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WRRC
Bulletin 105

THE NATURE AND EFFECTS OF COUNTY DRAINAGE DITCHES IN SOUTH CENTRAL MINNESOTA

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WATER RESOURCES RESEARCH CENTER
UNIVERSITY OF MINNESOTA
GRADUATE SCHOOL

November 1980
Minneapolis, Minnesota

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FOREWORD

This bulletin is published in furtherance of the purposes of the Federal Water Resources Research Act of 1964. The purpose of the Act is to stimulate, sponsor, provide for, and supplement present programs for the conduct of research, investigations, experiments, and the training of scientists in the field of water and resources which affect water. The Act is promoting a more adequate National program of water resources research by furnishing financial assistance to non-Federal research.

The Act provides for establishment of Water Resources Research Centers at Universities throughout the Nation. On September 1, 1964, a Water Resources Research Center was established in the Graduate School as an Interdisciplinary component of the University of Minnesota. The Center has the responsibility for unifying and stimulating University water resources research through the administration of funds covered in the Act and made available by other sources; coordinating University research with water resources programs of local, State and Federal agencies and private organizations throughout the State; and assisting in training additional scientists for work in the field of water resources through research.

This bulletin is number 105 in a series of publications designed to present information bearing on water resources research in Minnesota and the results of some of the research sponsored by the Center. This bulletin describes the results of a quantitative geomorphic and water quality study of agricultural drainage systems in South Central Minnesota.

This bulletin serves as the final completion report for the following project:

OWRT Project No.: A-040-Minn.

Project Title: The effect of county drainage ditches on water quality and quantity in South Central Minnesota.

Principal Investigator: Henry W. Quade, Department of Biological Sciences, Mankato State University.

Project Began: October 1, 1977 Project Completed: September 30, 1980

FCST, COWRR Research Category: VG;IVA/4

Publication Descriptors: *Drainage/*Water Quality/*Fluvial Geomorphology/ Non-Point Source Pollution/Riparian Green Belt/ Runoff.

Publication Abstract:

The extent of county drainage was determined for four counties in South Central Minnesota followed by a study of the gemorphic nature of man's drainage in contrast to natural drainage. Selected drainage ditches and low order rivers were sampled for water quality and quantity in order to determine the contributions and timing of nutrient loads from each.

Seventy-nine percent of the drainage ditches were found to terminate into rivers and they more than doubled the length of the surface fluvial systems. The closeness of fit of the drainage ditch systems to the low order Strahler classification scheme suggests that man has taken an immature lake-marsh environment and within 100 years created a geomorphically mature fluvial landscape.

Nutrient loading by ditches into receiving bodies was found to vary by season, by individual ditch or river, and by stream order indicating that each ditch was unique. Water quality of one ditch during this wet study year was compared to a previous dry year study and the nutrient loading data was consistent and predictable. The most significant loading nutrient chemical parameter to the Minnesota River was found to be nitrate-nitrogen. Flow showed flashy response to storm events in some ditches and some were quite conservative. Sediment load was directly correlated to flow.

ACKNOWLEDGEMENTS

The authors are indebted to Paul Trcka, Jeff Schroeder and Kristi Prinsen for their efforts in the ditch vegetation section and Mr. Kevin King for his help in the ditch site selections. The County Boards of Blue Earth, Le Sueur, Nicollet, and Brown gave both cooperative and financial support which was appreciated.

We wish to thank Ann Quade who provided final copy mock up and Rita McEvoy who typed numerous drafts of this final report.

This study was partially supported by funds from Mankato State University.

The work upon which this publication is based is supported in part by funds provided through the University of Minnesota Water Resources Research Center by the Office of Water Research and Technology, U.S. Department of the Interior, as authorized by the Water Research and Development Act of 1978, P.L. 95-467.

INTRODUCTION

In South Central Minnesota we take pride in and value our agriculture and our recreational waters. Many consider the two mutually exclusive and a real paradox when one thinks in terms of Quality of Life.

The 1972 Amendments to the Federal Water Pollution Control Act specify that state agencies develop guidelines to identify, evaluate, and control non-point source pollution resulting from various activities including agriculture. As agriculture is Minnesota's most important industry and since much of our agriculture is associated with or affected by man made drainage systems the relevance of limnological studies on ditches is quite apparent. There does not exist at present an adequate base from which to develop policies and management guidelines from either the point of view of water quality or water quantity for present ditching practices. Any "208" plan formulation that does not include the effect of ditches on water as well as on the land in its mix could lead to questionable policies.

The ditch studies which have been reported and the concerns which have surfaced generally relate to only one component of the drainage ecosystem. One should examine the changes in water quality and quantity of the receiving body as well as the effects on the drained riparian habitat. We have cases in our area where ditches are entering lakes and other ditches are extracting water from the same lakes. Some ditches terminate at levels lower than the lakes they are entering and the water must be pumped up into the lake which acts as a sealed holding pond. Many studies document the destruction of riparian habitat due to drainage, but few look at the potentially new riparian habitat created. The miles of open ditches, many with berms, surpass the miles of natural river channel in many of our townships. There is a rising concern for our roadside ditches as potential wildlife habitat but drainage ditches have been neglected. At present drainage ditches are constructed for the removal of water and managed for easy cleanout. It is our contention that they should be constructed for and managed with wildlife, flood control, and water quality concerns added to the mix.

In this area drainage ditches form the basis for much of our agriculture, yet little is known about their limnological impacts. For example, South Central Minnesota newspapers are reporting many new controversies involving drainage ranging from their effects on lake levels, lake water quality and wetland modification to problems of the management of riparian vegetation. The effects of upland drainage on the flood levels of our rivers and streams has not been studied adequately. Our local County Board Commissioners have expressed difficulty dealing with ditch requests because of a lack of information. Proposals for new drainage and improvement of existing drainage in Southern Minnesota are increasingly finding their way to the State Supreme Court. Judge Lawrence Yetka, with the concurrence of Judges James Otis, C. Donald Peterson, and Fallon Kelly, declared that, "Surely, under the new environmental laws serious doubt as to the desirability of any general drainage schemes must exist" (March 11, 1977, Mankato Free Press).

The citizens themselves (from our predominantly agricultural region) are placing "water quality" as the most important water problem. In his report "The Citizen and Water Management: An Atlas of Water Attitudes in Southern Minnesota" (OWRR Project B-042 Minn.) Moline (1974) investigated the spatial variation in the perception of water resources and water problems in South Central Minnesota. His study involved both a stratified (areal) random poll of residents and a select group poll of individuals concerned with water management and planning within the basin. When asked to rank the three major water resource problems in this area the respondents, surprisingly, in both the random poll and the select group poll indicated that "water pollution" was clearly number one with "inadequate water resource planning" number two. "Wet agricultural fields" was the number three priority for the stratified random sample poll.

The overall objective of this study was to develop an understanding of the nature of and effects of agricultural drainage in South Central Minnesota.

The specific objectives covered in this study are as follows:

1) To determine the extent and location of public drainage in a four county area of South Central Minnesota.

2) To document the legal history of drainage and wetlands status.

3) To determine the quantitative geomorphic nature of the drainage systems.

4) To survey the nature of the riparian strip associated with drainage ditches.

5) To assess the effects of agricultural drainage on water quality and quantity of the receiving bodies of water.

6) To determine the degree of variation from ditch to ditch to river for water quality and quantity in relation to a previous research effort on a single ditch-river system.

7) To establish management guidelines and predictive models of the effects of agricultural drainage insofar as possible.

To meet the above objectives study components which were undertaken included: the determination of the extent and location of public drainage for the four county area, the determination of quantitative and descriptive drainage ditch geomorphology, a survey of public drainage ditch riparian vegetation, the determination of water quality and quantity at selected drainage ditch and river sites based on the above and the determination of bed and suspended sediment load for each site. Two

other study components: an investigation of the history of drainage law with special emphasis on the legal status of wet lands and secondly a determination of the water quality properties of the Minnesota River which could be used for contrast to the drainage ditches are being published separately from this bulletin and will be in circular form.

EXTENT OF PUBLIC DRAINAGE

Introduction

A publication prepared by the U.S. Department of Commerce, "Drainage of Agricultural Lands", for the United States Census of Agriculture, 1959, indicated that by the end of the 1950's Minnesota had drained 11.7 million acres of land or 23 percent of the land in Minnesota. This represented 11.5 percent of all drained agricultural land in the United States and Minnesota was second only to Indiana nationally.

In the four South Central Minnesota counties: Blue Earth, Brown, Le Sueur, and Nicollet we have several hundred county and judicial ditches. The United States Geological Survey in their 1971-1972 drainage survey of Minnesota lists Blue Earth County with 50.4% of land affected by drainage (713 miles of drainage ditch), Brown County with 48.2% (235 miles), Le Sueur County with 43.5% (309 miles), and Nicollet County with 59.4% (422 miles). The above does not include private drainage ditches.

The data for the above was based on responses solicited from respective county engineers. Many problems surfaced such as whether an improved "Channel" should be regarded as a constructed ditch, the present efficiency of earlier constructed ditches and tile systems, relationship to private systems, and the determination of actual ditch sheds to name a few.

A 1978 survey of drainage practices conducted by the University of Minnesota Department of Agricultural Engineering involved the mailing of a questionnaire to the District Conservationists of the Soil Conservation Service located in each county (Allred and Geiser, 1978). The survey is to be used in Minnesota "208" water quality planning.

Blue Earth County was listed as having 14.9% of its total area artificially drained, Brown-34.7%, Le Sueur-14.3%, and Nicollet-20.2%. Further, all except Brown County indicated that less than 50 percent of estimated wet crop and pasture land was presently artificially drained. These figures vary significantly from those of the 1971-1972 U.S.G.S. report cited above.

Because of the lack of dependable data as to the extent of drainage in the counties of South Central Minnesota, it was necessary to enter into an extensive mapping program. This becomes critical if significant differences in extent of drainage data would result in differences in water resources planning by county, state or federal planners.

Methods

Initially it was necessary to compile a list of all ditches in each county. The years of establishment, repairs and improvements for each ditch were obtained from lien statements found in the Drainage Ditch Files of the respective county court houses. If a particular ditch file lacked the lien statement then the insurance policies or contracts of work were used to establish the date of completion.

Microfilm prints were then made from the ditch maps found in the county court houses. The individual ditch prints were superimposed on seven and one-half minute U.S.G.S. Topographic Maps. For those ditches which were not on microfilm we made tracings from the original maps, and then superimposed these onto the topographic maps. In this way all ditches within the county were at the same scale, a factor which facilitated later computations. Some of the ditch maps showed private tiling, but for consistency these tilings were not included.

After the ditches were transferred onto the topographic maps, ditchsheds, riversheds, and lakesheds were determined. Determinations were made by relief variations in U.S.G.S. topographic maps rather than from individual ditch maps since the former depicted true surface hydrology more accurately. Because ditches often affect natural lakesheds by either adding or subtracting areas, it was essential to map the ditchsheds first.

The next step was to make tracings from the U.S.G.S. Topographic Maps, which had been previously modified to include ditchsheds, riversheds, lakesheds, and public ditches. From these tracings all sheds were planimetered using a Numonics Corporation Electronic Graphic Calculator. The individual township maps and planimetered data were then aggregated to obtain four County Composite Maps and respective data bases.

The U.S.G.S. topographic maps which were the foundation of our data base are on file at the Biology Department at Mankato State University along with the complete set of drafting notes.

In order to compare present surface hydrology to preagricultural conditions in the four counties we utilized the General Land Survey (Circa 1860). Microfilm copies of the Survey were used to obtain enlarged prints of each Congressional Township. These prints were traced and the areas of lakes and swamps were then planimetered. It should be emphasized that the designation of "swamp" (wetlands) for this survey is not necessarily synonymous with present day agricultural "wetland."

The Minnesota Land Management Information System (MLMIS) has developed a computerized data system which uses the forty acre parcel as its basic areal unit. This system was most useful to us in that it is consistent with the United States land survey system.

For each Congressional Township there are 36 sections (one mile square), and in each section there are 16 forty acre parcels. This gave a data base of 576 entries for each standard township for each variable. The Brown County data base included a total of 9,949 entries;

Le Sueur County a total of 7,479; Nicollet County a total of 7,597; and Blue Earth County a total of 12,312.

MLMIS variables of land use, soil landscape, and geomorphic region were utilized. Another MLMIS variable, water orientation, was included so that our data could be compared to MLMIS.

MLMIS data for the county and townships were obtained directly from the State Data Bank. Because MLMIS did not have the State of Minnesota data base divided up into riversheds, these had to be superimposed onto the county maps for all four variables and then hand counted for each data level.

Results

The extent of drainage for each county is shown in Figures 1, 2. 3, 4, and Tables I, II, III, IV along with the respective General Land Survey data (Tables V, VI, VII, VIII). Detailed compilations and maps of the present extent of drainage, General Land Survey data, and Minnesota Land Management Information System information by individual township and rivershed for each of the four counties is give in (Dunsmore, L. and H. Quade, 1979a; Dunsmore and Quade, 1979b; Dunsmore and Quade, 1979c; Dunsmore, L., R. Oelerich, and H. Quade 1979).

We calculate Blue Earth County to have 39.9 percent of its total area artificially drained by public drainage (1971 report = 50.4%; 1978 report = 14.9%); Le Sueur County 46.7 percent (1971 report = 43.5%, 1978 report = 14.3%); Nicollet County 58.9 percent (1971 report = 59.4%, 1978 report = 20.2%); and Brown County 45.9 percent (1971 report = 48.2%, 1978 report = 34.7%) (Tables I, II, III, IV). It is our opinion that the data from the 1978 report is grossly and significantly in error.

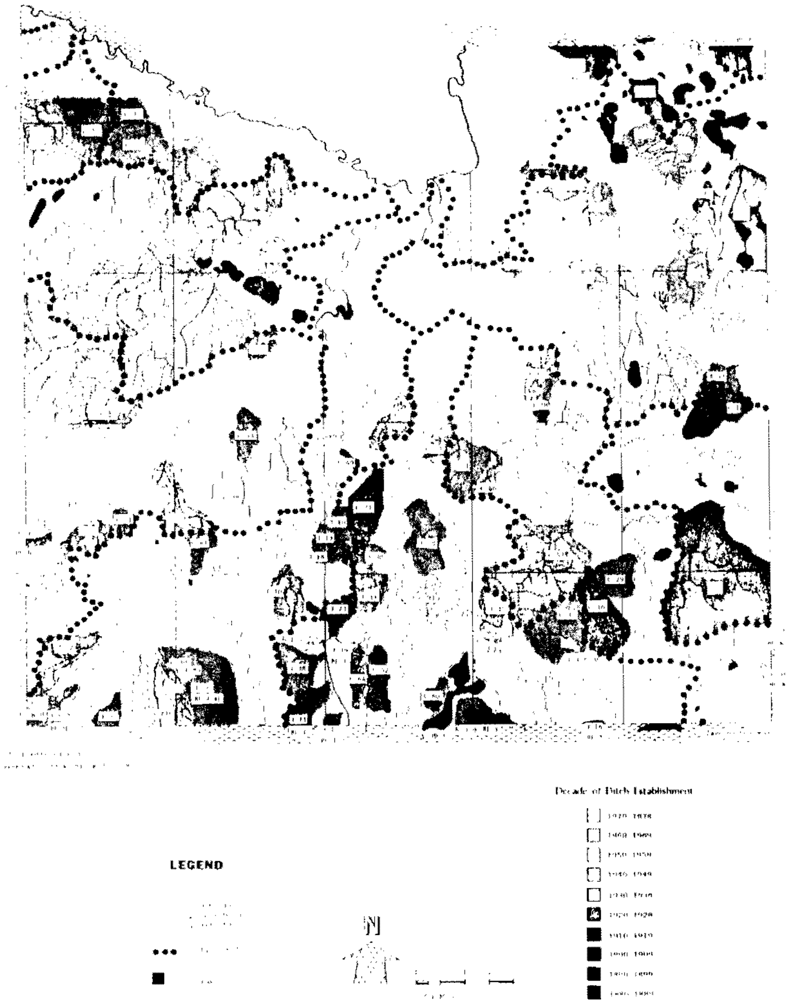
The total of open ditches to river miles is 687.7 to 1,055.5 miles which gives one an apprecation for the extent of public ditching (Tables I, II, III, IV). The lowest natural river miles are in Le Sueur County but it has three times the amount of area in lakesheds (Table II). Blue Earth County is the only one of the four which has more miles of river than open ditch which is perhaps related to is more developed natural drainage system (Figure 1).

The General Land Survey data indicates that Le Sueur County had the greatest amount (on a percentage basis) of swamp and lakes whereas Brown County had the least (Tables V, VI, VII, VIII). However, we find that Nicollet County is the most heavily drained and Blue Earth County the least.

Conclusion

The results of our four county mapping and compilation procedure indicates that the extent of public drainage is significantly far more than indicated by the above mentioned 1978 survey and differs significantly in Blue Earth County for the 1971-72 survey. The data base generated in this extent of public drainage chapter will serve as primary

