# 1997 PROJECT ABSTRACT

For the Period Ending June 30, 1999
This Project was supported by the MN Future Resource Fund.

**I. PROJECT TITLE:** REDUCING MINNESOTA RIVER POLLUTION FROM LACUSTRINE SOILS C-10

**PROJECT MANAGER:** Gerald F. Heil
**AFFILIATION:** Minnesota Department of Agriculture
**MAILING ADDRESS:** 90 West Plato Blvd.
St. Paul, MN 55107
**WEB PAGE ADDRESS:** http://farm-water.coafes.umn.edu/

**APPROPRIATION AMOUNT :** $250,000

**LEGAL CITATION**: ML 1997, [Chap. 216 ], Sec.[ 15 ], Subd 7 (e)

**Statement of Objectives:**

1. To evaluate the quantity and quality of snowmelt and rainfall runoff that enters surface tile inlets in lacustrine watersheds under a conservation tillage system (rotation of chisel and no tillage following corn and soybeans respectively) in the Minnesota River Basin.
2. Establishes the impact of farming systems utilizing crop residue for erosion control on lacustrine landscapes using rainfall simulation techniques.
3. Evaluate the crop yield of a conservation tillage system against the conventional approach (rotation of chisel-moldboard plow following soybeans and corn respectively).

**Overall Project Results**

Runoff, sediment, phosphorus, chemical-oxygen demanding materials, and nitrogen losses into surface tile inlets were low. Maximum annual runoff (28.0 mm) was less than 5% of annual precipitation. The maximum 3-yr cumulative pollutant losses were: 138 kg ha$^{-1}$ sediment, 20 kg ha$^{-1}$ Chemical oxygen demand, 363 g ha$^{-1}$ total P, 205 g ha$^{-1}$ dissolved molybdate reactive phosphorus, 1.3 kg ha$^{-1}$ total dissolved inorganic N and 1.1 kg ha$^{-1}$ nitrate-N. Ponding in the landscape after major storms reduced sediment losses and its associated particulate P and COD losses. Intensive-rainfall simulation indicated that maintaining surface residue cover above 10% (no till-chisel system) reduced pollutant losses in surface runoff compared to conventional system (chisel-moldboard) two to eight times. Using a crop residue system soybean yield was reduced 0.1 Mg ha$^{-1}$. There were no tillage effects on corn yield. This small soybean yield reduction is not economically significant. More data is needed to get a definitive answer to the economics question.

**Project Benefits for Minnesotans**

Minnesota will greatly benefit from this project. There has not been any successful direct measurement of pollutants entering surface tile inlets in the lacustrine landscape of southern Minnesota. The database provided by this project will allow for recommendations for southern

Minnesota soils, landscapes, and climate. This project will provide a crop residue management system that reduces erosion while providing a profitable alternative to the current approach.

**Project educational-outreach**: The educational dimension of this project directly reaches agricultural clientele such as farmers, crop consultants, and extension personnel. Through scientific publication and meetings, the education project also reached various national and international scientists.

**Data access, dissemination and extent of use:** Data can be accessed through the project web site (http://farm-water.coafes.umn.edu/). We think our project findings will be used widely because these data were presented to people responsible for advising farmers. This includes crop consultants as well as field staff of the University of Minnesota Extension Service, Natural Resource Conservation Service, Soil and Water Conservation Districts, and other interested advisors.

Dissemination of results was met through formal and informal meetings. Presentation and/or brochure or fact sheet distribution was done at many events such as: Tilney Farm field day on August 23 1997 and 1998 (See Appendix 4); At Farm Fest (see Appendix 5) we distributed fact sheets about residue management and erosion. Scientific presentation was made at the International Soil Conservation Organization (ISCO) meeting at Purdue University, May 1999. A paper has been published in the proceedings for this conference (See appendix 2). A presentation was made at the American Society of Agronomy meetings, Baltimore, Maryland, October 1998. Presentations were made at the West Central Research and Outreach Center, Morris, MN, March 1999. A presentation was made at the Rainfall Simulation Workshop, March 1999, in Nebraska. Also, the results have been accepted for publication in the peer reviewed Journal of Environmental Quality (See Appendix 1).

JUL 01 1999

# REDUCING MINNESOTA RIVER POLLUTION FROM LACUSTRINE SOILS C-10

## LCMR FINAL REPORT-DETAILED-RESEARCH

ML 1997, [Chap. 216], Sec. [15], Subd 7(e)

Department of Soil, Water and Climate
University of Minnesota

And

Minnesota Department of Agriculture

June 30, 1999

**Date of Report:** July 1, 1999

**LCMR Final Work Program Report**

**Date of Work program Approval:**

**Project Completion Date:** This continues a project started in the 1995-1997 biennium and recommended by the peer review to continue a minimum of 6 years (dependent on weather).

**LCMR Work Program 1997 - 1999**

## I. PROJECT TITLE: REDUCING MINNESOTA RIVER POLLUTION FROM LACUSTRINE SOILS C-10

**Project Manager:** Gerald F. Heil
**Affiliation:** Minnesota Department of Agriculture
**Mailing Address:** 90 West Plato Blvd.
St. Paul, MN 55107
**Telephone:** (612) 296-1486 FAX (612) 297-7678
**Web Page Address:** http://farm-water.coafes.umn.edu/

**Total Biennial Project Budget:**

| | |
|---|---|
| **$ LCMR:** | $250,000 |
| **-$LCMR Amount Spent:** | $250,000 |
| **=$LCMR Balance:** | $ 0 |

**A. Legal Citation: ML 1997, [Chap. 216 ], Sec.[ 15 ], Subd 7 (e)**

**Appropriation Language**: REDUCING MINNESOTA RIVER POLLUTION FROM LACUSTRINE SOILS. This appropriation is from the future resources fund to the commissioner of agriculture in cooperation with the University of Minnesota for the second biennium to research the impact of farming systems utilizing crop residue for sediment control on lacustrine landscapes in the Minnesota River Basin.

**II. PROJECT SUMMARY AND RESULTS:** Lacustrine soils formed in sediments from glacial lakes. These soils have a high proportion of clay and are flat, resulting in poor surface and internal drainage. Even though they have little slope, river water monitoring data implicates this type of landscape or agroecoregion as a potentially significant contributor to sediment in the Minnesota River. A major strategy being recommended to reduce potential sedimentation is to increase the practice of conservation tillage on these soils. However, the recommendation to leave crop residues on the soil to reduce runoff losses is untested for effectiveness or economic risk on these landscapes and soils. During the 1995-1997 biennium a baseline of data was established to provide the basis of the analysis.

This research and educational program is designed to evaluate these practices using a paired watershed technique and to disseminate the information through existing educational vehicles. Monitoring of runoff losses (snow melt and rain runoff) will be continued on a pair of watersheds in south central Minnesota that are about 100 hectares in size and cropped with corn and soybeans.

In an attempt to evaluate the profitability of improved farming systems, replicated strips with conventional and an improved approach utilizing crop residues to control erosion will be compared. Crop response and yields as well as accounting of inputs will provide a comparison of profitability. These data in conjunction with the runoff data on the paired watersheds will allow determination of a cost per unit pollutant. This will be used in educational programs throughout the Minnesota River Basin in areas with similar agroecoregions.

The budget is primarily for personnel. Most of the equipment needed to complete the project was purchased during the 1995-1997 biennium. The Post Doctoral Research Associate has overall responsibility for this project. It is his responsibility to see that: samples are retrieved and analyzed in a timely fashion, equipment is maintained and works properly, and the data are organized for interpretation and reporting.

The Scientist on this project is responsible for the data acquisition hardware and software. This project necessitates remotely monitoring runoff events at a time resolution of minutes with a system that is custom tailored for this application. We are doing this with a combination of commercially available data loggers and associated hardware as well as “in house” developed hardware and software. The Scientist on this project is responsible for the development and maintenance of the data acquisition system.

The Research Fellow is responsible for the laboratory analysis of water, soil, and plant tissue samples. A water quality laboratory is equipped to run biochemical oxygen demand, chemical oxygen demand, soluble P, total P, bio-available P, total suspended solids, ammonium, nitrate, and soil test P. This person will be responsible for logging in samples and completing a suite of chemical analysis to assess the impact of the measured runoff as well as the crop response to the changed management. The undergraduate staff on this study will assist in preparing samples for analysis, the physical and chemical characterization of the watersheds, and data processing. This project addresses the question: What is the economic risk and environmental impact of farming systems that utilize crop residues to reduce contaminant losses to surface tile inlets on lacustrine soils?

This project is being done on a rather large scale with cooperation of farmers. They will assist in establishment of conventional and alternative farming systems on fields, which have 90-130 ha watersheds under monitoring. The producers will also establish randomized and replicated tillage strips about 1km x 27m in size to evaluate the economic risk from a statistical approach. They will be compensated for their input, assistance, and economic risk. Product delivery depends on the frequency of runoff events.

## III. PROGRESS SUMMARY:

Paired watershed study: Collection of runoff samples and chemical analysis for phosphorus, nitrogen, and oxygen demand were done. Snow depth and density were measured. Rainfall simulation was conducted on three replications of tillage strips in June 1997 and June 1998. Runoff measurements, analysis of runoff for sediment, P, N, and COD were accomplished.

Profitability study: Soybean and corn from strips of two tillage treatments were harvested in October 1997 and November 1998, respectively. . Statistical analysis was done on yield data collected with weigh wagons. Soybean and corn yield maps were generated using yield data from a combine equipped with a GPS/GIS system.

## IV. OUTLINE OF PROJECT RESULTS:

Result 1

A. Interpretation of baseline data $0

In order to use a paired watershed technique the relationship of the response to runoff losses between two similar watersheds managed the same must be established before introducing a different management regime to the experimental watershed. This is called baseline data. We will take the data collected during the first biennium and develop equations that describe the relationship between the two watersheds in response to runoff events such as snowmelt or rainfall. This will require data screening, merging of files, and organization for equation development. It will be completed after the first quarter.

A **mathematical function** that describes the relationship between the watershed pairs in response to runoff events will be developed.

B. Upgrade the data acquisition systems $0

Upgraded systems are used to monitor pollutant losses to make them more reliable and collect a wider array of data. Although there are many precipitation (snow and rain) events annually only a handful result in runoff. Of those, one or two large ones are often responsible for most of the runoff and loss of pollutants. We have had transducers and sensors fail on occasion and have lost data. We would like to make the systems more reliable by building in redundancy where appropriate so if one system fails there will be a backup which can be used also as a cross check. We would also like to install additional data loggers that are more flexible than the ones that we currently have in place (the manufacturer prohibits altering the computer code to accommodate our rather unique application). This would also allow us to install additional sensors and grab samplers to characterize runoff events in more detail. Our data have shown that there is large differences in concentration of various pollutants that get delivered to the ponding area around surface tile inlets and what actually enters the tile system and surface waters.

Time line

| Activity | Completion Date |
|---|---|
| Organize data files into proper format and screen for outliers | September 1997 |
| Develop regression equations to establish runoff response relationship between watersheds. | January 1, 1998 |
| Upgrade data acquisition hardware | June 30, 1999 |

Status:

We have developed regression equations to establish the runoff response relationship between watersheds for snowmelt runoff. Due to the small number of snowmelt and rainfall runoff during the 1997-1999 biennium the relationship between the two watersheds was not improved very much.

For current work (see Result 2 of this report) and future work, when climatic parameters are different between two watersheds during collection of baseline data, the watersheds should be treated as replications. By doing so, ranges of values of runoff and pollutant losses are derived. This will give an idea how lacustrine watersheds respond to different precipitation. The emphasis is shifted from "comparing two management systems at the same climatic parameters", which is hard to control to "evaluating specific management systems at various climatic parameters". As in this project, to be able to compare two management systems at the same climatic regime, additional runoff simulations are necessary (see Result 3). Runoff simulation is done under intense simulated rainfall to simulate the rare storms that will result in most of the pollution over a period of time. A comparison of the residue management effects from simulated precipitation can be used with the value from the watersheds (provided one residue management in the rainfall simulation matches that in the existing watershed) to estimate the effectiveness of the residue management system on a larger scale.

We have upgraded data acquisition systems.

Result 2

| | |
|---|---|
| A. Continue existing watersheds | $0 |

This will require the most effort over the entire biennium. The data retrieval systems must be maintained and the data stream sustained. They will be upgraded to facilitate data acquisition. Chemical analysis needs to be performed on samples as they are collected and data files created. The data needs to be continually screened, organized, and added to the database. Ultimately the weather will determine the total amount of runoff events and associated data. If the analysis of the data in Result 1 show that the baseline relationship has been sufficiently established between the paired watershed, then the improved farming system will be imposed on one of them.

The result of this activity will be the expanded database.

B. Upgrade the data acquisition systems $0

Upgraded system is used to monitor pollutant losses to make them more reliable and collect a wider array of data. Although there are many precipitation (snow and rain) events annually only a handful result in runoff. Of those, one or two large ones are often responsible for most of the runoff and loss of pollutants. We have had transducers and sensors fail on occasion and have lost data. We would like to make the systems more reliable by building in redundancy where appropriate so if one system fails there will be a backup which can be used also as a cross check. We would also like to install additional data loggers that are more flexible than the ones that we currently have in place (the manufacturer prohibits altering the computer code to accommodate our rather unique application). This would also allow us to install additional sensors and grab samplers to characterize runoff events in more detail. Our data have shown that there is large differences in concentration of various pollutants that get delivered to the ponding area around surface tile inlets and what actually enters the tile system and surface waters.

Time line

| Activity | Completion Date |
|---|---|
| Collect runoff samples for chemical analysis | December 31, 1999[1] |
| Download runoff data and organize for addition to the database | December 31, 1999[1] |
| Upgrade current data acquisition systems | June 30, 1999[1] |

[1] This is the second biennium of a three biennium project. This activity will be maintained the year around to allow monitoring of snow melt and rainfall runoff. A final report for this will be submitted at the end of this biennium. This activity will extend into the next biennium however.

Status:

We have continued to collect data. We have also reorganized the data collected in 1996, 1997, and 1998 for a more comprehensive summary of this project. Runoff, sediment, phosphorus, chemical-oxygen demanding materials, and nitrogen losses into surface tile inlets were low. Maximum annual runoff (28.0 mm) was less than 5% of annual precipitation. The 3-yr cumulative pollutant losses were: 138 kg $ha^{-1}$ sediment, 20 kg $ha^{-1}$ Chemical oxygen demand, 363 g $ha^{-1}$ total P, 205 g $ha^{-1}$ dissolved molybdate reactive phosphorus, 1.3 kg $ha^{-1}$ total dissolved inorganic N and 1.1 kg $ha^{-1}$ nitrate-N.

Most of the runoff and pollutant losses were due to two sequential rainfalls on 20-22 July 1997 for one of the watersheds. Details are presented in Appendix 1. The significance of the findings is: even during the rare scenario of heavy rainfall events (the main culprit for pollutant losses), conservation tillage for residue management (no till after soybeans and chisel plowing after corn) in lacustrine landscapes of Southern Minnesota resulted in small losses of pollutants. Temporary ponding due to the landscape features (gentle slope and concave shape) helps to reduce sediment and associated particulate pollutants from entering tile inlets.

We have upgraded the monitoring system.

Result 3 - Evaluate profitability of conservation systems $0

A. The products from Results 1 and 2 deal with the evaluation of improved farming systems on the reduction of diffuse source losses of potential pollutants. This establishes one side of the new technology adoption equation. That is: how environmentally effective are the alternative farming systems? The other side of the equation deals with the effect of the alternative systems on profitability. For any alternative to be acceptable it must be at least as profitable as the current conventional practice. Since crop yields and inputs usually drive the economics of any farming system, the effect of the alternative farming system on these is established in Result 3. This will be done with replicated, randomized strips about 1000 x 90 feet in size. Yields will be measured and inputs tallied. There will be six replications. There are soils that have developed in lacustrine and glacial till materials in this field. A yield monitor will be installed on the co-operators combine. This will allow quantification of the interaction between tillage and soil type or position on the landscape. Over the life of this project crop response will be evaluated over a range in climatic variability.

This activity will provide an evaluation of the profitability of the alternative farming systems on differing soils, landscapes, and climate.

B. Enhance our outreach and data processing efforts. $0

We are excited about our findings so far and want to reach a larger audience. We have held annual field tours and created printed media to get our data out to interested people. This approach is limited in the number of people that we can reach. We are proposing to develop a web site dedicated to getting our findings out to a world wide audience and also enhance our Minnesota outreach effort. We will develop a site that pictorially shows major runoff events during different periods of the year. We will also highlight data with graphs and tables. We will use animation to introduce readers to the paired watershed technique and show specific results. We will also incorporate information from other similar LCMR funded projects to provide a comprehensive site addressing agricultural practices and water quality. We will provide links to academic departments at the University of MN, the MN Department of Agriculture, the MPCA, the LCMR, and others.

Time line

| Activity | Completion Date |
|---|---|
| Establish tillage treatments being evaluated | December 31, 1997[1] |
| Characterize the crop response including final grain yield by soil | December 31, 1998[1] |
| Reestablish tillage treatments being evaluated | December 31, 1998[1] |
| Characterize the crop response including final grain yield by soil | December 31, 1999[1] |
| Develop web site to disseminate project results | June 30, 1999 |

[1] This is the second biennium of a three biennium project. A final report for this will be submitted at the end of this biennium. This activity will extend into the next biennium however to allow evaluation over a range in climatic conditions.

Status:

The evaluation of profitability and water quality effects of the two tillage systems i.e., the conservation (rotation of no till-after beans and chisel plowing after corn) and conventional systems (chisel after soybean and moldboard after corn) has been done. Both tillage systems were evaluated on strips about 1 km long and 27m wide and replicated 6 times. Statistical analysis indicated that soybean yield in 1997 under the conventional tillage system was 0.1 Mg ha$^{-1}$ higher than conservation tillage system. Corn yield in 1998 was similar between both tillage systems (See Appendix 3). Overlain maps of soil type and crop yield indicated that soil and landscape position (not soil type) had greater effects on soybean yield in 1997. In 1998, the landscape and soil type effects were not significantly visible on corn yield.

Rainfall simulation was done in 1997 and 1998. In both years, there were on average of 3 times higher residue cover in the conservation tillage system than conventional tillage system. In each tillage-strip, 7m by 1m runoff plots were prepared with corrugated metal borders and collection troughs. Using a rain machine, we applied rainfall at the rate of 6.25cm hr$^{-1}$ until steady state runoff measurements were obtained. Details of procedures and results are presented in Appendix 2. The conservation tillage system produced much lower pollutants in runoff compared to moldboard-plow-based system. The amount of sediment loss for 10cm of water was eight times and five times higher in the conventional tillage system in 1997 and 1998, respectively. A similar trend was observed for other pollutant losses.

The significance of this finding is that during wet years, when intensive storms occur, the conservation tillage system consistently reduces runoff and pollutant losses from farm fields on these landscapes. Environmental benefits of residue management system are great but there may be a slight risk of lower yields. In our study the yield reduction was so small that it was not economically significant. It was offset by the reduced inputs associated with the residue management system. To determine a more quantitative risk assessment of yield performance, long-term data are needed.

We have developed a web site to get our results out. The address is http://farm-water.coafes.umn.edu/. A detailed pictorial summary of this project and similar LCMR projects can be found at this site. We have also included several of the lay publications developed with information from this project in the appendix.

**V. DISSEMINATION:** Results will be disseminated through the Web Page, publications, and field tours. The in-place programmatic network of Minnesota Extension Service, Soil and Water Conservation District, and Natural Resource Conservation Service will be relied on heavily for information dissemination.

## VI. CONTEXT:

### Significance:

The Minnesota Department of Agriculture in cooperation with the University of Minnesota is developing a plan to implement best management practices that will mitigate or prevent agriculture sources of non-point source (NPS) pollution in the Minnesota River Basin. This plan includes a review of the recommendations of both the Minnesota River Assessment Project (MRAP) and Minnesota River Citizens Advisory Committee (CAC) Report, as well as an extensive review of the available research and literature on agriculture practices. As part of the assessment, the University of Minnesota was asked to identify areas or gaps where critical research was needed but not available. It was found that there is no research that establishes the impact of farming systems utilizing crop residue for sediment control on lacustrine landscapes which represent about 20% of the Minnesota River Basin. Also of concern is the fact that there is no research evaluating the economic risks of these farming approaches.

There has been much uncertainty concerning the relative contribution of sediment to the Minnesota River by soils developed in flat lacustrine sediments with poor internal drainage. These fields are usually tiled with surface and subsurface tile. Based on river water monitoring data, this type of landscape and soil or agroecoregion has been implicated as a significant contributor to the degradation of the Minnesota River. There is an equal amount of uncertainty surrounding the benefits of crop residue and manure management approaches on these soils to control these losses.

Farmers are being asked to adopt crop residue management systems in order to reduce or prevent pollutant discharges in the Minnesota River Basin. In regard to lacustrine landscapes and soils, recommendations to leave crop residues on the soil to reduce runoff losses are untested and have unproven environmental benefits. Such residue management systems carry significant economic risks for producers and need to be evaluated.

This research and educational program is designed to evaluate these practices using a paired watershed technique; scientifically evaluate economic risks; and disseminate the information through existing educational vehicles. Focus groups research conducted by the University of Minnesota and the Minnesota Department of Agriculture, as well as the conclusions of the Minnesota River Agriculture Team emphasize the need for this type of project to develop sound recommendations for these critical areas in the Minnesota River Basin.

**B. Time:** This project began in the 1995-1997 biennium and will continue for at least two more biennia.

**C. Budget Context:**

| | **July 1995- June 1997 Prior expenditures on this project** | **July 1997- June 1999 Proposed expenditures on this project** | **July 1999- June 2001 Anticipated future expenditures on this project** |
|---|---|---|---|
| **1. LCMR** | $100,000 | $250,000 | $250,000 |
| **2. Other State** | $ | $ | $ |
| **3. Non state cash** | $ | $ | $ |
| **Total** | $ | $ | $ |

**VII. COOPERATION:**

A. **Dr. Satish C. Gupta**, faculty, Soil, Water, and Climate Department, UM; 0 LCMR dollars, 5% time on project.

B. **Dr. John F. Moncrief**,faculty, Soil, Water, and Climate Department, UM; 0 LCMR dollars, 5% time on project.

C. **Dr. Daniel Ginting**, Post Doctoral Research Associate, Soil, Water, and Climate Department, UM; 100% LCMR dollars, 100% time on project.

D. **Dr. Mary J. Hanks**, Supervisor, Energy and Sustainable Agriculture Program, Minnesota Department of Agriculture; 0 LCMR dollars, 2% time on project.

E. **Mr. Gerald F. Heil**, Director, Agricultural Marketing and Development Division, Minnesota Department of Agriculture; 0 LCMR dollars, 5% time on project.

F. **Mr. Mark R. Zumwinkle**, Agricultural Development Specialist, Minnesota Department of Agriculture; 0 LCMR dollars, 5% time on project.

G. **Mr. Tom M.Urevig**, Manager, Tilney Farms, Lewisville, MN; 0 LCMR dollars, 3% time on project.

H. **Mr Joe Metz**, Foreman, Tilney Farms, Lewisville, MN; 0 LCMR dollars, 3% time on project.

**Mr. Chuck Davis**, Farm Worker, Tilney Farms, Lewisville, MN; 0 LCMR dollars, 3% time on project.

**VIII. LOCATION:** Research is near Lewisville, MN; the educational effort will be focused in the southern half of MN.

**IX. REPORTING REQUIREMENTS:** Periodic Work Program Progress Reports will be submitted not later than March 1 of each year. This will allow time for a final Work Program report and associated products to be submitted by June 30, 1999, or by the completion data as set in the appropriation.

**RESEARCH PROJECTS:** See addendum

# APPENDICES

# Runoff, Sediment, and Nutrient Delivery to Surface Tile Inlets with Conservation Tillage

**D. Ginting*, J.F. Moncrief, and S.C. Gupta**

---

D. Ginting, J.F. Moncrief, and S.C. Gupta, Dep. of Soil, Water, and Climate, Univ. of Minnesota, 1991 Upper Buford Circle, St. Paul, MN. *Corresponding author (dginting@soils.umn.edu).

## ABSTRACT

Surface tile inlets connected to subsurface tile lines provide a short cut for pollutants to enter water bodies. Losses of runoff, total solids (TS), and nutrients entering surface tile-inlets in two lacustrine watersheds of the Minnesota River Basin from 1995 to 1998 were evaluated. Tillage and crop rotations were: in the fall no tillage after soybean [*Glycine max* (L.)] or navy bean (*Phaseolus vulgaris*) and chisel plowing after corn [*Zea mays* (L.)]. Tillage operations during the growing season were spring field cultivation, planting, harrowing, and row cultivation. Over six watershed-years, maximum annual runoff (28.0 mm) was less than 5% of annual precipitation. Flow-weighted total P (TP) concentration ranged from 0.2 to 2.9 mg $L^{-1}$ in snowmelt and from 0.7 to 6.5 mg $L^{-1}$ in rainfall runoff. Concentrations of nitrate-N in snowmelt and rainfall runoff were lower than 10 mg $L^{-1}$. Prolonged ponding after major storms reduced particulate P and COD losses through the surface tile inlets. Ponding, however, increased dissolved molybdate reactive P (DMRP) losses through surface tile inlets. Total solid losses were predominantly of clay-size soil aggregates. Based on 3-yr data, the maximum cumulative pollutant losses were: 138 kg $ha^{-1}$ TS, 20 kg $ha^{-1}$ COD, 363 g $ha^{-1}$ TP, 205 g $ha^{-1}$ DMRP, 1.3 kg $ha^{-1}$ total dissolved inorganic N and 1.1 kg $ha^{-1}$ nitrate-N. No tillage after beans and chisel plowing after corn is an effective tillage system for low losses of sediment and nutrients from lacustrine landscapes.

**Abbreviations:** TS, total solids; COD, chemical oxygen demand; TP, total phosphorus; PP, particulate phosphorus; DMRP, dissolved molybdate reactive phosphorus; TDIN, total dissolved inorganic nitrogen; W20, watershed with 20-cm internal diameter inlet; W15, watershed with 15-cm internal diameter inlet; ER, enrichment ratio; PVC, polyvinyl chloride.

## INTRODUCTION

Economic studies of drainage by Schwab et al. (1966) in Ohio, and Leitch and Kerestes (1981) in Minnesota concluded that land drainage is synonymous with increased agricultural production. Schwab et al. (1966) reported that the benefit/cost ratio for surface drains, pattern tile, and the combination of pattern tile and surface drains was 10:1, 6:1, and 4:1, respectively. Leitch and Kerestes (1981) showed that benefit/cost ratio (after taxes) of subsurface tile drainage was 1.6 in south central Minnesota. However, these studies ignored the environmental impacts of tiling on ground and surface waters. Tiling short cuts the nitrate-N pathway from farm to waterways and rivers. Despite some advantages of soil drainage in reducing erosion and phosphorus loss by surface runoff (Bengtson et al., 1984), many authors (Drury et al., 1996; Kladivko et al., 1991) have reported significant nitrate-N leaching through tile drainage.

Frequently subsurface tile alone is not enough to rapidly drain snowmelt and rainfall runoff for timely crop planting or to prevent crop damage due to excessive soil moisture. Therefore, surface tile inlets are installed that quickly drain surface runoff into subsurface tile lines. Without surface inlets subsurface tile lines deliver mostly nitrate-N (Drury, 1993, Kladivko et al., 1991). Due to filtration by soil, negligible amounts of sediment, P, and K (Kladivko et al., 1991, Bengtson et al., 1984) are transported in subsurface tile lines. With surface tile inlets, however, other non-point source pollutants such as suspended sediment, nutrients, and chemical oxygen demanding materials enter subsurface tile lines directly without filtration by soil. The direct entry of suspended sediment, nutrients, and chemical oxygen demanding materials through surface tile inlets have raised some water quality concerns.

The predominantly lacustrine landscapes in the Blue Earth River basin have been reported as a major contributor of sediment and phosphorus into the Minnesota River. It has been reasoned that soil erosion on the landscape and the direct entry of surface runoff, solids, and nutrients into surface tile are responsible for a large portion of the water quality problem. A promising solution to reduce runoff and erosion in lacustrine landscape is crop residue management to reduce the water and associated contaminants that are delivered to the inlet. However, there was lack of field data on how residue management and the influence of water ponding will affect the quantity and quality of runoff and pollutants entering surface tile inlets. The objective of this study was to evaluate the quantity and quality of snowmelt and rainfall runoff that enters surface tile inlets in lacustrine watersheds under a conservation tillage system in the Minnesota River Basin.

## MATERIALS AND METHODS

### Site and Watershed Characteristics

Figure 1 shows the topography of two selected watersheds in a lacustrine landscape of South Central Minnesota. Both watersheds have subsurface pattern tile and are connected to surface tile inlets in local depressions. The watersheds are labeled as W20 (44.3 ha) and W15 (51.7 ha). The watershed identification number refers to the size of the tile inlet. Watershed W20 drains to a 20-cm internal diameter surface tile inlet and watershed W15 drains into two 15-cm internal-diameter surface tile inlets. Watershed W15 is naturally divided by saddle topography into east sub-watershed (13.2 ha) and west sub-watersheds (38.5 ha). Each sub-watershed has its own 15-cm diameter surface inlet.

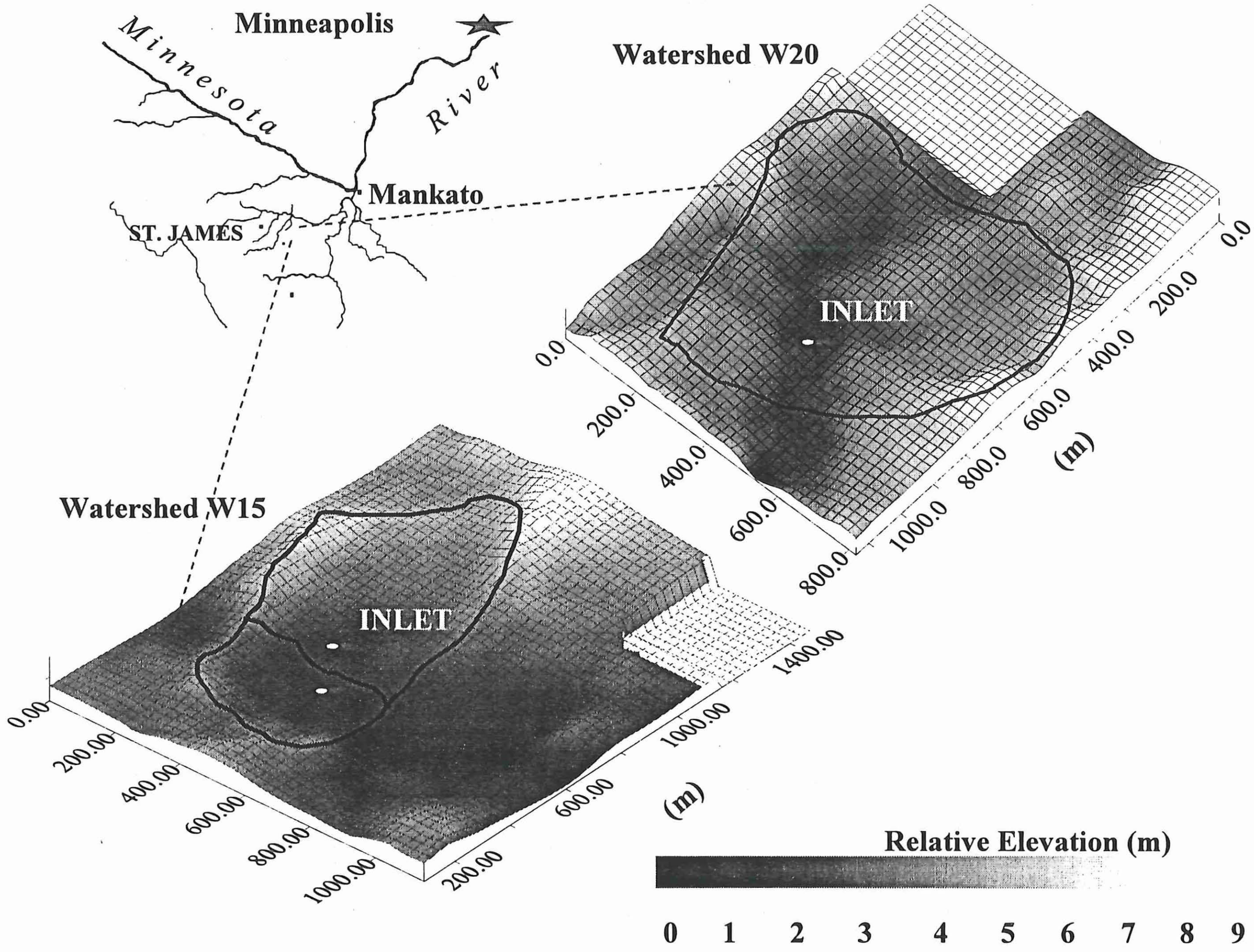


Fig. 1. Topographical representation and location of watersheds in the Minnesota River Basin.

Watersheds are gently rolling and characterized by concave hill-slopes and local depressions. Excess water from rainfall and snowmelt drains into these local depressions. The soil in the watersheds have developed predominantly in lacustrine sediments from Glacial Lake Minnesota in the Watonwan River Watershed, a part of the Blue Earth River sub-basin within the Minnesota River Basin. In the Minnesota River Basin, lacustrine soils comprise about 25% of the area and are very poorly drained.

Based on the Watonwan county, MN soil survey (USDA-SCS, 1992), the predominant soils in W20 are Madelia silty clay loam (Typic Haplaquolls) and Spicer silty clay loam (Typic Haplaquolls). Both these soils are developed in low-lying areas on lake plains. Other soils of smaller extent are Kingston silty clay loam (Aquic Hapludolls, low rises on lake plains), Clarion loam (Typic Haplaudolls, 1 to 4 % slopes, knolls and side slopes on till plains), Okoboji silty clay loam (Cumulic Haplaquolls, closed depression on till plains), Nicollet loam (Aquic Hapludolls, low rises on till plains), Truman silt loam (Typic Hapludolls, 1 to 4 % slopes, rises on lake plains), and Waldorf silty clay loam (Typic Haplaquolls, low-lying flats on lake plains). In October 1995, soil pH ranged from 6.3 to 6.8, Olsen-P from 22 to 23 mg kg$^{-1}$, and potassium from 127 to 139 mg kg$^{-1}$. These Olsen-P and potassium levels were high.

The predominant soil in W15 is Spicer silty clay loam. Other soils of smaller extent are Estherville (Typic Hapludolls, rims of depression and low flats on till plains and outwash plains), Crippin loam (Aquic Hapludolls, low rises on till plains), Fieldon (Typic Haplaquolls, closed depression on till plain), Canisteo (Typic Haplaquolls, flat areas and rims of depression on till plains), and Glencoe clay loam (Cumulic Haplaquolls, closed depressions on till plains). In

October 1995, soil pH ranged from 7.5 to 7.6, Olsen-P from15 to 27 mg $kg^{-1}$, and potassium from 106 to 133 mg $kg^{-1}$. This Olsen-P level was high and the potassium level was medium-high.

## Instrumentation

Runoff volume was measured using an ISCO[1] area-velocity sensor. This flow sensor consists of a Doppler-based velocity sensor and transducer-based water depth sensor. The velocity sensor transmits a high frequency sound wave into the flow and then detects the frequencies of the reflected sound waves. These reflected frequencies are related to the velocity in the flow stream at which the reflections occurred. The sensor is capable of measuring bi-directional flow, therefore back-flow can be detected. A flow data logger, connected to the flow sensor, processes the reflected frequencies to determine the average velocity in the flow stream. At the same time, the data logger calculates the cross sectional area of the flowing water from the water depth in the pipe. The data logger also registers the flow rate, which is flow area times velocity.

A tipping-bucket rain gage connected to the data logger recorded rainfall at 10-min intervals. Runoff water temperature was measured using a Hobo[1] temperature sensor and logger. The temperature sensor was placed downstream of the area-velocity sensor. Hourly water

---

[1] Mentioned of a product by name by the university of Minnesota does not imply endorsement of this product over similar products.

temperatures recorded during winter were used to determine whether the pressure detected by the water level sensor was due to snowmelt runoff or ice pressure.

Runoff samples were taken with an ISCO[1] 24 bottle sampler connected to the flow data logger. A suction line from the sampler was placed downstream of the flow sensor. The flow data logger sends a pulse signal to the sampler when the water level was greater than 2.5 cm for 2 min. Sampling was triggered when the water level was 2.5 cm deep to avoid air entry during sampling. For every six pulses received, the sampler took a 9 mL sub-sample. In each bottle a total of 10 sub-samples were collected.

Equipment was powered by three deep cycle 12 volt batteries continuously charged by a 20-W solar panel. Flow data loggers, sampler, and batteries were placed in a custom made housing 1 m away from the tile inlets. The housing was made of treated wood and consisted of a platform and equipment enclosure. The platform was 1.5 m above the ground to avoid inundation of equipment during a high rainfall or snowmelt.

A sloping trench was dug to give the 20.3-cm diameter polyvinyl chloride (PVC) pipe a 4% slope towards surface tile inlets. The PVC pipe was then connected to a T-shaped fitting which in turn was connected to the surface tile inlet with a 90-degree PVC elbow. The velocity sensor was secured to the bottom at the downstream end of the 2.5 m long PVC pipe. This was done to allow a more stable flow to the area-velocity sensor. The T-shaped fitting was used to allow access to the flow logger, temperature sensor cables, and sampler suction tube. Temperature-sensor cable and suction tube from the sampler were placed 20 cm downstream of the velocity sensor. Through the opening of the T-fitting, the sensor could be detached from the pipe bottom for maintenance. Except during maintenance, the opening of the T-fitting remained shut. Figure 2 shows a schematic representation of piping and instrumentation inside the wooden housing.

### Tillage and Cropping

Both watersheds were under a corn and bean rotation. Watershed W20 was cropped to soybean in 1995. Tillage related field operations in subsequent years were: no-till after soybean harvest in Oct. 1995, and injection of 157 kg $NH_3$-N $ha^{-1}$ on 9 Nov. 1995; field cultivation on 18 - 21 May 1996, corn planting on 18 - 21 May 1996, first row-cultivation on 12 - 15 June 1996, the second row cultivation on 6 - 8 July 1996, corn harvest in Oct. 1996, and chisel plowing in Nov. 1996; field cultivation on 15 May 1997, navy bean planting on 15 - 16 May 1997, harrowing on 16 May 1997, rotary hoeing on 10 June 1997, the first row cultivation on 1 July 1997, the second row cultivation on 15 July 1997, navy bean harvest on 26 Sep. 1997, and injection of 150 kg $NH_3$-N $ha^{-1}$ on 31 Oct. - 1 Nov. 1997; field cultivation on 21 - 22 Apr. 1998, corn planting on 22 Apr. 1998, harrowing on 4 May 1998, rotary hoeing on 18 May 1998, row cultivation on 4 June 1998, corn harvest on 5 - 8 Nov. 1998, and chisel plowing on 20 - 22 Nov. 1998.

Watershed W15 was also under a corn and bean rotation. The watershed was cropped to soybean in 1995. Tillage related operations in subsequent years were: no tillage after soybean harvest in Oct. 1995 and injection of 130 kg $NH_3$-N $ha^{-1}$ on 7 - 8 Nov 1995; field cultivation on 12 - 17 May 1996, corn planting on 12-18 May 1996, harrowing on 22 May 1996, the first row-cultivation on 8 - 12 June 1996, the second row cultivation on 3 - 6 July 1996, corn harvest in October 1996 and chisel plowing on Nov. 1996; field cultivation on 6 to 10 May 1997, soybean bean planting on 6 - 11 May 1997, harrowing on 10 - 12 May 1997, rotary hoeing on 5 - 6 June

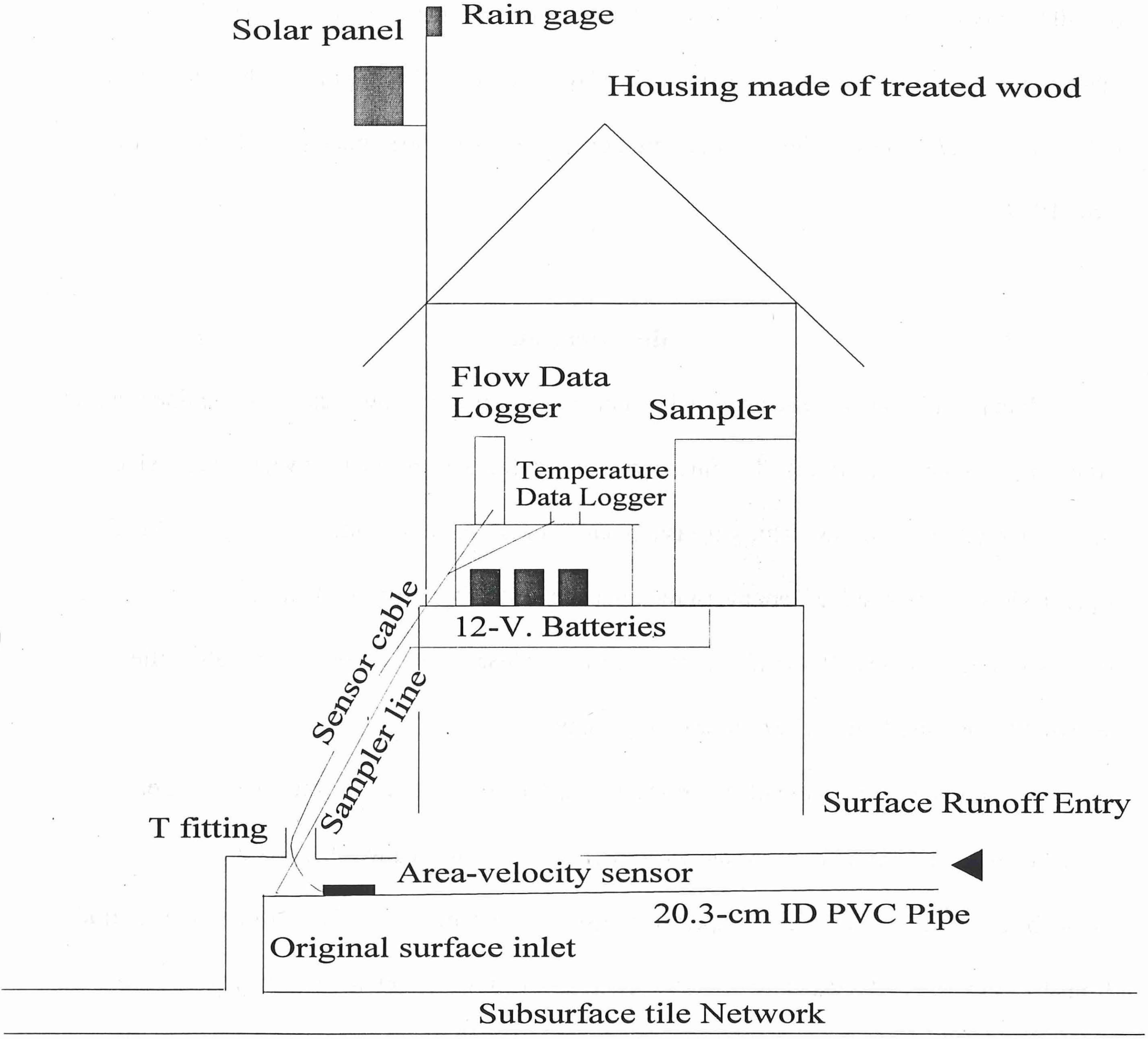


Fig. 2. Schematic diagram of surface inlet, piping, instrumentation and housing.

1997, row cultivation on 2 - 3 July 1997, soybean harvest on 29 Sep - 9 Oct. 1997, and injection of 140 kg $NH_3$-N $ha^{-1}$ on 10 and 12 Nov. 1997; field cultivation on 17 - 18 Apr. 1998, corn planting on 17 - 20 Apr. 1998, harrowing on 1 May 1998, rotary hoeing on 17 May 1998, row cultivation on 27 - 30 May 1998, corn harvest on 24 - 31 Oct. 1998, and chisel plowing on 1 - 6 Nov. 1998.

## Measurements

Plant residue cover was measured diagonally over the interrow area using the line transect procedure (Laflen et al., 1981). The interrow area is defined as the area between 10 cm wide strips centered over the row. Thirty measurements of residue were made at each date. On 25 April 1996 soybean residue were measured after snowmelt (before corn planting). Corn residue was measured on 4 Nov. 1996 (after corn harvest and chisel plowing), on 7 Apr. 1997 (after snowmelt), and on 26 June 1997 (after rotary hoeing).

Rainfall data on ten minute intervals were gathered from the rain gage at each site. Snowfall and temperature data during winter were gathered from a weather station at Winnebago, MN, 20 km from the experimental sites. The winter period is defined as the period from 1 November to 31 March of the next year. Normal (30-yr average) monthly rainfall from Winnebago was used as a reference for in situ rainfall data. In 1995-1996 no in-situ snow depth measurements were taken. In winter of 1996-1997 and 1997-1998, snow depth (water equivalent) was measured with a meter stick at 25 points along a 0.6 km transect in W20 and 1.1 km transect in W15. Snow density measurements were taken with a steel ring, 3 mm thick, 33 cm in diameter and 35 cm in height. The steel ring was gently pushed into the snow with a turning motion to avoid compaction until it hit the soil surface. At this point, snow was emptied to a pre-weighed plastic bag. The ring was pulled gently out and snow depth was measured. The snow was then weighed in the laboratory for snow density calculations.

During continuous runoff events, bottles of runoff samples were collected from the ISCO sampler daily and brought to the laboratory for solids, P, N, and COD analysis. Total solid concentrations were measured by evaporating 200 mL of runoff suspension at 105 °C. For selected major rainfall runoff events we measured aggregate size distribution of suspended solids as described by the sedimentation procedure of Nibling et al. (1983).

Runoff total P (TP) concentration was measured in a 20 mL aliquot of homogenized runoff suspension using the perchloric acid digestion technique as described by USEPA (1981) and Olsen and Sommers (1982). Dissolved molybdate reactive P (DMRP) concentration was measured in a 20 mL aliquot after filtering the runoff suspension through a 0.45-µm pore membrane. The DMRP was determined without acid predigestion. Runoff suspension particulate P (PP) concentration was determined by difference between TP and DMRP concentrations. All phosphorus fractions were determined with the ascorbic acid method of Murphy and Riley (1962).

Dissolved inorganic-N and ammonium-N concentration in the runoff suspension were determined using the conductimetric method (Carlson, 1978; and Carlson, 1983). Nitrate-N was determined by difference between total dissolved inorganic N (TDIN) and ammonium N.

Chemical oxygen demand (COD) of runoff was determined by chemical oxidation of runoff suspension as described by USEPA (1979). Soil COD is the soil oxidizable-carbon, which was derived from total soil organic carbon by assuming that 76% of the soil total organic carbon is oxidizable carbon (Walkley and Black, 1934).

In April 1998, before any field operations in the watershed, eight composite-samples were taken from 0- to 3-cm depth from the area away from the ponded depression around the surface tile inlets. Soil TP was determined after digestion with perchloric acid (Olsen and Sommers, 1982). Soil organic carbon was determined with high-temperature induction furnace method (Nelson and Sommers, 1982) after treating the soil with 1 M $HNO_3$. Enrichment ratio (ER) for TP in surface runoff was calculated by dividing the runoff TP concentration (per unit weight of TS) with soil TP (per unit weight of soil). Enrichment ratio for COD was calculated by dividing the runoff COD concentration (per unit weight TS) with soil COD (per unit weight of soil).

Due to the significant impact of major rainfall on pollutant losses, the delivery ratio for sediment, TP, COD, and DMRP were calculated only for selected major rainfall runoff events from 20 to 24 July 1998 in W20. Delivery ratio is the ratio between the pollutant that entered the surface tile inlet and the pollutant delivered into the pond surrounding the inlet. Rainfall runoff was selected because of its distinct pulse of inflow and outflow, thus water storage (volume) in the pond compared to snowmelt that runs off slowly and is influenced by night time freezing. Pond volumes were calculated from pond elevation data using Surfer□[1] software (Golden Software Inc., 1996). The inflow hydrograph was calculated by knowing the change of water storage in the pond and the outflow hydrograph into the tile inlets over time during runoff.

Changes of runoff inflow and outflow from the watershed showed the dynamics of stored water and suspended pollutants in the pond.

The amount of a given pollutant in the pond during inflow was calculated from the hydrograph and the concentration during the first two hours of ponding. This assumption was made considering that there was a rapid increase in the pond water level during the first hour of ponding. Also, the slope of the watershed area around the pond was gentle and concave in shape. All these factors cause the deposition of heavier aggregates before reaching the pond.

## RESULTS AND DISCUSSION

### Runoff

Total snowfall (water equivalent) in winter 1995-1996 was 122 mm compared to 169 mm in 1996-1997 and 138 mm in 1997-1998. The normal (30-yr average) for snowfall is 157 mm. More than 50% of snowfall drifted from the watersheds by wind. On 18 February 1997 before any snowmelt runoff occurred, in-situ snow pack (water equivalent) in W20 and W15 was 34% (58 mm) and 46% (77 mm) of the snow fall, respectively. On 6 February 1998, the in-situ snow pack was 46% (64 mm) and 46% (66 mm) of the snow fall in W20 and W15, respectively. In addition to the snow pack, two rainfalls in February totaling 8.4 mm in W20 and 9.4 mm in W15 occurred over the melting snow that resulted in the only runoff event in 1998. These low intensity rainfalls were regarded as snowfall because they occurred when snow was melting.

Snowmelt runoff entering surface tile inlets in 1996, 1997 and 1998 is given in Table 1. Every February and March, snowmelt runoff occurred when the mean daily air temperatures were continuously above 0 °C for two days or longer. For W20, snowmelt runoff was 4.9%, 5.0% and 4.4% of the total snowfall in 1996, 1997 and 1998 respectively. In 1997 and 1998 snowmelt runoff was equivalent to 14% and 8.3% respectively of water in the in-situ snow pack. For W15, snowmelt runoff was 7.7%, 3.5% and 2.6% of the total snowfall in 1996, 1997, and 1998, respectively. In 1997 and 1998 snowmelt runoff was 7.7% and 4.7% respectively of the water in the in-situ snow pack. Averaged over three years, snowmelt runoff entering surface tile inlets was 6.9 mm $yr^{-1}$ in W20 and 6.3 mm $yr^{-1}$ in W15, an equivalent of 4.8% and 4.4%, respectively of the average annual snowfall.

Although only 8 km apart, the rainfall amount and distribution was different between W20 and W15 watersheds. Typically rainfall runoff only occurred in these watersheds if rainfall occurred within 2 d prior to a runoff-causing-rainfall. The exception was large intense rainfalls. Annual rainfall amounts in 1996, 1997 and 1998 were lower than the normal of 624 mm. In watershed W20, annual rainfall was 236 mm (60 daily rainfalls) in 1996 compared to 424 mm (71 daily rainfalls ) in 1997 and 358 mm (55 daily rainfall) in 1998. Since most rainfall events in 1996 and 1998 were small and low intensity, there was no rainfall runoff in W20. In 1997, 15% of four rainfalls totaling 133 mm resulted in surface runoff from W20. For watershed W15, total rainfall was 259 mm (64 daily rains) in 1996 compared to 381 mm (68 daily rains) in 1997 and 305 mm (67 daily rains) in 1998. These low intensity rainfalls resulted in a small amount of runoff in 1996 and 1997, and no rainfall runoff in 1998 in watershed W15. Runoff was 2.7% of three runoff-causing rainfalls totaling 68 mm in 1996 and 3.2% of three runoff-causing rainfalls totaling 51 mm in 1997.

Table 1. Runoff and pollutant losses into surface tile inlets of Watershed W20 and W15, Watonwan, County, MN from 1996 to 1998.

| Runoff Events | Source | Runoff | TS | COD | TP | PP | DMRP | TDIN | NO3 |
|---|---|---|---|---|---|---|---|---|---|
| | | mm | ----------kg ha$^{-1}$-- | | ------------------g ha$^{-1}$---------------------------- | | | | |
| Watershed W20 | | | | | | | | | |
| 1996 | Snowmelt | 6.03 | 11.9 | 1.93 | 25.3 | 7.05 | 18.3 | 478 | 434 |
| | Rainfall□ | - | - | - | - | - | - | - | - |
| | Annual | 6.03 | 11.9 | 1.93 | 25.3 | 7.05 | 18.3 | 478 | 434 |
| 1997 | Snowmelt | 8.37 | 34.0 | 2.61 | 52.8 | 18.3 | 34.5 | 126 | 88.6 |
| | Rainfall | 19.6 | 90.9 | 13.2 | 195 | 131 | 64.1 | 219 | 177 |
| | Annual | 28.0 | 125 | 15.8 | 248 | 149 | 98.5 | 344 | 266 |
| 1998 | Snowmelt | 6.08 | 1.05 | 1.98 | 89.4 | 1.63 | 87.8 | 519 | 426 |
| | Rainfall□ | - | - | - | - | - | - | - | - |
| | Annual | 6.08 | 1.05 | 1.98 | 89.4 | 1.63 | 87.8 | 519 | 426 |
| Total for three years | | 40.1 | 138 | 19.7 | 363 | 158 | 205 | 1341 | 1126 |

Table 1. Continued.

Watershed W15

| Runoff Events | Source | Runoff | TS | COD | TP | PP | DMRP | TDIN | NO3 |
|---|---|---|---|---|---|---|---|---|---|
| | | mm | ----------kg ha$^{-1}$-- | | ------------------g ha$^{-1}$---------------------------- | | | | |
| 1996 | Snowmelt | 9.45 | 40.0 | 3.77 | 84.6 | 40.5 | 44.1 | 365 | 279 |
| | Rainfall | 1.83 | 51.4 | 1.86 | 30.3 | 21.3 | 9.0 | 85.5 | 83.6 |
| | Annual | 11.3 | 91.4 | 5.64 | 115 | 61.8 | 53.1 | 451 | 363 |
| 1997 | Snowmelt | 5.91 | 3.49 | 1.46 | 41.9 | 13.7 | 28.2 | 81.8 | 63.5 |
| | Rainfall | 1.65 | 3.57 | 0.87 | 11.7 | 9.65 | 2.09 | 3.56 | 3.41 |
| | Annual | 7.56 | 6.96 | 2.33 | 53.6 | 23.3 | 30.3 | 85.4 | 66.9 |
| 1998 | Snowmelt | 3.52 | 2.12 | 1.60 | 15.5 | 2.69 | 12.9 | 206 | 144 |
| | Rainfall□ | - | - | - | - | - | - | - | - |
| | Annual | 3.52 | 2.12 | 1.60 | 15.5 | 2.69 | 12.9 | 206 | 144 |
| Total for three years | | 22.4 | 101 | 9.56 | 184 | 87.7 | 96.3 | 742 | 574 |

□ No rainfall event caused runoff.

Over the six watershed years, snowmelt was the predominant source of runoff. In watershed W15, snowmelt was 84% and 78% of the annual runoff in 1996 and 1997, respectively. For 1998, annual runoff and pollutant losses were only from the snowmelt. In watershed W20, annual runoff and pollutant losses were only from snowmelt runoff both in 1996 and 1998. In 1997, 30% of the annual runoff was from snowmelt and the remainder from rainfall. Sixty eight percent of annual runoff in 1997 was from two intense rainfalls sequential (separated by 36 h) . Several studies (Edward and Owen, 1991; Ginting et al., 1998a) have shown that significant runoff has consistently been associated with severe-storms.

The dynamics of rainfall runoff from the watershed into the depressional area (inflow) and the outflow from the depressional area into the tile inlet are given in Fig. 3a and Fig. 3b. The first 2-h rainfall (56 mm) on 20 July 1997 had a maximum 30-min intensity of 74 mm $h^{-1}$. This rainfall resulted in 24-h of ponding and 6.6 mm of runoff that entered the tile inlet. The second rainfall (35 mm) on 22 July 1997 occurred only 5 h after the previous ponding ended. This second rainfall had a maximum 30-min intensity of 58 mm $h^{-1}$ and resulted in 48-h ponding. This rainfall resulted in 12.3 mm of runoff that entered the tile inlet. Tile systems are designed to handle a maximum rate of runoff based on historical rainfall records, landscape features and soil type. Prolonged ponding occurred in both of these events because tile outflow rates were restricted due to the limited capacity of the tile system (Fig. 3b).

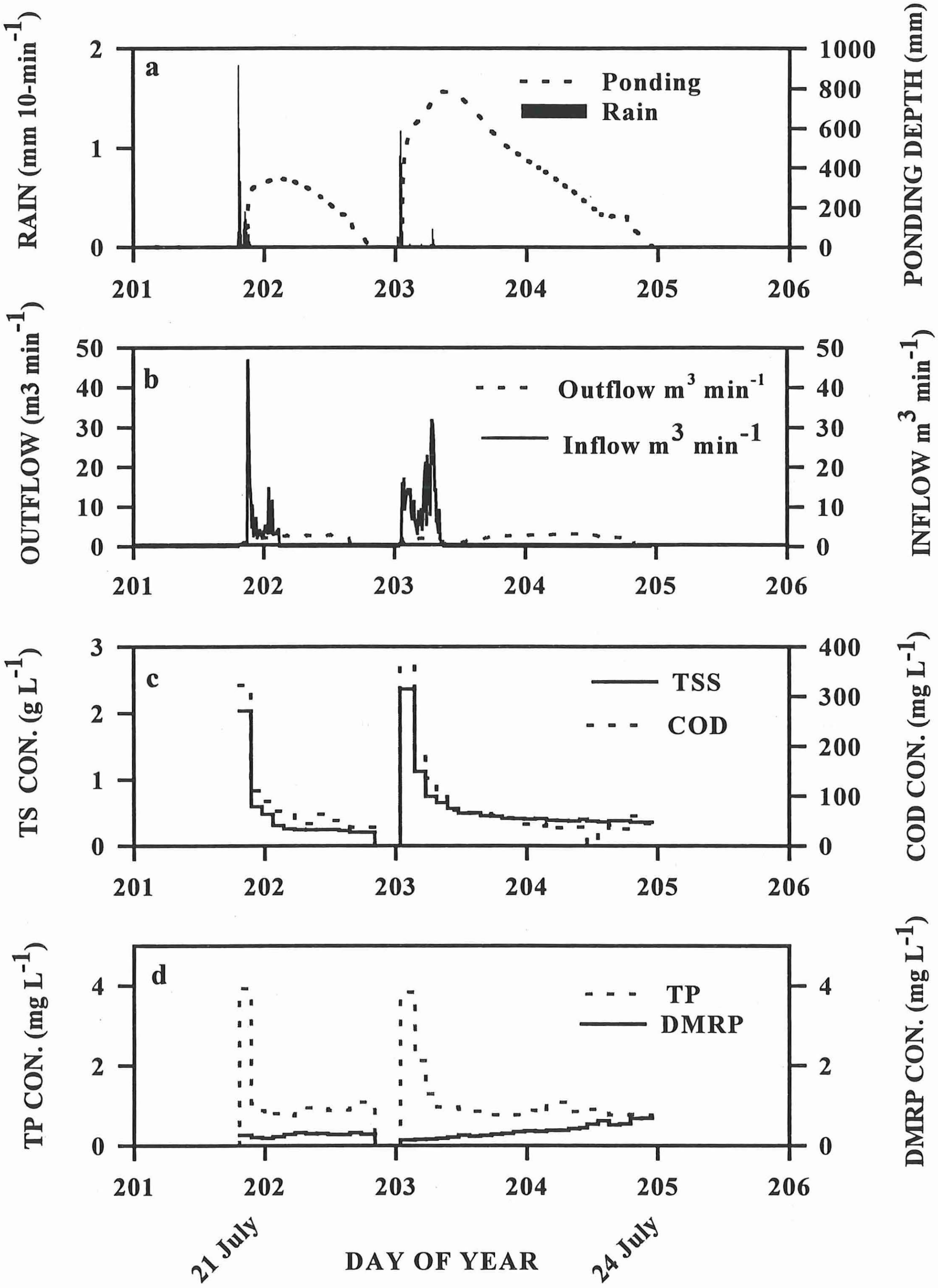


Fig. 3. The effects of a) rainfall and runoff ponding on b) inflow hydrograph in the pond and outflow hydrograph into surface tile inlets, c) TS and COD concentrations, and d) TP and DMRP concentrations.

## Total Solids

Losses of TS into tile inlets on an event by event bases was greatly dependent on runoff volume. For a given runoff volume, losses of TS in snowmelt runoff were generally lower than those from rainfall runoff. Flow-weighted TS concentrations in snowmelt runoff ranged from 90 to 410 mg $L^{-1}$ compared to 230 mg $L^{-1}$ to 13,900 mg $L^{-1}$ in rainfall runoff. High TS concentrations in rainfall runoff events were associated with small runoff volumes.

Differences in TS concentration between snowmelt and rainfall runoff was due to the differences in the erosion process between snowmelt and rainfall runoff events. The erosion process during snowmelt is mainly due to flowing water whereas in rainfall runoff, the erosion process is due to both detachment by raindrops and transport by runoff as well as detachment by flowing water. Soil detachment and breaking down of soil aggregates on raindrop impact provides a greater TS load in rainfall runoff. In addition to differences in the soil detachment process, surface residue cover was also much higher during snowmelt than rainfall runoff. This probably slowed the flow of snowmelt runoff thus reducing soil detachment. Soybean residue cover after snowmelt on 25 April 1996 was 52% in W20 and 48% in W15. Corn residue cover after snowmelt on 7 April 1997 was 19% in W20 and 20% in W15. After planting and harrowing, corn residue cover on 26 June 1997 was 5.3 % in W20 and 5.3%W15.

Suspended solids were both from upland and the area around the tile inlets. At the beginning of rainfall, soil aggregate detachment by rain drop impact around the tile inlets is important. With the rapidly increasing water level in the pond, however, the soil in the pond is protected from detachment by raindrop impact. Thus most TS entering the pond is from the upland area. With the increasing water level, the distance for entry of TS at the perimeter of ponding is also farther from surface tile inlets. This suggests that most TS will be deposited away from the tile inlets and most of the aggregates that enter the tile inlets will be very small.

To illustrate the effects of water level dynamics in the pond on TS concentration and composition, Fig. 3c is shown. The distribution of aggregate sizes in runoff entering tile inlets during the two consecutive major events described in Fig. 3a are shown in Fig. 4. During the first two hours of ponding, the water depth reached more than 350 mm and the distance from the ponding perimeter to the tile inlets was greater than 25 m. Consequently, TS concentration in the pond dropped from 2,000 mg $L^{-1}$ for the first two hours of ponding to 300 mg $L^{-1}$ after eight hours of ponding and further decreased to 200 mg $L^{-1}$ at the end of ponding (Fig. 3c). Aggregate size distribution of TS entering tile inlets in the first two hours of ponding was predominantly from 2 to10 μm (Fig 4). However for the remainder of the flow period, the predominant size was less than 2 μm These aggregates are likely to remain in suspension for a considerable time during transport in drainage channels. These results on aggregate size distribution are similar to the aggregate size distribution reported by Laflen et al. (1972) for surface runoff that entered a tile-outlet terrace during a severe storm (30-min intensity of >50 mm $hr^{-1}$) in Iowa. These authors observed that almost all TS lost from the tile-outlet terraces had diameters less than 16 μm and more than 50% of TS were less than 2 μm.

The two sequential rainfalls resulted in 420 kg $ha^{-1}$ of fine aggregates delivered to the ponding area, however, only 73 kg $ha^{-1}$ (17%) of very fine aggregates entered the tile lines. This suggests that ponding resulted in 83% of TS deposited in the inundated flat area around surface inlets. The inundated flat area around surface inlets functioned as a sedimentation pond and thus facilitated the gravitational settling of suspended solids (Jarret, 1993).

For a smaller and less intensive rainfall events ponding is shallow and of shorter duration. As a result ponding effects are negligible. For example, a gentle 20-h rainfall (totaling 40 mm) with maximum 30-min intensity of 15.6 mm $hr^{-1}$ resulted in less than 4-hr ponding with a maximum water depth of 80 mm. For this small runoff event, practically all 3.4 kg $ha^{-1}$ of the TS went into the tile inlet, a relatively small portion of the annual TS loss.

Annual TS losses entering surface tile inlets in snowmelt and rainfall runoff in 1996, 1997, and 1998 are given in Table 1. Cumulative TS losses over three years of snowmelt were 47 kg $ha^{-1}$ and 46 kg $ha^{-1}$ for W20 and W15, respectively. Cumulative TS losses over three years of rainfall runoff were 91 kg $ha^{-1}$ and 55 kg $ha^{-1}$ for W20 and W15, respectively. In 1997, a maximum 27 % of annual TS delivered to the pond is estimated to have entered the W20 tile inlet for severe rainfall runoff events. These results indicate that in these lacustrine watersheds, reduced tillage results in a small quantity of TS loss and a large portion is deposited in the flat depressions around the inlets before the runoff enters the tile lines.

## Chemical Oxygen Demand

The average soil total organic carbon in W20 was 30.6 g $kg^{-1}$ and in W15 was 28.0 g $kg^{-1}$. Assuming that 76% of total organic carbon is oxidizable carbon, the average chemical oxygen demand of soil was 61.9 g $kg^{-1}$ for W20 and 56.7 g $kg^{-1}$ for W15, respectively.

In general COD loss on an event by event bases was greater in snowmelt runoff than in rainfall runoff due to greater snowmelt runoff volume. Greater snowmelt runoff volume and low soil detachment resulted in lower concentration of COD (ranged from 19 to 115 mg $L^{-1}$) in snowmelt runoff than in rainfall runoff. Eighty five percent of the COD values in snowmelt runoff were less than 50 mg $L^{-1}$. At low TS concentration in snowmelt runoff, the COD contribution of the solution phase is an important component of the total COD. A similar observation was made by Timmons and Holt (1977) who reported that a majority of COD in snowmelt runoff from natural vegetative prairie was in the solution phase.

In rainfall runoff, however, COD was greatly dependent on total solids. This is also

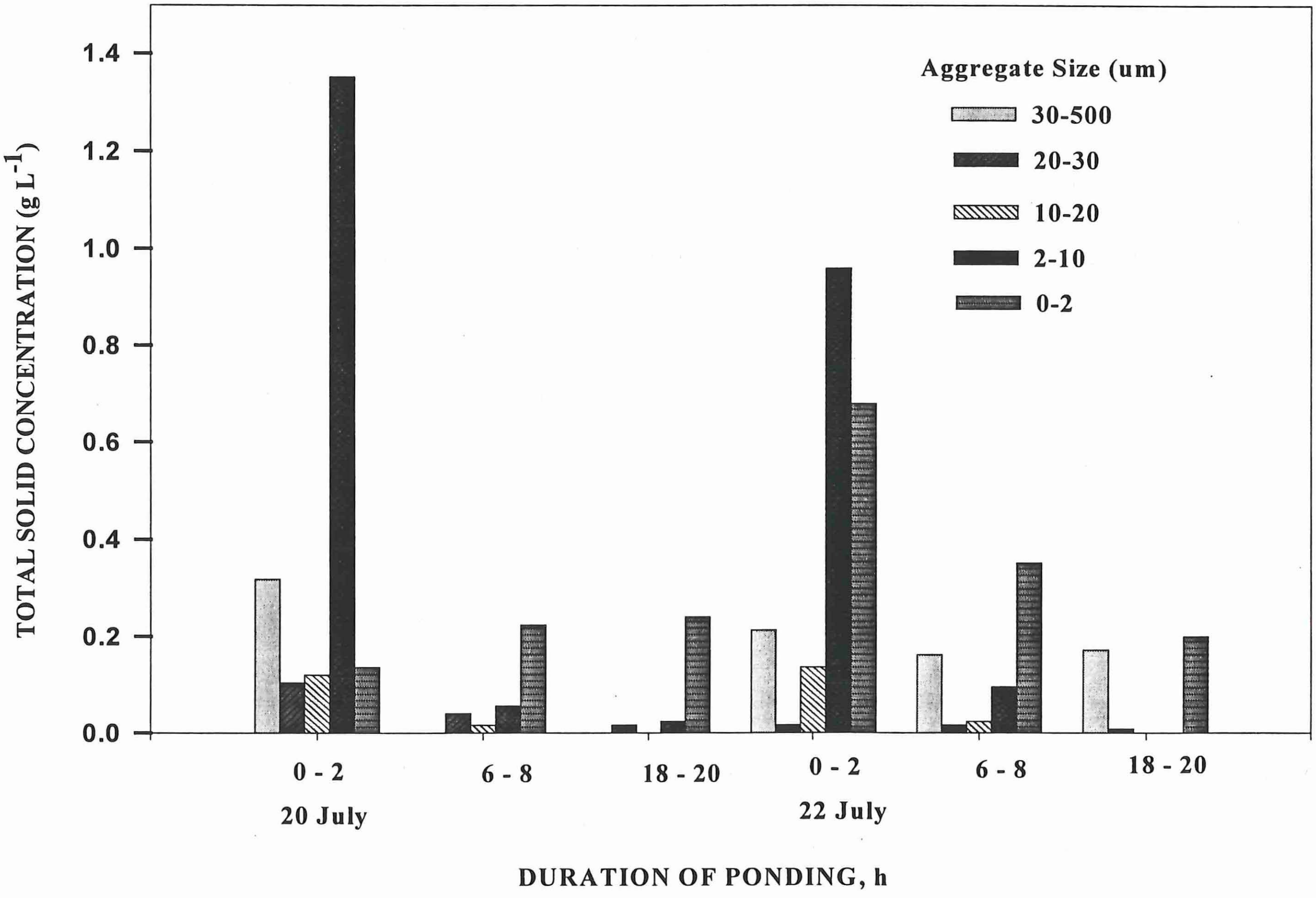


Fig. 4. Aggregate size distribution of sediment during a major rainfall runoff in July 1997 from watershed W20.

apparent from Fig. 3c where COD concentration closely follows the TS concentration. The COD concentration in rainfall runoff ranged 12 to 515 mg $L^{-1}$. Eighty percent of rainfall runoff events had COD greater than 60 mg $L^{-1}$. Higher COD concentration in rainfall runoff was due to higher TS concentration in rainfall runoff than those in snowmelt runoff.

Reduction of TS significantly reduced COD losses into tile inlets. In Fig. 3c, the close relationship of TS concentration and COD concentration in rainfall runoff is shown. As sediment concentration in the pond dropped from 2000 mg $L^{-1}$ during the first two hours of ponding to 200 mg $L^{-1}$ at the end of ponding, COD concentration also dropped from 360 mg $L^{-1}$ to 45 mg $L^{-1}$. The two sequential rainfalls resulted in 65 kg $ha^{-1}$ COD delivered to the ponding area, but only 9.7 kg $ha^{-1}$ (15%) COD entered the surface tile inlet. Eighty five percent of the COD was deposited with the sediment in the inundated area around the inlet.

Annual COD entering surface inlets in snowmelt and rainfall runoff for 1996, 1997, and 1998 are given in Table 1. Cumulative over three years, COD losses in snowmelt were 6.5 kg ha $^{-1}$ and 6.8 kg $ha^{-1}$ for W20 and W15, respectively. For rainfall runoff, the COD losses were 13 kg $ha^{-1}$ and 2.7 kg $ha^{-1}$ for W20 and W15, respectively. Based on the cumulative 3-yr value, the ER of COD in snowmelt was 4.5 for W20 and 4.8 for W15. The ER of COD in rainfall runoff was 4.8 in W20 and 1.8 In W15. Big differences in the ER of COD in rainfall runoff between W20 and W15 was mainly due to the two sequential storms that occurred in W20 and not W15.

## Phosphorus

### Total Phosphorus

Average soil TP was 608 mg $kg^{-1}$ and 637 mg $kg^{-1}$ in W20 and W15, respectively. As expected, TP losses entering tile inlets on an event by event basis increased with TS losses. For the same sediment load, TP losses in snowmelt runoff were generally higher than TP losses in rainfall runoff. Higher TP losses in snowmelt runoff were due to greater snowmelt runoff volume and the majority of the TP in snowmelt runoff were in the solution phase. This is consistent with the observations of Ginting et al. (1998b) who showed that contribution of P leached from plant material could be significant in snowmelt runoff.

Flow-weighted TP concentrations of snowmelt runoff ranged from 0.2 to 2.9 mg $L^{-1}$ compared to 0.7 to 6.5 mg $L^{-1}$ in rainfall runoff. One or two high TP concentration values were associated with high sediment concentrations in snowmelt runoff. Both in snowmelt and rainfall runoff, TP concentrations were higher than the 0.02 mg $L^{-1}$ limit for accelerated eutrophication of lakes and impoundments (Sharpley et al., 1987).

In rainfall runoff, TP losses were mainly particulate P (PP) associated with TS. The impact of TS deposition on reduction in TP loss is illustrated in Fig. 3d. As TS concentration in the pond dropped from 2,000 mg $L^{-1}$ during the first two hours of ponding to 200 mg $L^{-1}$ at the end of ponding (Fig. 3c), TP concentration also decreased from 4.0 mg $L^{-1}$ to 0.7 mg $L^{-1}$. Deposition of TS in the pond significantly reduced TP losses into tile inlets. The two sequential rainfalls in Fig. 3a resulted in 724 g $ha^{-1}$ TP in the ponding area, out of which only 189 g $ha^{-1}$ (26%) TP entered the tile inlet. Seventy four percent was deposited around the tile inlet.

Annual TP losses into surface tile inlets in snowmelt and rainfall runoff in 1996, 1997, and 1998 are summarized in Table 1. Cumulative over three years, TP losses in snowmelt were 168g $ha^{-1}$ and 142 g $ha^{-1}$ for W20 and W15, respectively. For rainfall runoff, TP losses were 195 g $ha^{-1}$ for W20 and 42 g $ha^{-1}$ for W15. Based on the cumulative 3-yr value, ER of TP in snowmelt was 5.8 for W20 and 4.8 for W15. Comparatively the ER of TP in rainfall runoff was

3.5 for W20 and 1.2 for W15. Higher ER of TP in rainfall runoff from W20 than W15 was mainly due to the two sequential storms that occurred in W20 and not W15. From a simulated rainfall study, Sharpley (1980) also observed that an increase in rainfall and runoff energy resulted in a significant increase in the slope of a relationship between ln (ER) and ln (TS).

The phosphorus losses in snowmelt and rainfall runoff from a chisel/no till based conservation tillage system on a concave landscape were low, even when there were two consecutive major rainfalls. These TP losses were lower than the 5-yr average of 398 and 529 g $ha^{-1}$ TP losses from < 5-ha watersheds cropped to wheat-sorghum-fallow rotation under a no-till system or reduced tillage system, respectively, in Bushland, TX (Sharpley et al., 1992).

## Dissolved Molybdate Reactive Phosphorus

Flow-weighted DMRP concentration ranged from 0.2 to 0.9 mg $L^{-1}$ in snowmelt runoff and 0.1 to 0.5 mg $L^{-1}$ in rainfall runoff. These DMRP concentrations were higher than the 0.01 mg $L^{-1}$ limit for accelerated eutrophication of lakes and impoundments (Sharpley et al., 1987). The DMRP concentrations entering the tile inlets were dependent not only on the release of phosphorus from surface residue (especially for snowmelt runoff) and soil in the upland portion but also on the effect of prolonged ponding near the surface inlet.

The change in DMRP concentration during prolonged ponding is illustrated in Fig. 3d. The concentration of DMRP in the runoff entering the tile inlet increased with time due to the P release from sediments in the ponding area. In a laboratory study, Sharpley et al. (1981) observed that the amount of soil P extracted by water is proportional to the exponential of contact time. During the first 28 h ponding period DMRP concentration increased from 0.26 to 0.32 mg

$L^{-1}$ where as during the next 48 h ponding period and from 0.14 to 0.68 mg $L^{-1}$ (Fig. 3d). This increase in DMRP concentration during ponding resulted in more DMRP entering the tile inlets than was delivered to the pond. These two sequential rainfalls in Fig. 3a delivered 34 g $ha^{-1}$ DMRP to the ponding area but 45 g $ha^{-1}$ (141%) DMRP left the pond through the surface inlet.

Annual DMRP losses in snowmelt and rainfall runoff in 1996, 1997, and 1998 through surface tile inlets are summarized in Table 1. The DMRP losses in snowmelt runoff were greater than those in rainfall runoff. Cumulative over three years, DMRP losses in snowmelt were 140 g $ha^{-1}$ from W20 and 85 g $ha^{-1}$ from W15. Comparatively DMRP losses in rainfall runoff were 64.1 g $ha^{-1}$ from W20 and 11 g $ha^{-1}$ from W15.

## Dissolved Inorganic Nitrogen

Nitrate-N concentrations in snowmelt runoff ranged from 1.0 to 8.3 mg $L^{-1}$ compared to 0.2 to 6 mg $L^{-1}$ in rainfall runoff. These nitrate-N concentrations were lower than the 10 mg $L^{-1}$ nitrate-N limit for drinking water standard (USEPA, 1973). Nitrate-N concentrations were higher in the year after beans than after corn. This is because of anhydrous ammonia that was applied in October or November after bean harvest. In W20, annual snowmelt in 1996 and 1998 (after beans) had nitrate concentrations 6.7 and 6.8 times the 1.1 mg $L^{-1}$ in 1997 (after corn). Similarly for W15, annual snowmelt in 1996 and 1998 had nitrate concentrations 2.8 and 3.8 times the 1.1 mg $L^{-1}$ in 1997.

Annual TDIN and nitrate-N losses into surface tile inlets in snowmelt and rainfall runoff in 1996, 1997, and 1998 are summarized in Table 1. Nitrate-N comprised 70% to 90 % of TDIN in snowmelt runoff and 81 to 98 % of TDIN in rainfall. Cumulative TDIN losses over three years of snowmelt runoff were 1.12 kg $ha^{-1}$ in W20 and 0.65 kg $ha^{-1}$ in W15. Cumulative TDIN losses in rainfall runoff over three years were 219 g $ha^{-1}$ for W20, and 89 g $ha^{-1}$ for W15.

## CONCLUSION

There has been much speculation that surface tile inlets are a major contributor to the degradation of surface waters with very little field scale measurements to support it. This study has shown that during large runoff events (which are responsible for most of the losses during channelized overland flow), pollutant losses into surface tile inlets are reduced because the capacity of the tile system is exceeded and water ponding is resulted. Water ponding around the tile inlets reduced TS losses. The TS losses entering surface tile inlets was predominantly clay-size aggregates. Deposition of TS during prolonged ponding after major storms facilitated reduction of particulate P, TP, and COD losses. Ponding, however, increased dissolved molybdate reactive P (DMRP) losses by dissolution of soil P during prolonged ponding. Concentration of nitrate-N in snowmelt and rainfall runoff entering surface inlets was lower than 10 mg $L^{-1}$. An aggressive soil and water conservation tillage system in a corn-soybean rotation is effective at keeping losses of sediment and nutrients from lacustrine landscapes.

## ACKNOWLEDGMENT

The authors thank the Tilney Farms, Inc., Lewisville, MN for the invaluable field assistance. This project is a contribution from the Department of Soil, Water, and Climate, University of Minnesota, St. Paul, MN 55108 and the Minnesota Agric. Exp. Stn. Partial funding for this research was provided by the Minnesota Legislature, ML 1997, Chapter 216, sec.15, subd. 7(e),

as recommenced by the Legislative Commission on Minnesota Resources from the Minnesota Future Resources Fund.

## REFERENCES

Bengtson, R.L., C.E. Carter, H.F. Morris and J.G. Kowalczuk. 1984. Reducing water pollution with subsurface drainage. Trans. ASAE 27:80–83

Carlson, R.M. 1978. Automated separation in conductimetric determination of ammonia and dissolved carbon dioxide. Anal. Chem. 50:1528–1524.

Carlson, R.M. 1983. Continuous flow of nitrate to ammonia with granular zinc. Anal. Chem. 58:1590–1591.

Drury, C.F., C.S. Tan, J. D. Gaynor, T.O. Oloya, and T.W. Welacky. 1996. Influence of controlled drainage-subirrigation on surface and tile drainage nitrate loss. J. Environ. Qual. 25:317-324.

Drury, C. F. , D. J. McKenney, W.I. Findlay, and J.D. Gaynor. 1993. Influence of tillage on nitrate loss in surface runoff and tile drainage. Soil Sci. Soc. Am. J. 57:797–802.

Edwards, W.C., and L. B. Owens. 1991. Large storm effects on total soil erosion. J. Soil Water Conserv. 46:75–78.

Ginting, D., J.F. Moncrief, S.C. Gupta, and S.D. Evans. 1998a. Corn yield, runoff, and sediment losses from manure and tillage systems. J. Environ. Qual. 27:1396-1402.

Ginting, D., J.F. Moncrief, S.C. Gupta, and S.D. Evans. 1998b. Interaction between manure and tillage system on phosphorus uptake and runoff losses. J. Environ. Qual. 27:1403-1410.

Golden Software Inc.. 1996. Surfer□ for windows. Version 6. Contouring and 3D surface mapping. Golden, CO.

Jarret, A.R. 1993. Design of perforated risers to control dewatering of sedimentation basins. Applied Eng. Agric. 9:37–42.

Kladivko, E.J., G.E. Van Scoyoc, E.J. Monke, K.M. Oates, and W. Pask. 1991. Pesticide and nutrient movement into subsurface tile drains on a silt loam soil in Indiana. J. Environ. Qual 20:264–270.

Laflen, M.J., H.P. Johnson, and C. Reeve. 1972. Soil loss from tile-outlet terraces. J. Soil Water Conserv. 27:74–77.

Laflen, J.M., M. Amemiya, and E.A. Hintz. 1981. Measuring residue cover. J. Soil Water Conserv. 32:341–343.

Leitch, J.A. and D. Kerestes. 1981. Agricultural land drainage costs and returns in Minnesota. Staff Paper P81-15. Prepared for the U.S. Army Corps of Engineers, St. Paul, MN and the Minnesota Water Planning Board, St. Paul, MN. Dep. Agricultural and Applied Economics. University of Minnesota, St. Paul, MN.

Murphy, J., and J. Riley. 1962. A modified single solution method for the determination of phosphate in natural waters. Anal. Chem. Acta 27:3–36.

Neibling, W. H., W.C. Moldenhauer, and B.M. Holmes. 1983. Evaluation and comparison of two methods for characterization of sediment size distribution. Trans ASAE 26(2):472-480.

Nelson, D.W. and L.E. Sommers. 1982. Total carbon, organic carbon, and organic matter. *In* A.L. Page et al. (ed.) Methods of soil analysis. Part 2. 2nd ed. Agronomy 9:539-577.

Olsen, S.R. and L.E. Sommers. 1982. Phosphorus. *In* A.L. Page et al. (ed.) Methods of soil analysis. Part 2. 2nd ed. Agronomy 9:403–430.

Schwab, G.O., G. S. Taylor, J. L. Fouss, and E. Stibbe. 1966. Crop response from tile and surface drainage. Soil Sci. Am. Proc. 30:634–637.

Sharpley, A. N. 1980. The enrichment ratio of soil phosphorus in runoff sediments. J. Environ. Qual. 9:521-526.

Sharpley, A. N., S. J. Smith, O.R. Jones, W.A. Berg, and G.A Coleman. 1992. The transport of bioavailable phosphorus in agricultural runoff. J. Environ. Qual. 21:30–35.

Sharpley A. N., L.R. Ahuja, M. Yamamoto, and R.G. Menzel. 1981. The kinetics of phosphorus desorption from soil. Soil Sci. Soc. Am. J. 45:493–496.

Sharpley, A.N., S.J. Smith, and J.W. Naney. 1987. Environmental impact of agricultural nitrogen and phosphorus use. J Agric. Food Chem. 35:812–817.

Timmons, D.R. and R.F. Holt. 1977. Nutrient losses in surface runoff from a native prairie. J. Environ. Qual. 6:369–373.

U.S. Dep. Agric. and Soil Conserv. Serv. 1992. Soil survey of Watonwan county, MN.

U.S. EPA. 1973. Water Quality Criteria. U.S. Gov. Print. Office, Washington, DC.

U.S. EPA. 1979. Methods for chemical analysis of water and wastes. U.S. Government Printing Office. Washington, DC. EPA-600/4-79-020.

U.S. EPA. 1981. Procedures for handling and chemical analysis of sediment and water samples. US Environmental Laboratory. US Army Engineer Water Ways Exp. Stn., Vicksburg, MS.

Walkley, A., and I.A. Black. 1934. An examination of the Degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. Soil Sci. 37:29-3

# Delivery Ratios Of Pollutants Entering Surface Tile Inlets

**D. Ginting, J.F. Moncrief*, and S.C. Gupta**

---

D. Ginting, J.F. Moncrief, and S.C. Gupta, Dep. of Soil, Water, and Climate, Univ. of Minnesota, 1991 Upper Buford Circle, St. Paul, MN. *Corresponding author (moncrief@soils.umn.edu).

## ABSTRACT

Surface tile inlets connected to subsurface tile lines provide a direct route for pollutants to enter water bodies. Losses of runoff, total solids (TS) and nutrients entering surface tile-inlets during intensive natural storms were evaluated. Tillage operations used in a corn-soybean rotation were: fall no tillage after navy bean [*Phaseolus vulgaris(L.)*] and chisel plowing after corn [*Zea mays* (L.)]. Tillage operations during the growing season were spring field cultivation, planting, harrowing, and row cultivation. Under simulated heavy rainfall, runoff was generally less than 10% of rainfall and sediment losses were less than 300 kg $ha^{-1}$. Residue cover further reduced runoff, sediment, and P losses significantly. Under natural intensive rainfall, the amount of sediment (420 kg $ha^{-1}$), chemical oxygen demand (COD, 9.7 kg $ha^{-1}$ ), total phosphorus (TP, 724 g $ha^{-1}$ ), and dissolved molybdate reactive P (DMRP, 34 g $ha^{-1}$ ) reaching the depressional area of the watershed were low. Prolonged ponding after major storms further reduced particulate P and COD, but increased DMRP losses through the surface inlets. The delivery ratio of sediment, TP, COD and DMRP was 0.17, 0.20, 0.15, and 1.32 respectively. Total solid losses were predominantly of clay-size soil aggregates. No tillage after beans and chisel plowing after corn is an effective tillage system for low losses of sediment and nutrients from lacustrine landscapes. Ponding at the surface inlet further reduces total pollutant losses for large storms.

## INTRODUCTION

Economic studies have shown that land drainage is synonymous with increased agricultural production. In the upper Midwest, frequently surface tile inlets are connected to subsurface tile lines to drain surface runoff. Subsurface drainage alone is not enough to rapidly drain snowmelt and major rainfall runoff. Presence of surface inlet drainage, however, short cuts the agricultural runoff pathway from farm to waterways and rivers. Without surface inlets, subsurface tile lines mostly deliver nitrate-N (Drury, 1993, Kladivko et al., 1991). With surface tile inlets, other non-point source pollutants such as suspended sediment, nutrients, and chemical oxygen demanding materials also enter subsurface tile lines directly without filtration by soil, which have raised some water quality concerns.

Several studies have shown that significant runoff has mostly been associated with severe-storms (Edward and Owen, 1991; Ginting et al., 1998). The objective of this study was to evaluate the quantity and quality of runoff entering surface tile inlets during severe storms in lacustrine watersheds under a conservation tillage system. Simulated rainfall was also used to evaluate tillage effects on runoff losses.

## MATERIALS AND METHODS

### Watershed Study Under Intense Natural Rainfall

This study is part of an on-going paired watershed study since 1995. During the six watershed-years, only two back to back heavy rainstorms caused major runoff and erosion. The data during these major storms are presented here.

#### Site and Watershed Characteristics

Subsurface pattern tiles are connected to a surface tile inlet in a local depression. The watershed is gently rolling with concave hill-slopes and local depressions. Excess water from major rainfall and snowmelt drains into these local depressions forming a temporary pond. The soils in the watershed are predominately Madelia and Spicer silty clay loams (Typic Haplaquolls). Soil tests taken in October 1995 showed that: pH ranged from 6.3 to 6.8; Olsen-P from 22 to 23 mg $kg^{-1}$;

and potassium from 127 to 139 mg $kg^{-1}$. The soil Olsen-P and potassium levels are considered high.

Corn and beans in rotation were grown in the watershed. Tillage field operations were: corn harvest in Oct. 1996 and chisel plowing in Nov. 1996; field cultivation on 15 May 1997, navy bean planting on 15 - 16 May 1997, harrowing on 16 May 1997, rotary hoeing on 10 June 1997, the first row cultivation on 1 July 1997, and the second row cultivation on 15 July 1997. A major rainfall and subsequent ponding occurred on 21-24 July 1997 after the watershed was field cultivated, harrowed, and row cultivated twice. Navy beans had developed pods at this time. The navy bean canopy cover was 15% whereas corn residue cover was 4%.

## Instrumentation

In 1995, a sloping trench was dug to give the 20.3-cm diameter polyvinyl chloride (PVC) pipe a 4% slope towards surface tile inlets. The PVC pipe was then connected to a T-shaped fitting, which in turn was connected to the surface tile inlet with a 90-degree PVC elbow. The T-shaped fitting was used to allow access to the sensor cables, and sampler suction tube for cleaning and maintenance. Flow entering surface inlets was measured using an ISCO[1] area-velocity sensor and flow data logger. The velocity sensor was secured to the bottom at the downstream end of the 2.5 m long PVC pipe.

Flow data loggers, sampler, and deep cycle 12-V batteries were placed 1.5 m above ground in a custom made housing, 1 m away from the tile inlets. The batteries were continuously charged by a 20-W solar panel to power the electronic equipment. A tipping-bucket rain gage

---

[1] Mentioned of a product by name by the university of Minnesota does not imply endorsement of this product over similar products.

connected to the data logger recorded rainfall at 10-min intervals. Runoff samples were taken with an ISCO[1] 24-bottle sampler connected to the flow data logger. In each bottle a composite of 10 sub-samples were collected. Sampling was triggered when the water level was 2.5 cm deep to avoid air entry during sampling.

### Measurements

During continuous runoff events, bottles of runoff samples were collected from the ISCO sampler daily and brought to the laboratory for analysis of total solids, total P and DMRP (USEPA, 1981; Olsen and Sommers, 1982; Murphy and Riley, 1962), and COD (USEPA, 1979). Plant residue cover was measured diagonally over the inter-row area using the line transect procedure (Laflen et al., 1981). The inter-row area is defined as the area between 10 cm wide strips centered over the row. Thirty measurements of residue were made at each date.

Due to the significant impact of major rainfall from 20 to 24 July 1997, the delivery ratio for sediment, TP, COD, and DMRP were calculated. The delivery ratio is the ratio between the pollutants that entered the surface tile inlet and those that were delivered to the pond.

Pond volumes were calculated from pond elevation data using Surfer®[1] software (Golden Software Inc., 1996). By knowing water depth, water volume in the pond was determined. Due to the distinct start and ending pulse of rainfall and runoff, we were able to calculate inflow into the pond. The inflow hydrograph to the pond was calculated by knowing the change of water storage in the pond and the measured outflow hydrograph to the tile inlets. The amount of a given pollutant in the pond during inflow was calculated from the inflow hydrograph and the pollutant concentration during the first two hours of ponding. The first two-hour pollutant concentration was assumed to represent the runoff entering the pond edge. There was a rapid increase in water level during the first hour of ponding. Rapid ponding results in the deposition of heavier aggregates before reaching the surface inlets where samples for concentration measurements were taken. Therefore, using the pollutant concentrations beyond the first 2-h ponding will underestimate the inflow of pollutants to the pond.

## Erosion Plot Study Under Simulated Intense -Rainfall

The watershed study quantifies the quantity and quality of runoff losses at a landscape scale. These measurements reflect both erosion and deposition of sediment during transport across the landscape. However, the watershed runoff events are restricted to natural storms that occur infrequently. For example, the storms in this study occurred when there was 15% crop canopy and 4% surface residue cover. The above limitation makes it impossible to quantify water quality for other crop and surface residue conditions. Since there is a need to quantify landscape erosion during heavy storms under various surface residue cover conditions, rainfall simulation on smaller plots provides another mean to obtain these data. Simulated rainfall mainly simulates sheet erosion and will not completely account for processes occurring on a watershed scale. Simulated heavy storms, however, are useful to quantify potential of soil erosion.

On the same lacustrine landscape, 1 km from the watershed, a simulated-rainfall study was conducted in 1997 and 1998. This site was part of the tillage study started in 1996 with corn-soybean rotation. The study compared a conservation tillage system (chisel after corn-no till after bean) against conventional tillage system (moldboard after corn-chisel after bean). The landscape was divided into strips to accommodate 6 replications of each tillage system. Rainfall simulation was done in 1997 and 1998 on three replications of tillage strips.

In June 1997, rainfall simulation were made after field cultivation and harrowing when bean was at the unifoliate growth stage. Corn surface residue cover was 25% in the conservation tillage and 7% in the conventional tillage system. In 1998, rainfall simulation was done after field cultivation and harrowing when corn had 3 leaves. Soybean residue cover was 13% in the conservation tillage system and 4% in conventional tillage system.

In each tillage-strip, 7.3-m by 0.8-m (between plant rows) runoff plots were isolated with corrugated sheet metal and collection troughs. Using a rain machine, rainfall at the rate of 6.3 cm $h^{-1}$ was applied until steady state runoff measurements were obtained. Runoff flow rate and samples were taken for one minute at every five-minute interval. Three samples were then composited, brought to laboratory for sediment, phosphorus, and chemical oxygen demand (COD) analysis. Geometric means are used to represent the total runoff and pollutant losses from each tillage system.

## RESULTS AND DISCUSSIONS

### Watershed Study

Runoff, Ponding and Dynamics of Pollutant Concentrations

The dynamics of rainfall runoff from the watershed into the depressional area (inflow) and the outflow from the depressional area into the tile inlet are given in Fig. 1a and Fig. 1b. The first 2-h rainfall (56 mm) on 20 July 1997 had a maximum 30-min intensity of 74 mm $h^{-1}$. This rainfall resulted in 24-h ponding and 6.6 mm of runoff entered the tile inlet. The second rainfall (35 mm) on 22 July 1997 occurred only 5 h after the previous ponding ended. This second rainfall had a maximum 30-min intensity of 58 mm $h^{-1}$ and resulted in 48-h ponding. This 104-mm rainfals resulted in 12.3-mm runoff that entered the surface inlet. Prolonged ponding occurred in both events because tile outflow rates were restricted by the flow of the subsurface tile system (Fig. 1b).

Total solids were both from upland and the area around the tile inlets. At the beginning of rainfall, soil detachment by raindrop impact around the tile inlets is important. With the rapidly increasing water level in the pond, however, the soil in the pond is protected from raindrop impact. Thus most TS entering the pond is from the upland area. With the increasing water level, the distance for entry of TS at the perimeter of ponding is also farther from surface tile inlets. This suggests that most TS will be deposited away from the tile inlets and most of the aggregates that enter the tile inlets will be small.

The effects of water level dynamics in the pond on TS concentration and composition, are shown in Fig. 1c. During the first two hours of ponding, the water depth was >350 mm and the distance from the ponding perimeter to the tile inlets was >25 m. Consequently, TS concentration in the pond dropped from 2,000 mg $L^{-1}$ for the first two hours of ponding to 300 mg $L^{-1}$ after eight hours of ponding and further decreased to 200 mg $L^{-1}$ at the end of ponding (Fig. 1c). Aggregate size distribution of TS entering tile inlets in the first two hours of ponding was predominantly from 2 to10 μm. However for the remainder of the flow period, the predominant size was less than 2 μm. These aggregates are likely to remain in suspension for a considerable time during transport in drainage channels.

Reduction of TS significantly reduced pollutants associated with organic material and soil particles such as COD, TP and PP. As sediment concentration in the pond dropped during ponding, COD concentration also dropped from 360 mg $L^{-1}$ to 45 mg $L^{-1}$ (Fig. 1c). In rainfall runoff, TP losses were mainly particulate P (PP). As TS concentration in the pond dropped TP concentration also decreased from 4.0 mg $L^{-1}$ during the first two hours of to 0.7 mg $L^{-1}$ at the end of ponding (Fig. 1d). Deposition of TS in the pond significantly reduced TP losses into tile inlets.

While particulate P associated with TS deposition was decreasing with time in the pond, the concentration of DMRP in the runoff entering the tile inlet increased (Fig. 1d), due to P release from soil and sediments in the ponding area. In a laboratory study, Sharpley et al. (1981) also observed that the amount of soil P extracted by water was proportional to contact time. In our case it is the ponding time. During the first 28 h ponding period DMRP concentration increased from 0.26 to 0.32 mg $L^{-1}$ whereas during the next 48 h ponding period, DMRP concentration increased from 0.14 to 0.68 mg $L^{-1}$ (Fig. 1d). This increase in DMRP concentration during ponding resulted in more DMRP entering the tile inlets than it was delivered to the pond.

Sediment and Nutrient Delivery Ratio

The amount of sediment, TP, DMRP and COD delivered to the pond and entering surface inlet are presented in Table 1. The two sequential rainfalls resulted in 420 kg $ha^{-1}$ of fine aggregates delivered to the ponding area, however, only 73 kg $ha^{-1}$ (17%) of very fine aggregates entered the tile lines. This suggests that ponding resulted in 83% of TS deposited in the inundated flat area around surface inlets. The inundated flat area around surface inlets functioned as a sedimentation pond and thus facilitated the gravitational settling of suspended solids (Jarret, 1993).

Due to sediment deposition, only 9.7 kg $ha^{-1}$ (15%) entered the surface tile inlet, compared to 65 kg $ha^{-1}$ COD delivered to the ponding area. Eighty five percent of the COD was deposited with the sediment in the inundated area around the inlet. Similarly, out of 724 g $ha^{-1}$

TP in the ponding area, only 189 g $ha^{-1}$ (26%) TP entered the tile inlet. Seventy four percent was deposited around the tile inlet. In contrast to COD and TP, these two sequential rainfalls delivered 34 g $ha^{-1}$ DMRP to the pond area but 45 g $ha^{-1}$ (141%) DMRP left the pond through the surface inlet.

## Simulated Intensive Rainfall

The amount of runoff and pollutant losses from the rainfall simulation study are presented in Fig. 2. Overall, sediment and phosphorus losses from the rainfall simulations were low, due to the gentle slope (1%) of the lacustrine landscape. Except for very low soybean residue cover, runoff was less than 10% of the applied intensive rainfall and sediment loss was less than 300 kg $ha^{-1}$. Maximum sediment loss was 1067 kg $ha^{-1}$ with 4% soybean residue cover. Total phosphorus losses was less than 45 g $ha^{-1}$. Although runoff and pollutant losses were low, the effect of tillage system was significant on the pollutant losses, which varied with the type and amount of residue cover.

### 1997 Simulation

Corn residue cover in the fall-moldboard system was 30% of that in the fall chisel based system, which resulted in 8 times more runoff (Fig. 2a). More residue cover reduced the heavy rainfall impact on surface sealing, increased infiltration, and slowed runoff. The time to initial runoff was twice as long with chisel plowing (59 min) compared to the moldboard system (31 min). Greater runoff also resulted in 10 times greater sediment loss from the fall moldboard system compared to fall chisel system (Fig. 2b). Total phosphorus loss was predominantly PP, associated with sediment losses. The DMRP loss is very small fraction of the TP loss (Fig. 2c).

Reduction of runoff and sediment losses with more surface residue in the fall chisel system resulted in 7 times less total P loss compared to fall moldboard chisel system.

### 1998 Simulation

Soybean residue cover in a fall-chisel system was 30% of that in fall no-till system. Runoff from the fall chisel system was 1.6 times higher than that of fall no-till system. (Fig 2a). The amount of sediment loss was five times higher in the fall chisel system compared to fall no-till system. Similarly TP loss was 1.4 and DMRP loss was 2.2 times higher in fall chisel system compared fall moldboard system (Fig.2c). In summary, in 1998, the fall no-till after bean tillage system produced much lower pollutants in runoff compared to the fall chisel after bean tillage system.

## CONCLUSIONS

There has been much speculation that surface tile inlets are major contributors to the degradation of surface waters with very little field scale measurements to support it. The watershed study showed that during large runoff events (which are responsible for most of the losses during channelized overland flow) particulate pollutant losses into surface tile inlets are reduced because of water ponding in the depressional area around surface inlets. The TS entering surface tile inlets were predominantly clay-size aggregates. Deposition of TS during prolonged ponding after major storms facilitated reduction of particulate P, TP, and COD losses. Prolonged ponding, however, increased dissolved molybdate reactive P (DMRP) losses by dissolution of soil P. A plot scale study under simulated intensive rainfall showed that pollutant losses are generally low. Residue management further reduces pollutant losses from these soils.

An aggressive soil and water conservation tillage system in a corn-soybean rotation is an effective way to reduce sediment and nutrients losses from lacustrine landscapes even during a heavy and intense rainfall.

## ACKNOWLEDGMENT

The authors thank the Tilney Farms, L.L.P., Lewisville, MN for the invaluable field assistance. This project is a contribution from the Department of Soil, Water, and Climate, University of Minnesota, St. Paul, MN 55108 and the Minnesota Agric. Exp. Stn. Partial funding for this research was provided by the Minnesota Legislature, ML 1995, Chapter 220, sec.19, subd. 5(h), as recommenced by the Legislative Commission on Minnesota Resources from the Minnesota Future Resources Fund.

## REFERENCES

Drury, C.F., C.S. Tan, J. D. Gaynor, T.O. Oloya, and T.W. Welacky. 1996. Influence of controlled drainage-subirrigation on surface and tile drainage nitrate loss. J. Environ. Qual. 25:317-324.

Edwards, W.C., and L. B. Owens. 1991. Large storm effects on total soil erosion. J. Soil Water Conserv. 46:75–78.

Ginting, D., J.F. Moncrief, S.C. Gupta, and S.D. Evans. 1998. Corn yield, runoff, and sediment losses from manure and tillage systems. J. Environ. Qual. 27:1396-1402.

Golden Software Inc., 1996. Surfer® for windows. Version 6. Contouring and 3D surface mapping. Golden, CO.

Jarret, A.R. 1993. Design of perforated risers to control dewatering of sedimentation basins. Applied Eng. Agric. 9:37–42.

Kladivko, E.J., G.E. Van Scoyoc, E.J. Monke, K.M. Oates, and W. Pask. 1991. Pesticide and nutrient movement into subsurface tile drains on a silt loam soil in Indiana. J. Environ. Qual 20:264–270.

Laflen, J.M., M. Amemiya, and E.A. Hintz. 1981. Measuring residue cover. J. Soil Water Conserv. 32:341–343.

Murphy, J., and J. Riley. 1962. A modified single solution method for the determination of phosphate in natural waters. Anal. Chem. Acta 27:3–36.

Olsen, S.R. and L.E. Sommers. 1982. Phosphorus. *In* A.L. Page et al. (ed.) Methods of soil analysis. Part 2. 2nd ed. Agronomy 9:403–430.

Sharpley A. N., L.R. Ahuja, M. Yamamoto, and R.G. Menzel. 1981. The kinetics of phosphorus desorption from soil. Soil Sci. Soc. Am. J. 45:493–496.

U.S. EPA. 1979. Methods for chemical analysis of water and wastes. U.S. Government Printing Office. Washington, DC. EPA-600/4-79-020.

U.S. EPA. 1981. Procedures for handling and chemical analysis of sediment and water samples. US Environmental Laboratory. US Army Engineer Water Ways Exp. Stn., Vicksburg, MS.

Table 1. Delivery ratios of sediment, COD and phosphorus from lacustrine watershed with surface inlets during heavy storms on 20 and 22 July 1997, Watonwan County, MN.

| Pollutants | Entering the pond (a) | Entering Surface Inlet (b) | Delivery Ratio (b/a) |
|---|---|---|---|
| Total Solid (kg $ha^{-1}$) | 419 | 73 | 0.17 |
| COD (kg $ha^{-1}$) | 65 | 10 | 0.15 |
| TP(kg $ha^{-1}$) | 724 | 145 | 0.20 |
| DMRP(kg $ha^{-1}$) | 34 | 45 | 1.32 |

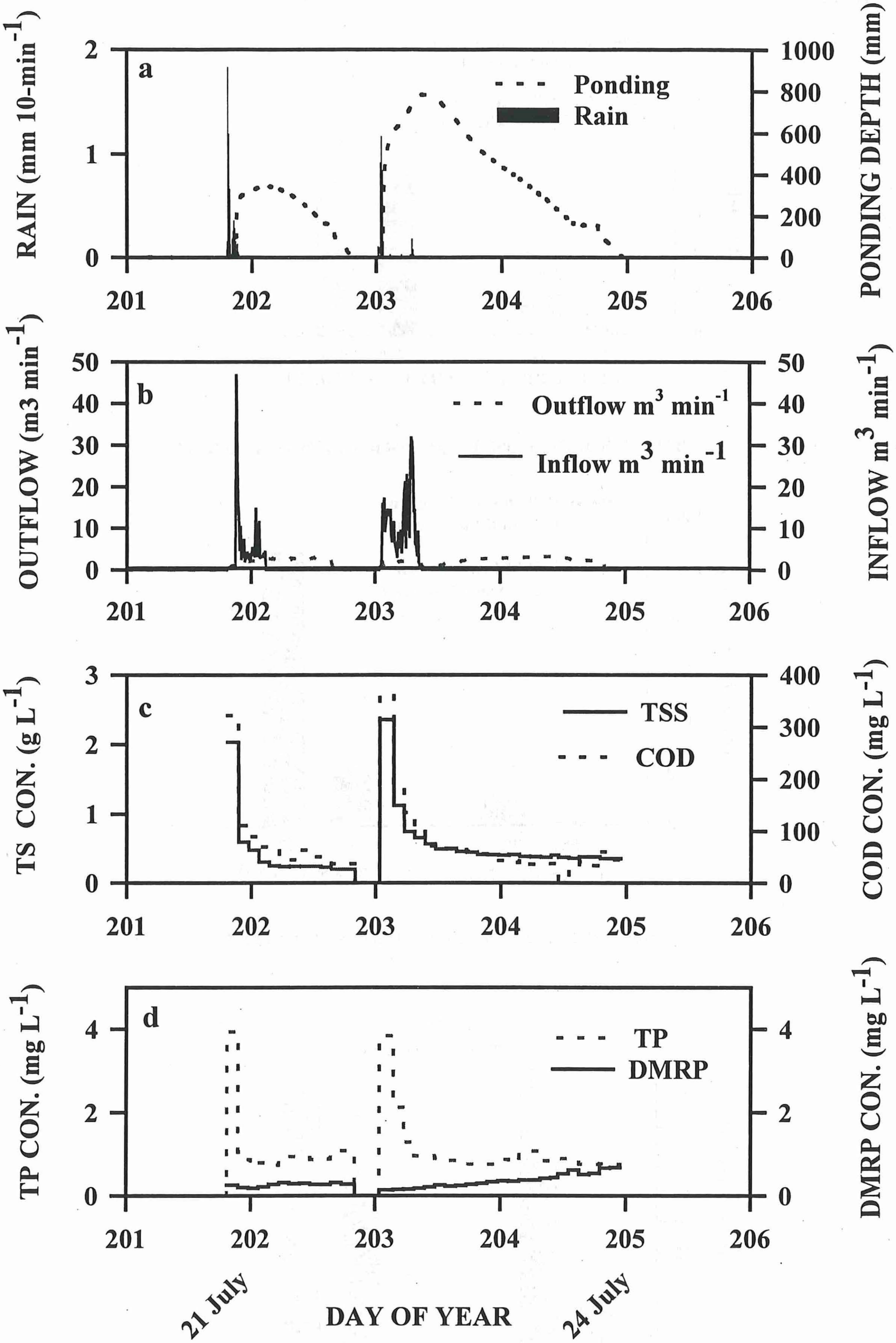
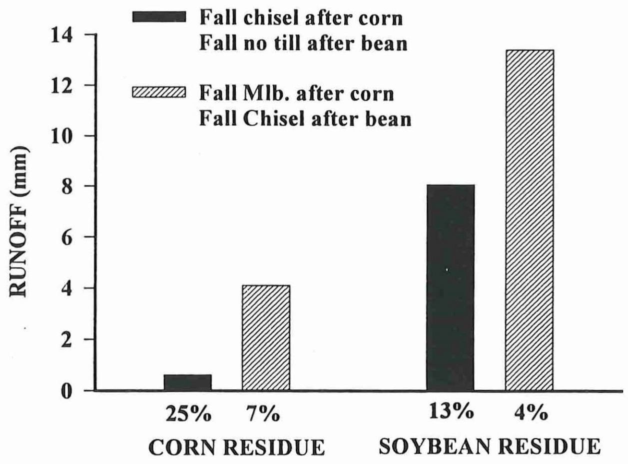


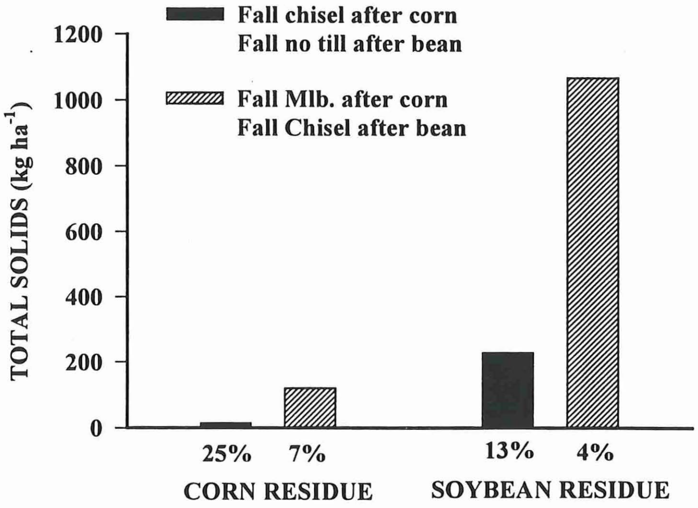
Fig. 1. The dynamics of a) rainfall and runoff ponding , b) inflow hydrograph in the pond and outflow hydrograph into surface inlets, c) TS and COD concentrations, and d) TP and DMRP concentrations

APPENDIX 2

SURFACE RUNOFF FROM 100 mm SIMULATED RAIN



TOTAL SOLIDS LOSS FROM 100 mm SIMULATED RAIN



PHOSPHURUS LOSS FROM 100 mm SIMULATED RAIN

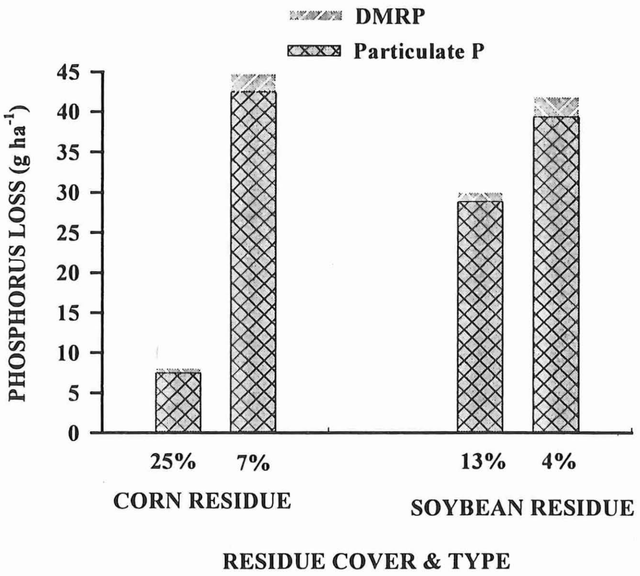


Fig. 2. The effect of tillage system on surface residue cover and losses of: a) runoff, b) total solids, and c) phosphorus, under simulated heavy rainfall.

## Crop Yield and Residue Management Systems on Poorly Drained Landscapes

To evaluate the profitability of the conservation (no till after bean-chisel after corn) and conventional (chisel after bean-moldboard after corn), strips about 2/3 mile long and 90 feet wide and replicated 6 times are being farmed on a field with glacial lake bed and glacial till soils (Fig.1). Sequence of field operations in each tillage system is also presented in Fig. 1. For example of tillage systems in 1998 following soybean were:

- Conservation tillage strips were not tilled in the fall 1997, field cultivated on 23 April, planted to corn on 24 April 1998, harrowed on 5 May 1998, rotary hoed on 19 May, and harvested and chisel plowed in November 1998.
- Conventional tillage strips were chiseled in the fall 1997, field cultivated on 23 April, planted to corn on 24 April 1998, harrowed on 5 May 1998, rotary hoed on 19 May, harvested and chisel plowed in November 1998.

In the conservation tillage system, the average corn surface-residue cover was 24% compared to 7% in conventional tillage system after bean planting in 1997. In 1998 after field cultivation and rotary hoeing, the average soybean residue cover in conservation tillage system was 13% compared to 4% in conventional tillage system

Statistical analysis indicated that soybean yield in 1997 under conventional tillage system was 0.1 Mg ha$^{-1}$ higher than conservation tillage system (Table 1). Corn yield in 1998, however, was similar between both tillage system.

Table 1. The effects of conservation and conventional tillage system on soybean and corn yield.

| | 1997 Following Corn | | 1998 Following Bean | |
|---|---|---|---|---|
| System | Tillage | Soybean yield | Tillage | Corn yield |
| | | Mg ha$^{-1}$ | | Mg ha$^{-1}$ |
| Conservation | Fall Chisel | 2.6b | Fall No-till | 8.1a |
| Conventional | Fall Moldboard | 2.7a | Fall Chisel | 8.2a |

Yield values in the same column followed by the same letter are not statistically significant at statistic $P \leq 0.05$.

Overlaid maps of soil and crop yield indicated that soil and landscape position (not soil type) had greater effects on soybean yield in 1997 (Fig. 2). During this wet year, eastern side of the landscape had lower yield than the western side due to excess moisture in the lower eastern side. In 1998, the landscape and soil type effects were not visible on corn yield. In 1998, we observed corn lodging due to wind damage, which probably contributed to corn yield variability.

Based on these two years data, there is a risk of lower yield with the application of conservation tillage system in poorly drained lacustrine landscape. The yield reduction may not be significant considering higher energy requirements in conventional tillage systems compared to conservation tillage system. There is a need for along-term yield data, which will produce a more quantitative and reliable risk assessment of yield performance of lacustrine landscape.

Figure 1. Yield trial for conservation and conventional tillage systems in a corn-bean rotation, Tilney Farm.

Soil

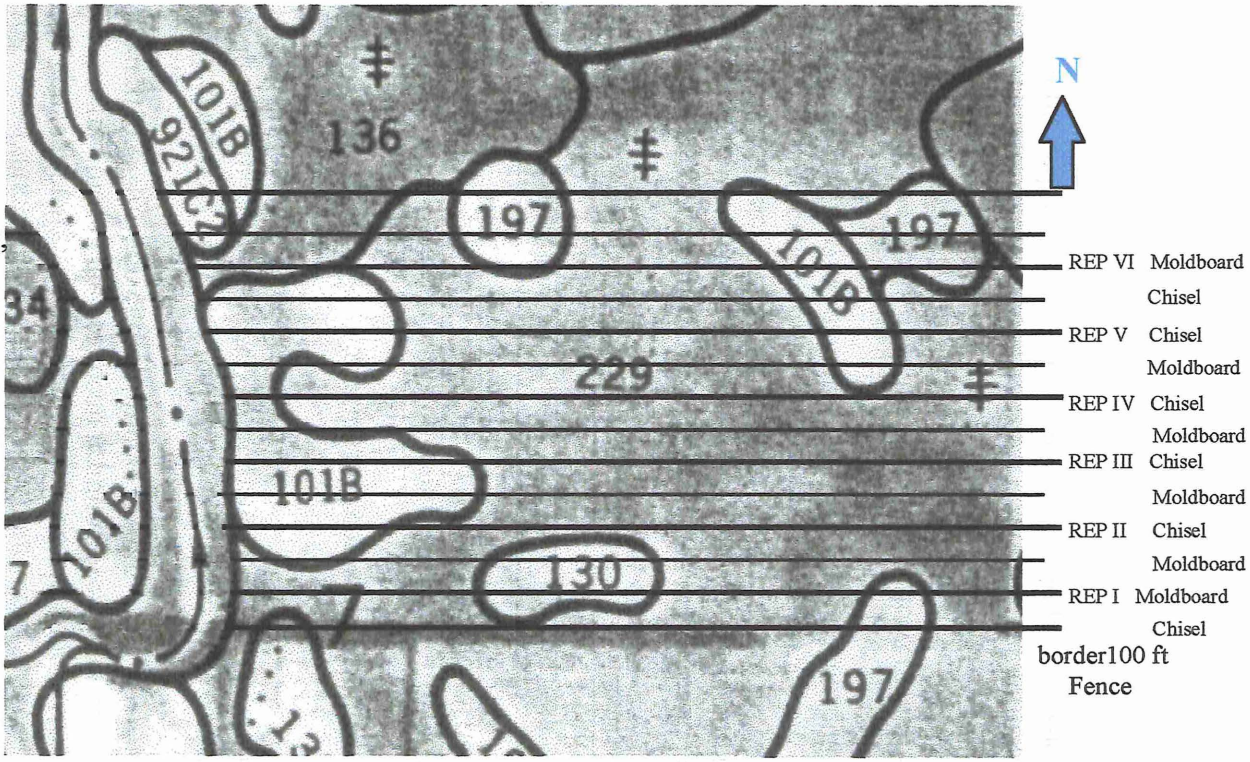
101B =Truman silt loam (Typic Hapludolls), 1 to 4 % slopes, rises on lake plains

130 =Nicollet loam (Aquic Hapludolls), low rises on till plains

197 =Kingston silty clay loam (Aquic Hapludolls), low rises on lake plains

229 =Waldorf silty clay loam (Typic haplaquolls), low lying flats on lake plains

921C2=Clarion (Typic Hapludolls )-Storden (Typic Udorthents) loams, 6 to 12 % slopes, eroded



Treatments for strips of 90-ft width

| | 1997, Following Corn | | | 1998, Following Soybean | | | |
|---|---|---|---|---|---|---|---|
| Tillage | F all 1996 | Spring 1997 | Summer 1997 | F all 1997 | Spring 1998 | Summer 1998 | Fall 1998 |
| Conventional | chop stalk moldboard | field Cultivtion, harrowing, bean planting | 2 row cultivate | bean harvest<br>anh ammonia<br>chisel | field Cultivation corn planting, harrowing | rotary hoeing | corn harvest |
| Conservation | chop stalk chisel | field Cultivation harrowing, bean planting | 2 row cultivate | bean harvest<br>No till<br>anh. ammonia | field cultivation corn planting, harrowing | rotary hoeing | corn harvest |

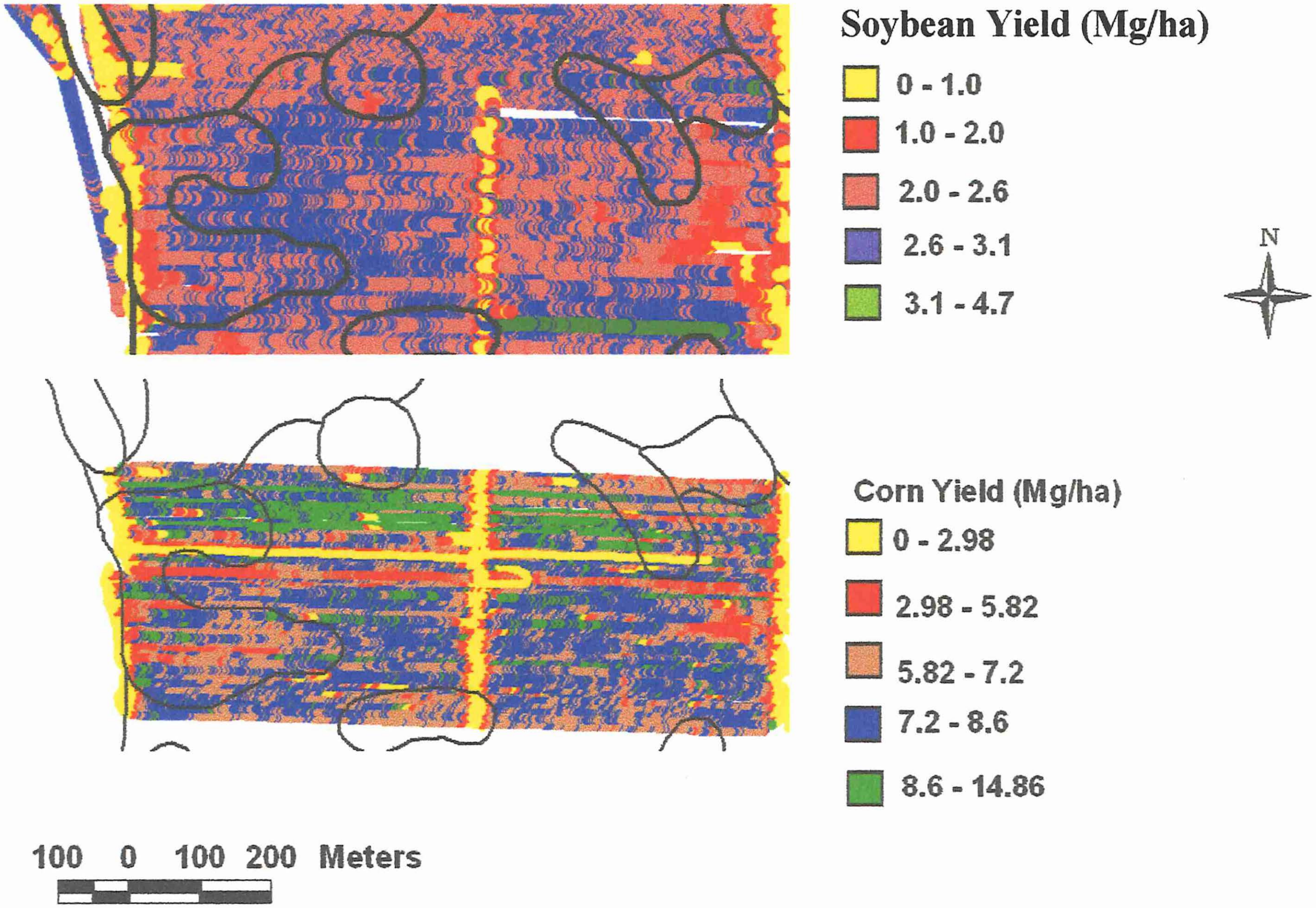


Figure 2. Distribution of soybean and corn yield across the lacustrine landscape. Yellow pixels in the center and edge of field are head rows. Soybean yield (red and yellow pixels) was low at lower part of the landscape in 1997. At the same location, small area of low corn yield was due to excessive water during harvest.

Tilney Farm Field Day, 13 August 1998

# WATER QUALITY RESEARCH

## INTRODUCTION

A substantial portion of the total sediment load and associated pollutants to the Minnesota River are from the Blue Earth Subasin (includes the Watonwan, Blue Earth, and LeSueur tributaries). Since crop residue management is the most cost effective method of reducing runoff and erosion, this study is designed to evaluate a promising alternative to a moldboard based tillage system by utilizing a rather unique form of chisel plowing. sel tillage is done with a parabolic shank equipped with wings that is can be pulled 10-14 inches deep (although deep tillage is not likely to be cost effective). The study area is located on glacial lake bed sediments that have soils with very poor drainage (soils developed in these sediments are called lacustrine) . For this reason they are fairly responsive to tillage.

In the last Tilney Farm field day, we presented the background and the objective of this study i.e. :
1) How effective are residue management systems (chisel plow based) on reducing runoff losses on these soils and landscapes?
2) Is there a risk of yield loss on these soils with chisel plow based residue management systems?

This year we are presenting answers to these two questions.

## RUNOFF STUDY

There are two runoff studies. One is monitoring runoff from watersheds due to natural rain or snow melt (see picture above). In this study several surface tile inlets are being monitored. The other one is using simulated rainfall with a rain machine.

### 1 Watershed.

Most investigation on the effects of conservational tillage on quantity and quality of surface runoff from agricultural land have used small plots. The small plots observations is useful for more detail investigation on processes and making treatment comparisons in a more controlled or less spatial variability. However, apolating the treatment effects on small plot can overestimate the treatment effects on a watershed scale. e of the reasons commonly given are greater deposition of sediment and retardation of runoff in a depressional landscape in the watershed, complex slope attributes and greater soil spatial variability. For evaluation of tillage effects on water quality in a larger scale, such as river basins, watershed scale is more appropriate. Particularly the watershed that drained to a waterways either naturally or by anthropogenic structure such as tile inlet.

Ideally, watershed should be selected on the basis of representativeness of a region so that the results obtained can be transferred to unmeasured watershed with similar characteristics.

Many investigators has used watershed in their investigation to compare the losses from watershed. This comparison however was not calibrated or replicated, i.e, the differences between watershed not limited by the treatment effects, but also by many uncountable variabilities in the watersheds. Paired watershed approach has emerged as a principle means to avoid the uncountable variabilities. Paired watershed use a control catchment and one or more catchment to be treated. The catchments are selected in similarity of size, shape, topography, crop, and land use. Typically the watersheds are first calibrated against each other for a period long enough to be confident for establishing the response of one watershed to the other on varieties of runoff events. This calibration data is also called baseline data. Following the calibration period, a treatment is imposed on one or more watershed while the control is left undisturb, and the effects of the treatments are measured as departure from its calibrated behavior. If the characteristics of the control watershed have remained unaltered, the changes in the water yield are attributed to the treatment.

This paired watershed study has been running since fall 1995. We are establishing baseline data. The data we presented in this paper are baseline data. At the present time both fields are being farmed with the chisel based tillage system for corn and soybeans in rotation (see tillage definitions on illustration). In the fall of 1998 one field will be farmed with a moldboard based system. The change in runoff losses will quantitatively show the impact of the residue management system on losses.

***Materials and Methods***. Two fields, hereafter named watershed W20 (97 acres) and watershed W15 (114 acres) presented in Fig. 1, with surface tile inlets have been monitored since 1996. The volume of flow has been measured and grab samples taken for chemical analysis year around (both snow melt and rainfall runoff). At the present time both fields are being farmed with a chisel based tillage system for a corn and soybeans rotation.

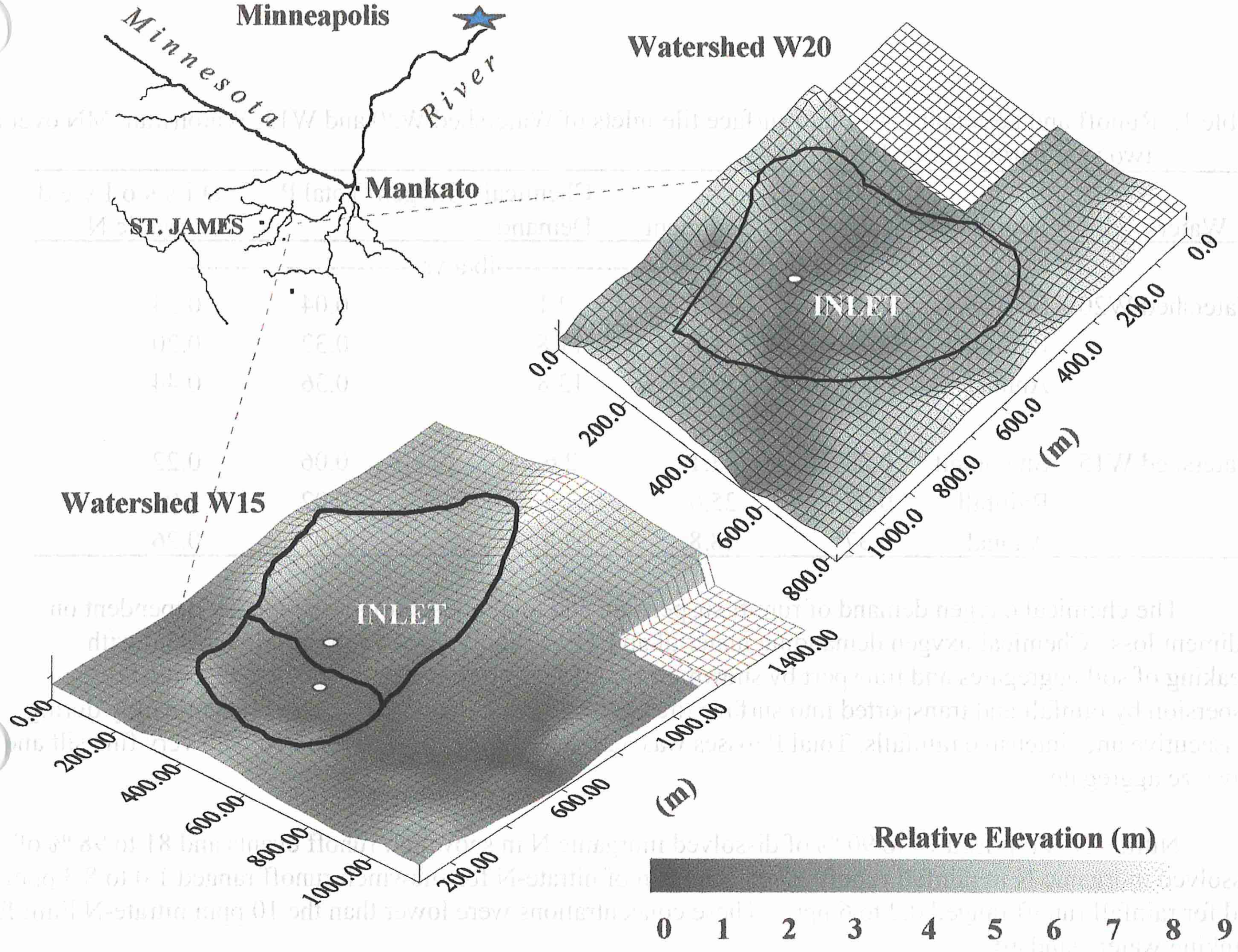
Watershed W20 was cropped to soybean in 1995. Field operations in subsequent years were: no fall tillage and anhydrous ammonia injection (150 lb/a $NH_3$-N) after soybean harvest in October 1995; field cultivation and corn planting in May 1996 followed by two row-cultivations, once in June and once in July; corn harvest followed by chisel plowing in October 1996; field cultivation, navy bean planting, and dragging in May 1997; and navy bean harvest in October 1997.

Watershed W15 was also cropped to soybean in 1995. Field operations in subsequent years were: no fall tillage and anhydrous ammonia application (150 lb/a $NH_3$-N) after soybean harvest in October 1995; field cultivation and corn planting in May 1996 followed by two row- cultivations, once in June and once in July 1996; corn harvest followed by chisel plowing in November 1996; field cultivation, soybean planting and dragging in May 1997; and soybean harvest in October 1997.

In the fall of 1998 one of the paired watersheds will be farmed with a moldboard based system.

***Results.*** Surface Runoff, sediment, nutrient losses, and oxygen demanding materials in both snowmelt runoff an rainfall runoff were given in Table 1.

Snowfall amount in 1996 and 1997 were 6.5 and 8.3 inch, respectively. About 70% was blown from the watershed. Snowmelt runoff was 4% of the average annual snowfall or 13% of remaining snowpack. The



rainfall distribution was different between the W20 and W15 watersheds although only 5 miles apart. Total rainfall was 9.3 inch (60 daily rainfalls) in 1996 compared to 16.7 inch (71 daily rainfalls ) in 1997 in watershed W20. Since most rainfalls in 1996 were small and of low intensity, there was no rainfall runoff in W20. In 1997, 15% of four rainfalls totaling 5.2 inch because surface runoff in W20. For watershed W15, the total rainfall was 10.2 inch (64 daily rainfalls) in 1996 compared to 15 inch (68 daily rainfalls) in 1997. These rain were small and had low intensity. Runoff was 1.6% of three rainfall events totaling 2.7 inch in 1996 and 2.1% of three rainfall events totaling 0.3 inch in 1997.

Due to the concave shape of the watershed landscape, gentle slope and ponding around the surface inlets during the runoff events, coarse sediment was deposited away from tile inlets. Sediment loss into tile inlets was mainly very fine silt and clay size aggregates. Flow weighted concentrations of SS in snowmelt runoff ranged 90 to 410 ppm whereas in rainfall runoff SS concentrations ranged from 230 ppm to 13,900 ppm. High centration of sediment in rainfall runoff is associated with small rainfall runoff.

Table 1. Runoff and pollutant losses into surface tile inlets of Watershed W20 and W15, Watonwan, MN over a two year period (1995-1997).

| Watershed | Source | Runoff | Sediment | Chemical Oxygen Demand | Total P | Dissolved inorganic N |
|---|---|---|---|---|---|---|
| | | inch | --------------------------lb/a/yr | | | ------------------------- |
| Watershed W20 | Snowmelt | 0.28 | 22.1 | 2.1 | 0.04 | 0.24 |
| | Rainfall† | 0.77 | 89.3 | 11.8 | 0.32 | 0.20 |
| | Annual | 1.06 | 111.4 | 13.8 | 0.36 | 0.44 |
| Watershed W15 | Snowmelt | 0.30 | 23.1 | 2.6 | 0.06 | 0.22 |
| | Rainfall | 0.07 | 25.6 | 1.3 | 0.02 | 0.04 |
| | Annual | 0.37 | 48.8 | 3.8 | 0.08 | 0.26 |

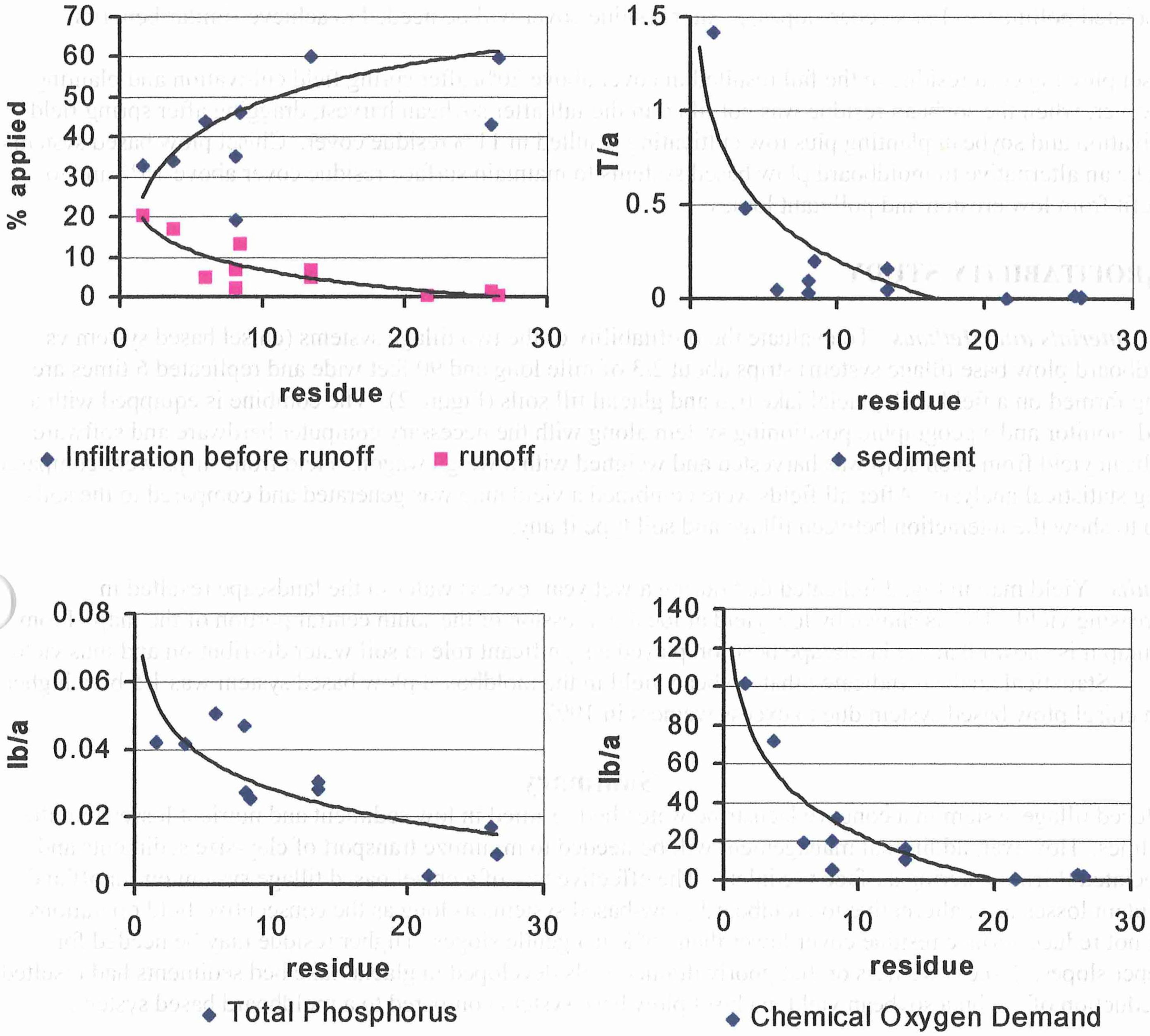
The chemical oxygen demand of runoff suspension and total phosphorus were greatly dependent on sediment loss. Chemical oxygen demanding material and TP in runoff suspension were associated with breaking of soil aggregates and transport by snowmelt runoff during snowmelt or soil detachment/clay dispersion by rainfall and transported into surface tile inlet by runoff. Total P loss was predominantly during consecutive and intensive rainfalls. Total P losses was less than 0.5 lb/a/year, associated with very fine silt and clay size aggregate.

Nitrate N comprised 70 to 90 % of dissolved inorganic N in snowmelt runoff events and 81 to 98 % of dissolved inorganic N in rainfall runoff. Concentration of nitrate-N for snowmelt runoff ranged 1.0 to 8.3 ppm and for rainfall runoff ranged 0.2 to 6 ppm. These concentrations were lower than the 10 ppm nitrate-N limit for drinking water standard.

## 2 RAINFALL SIMULATION.

***Method and Materials.*** Rainfall simulation was conducted on strips with chisel and moldboard plow based systems. The slope is 1%. After corn harvest in 1996 the land strips was either chiseled or moldboard plowed. In the spring 1997, tillage strips were field cultivated and planted to soybean. At 2-trifolia growth stage on 2 June 1997, rainfall simulation was conducted for three replication of the tillage strips. There was 25% and 7% corn residue cover for the chisel and moldboard based tillage systems, respectively. After soybean harvest, chisel-tillage strips were not tilled in the fall, field cultivated in the spring 1998, planted to corn and dragged. Moldboard-plow tillage strips were chiseled in the fall, field cultivated in the spring 1998, planted to corn and dragged. Rainfall simulation was done on 10 June 1998 for three replication of the tillage strips after row cultivation when corn had 3 leaves. There was on the average of 11% and 6% corn residue cover for the chisel and moldboard based tillage systems, respectively.

In each tillage strip, 24-ft by 30-inch runoff plots were prepared with currogated metal borders and collection troughs. Using a rain machine, we applied rainfall at the rate of 2.5 inch/hr until steady state runoff measurements were obtained. After initiation of runoff, one-minute water samples were taken for every 5 minutes of runoff. Three samples were combined and sub-sampled for measurements of sediment, phosphorus, and chemical oxygen demand (COD) for the runoff suspension. The COD-equivalent organic carbon was



calculated from the COD.

***Results:*** The effect of residue management on simulated rainfall runoff are summarized in Fig. 2. From the 4 h of rainfall applied, more than 50% (2 inch) infiltrated before the onset of runoff when surface residue cover

Fig. 2. The effects of residue cover on: a) water infiltration before runoff and surface runoff, b) sediment losses, c) Total Phosphorus loss and d) Chemical Oxygen Demand.

was greater than 15% (Fig 2a). At this level of residue cover, the amount of runoff was less than 5% (0.2 inch) of the applied 4-inch rainfall. Consequently, sediment loss was less than 0.1 T/a (Fig. 2b), total P loss was less than 0.03 lb/a (Fig 2c) and chemical oxygen demand was less than 10 lb/a (Fig. 2d) if surface residue cover was at 15% or more. These data illustrate the effectiveness of surface residue cover on runoff losses of sediment and associated pollutants. For steeper slopes, greater residue cover will be needed to achieve similar benefits.

Chisel plowing corn residue in the fall resulted in cover above 20% after spring field cultivation and planting. However, when the soybean residue was not tilled in the fall after soybean harvest, dragging after spring field cultivation and soybean planting plus row cultivating resulted in 11% residue cover. Chisel plow based systems will be an alternative to moldboard plow based systems to maintain surface residue cover above 15% and to benefit from low erosion and pollutant losses.

## PROFITABILITY STUDY

***Materials and Methods***. To evaluate the profitability of the two tillage systems (chisel based system vs moldboard plow base tillage system) strips about 2/3 of mile long and 90 feet wide and replicated 6 times are being farmed on a field with glacial lake bed and glacial till soils (Figure 2). The combine is equipped with a yield monitor and a geographic positioning system along with the necessary computer hardware and software. Soybean yield from each strip was harvested and weighed with a weigh wagon. Yield from strips were compared using statistical analysis. After all fields were combined a yield map was generated and compared to the soils map to show the interaction between tillage and soil type if any.

***Results***. Yield map in Fig. 3 indicated that during a wet year, excess water in the landscape resulted in decreasing yield. This is shown by low yield at local depression of the south central portion of the map. From the map it is shown that the landscape position played a significant role in soil water distribution and thus yield.

Statistical analysis indicated that soybean yield in the moldboard plow based system was 1.5 bu/a higher than chisel plow based system due to excess wetness in 1997.

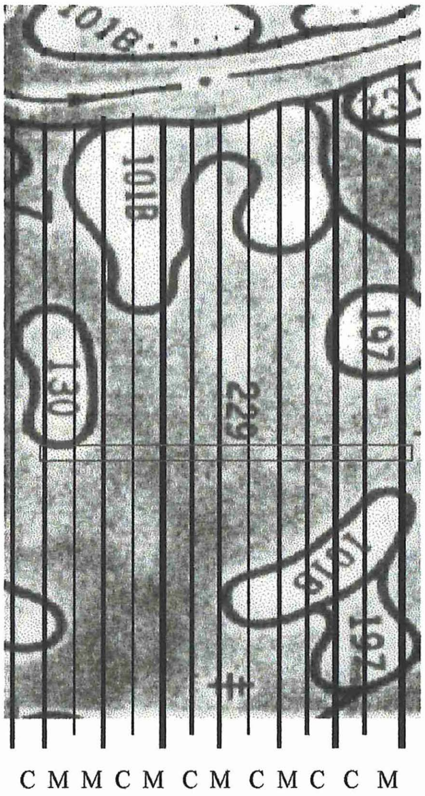
## Summary

Reduced tillage system in a concave lacustrine watershed resulted in low sediment and nutrient losses into the tile lines. However, additional management will be needed to minimize transport of clay-size sediments and associated P from entering surface tile inlets. The effectiveness of a chisel based tillage system on runoff and pollutant losses is an alternative to moldboard plow-based systems as long as the consecutive field operations will not reduce surface residue cover lower than 15% in a gentle slopes. Higher residue may be needed for steeper slopes. Excess wetness on flat poorly drained soils developed in glacial lake bed sediments had resulted in reduction of 1.5 bu/a soybean yield in chisel plow base system compared to a moldboard based system.

---

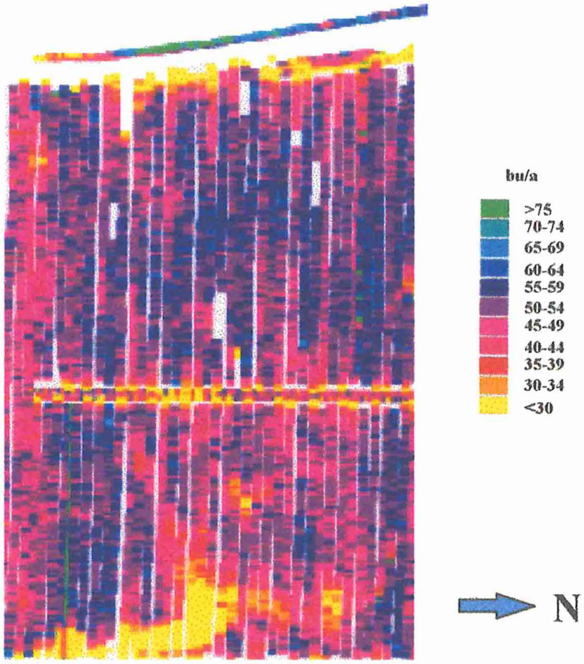
Edited by **D. Ginting, J.F. Moncrief, and S.C. Gupta**, Post-doctoral Associate and Professors, respectively.

This research is supported by the Minnesota Department of Agriculture, the University of Minnesota, and the Legislative Commission on Minnesota Resources. All are appreciative for the assistance and cooperation of the Tilney Farm. This farm has unique soils and landscapes that are not represented at agricultural experiment stations. Without the assistance of numerous specialists and scientists of the University of MN and the MN Department of Agriculture this project could not have been done. For more information contact Tom M.Urevig Manager, Tilney Farm, Lewisville, MN; John F. Moncrief, Professor, Department of Soil, Water, and Climat University of Minnesota, St. Paul, MN; or Gerald Heil, Divison Director, MN Department of Agriculture, St. Paul, MN.



C = Chisel based system

M= Moldboard based system



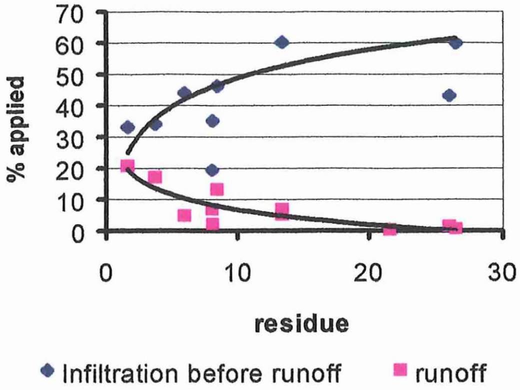
Soil:
101 B =Truman silt loam (Typic Hapludolls), 1 to 4 % slopes, rises on lake plains
130 =Nicollet loam (Aquic HapludollsI, low rises on till plines
136 =Madelia silty clay loam (Typic Haplaquolls), low lying flats on lake plains
197 =Kingston silty clay loam (Aquic Hapludolls), low rises on lake plains
229 =Waldorf silty clay loam (Typic Haplaquolls), low lying flats on lake plains

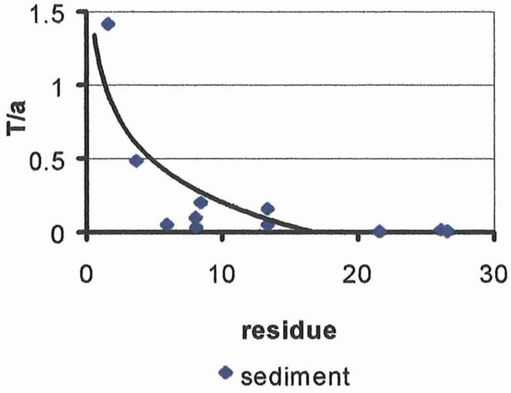
**Treatments for strips of 27-m width**

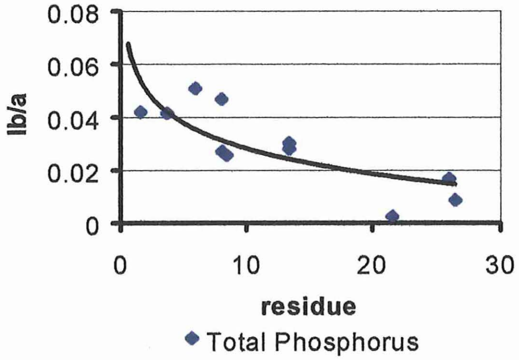
| Following Corn 1996 | | | | Following soybean 1997 | | | |
|---|---|---|---|---|---|---|---|
| Tillage | Fall 1996 | Spring 1996 | Summer 1997 | Tillage | Fall 1997 | Spring 1998 | Summer 1998 |
| Moldboard | Chop stalk<br>Moldboard | 2x field cultivate<br>rotary hoe, drag | 2x row cultivate | Moldboard | anh. ammonia<br>Moldboard | 2x field cultivate<br>Rotary hoe, drag | 2x row cultivate |
| Chisel | Chop stalk<br>Moldboard | 1 field cultivation<br>rotary hoe, drag | 2x row cultivate | Chisel | anh. ammonia<br>Chisel | 1x field cultivate<br>Rotary hoe, drag | 2x row cultivate |

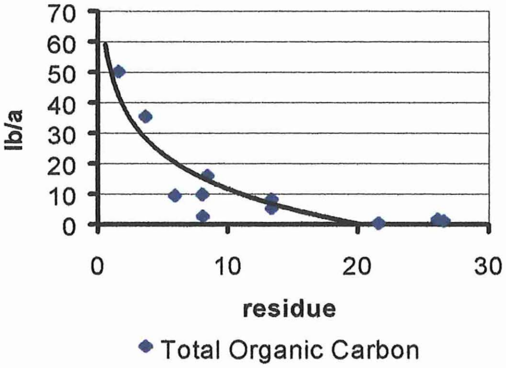
## Residue Cover Effects on Erosion and Nutrient Losses During Intense Simulated Rainfall

**Location: Tilney Farm, Watonwan Co. Soil: Waldorf (Typic Haplaquoll)**
**Land Slope = 1% Rainfall Simulation: Intensity 2.5"/hour Total Application = 4"**









**SUMMARY:** For a very gentle slope lacustrine landscape of south central Minnesota, tillage operations that maintained 15% or more residue cover after planting resulted in :

1. More than 50% of the total applied rainfall infiltrated into the soil before the runoff started.
2. Less than 5% of the applied rain ran off.
3. Sediment loss was less than 0.1 T/a.
4. Total P loss was less than 0.03 lb/a.
5. Total organic carbon loss was less than 5 lb/a.

**For Further information, please contact:**
Daniel Ginting, 612-624-7737, email: dginting@soils.umn.edu and John Moncrief, 612-625-2771, email:moncrief@soils.umn.edu, Department of Soil, Water and Climate, University of Minnesota, and Mark Zumwinkle, 612-282-6204, MN. Department of Agriculture.