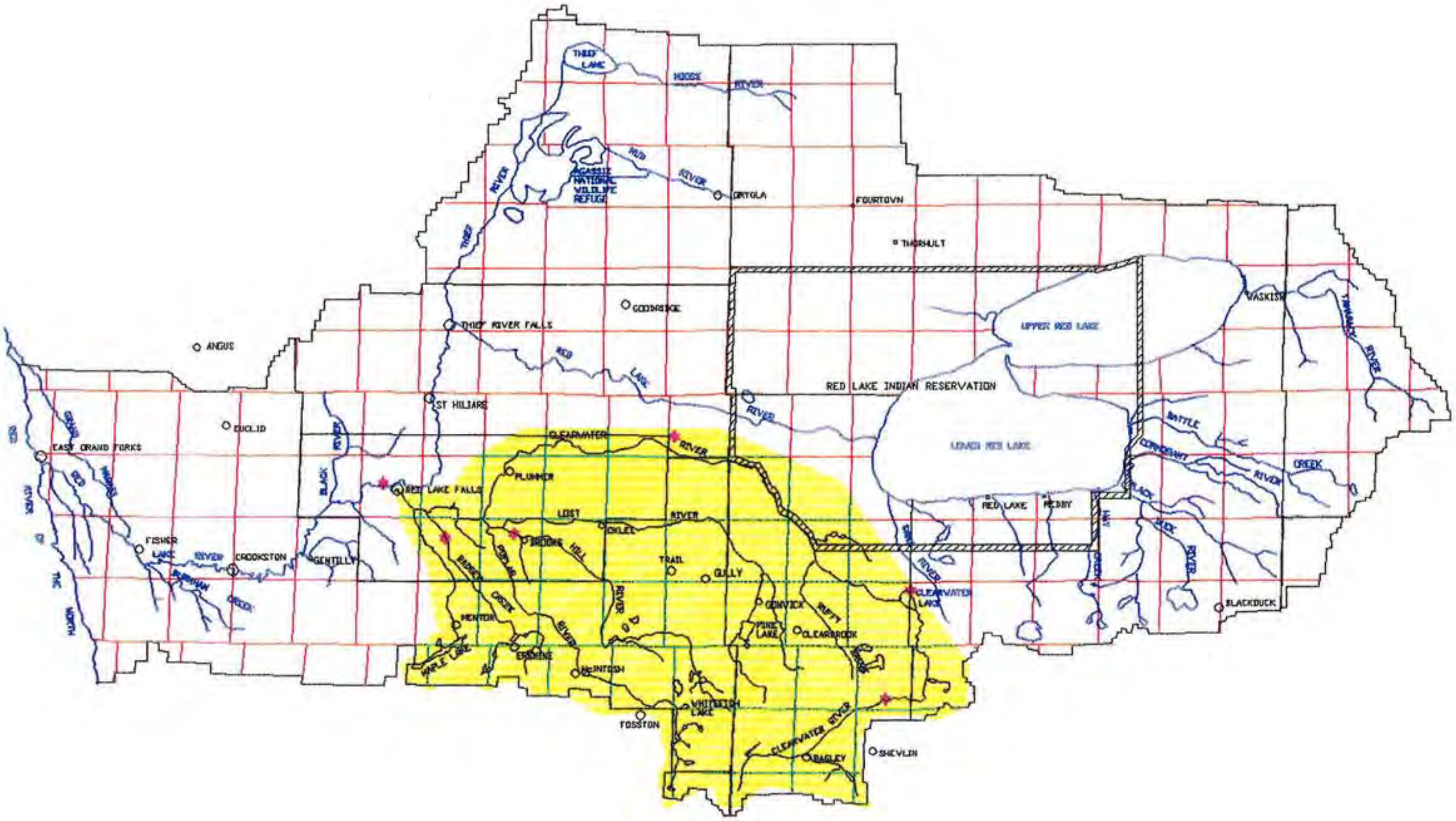
CLEARWATER RIVER ENVIRONMENTAL STUDY

RED LAKE WATERSHED DISTRICT

Project No. 72

August 1991



<u>Cooperating Agencies</u>

Red Lake Watershed District
Northwest Experiment Station, University of Minnesota, Crookston
International Coalition
Soil and Water Conservation District
Soil Conservation Service

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TABLE OF CONTENTS

Appendix

Tables

CLEARWATER RIVER ENVIRONMENTAL STUDY

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INTRODUCTION

The Clearwater River, which traverses portions of Polk, Pennington, Beltrami, and Clearwater Counties and most of Red Lake County, serves as a recreational/fishing water body, a water source for wild rice irrigation and discharge, and a waste water discharge area for the communities of Plummer and Bagley. The river also serves as a source of freshwater for a fishery located adjacent to the river on the Red Lake Indian Reservation. The Clearwater River basin is characterized by diversified dryland agricultural production of small grain and row crops, as well as hay and livestock.

The goal of the Clearwater River Environmental Study, proposed under the Minnesota Board of Water and Soil Resources Environmental Agriculturalist Education program was to:

> improve the knowledge and understanding of agricultural producers in the Clearwater River Basin and propose to them how they can alter their land management practices to provide a greater degree of surface water, groundwater, and other natural resources protection.

The specific objectives undertaken to achieve this goal were to:

a) Complete an assessment of water quality problems associated with agricultural practices, i.e. pesticide applications related to the production of small grain, corn, potato, and wild rice.

b) Inform and advise agricultural producers on the impact of those farming practices to show the relationship between land management practices and water quality.

Testing of ten (10) common water quality parameters at four sites on the Clearwater River has been ongoing since 1984. This baseline information has continued to be collected, but was supplemented with analyses of pesticide concentrations and parameters related to chemical oxygen demand (COD). Concurrent with the collection of water and sediment samples, information was also collected relating to the Clearwater River basins land cover and land use, as well as additional information regarding human activities and natural forces that affect the quality of the Clearwater River.

ACCOMPLISHMENT OF OBJECTIVES

Objective 1

Complete an assessment of water quality problems associated with agricultural practices, i.e. pesticide application related to the production of small grain, corn, potato, and wild rice.

As indicated earlier, testing of ten (10) common parameters at four sites on the river has been ongoing since 1984. The present work goes beyond this baseline information, however, by incorporating data collection and analyses intended to determine pesticide concentrations and parameters related to chemical oxygen demand (COD). The study may also be useful in the future in assessing time series trends related to acid rain.

The following tasks were completed to achieve this objective:

- Selection of Sampling Sites

Seven sampling sites were selected for water and sediment analyses (Table 1). These sites have been selected as representative of the diversity of the river and the river basin and for their general proximity to the agriculture practices of interest, i.e. small grain, row crops, and wild rice. In addition to the seven river sampling sites for water and sediments, runoff sites were selected in a small grain field, a corn field, and a potato field. Also, a wild rice field was selected for collection of samples at the time of water release back into the river (Fig. 1, Table 1).

- Water Quality Parameters

Water and sediment samples were analyzed to determine whether identified site specific or seasonal water quality problems are associated with particular land use practices. This assessment was undertaken by the University of Minnesota, Northwest Experiment Station, Crookston, and the Red Lake Watershed District in consultation with the participating Soil and Water Conservation Districts (SWCD), and the Soil Conservation Service (SCS). Field and laboratory analysis of the samples for selected tests was performed by the University of Minnesota, Northwest Experiment Station, Crookston, and the Red Lake Watershed District. These analyses include: pH, temperature, turbidity, chemical oxygen demand (COD), dissolved oxygen (DO), total dissolved solids (TDS), conductivity, alkalinity, nitrate nitrogen, ammonia nitrogen, total nitrogen, ortho-phosphate, and total phosphorus. Analysis of pesticide concentrations was performed by Minnesota Valley Testing Laboratories in New Ulm, Minnesota and include the following pesticides: Atrazine, Alachlor (Lasso), Dicamba, 2,4-D, MCPA, Organo-phosphate screen, Trifluralin (Treflan), Metribuzen (Sencor), Phosphamidon, Furadan, Propiconazole (Tilt), Malathion, Cyanazine (Bladex), Assert, and Bromoxynil (Bronate).

- Sampling Frequency

Sampling events were as follows:

1. May 3, 1990 - Water and sediment samples at all river sites (1 through 7) - analyzed for all inorganic and all pesticide parameters. Samples for nitrogen and phosphorus were destroyed in shipping (Tables 2, 3, and 4).

2. May 30, 1990 - River sites 4 through 7 for all inorganic parameters. River sites 3 through 7 for Alachlor, Dicamba, 2,4-D, and Trifluralin (Tables 5 and 6).

3. June 4, 1990 - Runoff samples were collected from sites B, C, and D and analyzed for all inorganic parameters. Adjacent river sites (4, 5, and 6) were also collected and analyzed for all inorganic parameters. The following pesticide analyses were run on the same river and runoff sites: Dicamba, 2,4-D, Metribuzen, Phosphamidon, Assert and MCPA (Tables 7, 8, 9 and 10).
4. June 21, 1990 - Runoff samples at sites B, C, and D, and river sites 5 and 6 for inorganic analyses (Tables 11 and 12).
5. July 11, 1990 - River sites 1, 2, and 3 for inorganic analyses. Also runoff sites C and D for 2, 4-D, Bromoxynil, and MCPA as well as nitrogen and phosphorus (Tables 13 and 14).
6. August 3, 1990 - Water release at wild rice area and adjacent river sites for selected inorganic and selected pesticides (Table 15).
7. August 27, 1990 - All river sites and selected runoff sites for inorganic analyses and selected pesticides (Tables 16, 17, 18, and 19).
8. October 25, 1990 - Water and sediment samples at all river sites (1 through 7) for all inorganic and all pesticide parameters (Tables 20, 21, and 22).

•Time of Travel Study

A time of travel study from Clearwater Lake to Plummer was conducted by the Department of Natural Resources (DNR). The study has been completed for the same area at a low level flow in 1987. The current study was completed at high flow (Appendix i).

Objective 2

Inform and advise agricultural producers on the impact of farming practices, including use of geographic information systems (GIS) to show the relationship between land management practices and water quality.

The elements of the work plan to complete this objective included a series of workshops throughout a three-county area to increase the awareness of the relationships between land-use practices and water quality. Geographic information system (GIS) technology was used to report the findings of the water quality assessment, compare land characteristics which may impact the relationship between pesticides and water quality, and explore the land management practice that could be used.

The target audience for the workshops included farmers, county commissioners, CLWP Task Forces, watershed districts, soil and water conservation districts, township boards, commercial pesticide applicators, and other interested groups.

The following tasks were carried out to accomplish this objective:

- Land use - Geographic Information System (GIS) Strategy

  Data was gathered on pesticide application and chemical use in the study area.

  Pesticide data and sampling results generated by the study were entered into a GIS database.

- Education Strategy

1. Development of an educational program to increase the awareness of the relationships between land use practices and water quality and applications of GIS for land management.

2. Six workshops were conducted, two in each of the affected counties, to inform citizens of the study that was to be conducted. The dates and locations of the workshops were as follows:

   A. June 11, 1990 - Gully City Hall
   B. June 12, 1990 - McIntosh City Hall
   C. June 13, 1990 - Red Lake Falls City Hall
   D. June 14, 1990 - Plummer Community Center
   E. June 18, 1990 - Clearbrook Senior Citizens Center
   F. June 19, 1990 - Hickory Township Hall

3. Three workshops were conducted at the end of the study which incorporated the results of the water quality assessment. These workshops included overlaying sampled information on other land and water characteristics to determine the relationships between pesticides and water quality, and to explore land management practices that could be used to reduce pesticide movement to water sources. The dates and locations of these workshops were as follows:

   A. June 17, 1991 - Clearbrook Senior Citizens Center
   B. June 18, 1991 - Hickory Township Hall
   C. June 19, 1991 - Plummer Community Center

DISCUSSION

Selection of Sampling Sites

The major emphasis of this work on the Clearwater River was to conduct a general environmental study on 132.5 miles of river from Bagley to its confluence with the Red Lake River in Red Lake Falls. Upon traversing this area numerous times (once by aircraft), seven river sites were selected to represent, as best possible, the general land use and agricultural practices of interest in the area. As can be concluded upon examination of Figure 1, seven river sites do not adequately represent this 132.5 miles of river. Three rivers drain into the Clearwater River; the Poplar, the Lost and the Hill Rivers. Of these three rivers, only the Poplar River had a sampling site (Site 6, Table 1). Also, site 2 is the only sampling to represent the waters draining from the Clearwater Lake. More meaningful data could have been collected had there been sampling sites immediately before the lake, sites in the lake, and collections taken from the watershed around the lake.

In addition the seven river sites from which water and sediments were collected, several runoff sites were chosen with the cooperation of farmers with fields directly adjacent to the Clearwater River. Sites B, C, and D were selected to represent farming operations of potato, corn, and small grain respectively (Table 1). These sites were selected in the natural drainage of each respective field with the aid of diversion boards used to help funnel the water to a collection point. Also, one cooperator was selected to represent commercial wild rice production (Site A, Table 1).

Wild rice is an aquatic plant produced under flooded conditions. It is a typical practice of commercial wild rice producers to obtain water from the rivers to flood the paddies, and then to release this same water back into rivers before harvest. The same farm was used for collection of water at the time of water release back into the river (Sites L, M, O, and P, Fig.1 and Table 1). Table 15 shows the result of water released back into the river at the wild rice site. Sites O and M, which are up-river from rice paddy A, show higher levels of phosphorus than sites P or L which are down river from the rice paddy. The same general trend can be seen for nitrogen, but not for the other parameters. However, samples taken at sites 5 and 6 show a general return to background levels for most parameters.

Water Quality Parameters

The inorganic water quality parameters represent a relatively complete list of analyses for water bodies. Tables 24 through 32 show a general increase in most parameters throughout the growing season with a return to background levels by the 10/25/90 sampling date.

Nature of Potential Pollutants

Phosphorus: This element is an important plant nutrient which, in most aquatic situations, is the limiting factor in plant growth. Thus, if this nutrient can be controlled, many of the undesirable side effects of dense macrophyte growth and algae blooms can be avoided. The addition of small amounts of P can trigger these massive growths. Concentrations of less than 0.001 mg/L have been shown to support aquatic plant life. Algae blooms have occurred in water bodies when P concentration was no more than 0.01 mg/L. Usually the other necessary elements (carbon, nitrogen, light, and trace elements, etc.) are present in quantities sufficient to allow excessive growth of plants. Phosphorus, thus, is the limiting nutrient in plant growth in most aquatic situations.

Two forms of phosphorus are usually measured. Total P is the total amount of P in the sample expressed as mg/L as P, and soluble P or ortho P, that phosphorus which is dissolved in the water sample and is supposedly "available" to plants for uptake and growth. Both are valuable parameters useful in judging eutrophication problems.

Nitrogen: There are various forms of nitrogen which are measured in the laboratory using any number of approved methods. The most reduced form of nitrogen, ammonia (NH_3) is usually formed in the absence of dissolved oxygen and from the breakdown of proteins. Thus, high concentrations are sometimes found at or near the bottom of lakes or back waters of slow moving streams under anoxic conditions. Ammonia is reported as mg/L as N and is toxic in high concentrations to fish and other sensitive invertebrates. Ammonia is converted to nitrates (NO_3^-) when exposed to oxidizing effects of oxygen. Nitrite (NO_2^-) is a brief form intermediate between ammonia and nitrates, which is sometimes measured. Nitrites are rapidly converted to nitrates when adequate dissolved oxygen is present. Total nitrogen and nitrate are the commonly measured nutrient in aquatic studies and gives a good indication of the amount of this element available for plant growth.

Chemical Oxygen Demand: The chemical oxygen demand (COD) analysis indicates the quantity of oxidizable materials present in water.

Dissolved Oxygen: This dissolved gas is one of the most significant chemical substances in natural waters. It regulates the activity of the living aquatic community and serves as an indicator of aquatic conditions. Flowing waters are not normally as low in dissolved oxygen as are lakes. Most oxygen in water is the result of the photosynthetic activity of plants, turbulence of rapid flow, the algae, and aquatic macrophytes. Some oxygen enters the water through diffusion from atmospheric oxygen. Animals use this oxygen while giving off carbon dioxide (CO_2) during respiration.

Total Dissolved Solids: Total dissolved solids are made up primarily by inorganic salts with varying concentrations of organic matter. Contributory ions are mainly carbonate, bicarbonate, chloride, sulfate, nitrate, sodium, potassium, calcium and magnesium. Major contributions to total dissolved solids in water is the natural contact with rocks and soil with varying contributions from pollution in general, including runoff.

The purpose of this parameter is to evaluate and measure all suspended and dissolved matters in water. In spite of the chemical composition, solids are classified among the general parameters of water quality. Total solids content of 500 mg/L is a desirable upper limit, although, values of up to 1,000 mg/L of total solids have been found in drinking waters.

Conductivity: This measurement is a useful test in water for quick determination of minerals. Conductivity is a measure of the electric current in the water sampled carried by the ionized substances; therefore, the dissolved solids are basically related to this measure, which is also influenced by the good conductivity of inorganic acids, bases, and salts; and the poor conductivity characteristics of organic compounds.

Alkalinity: The amount of acid (H^+ ion) that needs to be added to a water sample to get a sample to a pH of 4.5 is a measure of the buffering capacity of the water and can be quantitatively determined as mg/L $CaCO_3$. This measurement is termed total alkalinity and serves as an indicator of basic productivity and an estimate of the total carbon source available to plants. Alkalinity is a measure of hydroxides (OH^-), carbonates ($CO_3^=$), and bicarbonates (HCO_3^-) present. Plants utilize carbon dioxide until that is exhausted and then begin to extract CO_2 from the carbonate-bicarbonate buffer system through chemical shifts. This decrease in CO_2 concentration causes great pH increases during the day and a pH drop during the night.

Turbidity: This parameter is a measure of light penetration reduction by both suspended and dissolved solids. Water with a high suspended solids content will usually have a high turbidity, but turbid water can also be caused by colored dissolved material. High turbidity reduces the depth of light penetration thus, reducing aquatic plant growth. Suspended solids can interfere with fish spawning by reducing oxygen transfer to eggs.

Fecal Coliform: This general group of bacterial organisms is extremely important in the biology of water bodies in that they are responsible for all the decomposition that occurs in the water as well as many chemical transformations. Fecal coliform bacteria which, when present, can indicate that sewage has somehow entered the water body, or an indication of contamination of water from human or animal sources.

Herbicides:

Atrazine: This product is a widely used selective herbicide for control of broadleaf and grassy weeds in corn, sorghum, rangeland and sugarcane.

Alachlor: For control of most annual grasses and certain broadleaf weeds. Tolerant crops are corn, soybeans, dry beans, potato and sunflower.

Dicamba: Premergence and postemergence application of this product controls annual broadleaf weeds. Registered uses cover small grain, corn, and sorghum.

2,4-D: A systemic herbicide widely used for control of broadleaves in cereal crops.

MCPA: A selective foliage broadleaf killer, similar to 2,4-D, however, more selective than 2,4-D at equal rates on cereals, legumes and flax.

Trifluralin: Selective grass and broadleaf control in field corn, winter wheat, barley, soybean, dry bean and canola.

Metribuzen: Effective against annual grasses and numerous broadleaf weeds in potato, established alfalfa, sugarcane, asparagus and tomato.

Cyanazine: Useful for control of annual grasses and broadleaf weeds in corn, grain sorghum, and cotton.

Assert: Control of wild oat, wild mustard, wild buckwheat, field pennycress, and wild radish in wheat, barley, and sunflower.

Bromoxynil: Broadleaf control in wheat, oats, barley, rye and flax.

Insecticides:

Phosphamidon: Used for control of aphids, leafhoppers, thrips, beetles and grasshoppers in potato, wheat, barley and various vegetable crops.

Furadan: For use in corn, small grain, alfalfa, soybean, sunflower and potato in the control of corn rootworm, wireworm, thrips, rice water weevil, armyworm and corn borer.

Malathion: Controls aphids, leafhoppers, thrips, mealybugs, spittlebugs, corn earworms, grasshoppers, army worms and many others in a very large variety of crops.

Fungicides:

Propiconazole: For use in grasses grown for seed, barley, wheat, rye and turf. This product is being tested on soybean, celery, corn, bean, grapes and rice for control of early blight, rusts, white mold, cercospera, sheath blight, red thread and powdery mildew.

The selection of pesticides for analysis was based largely on the type of agriculture along the river and partially based on conversations with producers as to their selections of chemicals commonly used. Tables 3 and 4 show relatively high levels of 2,4-D in the water and sediments at site 2 (outlet of the Clearwater Lake) with the higher levels found in the sediments. However, the levels are below the Recommended Allowable Levels (RAL's) of 60 ug/L. The discovery of pesticides at this time of year (5/3/90) is surprising since, normally, pesticides would not have been applied this early in the growing season. There was a report of ditch spraying in this area the previous fall with the use of Weedone, a 2,4-D product. Due to the lack of sampling sites above the Clearwater Lake, or in the lake itself, it is impossible to ascertain the point of origin of the 2,4-D. Low levels of 2,4-D continued to be found at various sites during the growing season (Tables 6, 8, 17). The last sampling of the season (10/25/90) shows higher levels of 2,4-D in the sediments down river from its original discovery at site 2 (Table 22). Tables 4 and 22 suggest an apparent movement of soil particles down river from sampling date 5/3/90 to 10/25/90. Sites 3 and 5 show levels of 20 and 60 ug/L in the sediments respectively, but no 2,4-D was found in the water samples.

Relatively high levels of MCPA were found in the sediments at sites 3 and 5 on the last sampling date of 10/25/90 (Table 22). The Recommended Allowable Level (RAL) for MCPA is 3.6 ug/L which is considerably lower than that which was detected . Again, however, no

MCPA was detected in the water samples (Table 21). Low levels of Bromoxynil, Cyanine, and Dicamba were also detected in the sediments of 10/25/90. However, no pesticides were discovered in any of the water samples of the same date.

Runoff samples collected on 6/4/90 show higher than normal levels of phosphorus at sites B, C, and D (potato, corn and small grain respectively), but higher than normal levels of nitrogen at site D only (Table 9). Nitrogen and phosphorus levels in samples of runoff collected 6/21/90 for sites B, C, and D (potato, corn, and small grain) show high levels of nitrogen for all three crops with small grain showing the highest followed by potato. Phosphorus levels were highest for small grain, again followed by potato (Figures 4 and 5). Both phosphorus and nitrogen levels were highest in small grain followed by potato and corn. This can possibly be accounted for by the fact that the organic matter content for each crop was 3.8 for small grain, 3.2 for potato and 2.9 for corn.

The runoff sample from site C (corn) shows low level concentrations of Bromoxynil on sampling date 7/11/90. Also, on sampling date 8/27/90, low concentrations of Alachlor and Cyanazine were discovered at the same site (Table 19). This data is not considered valid, however, due to the fact that even though numerous dates show runoff collection (6/4/90, 6/21/90, 7/11/90, and 8/27/90), there was only one major runoff event for 1990, which was collected on 6/4/90. Runoff for pesticides on sites B, C and D - potato, corn and small grain respectively, on 6/4/90 sampling date shows no detectable levels of Dicamba, 2,4-D, Metribuzen, Phosphamidon, MCPA or Assert (Table 10). Runoff collections on all other dates were of very low quantity (< 500 mls) and, although collection containers were changed twice weekly, it is suspected they were contaminated at times of pesticide applications.

Sampling Frequency

Tentative sampling events were as follows, but needed further evaluation dependent upon weather and fluctuations:

1. April - Water and sediment samples after ice breakup and at the time of runoff from fields.
2. Late May - Water samples after crops were planted.
3. Mid/late June - Water samples after chemicals had been applied.
4. Late July/early August - When rice paddy water is released.
5. Late August/September - Water and sediment samples at the end of the growing season.
6. One mid winter sampling of water to establish the low levels of chemicals.

By 1990, Minnesota was entering its third year of a severe drought. Therefore, the first sampling of the year (May 3, 1990) did not include runoff from adjacent fields. Sampling events were modified to accommodate the weather for 1990. Only one major runoff event occurred for the entire season; June 4, 1990. Because the two previous growing seasons produced lower than normal yields in the area, runoff samples would be expected to contain higher levels of nutrients than would normally be seen in runoff samples. Because this study included only one year of sampling, this cannot be ascertained with any confidence.

Time of Travel Study

The Clearwater River time of travel study was completed by the Department of Natural Resources (DNR). The original Clearwater River time of travel study completed in 1987 followed United States Geological Survey (USGS) guidelines for a low level time of travel study. However, growing concerns for the environment necessitated further studies on time of travel which has resulted in a high flow level in addition to the original low level study in order to better define water quality issues. The time of travel study of 1987 was conducted at a flow level of 36 cfs. The 1990 study attempted to complete the study at a high level flow of 300 cfs. However, this level was not reached. The study was completed over a two-time period with an average discharge of 234 cfs.

For the time of travel study results, please see appendix i.

Land Use - Geographic Information System (GIS) Strategy

There were basically two ways in which the use of GIS was to have benefitted this study:

A. Information was to have been collected relating to the soils and geology of the land adjacent to the Clearwater River.

B. Sampling data from runoff samples at sites B, C, and D (Table 1, Fig. 1) was to have been used to show relationships between land management practices and water quality.

Unfortunately numerous problems arose to prevent the collection of information on the soils and geology of this area and collection of runoff data. The individual that was to have collected the information on the soils and geology was moved to another position within the same agency and, therefore, was unable to complete the project. In addition, due to a "breakdown in communications" another person was not assigned this task. Therefore, this information was not collected as a part of the Clearwater River Environmental Study. Also, 1990 proved to be the third year of a severe drought in northwest Minnesota resulting in very little runoff from sites B, C, and D.

Due to the absence of data from soils and geology of the area and the lack of runoff data, the International Coalition felt it necessary to develop a presentation for the public using hypothetical data input. This proved to be one of the highlights of our workshops in June 1991. (Appendix ii).

Education Strategy

In June of 1990, six workshops were conducted in the affected counties to inform citizens of the Clearwater River Environmental Study and to solicit input as to their concerns. Although the attendance at these workshops was relatively low, except for Hickory Township, county commissioners, watershed board members, radio and newspaper personnel, as well as interested farmers were in attendance. In addition to the six workshops in 1990 and the three workshops held in 1991 to discuss the results, numerous newspaper articles have appeared, before and after the study was completed. Also, there have been speaking engagements at the Lion's Club in Crookston, Kiwanis Club in Thief River Falls, Rotary Club in Crookston, and the Lion's Club in Devils Lake. The Clearwater River Environmental Study was the keynote discussion at the Red River Valley Winter Shows in 1991.

SUMMARY

Except for 2,4-D and MCPA, there appears not to be a pesticide contamination problem in the Clearwater River. I will repeat, however, that this was only a one-year study and only 14 pesticides were targeted for analysis. Also, the investigators have concluded that there were not nearly enough sampling sites along the 132.5 miles of Clearwater River in this investigation. It also appears that the commercial wild rice farms are adversely impacting the quality of the water in this river. However, by the time the water, which is released from the rice paddies back into the river has traveled a short distance down stream, the water is back to ambient levels with regard to most parameters tested. It does not appear that the commercial wild rice operations are impacting the Clearwater River to a greater degree than any other farming operation along the river.

Erosion of paddy dikes and ditches in the rice areas adjacent to the Clearwater River do not appear to be a major source of water contamination. However, bank erosion on the Clearwater River does represent a potential source of water pollution in much of the area between the Clearwater Lake and Plummer where much of Minnesota's commercial wild rice is produced. The U. S. Army Corps of Engineers straightened and channelized much of the Clearwater River between Ruffy Brook and the city of Plummer in an effort to reduce flooding in the Red Lake Watershed. Straightening and channelizing of rivers may very well help prevent flooding in certain areas at certain times. However, faster moving water represents an increased potential for erosion, thus, increasing the risk of water contamination. Most often this kind of practice simply moves the problem from one area to another, resulting in only a temporary solution.

Information collected from the Clearwater River Environmental Study was used as a basis for another grant on the Clearwater River funded by the Minnesota Pollution Control Agency (MPCA). This study will begin Fall 1991.

RECOMMENDATIONS:

The following recommendations are taken from the 1979 Wild Rice Study prepared by the Minnesota Pollution Control Agency because they remain important and many of the results of the current study are the same:

A. Water control structures should be closed following harvest to minimize loss of soil and nutrients from erosion.

B. Annual soil testing is recommended to prevent over fertilization and insure water quality protection.

C. Management alternatives where discharges are suspected of contributing a significant portion of the critical phosphorus loading to lakes:
   1. Construct reservoirs for recycling.
   2. Provide treatment by overland flow to adjacent wetlands.
   3. Flood adjacent fallowed paddies or low lying areas.
   4. Develop a diversion to surface water where phosphate standards do not apply.

In addition to the above recommendations, the investigators of the current study feel the following recommendations are important:

1. Farming operations adjacent to the Clearwater River should leave a buffer strip of at least 30 feet between the crop and the river bank.

2. Fertilizers and pesticides should be ground applied to help prevent direct movement of these chemicals into the water due to aerial drift.

3. Cattle should not be allowed to graze at the river's edge thereby helping to prevent soil and fecal coliform movement into the water.

4. Plant crops parallel to the river to help prevent movement of soil into the river.

5. Dairy operations should construct waste lagoons to help prevent overland movement of wastes into the river.

RECOMMENDATIONS FOR FUTURE RESEARCH

Future research on the Clearwater River should be conducted relating to runoff from the watersheds of the Clearwater River. The investigators of this study feel that the quality of the water in the Clearwater River is controlled by the land use adjacent to the River. Also, the information collected for 1990 suggests that more information should be gathered on 2,4-D and MCPA in the Clearwater River. These two pesticides are used very widely throughout the area adjacent to the Clearwater River.

Table 1. Clearwater River Basin Environmental Study Sampling Sites, 1990-1991.

Site #	Description
1.	Clearwater River near Shevlin, C.S.A.H. #2, Sec. 4,5, Shevlin Twp.
2.	Outlet at Clearwater Lake Dam, Section 12, Sinclair Twp. Clearwater Co.
3.	Gunvalson Bros., Rice Farm, Clearwater River, Trail Road, Sec. 32, Hickory Twp.
4.	Clearwater River Guage, Plummer, Sec. 4, Emardville Twp.
5.	Clearwater River, Terrebonne Brdige, Sec. 2, Terrebonne Twp.
6.	Poplar River Bridge off Hwy. #92, Sec. 8, 17, Poplar River Twp.
7.	Clearwater River near Red Lake Falls Gauge, Klondike Bridge, Sec. 22, Red Lake River Twp.
A.	Rice Paddy, Gunvalson Bros., Section 31, Hickory, Pennington County
B.	Paquin Bros., Potato Field
C.	St. Marie Bros., Corn Field
D.	St. Marie Bros., Small Grain (Barley) Field
L.	100 Ft. West of Site 3
M.	Gunvalson Bros. Farm - East Side of Gully Road
O.	Upstream on Clearwater River - 50' East of Site M
P.	Downstream on Clearwater River - 500' West of Site 3

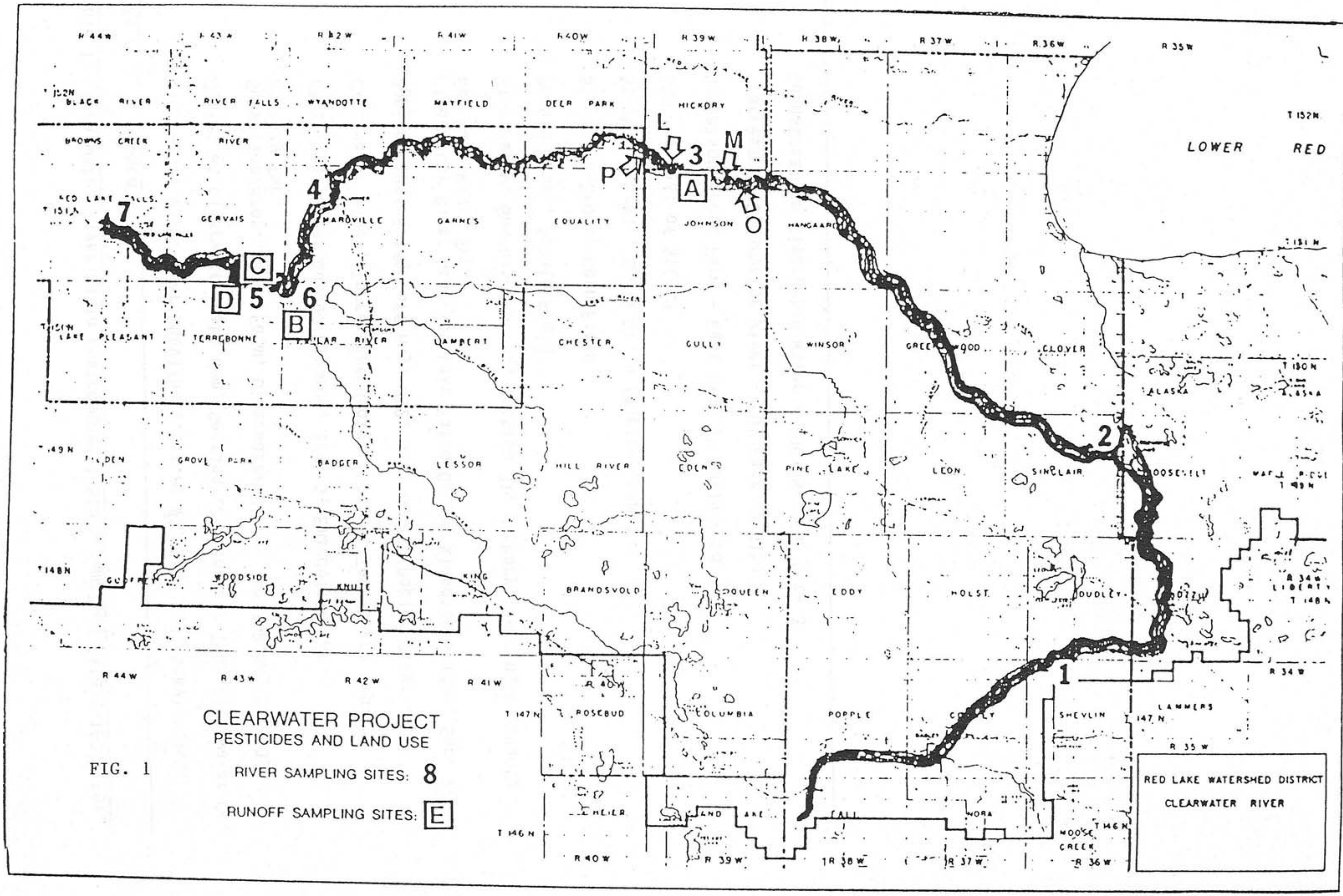

FIG. 1

CLEARWATER PROJECT
PESTICIDES AND LAND USE

RIVER SAMPLING SITES: 8

RUNOFF SAMPLING SITES: E

RED LAKE WATERSHED DISTRICT
CLEARWATER RIVER

Table 2. WATER SAMPLES - INORGANICS, 5/3/90.

	Site						
	1	2	3	4	5	6	7
Phosphorus (mg/L)							
TP	XX	XX	XX	XX	XX	XX	XX
Ortho P	XX	XX	XX	XX	XX	XX	XX
Nitrogen (mg/L)							
TN	XX	XX	XX	XX	XX	XX	XX
NO_3^--N	XX	XX	XX	XX	XX	XX	XX
NH_3-N	XX	XX	XX	XX	XX	XX	XX
pH							
	8.37	8.35	8.50	8.64	8.61	8.54	8.64
Chemical Oxygen Demand (COD) (mg/L)							
	22.0	22.0	29.0	31.0	30.0	36.0	28.0
Dissolved Oxygen (DO) (mg/L)							
	12.8	11.0	12.3	X	12.3	10.6	10.5
Total Dissolved Solids (mg/L)							
	214	224	257	258	312	305	304
Conductivity (uS/cm)							
	448	448	513	514	626	608	608
Alkalinity (mg/L)***							
	244	245	239	239	250	274	248
Turbidity (FTU)**							
	10.0	1.0	8.0	7.0	7.0	8.0	7.0
Fecal Coliform*							
	0/100	0/100	100/100	0/100	10/100	20/100	0/100

X = No sample taken
XX = Sample destroyed
* = Colonies/100 ml
** = Formazin turbo units (FTU)
*** = mg/L as $CaCO_3$
BDL = Below detectable limits

Table 3. WATER SAMPLES - PESTICIDES, 5/3/90.

	Site						
	1	2	3	4	5	6	7
Atrazine (ug/L)	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Alachlor (ug/L)	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Dicamba (ug/L)	BDL	BDL	BDL	BDL	BDL	BDL	BDL
2,4-D (ug/L)	BDL	0.54	0.53	0.70	17.47	BDL	BDL
MCPA (ug/L)	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Trifluralin (ug/L)	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Metribuzen (ug/L)	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Phosphamidon (ug/L)	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Furadan (ug/L)	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Propiconazole (ug/L)	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Malathion (ug/L)	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Cyanazine (ug/L)	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Assert (ug/L)	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Bromoxynil (ug/L)	BDL	BDL	BDL	BDL	BDL	BDL	BDL

X = No sample taken
XX = Sample destroyed
* = Colonies/100 ml
** = Formazin turbo units (FTU)
*** = mg/L as $CaCO_3$
BDL = Below detectable limits

Table 4. SEDIMENT SAMPLES - PESTICIDES, 5/3/90.

	Site						
	1	2	3	4	5	6	7
Atrazine (ug/L)	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Alachlor (ug/L)	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Dicamba (ug/L)	BDL	BDL	BDL	BDL	BDL	BDL	BDL
2,4-D (ug/L)	5.32	22.50	5.18	3.84	1.42	BDL	BDL
MCPA (ug/L)	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Trifluralin (ug/L)	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Metribuzen (ug/L)	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Phosphamidon (ug/L)	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Furadan (ug/L)	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Propiconazole (ug/L)	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Malathion (ug/L)	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Cyanazine (ug/L)	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Assert (ug/L)	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Bromoxynil (ug/L)	BDL	BDL	BDL	BDL	BDL	BDL	BDL

X = No sample taken
XX = Sample destroyed
* = Colonies/100 ml
** = Formazin turbo units (FTU)
*** = mg/L as $CaCO_3$
BDL = Below detectable limits

Table 5. WATER SAMPLES - INORGANICS, 5/30/90.

	Site						
	1	2	3	4	5	6	7
Phosphorus (mg/L)							
TP	X	X	X	0.27	0.27	0.32	0.28
Ortho P	X	X	X	0.25	0.25	0.28	0.26
Nitrogen (mg/L)							
TN	X	X	X	<1.0	<1.0	<1.0	<1.0
NO_3^--N	X	X	X	<0.2	<0.2	<0.2	<0.2
NH_3-N	X	X	X	<0.2	<0.2	<0.2	<0.2
pH							
	X	X	X	8.36	8.42	8.37	8.25
Chemical Oxygen Demand (COD) (mg/L)							
	22	22	29	31	30	36	28
Dissolved Oxygen (DO) (mg/L)							
	12.8	11.0	12.3	XX	12.3	10.6	10.5
Total Dissolved Solids (mg/L)							
	X	X	X	273	298	363	296
Conductivity (uS/cm)							
	X	X	X	540	561	731	589
Alkalinity (mg/L)***							
	X	X	X	258	260	342	238
Turbidity (FTU)**							
	X	X	X	10	10	10	11
Fecal Coliform*							
	X	X	X	0/100	0/100	0/100	0/100

X = No sample taken
XX = Sample destroyed
* = Colonies/100 ml
** = Formazin turbo units (FTU)
*** = mg/L as $CaCO_3$
BDL = Below detectable limits

Table 6. WATER SAMPLES - PESTICIDES, 5/30/90.

	Site						
	1	2	3	4	5	6	7
Alachlor (ug/L)	X	X	BDL	BDL	BDL	BDL	BDL
Dicamba (ug/L)	X	X	BDL	BDL	BDL	BDL	BDL
2,4-D (ug/L)	X	X	0.46	BDL	BDL	BDL	BDL
Trifluralin (ug/L)	X	X	BDL	BDL	BDL	BDL	BDL

X = No sample taken
XX = Sample destroyed
* = Colonies/100 ml
** = Formazin turbo units (FTU)
*** = mg/L as $CaCO_3$
BDL = Below detectable limits

Table 7. WATER SAMPLES - INORGANICS, 6/4/90.

	Site						
	1	2	3	4	5	6	7
				Phosphorus (mg/L)			
TP	X	X	X	0.27	0.29	0.30	0.29
Ortho P	X	X	X	0.26	0.25	0.27	0.26
				Nitrogen (mg/L)			
TN	X	X	X	<1.0	<1.0	1.8	1.0
NO_3^--N	X	X	X	0.4	<0.2	1.8	1.0
NH_3-N	X	X	X	<0.2	<0.2	<0.2	<0.2
				pH			
	X	X	X	8.18	8.29	8.21	X
				Chemical Oxygen Demand (COD) (mg/L)			
	X	X	X	38	37	50	42
				Dissolved Oxygen (DO) (mg/L)			
	X	X	X	8.9	9.3	8.3	8.8
				Total Dissolved Solids (mg/L)			
	X	X	X	242	280	328	290
				Conductivity (uS/cm)			
	X	X	X	479	556	654	583
				Alkalinity (mg/L)***			
	X	X	X	168	225	292	290
				Turbidity (FTU)**			
	X	X	X	17	13	13	X
				Fecal Coliform*			
	X	X	X	0/100	0/100	0/100	0/100

X = No sample taken
XX = Sample destroyed
* = Colonies/100 ml
** = Formazin turbo units (FTU)
*** = mg/L as $CaCO_3$
BDL = Below detectable limits

Table 8. WATER SAMPLES - PESTICIDES, 6/4/90.

	Site						
	1	2	3	4	5	6	7
Dicamba (ug/L)							
	X	X	X	BDL	BDL	BDL	X
2,4-D (ug/L)							
	X	X	X	BDL	2.3	3.7	X
Metribuzen (ug/L)							
	X	X	X	BDL	BDL	BDL	X
Phosphamidon (ug/L)							
	X	X	X	BDL	BDL	BDL	X
MCPA (ug/L)							
	X	X	X	BDL	BDL	BDL	X
Assert (ug/L)							
	X	X	X	BDL	BDL	BDL	X

X = No sample taken
XX = Sample destroyed
* = Colonies/100 ml
** = Formazin turbo units (FTU)
*** = mg/L as $CaCO_3$
BDL = Below detectable limits

Table 9. RUNOFF SAMPLES - INORGANICS, 6/4/90.

	Site		
	B	C	D
		Phosphorus (mg/L)	
TP	1.46	0.94	1.70
Ortho P	0.42	0.59	1.40
		Nitrogen (mg/L)	
TN	<1.0	<1.0	4.4
NO_3^--N	<0.2	0.4	<0.2
NH_3-N	0.28	0.42	2.17
		pH	
	7.00	7.10	6.90
		Chemical Oxygen Demand (COD) (mg/L)	
	175	39	74
		Dissolved Oxygen (DO) (mg/L)	
	X	X	X
		Total Dissolved Solids (mg/L)	
	71	32	53
		Conductivity (uS/cm)	
	153	62	105
		Alkalinity (mg/L)* **	
	84	25	37
		Turbidity (FTU) **	
	1210	357	43
		Fecal Coliform*	
	0/100	0/100	0/100

X = No sample taken
XX = Sample destroyed
* = Colonies/100 ml
** = Formazin turbo units (FTU)
*** = mg/L as $CaCO_3$
BDL = Below detectable limits

Table 10. RUNOFF SAMPLES - PESTICIDES, 6/4/90.

	Site		
	B	C	D
Dicamba (ug/L)			
	BDL	BDL	BDL
2,4-D (ug/L)			
	BDL	BDL	BDL
Metribuzen (ug/L)			
	BDL	BDL	BDL
Phosphamidon (ug/L)			
	BDL	BDL	BDL
MCPA (ug/L)			
	BDL	BDL	BDL
Assert (ug/L)			
	BDL	BDL	BDL

X = No sample taken
XX = Sample destroyed
* = Colonies/100 ml
** = Formazin turbo units (FTU)
*** = mg/L as $CaCO_3$
BDL = Below detectable limits

Table 11. WATER SAMPLES - INORGANIC, 6/21/90.

	Site						
	1	2	3	4	5	6	7
				Phosphorus (mg/L)			
TP	X	X	X	0.25	0.24	0.26	0.26
Ortho P	X	X	X	0.24	0.23	0.24	0.23
				Nitrogen (mg/L)			
TN	X	X	X	2.9	2.2	3.6	3.6
NO_3^--N	X	X	X	0.3	0.4	0.2	0.2
NH_3-N	X	X	X	0.13	0.16	0.11	0.11
				pH			
	X	X	X	8.10	8.15	8.23	8.30
				Chemical Oxygen Demand (COD) (mg/L)			
	X	X	X	38	34	43	40
				Dissolved Oxygen (DO) (mg/L)			
	X	X	X	7.8	7.0	8.7	8.6
				Total Dissolved Solids (mg/L)			
	X	X	X	X	400	453	410
				Conductivity (uS/cm)			
	X	X	X	X	601	677	660
				Alkalinity (mg/L)***			
	X	X	X	X	228	324	350
				Turbidity (FTU)**			
	X	X	X	28	30	14	13
				Fecal Coliform*			
	X	X	X	X	0/100	0/100	0/100

X = No sample taken
XX = Sample destroyed
* = Colonies/100 ml
** = Formazin turbo units (FTU)
*** = mg/L as $CaCO_3$
BDL = Below detectable limits

Table 12. RUNOFF SAMPLES - INORGANICS, 6/21/90.

	Site		
	B	C	D
Phosphorus (mg/L)			
TP	4.25	1.06	1.88
Ortho P	4.01	0.98	1.82
Nitrogen (mg/L)			
TN	44.5	7.70	14.90
NO_3^--N	2.3	0.40	<0.20
NH_3-N	9.16	3.24	0.68
pH			
	7.21	7.56	7.09
Chemical Oxygen Demand (COD) (mg/L)			
	172	21	58
Dissolved Oxygen (DO) (mg/L)			
	X	X	X
Total Dissolved Solids (mg/L)			
	78	68	85
Conductivity (us/cm)			
	116	102	126
Alkalinity (mg/L)***			
	56	36	56
Turbidity (FTU)**			
	455	20	145
Fecal Coliform*			
	0/100	0/100	0/100

X = No sample taken
XX = Sample destroyed
* = Colonies/100 ml
** = Formazin turbo units (FTU)
*** = mg/L as $CaCO_3$
BDL = Below detectable limits

Table 13. WATER SAMPLES - INORGANICS, 7/11/90.

	Site						
	1	2	3	4	5	6	7
Phosphorus (mg/L)							
TP	79.6	0.25	0.51	X	X	X	X
Ortho P	75.2	0.22	0.47	X	X	X	X
Nitrogen (mg/L)							
TN	1.7	<1.0	<1.0	X	X	X	X
NO_3^--N	0.4	<0.2	<0.2	X	X	X	X
NH_3-N	0.6	0.3	<0.2	X	X	X	X
pH							
	7.8	8.1	7.9	X	X	X	X
Chemical Oxygen Demand (COD) (mg/L)							
	90	116	95	X	X	X	X
Dissolved Oxygen (DO) (mg/L)							
	2.8	3.8	3.2	X	X	X	X
Total Dissolved Solids (mg/L)							
	541	547	533	X	X	X	X
Conductivity (uS/cm)							
	X	X	X	X	X	X	X
Alkalinity (mg/L)***							
	290	286	288	X	X	X	X
Turbidity (FTU)**							
	33	32	33	X	X	X	X
Fecal Coliform*							
	0/100	0/100	0/100	X	X	X	X

X = No sample taken
XX = Sample destroyed
* = Colonies/100 ml
** = Formazin turbo units (FTU)
*** = mg/L as $CaCO_3$
BDL = Below detectable limits

Table 14. RUNOFF SAMPLES - PESTICIDES, 7/11/90.

	Site	
	C	D
2,4-D (ug/L)		
	BDL	BDL
Bromoxynil (ug/L)		
	0.04	BDL

X = No sample taken
XX = Sample destroyed
* = Colonies/100 ml
** = Formazin turbo units (FTU)
*** = mg/L as $CaCO_3$
BDL = Below detectable limits

Table 15. INORGANICS AND PESTICIDES IN RELEASE WATER IN RICE AREA, 8/3/90.

	Site						
	L	M	O	P	3	5	6
				Phosphorus (mg/L)			
TP	0.14	0.64	0.32	0.16	0.15	0.29	0.16
Ortho P	0.12	0.62	0.30	0.14	0.13	0.28	0.15
				Nitrogen (mg/L)			
TN	1.10	1.50	1.14	1.20	1.00	1.20	1.00
NO_3^--N	0.01	0.40	0.13	0.02	0.10	0.24	0.38
NH_3-N	0.02	0.50	0.15	0.30	0.02	0.30	0.46
				Chemical Oxygen Demand (COD) (mg/L)			
	169	198	93	50	123	90	85
				Dissolved Oxygen (DO) (mg/L)			
	XX	7.6	5.0	5.0	1.5	4.0	8.5
				Total Dissolved Solids (mg/L)			
	671	757	459	445	742	480	447
				Conductivity (uS/cm)			
	1007	1139	1687	668	1110	720	672
				Alkalinity (mg/L)***			
	308	200	264	268	258	250	232
				Fecal Coliform*			
	0/100	0/100	0/100	0/100	0/100	30/100	10/100
				Furadan (ug/L)			
	BDL	BDL	BDL	BDL	BDL	BDL	BDL
				Propiconazole (ug/L)			
	BDL	BDL	1.0	BDL	BDL	BDL	BDL

X = No sample taken
XX = Sample destroyed
* = Colonies/100 ml
** = Formazin turbo units (FTU)
*** = mg/L as $CaCO_3$
BDL = Below detectable limits

Table 16. WATER SAMPLES - INORGANICS, 8/27/90.

	Site						
	1	2	3	4	5	6	7
				Phosphorus (mg/L)			
TP	0.18	0.03	0.02	0.13	0.10	0.08	0.13
Ortho P	0.16	0.01	0.01	0.11	0.07	0.05	0.11
				Nitrogen (mg/L)			
TN	<1.0	<1.0	1.01	1.32	1.00	<1.0	<1.0
NO_3^--N	<0.2	<0.2	0.55	0.27	<0.2	<0.2	<0.2
NH_3-N	<0.2	<0.2	0.60	0.32	<0.2	<0.2	<0.2
				pH			
	8.40	8.42	8.38	8.56	8.66	8.47	8.65
				Chemical Oxygen Demand (COD) (mg/L)			
	18	27	82	77	56	46	64
				Dissolved Oxygen (DO) (mg/L)			
	7.0	7.8	6.5	9.4	8.6	7.5	8.0
				Total Dissolved Solids (mg/L)			
	329	253	551	515	457	383	441
				Conductivity (uS/cm)			
	493	387	825	774	680	574	660
				Alkalinity (mg/L)***			
	256	190	304	296	286	222	256
				Turbidity (FTU)**			
	9.0	5.0	41	24	18	14	17
				Fecal Coliform*			
	50/100	0/100	60/100	250/100	90/100	50/100	20/100

X = No sample taken
XX = Sample destroyed
* = Colonies/100 ml
** = Formazin turbo units (FTU)
*** = mg/L as $CaCO_3$
BDL = Below detectable limits

Table 17. WATER SAMPLES - PESTICIDES, 8/27/90.

	Site						
	1	2	3	4	5	6	7
Alachlor (ug/L)							
	X	X	BDL	BDL	BDL	BDL	BDL
2,4-D (ug/L)							
	X	X	0.1	BDL	BDL	BDL	BDL
Furadan (ug/L)							
	X	X	BDL	BDL	BDL	BDL	BDL
Propiconazole (ug/L)							
	X	X	BDL	BDL	BDL	BDL	BDL
Cyanazine (ug/L)							
	X	X	BDL	BDL	BDL	BDL	BDL

X = No sample taken
XX = Sample destroyed
* = Colonies/100 ml
** = Formazin turbo units (FTU)
*** = mg/L as $CaCO_3$
BDL = Below detectable limits

Table 18. RUNOFF SAMPLES - INORGANICS, 8/27/90.

	Site	
	B	C
Phosphorus (mg/L)		
TP	X	X
Ortho P	1.75	1.23
Nitrogen (mg/L)		
TN	X	X
NO_3^--N	0.46	0.26
NH_3-N	X	X
pH		
	7.29	7.42
Chemical Oxygen Demand (COD) (mg/L)		
	X	96
Dissolved Oxygen (DO) (mg/L)		
	X	X
Total Dissolved Solids (mg/L)		
	1060	88
Conductivity (uS/cm)		
	1570	131
Alkalinity (mg/L)* **		
	612	51
Turbidity (FTU)**		
	Over Range	169
Fecal Coliform*		
	310/100	0/100

X = No sample taken
XX = Sample destroyed
* = Colonies/100 ml
** = Formazin turbo units (FTU)
*** = mg/L as $CaCO_3$
BDL = Below detectable limits

Table 19. RUNOFF SAMPLES - PESTICIDES, 8/27/90.

	Site	
	A	C
Alachlor (ug/L)		
	BDL	1.0
2,4-D (ug/L)		
	BDL	BDL
Furadan (ug/L)		
	BDL	BDL
Propiconazole (ug/L)		
	BDL	BDL
Cyanazine (ug/L)		
	BDL	10.0

X = No sample taken
XX = Sample destroyed
* = Colonies/100 ml
** = Formazin turbo units (FTU)
*** = mg/L as $CaCO_3$
BDL = Below detectable limits

Table 20. WATER SAMPLES - INORGANICS, 10/25/90.

	Site						
	1	2	3	4	5	6	7
Phosphorus (mg/L)							
TP	0.03	0.02	0.03	0.06	0.08	0.19	0.08
Ortho P	0.01	0.01	0.02	0.04	0.05	0.17	0.02
Nitrogen (mg/L)							
TN	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
NO_3^--N	<0.2	<0.2	0.35	<0.2	<0.2	<0.2	<0.2
NH_3-N	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
pH							
	8.01	8.31	8.27	8.31	8.51	7.86	8.51
Chemical Oxygen Demand (COD) (mg/L)							
	23	27	31	28	25	36	25
Dissolved Oxygen (DO) (mg/L)							
	4.0	7.5	5.0	8.5	10.8	4.0	4.7
Total Dissolved Solids (mg/L)							
	290	221	274	259	253	368	286
Conductivity (uS/cm)							
	551	424	546	501	496	763	538
Alkalinity (mg/L)***							
	228.5	153.9	190.2	181.5	161.4	259.7	193.4
Turbidity (FTU)**							
	6	7	8	4	4	14	5
Fecal Coliform*							
	0/100	0/100	0/100	0/100	0/100	0/100	0/100

X = No sample taken
XX = Sample destroyed
* = Colonies/100 ml
** = Formazin turbo units (FTU)
*** = mg/L as $CaCO_3$
BDL = Below detectable limits

Table 21. WATER SAMPLES - PESTICIDES, 10/25/90.

	Site						
	1	2	3	4	5	6	7
Atrazine (ug/L)	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Alachlor (ug/L)	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Dicamba (ug/L)	BDL	BDL	BDL	BDL	BDL	BDL	BDL
2,4-D (ug/L)	BDL	BDL	BDL	BDL	BDL	BDL	BDL
MCPA (ug/L)	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Trifluralin (ug/L)	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Metribuzen (ug/L)	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Phosphamidon (ug/L)	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Furadan (ug/L)	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Propiconazole (ug/L)	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Malathion (ug/L)	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Cyanazine (ug/L)	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Assert (ug/L)	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Bromoxynil (ug/L)	BDL	BDL	BDL	BDL	BDL	BDL	BDL

X = No sample taken
XX = Sample destroyed
* = Colonies/100 ml
** = Formazin turbo units (FTU)
*** = mg/L as $CaCO_3$
BDL = Below detectable limits

Table 22. SEDIMENT SAMPLES - PESTICIDES, 10/25/90.

	Site						
	1	2	3	4	5	6	7
Atrazine (ug/L)	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Alachlor (ug/L)	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Dicamba (ug/L)	BDL	BDL	BDL	BDL	10	BDL	BDL
2,4-D (ug/L)	BDL	BDL	20	BDL	60	BDL	BDL
MCPA (ug/L)	BDL	BDL	118.0	BDL	524.0	BDL	BDL
Trifluralin (ug/L)	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Metribuzen (ug/L)	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Phosphamidon (ug/L)	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Furadan (ug/L)	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Propiconazole (ug/L)	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Malathion (ug/L)	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Cyanazine (ug/L)	BDL	BDL	BDL	BDL	BDL	11.0	BDL
Assert (ug/L)	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Bromoxynil (ug/L)	BDL	1.0	2.0	BDL	2.0	1.0	BDL

X = No sample taken
XX = Sample destroyed
* = Colonies/100 ml
** = Formazin turbo units (FTU)
*** = mg/L as $CaCO_3$
BDL = Below detectable limits

Table 23. MINIMUM DETECTABLE LEVELS FOR PESTICIDES.

Pesticide	Minimum Detectable Level (ug/L)
Aláchlor	1.00
Atrazine	1.00
Assert	1.00
Bromoxynil	0.04
Cyanazine	5.00
Dicamba	1.63
Furadan	2.00
Malathion	1.00
MCPA	20.00
Metribuzen	1.00
Phosphamidon	1.00
Propiconazole	5.00
Trifluralin	1.00
2,4-D	0.10

X = No sample taken
XX = Sample destroyed
* = Colonies/100 ml
** = Formazin turbo units (FTU)
*** = mg/L as $CaCO_3$
BDL = Below detectable limits

Table 24. PHORSPHORUS (mg/L).

	Site							
DATE	1	2	3	4	5	6	7	Form of P
5/3/90	XX	XX	XX	XX	XX	XX	XX	Total P
	XX	XX	XX	XX	XX	XX	XX	Ortho P
5/30/90	X	X	X	0.27	0.27	0.32	0.28	Total P
	X	X	X	0.25	0.25	0.28	0.26	Ortho P
6/4/90	X	X	X	0.27	0.29	0.30	0.29	Total P
	X	X	X	0.26	0.25	0.27	0.26	Ortho P
6/21/90	X	X	X	0.25	0.24	0.26	0.26	Total P
	X	X	X	0.24	0.23	0.24	0.23	Ortho P
7/11/90	79.6	0.25	0.51	X	X	X	X	Total P
	75.2	0.22	0.47	X	X	X	X	Ortho P
8/27/90	0.18	0.03	0.02	0.13	0.10	0.08	0.13	Total P
	0.16	0.01	0.01	0.11	0.07	0.05	0.11	Ortho P
10/25/90	0.03	0.02	0.03	0.06	0.08	0.19	0.08	Total P
	0.01	0.01	0.02	0.02	0.05	0.17	0.02	Ortho P

X = No sample taken
XX = Sample destroyed
* = Colonies/100 ml
** = Formazin turbo units (FTU)
*** = mg/L as $CaCO_3$
BDL = Below detectable limits

Table 25. NITROGEN (mg/L).

DATE	Site 1	2	3	4	5	6	7	Form of P
5/3/90	XX	XX	XX	XX	XX	XX	XX	TN
	XX	XX	XX	XX	XX	XX	XX	NO_3^--N
	XX	XX	XX	XX	XX	XX	XX	NH_3-N
5/30/90	X	X	X	<1.0	<1.0	<1.0	<1.0	TN
	X	X	X	<0.2	<0.2	<0.2	<0.2	NO_3^--N
	X	X	X	<0.2	<0.2	<0.2	<0.2	NH_3-N
6/4/90	X	X	X	<1.0	<1.0	1.8	1.0	TN
	X	X	X	0.4	<0.2	1.8	1.0	NO_3^--N
	X	X	X	<0.2	<0.2	<0.2	<0.2	NH_3-N
6/21/90	X	X	X	2.9	2.2	3.6	3.6	TN
	X	X	X	0.3	0.4	0.2	0.2	NO_3^--N
	X	X	X	<0.2	<0.2	<0.2	<0.2	NH_3-N
7/11/90	1.7	<1.0	<1.0	X	X	X	X	TN
	0.2	<0.2	<0.2	X	X	X	X	NO_3^--N
	0.6	0.3	<0.2	X	X	X	X	NH_3-N
8/27/90	<1.0	<1.0	1.01	1.32	1.0	<1.0	<1.0	TN
	<0.2	<0.2	0.55	0.27	<0.2	<0.2	<0.2	NO_3^--N
	<0.2	<0.2	0.60	0.32	<0.2	<0.2	<0.2	NH_3-N
10/25/90	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	TN
	<0.2	<0.2	0.35	<0.2	<0.2	<0.2	<0.2	NO_3^--N
	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	NH_3-N

X = No sample taken
XX = Sample destroyed
* = Colonies/100 ml
** = Formazin turbo units (FTU)
*** = mg/L as $CaCO_3$
BDL = Below detectable limits

Table 26. CHEMICAL OXYGEN DEMAND (mg/L).

	DATE						
Site	5/3/90	5/30/90	6/4/90	6/21/90	7/11/90	8/27/90	10/25/90
1	22	X	X	X	90	18	23
2	22	X	X	X	116	27	27
3	29	X	X	X	95	82	31
4	31	42	38	38	X	77	28
5	30	36	37	34	X	56	25
6	36	50	50	43	X	46	36
7	28	35	40	40	X	64	25

X = No sample taken
XX = Sample destroyed
* = Colonies/100 ml
** = Formazin turbo units (FTU)
*** = mg/L as $CaCO_3$
BDL = Below detectable limits

Table 27. DISSOLVED OXYGEN (mg/L).

Site	5/3/90	5/30/90	6/4/90	6/21/90	7/11/90	8/27/90	10/25/90
	DATE						
1	12.8	X	X	X	2.8	7.0	4.0
2	11.0	X	X	X	3.8	7.8	7.8
3	12.3	X	X	X	3.2	6.5	5.0
4	XX	7.2	8.9	7.8	X	9.4	8.5
5	12.3	8.8	9.3	7.0	X	8.6	10.5
6	10.6	9.1	8.3	8.7	X	7.5	4.0
7	10.5	7.7	8.8	6.8	X	8.0	4.7

X = No sample taken
XX = Sample destroyed
* = Colonies/100 ml
** = Formazin turbo units (FTU)
*** = mg/L as $CaCO_3$
BDL = Below detectable limits

Table 28. TOTAL DISSOLVED SOLIDS (mg/L)

	DATE						
Site	5/3/90	5/30/90	6/4/90	6/21/90	7/11/90	8/27/90	10/25/90
1	214	X	X	X	541	329	290
2	224	X	X	X	547	253	221
3	257	X	X	X	533	551	274
4	258	273	242	XX	X	515	259
5	312	298	280	400	X	457	253
6	305	363	328	453	X	383	368
7	304	296	290	410	X	441	286

X = No sample taken
XX = Sample destroyed
* = Colonies/100 ml
** = Formazin turbo units (FTU)
*** = mg/L as $CaCO_3$
BDL = Below detectable limits

Table 29. CONDUCTIVITY (uS/cm).

	DATE						
Site	5/3/90	5/30/90	6/4/90	6/21/90	7/11/90	8/27/90	10/25/90
1	448	X	X	X	X	493	551
2	448	X	X	X	X	387	424
3	513	X	X	X	X	825	546
4	514	540	479	XX	X	774	501
5	626	561	556	601	X	680	496
6	608	731	654	677	X	574	763
7	608	589	583	660	X	660	538

X = No sample taken
XX = Sample destroyed
* = Colonies/100 ml
** = Formazin turbo units (FTU)
*** = mg/L as $CaCO_3$
BDL = Below detectable limits

Table 30. ALKALINITY (mg/L)***.

	DATE						
Site	5/3/90	5/30/90	6/4/90	6/21/90	7/11/90	8/27/90	10/25/90
1	244	X	X	X	290	256	229
2	245	X	X	X	286	190	154
3	239	X	X	X	288	304	190
4	239	258	168	XX	X	296	182
5	250	260	225	228	X	286	161
6	274	342	292	324	X	222	260
7	245	238	290	350	X	256	193

X = No sample taken
XX = Sample destroyed
* = Colonies/100 ml
** = Formazin turbo units (FTU)
*** = mg/L as $CaCO_3$
BDL = Below detectable limits

Table 31. TURBIDITY (FTU)**.

	DATE						
Site	5/3/90	5/30/90	6/4/90	6/21/90	7/11/90	8/27/90	10/25/90
1	10	X	X	X	33	9	6
2	1	X	X	X	32	5	7
3	8	X	X	X	33	41	8
4	7	10	17	28	X	24	4
5	7	10	13	30	X	18	4
6	8	10	13	14	X	14	14
7	7	11	X	13	X	17	5

X = No sample taken
XX = Sample destroyed
* = Colonies/100 ml
** = Formazin turbo units (FTU)
*** = mg/L as $CaCO_3$
BDL = Below detectable limits

Table 32. FECAL COLIFORM*.

Site	5/3/90	5/30/90	6/4/90	6/21/90	7/11/90	8/27/90	10/25/90
1	0/100	X	X	X	0/100	50/100	0/100
2	0/100	X	X	X	0/100	0/100	0/100
3	0/100	X	X	X	0/100	60/100	0/100
4	0/100	0/100	0/100	XX	X	250/100	0/100
5	10/100	0/100	0/100	0/100	X	90/100	0/100
6	20/100	0/100	0/100	0/100	X	50/100	0/100
7	0/100	0/100	0/100	0/100	X	20/100	0/100

X = No sample taken
XX = Sample destroyed
* = Colonies/100 ml
** = Formazin turbo units (FTU)
*** = mg/L as $CaCO_3$
BDL = Below detectable limits

APPENDIX

CLEARWATER RIVER

TIME OF TRAVEL STUDY

APRIL , 1991

MINNESOTA DEPARTMENT
OF NATURAL RESOURCES
DIVISION OF WATERS
Surface Water Section

Acknowledgements:

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INTRODUCTION

Today in Minnesota there is a growing concern over the environment. Keeping pace with this environmental upsurge is an increased use and pressure to develop and utilize our natural resources. The Clearwater River is one of these limited natural resources. The Clearwater River which comprises 23 percent of the Red Lake watershed has many users and is becoming increasingly limitted in its ability to satisfy its users in respect to water supply and water quality. In order to examine the water supply and quality problems associated with the Clearwater River, the Department of Natural Resources (DNR), in cooperation with the Red Lake Watershed District (RLWD) and the University of Minnesota (Crookston), initiated a time of travel study in 1987.

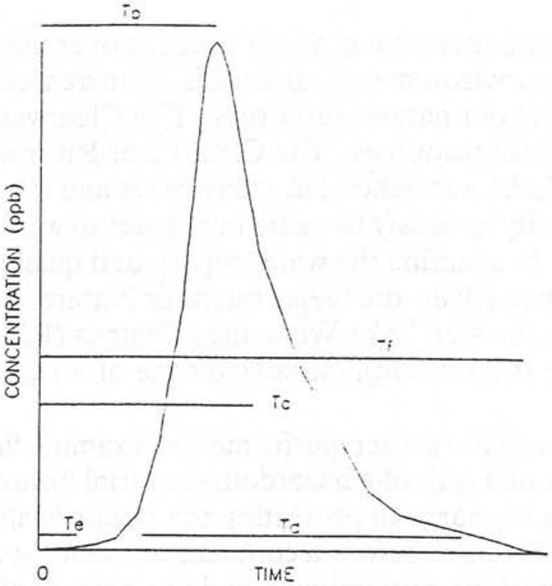
Time of travel studies are often performed to examine flow characteristics of a river in the event of a spill of a hazardous material upstream of a public water supply. Agencies in charge of protecting the public health need to know the amount of time they have before a contaminant reaches a water supply intake, the concentration of the contaminant, and the amount of time required for the pollutant to sufficiently disperse and move past an intake site.

The Clearwater River study was initiated to provide information on allocating water to various instream and out of stream uses, and to better understand the movement of contaminants at different flow levels in the river.

1.0. DYE TRACING AND TIME OF TRAVEL

Time of travel refers to the movement of water or waterborne materials from point to point in a stream for steady or gradually varied flow conditions (Hubbard et al. 1982). Because dye particles act similar to water particles dye can be used as a tracer to track the movement of water or water soluble particles in a stream. The injection of dye into a stream and the measurement of the time required for the dye cloud to pass a downstream point represents the time necessary for water to move through a stream segment at a known discharge. The dispersion rate of a dye cloud as it moves downstream is also used to assess the dispersion of water borne contaminants. (The downstream movement of water or dye can be represented by a time of concentration curve (Figure 1.1)).

Figure 1.1 Time of concentration curve



Where:

T_e = Time required for the arrival of the leading edge of a dye cloud at a sample point.

T_p = Time required for the arrival of the peak concentration of a dye cloud (also known as the time to peak)

T_c = Time required for the arrival of the centroid (center) of the dye cloud at a sample point.

T_f = Time required for the arrival of the trailing edge of a dye cloud.

T_d = Time required for the entire dye cloud to pass a given point or river reach and is equal to $T_f - T_e$

Time of travel is then defined as the time necessary for the dye cloud to pass between sampling points or travel a known length of river. Since time of travel is a function of discharge, the delivery time of a quantity of water can be predicted for locations along a known length of river.

The dispersion of a dye cloud is also a function of discharge. Knowing the dispersion rate of a dye cloud is useful in determining the concentration of water soluble contaminants along a river segment. The instantaneous injection of a known quanity of dye at a point and the quantity measured (or recovered) at a downstream location over time determines concentration of a substance in water at a known discharge.

A typical dye used in time of travel studies is Rhodamine WT. Rhodamine WT is a nonhazardous, odorless powder, dark red in color, that is usually mixed with water prior to use. (For the purpose of this study a 20% Rhodemine WT dye solution was used). Concentrations of this fluorescent dye are easily measured using a fluorometer. (Fluorometers measure the luminescence of a substance. The higher the fluorecence measured the higher the concentration of the substance.)

2.0. CLEARWATER RIVER WATERSHED CHARACTERISTICS

The Clearwater River is located in northwest Minnesota and is part of the Red Lake River Watershed. The Clearwater River watershed itself is 1396 square miles in size and is one of the 81 major watershed of the state (MnDNR, Office of Planning, 1981). This watershed includes portions of Beltrami, Clearwater, Mahnomen, Pennington, Polk, and Red Lake Counties. From its headwaters at Lower Long Lake near Ebro, to the confluence with the Red Lake River at Red Lake Falls, the river is 150 miles in length. It has over 30 tributary streams, rivers and ditches making up a stream network over 1700 miles in length.

The surficial geology of the watershed is composed primarily of ground moraines, stagnation moraines, and drumlins in the headwater region to Clearwater Lake. At Clearwater Lake, the undulating to hilly terrain changes as the river flows into the lake bottom of glacial lake Agassiz; a level featureless plain composed of lake modified tills, sand, gravel and small peat formations.

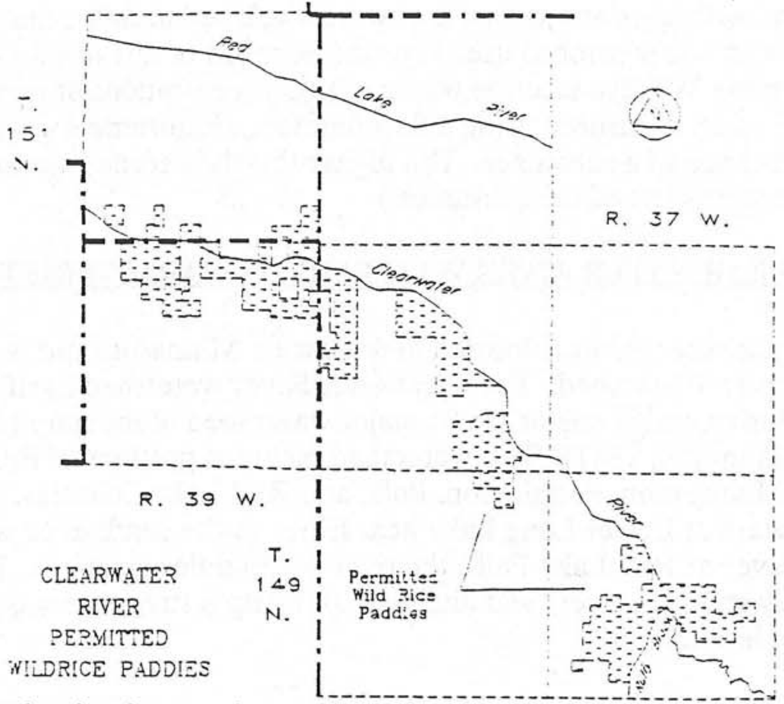
Soils in the area are light colored, well drained sandy loams and sand silts in the headwater areas to Clearwater Lake. A large portion of the watershed however, is composed of humic soils of silt, loam, peat and clay developed from lake modified tills. The transition to organic and silt-clay soils occurs at the fringe of the glacial lake plain. These soils are poorly drained and dark in color (U.S. Dept. of Ag. 1969, and U.S.Dept. of Ag. 1984).

In the 1950's, sections of the river were straightened and channelized by the U.S. Army Corps of Engnineers as part of a plan to reduce flooding in the Red Lake River watershed. Approximately 47 miles of river, beginning at the mouth of Ruffy Brook, were modified to provide capacity for floods of ten-year frequency (MnDNR Bulletin 10, 1959).

3.0 WILD RICE INDUSTRY

The major industry in the Clearwater River watershed is agriculture of which wild rice production is a large component. Nearly half of all Minnnesota's commercial wild rice is produced along a 25 mile stretch of the Clearwater River between Clearwater Lake and the city of Plummer (Figure 3.1).

Figure 3.1 Wild rice paddies along the Clearwater River currently under permit.



Wild rice production began along this reach of river in 1968 with a small 50 acre operation. By 1973 more than 6000 acres of wild rice paddies were in production, and in 1981 the number had increased to 11,000 acres. Currently there are 14,498 acres of wild rice paddies in the watershed (MnDNR Water Appropriation Index, 1990).

Commercial wild rice operations require the flooding of paddies with up to eighteen inches of water in early spring or late fall. The spring flooding of the rice paddies typically begins in mid-March or early-April depending on the timing of spring runoff. This water cover must be maintained through the growing season which extends into midsummer (late July). A total of 30 inches of water is usually required to saturate the subsoil and maintain a constant water level throughout the growing season.

In the Clearwater River watershed, 99.5 percent of the water required for commercial wild ricing is provided by the Clearwater River and its tributaries. In some years the spring runoff flows of the Clearwater are not sufficient to supply all the ricing operations with water and still provide flows for instream flow requirements and other downstream users. The combined water appropriation of the wild rice operations is over 400 cubic feet per second (cfs). In times of low flow, because these operations have the capability of pumping the river dry water shortages and conflicts occur, therefore the timing of spring runoff and the allocation of water from the river is extremely important.

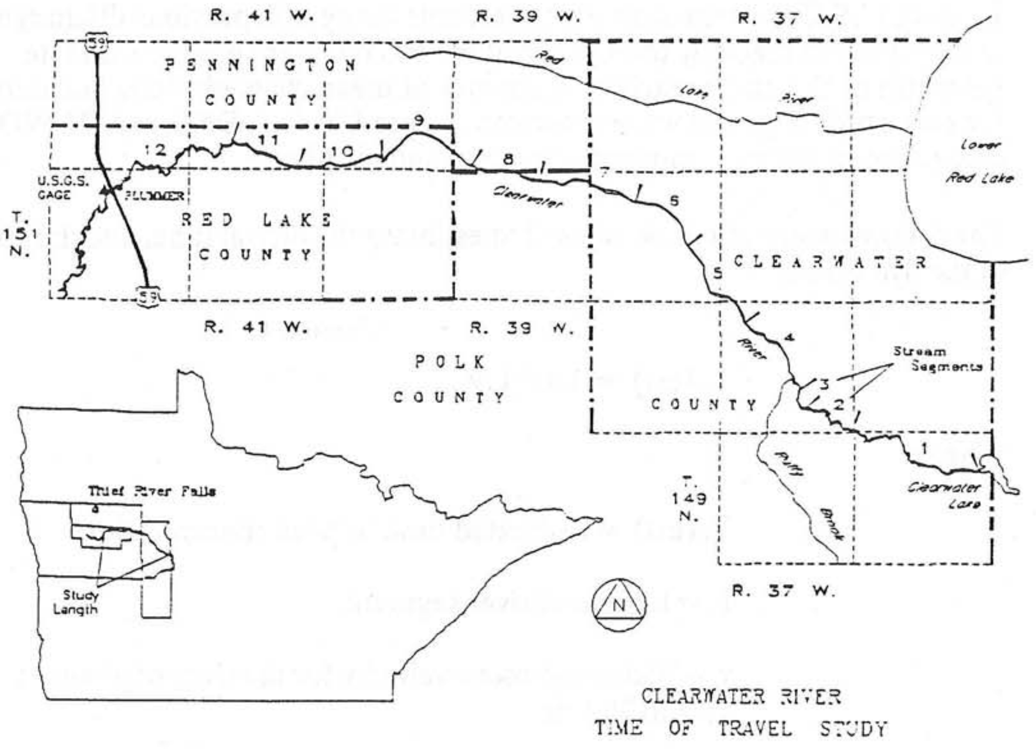
During the growing season the paddies are treated with a variety of chemical pesticides and fertilizers. In mid to late summer the paddies are drawn down for harvest by draining the paddy water back into the Clearwater River. The pesticides and fertilizers contained in the paddy water may impact the river water quality, and is a concern to downstream users.

4.0 STUDY DESIGN AND METHODOLOGY

The Clearwater River time of travel study was intially designed following the United States Geological Survey (U.S.G.S) guidelines for a low level time of travel and dispersion study (Hubbard et al. 1982).

The focus of the study was the heavily appropriated 69.4 mile stretch of river from Clearwater Lake (T.149N., R.37W., S.12) to the U.S.G.S. stream gaging station (U.S.G.S #05078000) near Plummer (T.151N., R.42W., S.4). Topographic maps and air photos were examined to determine the hydraulic and channel characteristics that may affect travel time. Detention areas such as backwaters and large pools were noted because they can negatively influence the dye travel time and concentration. Channel geometry, channel pattern, slope variations, diversions, impoundments, tributaries, river access points, and river miles were also marked on topgraphic maps. The study reach was then divided into 12 study segments based on these criteria (Figure 4.1).

Figure 4.1 Clearwater River Time of Travel Study location.



Following U.S.G.S. guidelines, a quantity of dye is injected at the upstream end of the study reach. The dye cloud is then sampled at specific location as it dispersed and traveled downstream. For the purposes of this study, dye was injected at the upstream end of all 12 study segments. A single dye injection was not practical for a number of reasons:

1. The wild rice growers along the study segment may be approriating water during the first measurement period. The possibility of losing dye at pumping sites required short subreaches with individual dye injections.

2. The Red Lake watershed district is interested in the delivery time of water supplies to appropriators. Because velocity is not uniform along the entire river reach, several subreaches enable better estimates of flow travel time from appropriator to appropriator .

3. The time of travel for flow from Clearwater Lake to Plummer was estimated at 108 hours at the low flow discharge (36 cfs). A single dye injection at this flow level was considered a constraint.

4.1 Estimates Of Velocity, Travel Time and Dye Quantities

Sampling schedule design and estimates of dye quantities, requires estimates of average channel velocity, depth, width and segment length.

Existing U.S.G.S streamflow gaging records along with previous discharge measurements made by the DNR and the RLWD were used to estimate velocities in the study reaches. Estimates of mean channel width, and depth for each study segment were determined from U.S.G.S, DNR and RLWD discharge cross-sections, topographic maps, and air photos.

The following equations were used to estimate the arrival time, and duration of the dye cloud:

Equation 4.1

$$T_p(est) = 1.47*L/v$$

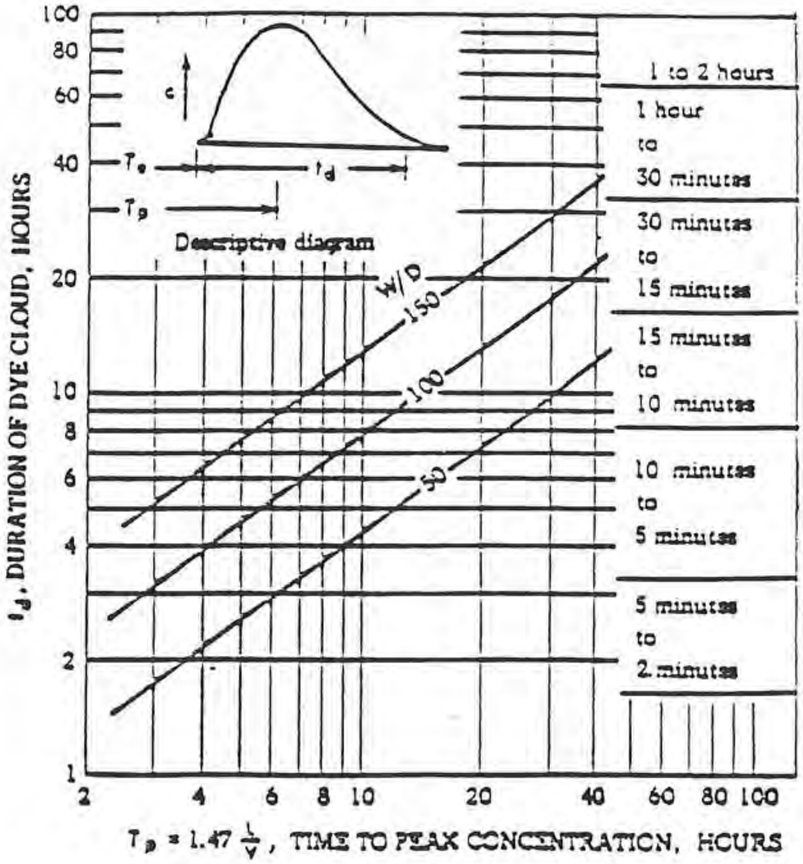
Where:

$T_p(est)$ = Estimated time to peak concentration

L = Length of river segment

v = Estimated mean velocity for the river segment at 36 and 300 cfs

Figure 4.2 Dye cloud duration estimation chart (from Hubbard et. al. 1982)



In order to know when to begin sampling an estimate of the arrival time for the leading edge ($T_e$est) of the dye is necessary and is given by:

Equation 4.2

$$T_e(est) = T_p(est) - (t_d / 2)$$

(this assumes the dye cloud is symmetrical in shape)

An estimate of the elapsed time to the trailing edge of the dye cloud $T_f(est)$ is given by:

Equation 4.3

$$T_f(est) = T_e(est) + t_d$$

The following tables contain the estimated average velocity, dye quanity, and arrival and duration times for each of the twelve study segments.

Discharge = 300cfs

REACH	Length (mi.)	V est. (ft/sec)	Te est. (hrs)	Tp est. (hrs)	Td est. (hrs)	Est. Volume of dye (g.)
1	8.2	2.5	4	4.82	1.75	2450
2	8.9	2.5	4.31	5.23	1.85	2630
3	3.9	1.86	2.53	3.08	1.1	1591
4	4.1	2	2.46	3	1.1	1591
5	5	2.1	2.93	3.5	1.15	1818
6	3.8	2.1	2.14	2.66	1.05	1409
7	4.4	2.1	2.58	3.08	1	1591
8	3.3	2.1	1.89	2.31	0.85	1227
9	5.4	3.5	1.85	2.27	0.85	1227
10	4.1	3.5	1.36	1.72	0.72	909
11	3.8	3.5	1.25	1.6	0.7	863
12	14.6	1.6	12.2	14.2	4	6727

Discharge = 36cfs

REACH	Length (mi.)	V est. (ft/sec)	Te est. (hrs)	Tp est. (hrs)	Td est. (hrs)	Est. Volume of dye (g.)
1	8.2	0.85	11.38	14.18	5.6	907
2	8.9	0.85	12.4	15.4	6	952
3	3.9	0.85	5.19	6.73	3.1	454
4	4.1	1	4.7	6.17	3	408
5	5	1	5.65	7.35	3.4	454
6	3.8	1	4.23	5.6	2.75	363
7	4.4	1	4.92	6.47	3.1	431
8	3.3	1	3.6	4.85	2.5	349
9	5.4	1	6.04	7.94	3.6	499
10	4.1	1	4.58	6.03	2.9	397
11	3.8	1	4.23	5.6	2.75	374
12	14.6	1.1	15.9	19.5	7.2	1200

The quanity of dye required to accurately measure travel time and concentration for discharges of 36 cfs and 300 cfs were estimated to obtain a desired peak concentration of 10 part per billion (ppb).

Sampling design was set up in the following manner:

1. A discharge measurement was made at the injection point and sampling location for each segment prior to injection and sampling.

2. Dye was then injected at the top of a study reach and the time of injection and quantity of dye was recorded.

3. Automatic samplers located at the bottom of each study segment were set to begin sampling based on estimates of arrival time for the dye cloud.

4. Collected samples were marked, and relative dye concentrations were measured on site.

5.0 RESULTS

Flows declined rapidly during the high flow data collection, therefore a discharge of 300 cfs was not attained. Over the two day period an average discharge of 234 cfs was measured at the U.S.G.S. gage at Plummer. Discharges of 234 and 36 cfs roughly correspond to the 20 and 90 percent annual exceedence discharges.

Tables 5.1a and 5.1b summarize the results of the high and low flow studies. The total travel time from Clearwater Lake to Plummer at 234 and 36 cfs is 69.4 and 122.2 hours respectively. Total travel time is derived by summing the individual study reach centroid travel times.

Four families of graphs were produced to describe the flow characterstics throughout the study segment:

1. General timing and dye distribution curves (Figure 5.1). (See appendix A for individual study reach response curves.) In some instances the leading edge or tail of the dye cloud was not well defined during sampling and had to be estimated.

2. Travel time-distance relationships for the high and low flow conditions (Figure 5.2a and 5.2b).

3. Traveltime for peak concentrations through each study reach (Figure 5.3) based on discharge measurements made within each reach. (See appendix B for individual reache peak-travel time relationships).

4. Average velocity vs. discharge relationships for all sites over the range of flows between 36 and 234 cfs (Figure 5.4, see appendix C for all the study sites.). Table 5.2 describes the average velocity through the study segments derived from the arrival time of the peak concentration.

These graphs represent a few ways of presenting time of travel data and are not all inclusive. Tables 5.1a and 5.1b contain the data neecssary for other graphic representations. Please refer to Hubbard, 1982 for other examples of graphical presentation.

CLEARWATER RIVER TRAVEL TIME STUDY
LEADING EDGE,PEAK,CENTROID,TRAILING EDGE

TABLE 5.1A

DATA COLLECTED 5-11 TO 5-14-87

INDEX GAGE DISCHARGE: 36 cfs *

REACH	REACH LENGTH (mi.)	CUMULATIVE RCH. LGTH. (mi.)	QUANITY OF DYE (g)	LEADING EDGE (HR.)		PEAK (HR.)		CENTROID (HR.)		TRAILING EDGE(HR.)		MEASURED DISCHARGE IN REACH (cfs)	PEAK CONC. (PBB)	TIME PASSAGE OF CLOUD (HRS.)	
				REACH	CUMULATIVE	REACH	CUMULATIVE	REACH	CUMULATIVE	REACH	CUMULATIVE			REACH	CUMULATIVE
1	8.2	8.2	710.8	10.92	10.92	13.42	13.42	14.01	14.01	22.5	22.5	44	12.2	11.58	11.58
2	8.8	17	7775	11.3	22.22	13.3	26.72	13.4	27.41	19.7	42.2	44	15	8.4	19.98
3	3.9	20.9	472.8	3.7	25.92	4.2	30.92	4.43	31.84	5.9	48.1	-	21.8	2.2	22.18
4	4.1	25	416.2	5.08	31	5.58	36.5	5.91	37.75	8.5	56.6	-	20.5	3.42	25.6
5	5	30	469.3	5.92	36.92	6.92	43.42	7.29	45.04	9.7	66.3	-	23.5	3.78	29.38
6	3.8	33.8	259.1	4.17	41.09	4.67	48.09	4.91	49.95	6.9	73.2	-	12.6	2.73	32.11
7	4.4	38.2	445.3	5.8	46.89	6.38	54.47	6.58	56.53	10.5	83.7	-	20.5	4.7	36.81
8	3.3	41.5	330.5	4.83	51.72	5.33	59.8	5.71	62.24	9	92.7	-	12.1	4.17	40.98
9	5.4	46.9	494.5	8.5	60.22	10.5	70.3	10.75	72.99	16.6	109.3	-	12.1	8.1	49.08
10	4.1	51	500.8	5.98	66.2	6.88	77.18	7.38	80.37	11.5	120.8	35	14.6	5.52	54.6
11	3.8	54.8	495.3	4.37	70.57	4.87	82.05	5.36	85.73	9.2	130	36.6	19.4	4.83	59.43
12	14.6	69.4	1018.3	29.58	100.15	35.08	117.13	36.42	122.15	50.9	180.9	36	7.3	21.32	80.75

* : FOUR DAY AVERAGE AT PLUMMER GAGE

TABLE 5.1B

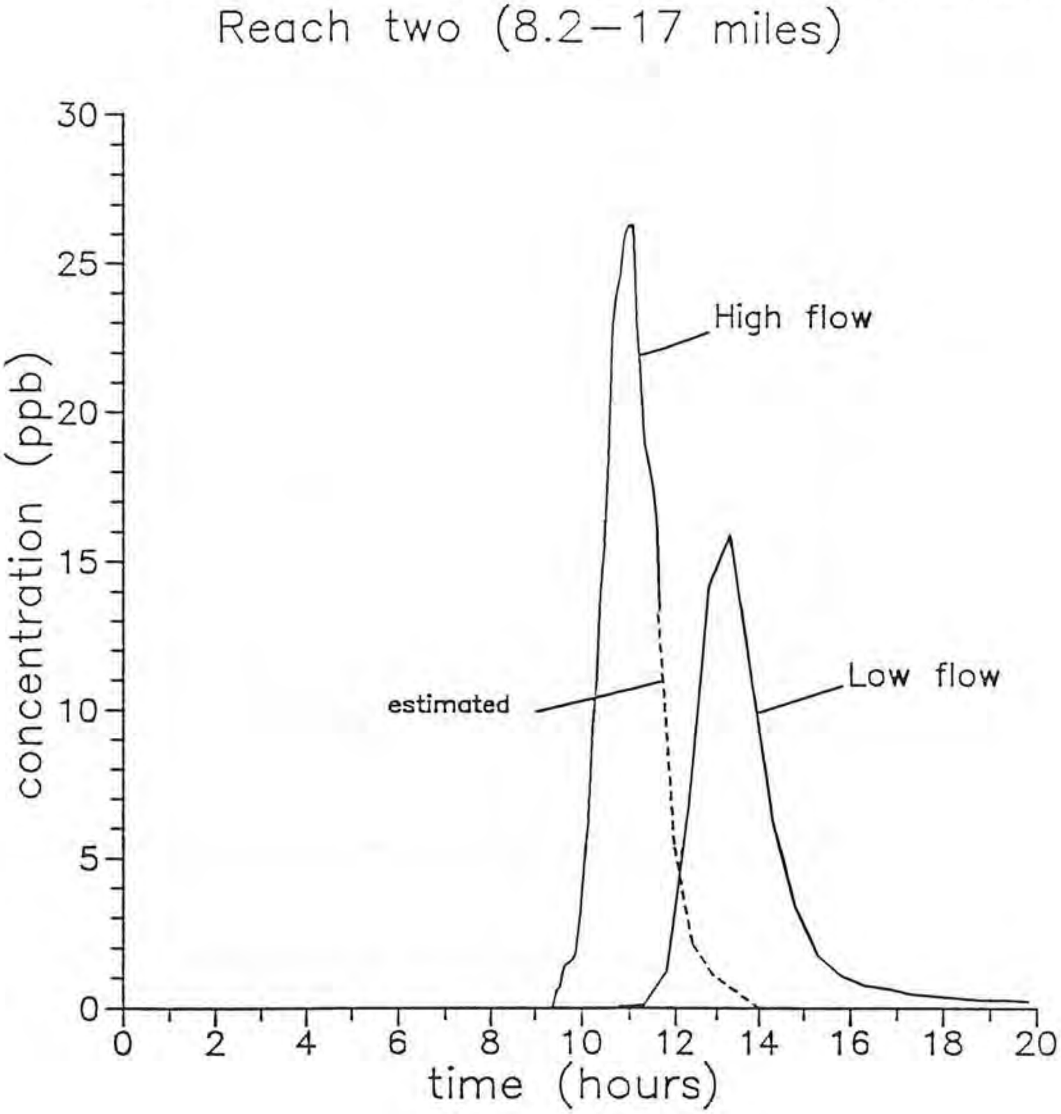
DATA COLLECTED 6-26 TO 6-27-90

INDEX GAGE DISCHARGE: 234 cfs *

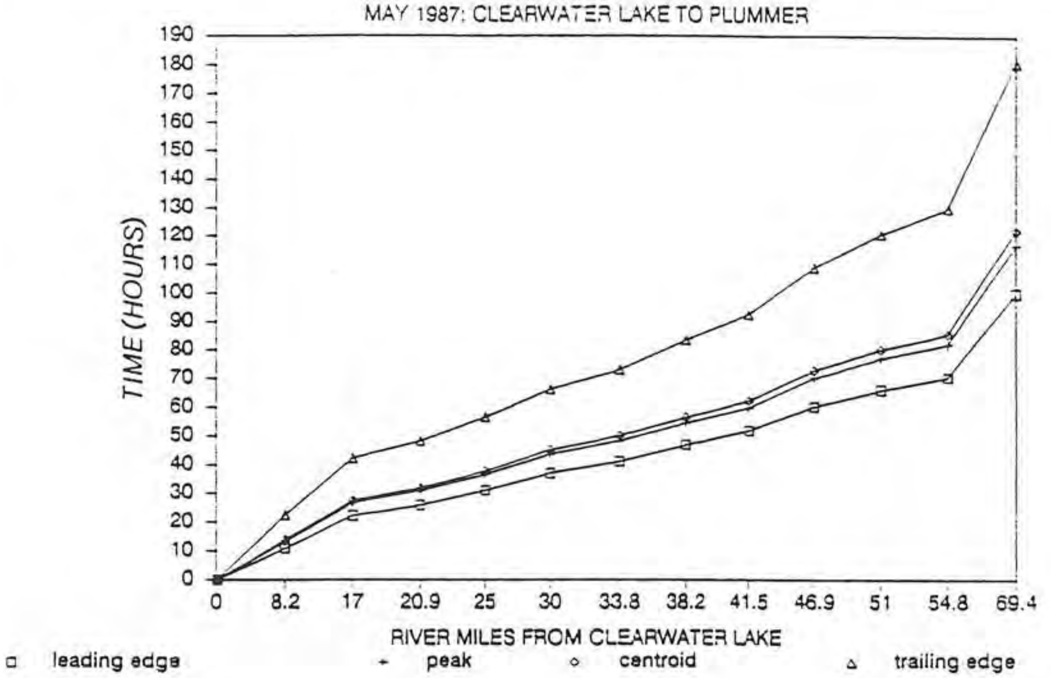
REACH	REACH LENGTH (mi.)	CUMULATIVE RCH. LGTH. (mi.)	QUANITY OF DYE (g)	LEADING EDGE (HR.)		PEAK (HR.)		CENTROID (HR.)		♦ TRAILING EDGE(HR.)		MEASURED DISCHARGE IN REACH (cfs)	PEAK CONC. (PBB)	TIME PASSAGE OF CLOUD (HRS.)	
				REACH	CUMULATIVE	REACH	CUMULATIVE	REACH	CUMULATIVE	REACH	CUMULATIVE			REACH	CUMULATIVE
1	8.2	8.2	2123.3	8.11	8.11	9.53	9.53	9.61	9.61	11.9	11.9	97	22.98	3.79	3.79
2	8.8	17	2170.6	9.47	17.58	11.01	20.54	11	20.61	12.4	24.3	110	26.3	2.93	6.72
3	3.9	20.9	1482.3	3.33	20.91	4.17	24.71	4.26	24.87	5.3	29.6	121	34.08	1.97	8.69
4	4.1	25	1523	2.92	23.83	3.5	28.21	3.6	28.47	4.17	33.8	196	32.6	1.25	9.94
5	5	30	1812.4	3.35	27.18	3.77	31.98	3.84	32.31	4.4	38.2	196	83.16	1.05	10.99
6	3.8	33.8	1367.4	2.82	30	3.23	35.21	3.32	35.63	3.9	42.1	204	69.66	1.08	12.07
7	4.4	38.2	1464.3	2.67	32.67	3.34	38.55	3.39	39.02	4.28	46.4	204	16.16	1.61	13.68
8	3.3	41.5	1025.7	2.64	35.31	3.3	41.85	3.42	42.44	4.2	50.6	237	35.79	1.56	15.24
9	5.4	46.9	1237.5	4.4	39.71	5	46.85	5.11	47.55	5.95	56.5	237	10.25	1.55	16.79
10	4.1	51	905.7	3.18	42.89	3.47	50.32	3.63	51.18	4.43	60.9	244	9.6	1.25	18.04
11	3.8	54.8	469.2	2.8	45.69	3.13	53.45	3.22	54.4	3.8	64.7	244	30.39	1	19.04
12	14.6	69,4	4485.8	13.35	59.04	14.85	68.3	14.98	69.38	16.85	81.6	234 *	15.65	3.5	22.54

♦ : BASED ON 10% OF PEAK CONC. STANDARD
* : TWO DAY AVERAGE AT PLUMMER GAGE

Figure 5.1 Study reach response to dye injections for the high and low flow conditions.



Figures 5.2a Travel-time distance relationships for the low flow condition (36cfs).



Figures 5.2b Travel-time distance relationships for the high flow condition (234cfs).

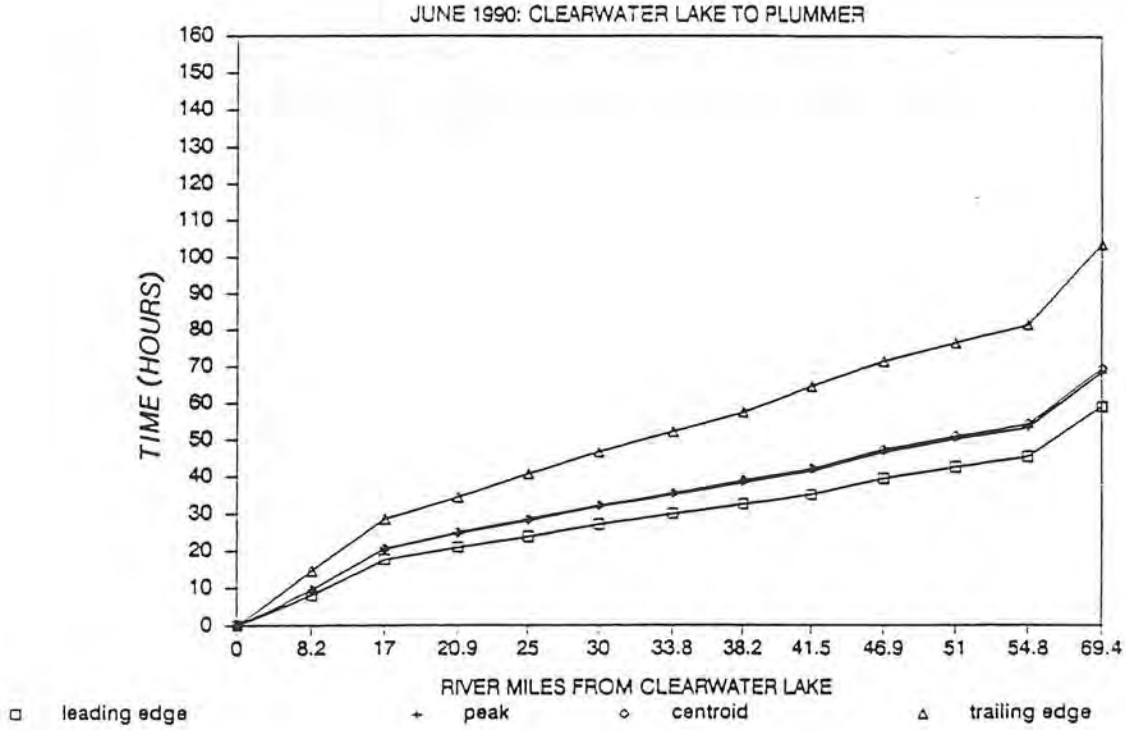


Figure 5.3

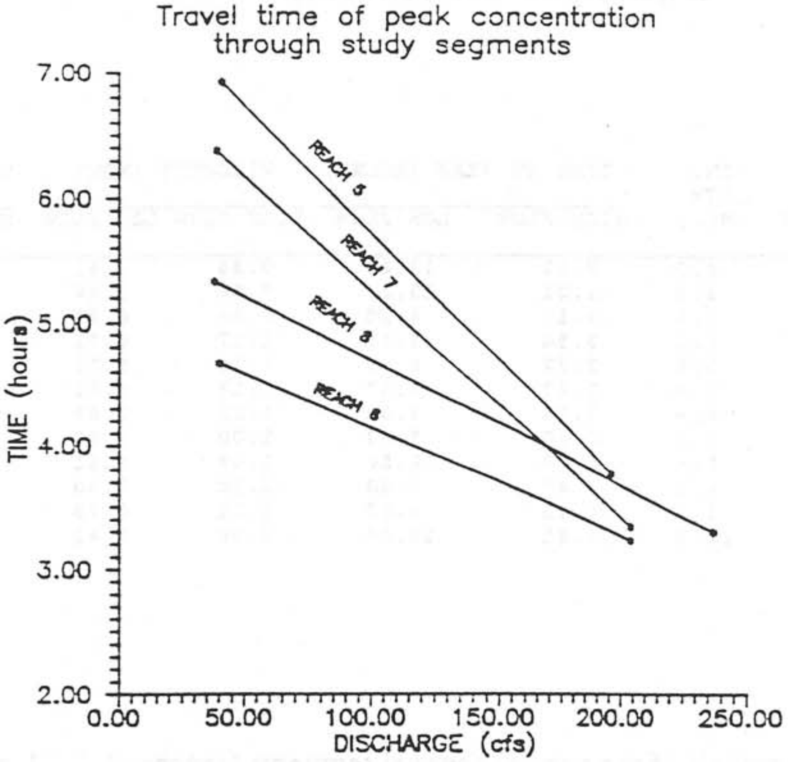


Figure 5.4

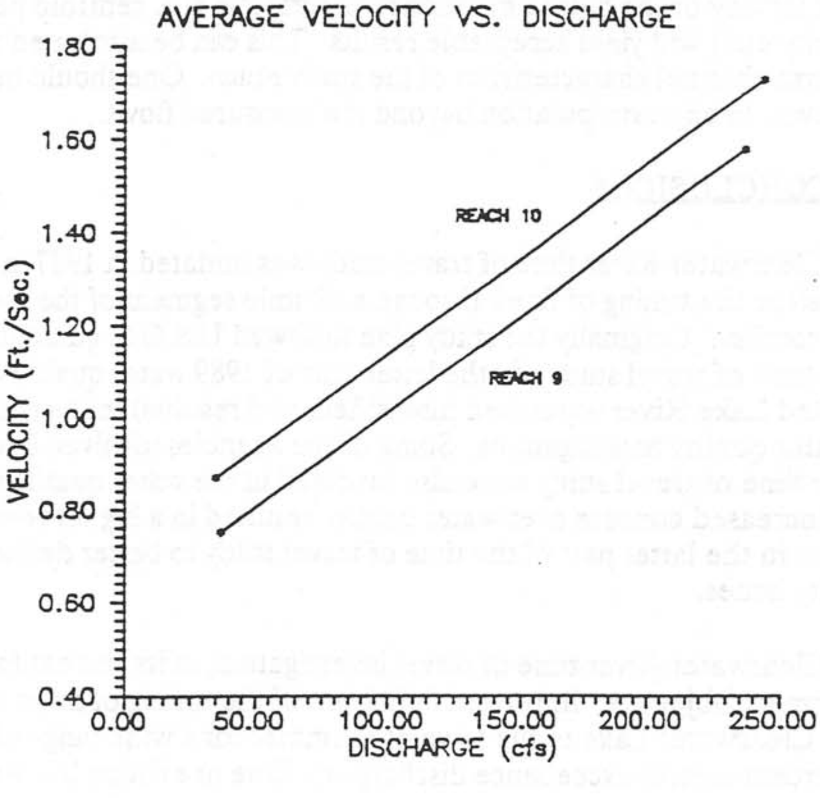


Table 5.2 Average velocity to discharge developed from time to peak for high flow (234 cfs), and low flow (36 cfs) dye tracings.

REACH	RCH. LGTH. (Mi.)	TIME TO PEAK (HOURS)		VELOCITY (MPH)		VELOCITY (FT/SEC)	
		HIGH FLOW	LOW FLOW	HIGH FLOW	LOW FLOW	HIGH FLOW	LOW FLOW
1	8.2	9.53	13.42	0.86	0.61	1.26	0.90
2	8.8	11.01	13.30	0.80	0.66	1.17	0.97
3	3.9	4.17	4.20	0.94	0.93	1.37	1.36
4	4.1	3.50	5.58	1.17	0.73	1.72	1.08
5	5.0	3.77	6.92	1.33	0.72	1.95	1.06
6	3.8	3.23	4.67	1.18	0.81	1.73	1.19
7	4.4	3.34	6.38	1.32	0.69	1.93	1.01
8	3.3	3.30	5.33	1.00	0.62	1.47	0.91
9	5.4	5.00	10.50	1.08	0.51	1.58	0.75
10	4.1	3.47	6.88	1.18	0.60	1.73	0.87
11	3.8	3.13	4.87	1.21	0.78	1.78	1.14
12	14.6	14.85	35.08	0.98	0.42	1.44	0.61

In general all of the natural channel segments (reaches 1, 2, 11, and 12) showed similar flow characteristics. The channelized reaches also showed similar relationships. Straight line interpletation between the two measured flows for any of the before mentioned descriptors (i.e. centroid peak, average velocity etc.) will yield acceptable results. This can be attributed to the uniform channel characteristics of the study reach. One should be cautious however, in any extrapolation beyond the measured flows.

6.0 CONCLUSIONS

The Clearwater River time of travel study was initiated in 1987 in order to better define the timing of flows through a 69 mile segment of the river with high user conflict. Originally the study plan followed U.S.G.S. guidelines for a low level time of travel study. In the latter part of 1989 water quality concerns in the Red Lake River watershed intensified, and resulted in the commencement of water quality investigations. Some of the agencies involved in the Clearwater time of travel study were also involved in the water quality research. The increased concern over water quality resulted in a higher level of data collection in the latter part of the time of travel study to better define water quality issues.

The Clearwater River time of travel investigation, in its current form, achieved its primary objective: Improved definition of the timing of flows on the river from Clearwater Lake to the town of Plummer for a wide range of flows (20 to 90 percent annual exceedence discharges). Due to existing low water conditions in the region the study was unable to examine a flow above 300 cfs. Further definition of time of travel above this level would enhance the existing work and improve our understanding of the river. In order to examine the dispersion rate of contaminants when addressing water quality issues, additional information would be needed at the low flow level (36 cfs) and also at any higher flow to be studied in the future.

If the reader has any questions related to this study or would like to discuss specific applications of the results, please contact Greg Kruse (612) 297-2402, or Dave Leuthe (612) 297-3886.

BIBLIOGRAPHY

Gunard K.T., J.H.Hess, J.I.Zirbel, and C.E. Cornelius. 1989. U.S. Geological Survey, Water Resources Data Minnesota Water Year 1987, Vol. I., Report No. USGS/WRD/HD-89/269.

Hubbard E.F., F.A. Kilpatrick, L.A. Martens, and J.F. Wilson. 1982. Measurement of time of travel and dispersion in streams by dye tracing. Techniques of Water Resources Investigations of the U.S.G.S., Book 3, Chapt. A9.

MNDNR. April, 1959. Hydrologic Atlas of Minnesota. MNDNR Div. of Waters Bulletin #10, Unit 11.

MNDNR, Office of Planning. 1981. Stream Inventory and Data Retrieval Systems. The developement of a statewide hydrologic reference system. SIDRS Report No. 7001.

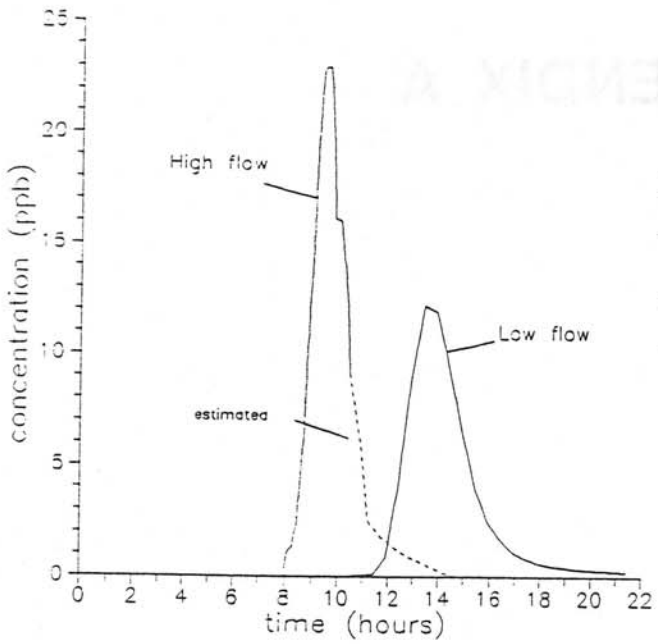
MNDNR Water Appropriation Index. 1990.

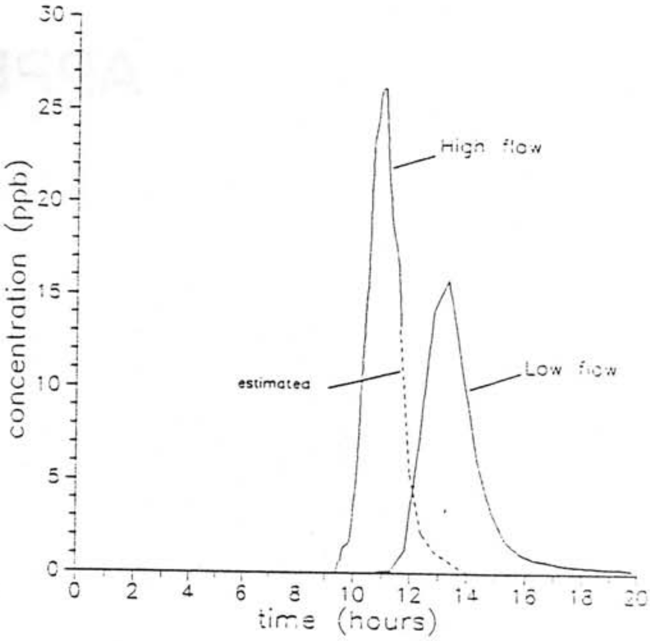
U.S. Department of Agriculture. February, 1984. Soil Survey of Pennington County Minnesota.

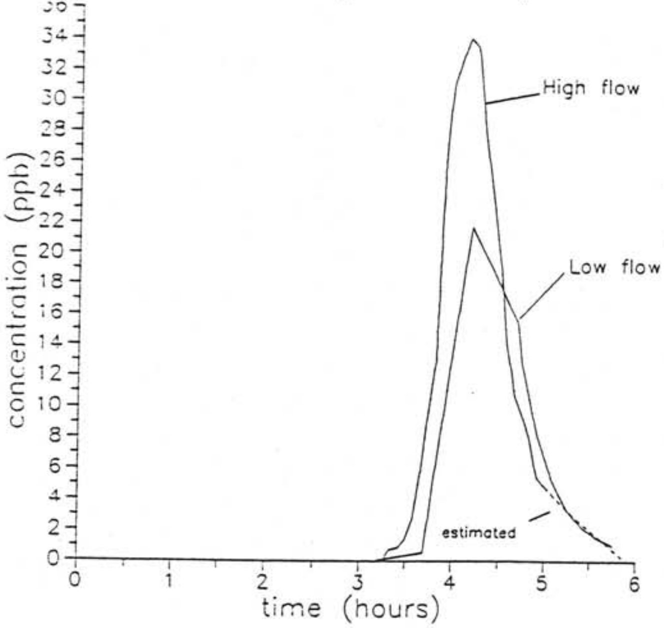
U.S. Army Corps of Engineers. December 1980. Red River of the North reconnaissance report. GSRI Project No. 955.

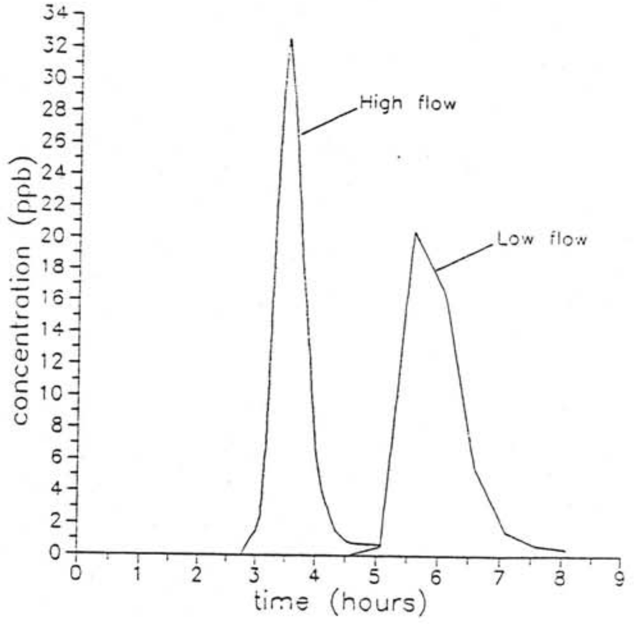
University of Wisconsin, Agricultural Experiment Station. June, 1969. Soils of the North Centeral Region of the U.S. Bulletin 544, North Centeral Region, Publication No. 76.

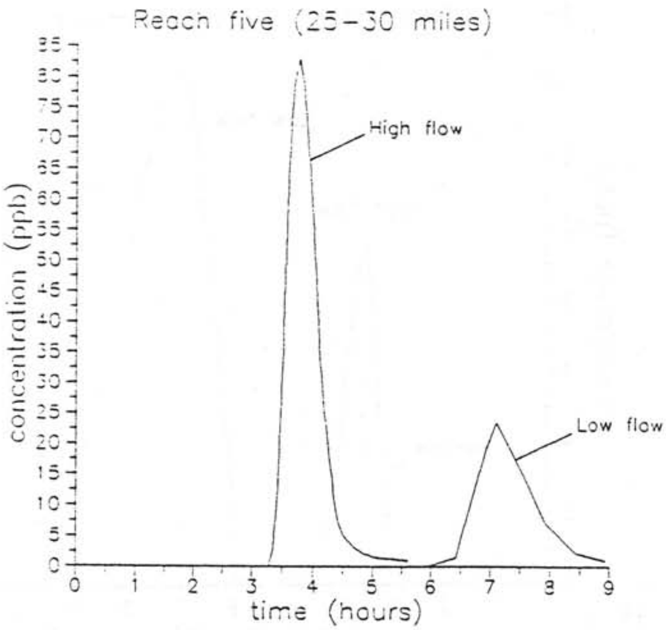
APPENDIX A

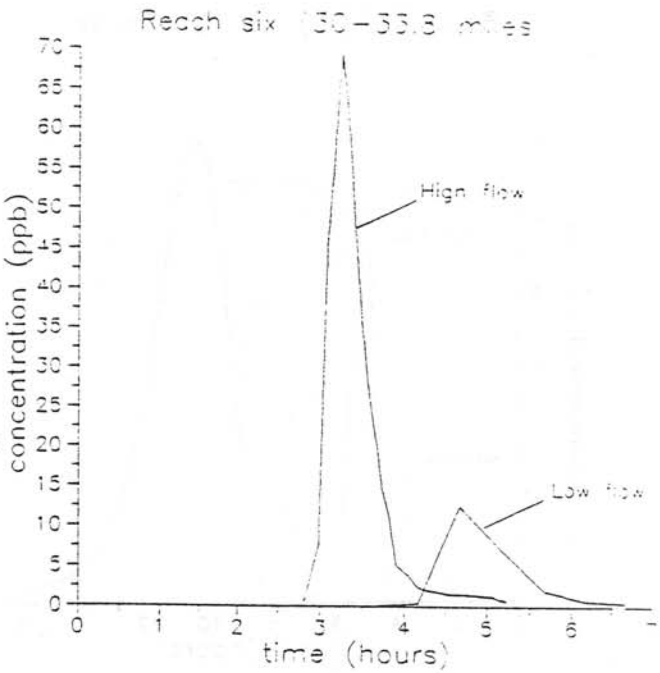

Reach one (0–8.2 miles)

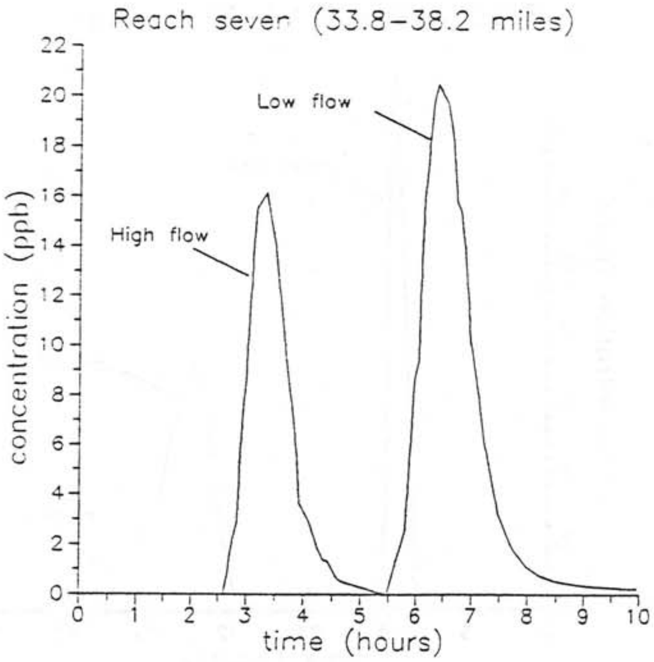

Reach two (8.2–17 miles)

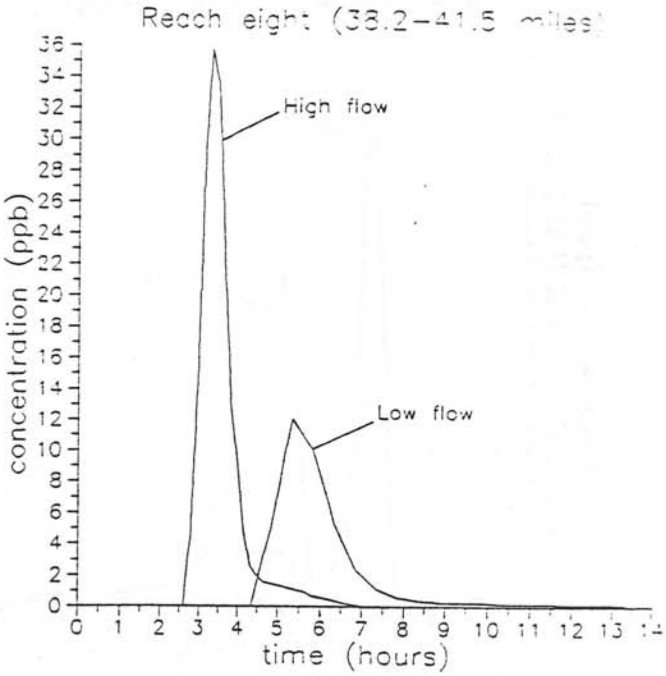

Reach three (17–20.9 mi)

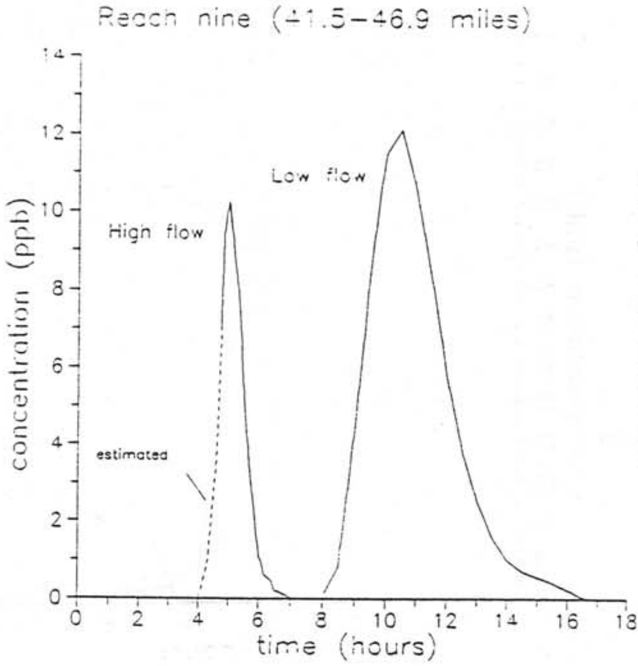

Reach four (20.9–25 miles)


Reach five (25-30 miles)

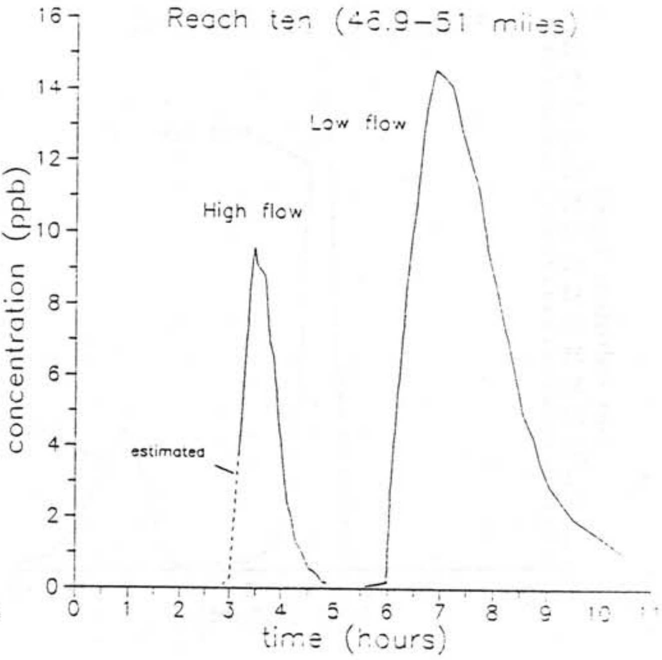

Reach six (30-33.8 miles)


Reach seven (33.8-38.2 miles)

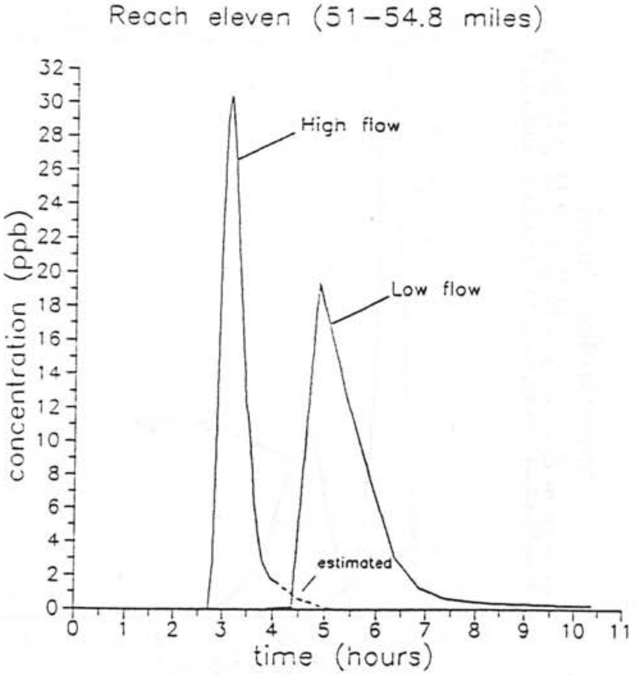

Reach eight (38.2-41.5 miles)



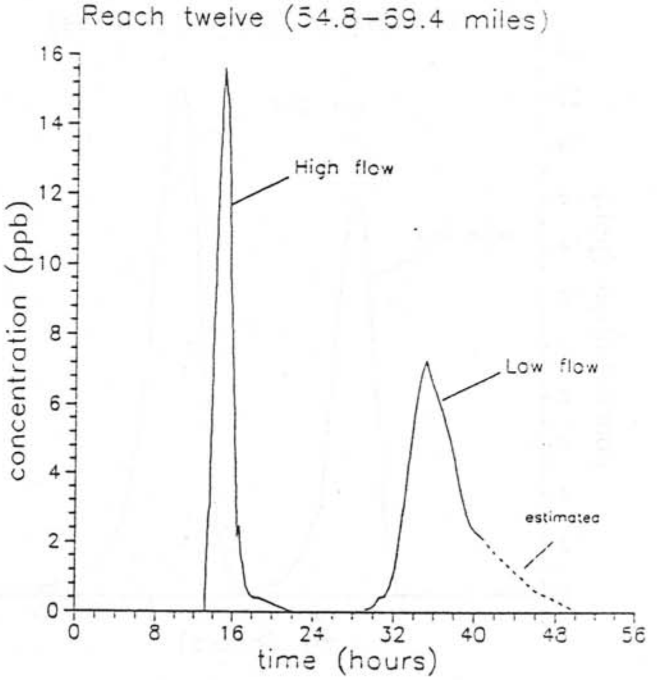
Reach nine (41.5–46.9 miles)



Reach ten (46.9–51 miles)

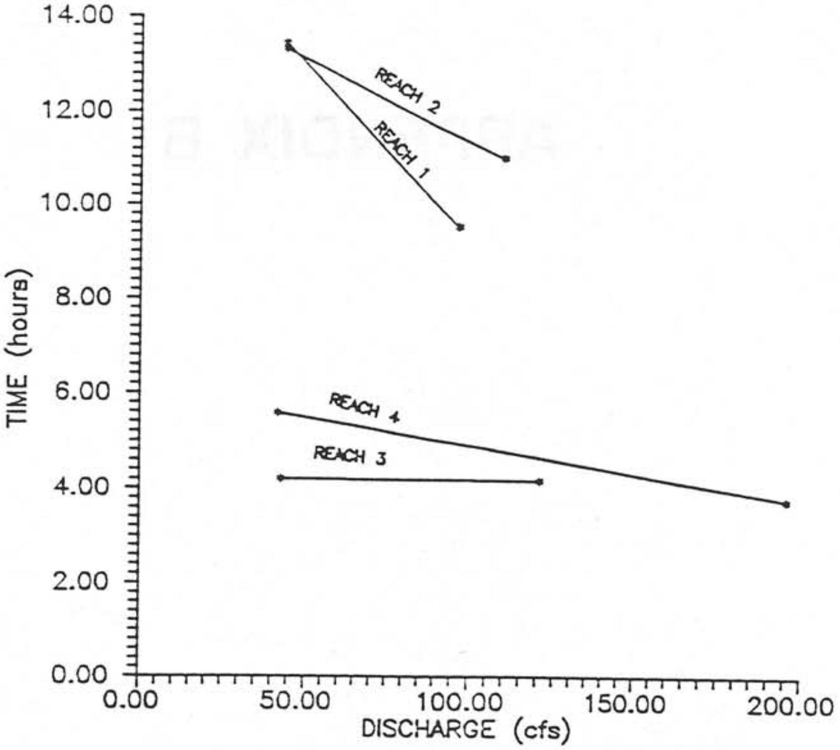


Reach eleven (51–54.8 miles)

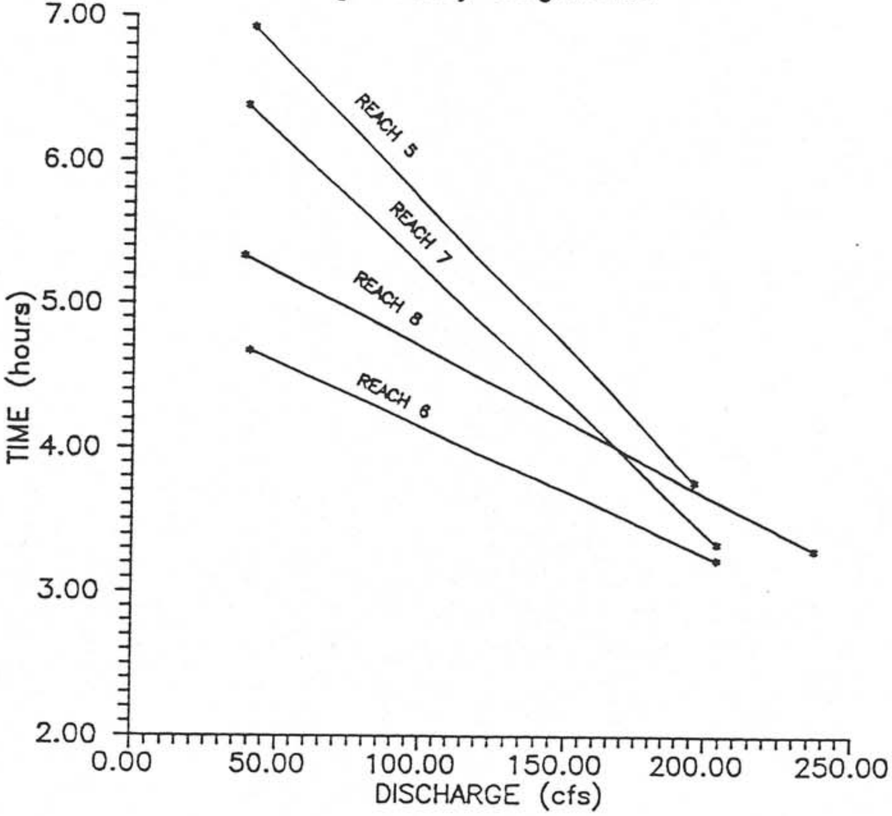


Reach twelve (54.8–69.4 miles)

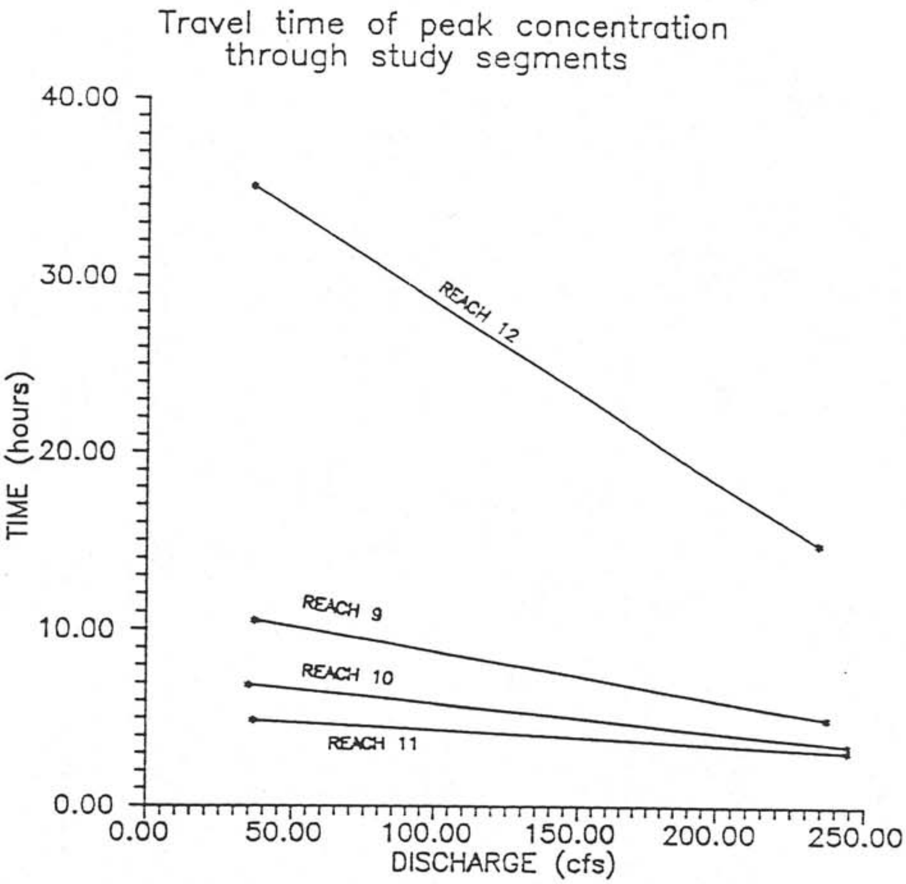
APPENDIX B



Travel time of peak concentration through study segments

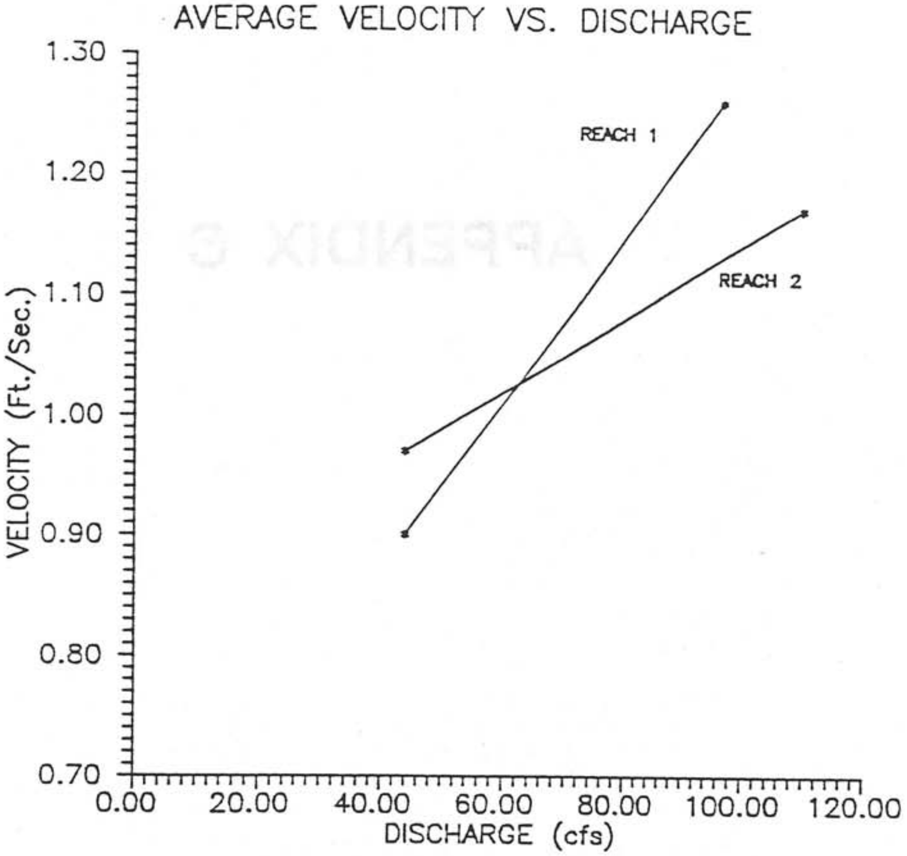


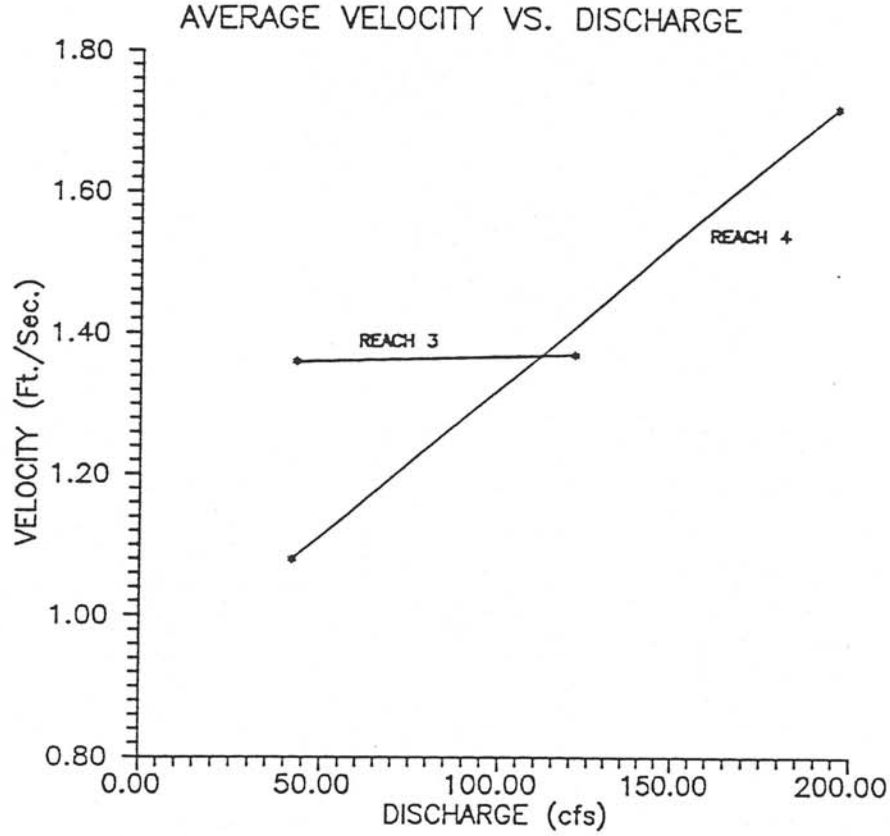
Travel time of peak concentration through study segments

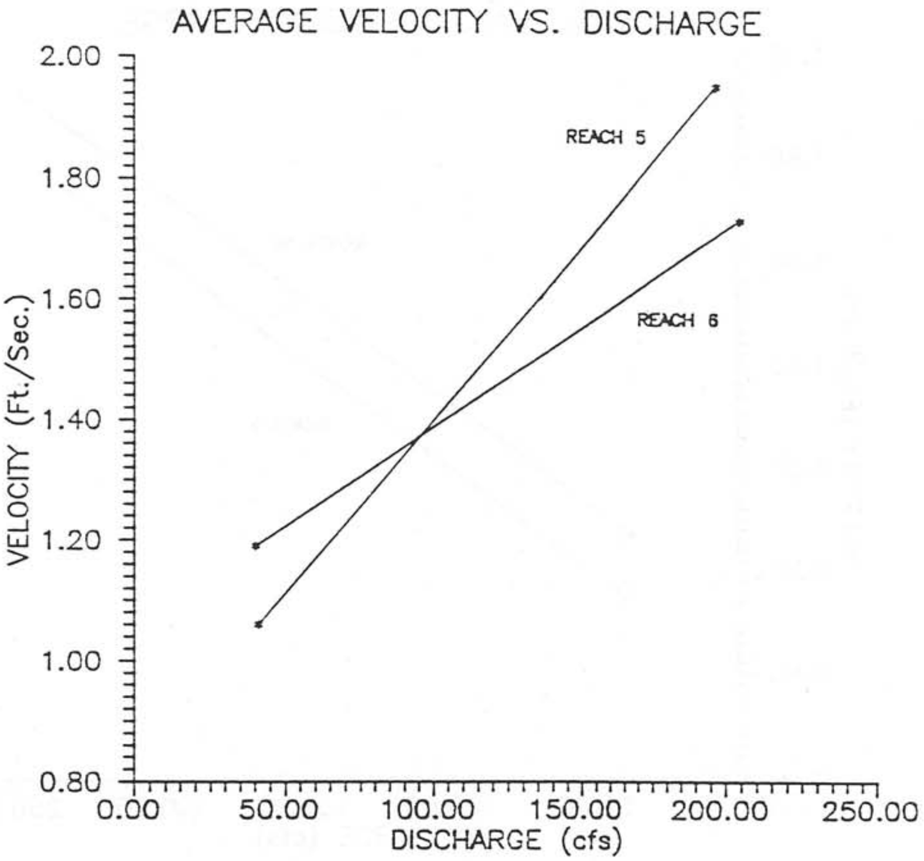


Note: The velocity and discharge relationships have been derived for actual discharge measured within the individual study segments and are not based on the index gage at Plummer.

APPENDIX C


AVERAGE VELOCITY VS. DISCHARGE
VELOCITY (Ft./Sec.)
DISCHARGE (cfs)
1.30
1.20
1.10
1.00
0.90
0.80
0.70
0.00
20.00
40.00
60.00
80.00
100.00
120.00
REACH 1
REACH 2


AVERAGE VELOCITY VS. DISCHARGE
VELOCITY (Ft./Sec.)
DISCHARGE (cfs)
1.80
1.60
1.40
1.20
1.00
0.80
0.00
50.00
100.00
150.00
200.00
REACH 3
REACH 4


AVERAGE VELOCITY VS. DISCHARGE
VELOCITY (Ft./Sec.)
DISCHARGE (cfs)
REACH 5
REACH 6
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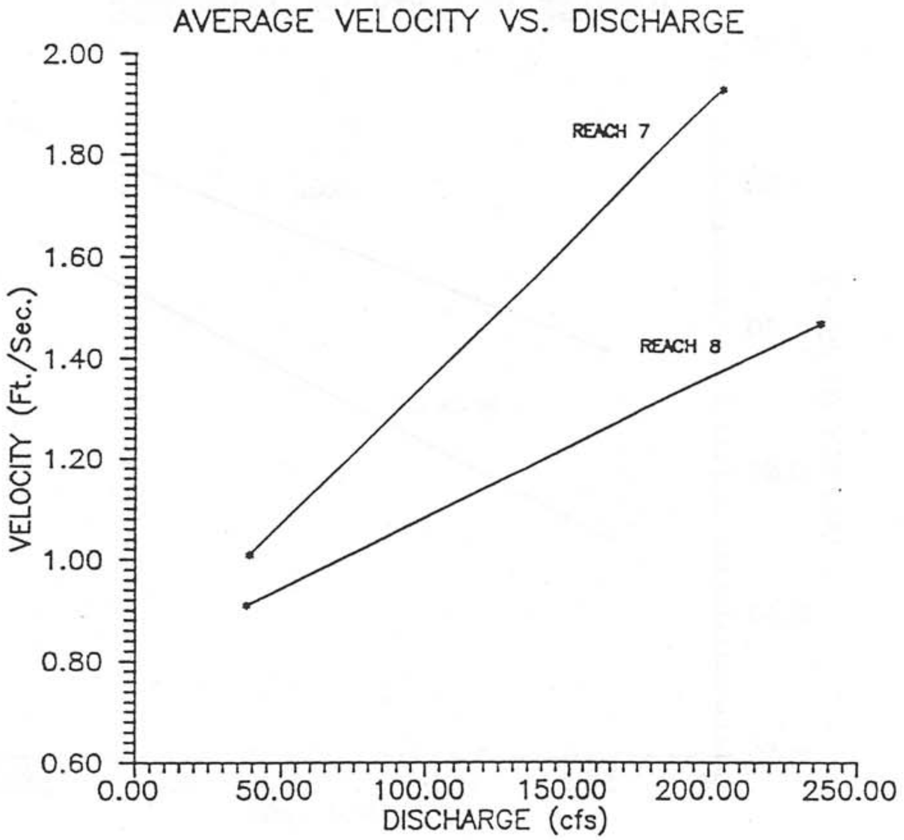
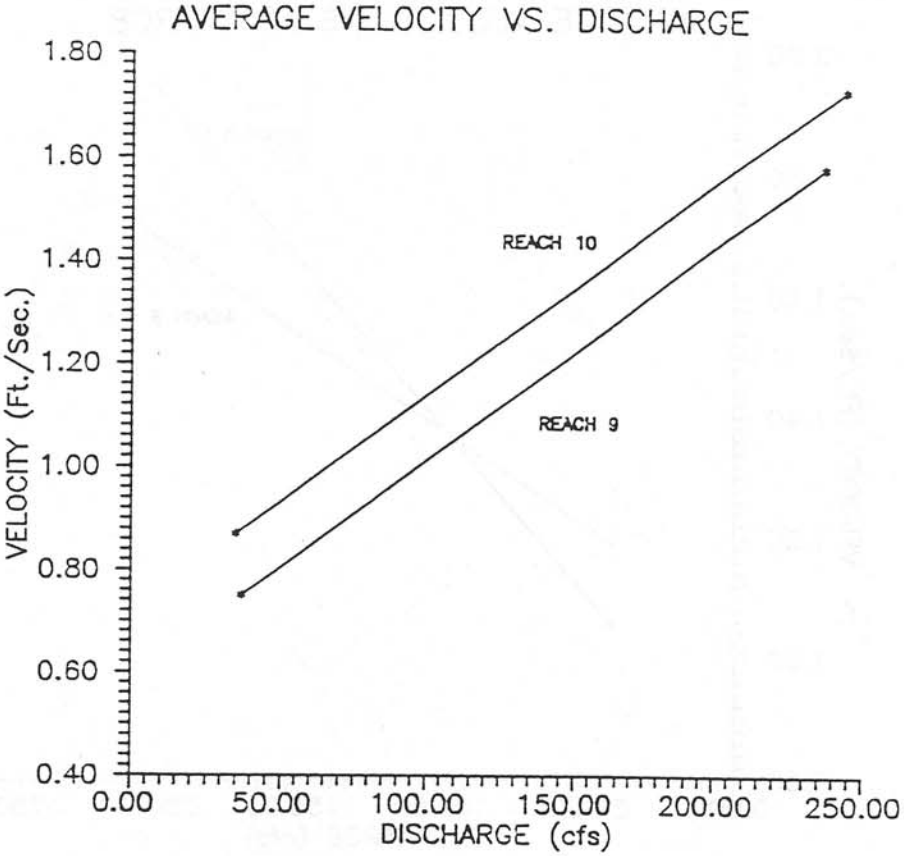
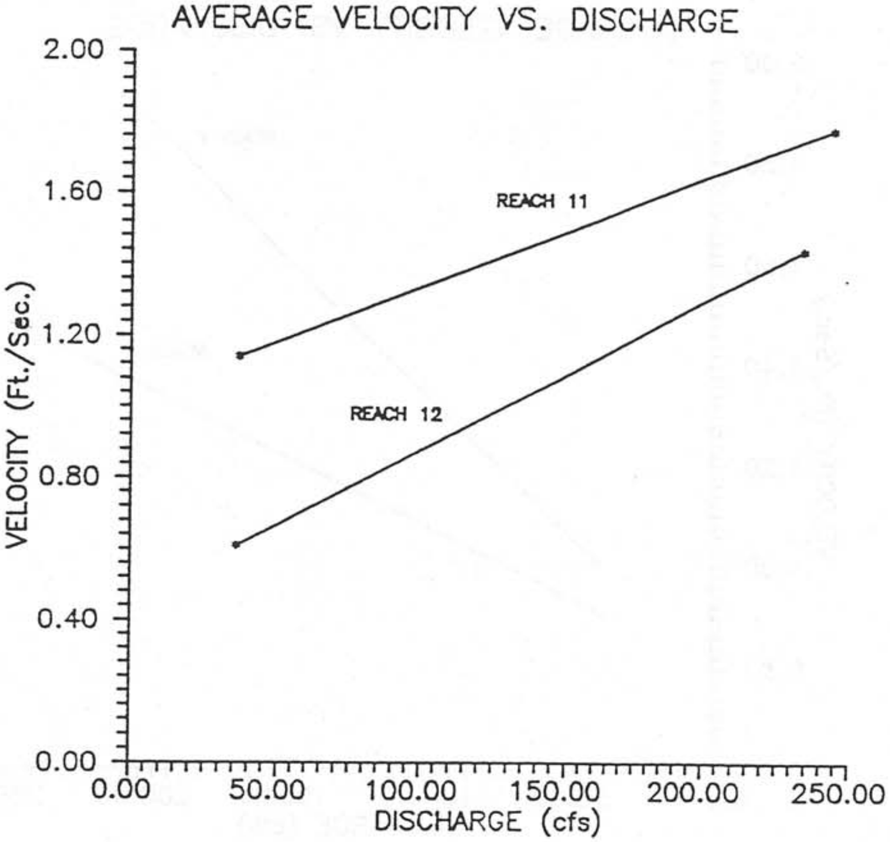
1.40
1.20
1.00
0.80
0.00
50.00
100.00
150.00
200.00
250.00


AVERAGE VELOCITY VS. DISCHARGE
VELOCITY (Ft./Sec.)
DISCHARGE (cfs)
REACH 7
REACH 8
2.00
1.80
1.60
1.40
1.20
1.00
0.80
0.60
0.00
50.00
100.00
150.00
200.00
250.00


AVERAGE VELOCITY VS. DISCHARGE
VELOCITY (Ft./Sec.)
1.80
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.00
50.00
100.00
150.00
200.00
250.00
DISCHARGE (cfs)
REACH 10
REACH 9


AVERAGE VELOCITY VS. DISCHARGE
VELOCITY (Ft./Sec.)
2.00
1.60
1.20
0.80
0.40
0.00
0.00
50.00
100.00
150.00
200.00
250.00
DISCHARGE (cfs)
REACH 11
REACH 12

Note: The velocity vs. discharge relationships have been derived for actual discharge meausred within the individual study segments and are not based on the index gage at Plummer.

GEOGRAPHIC INFORMATION SYSTEM PRESENTATION

The following is a condensed version of a presentation given in June of 1991 at three separate local meetings. There was no actual data available from the Clearwater study, so this presentation was developed to educate the local citizens on the functions and capabilities of a Geographic Information System using a hypothetical watershed.

General Introduction

The Geographic Information System (GIS) is a computer-based tool that captures, displays, and manipulates data that is geographically referenced by latitude and longitude or other map projection systems. GIS has the following functional capabilities:

1. The ability to display a target environment visually and numerically. The system converts all input maps and numerical data to a similar scale. The objective is consistency, so that data from many sources such as satellites and aerial photography, resource inventories, statistical reporting and interviews, can be integrated and translated into comparable data that is shown on a map or a series of maps.

2. The ability to explore relationships among data sets. Statistical relationships can be determined among spatial data sets. The purpose is to determine closely related factors to direct research into causal relationships, to establish correlation coefficients and regression equations for use in predictive modeling and to understand mechanisms of change.

3. The ability to identify locations that meet specified criteria. In the search for ideal sites consideration must be given to multiple criteria of either absolute or relative weight. Searches may be conducted to identify sites or areas for resource development, processing facilities, retail outlets, distribution centers, or land for transfer to other uses. Criteria can be varied to examine the sensitivity of selected uses.

4. The ability to analyze spatial trade-off decisions. An essential activity in resource management decision-making is allocation of land or territories to particular uses. This allocation may involve an individual land holding, a community, region, or nation. Data required for such allocation exercises may include land use, production trends, economic valuation of competing land uses, and models that simulate the demands and preferences for land.

5. The ability to assess impacts or changes created by new projects, new programs, or natural events can be assessed statistically and visually. Using studies, derived relationships or rules of thumb, multiple layers of data can be combined in one or a series of steps to simulate the impact of various decisions.

There are three different GIS data structures available: vector, raster, and quadtree (Figure 1). ARC/INFO, a vector (line) system, uses points connected by lines to represent geographic attributes, such as a tree stand or a gravel pit. Eppl 7 (Environmental Planning

VECTOR

A system of points connected by lines.

RASTER

A system of grid cells with uniform size.

QUADTREE

A system of grid cells that sub-divides the cell until only one characteristic is in each cell.

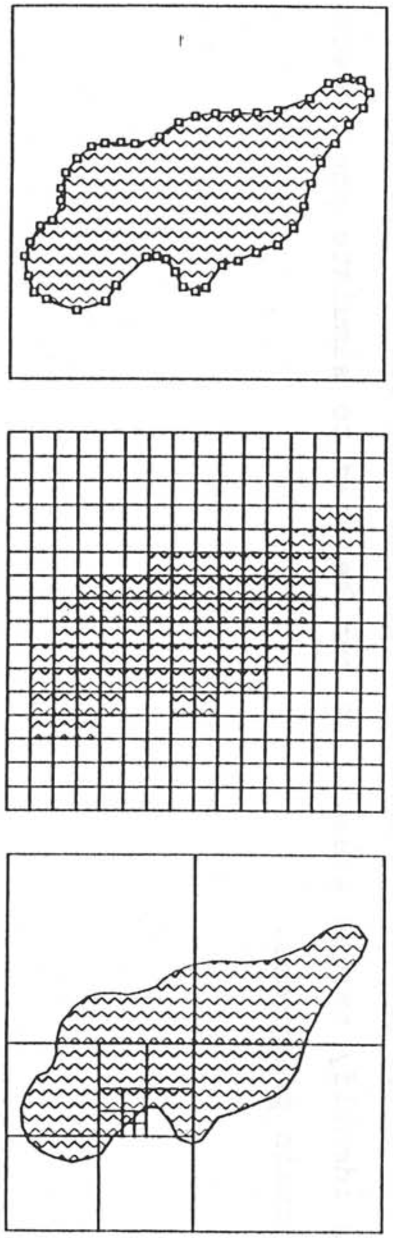


Figure 1 Examples of Vector, Raster, and Quadtree GIS programs.

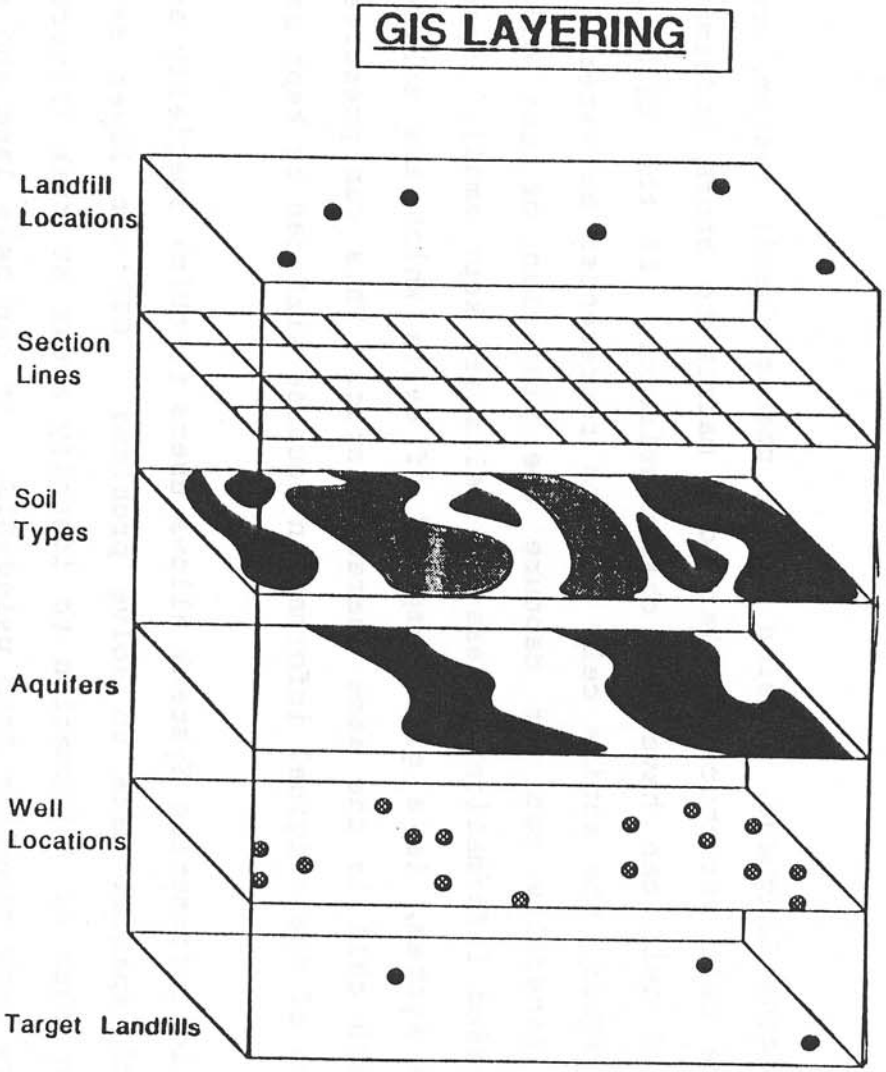


Figure 2 Layering of land Descriptor Variables in a Geographic Information System.

& Programing Language, Version 7), a raster (cell) system, uses a grid-like cell structure similar to a matrix to store information. Each grid cell can have one characteristic. If the cell is 51 percent water, the entire cell will be represented as water. Cell systems generally can not capture the precision of the original vector-based information, unless the cells are kept small. Spans, a quadtree system, is a grid composed of cells which are subdivided until each cell is the same characteristic. This can preserve the precision of the original information because size can be kept small.

Geographic Information Systems allows users to think spatially and to work with spatial data to solve problems. GIS can layer several different sets of information to identify areas at risk (Figure 2). There are many benefits from using GIS. It can help land and water mangers make better decisions and save limited public funds. It provides quick access to soil, water, and land resource information. It displays information in an understandable format. It may be used to identify target areas. It can be used to simulate the impact of certain practices.

MANIPULATING WATERSHED DATA

Clearwater River Project

The following information is based on a hypothetical watershed. We will look at the quantity and quality of the runoff of this watershed.

The first step in the process is to enter relevant data from the study area into your data base. In the following hypothetical example, some of the data entered for both quantity and quality would be type of soils, slope of the land, and current land use (Figure 3).

GIS and Water Quantity

Water quantity is analyzed by using Soil Conservation Service (SCS) methods. Some of the variables entered into the data base in addition to the previously mentioned variables would be the watershed boundaries, the sub-watershed boundaries, and precipitation totals (Figures 4 & 5).

The GIS program will produce a runoff curve number and a runoff lag time. The numbers generated are entered into a Flood Hydrograph program like HEC-1(Hydologic Engineering Center of the Army Corps of Engineers). This calculates expected surface water runoff based on precipitation events. This generates runoff flow rates (Figure 6).

Figures 7 through 11 analyze each Sub Watershed Basin after conversion from the current land use to an alternate land use. The vertical axis identifies the volume of water in cubic feet per

GEOGRAPHIC INFORMATION SYSTEMS
AND
WATER RESOURCES

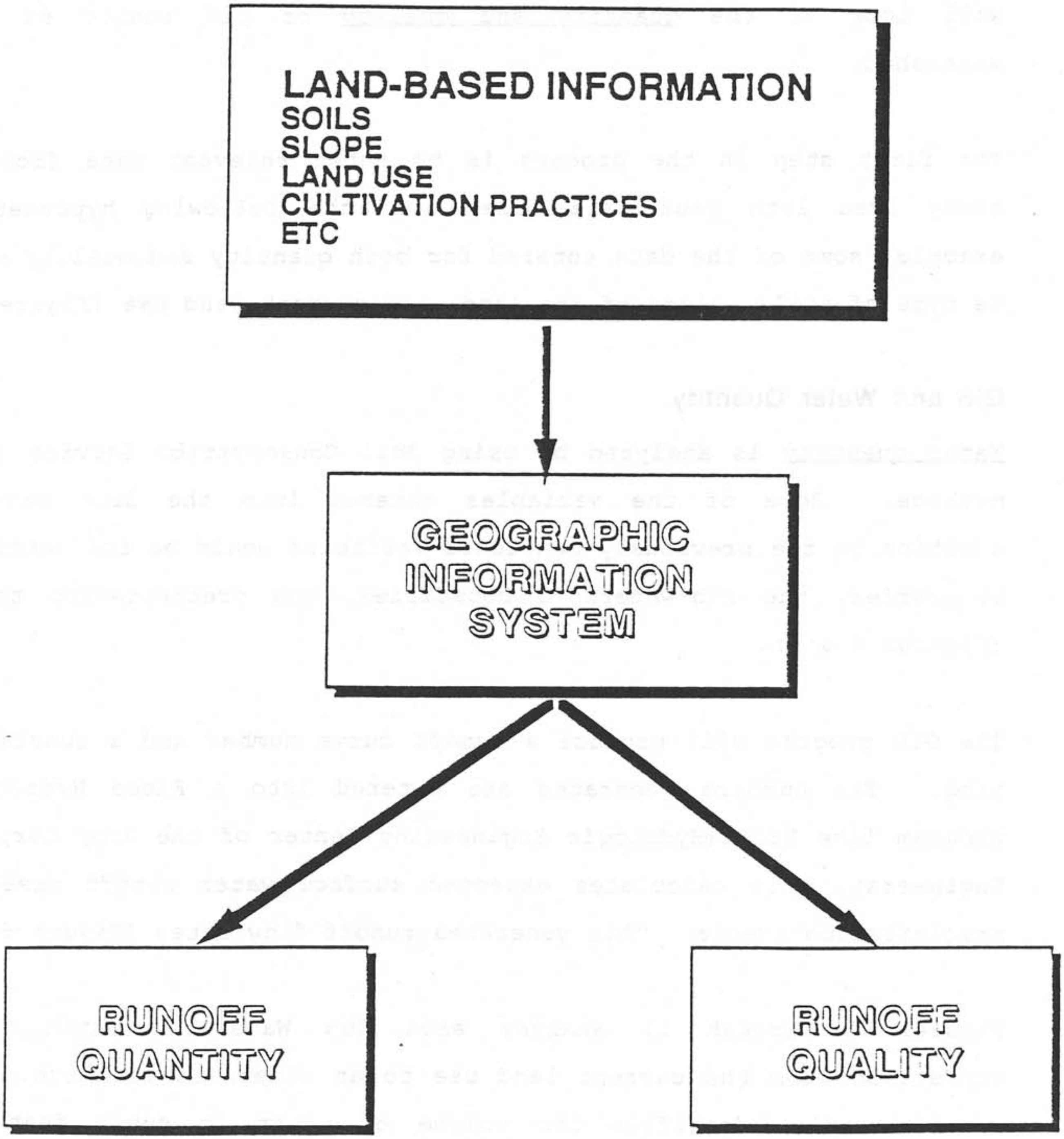


Figure 3 Flow diagram showing information put into a GIS program and two of the possible results.

Clearwater Project
Hypothetical Demonstration Watershed

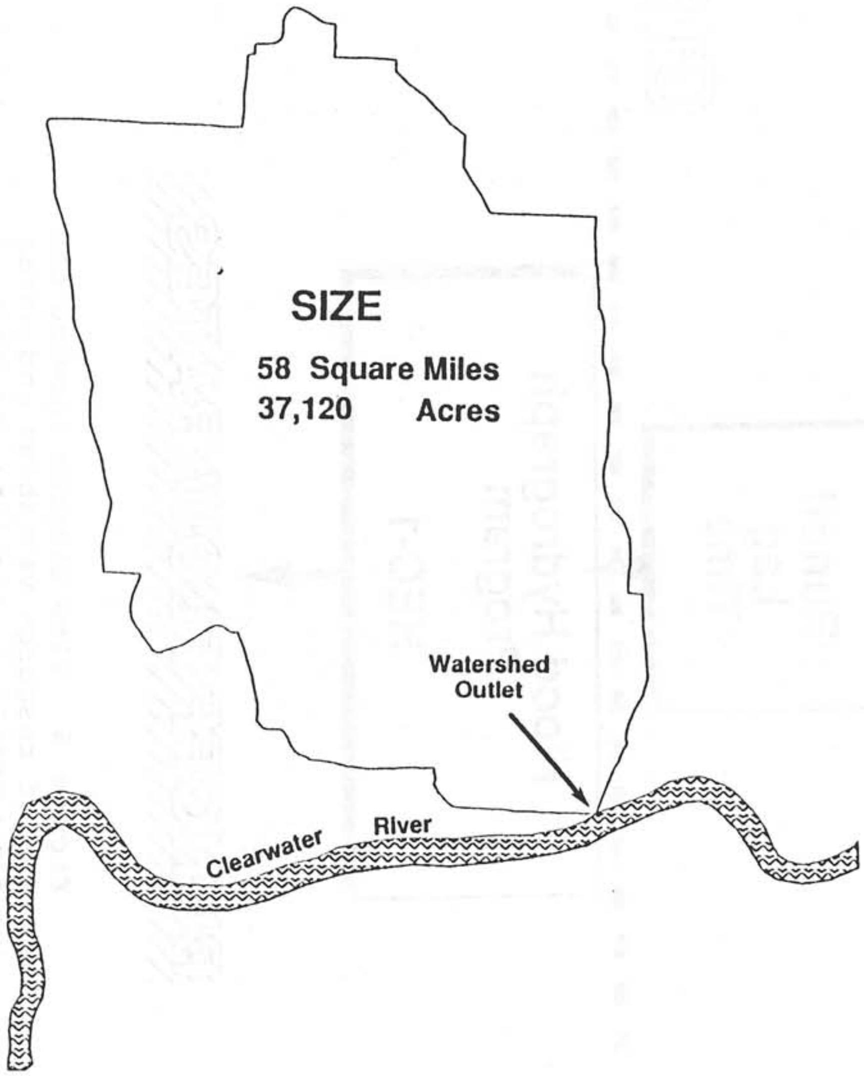


Figure 4

Clearwater Project
Subbasins and Streams

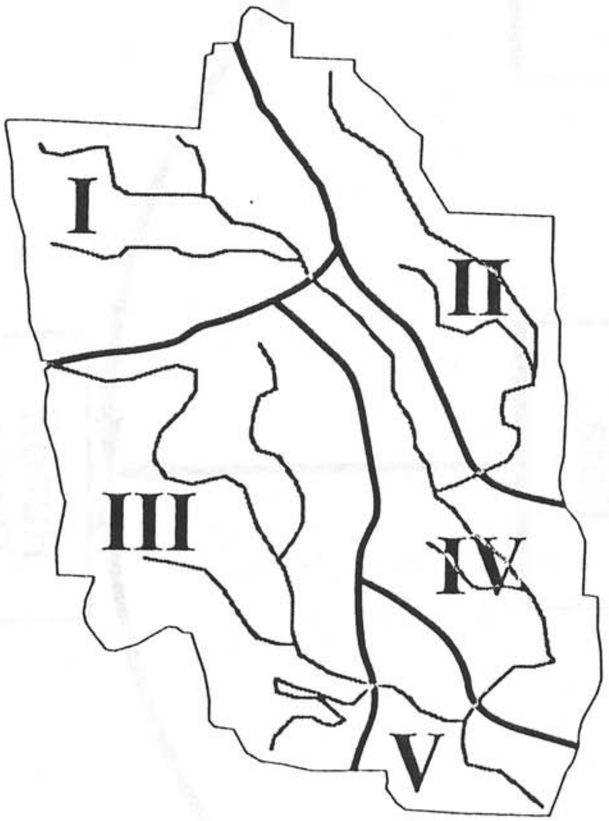


Figure 5

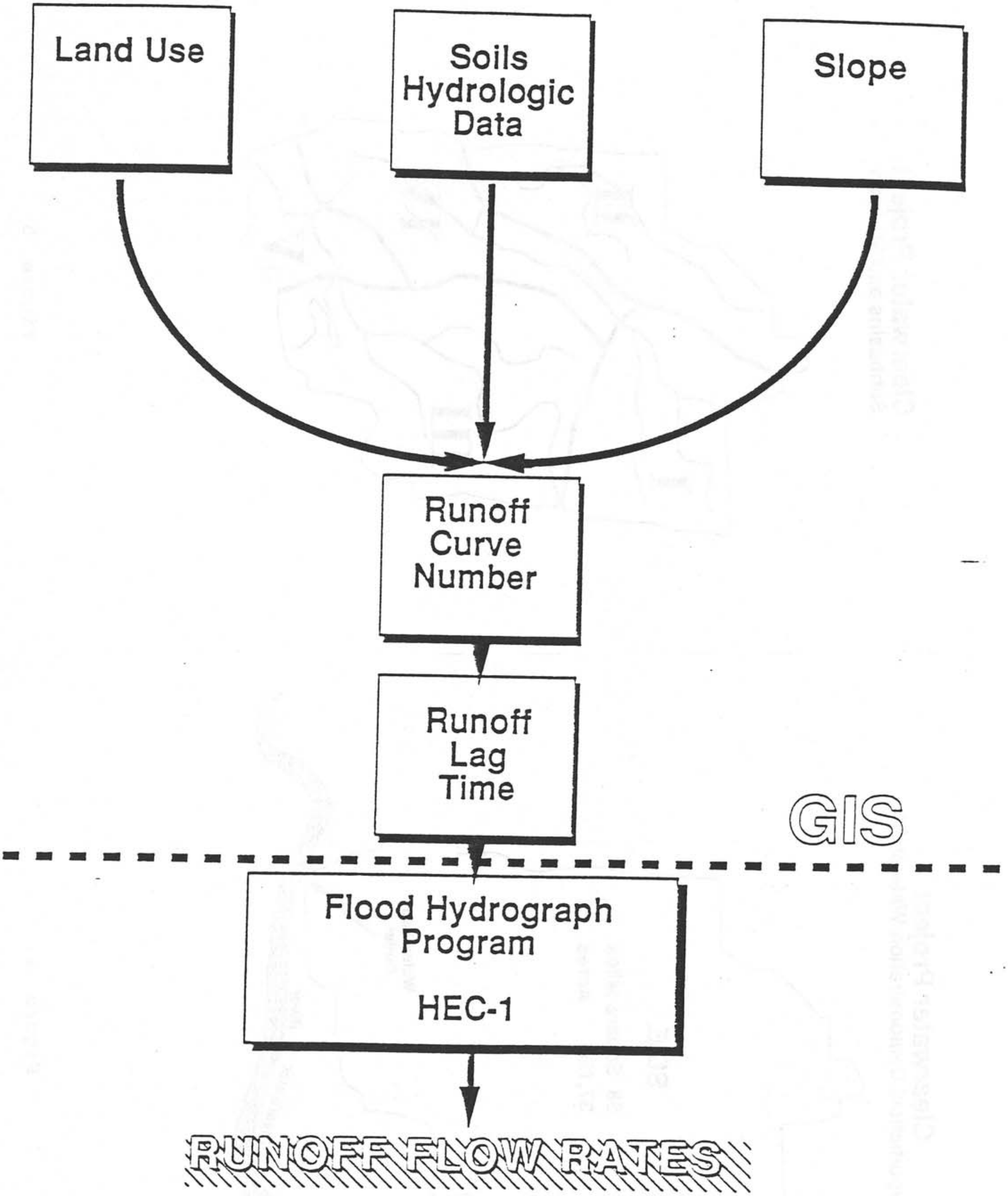


Figure 6 Flow diagram showing the use of resource variables and water flow models to simulate runoff flow rates.

second. The horizontal axis shows the percent exceedence. Percent exceedence is the number of times it will flood in 100 years. Therefore, a 1% exceedence is a 1 in 100 year flood, and 50% exceedence is a flood every other year.

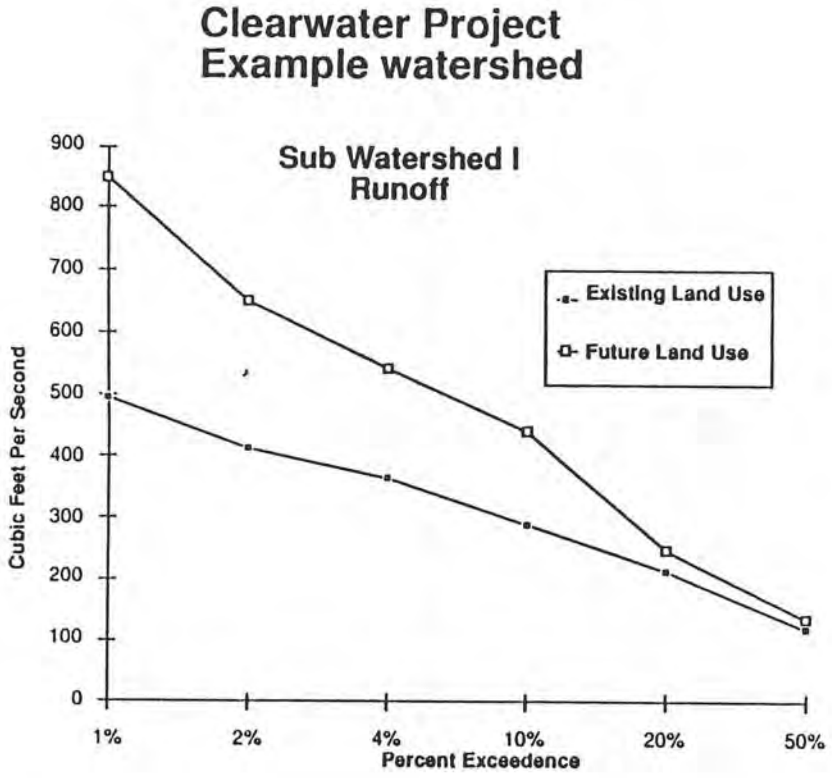
In Sub Watershed Basin I, (Figure 7) the land use is changed from pasture and hay lands to small grains. In the every other year event, the percent exceedence changes very little; as you experience larger precipitation events, the volume of runoff increases until the 100 year flooding event shows a significant increase in the amount of runoff.

Sub Watershed Basin II, (Figure 8) existing land use is pasture and hay lands. Future land use is small grain and row crops. Note that again the conversion makes little difference in small precipitation events, but an even larger increase in the amount of runoff in the 100 year event.

Note that in Sub Watershed Basin III, (Figure 9) existing land use is small grains that are converted to Conservation Reserve Programs. The future land use reduces runoff in larger events, but shows similar characteristics during smaller events.

Existing land use in Sub Watershed Basin IV (Figure 10) is row crops; future land use is pasture and hay lands. In this case, the conversion lowers runoff rates in all events, but especially during the larger events.

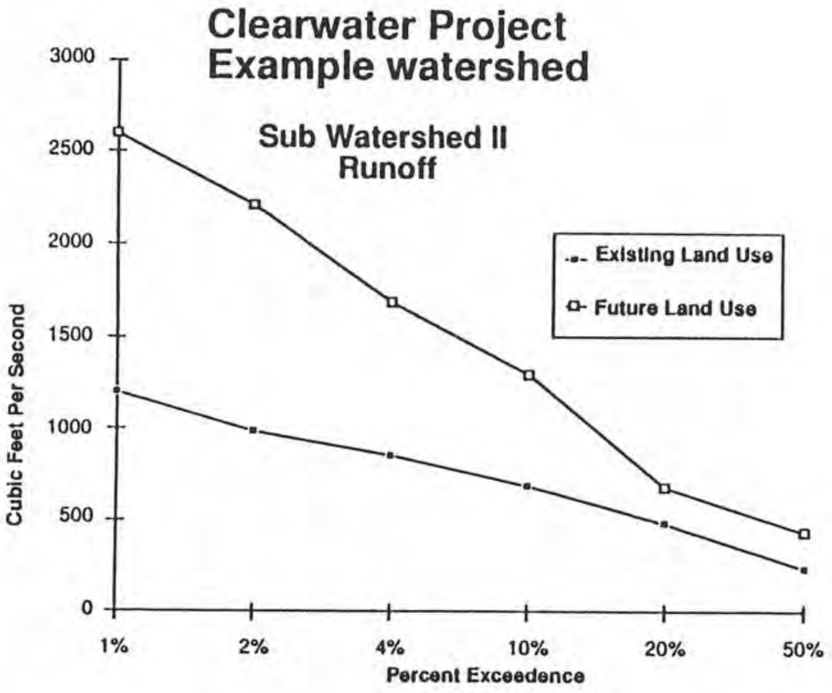
Sub Watershed Basin V (Figure 11) shows the conversion of



Notes: Land use changes increase runoff; particularly at higher runoff rates.

Example: Converstion of pasture and haylands to small grain.

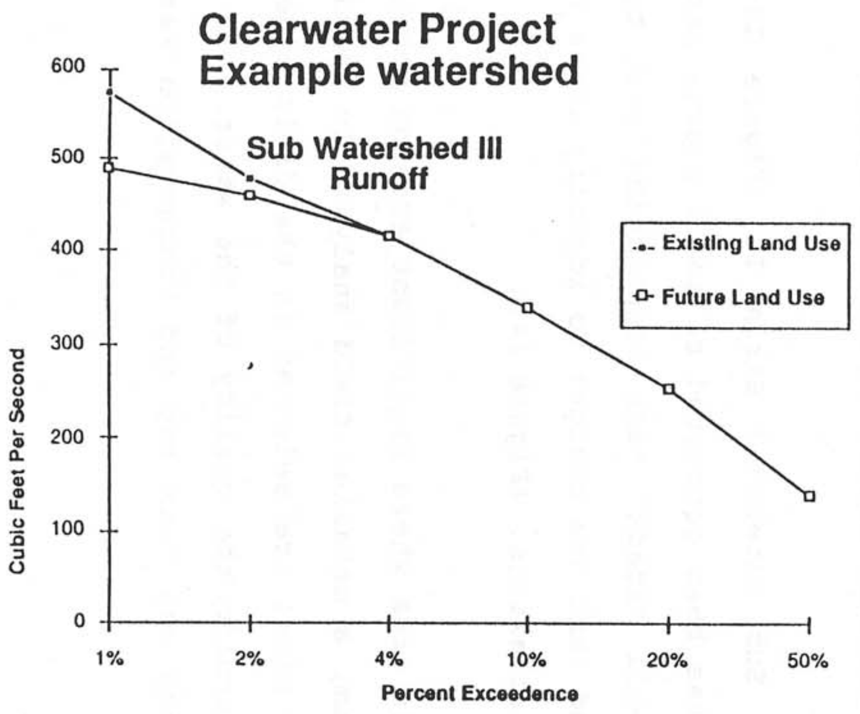
Figure 7



Notes: Future land use changes significantly increase runoff; particularly at higher runoff rates.

Example: Converstion of pasture and haylands to small grain and row crops.

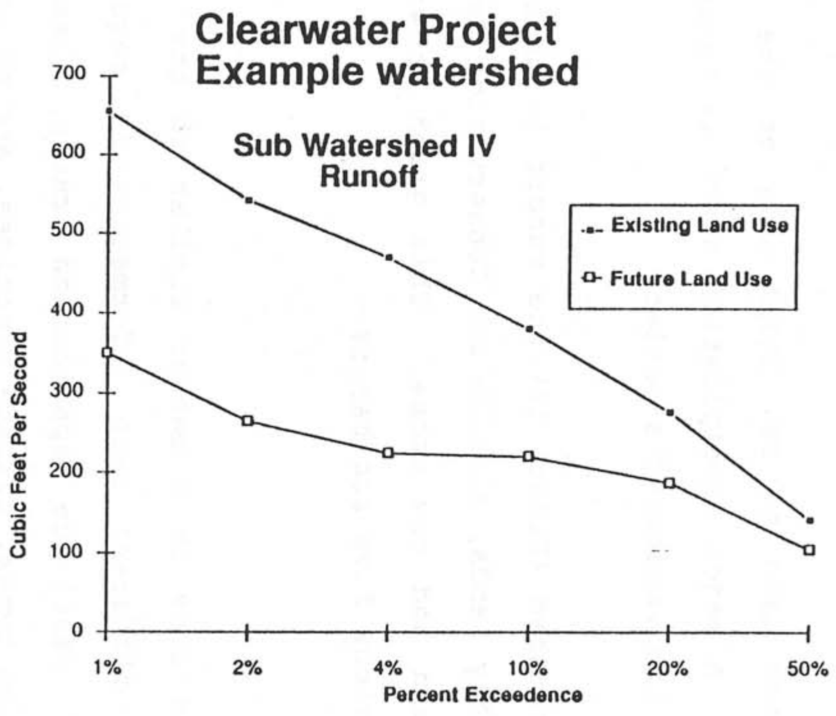
Figure 8



Notes: Future land use changes reduce runoff; particularly during higher runoff rates; has similar characteristics at low flow.

Example: Converstion of small grain lands to Conservation Reserve Program lands.

Figure 9



Notes: Future land use changes significantly reduce runoff; particularly at higher runoff rates.

Example: Converstion of row crops to pasture and haylands.

Figure 10

Conservation Reserve Program land to row crops only at the upper reaches of the sub basin. A major precipitation event is needed to notice increased runoff at the watershed's outlet.

In analyzing the Total Watershed (Figure 12) the runoff is increased by changing land use from hay lands, alfalfa and Conservation Reserve Program land to small grain and row crops. This graph shows the combined effect of the previous five sub basins.

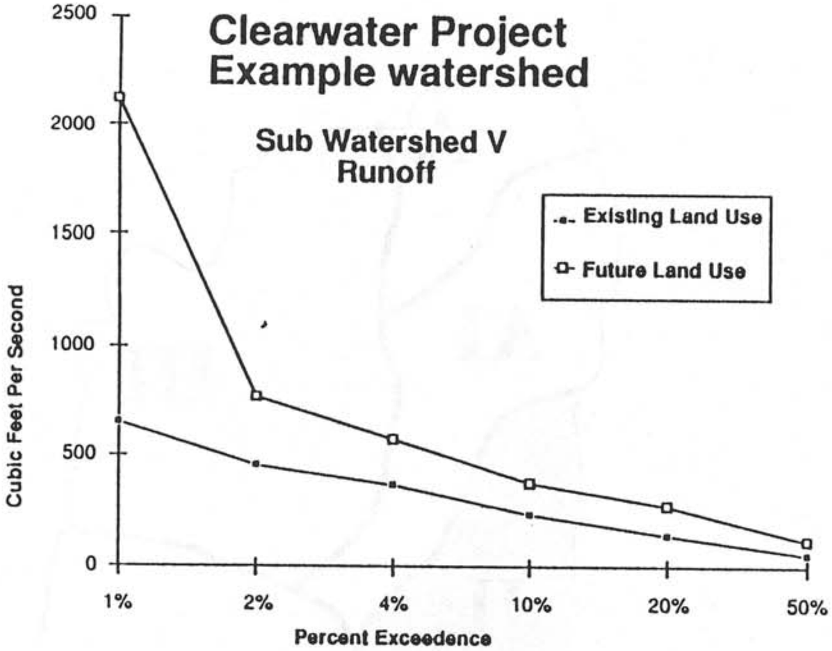
GIS and Water Quality

Analyzing water quality is done in a manner similar to the water quantity analysis. Some different base information is required, including fertilizer and pesticide application rates, leaching properties of the soils, crop types, tillage practices, and so on.

Knowing contaminates are carried by suspended solids from eroding land, the GIS program will identify areas of potential erosion.

The existing land use in Sub Watershed Basin II (Figure 13) is pasture and hay land that has been converted to small grains and row crops. The GIS program will "stack" maps identifying soil types, potential erosion areas, and land use changes to identify areas where significant erosion potential exists. (Figure 14).

After identifying a specific area where significant erosion potential exists using the GIS program, a detailed field analysis is completed (Figure 15). Various test sites are selected in the field based on the land use change to determine the quality of the water. In this example, the land use change was from hay and Conservation Reserve



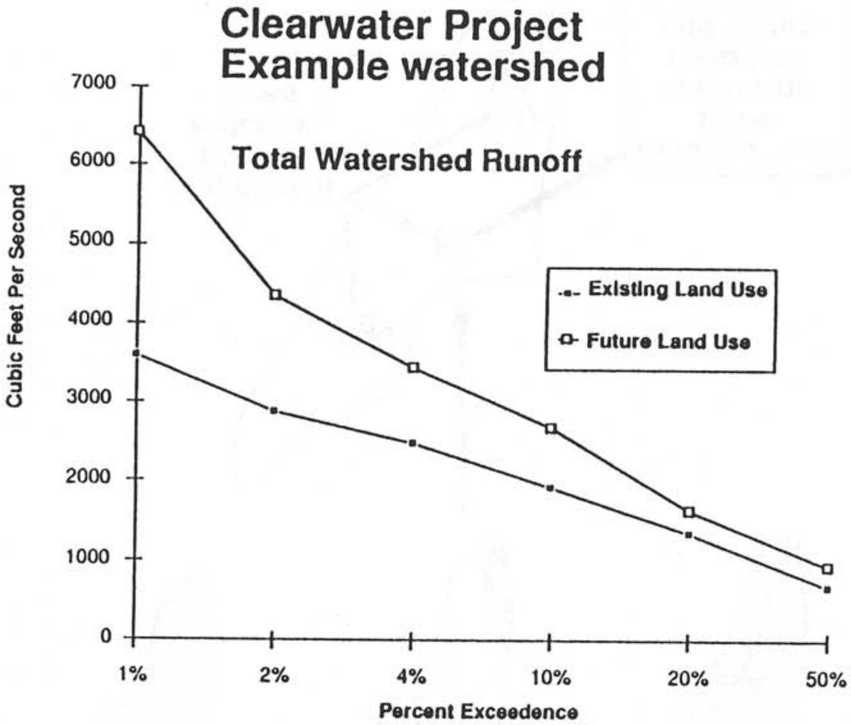
Clearwater Project
Example watershed

Sub Watershed V
Runoff

Notes: Future land use changes significantly increase runoff during periods of high runoff; increase runoff rates only slightly during other periods.

Example: Converstion of Conservation Reserve Program lands to row crops at upper reaches of watershed; major runoff event required to notice increased runoff at watershed outlet.

Figure 11



Clearwater Project
Example watershed

Total Watershed Runoff

Notes: Future land use changes increase runoff; with most effects at higher runoff rates.

Example: Overall change of watershed from predominantly haylands, alfalfa, and Conservation Reserve Lands to small grain and row crops.

Figure 12

Clearwater Project
Subbasin Change Example

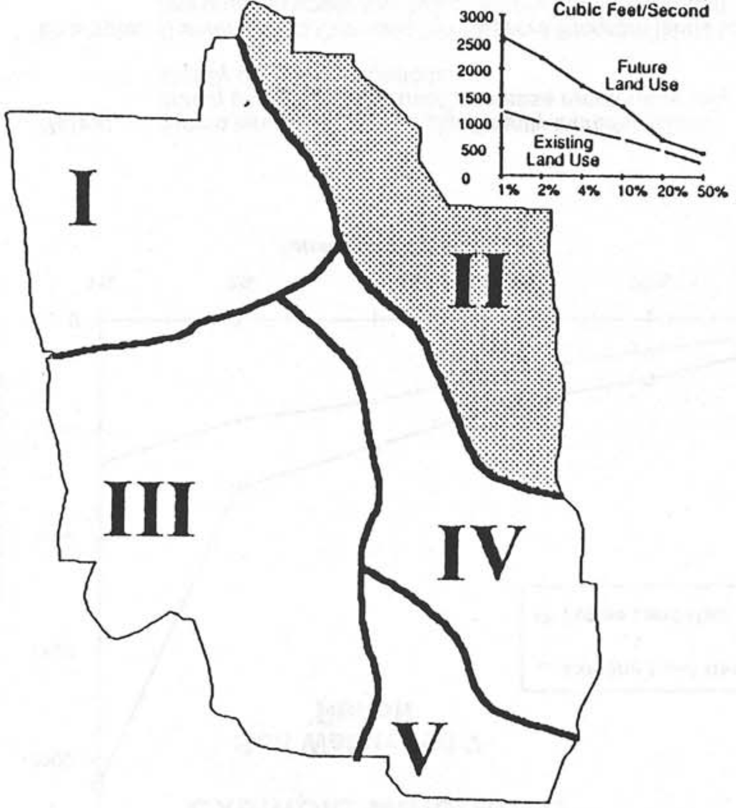


Figure 13

Clearwater Project
Erosion Analysis Example

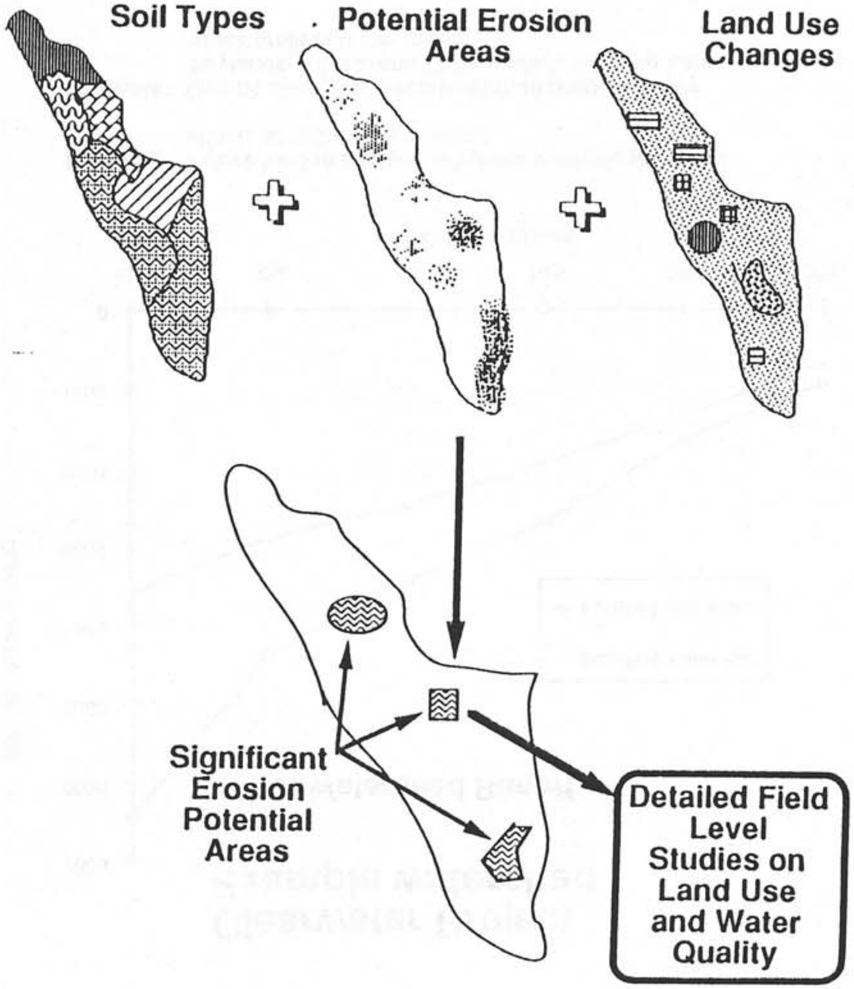
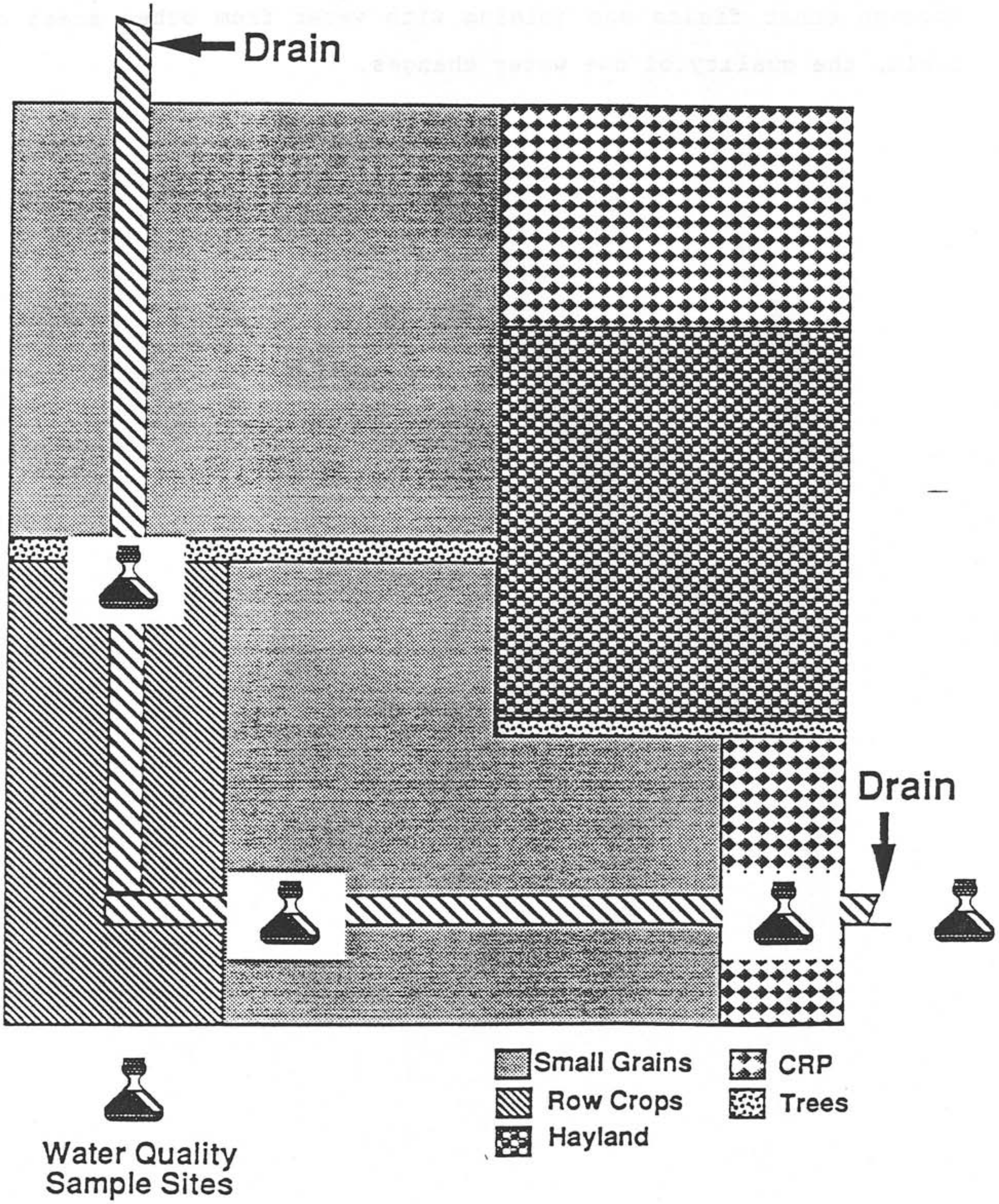


Figure 14



Clearwater Project
Runoff Analysis Example

Figure 15 Detailed field analysis diagram showing locations of water quality test sites.

Program land to small grains and row crops. Testing occurs before the water enters the target area and again after the water passes out of the target area to determine the quality of the water. It is also tested at the end of the entire field to determine if, by passing through other fields and joining with water from other areas of the field, the quality of the water changes.

GIS Conclusions

In summary, the following conclusions may be drawn about the Geographical Information System.

1. Geographical Information System technology is revolutionizing the way we create, store, and analyze spatial, land-related information.

2. Geographical Information System technology provides a new range of tools to identify and analyze sources of surface and ground water problems.

3. Geographical Information System technology can numerically demonstrate how land use changes affect water quality or quantity.

4. Integration of Geographical Information System technology with water resource investigations provides a complete analysis package to identify sources, mechanisms, and results of water quantity and quality problems.

5. Integration of Geographical Information System technology with water resources investigations also provides the capability to simulate alternative remedial measures to correct water problems.

6. Geographical Information System technology provides a cost-effective means to store land related data to study long-range trends.