Figure 1. Blue Earth County Ditch Map



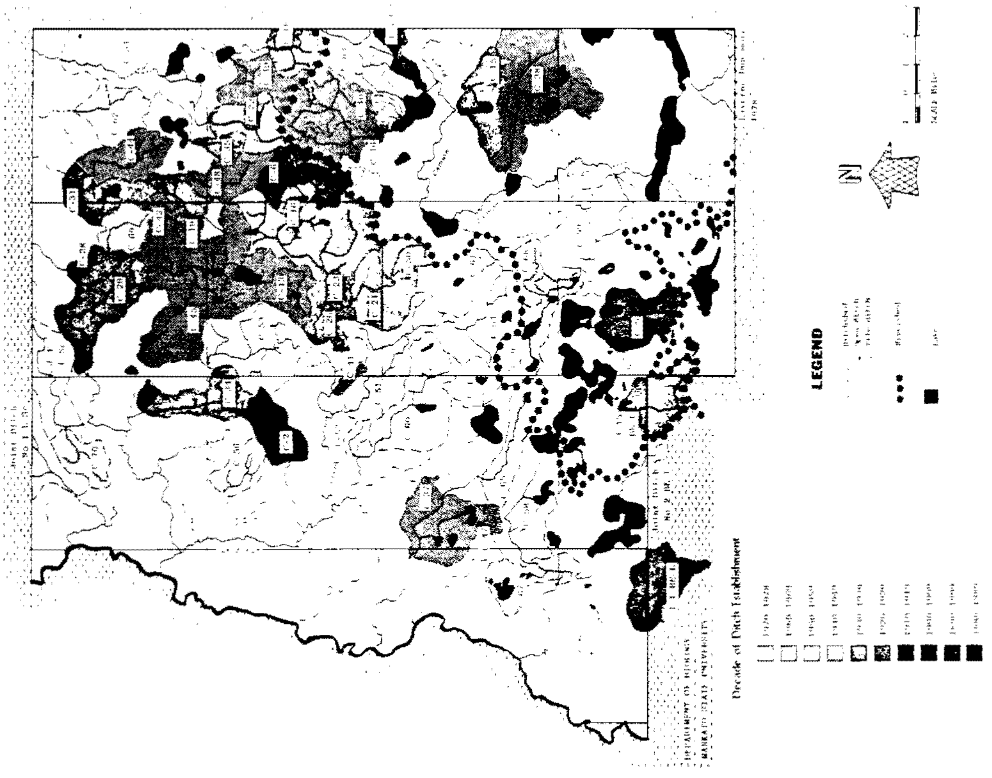


Figure 2. Le Sueur County Ditch Map

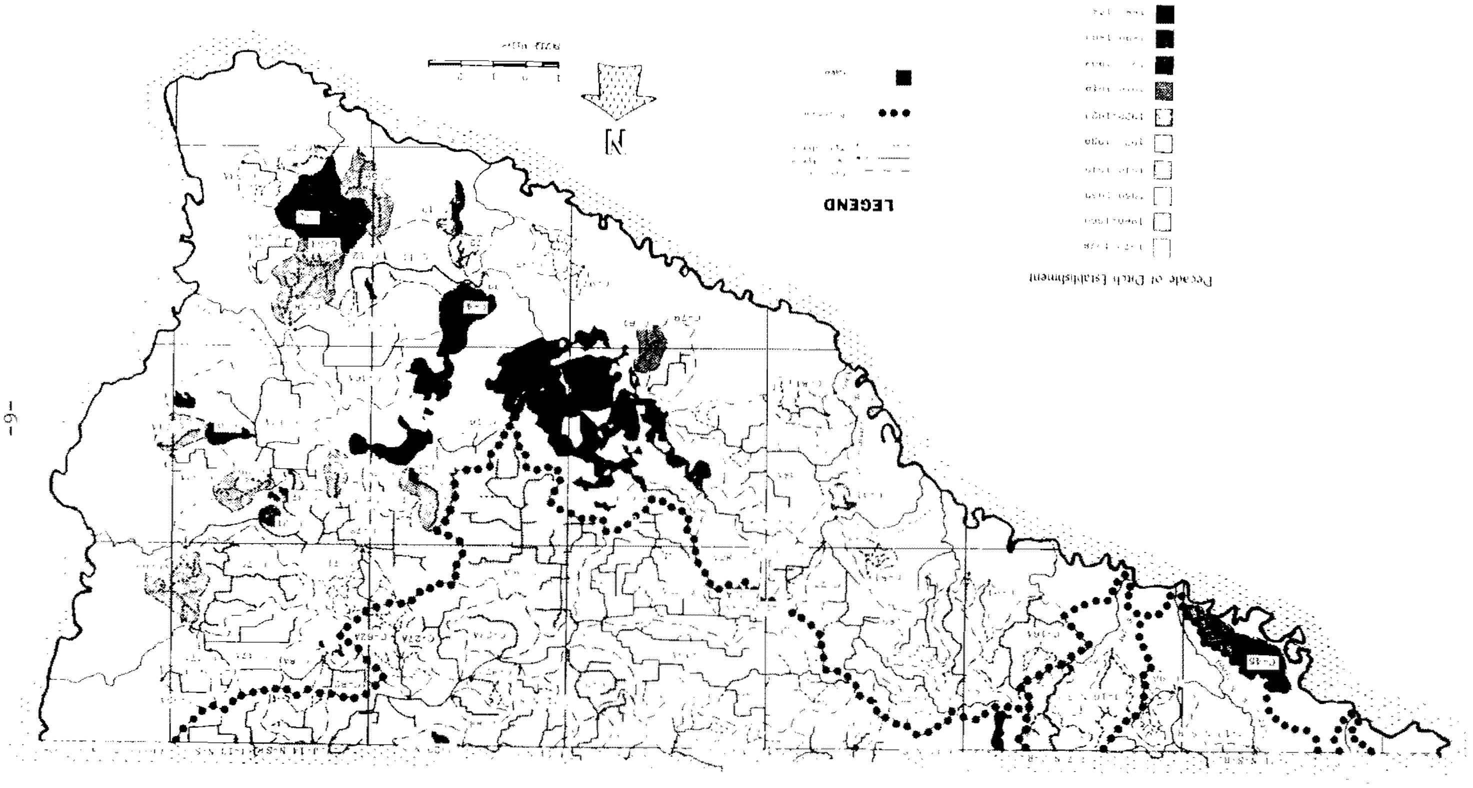


Figure 3. Nicollet County Ditch Map

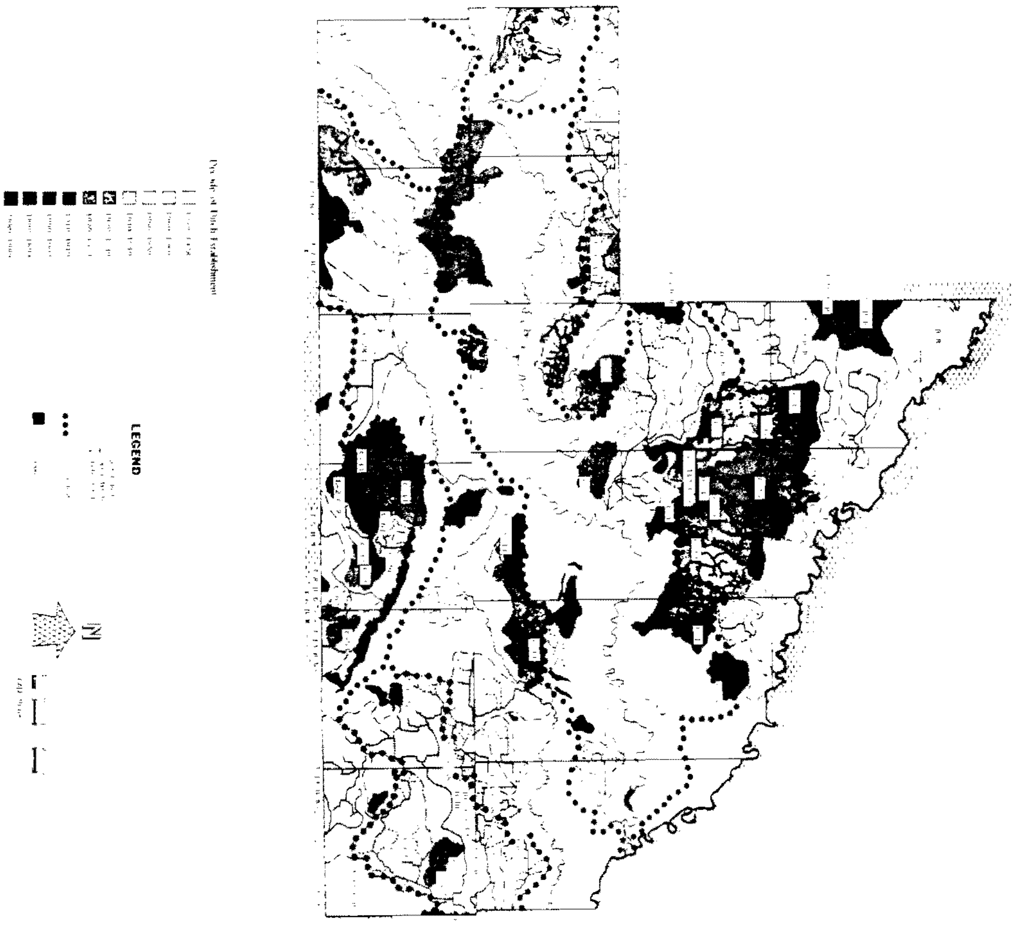


Figure 4. Brown County Ditch Map

Table I. Blue Earth County surface hydrology by township expressed as percent

Congressional Township	Civil Township	Blue Earth County	Ditchsheds	Lakesheds	Miles of Open Ditch	Miles of River	Total Minnesota	Total Blue Earth	Maple River	Watonwan River	Big Cobb River	Little Cobb River	Le Sueur River	Direct Blue Earth River	Minneopa Creek	Morgan Creek	Little Cottonwood	Direct Minnesota River	Cannon River
106N 26W	Beauford	4.70	32.4	3.6	4.89	21.48	100.1	100.1	-	-	92.3	7.2	.6	-	-	-	-	-	-
109N 27W	Belgrade	.14	0.0	0.0	0.00	4.73	100.0	0.0	-	-	-	-	-	-	-	-	-	100.0	-
108N 29W	Butternut Valley	4.70	86.9	11.3	19.24	0.00	99.8	0.0	-	-	-	-	-	-	65.2	20.9	-	13.7	-
109N 29W	Cambria	2.51	25.9	0.0	1.70	11.47	100.4	0.0	-	-	-	-	-	-	-	41.5	15.7	43.2	-
106N 29W	Ceresco	4.72	14.8	.6	1.19	9.10	99.4	99.4	-	82.5	-	-	-	16.9	-	-	-	-	-
105N 25W	Danville	4.73	28.8	18.0	7.62	17.98	100.0	100.0	19.5	-	54.6	25.9	-	-	-	-	-	-	-
107N 26W	Decoria	4.69	45.0	0.0	8.97	18.56	99.8	99.8	-	-	40.2	-	59.6	-	-	-	-	-	-
107N 28W	Garden City	4.71	30.8	45.1	4.85	13.94	99.9	54.8	-	46.1	-	-	-	8.7	45.1	-	-	-	-
109N 25W	Jamestown	2.37	26.4	65.6	3.23	0.00	86.6	30.5	-	-	-	-	30.5	-	-	-	-	56.1	13.4
108N 28W	Judson	4.65	44.5	14.9	2.08	9.75	100.1	6.5	-	-	-	-	-	6.5	52.4	-	-	41.2	-
108N 25W	LeRay	4.71	47.9	36.3	5.18	6.04	100.0	98.6	-	-	-	-	98.6	-	-	-	-	1.4	-
109N 26W	Lime	2.35	17.0	19.9	1.29	0.00	100.0	10.4	-	-	-	-	10.4	-	-	-	-	89.6	-
107N 29W	Lincoln	4.64	91.3	0.0	9.31	1.09	100.1	52.8	-	52.8	-	-	-	-	47.3	-	-	-	-
106N 27W	Lyra	4.69	46.0	0.0	1.66	18.78	99.9	99.9	66.8	-	7.9	-	-	25.2	-	-	-	-	-
108N 26W	Mankato	4.65	16.7	13.3	2.70	9.03	99.8	57.5	-	-	-	-	57.5	-	-	-	-	42.3	-
105N 26W	Mapleton	4.72	48.6	14.9	7.27	12.05	100.0	100.0	73.5	-	26.4	-	-	-	-	-	-	-	-
107N 25W	McPherson	4.72	64.2	22.0	17.83	7.28	99.9	99.9	-	-	-	11.6	88.3	-	-	-	-	-	-
106N 25W	Medo	4.71	29.8	31.1	7.56	19.87	100.0	100.0	-	-	16.9	82.6	.5	-	-	-	-	-	-
109N 28W	Nicollet	.29	0.0	0.0	0.00	6.15	100.0	0.0	-	-	-	-	-	-	-	-	-	100.0	-
105N 29W	Pleasant Mound	4.71	34.3	0.0	10.16	0.00	100.0	100.1	-	16.3	-	-	-	83.8	-	-	-	-	-
107N 27W	Rapidan	4.67	3.1	0.0	0.00	31.66	102.4	102.4	22.5	-	4.1	-	22.6	53.2	-	-	-	-	-
105N 28W	Shelby	4.72	48.5	1.1	4.21	12.85	100.1	100.1	20.2	-	-	-	-	79.9	-	-	-	-	-
108N 27W	South Bend	3.06	3.7	0.0	0.00	23.77	99.6	53.3	-	-	-	-	11.0	42.3	11.6	-	-	34.7	-
105N 27W	Sterling	4.72	46.1	0.0	8.50	11.14	100.0	100.0	96.6	-	-	-	-	3.4	-	-	-	-	-
106N 28W	Vernon Center	4.72	54.6	0.0	8.19	14.67	100.1	100.1	-	61.9	-	-	-	38.2	-	-	-	-	-
	Blue Earth County		39.9	12.0	137.63	281.39	100.3	77.1	14.7	12.2	11.4	6.0	16.7	16.1	10.2	2.0	.4	10.6	.3

Table II. Le Sueur County surface hydrology by township expressed as percent

Congressional Township	Primary Civil Township	Le Sueur County	Ditchsheds	Lakesheds	Miles of Open Ditch	Miles of River	Cannon	Total Minnesota	Blue Earth Subshed (Le Sueur)	Direct Minnesota
109N 27W	Kasota	0.135	0.00	0.00	0.00	9.10	-	100.00	-	100.00
110N 25W	Cleveland	7.598	64.14	40.42	17.07	0.00	3.52	96.48	-	96.48
110N 24W	Cordova	7.653	63.68	40.51	23.75	1.41	44.73	55.27	-	55.27
112N 24W	Derryname	7.589	67.05	24.61	29.94	0.00	-	100.00	-	100.00
109N 24W	Elysian	7.655	39.88	82.33	13.56	0.00	63.75		36.25	-
112N 26W	Ottawa	0.778	0.00	0.00	0.00	9.79	-	100.00	-	100.00
110N 26W	Kasota	4.355	21.63	10.06	2.97	9.03	-	100.00	-	100.00
110N 23W	Kilkenny	7.651	38.65	50.94	16.97	12.65	100.00	-	-	-
112N 23W	Lanesburgh	7.554	64.25	29.70	23.43	0.00	-	100.00	-	100.00
111N 24W	Lexington	7.670	90.59	26.34	42.16	1.60	1.12	98.88	-	98.88
109N 26W	Kasota	3.748	11.64	10.27	3.08	0.95	-	100.00	-	100.00
111N 23W	Montgomery	7.697	92.66	81.20	44.36	0.00	39.82	60.18	-	60.18
111N 26W	Ottawa	3.393	0.00	0.00	0.00	9.52	-	100.00	-	100.00
111N 25W	Sharon	7.562	30.83	4.76	14.54	17.56	-	100.00	-	100.00
112N 25W	Tyrone	7.480	27.43	0.66	14.48	1.50	-	100.00	-	100.00
109N 25W	Washington	3.826	7.22	99.41	2.06	0.00	54.95	45.05	-	45.05
109N 23W	Waterville	7.639	9.98	48.92	2.06	4.00	99.39	-	0.61	-
	Le Sueur County		46.07	38.41	250.43	77.11	29.06	70.92	2.82	68.10

Table III. Nicollet County surface hydrology by township expressed as percent

Congressional Township	Nicollet County	Ditchsheds	Lakesheds	Miles of Open Ditch	Miles of River	Total Minnesota	Fort Ridgely Creek	Little Rock Creek	Eight Mile Creek	South Bend Rush River	Direct Minnesota River
111N 33W	0.25	0.00	0.00	0.00	0.32	100.00					100.00
111N 32W	3.70	24.33	0.00	3.43	26.08	100.00	3.89	48.81			47.30
111N 31W	7.85	54.45	4.00	23.67	13.84	100.00		16.06	33.13	5.69	45.12
111N 30W	7.66	91.29	1.63	36.10	0.00	100.00				34.68	65.32
111N 29W	7.68	100.64	7.44	51.86	0.00	100.00				93.68	6.32
111N 28W	7.73	100.52	10.55	44.00	0.00	100.00				88.17	11.83
111N 27W	7.71	89.41	3.28	41.84	0.00	100.00				24.48	75.52
111N 26W	4.14	6.30	0.00	0.76	10.00	100.00					100.00
110N 26W	3.18	3.49	0.59	0.60	9.60	100.00					100.00
110N 27W	7.69	81.76	12.72	37.23	0.00	100.00					100.00
110N 28W	7.72	50.81	68.23	22.40	0.00	100.00				24.60	75.40
110N 29W	7.68	43.84	63.98	24.07	0.00	100.00				10.65	89.35
110N 30W	5.45	46.06	3.08	13.25	12.80	100.00					100.00
110N 31W	0.33	0.00	0.00	0.00	5.48	100.00					100.00
109N 30W	0.44	0.00	0.00	0.00	3.40	100.00					100.00
109N 29W	3.46	11.25	26.74	0.28	12.64	100.00					100.00
109N 28W	7.23	44.67	1.32	10.98	6.68	100.00					100.00
109N 27W	7.22	59.44	1.40	12.36	10.24	100.00					100.00
109N 26W	0.03	0.00	0.00	0.00	0.40	100.00					100.00
108N 26W	0.06	0.00	0.00	0.00	1.80	100.00					100.00
108N 27W	2.66	0.00	0.00	0.00	9.80	100.00					100.00
108N 28W	0.13	0.00	0.00	0.00	2.80	100.00					100.00
Nicollet County		58.91	14.55	322.83	125.88	99.99	0.14	3.06	2.59	21.72	72.48

Table IV. Brown County surface hydrology by township expressed as percent

Congressional Township	Brown County	Ditchsheds	Lakesheds	Miles of Open Ditch	Miles of River	TOTAL MINNESOTA	DIRECT MINNESOTA	COTTONWOOD RIVER	Direct Cottonwood	Sleepy Eye Creek	Coal Mine Creek	Mound Creek	LITTLE COTTONWOOD RIVER	MORGAN CREEK	BLUE EARTH (N. Branch, N. Fork Watonwan River)	MINNEOPA CREEK
112N 33W	1.12	3.00	1.87	0.65	9.37	100.00	100.00									
111N 33W	5.73	71.47	1.86	32.53	2.51	100.00	99.00	1.00	1.00							
111N 32W	2.98	25.68	0.00	9.68	14.86	100.00	100.00									
111N 31W	0.39	0.00	25.48	0.00	5.64	100.00	100.00									
110N 33W	5.90	98.69	4.10	36.99	0.23	100.00	20.18	79.82	75.58	4.23						
110N 32W	5.78	73.62	6.04	39.08	3.81	100.00	51.08	48.92	48.92							
110N 31W	6.06	24.70	5.22	5.18	8.88	100.00	41.92	58.08	58.08							
110N 30W	1.67	0.00	0.00	0.00	17.52	100.00	46.94	53.06	53.06							
109N 35W	5.83	39.55	0.00	16.65	14.02	99.99		99.99	44.44	24.78	30.06	0.71				
109N 34W	5.87	38.26	3.52	17.17	13.56	100.00		100.00	75.89	24.11						
109N 33W	5.78	27.46	3.64	29.94	19.20	100.00		99.57	72.85	26.72			0.43			
109N 32W	5.81	21.38	6.66	12.42	14.32	100.00		70.64	70.64				29.36			
109N 31W	6.36	40.88	13.87	13.56	18.86	100.00		46.34	46.34				53.66			
109N 30W	5.45	39.26	0.00	18.25	15.77	100.00	12.82	16.41	16.41				47.46	23.31		
108N 35W	5.81	10.43	0.00	4.08	20.08	100.00		86.23	7.77			78.46	13.77			
108N 34W	5.82	40.48	4.82	7.69	9.71	100.00		22.93	19.83			3.10	76.07		1.00	
108N 33W	5.82	32.62	21.79	9.37	9.64	100.00		7.36	7.36				64.04		28.60	
108N 32W	5.71	60.06	73.13	26.59	5.33	100.00							25.83		74.17	
108N 31W	6.31	57.58	25.81	30.32	0.00	100.00							33.07	36.18	30.75	
108N 30W	5.78	94.35	5.63	33.94	0.00	99.99							2.09	57.16	20.41	20.33
Brown County	99.98	45.98	10.50	344.68	203.31	99.56	18.33	43.75	32.56	4.65	1.75	4.78	20.37	6.86	9.08	1.17

Table V. Blue Earth County General Land Survey by township

Congressional Township	Civil Township	Percent Swamp	Percent Lake
106N 26W	Beauford	3.1	1.1
109N 27W	Belgrade	0.0	0.0
108N 29W	Butternut Valley	6.6	6.2
109N 29W	Cambria	0.4	0.0
106N 29W	Ceresco	2.7	0.0
105N 25W	Danville	8.8	0.7
107N 26W	Decoria	1.7	0.3
107N 28W	Garden City	6.5	6.3
109N 25W	Jamestown	4.8	21.6
108N 28W	Judson	6.0	2.5
108N 25W	LeRay	12.9	10.0
109N 26W	Lime	6.2	4.3
107N 29W	Lincoln	16.3	0.1
106N 27W	Lyra	2.3	0.0
108N 26W	Mankato	5.7	2.2
105N 26W	Mapleton	7.6	0.9
107N 25W	McPherson	4.8	2.3
106N 25W	Medo	4.6	1.6
109N 28W	Nicollet	0.0	0.0
105N 29W	Pleasant Mound	2.4	0.0
107N 27W	Rapidan	0.5	0.0
105N 28W	Shelby	1.4	2.9
108N 27W	South Bend	1.5	1.7
105N 27W	Sterling	4.2	9.0
106N 28W	Vernon Center	2.8	0.0
Blue Earth County Total		5.1	3.3

Table VI. **Le** Sueur County General Land Survey by township

Congressional Township	Primary Civil Township	Percent Swamp	Percent Lake
109N 27W	Kasota	0.0	1.1
110N 25W	Cleveland	4.7	9.3
110N 24W	Cordova	19.6	4.4
112N 24W	Derryname	18.0	1.8
109N 24W	Elysian	10.0	19.3
112N 26W	Ottawa	0.7	0.0
110N 26W	Kasota	1.3	1.5
110N 23W	Kilkenny	17.8	6.2
112N 23W	Lanesburgh	12.1	6.1
111N 24W	Lexington	13.6	2.8
109N 26W	Kasota	3.0	0.9
111N 23W	Montgomery	17.5	4.2
111N 26W	Ottawa	0.0	0.0
111N 25W	Sharon	3.8	1.5
112N 25W	Tyrone	6.2	0.3
109N 25W	Washington	5.1	27.5
109N 23W	Waterville	9.4	10.7
Le Sueur County Total		9.9	5.8

Table VII. Nicollet County General Land Survey by township

Congressional Township	Percent Swamp	Percent Lake
111N 33W	0.0	0.0
111N 32W	1.4	0.0
111N 31W	1.9	1.4
111N 30W	8.2	0.0
111N 29W	17.6	0.3
111N 28W	17.0	0.0
111N 27W	7.9	0.8
111N 26W	4.6	0.0
110N 26W	1.0	0.0
110N 27W	6.5	11.6
110N 28W	5.5	26.8
110N 29W	10.3	25.8
110N 30W	8.2	0.0
110N 31W	0.0	0.0
109N 30W	0.0	0.0
109N 29W	3.8	3.3
109N 28W	3.8	1.5
109N 27W	5.7	0.4
109N 26W	0.0	0.0
108N 26W	0.0	0.0
108N 27W	0.1	0.0
108N 28W	0.0	0.0
Nicollet County	7.3	5.4

Table VIII. Brown County General Land Survey by township

Congressional Township	Percent Swamp	Percent Lake
112N 33W	0.0	0.0
111N 33W	1.8	0.9
111N 32W	0.0	1.4
111N 31W	3.2	0.0
110N 33W	2.8	0.4
110N 32W	0.9	4.3
110N 31W	1.4	0.1
110N 30W	3.4	0.0
109N 35W	2.8	0.0
109N 34W	1.5	0.8
109N 33W	0.2	0.6
109N 32W	1.9	0.9
109N 31W	3.4	2.0
109N 30W	3.6	0.0
108N 35W	0.3	0.1
108N 34W	3.5	1.4
108N 33W	4.7	0.5
108N 32W	3.1	3.6
108N 31W	7.1	6.7
108N 30W	4.6	6.6
Brown County Total	2.6	1.8

base data for the following quantitative and descriptive geomorphology of public drainage section. It is presumed that differences in slope, natural drainage, outlet availability, and in the distribution of soils and geomorphology within each county have resulted in differences in the extent of resultant public drainage. The next chapter will attempt to address these questions.

QUANTITATIVE AND DESCRIPTIVE DRAINAGE DITCH GEOMORPHOLOGY

Introduction

The purpose of this component was to determine the quantitative and geomorphic effects of artificial drainge ditches on an immature landscape. When literature was available comparisons and contrasts were made between the quantitative geomorphology of artificial drainage versus natural drainage systems. Another aspect of this research was to relate drainage ditch quantitative geomorphic parameters to descriptors such as: termination, origin, decade, geomorphic type and soil type. Finally, the descriptors were isolated and analyzed to discern any unusual characteristics of artificial drainage ditches.

To obtain the above objectives this research involved the determination of quantitative geomorphic parameters and descriptors of 269 artificial drainage ditches in South Central Minnesota. The statistical analysis utilized includes, Pearson's product-moment correlation, frequencies, scatter diagrams and crossbreaks. These statistics involved an examination of isolated geomorphic parameters, interparameter relationships, descriptor-parameter relationships and descriptor analysis.

Methods

Ditch Quantitative Geomorphic Parameters

A series of 18 quantitative geomorphic parameters were determined for 269 drainage ditches in Blue Earth, Le Sueur, Nicollet and Brown Counties of South Central Minnesota. Those investigated included all ditches wholly contained within the four counties as well as those that extended less than five percent of their drainage shed area across the county lines of other counties. The first 12 parameters as shown in a sample data sheet (Figure 5) include: drainage area, drainage density, length of overland flow, length of open ditch, length of closed ditch, length of main stream, longest basin length, longest basin width, ditch gradient, ditchshed gradient, texture ratio and channel maintenance. The last six parameters are all basin shape types which include: form f, shape 1, shape 2, circularity ratio, elongation ratio and lemniscate ratio.

The major sources of data used to determine the above parameters came from "Public Drainage Atlas, Brown County (Dunsmore Oelerich and Quade, 1979); "Public Drainage Atlas, Blue Earth County" (Dunsmore and Quade, 1979a); "Public Drainage Atlas, Le Sueur County" (Dunsmore and Quade, 1979b); "Public Drainage Atlas, Nicollet County" (Dunsmore and

Figure 5. Sample data tabulation sheet for ditch quantitative geomorphic parameters.

County Ditch No.____________________
Location-County____________________
Civil Township____________________
Congressional Township____________________
Rivershed____________________
Termination Point____________________
Origin____________________
Year Established____________________
Repair____________________
Improved____________________
Data Base____________________

1) Drainage Area =
2) Drainage Density =
3) Length of Overland Flow
% Open =
% Closed =
4) Length of main stream =
5) Longest Basin Length =
6) Longest Basin Width =
7) Ditch Gradient (slope) =
8) Ditchshed Gradient =
9) Relief Ratio Max. Min. Range
Ditch =
Ditchshed =
10) Texture Ratio =
11) Channel maintenance =
12) Form F =
13) Shape S_1 =
14) Shape S_2 =
15) Circularity ratio C =
16) Elongation ratio E =
17) Lemniscate ratio K =

Quade, 1979c); and the corresponding seven and one-half minute series topographic maps by the United States Geological Survey, Department of the Interior.

The drainage area was obtained from the respective county public drainage atlases.

The drainage density is the miles of open and closed ditch per square mile of drainage area. Each open and closed ditch in each drainage area was measured twice with a map reader and averaged. The combined miles of drainage network divided by drainage area gave drainage density.

The length of overland flow is the total miles of open and closed ditch. Each ditch was traced twice with a map reader and converted to miles.

The length of open ditch and length of closed ditch was determined by subtraction from the length of overland flow.

The length of main stream is the longest ditch network which includes both open and closed ditch. The longest ditch was traced twice with a map reader, averaged and converted to miles.

The longest basin length was found by determining a straight line between the termination point and the most distance opposite point without crossing the drainage area perimeter. This line was traced twice with a map reader, averaged and converted to miles

The longest basin width is a straight line perpendicular and half the distance up the longest basin length. The basin width line was traced twice with a map reader and converted to miles.

The ditch gradient is the slope in feet per mile from the termination point to the beginning of the longest main stream. Calculating the longest main stream starting point elevation subtracted by the termination point elevation, divided by the largest main stream in miles determines ditch gradient.

The texture ratio is a measure of closeness of channel spacing. This parameter is only concerned with spacing of ephemeral streams in the drainage area. To obtain the texture ratio you find the contour line with the maximum number of crenulations, divided by the drainage area perimeter which was traced twice, averaged and converted to miles.

Channel maintenance is the square miles of surface required to maintain each mile of channel length. Channel maintenance in square miles is the inverse of drainage density.

The first of the six basin shape types is form f (Horton, 1932). This was calculated as drainage area divided by the basin length squared.

The second type of shape determination is shape 1 (Corps of Engineers). Shape 1 is the reciprocal of form f.

Shape 2 is the third type of basin shape determination (Horton, 1932). It was calculated as basin length divided by basin width.

Circularity ratio (Miller, 1953) was calculated by dividing drainage area by the area of a circle with the same basin perimeter.

Elongation ratio (Schumm, 1956) was the diameter of a circle equal to the drainage area divided by the maximum length of the basin.

The last type, lemniscate ratio (Chorley, et. al., 1957) was calculated as basin length squared divided by four times the drainage area.

Drainage Ditch Descriptors

The ditch descriptors include: termination point, origin, decade established, geomorphic type, and soil type. Determination of specific descriptors for each ditch came from the respective public drainage atlases and seven and one-half minute series topographic maps.

The termination point was classified into three categories: ditch, lake, and river or stream using the seven and one-half minute topographic map series.

The origin was determined using the respective general land survey maps. Categorizations of origin were: lake, lake and marsh, marsh, and land.

Geomorphic and soil types for each ditch were determined by using MLMIS (Minnesota Land Management Information System) maps. Film positives of each county drainage map was superimposed onto each MLMIS county sheet using a map-o-graph. A count was made of the number of units for each type and a percentage for each particular drainage shed area was calculated.

Statistical Treatment

All data was analyzed using SPSS (Statistical Package for the Social Sciences) on a Univac 1106 computer at Mankato State University. A four part series was developed to analyze different aspects of the data which were termed: Pearson's product-moment correlation, frequency distribution, scatter diagram and crossbreak.

The most common correlation coefficient in statistics is called the product-moment correlation coefficient as derived by Karl Pearson. The correlation coefficient was obtained for all pairs of continuous variables.

The second series was frequency distribution on all parameters and descriptors which gave the mean, mode, kurtosis, minimum, standard error, standard deviation, skewness, maximum, median, variance, and range in this order.

The scatter diagram showed graphically the relationship between each parameter and all the others, as well as determining intercept (A) and slope (B) for the least-square line. This discussion will not be involved here but can be found in Silis (1979).

The fourth and final series, termed crossbreak, was a bivariate correlation which provides a set of numbers that summarizes the relationship between two discrete variables, when analyzing a third continuous one. By comparing all parameters and descriptors as the two variables, it gave the mean, number of ditches, total sum, and standard deviation for a particular parameter.

Results

Descriptive Statistics of Quantitative Geomorphic Parameters

The ranges obtained for all 18 quantitative geomorphic parameters were broad (Table IX). With most parameters the mean was higher than the median indicating a limited number of large parameter readings.

The drainage area had a maximum of 22.70 square miles and a minimum of 0.23 square miles. Drainage area mean indicated that the majority were not large, being 3.34 square miles in area. The median of 2.08 square miles further indicated that the ditch areas in general are to the small side of the mean.

Length of overland flow had a maximum of 43.42 miles and a minimum of 0.27 miles. In South Central Minnesota it appears that the length of closed ditch and open ditch are quite similar with means of 2.67 versus 3.34 miles.

The ditch and ditchshed gradients expressed in feet per mile showed a broad range of 81.52 to 1.50 and 99.18 to 5.25 respectively (Table IX).

The results for channel maintenance showed a maximum of 3.05 and a minimum of .13 in area drained per mile of ditch, although the median of .51 indicated skewness.

The six basin shape calculations indicated that there were three groups regarding range. The form f, shape 1 and lemniscate ratio all showed a range of about 50 fold. Shape 2 and circularity ratio showed a range of close to 15 fold whereas the elongation ratio range separates the least with a range of around six fold. In all six basin shapes the median and mean are quite close (Talbe IX). It is interesting to note that the median or middle value was almost always less than the mean. Only in the elongation ratio was the median and mean the same value. This indicates the majority of the ditches are less than the mean and, that there was a small number of ditches with extreme maximums that tend to pull the mean higher.

Table IX. Descriptive statistics of quantitative geomorphic parameters.

Parameters	Ditches	Mean	Standard Deviation	Maximum	Minimum	Median	Range
Drainage Area (sq. miles)	269	3.34	3.587	22.70	.23	2.08	22.47
Drainage Density (miles/sq. mile)	269	2.18	1.108	7.62	.33	1.94	7.29
Length of Overland Flow (miles)	269	6.00	6.160	43.42	.27	3.99	43.15
Length of Open Ditch (miles)	269	3.34	4.597	27.24	.00	1.98	27.24
Length of Closed Ditch (miles)	269	2.67	4.039	29.00	.00	1.14	29.00
Length of Main Stream (miles)	269	2.96	2.096	17.33	.27	2.43	17.06
Longest Basin Length (miles)	269	2.44	1.420	10.76	.43	2.09	10.33
Longest Basin Width (miles)	269	1.46	.826	5.09	.28	1.24	4.81
Ditch Gradient (ft./mile)	269	11.98	10.051	81.52	1.50	9.54	80.02
Ditchshed Gradient (ft./mile)	269	24.57	15.102	99.18	5.25	20.66	93.93
Texture Radio (miles)	269	1.38	1.021	6.30	.00	1.17	6.30
Channel Maintenance (sq. miles)	269	.59	.333	3.05	.13	.51	2.92
Form F	269	.53	.422	5.65	.12	.46	5.53
Shape 1	269	2.33	1.006	8.50	.18	2.18	8.32
Shape 2	269	1.85	.836	5.95	.35	1.68	5.60
Circularity Ratio	269	.62	.185	2.34	.20	.60	2.14
Elongation Ratio	269	.73	.154	2.26	.39	.73	1.87
Lemniscate Ratio	269	.59	.252	2.12	.04	.54	2.08

Pearson's Product-Moment Correlation Coefficient of Quantitative Geomorphic Parameters

The nature of the correlations between the 18 quantitative geomorphic parameters are shown in Figure 6. Almost one-third (30.7%) of the cells showed very strong positive correlation (99%) and 29.4 percent showed very strong negative correlation (99%).

Drainage area and drainage density were very strongly negatively correlated (99%) between each other (Figure 6). Although drainage area was very strongly positively correlated to basin width, basin length and main stream, all of these showed very strong negative correlation (99%) to drainage density.

This was also evident in ditch and ditchshed gradient where they are very strongly negatively correlated (99%) to drainage area and very strongly positively correlated (99%) to drainage density. It is seen that closed ditch was very strongly positively correlated (99%) to both parameters and yet this does not hold true for open ditch where drainage density was very strongly negatively correlated (99%).

Length of overland flow, open ditch and closed ditch were all at least strongly negatively correlated (95, 99%) to ditch and ditchshed gradients (Figure 6). But these same three parameters were very strongly positively correlated (99%) to basin width, basin length, and main stream. An interesting observation in the cross correlation is that although overland flow was very strongly positively correlated (99%) to closed and open ditch, open ditch was not significantly positively correlated to closed ditch.

Length of main stream, basin length and basin width are all very strongly negatively correlated (99%) to ditch and ditchshed gradients as well as drainage density. These three particular parameters showed very strong positive correlation (99%) to drainage area, overland flow, open ditch and closed ditch.

Ditch and ditchshed gradients showed very strong positive correlation (99%) to themselves, texture ratio and drainage density but revealed a very strong negative correlation (99%) pattern to overland flow, open ditch, main stream, basin length and basin width.

Texture ratio shows very strong positive correlation (99%) to only ditch and ditchshed gradients but shows a negative correlation to 11 of the 15 parameters.

Channel maintenance shows no real pattern and was negatively correlated to nine parameters and positively correlated to eight parameters. It revealed a very strong negative correlation (99%) to closed ditch and a very strong positive correlation (99%) to open ditch.

The six basin shape parameters showed that among themselves nine correlations are negatively correlated and five are positively correlated. It is observed that form f was strongly positively correlated at 95 percent confidence level to circularity ratio and all other basin shapes are either very strongly negatively or positively correlated (99%).

Figure 6. Significance or nonsignificance of association of drainage ditch quantitative geomorphic parameters as measured by Pearson's product-moment correlation coefficient.

	Lemniscate Ratio	Elongation Ratio	Circularity Ratio	Shape 2	Shape 1	Form F	Channel Maintenance	Texture Ratio	Ditchshed Gradient	Ditch Gradient	Longest Basin Width	Longest Basin Length	Length of Main Stream	Length of Closed Ditch	Length of Open Ditch	Length of Overland Flow	Drainage Density	Drainage Area
Drainage Area	+	-	-**	+$	+	+$	+**	-$	-**	-**	+**	+**	+**	+**	+**	+**	-**	
Drainage Density	+	-	+$	-	+	-	-**	-	+**	+**	-**	-**	-**	+**	-**	-		
Length of Overland Flow	+	-$	-**	+	+	+$	-$	-$	-**	-**	+**	+**	+**	+**	+**			
Length of Open Ditch	+$	-*	-**	+**	+*	-	+**	-$	-**	-**	+**	+**	+**	+				
Length of Closed Ditch	-	+	-$	-*	-	+**	-**	-	-**	-*	+**	+**	+**					
Length of Main Stream	+**	-**	-**	+**	+**	+	+*	-*	-**	-**	+**	+**						
Longest Basin Length	+**	-**	-**	+**	+**	-**	+**	-$	-**	-**	+**							
Longest Basin Width	-**	+**	-**	-**	-**	+**	+**	-	-**	-**								
Ditch Gradient	+	-	+*	+	+	-	-**	+**	+**									
Ditchshed Gradient	-**	+$	+**	-**	-**	+**	-$	+**										
Texture Ratio	-	+	+	-	-	+	+											
Channel Maintenance	-$	+	-	-	-$	+												
Form F	-**	+**	+*	-**	-**													
Shape 1	+**	-**	-**	+**														
Shape 2	+**	-**	-**															
Circularity Ratio	-**	+**																
Elongation Ratio	-**																	
Lemniscate Ratio																		

(+) - Positive correlation
(-) - Negative correlation
($) - Probability less than or equal to .25 that this coefficient was due to chance alone (weak correlation)
(*) - Probability less than or equal to .05 that this coefficient was due to chance alone (strong correlation)
(**)- Probability less than or equal to .01 that this coefficient was due to chance alone (very strong correlation)

Descriptive Statistics of Drainage Ditch Descriptors

From observation of Table X it was seen that 150 ditches (55.8%) terminate into existing rivers or streams. Only 37 ditches (13.8%) terminate in lakes and approximately one out of three ditches terminate into another ditch. By calculation this means that 212 ditches (78.8%) terminate in rivers or streams and 57 ditches (21.2%) terminate in lakes.

The origin of the drainage ditches were categorized into lake, lake and marsh, marsh, and land, as documented in General Land Survey for each respective county. The presence of both lake and marsh (regardless of relative percentage) placed that ditch in the "lake and marsh" category by our system. The land category was used to indicate the absence of lake and marsh in the drainage shed from the respective General Land Survey.

A predominate number of ditches originated from marsh, amounting to 53.2 percent of the total (Table XI). Combining the categories of "lake and marsh" with "marsh," makes up 77 percent of the total.

The development of drainage ditches fluctuated widely by decade (Table XII). In 1910-1919, 26 percent of all ditches were established, and in 1930-1939 only one ditch (0.4%) was developed. From 1950-1979 35.6 percent of all ditches were constructed, which showed that more than one out of three ditches were developed in the last thirty years, which represents less numbers of ditches per decade than in the past.

The geomorphic analysis revealed that 66.9 percent of all ditches are of two predominate types (Table XIII). The largest category is "Waconia-Waseca Moraine, loamy rolling" of which there were 101 ditches (37.5%) and the second largest is "Blue Earth Till Plain, undulating, loamy" consisting of 79 ditches (29.4%).

The soil types tend to follow the same pattern as geomorphic types, since 65.4 percent of the ditches are of two specific soil types (Table XIV). The first category has 92 ditches (34.2%) of the total and was described as "Below five feet is loamy or silty, the top five feet is loamy or silty, poorly drained, and the color of the surface material is dark." The second major type has 84 ditches (31.2%) and was described as "Below five feet is loamy or silty, the top five feet is loamy or silty, drainage is good, and the color of the surface material is dark."

Crossbreak Analysis of Descriptors to Quantitative Geomorphic Parameters

A crossbreak analysis summary of all data is given in Table XV. This type of analysis provides the means for the various descriptors versus the parameters.

The drainage area mean of no repairs and no improvements was smaller than those of repairs and improvements. Discussion of these two descriptors can be found in Silis (1979). The ditch gradient mean was smaller for no repairs but the ditchshed gradient was larger.

Table X. Frequency of drainage ditch termination.

Termination Point	Absolute Frequency	Relative Frequency %
Ditch	82	30.5
Lake	37	13.8
River or Stream	150	55.8
TOTALS	269	100.0

Table XI. Frequency of drainage ditch origin.

Origin	Absolute Frequency	Relative Frequency %
Lake	13	4.8
Lake and Marsh	64	23.8
Marsh	143	53.2
Land	49	18.2
TOTALS	269	100.0

Table XII. Frequency of drainage ditch construction by decade.

Years by Decade	Absolute Frequency	Relative Frequency (%)
No Information	11	4.1
1880-1889	4	1.5
1890-1899	5	1.9
1900-1909	35	13.0
1910-1919	70	26.0
1920-1929	36	13.4
1930-1939	1	.4
1940-1949	11	4.1
1950-1959	34	12.6
1960-1969	41	15.2
1970-1979	21	7.8
TOTALS	269	100.0

Table XIII. Frequency of drainage ditches by geomorphic type.

Geomorphic Type	Absolute Frequency	Relative Frequency (%)
Minnesota Valley Outwash	4	1.5
Lonsdale-Lerdal Till Region, clayey, rolling	20	7.4
Waconia-Waseca Moraine, loamy, rolling	101	37.5
Wells-Rush River Ground Moraine, clayey, level	20	7.4
Blue Earth-Garden City Ground Moraine, silty, rolling	5	1.9
Minnesota Lake Plain, clayey	28	10.4
Blue Earth Till Plain, undulating, loamy	79	29.4
Emmons-Faribault Moraine, irregular, rolling	4	1.5
No Predominate Geomorphic Type	8	3.0
TOTALS	269	100.0

Table XIV. Frequency of drainage ditches by soil type.

Soil Type	Absolute Frequency	Relative Frequency (%)
Alluvial Soils	1	.4
Below five feet is clayey, the top five feet is clayey, poorly drained, and the color of the surface material is dark.	3	1.1
Below five feet is loamy or silty, the top five feet is clayey, poorly drained, and the color of the surface material is dark.	38	14.2
Below five feet is loamy or silty, the top five feet is clayey, drainage is good, and the color of the surface material is dark.	2	.7
Below five feet is loamy or silty, the top five feet is loamy or silty, poorly drained, and the color of the surface material is dark.	92	34.2
Below five feet is loamy or silty, the top five feet is loamy or silty, drainage is good, and the color of the surface material is dark.	84	31.2
Peat over Loamy Soils	1	.4
Marsh	1	.4
Non-Acid Peat	1	.4
Peat Deposits	3	1.1
Below five feet is sandy, the top five feet is loamy or silty, poorly drained, and the color of the surface material is dark.	4	1.5
No Predominate Soil Type	39	14.5
TOTALS	269	100.0

Table XV. Crossbreak analysis (means) of drainage ditch descriptors by quantitative geomorphic parameters.

	Number of Ditches		Drainage Area	Drainage Density	Length of Overland Flow	Length of Open Ditch	Length of Closed Ditch	Length of Main Stream	Longest Basin Length	Longest Basin Width	Ditch Gradient	Ditchshed Gradient	Texture Ratio	Channel Maintenance	Form F	Shape 1	Shape 2	Circularity Ratio	Elongation Ratio	Lemniscate Ratio
No Repairs	(137)	Mean	3.07	2.19	5.71	2.79	2.92	2.80	2.30	1.40	11.79	24.60	1.37	.56	.53	2.29	1.78	.63	.75	.57
Repairs	(132)	Mean	3.62	2.16	6.30	3.92	2.40	3.14	2.60	1.52	12.17	24.54	1.40	.62	.54	2.38	1.92	.60	.71	.60
No Improvements	(238)	Mean	3.21	2.23	5.93	3.25	2.70	2.90	2.37	1.41	12.41	24.85	1.36	.57	.54	2.31	1.84	.62	.73	.58
Improvements	(31)	Mean	4.29	1.76	6.53	4.12	2.42	3.49	3.01	1.81	8.63	22.43	1.59	.70	.49	2.53	1.89	.56	.76	.63
Terminates into Ditch	(82)	Mean	2.97	1.95	5.25	3.49	1.75	2.70	2.37	1.37	10.32	21.97	1.32	.60	.49	2.39	1.84	.62	.72	.60
Terminates into Lake	(37)	Mean	3.62	1.90	6.12	3.65	2.47	3.11	2.40	1.51	8.82	27.50	1.29	.70	.66	2.30	1.73	.62	.75	.53
Terminates into River or Stream	(150)	Mean	3.47	2.37	6.38	3.19	3.21	3.07	2.50	1.51	13.66	25.28	1.44	.55	.52	2.36	1.88	.61	.74	.59
Originates from Lake	(13)	Mean	1.69	2.19	3.83	2.60	1.24	2.03	1.89	1.09	17.04	23.22	1.07	.53	.52	2.38	1.78	.66	.70	.60
Originates from Lake and Marsh	(64)	Mean	6.61	1.57	10.12	7.00	3.17	4.62	3.56	2.10	7.23	19.58	1.30	.81	.57	2.22	1.87	.54	.74	.56
Originates from Marsh	(143)	Mean	2.79	2.16	5.37	2.59	2.78	2.78	2.33	1.39	10.94	23.83	1.35	.55	.53	2.42	1.87	.63	.73	.61
Originates from Land	(49)	Mean	1.12	3.01	3.03	.98	2.05	1.59	1.46	.92	19.86	33.61	1.67	.40	.51	2.23	1.79	.67	.74	.56
Ditches started in 1880-1889	(4)	Mean	2.79	1.18	2.84	2.84	.00	2.39	2.41	1.43	6.24	14.70	1.17	.95	.43	2.39	1.87	.68	.74	.60
Ditches started in 1890-1899	(5)	Mean	3.19	1.36	4.01	3.20	.81	2.38	2.25	1.50	7.22	32.98	1.28	1.14	.63	1.73	1.46	.68	1.12	.43
Ditches started in 1900-1909	(35)	Mean	4.24	1.33	5.30	4.54	.86	3.46	3.00	1.74	12.48	25.89	1.61	.87	.48	2.60	2.02	.56	.72	.65
Ditches started in 1910-1919	(70)	Mean	2.50	2.66	5.25	1.71	3.55	2.48	2.13	1.36	11.89	22.05	1.37	.48	.50	2.29	1.73	.63	.74	.57
Ditches started in 1920-1929	(36)	Mean	2.47	2.98	6.93	1.98	4.95	2.59	2.13	1.36	14.39	28.47	1.47	.38	.56	2.34	1.86	.66	.73	.59
Ditches started in 1930-1939	(1)	Mean	.82	4.18	3.43	.00	3.43	1.71	1.57	.76	35.00	38.20	1.73	.24	.33	3.00	2.06	.63	.65	.76

Table XV. (continued)

	Number of Ditches		Drainage Area	Drainage Density	Length of Overland Flow	Length of Open Ditch	Length of Closed Ditch	Length of Main Stream	Longest Basin Length	Longest Basin Width	Ditch Gradient	Ditchshed Gradient	Texture Ratio	Channel Maintenance	Form F	Shape 1	Shape 2	Circularity Ratio	Elongation Ratio	Lemniscate Ratio
Ditches started in 1940-1949	(11)	Mean	4.34	1.65	6.60	5.50	1.09	3.03	2.55	1.79	7.00	20.73	1.30	.77	.57	1.92	1.50	.63	.77	.48
Ditches started in 1950-1959	(34)	Mean	5.91	1.75	9.89	7.24	2.65	4.34	3.52	1.79	8.83	19.08	1.22	.62	.42	2.62	2.13	.55	.69	.66
Ditches started in 1960-1969	(41)	Mean	3.19	2.09	5.28	3.61	1.68	3.09	2.28	1.20	12.69	28.44	1.43	.55	.57	2.33	1.97	.63	.70	.59
Ditches started in 1970-1979	(21)	Mean	2.02	2.02	3.90	1.91	1.99	2.30	1.95	1.29	15.30	26.54	1.33	.56	.56	2.13	1.62	.64	.73	.54
Minnesota Valley Outwash	(4)	Mean	6.61	3.58	16.72	2.60	14.12	4.75	3.70	2.07	5.99	12.23	.41	.39	.48	2.33	1.74	.59	.68	.59
Lonsdale, Lerdal Till Region, clayey, rolling	(20)	Mean	3.11	1.96	4.95	3.09	1.86	2.93	2.51	1.55	11.71	27.02	1.66	.66	.48	2.37	1.74	.60	.75	.59
Waconia-Waseca Moraine, loamy, rolling	(101)	Mean	3.61	1.69	5.33	4.34	.99	3.04	2.50	1.44	10.96	25.86	1.45	.71	.52	2.27	1.87	.61	.72	.57
Wells-Rush River Ground Moraine, clayey, level	(20)	Mean	2.27	2.30	5.10	1.49	3.61	2.33	1.94	1.48	12.87	23.28	1.37	.48	.59	2.11	1.54	.72	.84	.53
Blue Earth-Garden City Ground Moraine, silty, rolling	(5)	Mean	4.38	2.26	7.79	1.94	5.85	2.96	2.62	1.59	18.42	22.85	1.58	.47	.45	2.28	1.67	.70	.75	.57
Minnesota Lake Plain, clayey	(28)	Mean	2.57	2.67	4.99	.96	4.02	2.29	2.13	1.37	13.25	21.25	1.31	.50	.49	2.42	1.83	.62	.75	.61
Blue Earth Till Plain, undulating, loamy	(79)	Mean	3.34	2.65	7.20	3.70	3.55	3.18	2.51	1.45	12.50	23.32	1.30	.45	.55	2.47	1.92	.59	.70	.62
Emmons-Faribault Moraine, irregular, rolling	(4)	Mean	5.41	1.00	5.32	5.06	.26	3.76	2.92	1.70	7.45	49.46	.97	1.02	1.12	1.74	1.73	.66	.81	.44
Alluvial Soils	(1)	Mean	3.16	.83	2.62	2.62	.00	3.43	3.81	.95	32.08	55.13	6.30	1.20	.22	4.59	4.00	.43	.48	1.14
Below five feet is clayey, the top five feet is clayey, poorly drained, and the color of the surface material is dark.	(3)	Mean	1.11	3.56	3.30	.00	3.30	1.47	1.46	.84	16.22	20.07	.88	.29	.40	2.98	2.32	.59	.70	.75

Table XV. (continued)

	Number of Ditches		Drainage Area	Drainage Density	Length of Overland Flow	Length of Open Ditch	Length of Closed Ditch	Length of Main Stream	Longest Basin Length	Longest Basin Width	Ditch Gradient	Ditchshed Gradient	Texture Ratio	Channel Maintenance	Form F	Shape 1	Shape 2	Circularity Ratio	Elongation Ratio	Lemniscate Ratio
Below five feet is loamy or silty, the top five feet is clayey, poorly drained, and the color of the surface material is dark.	(38)	Mean	2.76	2.43	5.70	1.00	4.70	2.52	2.18	1.50	12.34	20.05	1.41	.50	.56	2.21	1.67	.67	.81	.55
Below five feet is loamy or silty, the top five feet is clayey, drainage is good, and the color of the surface material is dark.	(2)	Mean	5.91	1.66	7.66	3.40	4.26	3.88	3.50	2.17	11.34	21.96	1.10	.73	.57	2.09	1.63	.59	.83	.53
Below five feet is loamy or silty, the top five feet is loamy or silty, poorly drained, and the color of the surface material is dark.	(92)	Mean	3.76	2.09	6.85	4.21	2.68	3.29	2.61	1.49	9.42	20.09	1.06	.57	.53	2.39	1.90	.62	.72	.60
Below five feet is loamy or silty, the top five feet is loamy or silty, drainage is good, and the color of the surface material is dark.	(84)	Mean	2.77	2.23	4.78	3.27	1.51	2.68	2.25	1.32	15.24	31.00	1.53	.59	.53	2.33	1.89	.61	.72	.58
Peat over Loamy Soils	(1)	Mean	3.15	3.23	10.16	2.64	7.52	3.43	2.38	2.09	8.75	16.80	.95	.31	.56	1.80	1.14	.74	.84	.45
Marsh	(1)	Mean	1.99	2.02	4.02	2.88	1.14	2.67	1.71	1.71	5.63	29.17	.46	.50	.68	1.48	1.00	.59	.67	.37
Non-Acid Peat	(1)	Mean	14.71	1.24	18.31	17.36	.95	10.66	2.38	1.38	2.81	18.90	.58	.81	2.60	.38	1.72	.27	.50	.10
Peat Deposits	(3)	Mean	4.23	1.73	6.90	6.90	.00	3.85	3.01	1.52	4.58	31.85	1.76	.60	.39	2.61	1.99	.60	.70	.66
Below five feet is sandy, the top five feet is loamy or silty, poorly drained, and the color of the surface material is dark.	(4)	Mean	6.61	3.58	16.72	2.60	14.12	4.75	3.70	2.07	5.99	12.23	.41	.39	.48	2.33	1.74	.59	.68	.59

The drainage area and open ditch means of termination into a lake was the highest among the three termination categories. The ditch gradient mean was the lowest for termination into lakes compared to the other two categories, but was the highest mean in ditchshed gradient. The circularity and elongation ratio for all termination types are very close and consistent.

The origin category of lake and marsh showed that drainage area, overland flow, open ditch, closed ditch, main stream, basin length and basin width have a considerably higher mean than the other three origin types. But it was important to note that the drainage density mean in origin of land was much higher than the other ditch categories. The ditch and ditchshed gradients for the origin of lake and marsh showed the lowest means respectively.

The category of decade of ditch construction showed that the largest in drainage area were developed in 1950-1959 and the smallest in 1930-1939 (one ditch only). The ditch gradient mean showed a slow increase from 1880-1939, then in 1940-1949 the mean dropped down to what it was in 1880-1889, and gradually increased to 15.30 feet per mile in 1970-1979. The basin type, shape 2, had the highest mean in 1950-1959 but the lowest circularity ratio mean in the same time period.

The two most predominate geomorphic types indicated that the drainage area means are quite similar but revealed a difference in drainage density means. The last geomorphic type in Table XV revealed the highest length of open ditch mean but the next two highest means are found in the two most predominate geomorphic types, 4.34 and 3.70 respectively. The widest range in means between ditch and ditchshed gradient was found in the last geomorphic type "Emmons-Faribault Moraine, irregular, rolling." "The Blue Earth Till Plain, undulating, loamy" and "Waconia-Waseca Moraine, loamy, rolling" showed the second and third largest ditch gradient means.

The means of drainage area and length of open ditch are extremely high for the soil type of Non-Acid Peat, but there was only one ditch in this category. The two predominate soil types have similar means in drainage area, drainage density, open ditch, main stream and basin width. The soil type "Below five feet is loamy or silty; the top five feet is loamy or silty, poorly drained, and the color of the surface material is dark," has lower ditch and ditchshed gradient than the soil type "five feet is loamy or silty, the top five feet is loamy or silty, drainage is good, and the color of the surface material is dark."

Discussion

A quantitative geomorphic study of artificial drainage in agricultural South Central Minnesota was lacking in the literature. It can be hypothesized that man's drainage projects in the immature landscape with unconsolidated sediment represents to some degree the path natural drainage would have taken, in time, in this region. This is especially true where adequate gradient exists. Due to the lack of regional drainage ditch literature, we have surveyed quantitative geomorphic literature on low order streams. Our results will be discussed first as isolated geomorphic parameters, secondly what the literature contains, and then a comparison of the two. The next section will examine combined geomorphic parameters in the literature in relation to our data emphasizing interparameter relationships. The third part of the discussion will be concerned with the descriptor-parameter relationship for which little literature exists and the final section will be the descriptor analysis for South Central Minnesota.

Isolated Quantitative Geomorphic Parameters

Drainage Area. In our South Central Minnesota study the average of 3.34 square miles of drainage area for a drainage ditch is significantly higher than that reported in the literature for first-order streams throughout the United States. The majority of first-order streams reported have drainage area means of approximately one square mile as reported by Chorley, Malm, Pogorzelski, 1957; Morisawa, 1957 (Ohio, Pennsylvania); Smith, 1950 (New Jersey, Arizona); Morisawa, 1962 (Virginia, Ohio, Pennsylvania, Maryland, Tennessee); Liao, Scheidegger, 1969; Leopold, Wolman, Miller, 1964 (United States).

Leopold, Wolman, Miller (1964) utilized a data base of 1,570,000 first-order streams in the United States and found the average area also to be one square mile. The large drainage areas reported for artificial agricultural drainage in South Central Minnesota could relate to several factors. Our flat, poorly drained area does not have extreme elevation differences to generate small drainage basins Secondly, one could question the logic of not calling the tile lines first-order streams and the open ditches as second-order streams as defined by Strahler. Strahler's (1957) definition of stream order is: Order one is channels without tributaries; order two is channels with only order one tributaries, but includes only the length segment between the junction upstream of order one channels and the junction downstream with another order two channel. This would place the area found for ditches closer to what Leopold, Wolman, Miller, 1964 (United States) found for second-order streams which is a drainage area of 4.7 square miles on a sample size of 350,000 streams.

Drainage Density. The drainage density which is the total length of streams per unit of drainage area was found to have a mean of 2.18 miles per square mile in this particular study. This included both open and closed ditches. In the literature it was found that the drainage density of first-order streams was above 2.65 as reported by Morisawa, 1957 (Pennsylvania, Ohio), Morisawa, 1962 (Ohio, Pennsylvania, Maryland Tennessee), Smith, 1950 (California, Pennsylvania). But looking at studies where the water networks were larger than first-order streams all drainage density figures were under 2.20 with the majority of figures between one-two as reported by Horton, 1932 (New York), Horton, 1945 (New Jersey, New York, Tributaries to Delaware River).

There seems to be a general trend that follows for drainage density. When you discuss first-order streams the values are quite high. The studies done on large systems, where drainage areas are 100 square miles or larger, tend to have drainage density values quite low around the range of one-two. This would fit drainage ditches in the second-order category.

Length of Overland Flow. The length of overland flow in this study was found to average six miles of open and closed ditch per drainage basin. This was considerabley higher than found in the literature, which was approximately one mile for first-order streams. Second and third-order streams averaged between two to eight miles as reported by Morisawa, 1957 (Pennsylvania); Smith, 1950 (Pennsylvania, California); Horton, 1945 (Tributaries to Delaware River, New York, Georgia); Scheidegger, 1968 (Appalachian Plateau Rivers); Leopold, Wolman, Miller, 1964 (United States).

This again indicates that drainage ditches in South Central Minnesota more closely fit second or even third-order streams by the Strahler numbering system. It can be presumed that the reasons for longer overland flows are that it is more economical for the landowner to connect as many drainage networks as possible. Secondly, the elevation gradients lack extreme differences which make it possible to convert short first-order streams into longer second-order streams which seems evident from the data comparisons.

Ditch and Ditchshed Gradients. The slope ratio of ditch gradient to ditchshed gradient was found to be an average of 0.50 with a range of 0.28-0.82 by calculation from Table XIII. In the literature Gray (1961), found a slope ratio range of 0.40-1.45 in Missouri, o.25-0.86 in Nebraska and 0.31-1.41 in Iowa, which compares with slope ratios in our study. Since the geographical locations are quite close these ranges show a similar relationship which you would expect.

Horton in 1932 found slope ratio ranges in New York of 0.14-0.30 and Horton, 1945 (Tributaries to Delaware River) of 0.27-0.37. These two are also quite close but are on the low side when comparing our ranges which would indicate there is a slight difference in slope gradients between New York and Minnesota, and perhaps also in the nature of the sediments.

Texture Ratio. The texture ratio in our study had a mean of 1.38 with a range of 0.00-6.30. The only values obtained in the literature were by Smith (1950) who found ranges of 1.11-4.00 (Pennsylvania), 4.21-23.84 (California), 139-246 (New Jersey) and 106-127 (Arizona).

Smith (1950) proposed that values below 4.0 were of coarse texture, resistant to erosion, basic drainage networks Medium textured topography ranging from 4.0-10 and above 10 were fine texture, highly erodable and intricate drainage networks. This would put our study area in the coarse texture category which compares with Pennsylvania in ranges. California, New Jersey and Arizona are considerably higher which shows that especially New Jersey and Arizona have an intricate drainage network. Smith (1950) also stated that these high texture ratio areas are humid-temporate regions with no vegetation. This would indicate a strong reason for the large difference since our study area is highly agricultural.

Channel Maintenance. Channel maintenance of 0.59 square miles in our study was considerably higher than that found in Morisawa, 1962 (Appalachian Plateau) 0.17-0.39 square miles and Strahler, 1957 (California) 0.13, (Perth-Amboy Badlands) 0.001.

By definition channel maintenance is the number of square miles of surface necessary to maintain each mile of channel. It is often considered a measure of how erodable the land surface is. Since our values are high compared to numbers reported in the literature this could indicate that the land surface is quite erodable. There may be a relationship between extensive row cropping and fall plowing in this region to erodability and a high channel maintenance value.

Shape 1, Form f. Shape 1 wich is also the reciprocal of form f had a mean of 2.33. In Morisawa, 1958 (Appalachian Plateau) shape 1 for a drainage area of 3.07 square miles which is close to our studies average showed a value of 2.20. Although this is only one particular basin one must take note of the similar values between these two studies.

Shape 2. Shape 2 which had a mean of 1.85 also compared closely to what Morisawa, 1958 (Appalachian Plateau) had of 1.53 for a drainage basin (3.07 square miles) similar to our study. There are similarities in shape 1 and 2, but further study is needed to assume these two basin shapes in Minnesota would be comparable to basins in the Appalachian Plateau.

Circularity Ratio. The circularity ratio in our study had a mean of 0.62 with a range of 0.20-2.34. Studies done by Gray (1961) showed ranges of: Iowa 0.39-0.80, Missouri 0.39-0.87, Nebraska 0.33-0.68, Ohio 0.35-0.77, Wisconsin 0.58-0.80, North Carolina 0.51-0.68, which all fall into the mean and range of our study. Morisawa, 1958 (Appalachian Plateau); Chorley, 1957 and Morisawa, 1962 (Ohio, Pennsylvania, Maryland, Tennessee) had values on individual basins that were in the range of 0.60-0.80.

The values are quite similar but it is important to note that our range is much greater than the ranges found in Gray (1961). This we would assume is because artificial drainage produces circularity ratio extremes 0.20 or 2.34 which can only be developed by man and not by nature. It was also mentioned in Gray (1961) that circularity values in these studies remain quite constant.

Elongation Ratio. The mean of the elongation ratio in our study was 0.73 which falls in the ranges found by Gray, 1961, Iowa 0.48-0.77, Missouri 0.46-0.90, Ohio 0.58-0.84, North Carolina 0.62-0.78. Morisawa, 1958 (Appalachian Plateau) had a value of 0.76 for one drainage basin which was similar in size to our study.

Although our mean of 0.73 is similar, the ranges (0.39-2.26) are broader than that found in the literature. This would indicate that artificial networsk tends to have a more diverse set of values when man has been part of the development process.

Lemniscate Ratio. The lemniscate ratio mean was found to be 0.59 in our study which is low when comparing Chorley (1957) of 0.806 and 0.886 respectively. Since there was no location given for these two values more study is needed to predict logical comparisons.

Quantitative Geomorphic Interparameter Relationships

Quantitative geomorphic data on interparameter relationships was quite limited in the literature. Those obtained were: length of main stream-drainage area; slope-drainage density; drainage area with overland flow, open ditch, length of main stream, basin length, basin width; and drainage density-texture ratio. In this section our results are discussed and compared to the literature when present.

Drainage area was found to be very strongly negatively correlated (99%) to drainage density. This would seem to indicate that as artificial drainage areas increase, intricate drainage networks decrease. This could be due to the high cost of developing many tributaries in a large drainage basin or the greater dependence on tile lines.

Drainage area was very strongly positively correlated (99%) to basin width, basin length and length of main stream. These types of correlations would be expected, because as the drainage area increases so would these particular parameters.

Gray (1961), Schenk (1963) and Morisawa (1968) reported that main stream length was positively correlated to drainage area. In our study this also was the case. Regardless of a natural or artificial drainage system a larger basin area would normally tend to have a longer main stream length.

Strahler (1950) reported that slope was positively correlated to drainage density and we found this also. This seems to indicate that as gradient increases, the flow rate of surface runoff increases, which would cause more erosion, developing more channels and, therefore, raising drainage density values.

Closed ditch was very strongly positively correlated (99%) to drainage density, but open ditch was very strongly negatively correlated (99%) to drainage density. The purpose of closed ditch is to save valuable land. So if more artificial drainage channels are needed they would try to be developed as closed ditch which increases drainage density and prevents loss of useable land.

Closed and open ditch were very strongly positively correlated (99%) to drainage area. This would be expected since length of closed and open ditches would increase along with drainage area (size).

Length of overland flow, open ditch and closed ditch were all at least strongly negatively correlated (95, 99%) to ditch and ditchshed gradients. It would seem to hold true that natural streams are positively correlated to both gradients since water flows towards least resistance. Since our study area has minimal gradient differences and was negatively correlated it could indicate that when developing artificial ditch networks man develops their own gradient right into the channel. The question could be asked whether channels are constructed in locations for man's convenience rather than determined by the gradients existing in the area.

Length of overland flow, open ditch and closed ditch were all very strongly positively correlated (99%) to basin width, basin length and length of main stream. One would presume this type of trend, because as your basin length, basin width and length of main stream increases your length of channels must increase to adequately drain that particular size area.

Texture ratio shows a very strong positive correlation to ditch and ditchshed gradients. This relationship is consistent with the observation that steeper gradients result in the formation of more ravines and gullies. On the other hand a flat gradient would not possess the erosional ability to produce these types of land topography. One must take into consideration the type of soil and how resistant to erosion that particular area is.

Channel maintenance shows very strong negative correlation (99%) to closed ditch and very strong positive correlation (99%) to open ditch. This relationship is probably related to the fact that closed ditches are covered, have a steeper gradient than open ditches and are less likely to silt in.

The six basin shape parameters showed that among themselves, nine correlations are very strongly negatively correlated (99%) and five are very strongly positively correlated (99%). Through the formulas it is evident to see why these correlations exist. Shape 1 and form f are reciprocals of each other. Shape 1 and shape 2 differ only because shape 1 squares the basin length in the formula while shape 2 does not. Morisawa (1968) states that circularity ratio may be used to predict certain hydrologic characteristics of a drainage basin. Elongation ratio may be used in studies of sediment loss in watersheds.

Drainage area showed positive linear relationships with overland flow, open ditch, main stream, basin length and basin width. Gray (1961) and Chow (1964) also found a linear relationship between these particular parameters. This would be expected because as the drainage area increases so would all these other parameters. For example, if the drainage area increases so would the basin length, this is a common observation of drainage basins.

Strahler (1957) and Leopold, Wolman and Miller (1964) showed that a positive linear relationship between drainage density and texture ratio exists. A positive linear relationship was not found in our study. An explanation could be that the texture ratio is used to count only natural ephemeral streams which does not include the artificial ditches.

Descriptor-Parameter Relationships

The relationship of descriptors to quantitative geomorphic parameters is not covered in the literature and thus direct comparisons were not possible. Selected morphometric parameters did exhibit interesting differences to many of the categories within the descriptors.

Those ditches terminating into other ditches had the lowest means for drainage area, overland flow and closed ditch. Ditches terminating into lakes had the highest means for drainage area and the lowest mean for ditch gradient. Further those ditches that terminate into rivers or streams had the highest means for drainage denstiy, overland flow, closed ditch and ditch gradient.

It was observed that ditches terminating into other ditches have small drainage areas with minimal channel lengths which could indicate that these are small tributaries being added on to larger ditch systems. Ditches terminating into lakes, might indicate that these were natural streams that flowed into lakes and that man has developed them further to adequately drain their own particular lands. Ditches terminating into rivers or streams had high values for drainage density, overland flow, closed ditch and ditch gradient, which tends to show that when you have a high ditch gradient the complexity of ditch networks increase. It appears that more miles of channel are needed to efficiently drain land that is associated with rivers or streams. This may be caused by a steeper gradient that is usually associated with natural rivers or streams.

Two origin categories showed strong distinguishing characteristics within the origin classification. Ditches originating from lake and marsh have the highest means for drainage area, overland flow, open ditch, closed ditch, length of main stream, basin length, basin width and the lowest mean for drainage density, ditch gradient and ditchshed gradient. Ditches originating from land show the highest means for drainage density, ditch gradient, ditchshed gradient and the lowest mean for drainage area, overland flow, open ditch, length of main stream, basin, length, basin width.

Ditches originating from lake and marsh would tend to have a larger drainage area since it contains two types of surface waters, and consequently a larger basin length and basin width. They also indicate that an intricate overland flow is needed in the form of open ditch, closed ditch and a longer main stream to adquately drain both types of surface waters. The lower drainage density values would seem to indicate that drainage is specifically of the lake and marsh and not of the surrounding drainage basin area which would decrease the drainage density value. You would expect a low ditch and ditchshed gradients since surface water is normally found in lower areas with minimal gradients.

The origin of land in this area indicates that land with no surface water retained on it has a high ditch and ditchshed gradient value. Since the drainage area, overland flow, open ditch, length of main stream, basin length, basin width were quite small, it appears that this origin category lacks a developed drainage network. This may indicate that in general, the soil porosity is large enough to allow direct seepage of water into the ground, rather than developing surface runoff channels.

Ditch development by decade revealed that the largest drainage areas were developed in 1950-1959 and the samallest in 1930-1939. Quade (1978) reported that there was an emphasis on making land usable in the early decades, and in the recent decades to protect land.

There seems to be a general trend that small drainage areas were artificially drained from 1880-1940, the largest ones in 1950-1959 and then it decreased in 1960-1978. This could be related to the fact that average farm size was much smaller in the early decades so the drainage areas were smaller at this time. The smallest drainage area in 1930-1939, which was only one ditch, could be related to drought and depression during this time period. The larger drainage area in 1950-1959 could be because the average farm size had increased, so that when ditches were developed, the landowners had more land to artificially drain. During this period many ditches were reclassified or lumped together and renamed as parts of it were developed or expanded which could cause the average drainage area to increase in an exaggerated fashion in the 1950's. The decline in 1960-1978 could possibly be, that the majority of larger drainage areas had been developed. Also reclassification declined so that the drainage areas decreased in size as is shown in 1960-1969 and 1970-1979.

Ditch development by decade showed a slow increase in ditch gradient from 1880-1939, dropped in 1940-1949 and gradually increased in 1970 to 1979. First of all, you would expect that artificial drainage would have its beginning where the ditch gradient would be rather small. This could indicate a trend to first drain low poorly drained areas, eventually developing artificial drainage in higher gradients. One could presume that the decreased gradient in 1940-1949 may be the fact that they developed larger areas with low ditch gradients that in decades past were never considered because of the large scale. In the past two decades the high ditch gradient could be associated with more closed ditches being developed and a decrease in open ditches in low ditch gradient areas to save valuable land.

In the first three decades the highest channel maintenance means occurred. One could presume that in early years natural streams were converted to artificial drainage networks by deepening or widening them, so it would still retain the high channel maintenance value. It tends to show that artificial drainage systems have a smaller channel maintenance mean than do converted natural streams. Since man has developed new channels, this may be why channel maintenance values are lower.

In the decade of 1950-1959 the highest basin shape mean was shape 2 and the lowest mean was circularity ratio. Shape 2 is related to drainage area because the formula is basin length over basin width, so when the drainage area is larger like in 1950-1959, the basin length and basin width are larger. Larger drainage areas with a long basin length and narrow basin width would give higher values. This indicates that basins in this decade had approximately two miles of basin length for every mile of basin width, which would tend to make it look oval shaped. The low circularity ratio value is expected since the shape 2 formula resembles an oval shape which would give a low circularity ratio because it tends to be further away from a circular shape.

In the geomorphic category, the two predominate types showed differences in drainage density values. This may be due to the porosity of each type. The geomorphic type "Waconia-Waseca Moraine, loamy, rolling" shows a very low closed ditch mean compared to the other predominate geomorphic type. This may indicate that closed ditch is not feasible in this geomorphic type.

In the soil categories, "non-acid peat" has an extremely high drainage area and drainage density mean. This might well be characteristic of this soil type, but it should be pointed out that only one ditch is in this category. More study and ditch numbers in this category are needed to show if these high means do exist in general.

The two predominate soil types show many similar parameter means. Interestingly, both soil type descriptions are similar with the only difference being, one is described as being poorly drained and the other has good drainage. This indicates that artificial drainage is quite similar in geomorphic parameters even if one soil type is poorly drained and the other is well drained. Further research in this area is continuing.

The soil type "Below five feet is loamy or silty; the top five feet is loamy or silty, poorly drained, and the color of the surface material is dark" shows a lower ditch and ditchshed gradient than the other predominate type which is described the same, but has good drainage. This would be expected since the soil type that is poorly drained would most likely be found on lower gradients. Also, the poorly drained soil type may not allow extensive seepage directly into the soil. Conversely the soil type with good drainage, that has a steeper gradient may allow better seepage into the soil.

Descriptor Analysis

This section on descriptor analysis was not covered in the literature. Relationships are discussed and developed to gain an insight as to why certain relationships within these descriptors exist.

Termination Point. In our four county area it was found that 78.8 percent of all drainage ditches terminated in rivers and 21.2 percent in lakes, an approximate four to one ratio. There are 687.7 miles of river (281.4 Blue Earth, 203.3 Brown, 77.1 Le Sueur, 125.9 Nicollet) and 1055.5 miles of open ditch (137.4 Blue Earth, 344.7 Brown, 250.4 Le Sueur, 322.8 Nicollet) which represents a 1.53 ratio of open ditches to rivers and since 78.8 percent terminated into rivers it more than doubles the effective river lengths.

The ditchsheds to lakesheds by county are: 39.9% to 12.0% for Blue Earth, 45.98% to 10.50% for Brown, 46.07% to 38.41% for Le Sueur, 58.91% to 24.31% for Nicollet, an average of 47.71% to 21.30% (Dunsmore and Quade, 1979a; Dunsmore, Oelerich and Quade, 1979; Dusnmore and Quade, 1979b; Dunsmore and Quade, 1979c). This indicates a two to one ratio in area of ditchsheds to lakesheds and since 78.8 percent of ditches terminate into rivers, it greatly increases the riversheds functional size. The 21.2 percent of ditches that terminate into lakes have increased the effective watershed of lakes without necessarily taking drainage from riversheds. However, the 78.8 percent of drainage ditches that terminate into rivers have diminished some lakesheds. The drainage ditch origin data derived in this study shows that 28.6 percent of drainage ditches originated in lakes and lake-marsh environments. Mathematically this would indicate an overall loss of lakeshed. One is led to conclude that termination into a lake most probably represents improved, not changed, lakeshed drainage, where as origin of a lake represents absolute loss of lakeshed and in some cases lakes.

Origin. The origin of the drainage ditches showed that 81.8 percent originated from surface water such as marsh, lake, lake-marsh categories and 18.2 percent from land. In our study area the General Land Survey gave the percent marsh to percent lake as: 5.1% to 3.3% for Blue Earth, 2.6% to 1.8% for Brown, 9.9% to 5.8% for Le Sueur and 7.3% to 5.4% for Nicollet; a four county average of 6.2% to 4.0% (Dunsmore and Quade, 1979a; Dunsmore, Oelerich and Quade, 1979; Dunsmore and Quade, 1979b; Dunsmore and Quade, 1979c).

In general the areal percentage for marsh and lake are quite small in size, but represent many in number as seen in the atlases (Dunsmore and Quade, 1979a; Dunsmore, Oelerich and Quade, 1979, Dunsmore and Quade, 1979b; Dunsmore and Quade, 1979c). Many small lakes that existed in the 1800's, have been drained and a lake type surface hydrology extensively changed. One also must look at the marsh category since they too, are small, but many in number. By calculation there is a ratio range of 1.35 to 1.7 for marsh to lake. The question should be asked: is this an important ratio that should be kept in this range for a normal surface hydrology balance? If this ratio is changed, could this cause an imbalance that may disrupt either marsh or lake water systems? What effects does eliminating marsh and lakes, or disrupting the ratio, have on ground water supply and increased runoff to downstream environments?

Decade. The development of drainage ditches by decade showed a maximum number in 1910-1919 and minimum number in 1930-1939. Quade (1978), showed a general trend was followed, that in the earlier decades making land useable was the reason for ditch development in later decades protecting land and highways were the primary reasons for development.

You would expect the early decades to place emphasis on the value of the land for agriculture. Ditches were developed to gain more useable acreage, control water levels, as well as water flow, and control flooding of existing agricultural land.

From 1930-1939 the causes for only one ditch being developed in this area could have included the abnormally dry weather and the depression.

Starting in the 1940's land was slowly becoming more valuable and the emphasis was on using all available land for agriculture. Due to this, development increased in 1950-1959 and 1960-1969. Some reasons that we would assume a development decline in 1970-1979 are most of the land that was available to drain had been already drained and laws established to determine what is public water could have caused a decline in development.

The later decades, petition reasons for protecting land, could be caused by all the development of artificial drainage in earlier decades. The question that comes to mind is has early development caused excessive flooding in other areas so ditches must be developed to protect land and highways that thirty years ago were not susceptable to flooding. Have we moved the problem by controlling water levels in one area and causing higher water levels downstream?

Geomorphic Types. Two predominate geomorphic types exit in our study area which are "Waconia-Waseca Moraine, loamy, rolling; Blue Earth Till Plain, undulating, loamy." The respective areal percentage by counties are: 2.6% to 20.2% Blue Earth, 0.0% to 80.5% Brown, 51.4% to 0.0% Le Sueur, 80.8% to 0.0% Nicollet.

It is seen that Blue Earth County does not show any dominance in geomorphic types, however, the other three counties show quite strong dominance of one particular type respectively. Brown and Le Sueur Counties have only three and five geomorphic types respectively.

Lake surface by counties are: 3.87% Blue Earth, 2.8% Brown, 10.3% Le Sueur, 5.1% Nicollet (MLMIS), (Dunsmore and Quade, 1979a; Dunsmore, Oelerich and Quade, 1979; Dunsmore and Quade, 1979b; Dunsmore and Quade, 1979c).

When comparing lake area to geomorphic types by county an interesting relationship develops. The lowest percent of lake area occurs in Brown County, which has a dominance of the geomorphic type "Blue Earth Till Plain, undulating loamy" (80.5%). The two highest percents of lake area are Le Sueur (10.3%) and Nicollet (5.1%) respectively and they have a predominate geomorphic type which is "Waconia-Waseca Moraine, loamy, rolling."

Soil Types. In our study area there was a dominance of two soil types which are "Below five feet is loamy or silty, the top five feet is loamy or silty, poorly drained and the color of the surface material is dark:" "below five feet is loamy or silty, the top five feet is loamy or silty, drainage is good, and the color of the surface material is dark". The percentage by county of these two are: 12.4% to 27.5% Blue Earth, 46% to 33% Brown, 9% to 63.4% Le Sueur and 44.6% to 38% Nicollet respectively (Dunsmore and Quade, 1979a; Dunsmore, Oelerich and Quade, 1979; Dunsmore and Quade, 1979b; Dunsmore and Quade, 1979c). By adding the two dominant soil type percentages together (39.9% Blue Earth, 79% Brown, 72.4% Le Sueur, 82.6% Nicollet), Blue Earth is quite low (40%) compared to the other three counties.

The only difference in description between these two soil types is one is poorly drained, and the other has good drainage. Since this is the only difference it could be assumed that poorly drained may indicate that it is associated with marsh and well drained may be more often associated with lakes. This seems to be evident in Le Sueur County where the well drained soil type has the highest percentage of any county, but it also has the highest percentage of lakes.

Conclusion

This study has found that artificial drainage ditches are best grouped into the first and second-order categories of Srahhler's (1957) stream numbering system and that the major impact of artificial drainage has been the extension of the river systems at the cost of lakes and marshes.

Through comparisons of artificial ditch quantitative parameters with natural stream systems there is strong evidence that man has produced, in a short time, a geomorphologically mature fluvial landscape. The quantitative geomorphic parameters which we found for open ditches compared favorably with the second-order natural stream data found in the literature.

The impact of artificial drainage ditch development in South Central Minnesota has been to greatly increase the riversheds functional size. It was found that 78.8 percent of the ditches terminate eventually into a river or stream. A 1,53 ratio of open ditch to rivers more than doubles the length of the overall surface fluvial system. Furthermore 21.2 percent of ditches terminate into lakes which increases the effectiveness of lakeshed drainage without necessarily taking drainge fom riversheds. This research found that 28.6 percent of the ditches originate from lakes and lake-marsh environments which indicates an overall loss of lakeshed and lakes.

Artificial drainage ditches, have definitely become a dominate surface hydrology factor in South Central Minnesota. Through this study it seems quite evident that man has taken a lake-marsh environment and has rapidly produced an area with ever increasing river-ditch channel systems, where the long term effects are not known.

This study indicates that artificial drainage ditches show a great variation in geomorphic values in the four county study area. In order to show specific relationships about individual parameters it is recommended that for future studies artificial ditches should be grouped into categories of either drainage area size or classified as Strahler's (1957) first and second-order streams.

PUBLIC DRAINAGE DITCH RIPARIAN VEGETATION

Introduction

The purpose of this section was to examine the vegetation on the inside slope and berm of the open drainage ditches in the four counties and to relate the vegetation to county drainage ditch management policy. We first determined the variation and range of drainage ditch morphometry and associated plants within the ditch embankment (slope) and berm by county. If differences are found the question to be examined would be whether the differences are caused by differences in county management, drainage ditch morphometry, or some other factor.

Blue Earth, Brown, Le Sueur and Nicollet Counties show typical South Central Minnesota landuse which is predominantly row crop agriculture. The major native vegetation is limited to river valleys, road side ditches, and drainage ditches. The extent of the length of open ditches exceeds the length of rivers in some of the counties and therefore can be looked upon as major potential natural habitats both for wildlife and affecting surface runoff. Blue Earth County has 138 miles of open ditches and 281 miles of river. Brown County has 345 miles of open ditches and 203 miles of river. Le Sueur County has 250 miles of open ditches and only 77 miles of river, and Nicollet County has 323 miles of open ditches and 126 miles of river. This study represents a preliminary survey of what exists in these zones from a botanical viewpoint.

In these four counties, different types of county ditch management policy are practiced. Brown and Nicollet prefer the broad use of herbicides whereas Blue Earth and Le Sueur Counties use limited amounts of herbicides, usually as a spot control by farmers and not by the county. All four counties tend to view ditch vegetation as a nuisance and feel its function should be to prevent erosion and to control weeds. When management practices are examined it may be possible to link these practices with common vegetation or the lack of it.

Methods

Drainage ditches, county and judicial, can be open or closed depending upon gradient. This study component deals only with open ditches. In the construction of an open ditch a drag line or power shovel is used with the resultant dredged material piled back of the edge of the ditch to form a berm. This survey examined the dominant mid-summer plants on the berm itself and the inside slope to the ditch.

During the summer of 1978 from June 23rd to August 15th each open ditch in the four county area was visited (a total of 210 ditches) making a single on sight determination of primary, secondary, and tertiary herbacious and tree vegetation and various characteristics of each ditch. No attempt was made to catalogue all vegetation, but rather to determine the primary, secondary, and tertiary trees and herbs by dominance. It should be noted these determinations were purely visual and if we had visited the ditches at other times of the year other herbacious vegetation could have been dominant. Each ditch was surveyed at its narrowest and widest segments where possible. Characteristics of the ditches were then expressed as numbers rather than dimensions or vegettion types and the data was run on a UNIVAC 1100/80 computer using data analysis by SPSS.

Results

The comparison of open ditch parameters by county is given in Table XVI. As can be seen, Le Sueur County has ditches two to three times wider than the other counties. Ditch height is similar in all four counties but because the ditches in Le Sueur County are wider they have less slope than the others. Berms, like ditches, are also two to three times wider in Le Sueur than in the other counties. Le Sueur County ditches on the average are twenty years older than those of Nicollet County. This could be the reason why Le Sueur County ditches are so much wider; the land was cheaper and less under demand. Drainage density were very similar among all four counties. The overland flow of Le Sueur County ditches are about one and one-half times less than Blue Earth's, possibly due to the topography. However Le Sueur's mean ditch gradient was the lowest while its ditch shed gradient was the highest of all four counties. Texture ratio, which is the number of miles of ditch per square miles of land, circulatory and elongation ratios which both deal with the shape of the basins, were similar in each county. Channel maintenance which is the square miles of land per miles of ditch, is also similar in all counties. The last repair and improvement parameter is most interesting. Blue Earth County has had less than half the repairs Brown has, even though Brown County's ditches are on the average four years younger than Blue Earth's. Also comparing Le Sueur and Nicollet County, they have had a similar amount of repairs; however, Nicollet's ditches are nearly twenty years younger than Le Sueur's.

A county by county comparison of vegetation on the inner ditch slope and outer berm for both the wide and narrow segment are shown in Tables XVII, XVIII, XIX, XX. The results of the arboreal survey of the drainage ditch inner slope are seen in Table XVII.

Blue Earth and Le Sueur Counties generally do not spray for broad leaves and have a greater percentage of woody plants. Blue Earth County shows a dominance of the genus populus, largely cottonwoods and some aspens, in both the wide and narrow ditch segments. Le Sueur has high occurrences of elm, willow and other unspecified types, largely boxelder. Brown and Nicollet Counties regularly spray for broad leaves and as a result have very few wooded ditches. Brown has poplar and unspecified types dominating, however with only four wide ditch segments and two

Table XVI. A county by county overview of ditch parameters.

		Total	Blue Earth	Brown	Le Sueur	Nicollet
Ditch Width (Wide)	M	26.3	15.4	16.9	55.0	15.8
(yard)	N	175	29	39	46	61
Ditch Width (Narrow)	M	19.4	13.4	13.9	32.7	15.6
(yard)	N	100	20	25	27	28
Ditch Height (Wide)	M	12.7	12.5	13.4	13.4	11.8
(feet)	N	175	29	39	46	61
Ditch Height (Narrow)	M	11.2	11.8	10.4	10.7	12.1
(feet)	N	100	20	25	27	28
Ditch Slope (Wide)	M	47.2	49.1	50.2	42.9	47.6
(degrees)	N	174	29	38	46	61
Ditch Slope (Narrow)	M	43.4	45.8	45.1	40.9	43.0
(feet)	N	96	17	24	27	28
Berm Width (Wide)	M	12.1	8.3	9.9	24.8	9.4
(feet)	N	151	27	37	27	60
Berm Width (Narrow)	M	9.2	8.0	7.6	14.0	9.5
(feet)	N	72	10	25	9	28
Year	M	1936.7	1931.8	1935.7	1927.7	1947.5
Established	N	205	41	56	46	62
Drainage Area	M	4.2	5.0	3.9	4.2	3.9
(sq. miles)	N	169	31	45	40	53
Drainage Density	M	2.0	2.0	2.7	1.4	1.8
(miles/sq. mile)	N	169	31	45	40	53
Length of Overland Flow	M	6.9	9.0	7.8	5.3	6.3
(miles)	N	169	31	45	40	53
Ditch Gradient in	M	11.2	11.6	12.1	9.2	11.8
ft/mile	N	169	31	45	40	53
Ditchshed Gradient	M	24.6	19.4	23.9	28.2	25.7
ft/mile	N	169	31	45	40	53
Texture Ratio	M	1.4	1.6	1.2	1.9	1.2
(mile)	N	169	31	45	40	53
Circulatory	M	.6	.6	.6	.6	.6
Ratio	N	169	31	45	40	53
Elongation	M	.7	.8	.7	.7	.7
Ratio	N	169	31	45	40	53.
Channel	M	.6	.6	.5	.8	.7
Maint.	N	169	31	45	40	53
# Repairs &	M	.9	.5	1.2	1.0	.8
Improvements	N	205	41	56	46	62

Table XVII. A county by county comparison of primary (1), secondary (2), and tertiary (3) slope tree vegetation for wide and narrow ditch segments expressed as numbers of occurrences (Blue Earth (15): number of open ditches in Blue Earth County with trees on slope of wide ditch segment).

		Blue Earth (15)				Brown (4)				Le Sueur (20)				Nicollet (11)			
VEGETATION		1	2	3	T	1	2	3	T	1	2	3	T	1	2	3	T
Poplar	Slope Tree Wide	6	4	1	11	1	1	0	2	2	1	1	4	4	0	1	5
Willow		6	1	0	7	1	0	0	1	7	2	2	11	4	2	0	6
Oak		0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0
Elm		0	0	0	0	0	0	0	0	6	2	1	9	0	0	1	1
Other		3	1	0	4	2	0	0	2	4	5	3	12	3	3	0	6
Ash		0	0	0	0	0	0	1	1	0	2	0	2	0	1	1	2
Maple		0	1	0	1	0	1	0	1	0	0	0	0	0	0	1	1

		Blue Earth (9)				Brown (2)				Le Sueur (10)				Nicollet (3)			
Poplar	Slope Tree Narrow	3	2	0	5	0	0	0	0	1	1	0	2	1	0	0	1
Willow		2	0	1	3	1	0	0	1	3	1	0	4	1	0	0	1
Maple		1	0	0	1	0	0	0	0	0	0	0	0	0	1	0	1
Elm		0	0	0	0	0	0	0	0	4	1	0	5	0	0	0	0
Other		3	1	0	4	1	0	0	1	2	0	2	4	1	0	0	1
Ash		0	0	0	0	0	0	0	0	0	1	0	1	0	0	1	1
Alder		0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0

Table XVIII. A county by county comparison of primary (1), secondary (2), and tertiary (3) berm tree vegetation for wide and narrow ditch segments expressed as numbers of occurrences (Blue Earth (4): number of open ditches in Blue Earth County with trees on berm or wide ditch segment).

		Blue Earth (4)				Brown (2)				Le Sueur (12)				Nicollet (5)			
VEGETATION		1	2	3	T	1	2	3	T	1	2	3	T	1	2	3	T
Poplar	Berm Tree Wide	2	1	1	4	1	1	0	2	1	1	0	2	2	0	1	3
Willow		1	1	0	2	0	0	0	0	3	0	3	6	3	2	0	5
Elm		0	0	0	0	0	0	0	0	3	4	1	8	0	0	0	0
Other		1	0	0	1	1	0	0	1	5	2	1	8	0	2	0	2
Maple		0	1	0	1	0	1	0	1	0	0	0	0	0	0	1	1
Oak		0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0
Ash		0	0	0	0	0	0	1	1	0	0	1	1	0	0	1	1

		Blue Earth (5)				Brown (0)				Le Sueur (3)				Nicollet (1)			
Poplar	Berm Tree Narrow	2	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0
Willow		1	0	0	1	0	0	0	0	0	0	0	0	1	0	0	1
Elm		0	0	0	0	0	0	0	0	2	0	0	2	0	0	0	0
Other		2	0	0	2	0	0	0	0	0	1	0	1	0	0	0	0
Ash		0	0	0	0	0	0	0	0	0	1	0	1	0	0	1	1
Maple		0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1

Table XIX. A county by county comparison of primary (1), secondary (2), and tertiary (3) slope herbaceous vegetation for wide and narrow ditch segments expressed as numbers of occurrences (Blue Earth (29): number of open ditches in Blue Earth County with herbs on slope of wide ditch segment).

		Blue Earth (29)				Brown (39)				Le Sueur (46)				Nicollet (63)			
VEGETATION		1	2	3	T	1	2	3	T	1	2	3	T	1	2	3	T
Reed Canary	Slope Herb Wide	16	8	0	24	9	20	9	38	40	3	2	45	30	23	7	60
Brome		12	6	0	18	22	5	0	27	1	13	5	19	24	7	1	32
Clover		0	1	2	3	7	4	5	16	2	3	2	7	6	5	3	14
Nettles		1	1	0	2	0	0	0	0	2	6	5	13	1	1	0	2
Other		0	0	3	3	1	2	4	7	18	13	5	37	2	4	3	9
Thapsium		0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Milkweed		0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1
Ragweed		0	1	1	2	0	0	0	0	0	0	0	0	0	1	1	2

		Blue Earth (16)				Brown (24)				Le Sueur (27)				Nicollet (29)			
Reed Canary	Slope Herb Narrow	9	5	0	14	7	14	7	28	20	7	0	27	17	7	4	28
Brome		5	4	1	10	16	2	0	18	4	5	4	13	10	3	1	14
Clover		1	0	0	1	1	2	3	6	0	0	1	1	1	5	2	8
Nettles		0	0	0	0	0	0	0	0	2	7	1	10	0	1	0	1
Other		1	0	1	2	0	0	0	0	1	5	8	14	1	1	1	3
Milkweed		0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1

Table XX. A county by county comparison of primary (1), secondary (2), and tertiary (3) berm herbaceous vegetation for wide and narrow ditch segments expressed as numbers of occurrences (Blue Earth (27): number of open ditches in Blue Earth County with herbs on slope of wide ditch segment).

		Blue Earth (27)				Brown (39)				Le Sueur (28)				Nicollet (63)			
VEGETATION		1	2	3	T	1	2	3	T	1	2	3	T	1	2	3	T
Reed Canary	Berm Herb Wide	9	1	0	10	5	8	1	14	14	3	0	17	16	10	2	28
Brome		16	2	0	18	29	2	0	31	7	2	0	9	44	1	1	46
Clover		0	0	2	2	1	0	1	2	0	1	1	2	0	5	1	6
Nettles		0	0	0	0	1	1	0	2	3	3	1	7	0	2	0	2
Other		2	1	1	4	3	1	0	4	4	5	2	11	3	2	1	6
Thapsium		0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Milkweed		0	0	0	0	0	0	1	1	0	0	0	0	0	1	0	1
Ragweed		0	0	0	0	0	1	0	1	0	1	0	1	0	1	2	3

		Blue Earth (13)				Brown (25)				Le Sueur (11)				Nicollet (29)			
Reed Canary	Berm Herb Narrow	2	1	0	3	5	3	0	8	8	1	0	9	6	7	0	13
Brome		8	1	1	10	19	2	0	21	0	0	0	0	21	1	0	22
Clover		1	0	0	1	1	0	1	2	0	0	0	0	1	2	0	3
Nettles		1	0	0	1	0	0	0	0	1	1	0	2	0	3	0	3
Other		1	0	0	1	0	1	0	1	2	1	0	3	1	2	0	3
Ragweed		0	1	0	1	0	0	0	0	0	0	0	0	0	0	1	1
Milkweed		0	0	1	1	0	0	0	0	0	0	0	0	0	0	1	1

narrow containing any trees it is difficult to say this data is reliable. Nicollet County had a few more wooded ditches. Wide ditch segments were dominated by willow, poplar, and unsepcified types when wooded but in the narrow segments there was no dominance.

Berm tree vegetation, Table XVIII, in Blue Earth County showed poplar again dominated; Le Sueur was dominated by elm, willow and unspecified trees as they were on the ditch slope (Table XII). Brown and Nicollet Counties again had few trees. Brown County's wide ditch berm segments had poplars dominating while the narrow ditch berm segments contained no trees. Willows dominated Nicollet County's wide ditch berm segments and no specific trees dominated the narrow segments.

Slope herbaceous vegetation was very similar in all counties (Table XIX). Reed Canary Grass dominated the four counties for wide and narrow segments, however, in Brown County the primary herb was brome grass even though reed canary was dominant. The ditches in Brown County may have been seeded with brome grass. There is a possible correlation of herbaceous distribution to spraying, mainly with 2,4-D. In Le Sueur County nettles and others, mainly broad leaves, which are dicots are present, this could indicate a lack of spraying. Berm herbaceous vegetation in all counties is different from the slope herbaceous vegetation, except in Le Sueur (Table XX). Both wide and narrow segments of the other three were dominated with brome grass, while Le Sueur had reed canary grass as it did for slope herbaceous vegetation.

Conclusion

Our data reveals a great deal of similarity in the four counties. They appear to be very monotinous in herbaceous vegetation. Some differences are seen in the arborial vegetation of Le Sueur and Blue Earth Counties but in Brown and Nicollet few trees exist in ditches or on the berms, probably due to their management practices which include the broad use of herbicides. Le Sueur County has an abundance of wooded ditches but composition could be presently changing due to the spread of Dutch Elm Disease. The advisability of establishing uniform limited vegetation associated with ditches such as in Brown and Nicollet needs to be further investigated from the standpoint of conservation, wildlife management, water quality (green belt), and overall preservation of plant diversity. The ditches in Blue Earth and Le Sueur Counties appear to be more desirable from a botanical point of view.

WATER QUALITY OF MAN-MADE DRAINAGE DITCHES AND NATURAL STREAMS IN SOUTH CENTRAL MINNESOTA

Introduction

The purpose of this component was to investigate the regional variation in water quality by measuring nutrient load in thirteen man-made drainage ditches and four rivers. This study was also intended to see if previous data on the Cannon River and County Ditch LS-C-59 by Quade, et. al., 1979, could be considered typical for the region studied. The relationship of water quality to stream order and rainfall was investigated in three seasons. The first season, "Spring Runoff", was from March 21, 1979 to May 30, 1979; the second season, "Growing Season", was from June 10, 1979 to October 11, 1979; and the third season, "Fall Harvest and Plowing", was from October 24, 1979 to November 16, 1979.

Seventeen sites were sampled from March 21, 1979 to November 16, 1979. During the spring runoff season samples were collected twice weekly and after the middle of May, once a week. The water was analyzed for the standard eutrophication measurements of total orthosphospate-phosphorous, total Kjeldahl-nitrogen, nitrate-nitrogen, and total dissolved solids. Statistical analysis included T-tests, Pearson's Product-Moment correlation, analysis of variance, and descriptive statistics.

Site Description

Locations

The seventeen sites were selected based on an airplane survey of the region the year before that showed all of the sites had water flowing in them for the entire ice free season. An attempt was also made to include as many varied soil types and geomorphic regions as possible. Each site was identified by their legal ditch name, N-C-40A for example is a county ditch, "C-40A" in Nicollet County.

Stream order of all ditches and rivers was determined according to Strahler, 1957, using USGS seven and one-half minute topographic maps. The initial tributary to a watershed is considered a first order stream (river). Only when two first-order streams combine does the stream become a second order stream. Most ditches are second order because tile lines are considered the initial tributary (Silis, 1979). Only when two second order streams, or ditches come together is the resulting stream a third order stream. In this study, the term river has been used for stream because the legal name of the sampled bodies of water are river. The Cannon River, the Little Cobb River, and Morgan Creek were third order rivers and Shanaska Creek was a second order river.

Second Order Ditches. Site N-C-40A was located in Nicollet County and can be located by going one and one-half miles south of the junction of County State Aid Highway 10 and County State Aid Highway 1 and then east one-fourth mile on the township road (Figure 7). Sampling was done at the round culvert. This is the only site where there was not flow for the entire sampling period. The ditch was bordered by farm land with upstream right and downstream right planted in corn and the land upstream left and downstream left was planted in soybeans.

Site N-C-38A was located in Nicollete County and can be located by going one mile north on State Highway 15 from the US Highway 14 and State Highway 15 junction, then east on a township road for one and one-fourth miles. Sampling was done at a round culvert. This ditch flowed along the road for one-fourth mile upstream of the sampling site and therefore upstream right was not bordered by cropland. Upstream left was planted in soybeans and beyond that corn while the land downstream left and right was planted in corn.

Site Br-J-29 was located in Brown County and can be located by going one mile south on the junction of County State Aid Highway 8 and County State Aid Highway 30 and then going one-fourth mile east on the township road. Sampling was done at the bridge. The ditch was deep with slow moving deep water all year. Corn was planted in the fields upstream left, upstream right and downstream right while downstream left was planted in soybeans.

Site Br-C-5 was located in Brown County and can be located by traveling one and one-fourth miles east of the junction of County State Aid Highway 8 and County State Aid Highway 28. Sampling was done at the round culvert. This ditch overall had minimal flow and was often choked with cattails and marsh-type vegetation. Soybeans were planted in all the fields left and right of the ditch.

Site Br-J-30 was located in Brown County and can be located by traveling one mile west of Sleepy Eye on County State Aid Highway 27, turning north one mile and then west one-fourth mile. Sampling was done at the bridge. Generally flow was fast moving. Upstream right was planted in soybeans, downstream right was planted in corn, upstream right and left were planted in small grains.

Site Br-J-10 was located in Brown County and can be located one-half mile east of County State Aid Highway 13 on County State Aid Highway 20. Sampling was done at the round culvert. This ditch was located in the farmland just above the Minnesota River Valley and the ditch was deep and the flow generally was slow moving. This ditch was sampled before it entered Morgan Creek.

Site BE-C-56 was located in Blue Earth County and can be located by going one-fourth mile east of the junction of County State Aid Highway 76 and County State Aid Highway 9 on the south edge of Lake Crystal. The Lake Crystal Ballpark is downstream left of the sample site. Samples were taken at the bridge. Upstream of the sampling site was low marshland and downstream was a developing residential area. The county garage is upstream right.

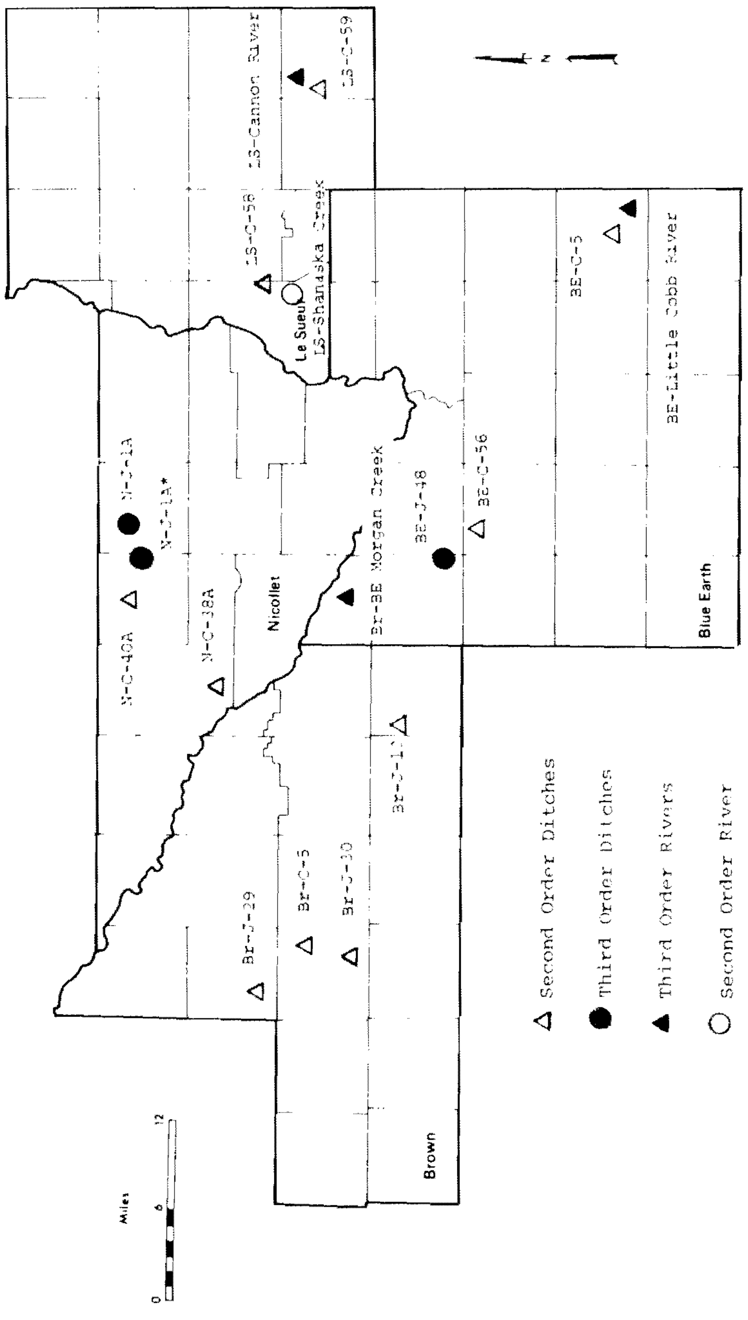


Figure 7. Ditch and river water quality study sampling sites.

Site BE-C-5 was located in Blue Earth County and can be located by traveling one-half mile north of the junction of County State Aid Highway 53 and County State Aid Highway 21, west one mile on a township road, and then one-half mile to the bridge. Samples were taken at the bridge. The ditch was located in a low marshy area bordered by grasses and a few willows upstream left and it entered a wooded area downstream. Upstream left and right were planted in soybeans up from the low area and downstream left was in corn. Downstream right was a farmer's house.

Site LS-C-59 was located in Le Sueur County and can be located by traveling three and one-half miles west of State Highway 13 on County State Aid Highway 12, north of Waterville, and then one-fourth mile north on the township road. Sampling was done at the bridge. Several years of water chemistry analysis has been run on this ditch as it enters the Cannon River downstream of this sampling site and has been documented by Quade, Hill, Larsen, Colakovic, et. al., 1979. Upstream left and right were planted in soybeans with small grain behind that. Downstream left was planted in corn and downstream right in small grain.

Site LS-C-58 was located in Le Sueur County and can be located by traveling south from the junction of State Highway 99 and County Road 106 on County Road 106 and then continuing south on a township road then east one mile to where the road bends south. Sampling was done at a round culvert. This ditch drains from a lake through farmland and then enters a wooded area just upstream of the sampling point. Upstream the farmland was planted in soybeans and through the wooded area the ditch appeared to be a natural stream. Downstream was farmland again with soybeans and some corn downstream right.

Third Order Ditches. Site BE-J-48 was located in Blue Earth County and can be located one-fourth miles north of County State Aid Highway 6 on County Road 111. The sampling was done at a square culvert. This ditch drains into Minneopa Creek downstream. The flow was fast for the entire season as was typical for the third order ditches. Soybeans were planted upstream left with corn planted in the other three quadrants.

Site N-J-1A was located in Nicollet County and can be located on State Highway 22, at the bridge, one mile north of New Sweden. Sampling was done at the bridge. The ditch was fast flowing and had high flow all year. Downstream right was planted with corn while soybeans were planted in the other three quadrants.

Site N-J-1A* (two miles upstream of site N-J-1A) was located in Nicollet County and was the same ditch as N-J-1A sampled above a major ditch tributary. The site can be located by traveling one-eight mile south of the junction on County State Aid Highway 4 and County Road 61 on County State Aid Highway 4. Sampling was done at the bridge. Flow was high throughout the whole year as for all third order ditches. A feedlot was located upstream right with a 25-foot green belt inbetween. Upstream left was planted in soybeans, dowsntream left in corn with a narrow small grain belt between the corn and the ditch, and downstream right was planted in small grain.

Third Order Rivers. Site Br-BE Morgan Creek was sampled in Blue Earth County. The sample site can be located traveling one-half mile east from the junction of County State Aid Highway 20 and the County State Aid Highway 13 on County State Aid Highway 20. The sampling was done at the bridge. Morgan Creek was sampled in the Minnesota River Valley and the Creek itself had a typical riffle-pool formation. Upstream left and right was a wooded area with downstream left and right wooded and pastureland for cows.

Site BE-Little Cobb River was sampled in Blue Earth County. The site can be located one-fourth mile north of the junction of County State Aid Highway 53 and County State Aid Highway 21. Sampling was done at the highway bridge. The river was a winding river lacking the riffle-pool configuration as seen at Morgan Creek. Soybeans were planted upstream left and right and also downstream left. Downstream was a low area with trees and grasses with corn planted downstream right.

Site LS-Cannon River was sampled in Le Sueur County. The site can be located by traveling two and three-fourth miles northwest of the junction of County State Aid Highway 12 and County State Aid Highway 5 on County State Aid Highway 5. Sampling was done at the suspension bridge. The river was wide and shallow and was sampled in a wooded area with some marshy type habitat. Farmland planted in corn and small grain was some distance from the river. Water quality of this river has been documented for several years by Quade, Hill, Larsen, Colakovic, et. al, 1979.

Second Order River. Site LS-Shanaska Creek was sampled in Le Sueur County and was the only second order river sampled. It can be located by traveling one and one-fourth miles northwest of County Road 147 on County State Aid Highway 19. Sampling was done at the bridge. Shanaska Creek is the outlet from Lake Washington and was sampled less than one-half mile from the lake. The site is surrounded in all four directions by a deciduous woods.

Rainfall

The best representation of actual rainfall at each site has been compiled from information from the State Climatological office for the sampling sites at Springfield, New Ulm, and North Mankato, Minnesota. Weather patterns in South Central Minnesota ususally move from the southwest to the northeast across the sampling area.

Local rainfall varied so sites between two rainfall stations were probably somewhere in between the values recorded (Table XXI).

The four second orderditches in Brown County, Br-J-29, Br-C-5, Br-J-30, and Br-J-10 were considered to be best represented by the Springfield station (Figure 7).

The sites in Nicollet County, N-C-38A, N-C-40A, N-J-1A, and N-J-1A* were considered to be represented best by the New Ulm station.

Table XXI. Comparison of average monthly rainfall and 1979 monthly rainfall (precipitation in inches).

	Springfield (1938-1978) Avg.	Springfield (1979)	New Ulm (1931-1978) Avg.	New Ulm (1979)	North Mankato (1955-1978) Avg.	North Mankato (1979)
January	.57	(.98)	.92	(1.26)	.74	(1.58)
February	.84	(.71)	1.04	(1.25)	.86	(1.05)
March	1.42	(4.29)	1.94	(3.52)	1.63	(3.38)
April	2.29	(1.73)	2.45	(1.11)	2.53	(1.80)
May	3.52	(3.94)	3.71	(3.30)	3.60	(2.36)
June	3.79	(4.92)	4.50	(3.91)	3.98	(4.35)
July	3.38	(2.85)	3.40	(8.19)	4.01	(3.16)
August	3.27	(5.79)	3.55	(10.38)	3.59	(6.80)
September	2.67	(1.70)	2.89	(3.16)	2.93	(1.88)
October	1.79	(4.96)	2.07	(3.08)	2.00	(2.52)
November	1.23	(1.45)	1.52	(2.32)	1.22	(2.77)
Total Average Jan. - Nov.	24.80	(33.32)	27.76	(41.48)	27.21	(31.71)

The sites in Blue Earth County and Le Sueur County were considered to be best represented by the North Mankato rainfall station.

At all sites rainfall was greater than the average for the total season (Table XXI). Rainfall was above average at all three stations, Springfield, New Ulm, and North Mankato, during March, August, October, and November. Rainfall during August was most atypical with 5.79 inches at Springfield, 10.38 inches at New Ulm, and 6.86 inches at North Mankato when the average is usually about 3.50 inches. During July the rainfall at New Ulm was 8.19 inches compared to the average value of 3.40 inches.

Earl Kuehnast (personal communication) of the State Climatological Office stated that all precipitation during the study sampling period probably entered the drainage ditches and rivers as overland flow since the soils in the study area were saturated for the entire study period.

Rainfall was similar at all three weather stations in the three seasons, "Spring Runoff", "Growing Season", and "Fall Harvest and Plowing" except for New Ulm during the "Growing Season" where about ten more inches of rainfall fell than in the other two station areas (Table XXII).

Table XXII. Total rainfall by season (precipitation in inches).

	SPRINGFIELD	NEW ULM	MANKATO
Spring Run Off			
Snow	5.98 inches	6.03 inches	6.01 inches
Rain	5.67 inches	4.41 inches	4.16 inches
Growing Season			
Rain	15.85 inches	26.23 inches	16.77 inches
Fall Harvest & Plowing			
Rain	4.80 inches	3.58 inches	3.75 inches

Soil Types

There was not a great deal of variation in soil type for the seventeen sampling sites and the drainage basins they drained. The soil was classified (MLMIS) as a soil landscape unit which is a group of soils generalized into a single identifiable unit based on soil texture below five feet, above five feet, soil drainage, and surface soil color. The most obvious variation depended on the soil drainage component.

The third order ditches N-J-1A and N-J-1A* of Nicollet County; all the second order ditches in Brown County, Br-J-29, Br-C-5, Br-J-30, and Br-J-10; three sites in Blue Earth County, Morgan Creek, a third order river, ditch BE-J-48, a third order ditch, and BE-C-56, a second order ditch; and all sites in Le Sueur County, second order ditches LS-C-59 and LS-C-58, the Cannon River (a third order river) and the second order river (Shanaska Creek) all had the loamy or silty, loamy or silty, below roots, dark classification of soil type (Dunsmore, Oelerich, Quade, 1979 and Dunsmore, Quade, 1979a,b,c).

The second order ditches in Nicollet County, C-40A and C-38A, were sampled in an area where soil type was loamy or silty, loamy or silty, within roots, dark (Dunsmore, Quade, 1979c).

Second order ditch BE-C-5 and the Little Cobb River in Blue Earth County had alluvial soil in the area where they were sampled surrounded by the clayey, loamy or silty, within roots, dark soil type (Dunsmore, Quade, 1979a).

There also were areas of peat in the drainage area of ditch LS-C-59 and the Cannon River sampling sites (Dunsmore, Quade, 1979b).

Geomorphic Regions

The seventeen sampling sites occurred in several geomorphic regions in the four counties which were part of this study.

All sites in Nicollet County, second order ditches C-40A and C-38A, third order ditches N-J-1A and N-J-1A*, and in Le Sueur County the second order river (Shanaska Creek) were of the Waconia-Waseca moraine, loamy, and rolling geomorphic type (Dunsmore, Quade, 1979b,c).

All sites in Brown County, second order ditches Br-J-29, Br-C-5, Br-J-30, Br-J-10; and three sites in Blue Earth County, second order ditch BE-C-56, third order ditch BE-J-48, and third order river Morgan Creek were of the Blue Earth Till Plain, undulating, loamy geomorphic type (Dunsmore, Oelerich, Quade, 1979).

Sites BE-C-5, a second order ditch, and the Little Cobb River, a third order river, in Blue Earth County were of the Minnesota Lake Plain, clayey geomorphic type (Dunsmore, Quade, 1979a).

In Le Sueur County, second order ditches LS-C-59, LS-C-58, and third order river the Cannon River were located in the Emmons-Faribault moraine, irregular, rolling geomorphic type (Dunsmore, Quade, 1979b).

Each geomorphic type represented a large area of the county.

Methods

Field Methods

Thirteen man-made agricultural drainage ditches and four rivers were sampled from March 21, 1979 to November 16, 1979 for water quality. The ditches and rivers are located in South Central Minnesota in four counties of Nicollet, Le Sueur, Brown, and Blue Earth. Water samples were collected twice a week from March 21 to May 2 and once a week for the rest of the sample period.

Water samples. Water samples were collected in a cross-sectional pattern with an integrating sampler and stored in acid-washed one liter glass bottles. The bottles were stored at 4°C after two ml of concentrated H_2SO_4 per liter were added.

Conductivity. Conductivity, the ability of a sample to conduct an electric current, is a means of estimating the total dissolved solids. Conductivity was measured with a Beckman model RA2A portable battery operated meter in the field.

Water temperature. Water temperature was measured at mid-river (mid-ditch) at a one foot depth with a centrigrade thermometer.

Water depth. Water depth was measured at each site for all sampling dates unless the water was frozen over. During high flow depth was measured by having a set point on a bridge or culvert which was the zero-point and the water level was measured relative to this. The exact value was extrapolated from this value later on in the season.

Cross sectional area. The cross sectional area of each drainage ditch and river was determined by plane table mapping with a rod and transit during low flow.

Velocity. Velocity was measured by either the Embody method or by use of a Kahl Scientific Instrument Corporation pygmy meter at mid-stream at a depth of 0.6 up from the maximum depth.

Sediment field methods. Bed sediment samples were collected at each site in the spring, May 27-31, and fall, November 15-17, with a US EMH-53 piston-type bed sampler. Samples were taken at three equadistant positions traversing the ditch-river channels and composited into a single whirlpack. The top four centimeters from each core were preserved and frozen until analyzed.

Laboratory Methods

Water analysis. Laboratory analysis included three chemical parameters, total orthophosphate-phosphorous, total Kjeldahl-nitrogen, and nitrate-nitrogen. Confidence in laboratory methods was established by good reproducibility in duplicate samples.

Total orthophosphate-phosphorous: Standard methods for the analysis of total orthophosphate-phosphorous using the stannus chloride method were used. (APHA, 1975).

Total Kjeldahl-nitrogen: Standard methods for the analysis of total Kjeldahl-nitrogen were used with a 250ml or 500ml sample depending on the concentration to assure reproducibility. (APHA, 1975).

Nitrate-nitrogen: Standard methods for the analysis of nitrate-nitrogen were used using the brucine-sulfanilic acid method because of its sensitivity. (APHA, 1975).

Sediment analysis. Frozen samples were thawed and homogenized by mixing before drying at 105°C for 24 hours.

Proximate chemistry: Proximate chemistry analyses, loss on ignition, for the organic, $CaCO_3$ equivalent, and ash portions on the sediments followed the procedure of Frey (1960). Sediment was dried in a tared crucible at 105°C for 24 hours to establish dry weight. The dried samples were ground in a crucible and passed through a 100 mesh screen. The dried sample was weighed and then ashed in a muffle furnace at 525°C for one hour, the loss of weight was taken as the organic equivalent. The sample was ashed at 925°C for three hours and the resulting loss of weight was taken as the loss of CO_2 from the carbonates, chiefly $CaCO_3$. This is a reasonable assumption when the $CaCO_3$ content of the sediment is high and the clay content is low (Quade, et. al., 1979). The loss in weight multiplied by 2.273 yields the weight of $CaCO_3$ which when subtracted from the weight after the ashing at 525°C gives the weight of the non-calcareous ash, mainly siliceous material. The three components are expressed as percentage of dry weight.

Total orthophosphate-phosphorous sediment: Anderson's (1976) ignition method was used to determine total orthophosphate-phosphorous.

Sediment was thawed and dried at 105°C for 24 hours and passed through a 100 mesh screen after grinding in an agate mortar. About 0.2 grams of the sediment was ignited in a muffle furnace at 550°C for one hour in a porcelain crucible. After cooling, the residue was washed into a 100 ml erlenmeyer flask with 25 ml of 1N HCL. The solution was diluted to one liter in a 1000 ml volumetric flask and when the particles had settled out, 50 ml was pipetted out into a 100 ml volumetric flask. The solution was brought back to neutrality, by addition of the necessary amount of 2M NaOH. Standard methods for total orthophosphate-phosphorous using the stannus chloride method were then used. (APHA, 1975). This is a spectrophotometric method which compares the unknown sample with a Beer's law plot of known standard KH_2PO_4 solutions.

Total Kjeldahl-nitrogen: Standard methods for total Kejldahl-nitrogen were used and results were expressed as mg/g of sediment. (APHA, 1975). The sediment was dried at 105°C for 24 hours, ground in a crucible, and passed through a 100 mesh screen before analysis.

Data Treatment and Statistics

Calculations in the laboratory for instantaneous flow using the field measures of water depth, velocity, and cross-sectional area were completed. Chemical loading for each site was calculated using the chemical concentrations from the analytical chemical analyses and the flow values.

Data were analyzed using a statistical package program, SPSS, and the Fortran language on the UNIVAC 1170/80A computer system at Mankato State University.

The data base included approximately 3,700 data points involving six parameters at thirty-seven dates for seventeen sites.

Flow. Water depth data was converted to cross-sectional area of the ditch or river using maps of the ditch and river channels generated by plane table mapping during low flow. Where square culverts existed, mapping was not necessary. Velocity of the water was multiplied by the cross-sectional area to obtain an instantaneous value for volume of water as flow. Since each sampling period was not on a rigid time frame, the time between each sampling date had to be calculated individually and used individually to approximate the best representation of period flow. This was done by taking one-half the time to the date previous, plus one-half of the time to the next sampling date and using this as a time period. The time period was then expressed as so many seconds (or minutes) in the period.

The instantaneous flow, in m^3 per second, multiplied by the number of seconds in the time period gave us the period flow in m^3/second. The value as m^3/minute was easily converted from this value.

Total flow for the entire collection season was obtained by the addition of all of the period flows.

Load. Period load was obtained by multiplying the period flow by the individual concentration in mg/l of total orthophosphate-phosphorous, total Kjeldahl-nitrogen, nitrate-nitrogen, and total dissolved solids with proper adjustments for the units used.

Total load was calculated as the sum of all individual period loads.

Total dissolved solids. An estimation of total dissolved solids was calculated from the conductivity field readings and water temperature readings. An equation was generated to describe the relationship of conductivity and temperature, taken from table values, by running regression analysis using the SPSS language. The equation generated was:

$$\text{T.D.S. in ppm} = 150.5892 + (\text{specific conductance}) \times (.8997397) + (\text{specific conductance})^2 \times (.00002898) + (\text{temperature } ^\circ\text{C}) \times (-14.0.970) + (\text{temperature } ^\circ\text{C})^2 \times (.2473544).$$

Descriptive statistics: General statistics as measures of central tendency and variation were generated on the UNIVAC 1170/80A computer using the SPSS language. All statistics were run on instantaneous values. Values for minimum, maximum, mean, and median were obtained for total orthophosphate-phosphorous, total Kjeldahl-nitrogen, nitrate-nitrogen, total dissolved solids, temperature, and flow.

Seasonal breakdown. The collecting period was broken down into three seasons with the duration of each season selected to represent the status of vegetation in the fields along the drainage ditches and rivers. The first season, "Spring Runoff", included the first fifteen sampling sites up to and including June 2, 1979. The second season, "Growing Season", included the next eighteen sampling dates from June 10, 1979 to October 10, 1979. The second season began when the crops began to come up and ended when harvesting began. The third season, "Fall Harvest and Plowing", was the final four sample dates through November 16, 1979 when some of the ditches were frozen over.

All parameters as total load were broken down by season and expressed as percentage of the total.

T-test. The "student's T-Test" can be used to compare the data from two sample sets to determine a significant difference between the means of the two sample sets. T-tests were run on the means of all instantaneous data.

This test was run on three different matched ditch and river pairs located in close proximity of each other for total orthophosphate-phosphorous, total Kjeldahl-nitrogen, nitrate-nitrogen, and total dissolved solids broken down by season. The ditch and river pairs were originally chosen to compare water quality in a ditch-river set which were closely located with similar land use and geomorphic-soil characteristics.

The three ditch-river pairs were first, ditch BE-C-5 and the Little Cobb River, and secondly, ditch LS-C-59 and the Cannon River, and thirdly, ditch LS-C-58 and Shanaska Creek.

Pearson's Product-Moment correlation coefficient. Each site was analyzed internally to see if the different parameters seemed to be correlated. If total orthophosphate-phosphorous increased, was there a corresponding increase in nitrate-nitrogen, or did it have a negative correlation where one parameter increased and the other decreased, or was there no correlated change at all. This was done for all possible combinations of the three chemical parameters, flow, total dissolved solids, and water temperature.

Analysis of variance. This test was run on the three matched ditch-river pairs mentioned above. The data was broken down by the seasons defined earlier.

The dependent variable was the difference of the mean of any parameter from the ditch-river pair, such as phosphate ditch mean minus phosphate river mean. This was analyzed to determine if there was a significant difference between the three pairs at a 95 percent confidence interval and also if there was a difference between the three seasons at the same confidence level.

Results

Water Chemistry

Total orthophosphate-phosphorous. The concentration data for total orthophosphate-phosphorous for all sites revealed a high level of variability between sites (Table XXIII). The maximum concentrations occurred in the early part of the "Spring Runoff" season, March 21 to April 8, and values close to the maximum were also recorded in the month of August (Boyum, 1980). Minimum values occurred generally in late "Spring Runoff".

Table XXIII. Total orthophosphate-phosphorous concentration and load summary by site.

	Site	Max. Conc. Mg/1	Min. Conc. Mg/1	Mean Mg/1	Load Kg
Second Order Ditches	N-C-40A	0.355	0.000	0.095	No Flow
	N-C-38A	0.264	0.010	0.135	1599.0
	Br-J-29	0.591	0.003	0.150	1200.3
	Br-C-5	0.263	0.007	0.092	51.5
	Br-J-30	0.587	0.011	0.193	8711.4
	Br-J-10	0.674	0.001	0.143	1009.3
	BE-C-56	0.427	0.028	0.144	2154.8
	BE-C-5	0.580	0.013	0.181	1275.4
	LS-C-59	0.319	0.010	0.105	795.4
	LS-C-58	0.636	0.025	0.191	326.0
Third Order Ditches	BE-J-48	0.385	0.000	0.099	2980.3
	N-J-1A	0.389	0.004	0.149	10973.2
	N-J-1A*	0.439	0.006	0.154	5533.5
Third Order Rivers	Br-BE Morgan Creek	0.371	0.000	0.120	8299.9
	BE-Little Cobb River	0.366	0.012	0.154	5985.9
	LS-Cannon River	0.611	0.003	0.238	12394.6
Second Order River	LS-Shanaska Creek	0.380	0.000	0.064	219.3

Second order ditches showed the most variability with ditch Br-J-10 having the greatest maximum and ditch Br-C-5 having the smallest maximum value (Table XXIII). Even with the large range of variability, mean values showed considerable uniformity.

Third order ditches showed the greatest uniformity with similar maximum values and similar mean values.

Third order rivers compare closely to the third order ditches in maximum and mean values except for the Cannon River (Table XXIII). The maximum value for total orthophosphate-phosphorous for the Cannon River is close the maximum values for second order ditches. The mean value for the Cannon River is the largest for all sites tested.

The second order river, Shanaska Creek, showed a maximum nearly the same as the third order rivers other than the Cannon River, with a mean value for total orthophosphate the smallest for all sites tested.

The individual loading determinations for total orthosphospate-phosphorous revealed the total load for third order ditches was found to be higher than all second order ditches except for Br-J-30 and higher than the second order river (Table XXIII). Ditch N-J-1A had a larger load than the other third order ditches and only had a smaller load than the Cannon River, a third order river.

Total Kjeldahl-nitrogen. The concentration data for total Kjeldahl-nitrogen revealed less variability than seen in total orthophosphate-phosphorous (Table XXIV). Maximum values were generally found during early "Spring Runoff" with some maxima in August (Boyum, 1980). Minimum values occurred in two periods, late spring and late fall.

Second order ditches had similar maximum values with the exception of ditches LS-C-59 and LS-C-58 which had the maximum values for all sites. Mean values in second order ditches showed more variability with the maximum mean values in ditches LS-C-59 and LS-C-58 and the minimum mean value in ditch N-C-40A (Table XXIV).

Third order ditches showed similar mean values but revealed large variability for maximum values of total Kjeldahl-nitrogen.

Third order rivers varied with the Cannon River being distinct from the other two rivers. The Cannon River had a mean which was larger than the maximum values of the other rivers.

The second order river had a maximum value similar to most of the second order ditches and a mean value higher than the third order rivers, other than the Cannon River.

The individual loading determinations for total Kjeldahl-nitrogen revealed the total load for third order ditches was found to be higher than all second order ditches except Br-J-30 and higher than the second order river (Table XXIV). Ditch N-J-1A had a larger load than the other third order rivers and only a smaller load than the Cannon River.

Table XXIV. Total Kjeldahl-Nitrogen concentration and load summary by site.

	Site	Max. Conc. Mg/1	Min. Conc. Mg/1	Mean Mg/1	Load Kg
Second Order Ditches	N-C-40A	2.841	0.273	0.939	No Flow
	N-C-38A	3.718	0.494	1.693	19250.6
	Br-J-29	3.102	0.273	1.705	11743.4
	Br-C-5	2.814	0.259	1.110	634.9
	Br-J-30	3.193	0.416	1.521	46608.8
	Br-J-10	3.586	0.334	1.573	9437.3
	BE-C-56	2.928	0.160	1.184	18666.5
	BE-C-5	3.212	1.125	2.291	17730.9
	LS-C-59	5.090	0.754	2.536	14626.1
	LS-C-58	5.012	0.321	2.065	4448.4
Third Order Ditches	BE-J-48	1.730	0.124	0.909	29922.3
	N-J-1A	2.905	0.124	1.232	100510.0
	N-J-1A*	3.718	0.259	1.313	37361.1
Third Order Rivers	Br-BE Morgan Creek	2.323	0.134	0.965	63328.5
	BE-Little Cobb River	1.963	0.273	0.841	30630.5
	LS-Cannon River	4.694	1.680	2.451	132032.0
Second Order River	LS-Shanaska Creek	2.940	0.353	2.090	9961.4

Nitrate-nitrogen. The concentration data for nitrate-nitrogen indicated variability in the sites tested with one ditch N-C-40A having a much larger maximum than all other sites (Table XXV). The mean value for N-C-40A was close to the highest maximum values seen in the other sites. This ditch had no flow for the entire collection period. Nitrate-nitrogen concentration showed no seasonal grouping of maximum and minimum values (Boyum, 1980).

Second order ditches varied for maximum values and mean values (Table XXV). Ditch N-C-40A was the most atypical second order ditch.

Third order ditches showed the greatest uniformity with mean values nearly identical.

Third order rivers had similar maximum and mean values as third order ditches except for the Cannon River which was very low in nitrate-nitrogen concentration.

Shanaska Creek had the lowest mean value for nitrate-nitrogen.

The individual loading determinations for nitrate-nitrogen indicated the third order ditches had a larger total load than all second order ditches, the second order river, and both the Cannon River and the Little Cobb River. Ditch N-J-1A had the largest total load for all sites with Morgan Creek ranking second.

Total Dissolved Solids. The concentration data for total dissolved solids revealed variability in the sites tested (Table XXVI). The maximum concentrations were grouped in two seasons, late spring and late August (Boyum, 1980). Minimum values occurred almost exclusively in the first two weeks of "Spring Runoff".

Second order ditches varied for maximum and mean values with ditch N-C-40A, which had no flow, having the highest maximum and highest mean values. All four ditches from Brown County Br-J-29, Br-C-5, Br-J-30, and Br-J-10, had similar means and maximum values.

The third order ditches varied with BE-J-48 having the smallest maximum and mean value for third order ditches.

Third order rivers showed variability with the Cannon River having the lowest maximum and mean values, while Morgan Creek had the highest maximum and mean.

The second order river, Shanaska Creek, compared to the Cannon River for maximum total dissolved solids with the lowest mean values for all sites.

The individual loading determinations for total dissolved solids revealed the total load for third order ditches was found to be higher than all second order ditches and the second order river (Table XXVI). Morgan Creek, a third order river, had the maximum value.

Table XXV. Nitrate-nitrogen concentration and load summary by site.

	Site	Max. Conc. Mg/l	Min. Conc. Mg/l	Mean Mg/l	Load Kg
Second Order Ditches	N-C-40A	121.00	4.25	46.00	No Flow
	N-C-38A	45.50	9.90	20.51	193882.2
	Br-J-29	33.50	4.83	15.12	116137.1
	Br-C-5	44.00	3.33	21.12	12190.7
	Br-J-30	42.50	3.50	15.58	302405.5
	Br-J-10	53.50	3.80	22.72	185116.1
	Be-C-56	31.30	2.70	16.44	158199.1
	BE-C-5	27.50	0.20	8.56	76149.5
	LS-C-59	52.50	0.22	9.20	80262.4
	LS-C-58	52.00	3.80	24.99	50935.3
Third Order Ditches	BE-J-48	38.30	9.30	22.69	588588.9
	N-J-1A	47.75	8.80	21.76	1176561.5
	N-J-1A*	42.70	5.00	20.76	658465.7
Third Order Rivers	Br-BE Morgan Creek	41.75	7.90	20.90	1033460.4
	BE-Little Cobb River	33.00	4.60	17.72	576006.7
	LS-Cannon River	16.00	0.20	3.64	254467.2
Second Order River	LS-Shanaska Creek	26.00	0.00	2.67	6753.3

Table XXVI. Total dissolved solids concentration and load summary by site.

	Site	Max. Conc. Mg/l	Min. Conc. Mg/l	Mean Mg/l	Load Kg
Second Order Ditches	N-C-40A	1503.4	365.8	992.4	No Flow
	N-C-38A	1083.2	365.8	828.3	6614791.7
	Br-J-29	1073.2	304.4	760.7	3973388.3
	Br-C-5	994.9	311.1	755.0	481305.0
	Br-J-30	1152.4	252.0	770.0	9988864.5
	Br-J-10	928.9	179.7	765.7	5822894.3
	BE-C-56	811.6	338.6	619.2	5947185.2
	BE-C-5	978.1	434.5	725.6	4478515.6
	LS-C-59	723.9	396.1	580.2	2629249.8
	LS-C-58	1051.8	432.8	830.5	1093212.5
Third Order Ditches	BE-J-48	931.0	288.3	671.2	16935025.5
	N-J-1A	998.3	352.1	816.5	35325877.5
	N-J-1A*	1076.6	361.2	872.9	21576960.0
Third Order Rivers	Br-BE Morgan Creek	909.7	381.9	743.4	38010640.0
	BE-Little Cobb River	827.1	293.0	653.1	16288744.1
	LS-Cannon River	629.1	290.2	435.6	20767024.7
Second Order River	LS-Shanaska Creek	621.8	268.0	377.3	1535491.0

Flow. The instantaneous flow data revealed variability in the sites tested (Table XXVII). During 1979 flow was generally highest in early "Spring Runoff" and also had a period of high flow in Qugust and September (Boyum, 1980). The minimum flow occurred generally in late June.

Second order ditches revealed uniformity in flow for maximum and mean values except for ditch N-C-40A which had no flow and ditch Br-J-30 which had very high flow values.

The third order ditches had much higher flow values than the second order ditches with BE-J-48 having the lowest values for the third order ditches. The maximum values showed a much greater range than the mean values.

The third order rivers had similar mean and median values with large variation in maximum values.

Shanaska Creek had low flow as maximum and mean indicate.

The individual cumulative load for each site indicated the third order ditches had a larger total flow than the second order ditches and the second order river (Table XXVII). Ditch N-J-1A had the largest total flow for all sites including all the rivers.

Total Cumulative Load. Third order ditches had larger total cumulative loads than second order ditches or the second order river for total orthophosphate-phosphorous, total Kjeldahl-nitrogen, nitrate-nitrogen, total dissolved solids, and total flow (Table XXVIII). The third order ditches and third order rivers had comparable ranges.

The second order ditch Br-J-30 had the maximum load values for all parameters while ditch Br-C-5 had the minimum load values for all parameters in the second order ditch groupings.

In the third order ditches, ditch N-J-1A had the maximum values for all parameters and ditch BE-J-48 had the minimum for all parameters.

The data for the third order rivers revealed maximum values for flow, total orthophosphate-phosphorous, and total Kjeldahl-nitrogen were found for the Cannon River. Morgan Creek had the largest total load for total dissolved solids and nitrate-nitrogen in third order rivers.

Shanaska Creek had low flow and low chemical loading.

Load to flow relationship. When the ratio of maximum to minimum value was calculated, by dividing the total load of the ditch (river) with the maximum value by the total load of the ditch (river) with the minimum value in each category, the data revealed that the range of values were not proportionally related (Table XXIX).

Second order ditches showed larger variability than third order ditches or third order rivers. When all parameters were compared to the maximum to minimum ratio of flow at 41.7 for second order ditches, nitrate-nitrogen at 24.8 and total dissolved solids at 21.6 were about one-half

Table XXVII. Flow rate and load summary by site.

	Site	Flow m^3/min.	Min. Flow m^3/min.	Mean Flow m^3/min.	Load 100,000 m^3
Second Order Ditches	N-C-40A	No Flow	No Flow	No Flow	0.0
	N-C-38A	124.0	1.7	30.3	93.9
	Br-J-29	79.1	0.0	21.7	75.7
	Br-C-5	6.4	0.0	1.7	5.8
	Br-J-30	714.2	3.36	100.9	242.0
	Br-J-10	104.3	0.0	19.2	70.0
	BE-C-56	183.8	4.9	33.6	107.0
	BE-C-5	96.8	0.0	29.9	78.3
	LS-C-59	94.9	0.0	24.2	58.9
	LS-C-58	42.2	0.5	6.3	17.7
Third Order Ditches	BE-J-48	312.3	14.1	78.4	260.8
	N-J-1A	1581.9	12.3	188.8	535.3
	N-J-1A*	966.0	10.9	95.0	280.8
Third Order Rivers	Br-BE Morgan Creek	778.5	30.9	141.2	482.5
	BE-Little Cobb River	352.8	9.2	101.1	303.4
	LS-Cannon River	597.2	6.7	177.0	528.7
Second Order River	LS-Shanaska Creek	36.3	1.2	13.4	45.2

Table XXVIII. Total cumulative load of water quality parameters by site in kg.

	Site	Total PO_4	TKN	NO_3	Total Dissolved Solid	Total Flow**
Second Order Ditches	N-C-40A	No Flow	No Flow	No Flow	No Flow	0.0
	N-C-38A	1599.0	19250.6	193882.2	6614791.7	93.9
	Br-J-29	1200.3	11743.4	116137.1	3973388.3	75.7
	Br-C-5	51.5	634.9	12190.7	481305.0	5.8
	Br-J-30	8711.4	46608.8	302405.5	9988864.5	242.0
	Br-J-10	1009.3	9437.3	185116.1	5822894.3	70.0
	BE-C-56	2154.8	18666.5	158199.1	5947185.2	107.0
	BE-C-5	1275.4	17730.9	76149.5	4478515.6	78.3
Third Order Ditches	LS-C-59	795.4	14626.1	80262.4	2629249.8	58.9
	LS-C-58	326.0	4448.4	50935.3	1093212.5	17.7
	BE-J-48	2980.3	29922.3	588588.9	16935025.5	260.8
	N-J-1A	10973.2	100510.0	1176561.5	35325877.5	535.3
	N-J-1A*	5533.5	37361.1	658465.7	21576960.0	280.8
Third Order Rivers	Br-BE Morgan Creek	8299.9	63328.5	1033460.4	38010640.0	482.5
	BE-Little Cobb River	5985.9	306330.5	576006.7	16288744.1	303.4
	LS-Cannon River	12394.6	132032.0	254467.2	20767024.7	528.7
Second Order River	LS-Shanaska Creek	219.3	9961.4	6753.3	1535491.0	45.2

**in 100,000 m^3

Table XXIX. Calculated maximum to minimum ratios of water quality parameter total loads by second order ditches, third order ditches, and third order rivers.

	Minimum	Maximum
Second Order Ditches		
Flow	1.0	41.7
Load:		
Total orthophosphate-phosphorous	1.0	169.2
Total Kjeldahl-nitrogen	1.0	73.4
Nitrate-nitrogen	1.0	24.8
Total dissolved solids	1.0	21.6
Third Order Ditches		
Flow	1.0	2.1
Load:		
Total orthophosphate-phosphorous	1.0	3.7
Total Kjeldahl-nitrogen	1.0	3.4
Nitrate-nitrogen	1.0	1.9
Total dissolved solids	1.0	2.1
Third Order Rivers		
Flow	1.0	1.7
Load:		
Total orthophosphate-phosphorous	1.0	2.1
Total Kjeldahl-nitrogen	1.0	4.3
Nitrate-nitrogen	1.0	4.1
Total dissolved solids	1.0	2.3

of that flow, total Kjeldahl-nitrogen at 73.4 was about one and three-fourths times that of flow, while total orthophosphate-phosphorous at 169.2 was about four times that of flow.

Third order ditches had a maximum to minimum ratio for flow of 2.1 while nitrate-nitrogen and total dissolved solids nearly equaled this value at 1.9 and 2.1 respectively, total Kjeldahl-nitrogen at 3.4 and orthophosphate-phosphorous at 3.7 were both less than twice the value of flow.

Third order rivers showed a different relationship with the maximum to minimum ratio of flow at 1.7, with total orthophosphate-phosphorous at 2.1 and total dissolved solids at 2.3 slightly higher than flow, nitrate-nitrogen at 4.1 and total Kjeldahl-nitrogen at 4.3 were about two and one-half times larger than flow.

Table XXIX reveals minimal difference between third order ditches and third order rivers.

Chemical loading in rivers was less related to flow than chemical loading in ditches when all ditches were compared to all rivers (Table XXX).

The maximum to minimum ratio of flow for ditches at 92.3 is larger than the total dissolved solids value at 76.4, nitrate-nitrogen at 96.5 is about the same as flow, total Kjeldahl-nitrogen at 158.3 is about one and three-fourth larger than flow, and total orthophosphate-phosphorous at 213.0 is two and one-fourths times larger than flow.

The maximum to minimum ratio of flow for rivers at 11.7 is slightly less than the value for total Kjeldahl-nitrogen at 13.3, total dissolved solids at 24.8 is twice that of flow, total orthophosphate-phosphorous at 56.5 is five times that of flow, and nitrate-nitrogen at 153.0 is thirteen times that of flow.

The actual maximum to minimum ratio within each ditch or river itself varied for different parameters when the maximum value was divided by the minimum value within each ditch or river. The range of values was not of the same proportion for all parameters when instantaneous concentration values were used in the calculations (Table XXXI).

Seasonal breakdown of loading. Generally when flow was greatest in one of the seasons the chemical load was also greatest in the same season (Table (XXXII). Ditch Br-J-30 of Brown County had the major loading of all parameters in the first season while ditch Br-J-10 of Brown County had the major loading in the second season.

The third order ditches and all the rivers had the major percentage of flow in the second season except for the Cannon River which had 49.8 percent in the first season. Five of the second order ditches had the major flow in the second season: ditch N-C-38 at 64.9 percent, Br-J-29 at 38.9 percent, Br-C-5 at 62.1 percent, Br-J-10 at 66.4 percent, and BE-C-56 at 65.2 percent. N-C-40A had no flow, and the remaining four ditches had the major flow in the first season: ditch Br-J-30 at 81.3

Table XXX. Calculated maximum to minimum ratios of water quality parameter total loads by ditches and rivers.

	Minimum	Maximum
All Ditches		
Flow	1.0	92.3
Load:		
Total orthophosphate-phosphorous	1.0	213.0
Total Kjeldahl-nitrogen	1.0	158.3
Nitrate-nitrogen	1.0	96.5
Total dissolved solids	1.0	76.4
All Rivers		
Flow	1.0	11.7
Load:		
Total orthophosphate-phosphorous	1.0	56.5
Total Kjeldahl-nitrogen	1.0	13.3
Nitrate-nitrogen	1.0	153.0
Total dissolved soilds	1.0	24.8

Table XXXI. Ratio of maximum value to minimum value at each site based on instantaneous values.

	Second Order Ditches									
	N-C-40A	N-C-38A	Br-J-29	Br-C-5	Br-J-30	Br-J-10	BE-C-56	BE-C-5	LS-C-59	LS-C-58
Flow	No Flow	73.8	***	***	212.6	***	37.5	***	***	84.5
Load										
Total orthophosphate-phosphorous	***	26.4	591.0	37.6	53.4	674.0	15.3	44.6	31.9	25.4
Total Kjeldahl-nitrogen	10.4	7.5	11.4	10.9	7.7	10.7	18.3	2.9	6.8	15.6
Nitrate-nitrogen	28.5	4.6	6.9	13.2	12.1	14.1	11.6	137.5	238.6	13.7
Total dissolved solids	4.1	3.0	3.5	3.2	4.6	5.2	2.4	2.3	1.8	2.4

	Third Order Ditches			Third Order River			Second Order River
				Br-BE	BE	LS	LS
	BE-J-48	N-J-1A	N-J-1A*	Morgan Cr.	Little Cobb R.	Cannon R.	Shanaska Cr.
Flow	22.1	128.6	95.6	25.2	38.4	89.1	30.3
Load							
Total orthophosphate-phosphorous	***	97.3	73.2	***	30.5	611.0	***
Total Kjeldahl-nitrogen	14.0	23.4	14.3	17.3	7.2	2.8	8.3
Nitrate-nitrogen	4.1	5.4	8.5	5.3	7.2	80.0	***
Total dissolved solids	3.2	2.8	3.0	2.4	2.8	2.2	2.3

*** - not able to calculate ratio when minimum = 0.00.

Table XXXII. Seasonal breakdown of water quality parameter loading as percentage of total.

	Second Order Ditches								
Seasonal Loads	**N-C-38A**	**Br-J-29**	**Br-C-5**	**Br-J-30**	**Br-J-10**	**BE-C-56**	**BE-C-5**	**LS-C-59**	**LS-C-58**
Flow									
Spring Run Off	23.8	28.6	37.9	81.3	20.0	31.9	67.7	64.4	60.2
Growing Season	64.9	38.9	62.1	13.2	66.4	65.2	31.1	35.6	32.9
Fall Harvest & Plowing	11.3	32.5	.0	5.5	13.6	2.8	1.2	.0	6.9
Total Orthophosphate-Phosphorous									
Spring Run Off	21.4	35.4	13.4	90.5	11.2	37.8	57.3	40.1	53.3
Growing Season	67.3	24.8	86.6	5.6	78.4	61.2	41.9	59.9	40.5
Fall Harvest & Plowing	11.3	39.8	0	3.9	10.4	1.1	.8	.0	6.1
Total Kjeldahl-Nitrogen									
Spring Run Off	22.6	36.0	25.8	86.6	15.6	25.2	64.6	56.3	66.2
Growing Season	68.1	39.7	74.2	9.3	77.0	74.0	34.0	43.7	28.6
Fall Harvest & Plowing	9.3	24.3	.0	4.1	7.4	.7	1.4	.0	5.2
Nitrate-Nitrogen									
Spring Run Off	23.1	20.7	39.6	73.5	21.4	30.5	73.7	78.0	58.2
Growing Season	64.8	43.0	60.4	16.5	63.7	65.3	25.5	22.0	33.7
Fall Harvest & Plowing	12.1	36.2	.0	10.0	14.8	4.2	.7	.0	8.1
Total Dissolved Solids (Conductivity)									
Spring Run Off	19.6	23.9	31.7	69.3	12.7	22.2	60.3	50.2	45.4
Growing Season	74.2	61.7	68.3	37.9	73.8	75.7	39.7	49.8	46.5
Fall Harvest & Plowing	6.2	14.4	.0	2.8	13.5	2.1	0	.0	8.1

Table XXXII. (continued).

Seasonal Loads	Third Order Ditches BE-J-48	 N-J-1A	 N-J-1A*	Third Order Rivers Br-BE Morgan Creek	 Br-BE Little Cobb River	 LS-Cannon River	Second Order River LS-Shanaska Creek
Flow							
Spring Run Off	26.3	42.0	26.5	21.3	40.9	49.8	32.0
Growing Season	65.9	50.1	63.2	66.4	48.5	42.7	61.8
Fall Harvest & Plowing	7.9	7.9	10.3	12.3	10.5	7.4	6.2
Total Orthophosphate-Phosphorous							
Spring Run Off	37.3	36.8	20.5	18.4	42.5	36.1	33.1
Growing Season	60.1	56.2	70.7	74.7	52.3	59.6	66.3
Fall Harvest & