11	0.37	N.D.	1.95
04/08/88	DO 2	12.44	0.26	N.D.	0.98
04/08/88	DO 3	13.68	0.25	N.D.	1.09
04/08/88	DO 4	14.37	0.22	N.D.	1.26
04/08/88	DO 5	13.54	0.22	N.D.	1.5
04/08/88	DO 6	12.65	0.25	N.D.	1.12
04/08/88	DO 7	9.53	0.16	N.D.	1.15
04/08/88	DO 8	12.98	0.19	N.D.	1.26
04/08/88	DO 9	12.65	0.31	N.D.	1.43
09/14/87	HWT 1	19.56	N.D.	N.D.	2.76
09/14/87	HWT 2	17.51	N.D.	N.D.	2.17
09/14/87	HWT 3	20	N.D.	N.D.	2.61
09/14/87	HWT 4	20	N.D.	N.D.	2.55
09/14/87	HWT 5	13.7	0.2	N.D.	2.34
09/14/87	HWT 6	17.72	N.D.	0.01	2.16
09/18/87	HWT 1	5.72	0.04	0.01	2.04
09/18/87	HWT 10	7.09	0.1	0.01	1.99
09/18/87	HWT 11	10.47	N.D.	0.01	1.98
09/18/87	HWT 12	N.S.	N.S.	N.D.	2.05
09/18/87	HWT 13	14.42	N.D.	N.D.	2.17
09/18/87	HWT 14	13.8	N.D.	N.D.	2.09
09/18/87	HWT 15	14.64	1.65	0.27	2.3
09/18/87	HWT 16	16.16	N.D.	0.01	2.13
09/18/87	HWT 17	15.51	N.D.	N.D.	2.17
09/18/87	HWT 18	16.55	N.D.	N.D.	2.2
09/18/87	HWT 19	15	N.D.	0.01	2.07
09/18/87	HWT 2	5.96	N.D.	0.01	2.09
09/18/87	HWT 20	16.86	N.D.	0.02	2.23
09/18/87	HWT 21	16.56	N.D.	N.D.	2.11
09/18/87	HWT 22	16.39	N.D.	0.01	2.09
09/18/87	HWT 23	10.29	N.D.	0.01	0.82
09/18/87	HWT 24	8.33	0.61	0.03	0.78
09/18/87	HWT 25	15.4	N.D.	N.D.	2.11
09/18/87	HWT 26	15.84	N.D.	N.D.	2.13
09/18/87	HWT 27	12.98	N.D.	N.D.	2.23
09/18/87	HWT 3	6.45	N.D.	N.D.	2.09
09/18/87	HWT 4	7.04	N.D.	0.01	2.05
09/18/87	HWT 5	7.39	N.D.	0.03	2.05
09/18/87	HWT 6	7.53	N.D.	N.D.	2.09
09/18/87	HWT 7	8.07	N.D.	N.D.	2.05
09/18/87	HWT 8	9.05	N.D.	N.D.	2.03

09/18/87	HWT 9	8.38	0.2	0.03	2.01
09/21/87	HWT 1	14.41	N.D.	N.D.	2.06
09/21/87	HWT 10	12.35	N.D.	0.02	1.99
09/21/87	HWT 2	13.22	0.21	N.D.	1.93
09/21/87	HWT 3	10.59	0.48	0.16	2.02
09/21/87	HWT 4	13.53	N.D.	N.D.	2.03
09/21/87	HWT 5	13.22	N.D.	N.D.	2.19
09/21/87	HWT 6	12.86	N.D.	N.D.	2.01
09/21/87	HWT 7	12.9	N.D.	0.09	1.93
09/21/87	HWT 8	12.25	N.D.	N.D.	2.06
09/21/87	HWT 9	11.78	0.15	0.28	2.01
10/06/87	HWT 10	10.96	0.07	0.01	2.17
10/06/87	HWT 11	9.99	N.D.	0.36	2.18
10/06/87	HWT 12	9.7	N.D.	0.06	2.02
10/06/87	HWT 13	9.99	N.D.	0.09	2.07
10/06/87	HWT 14	9.17	N.D.	N.D.	1.95
10/06/87	HWT 15	8.42	N.D.	0.09	1.92
10/06/87	HWT 16	8.27	N.D.	0.3	2.06
10/06/87	HWT 17	7.94	N.D.	N.D.	2.05
10/06/87	HWT 18	7.83	N.D.	N.D.	2.04
10/06/87	HWT 19	8.18	N.D.	N.D.	2.09
10/06/87	HWT 20	8.14	N.D.	0.13	2.03
10/06/87	HWT 21	8.08	N.D.	0.01	2.03
10/06/87	HWT 4	15.43	N.D.	N.D.	2.25
10/06/87	HWT 5	14.62	0.1	0.01	N.S.
10/06/87	HWT 6	14.17	N.D.	N.D.	2.04
10/06/87	HWT 7	6.78	7.21	0.42	3.18
10/06/87	HWT 8	12.07	N.D.	N.D.	2.08
10/06/87	HWT 9	11.45	N.D.	0.01	1.99
10/09/87	HWT 1	6.89	N.D.	0.08	2.75
10/09/87	HWT 10	7.66	N.D.	0.09	2.63
10/09/87	HWT 11	7.65	N.D.	0.44	2.74
10/09/87	HWT 12	7.91	N.D.	0.08	2.82
10/09/87	HWT 13	7.42	N.D.	0.05	2.69
10/09/87	HWT 14	8.17	N.D.	N.D.	2.66
10/09/87	HWT 2	7.05	N.D.	N.D.	2.64
10/09/87	HWT 3	7.1	N.D.	0.08	2.64
10/09/87	HWT 4	6.72	N.D.	0.02	2.71
10/09/87	HWT 5	7.07	N.D.	0.41	2.74
10/09/87	HWT 6	6.96	N.D.	0.1	2.64
10/09/87	HWT 7	6.98	N.D.	0.01	2.62
10/09/87	HWT 8	6.79	N.D.	0.24	2.72
10/09/87	HWT 9	6.97	N.D.	0.02	2.73
10/20/87	HWT 1	6.57	N.D.	0.89	2.93
10/20/87	HWT 2	2.7	N.S.	0.07	2.65
10/20/87	HWT 3	2.47	N.S.	0.04	2.65
10/20/87	HWT 4	2.35	N.S.	0.02	2.67
10/20/87	HWT 5	2.45	N.D.	0.04	2.63
10/20/87	HWT 6	2.48	N.D.	N.D.	2.67
10/20/87	HWT 7	2.47	N.D.	0.1	2.67
10/20/87	HWT 8	2.57	N.D.	0.05	2.66
10/20/87	HWT 9	2.4	N.D.	0.02	2.7
10/21/87	HWT	3.37	N.D.	0.03	2.46

GRAB					
10/21/87	HWT	2.9	N.D.	0.03	2.38
GRAB					
10/22/87	HWT 1	3.12	N.D.	0.04	2.45
10/23/87	HWT	3.88	N.D.	0.02	2.4
GRAB					
10/23/87	HWT 1	3.91	N.D.	0.03	2.44
10/23/87	HWT 2	3.99	N.D.	N.D.	2.39
10/23/87	HWT 3	3.96	N.D.	0.09	2.41
10/23/87	HWT 4	3.97	N.D.	0.06	2.37
10/23/87	HWT 5	5.37	N.D.	0.01	2.41
10/28/87	HWT 1	6.29	N.D.	0.04	N.S.
10/28/87	HWT 2	6.36	N.D.	0.05	2.48
10/28/87	HWT 3	6.52	N.D.	0.02	2.48
10/28/87	HWT 4	6.39	N.D.	0.04	2.44
10/28/87	HWT 5	6.28	N.D.	0.01	2.47
10/28/87	HWT 6	6.18	N.D.	0.04	2.46
10/28/87	HWT 7	6.04	N.D.	0.02	2.49
10/28/87	HWT 8	5.91	N.D.	N.D.	2.46
10/28/87	HWT 9	5.87	N.D.	0.11	2.45
10/31/87	HWT 10	4.48	N.D.	N.D.	2.5
10/31/87	HWT 11	4.16	N.D.	0.1	2.52
10/31/87	HWT 12	4.31	N.D.	0.02	2.51
10/31/87	HWT 13	4.15	N.D.	0.02	2.42
10/31/87	HWT 14	3.98	N.D.	N.D.	2.4
10/31/87	HWT 15	4.22	N.D.	0.09	2.35
10/31/87	HWT 16	3.87	N.D.	0.03	2.35
10/31/87	HWT 17	4.11	N.D.	N.D.	2.41
10/31/87	HWT 18	3.32	0.07	1.5	2.35
10/31/87	HWT 19	3.87	N.D.	0.04	2.32
10/31/87	HWT 2	5.59	N.D.	0.01	2.46
10/31/87	HWT 20	3.94	N.D.	0.01	2.49
10/31/87	HWT 21	3.41	N.D.	0.04	2.28
10/31/87	HWT 22	3.35	N.D.	0.01	2.33
10/31/87	HWT 23	3.5	N.D.	0.03	2.28
10/31/87	HWT 24	3.47	N.D.	0.4	2.34
10/31/87	HWT 25	3.31	0.08	0.13	2.28
10/31/87	HWT 26	3.03	N.D.	0.1	2.28
10/31/87	HWT 27	3.71	N.D.	0.06	2.4
10/31/87	HWT 28	3.95	N.D.	0.07	2.34
10/31/87	HWT 3	5.41	N.D.	0.04	2.41
10/31/87	HWT 4	5.14	N.D.	0.02	2.4
10/31/87	HWT 5	4.86	N.D.	0.5	2.47
10/31/87	HWT 6	4.86	N.D.	0.09	2.5
10/31/87	HWT 7	4.44	N.D.	0.02	2.45
10/31/87	HWT 8	4.61	N.D.	0.04	2.48
10/31/87	HWT 9	4.39	0.1	0.01	2.45
11/03/87	HWT 1	3.3	N.D.	0.04	2.56
11/06/87	HWT 1	5.01	0.04	0.06	2.35
11/06/87	HWT 2	5.02	0.03	0.04	2.33
11/06/87	HWT 3	4.88	0.07	0.09	2.31
11/06/87	HWT 4	4.18	N.D.	0.02	2.37
11/06/87	HWT 5	4.78	N.D.	N.D.	2.35

11/06/87	HWT 6	4.6	N.D.	0.06	2.3
11/06/87	HWT 7	4.72	N.D.	0.03	2.33
11/10/87	HWT 1	3.49	0.01	0.1	2.32
11/10/87	HWT 10	3.72	0.02	0.05	2.33
11/10/87	HWT 11	3.71	0.1	0.02	2.35
11/10/87	HWT 2	3.9	0.05	0.02	2.3
11/10/87	HWT 3	3.76	0.05	N.D.	2.32
11/10/87	HWT 4	3.78	N.D.	0.03	2.32
11/10/87	HWT 5	3.62	N.D.	0.05	2.38
11/10/87	HWT 6	3.66	0.1	0.09	2.36
11/10/87	HWT 7	3.64	0.07	0.02	2.29
11/10/87	HWT 8	3.63	N.D.	N.D.	2.36
11/10/87	HWT 9	3.82	N.D.	0.05	2.41
11/13/87	HWT	2.66	0.13	0.01	2.31
GRAB					
11/13/87	HWT	4.99	0.06	0.01	2.44
GRAB					
11/19/87	HWT 1	2.24	0.03	0.04	2.42
11/19/87	HWT 2	2.76	N.D.	0.03	2.34
11/19/87	HWT 3	2.69	N.D.	0.04	2.41
11/19/87	HWT 4	2.83	N.D.	0.01	2.36
11/19/87	HWT 5	2.67	0.04	0.01	2.42
12/01/87	HWT	2.46	N.D.	0.04	2.59
SNOW					
12/01/87	HWT GRB	1.93	5.21	N.S.	N.S.
12/04/87	HWTgrb	N.S.	N.D.	N.D.	1.15
12/10/87	HWT 1	1.15	5.08	0.1	1.15
12/10/87	HWT 10	15.1	N.D.	NP	7.6
12/10/87	HWT 11	15	5.86	0.06	8
12/10/87	HWT 12	15.09	N.D.	0.03	8.6
12/10/87	HWT 13	14.5	N.D.	N.D.	9
12/10/87	HWT 14	14.72	N.D.	N.D.	9.4
12/10/87	HWT 15	14.53	0.79	N.D.	9.5
12/10/87	HWT 16	15.1	N.D.	N.D.	9.6
12/10/87	HWT 17	15.1	4.24	N.D.	9.6
12/10/87	HWT 18	15.02	N.D.	N.D.	9.6
12/10/87	HWT 19	15.2	N.D.	N.D.	9.7
12/10/87	HWT 2	1.94	0.78	0.36	1.1
12/10/87	HWT 20	14.37	0.01	N.D.	9.7
12/10/87	HWT 21	14.39	N.D.	N.D.	9.6
12/10/87	HWT 22	14.96	N.D.	N.D.	9.5
12/10/87	HWT 3	2.34	0.06	0.03	1.15
12/10/87	HWT 4	2.01	0.07	N.D.	1.2
12/10/87	HWT 5	0.97	3.08	N.D.	1.2
12/10/87	HWT 6	1.23	N.D.	N.D.	1.25
12/10/87	HWT 7	2.81	N.D.	N.D.	2.1
12/10/87	HWT 8	8.13	N.D.	N.D.	3.9
12/10/87	HWT 9	14.54	N.D.	N.D.	7.1
12/14/87	HWT GRB	1.93	8.15	N.D.	N.S.
GRAB					
12/23/87	HWT 1	8.71	0.73	N.D.	8.9
12/23/87	HWT 10	N.D.	N.D.	N.D.	6.6
12/23/87	HWT 11	9.42	N.D.	N.D.	7.4

12/23/87	HWT 12	6.16	N.D.	N.D.	7.1
12/23/87	HWT 13	8.32	0.25	0.01	7.5
12/23/87	HWT 14	3.72	N.D.	N.D.	7.3
12/23/87	HWT 15	5.78	N.D.	N.D.	7.3
12/23/87	HWT 16	12.32	N.D.	0.01	7.5
12/23/87	HWT 17	6.96	N.D.	N.D.	7.8
12/23/87	HWT 18	4.64	N.D.	0.01	7.5
12/23/87	HWT 19	7.54	N.D.	N.D.	7.8
12/23/87	HWT 2	8.19	1.37	N.D.	7.5
12/23/87	HWT 20	4.84	N.D.	0.01	7.6
12/23/87	HWT 21	6.14	N.D.	N.D.	8
12/23/87	HWT 22	N.D.	N.D.	N.D.	7.8
12/23/87	HWT 23	1.16	N.D.	N.D.	5.8
12/23/87	HWT 24	7.16	7.94	N.D.	8.5
12/23/87	HWT 25	6.98	7.32	N.D.	8.5
12/23/87	HWT 26	4.46	N.D.	0.01	N.S.
12/23/87	HWT 27	7.49	N.D.	0.01	N.S.
12/23/87	HWT 28	2.01	1.69	0.01	N.S.
12/23/87	HWT 3	8.03	N.D.	0.05	7
12/23/87	HWT 4	7.22	N.D.	N.D.	6.4
12/23/87	HWT 5	3.47	N.D.	N.D.	6.4
12/23/87	HWT 6	8.13	N.D.	N.D.	6.4
12/23/87	HWT 7	7.23	N.D.	0.02	6.6
12/23/87	HWT 8	8.79	N.D.	N.D.	6.8
12/23/87	HWT 9	5.58	N.D.	N.D.	6.5
12/28/87	HWT 1	0.99	0.53	N.D.	N.D.
12/28/87	HWT 10	4.19	N.D.	N.D.	8
12/28/87	HWT 11	4.42	N.D.	0.01	6.8
12/28/87	HWT 12	4.31	N.D.	N.D.	7.5
12/28/87	HWT 13	3.27	N.D.	N.D.	7.5
12/28/87	HWT 14	4.44	N.D.	N.D.	8.1
12/28/87	HWT 15	4.07	N.D.	N.D.	8
12/28/87	HWT 16	4.49	N.D.	N.D.	7.7
12/28/87	HWT 17	3.4	N.D.	N.D.	7.6
12/28/87	HWT 18	5.02	N.D.	N.D.	7.6
12/28/87	HWT 19	2.39	N.D.	N.D.	7.1
12/28/87	HWT 2	0.57	0.04	N.D.	N.D.
12/28/87	HWT 20	2.61	N.D.	N.D.	6.8
12/28/87	HWT 21	4.53	N.D.	0.02	7.2
12/28/87	HWT 22	1.79	N.D.	N.D.	7.8
12/28/87	HWT 23	3.45	N.D.	0.01	7.6
12/28/87	HWT 24	3.56	N.D.	N.D.	7.6
12/28/87	HWT 25	2.52	2.32	N.D.	7.1
12/28/87	HWT 26	4.59	11.11	N.D.	7
12/28/87	HWT 27	1.61	3.93	N.D.	7.5
12/28/87	HWT 28	1.65	6.94	0.04	8
12/28/87	HWT 3	0.1	0.01	0.06	N.D.
12/28/87	HWT 4	2.48	0.72	0.08	N.D.
12/28/87	HWT 5	4.29	1.45	N.D.	8
12/28/87	HWT 6	4.5	0.28	N.D.	8
12/28/87	HWT 7	6.09	3.85	N.D.	8.8
12/28/87	HWT 8	4.96	N.D.	N.D.	8.2
12/28/87	HWT 9	3.84	N.D.	0.34	8

04/16/87	Head Stand ZONE C	5.08	0.09	N.D.	2
08/05/87	Head Stand ZONE C	0.57	0.06	0.09	5.5
08/05/87	Ditch Before Mapl	0.88	1	0.15	6.45
08/05/87	Field Outlet	0.57	N.D.	0.05	5.25
09/11/87	DITCHOUTLET	1.31	N.D.	0.1	3.04

ATRAZINE

DATE	STAND LOCATION	Gallons Repres.	ppb ATRAZINE
4/16/87	Head Stand ZONE A (DO)		0.18
5/18/87	Head Stand ZONE A (DO)		0.63
9/18/87	DO	(30,000)	1.29
9/18/87	DO	(30,000)	0.84
9/18/87	DO	(20,000)	0.60
9/21/87	DO	(27,500)	0.39
10/6/87	DO	(110,000)	0.33
10/20/87	DO	(100,000)	0.27
10/31/87	DO	(45,000)	0.22
11/10/87	DO	(45,000)	0.08
12/10/87	DO	(95,000)	1.63
01/20/88	DO	(40,700)	0.17
02/01/88	DO	(90,000)	0.67
03/01/88	DO	(89,000)	0.67
03/10/88	DO	(100,000)	0.67
03/15/88	DO	(270,000)	0.35
04/01/88	DO	(260,000)	0.24
4/16/87	Head Stand ZONE B	HWT	0.09
4/16/87	Head Stand ZONE B	HWT	0.13
5/18/87	Head Stand ZONE B	HWT	0.17
9/14/87	HWT	(6,000)	1.27
9/18/87	HWT	(30,000)	0.87
9/18/87	HWT	(30,000)	1.73
9/18/87	HWT	(20,000)	1.55
9/21/87	HWT	(25,000)	1.11
10/6/87	HWT	(180,000)	0.79
10/07/87	HWT	(140,000)	0.48
10/20/87	HWT	(150,000)	0.25
10/28/87	HWT	(150,000)	0.07
10/31/87	HWT	(190,000)	0.26
11/06/87	HWT	(45,000)	0.22
11/10/87	HWT	(90,000)	0.20
12/10/87	HWT	(205,000)	0.10
12/23/87	HWT	(120,000)	4.00
12/28/87	HWT	(170,000)	3.79
03/10/88	HWT	(9,500)	1.02
04/04/88	HWT	(240,000)	1.80

APPENDIX E

BANNISTER WEATHER STATION DATA

DATE	MAX TEMP C	MIN TEMP C	PRECIP mm/day	SOL RAD MJ/day
16-Apr-87	16.03	-3.36	4	11.09
17-Apr-87	20.46	4.46	0	24.13
18-Apr-87	24.89	5.36	0	24.88
19-Apr-87	24.97	7.41	0	24.23
20-Apr-87	27.83	7.54	0	24.99
21-Apr-87	22.95	7.50	0	18.12
22-Apr-87	8.91	4.10	5	4.13
23-Apr-87	16.41	7.83	3	11.64
24-Apr-87	11.80	1.84	0	26.63
25-Apr-87	14.71	-2.75	0	14.45
26-Apr-87	19.38	4.29	0	26.06
27-Apr-87	16.10	6.61	3	12.84
28-Apr-87	15.13	3.94	0	23.64
29-Apr-87	21.41	5.20	0	26.28
30-Apr-87	14.35	0.27	0	26.33
01-May-87	15.89	-0.06	0	13.15
02-May-87	19.17	7.54	0	25.13
03-May-87	16.72	3.23	0	22.09
04-May-87	16.67	0.85	0	27.70
05-May-87	20.03	-2.35	0	27.03
06-May-87	22.89	2.53	0	25.12
07-May-87	19.75	3.92	0	21.64
08-May-87	21.78	0.45	0	27.55
09-May-87	27.71	9.88	0	26.54
10-May-87	29.17	13.80	0	21.86
11-May-87	28.89	11.61	9	16.80
12-May-87	16.15	4.83	0	28.77
13-May-87	22.83	0.40	0	28.54
14-May-87	28.13	12.76	8	15.36
15-May-87	18.07	6.58	0	28.41
16-May-87	25.48	6.85	0	26.08
17-May-87	29.51	13.60	0	27.82
18-May-87	18.74	9.37	4	4.60
19-May-87	14.53	9.19	3	4.42
20-May-87	19.89	13.57	0	9.56
21-May-87	30.94	15.50	0	20.73
22-May-87	26.31	13.39	0	24.36
23-May-87	16.24	10.59	0	14.94
24-May-87	13.51	8.23	0	7.54
25-May-87	20.91	8.21	0	18.97
26-May-87	29.97	13.68	2	21.09
27-May-87	32.61	19.24	0	24.26
28-May-87	32.07	20.32	4	24.89

29-May-87	31.86	19.58	0	25.19
30-May-87	32.04	20.40	0	23.87
31-May-87	30.86	18.65	1	23.34
01-Jun-87	25.09	17.51	9	13.01
02-Jun-87	26.95	17.73	6	15.82
03-Jun-87	24.70	16.00	0	28.82
04-Jun-87	21.33	11.32	0	29.32
05-Jun-87	25.42	10.30	0	28.01
06-Jun-87	24.52	10.26	10	13.41
07-Jun-87	30.34	16.89	0	25.74
08-Jun-87	27.65	15.30	0	21.09
09-Jun-87	20.70	9.33	0	29.34
10-Jun-87	22.63	4.64	0	27.21
11-Jun-87	26.40	13.61	6	14.60
12-Jun-87	29.33	18.78	0	22.73
13-Jun-87	30.50	14.21	0	28.09
14-Jun-87	35.30	17.24	0	29.05
15-Jun-87	29.61	15.52	0	30.08
16-Jun-87	32.15	11.47	0	29.35
17-Jun-87	30.40	13.66	0	27.84
18-Jun-87	33.50	14.71	0	27.27
19-Jun-87	34.31	16.34	0	24.20
20-Jun-87	28.43	19.61	0	17.66
21-Jun-87	22.20	18.68	3	4.02
22-Jun-87	21.82	16.94	0	7.84
23-Jun-87	28.59	14.03	0	28.05
24-Jun-87	32.23	13.28	0	25.64
25-Jun-87	30.86	16.51	5	16.98
26-Jun-87	24.85	14.50	0	26.97
27-Jun-87	19.55	10.32	3	19.01
28-Jun-87	27.04	9.32	0	24.71
29-Jun-87	25.85	18.31	12	14.80
30-Jun-87	24.35	16.44	1	17.88
01-Jul-87	22.81	13.42	0	20.60
02-Jul-87	27.02	11.97	0	23.86
03-Jul-87	28.28	17.43	1	25.04
04-Jul-87	26.20	12.17	0	27.85
05-Jul-87	27.09	12.22	6	21.65
06-Jul-87	28.28	18.76	0	19.61
07-Jul-87	29.00	19.92	0	23.39
08-Jul-87	31.94	20.54	0	26.02
09-Jul-87	30.26	17.60	37	12.22
10-Jul-87	30.07	19.72	0	17.54
11-Jul-87	31.32	20.12	0	25.80
12-Jul-87	31.75	21.82	0	24.66
13-Jul-87	28.29	16.50	1	16.46
14-Jul-87	20.05	9.31	0	22.33
15-Jul-87	17.58	5.28	0	11.59
16-Jul-87	25.13	9.38	0	24.83
17-Jul-87	29.47	14.36	0	26.88
18-Jul-87	31.41	19.13	0	25.62
19-Jul-87	31.95	19.83	0	23.45
20-Jul-87	33.77	20.36	0	22.87

21-Jul-87	32.09	16.81	0	26.42
22-Jul-87	32.57	17.18	0	19.35
23-Jul-87	31.55	18.78	0	20.63
24-Jul-87	32.11	21.93	0	20.45
25-Jul-87	31.01	19.05	21	26.20
26-Jul-87	29.98	17.25	7	24.62
27-Jul-87	27.73	11.30	0	28.44
28-Jul-87	28.71	10.60	0	25.60
29-Jul-87	29.80	14.45	0	24.18
30-Jul-87	30.81	18.36	0	26.19
31-Jul-87	29.21	17.15	0	20.96
01-Aug-87	25.95	18.81	3	8.46
02-Aug-87	30.92	21.69	0	19.17
03-Aug-87	33.04	16.51	0	26.04
04-Aug-87	28.95	18.35	0	23.25
05-Aug-87	23.76	12.69	0	22.38
06-Aug-87	27.85	9.29	0	22.89
07-Aug-87	30.48	15.88	1	20.15
08-Aug-87	20.52	12.88	9	5.70
09-Aug-87	24.88	15.52	14	11.67
10-Aug-87	24.82	14.09	0	23.26
11-Aug-87	26.31	11.95	0	23.56
12-Aug-87	27.41	10.92	0	22.50
13-Aug-87	29.21	14.70	0	22.04
14-Aug-87	24.46	20.36	7	3.75
15-Aug-87	30.35	22.33	3	17.88
16-Aug-87	30.00	20.06	5	13.49
17-Aug-87	25.64	15.75	3	21.98
18-Aug-87	24.80	12.22	3	17.18
19-Aug-87	23.87	11.33	1	24.39
20-Aug-87	24.71	8.94	4	24.56
21-Aug-87	27.24	15.36	2	19.05
22-Aug-87	22.55	10.67	11	21.38
23-Aug-87	19.98	7.51	1	22.21
24-Aug-87	19.97	3.99	0	24.69
25-Aug-87	21.19	7.56	1	14.98
26-Aug-87	14.34	12.34	0	1.78
27-Aug-87	18.30	13.50	1	6.11
28-Aug-87	19.79	11.80	0	10.01
29-Aug-87	22.98	9.41	0	20.71
30-Aug-87	25.46	12.44	0	19.41
31-Aug-87	20.13	9.06	0	20.85
01-Sep-87	20.66	6.14	0	20.91
02-Sep-87	20.11	7.56	0	21.93
03-Sep-87	20.98	3.59	0	21.26
04-Sep-87	23.26	3.51	0	22.13
05-Sep-87	27.86	8.23	0	20.43
06-Sep-87	27.17	14.30	1	17.96
07-Sep-87	27.94	15.85	0	16.32
08-Sep-87	22.91	15.13	1	7.13
09-Sep-87	24.17	12.62	0	17.93
10-Sep-87	25.59	11.47	0	19.22
11-Sep-87	25.87	15.47	1272	17.28

12-Sep-87	25.11	12.80	0	13.44
13-Sep-87	20.79	7.93	0	13.00
14-Sep-87	21.63	6.14	6	19.58
15-Sep-87	23.12	8.24	6	13.33
16-Sep-87	21.66	11.86	13	4.86
17-Sep-87	24.14	16.91	6	10.36
18-Sep-87	17.83	13.71	0	2.48
19-Sep-87	21.25	9.67	1	16.49
20-Sep-87	17.97	9.33	0	9.61
21-Sep-87	15.51	6.44	1	6.92
22-Sep-87	20.38	6.44	0	10.40
23-Sep-87	22.13	7.41	0	19.27
24-Sep-87	19.89	7.63	0	16.70
25-Sep-87	18.60	1.30	0	19.42
26-Sep-87	24.10	6.16	0	16.17
27-Sep-87	27.85	7.72	5	15.72
28-Sep-87	27.77	11.83	3	14.88
29-Sep-87	22.03	11.59	19	9.01
30-Sep-87	16.72	5.07	1	10.79
01-Oct-87	15.82	0.52	0	9.34
02-Oct-87	14.73	4.67	2	6.20
03-Oct-87	8.63	0.54	0	11.53
04-Oct-87	17.32	-0.38	14	17.13
05-Oct-87	18.57	8.32	0	10.80
06-Oct-87	12.10	3.31	0	4.51
07-Oct-87	7.36	2.12	0	3.18
08-Oct-87	9.25	0.87	0	9.01
09-Oct-87	15.98	4.38	0	13.03
10-Oct-87	8.56	3.20	0	6.87
11-Oct-87	9.18	-0.57	0	5.80
12-Oct-87	11.56	-3.44	343	9.67
13-Oct-87	15.92	-4.39	2	15.14
14-Oct-87	18.41	4.36	0	13.80
15-Oct-87	21.83	8.07	0	11.99
16-Oct-87	21.56	5.94	0	12.54
17-Oct-87	16.29	8.77	53	3.22
18-Oct-87	17.60	5.10	0	13.84
19-Oct-87	12.76	4.57	4	6.26
20-Oct-87	7.35	3.84	10	2.69
21-Oct-87	7.49	-0.53	2	4.15
22-Oct-87	4.70	-1.13	5	1.35
23-Oct-87	9.42	0.60	2	5.90
24-Oct-87	5.41	-1.53	8	2.39
25-Oct-87	10.39	-3.43	0	13.71
26-Oct-87	12.47	-2.77	2	10.99
27-Oct-87	10.98	0.16	55	8.72
28-Oct-87	10.24	-2.87	0	8.44
29-Oct-87	9.66	-1.68	0	11.63
30-Oct-87	16.22	-1.18	0	11.27
31-Oct-87	14.24	-2.95	0	11.02
01-Nov-87	9.92	3.72	12	1.65
02-Nov-87	17.03	9.13	0	3.18
03-Nov-87	23.32	14.79	0	10.14

04-Nov-87	17.90	9.64	0	4.48
05-Nov-87	9.55	-0.05	0	6.15
06-Nov-87	7.93	-3.25	0	11.76
07-Nov-87	12.01	-1.96	0	9.31
08-Nov-87	11.95	2.35	41	2.09
09-Nov-87	3.37	-3.09	0	7.46
10-Nov-87	2.06	-4.52	0	6.19
11-Nov-87	3.50	-6.09	0	9.01
12-Nov-87	11.05	-0.97	0	10.00
13-Nov-87	11.18	2.71	1	6.22
14-Nov-87	8.92	-0.34	0	5.34
15-Nov-87	15.00	-1.89	0	7.92
16-Nov-87	16.04	4.21	0	5.79
17-Nov-87	16.53	8.69	1	3.12
18-Nov-87	8.75	-0.34	2	4.86
19-Nov-87	6.36	-1.74	0	4.44
20-Nov-87	-0.54	-6.72	0	5.67
21-Nov-87	-1.64	-11.12	0	8.06
22-Nov-87	7.12	-4.93	0	8.39
23-Nov-87	10.27	3.34	5	3.35
24-Nov-87	5.42	2.17	0	2.14
25-Nov-87	2.21	0.21	0	0.68
26-Nov-87	3.43	-0.02	0	2.52
27-Nov-87	3.55	-0.12	0	2.84
28-Nov-87	7.40	2.43	0	2.09
29-Nov-87	30.77	2.72	0	2.56
30-Nov-87	4.98	1.24	0	0.84
01-Dec-87	1.22	-2.87	0	3.24
02-Dec-87	-1.40	-3.11	0	3.41
03-Dec-87	-0.07	-1.91	0	2.52
04-Dec-87	-0.60	-5.50	0	6.79
05-Dec-87	1.31	-4.32	0	5.83
06-Dec-87	2.35	-8.25	0	8.15
07-Dec-87	1.61	-3.09	0	1.58
08-Dec-87	9.64	1.31	0	2.16
09-Dec-87	11.51	4.64	17	0.72
10-Dec-87	4.75	-0.10	0	2.29
11-Dec-87	4.59	-0.70	1	1.70
12-Dec-87	3.25	-0.15	5	1.62
13-Dec-87	0.82	-0.29	0	1.35
14-Dec-87	1.18	-0.74	0	2.63
15-Dec-87	2.13	-1.60	5	2.06
16-Dec-87	0.67	-1.16	0	3.30
17-Dec-87	-0.99	-3.58	0	2.40
18-Dec-87	-1.83	-5.70	0	3.57
19-Dec-87	1.33	-1.81	21	2.31
20-Dec-87	4.44	-0.54	2	1.18
21-Dec-87	3.57	-1.99	0	8.02
22-Dec-87	1.52	-0.35	3	2.69
1988				
16-Mar-88	-1.04	-2.87	0	6.78
17-Mar-88	3.72	-8.03	0	18.95
18-Mar-88	3.63	-3.07	0	10.66

19-Mar-88	1.39	-5.66	0	12.95
20-Mar-88	-3.24	-11.18	0	17.55
21-Mar-88	-1.49	-10.39	0	20.14
22-Mar-88	4.51	-6.45	0	16.02
23-Mar-88	19.22	0.41	0	16.12
24-Mar-88	7.41	-1.19	0	4.85
25-Mar-88	15.97	6.92	16	16.42
26-Mar-88	12.04	-1.42	0	12.48
27-Mar-88	2.66	-3.93	0	9.78
28-Mar-88	5.84	-4.85	1	4.72
29-Mar-88	14.09	5.73	96.99	5.27
30-Mar-88	8.52	-0.22	18	18.89
31-Mar-88	10.16	-2.82	0	15.92
01-Apr-88	12.77	-1.40	0	18.22
02-Apr-88	15.06	3.40	1	7.52
03-Apr-88	20.14	8.12	28	9.90
04-Apr-88	14.38	7.32	0	10.82
05-Apr-88	26.09	8.09	0	19.81
06-Apr-88	19.69	5.28	35	2.24
07-Apr-88	13.60	3.23	0	24.15
08-Apr-88	12.32	0.86	0	23.33
09-Apr-88	13.49	-1.84	0	23.60
10-Apr-88	16.62	0.33	0	23.08
11-Apr-88	14.86	4.24	0	21.58
12-Apr-88	15.93	0.00	0	24.44
13-Apr-88	18.07	1.56	0	18.05
14-Apr-88	13.19	1.11	4	11.17
15-Apr-88	2.34	-2.93	0	10.98
16-Apr-88	13.19	0.23	0	21.34
17-Apr-88	19.96	2.31	0	20.81
18-Apr-88	7.25	-1.53	0	23.94
19-Apr-88	7.75	-3.95	0	17.95
20-Apr-88	11.74	0.70	6	7.52
21-Apr-88	9.71	-3.03	0	24.08
22-Apr-88	12.57	-2.47	2	23.52
23-Apr-88	9.55	1.48	19	5.48
24-Apr-88	12.21	2.25	0	19.71
25-Apr-88	16.91	-1.70	0	23.66
26-Apr-88	14.15	6.05	0	18.88
27-Apr-88	7.03	2.89	1	8.40
28-Apr-88	11.59	2.27	1	11.14
29-Apr-88	14.83	1.84	0	17.83
30-Apr-88	20.60	1.58	0	26.07

APPENDIX F

OBSERVATION WELL WATER TABLE DEPTH READINGS

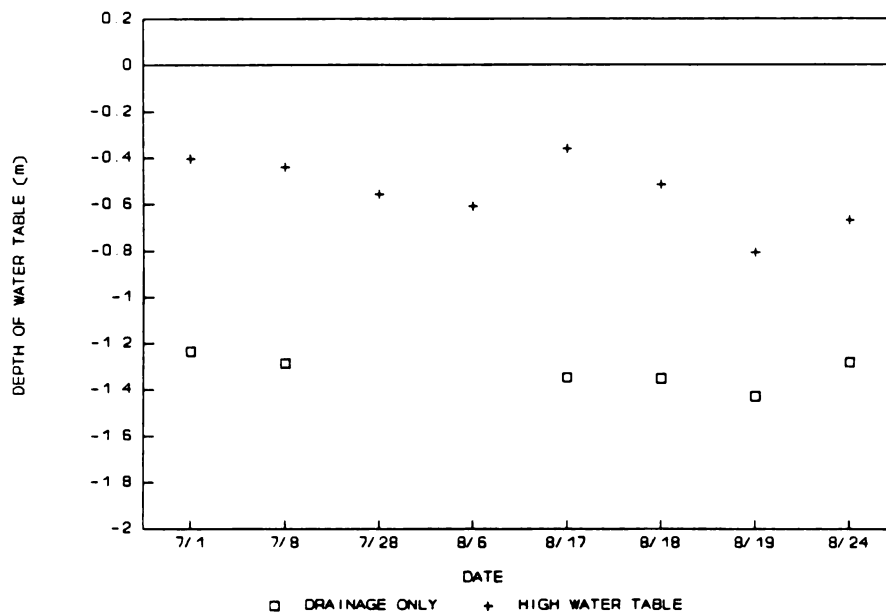


Figure 16. Observation well blow tube readings (depth to the water table from the ground surface) 1987.

APPENDIX G

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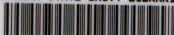
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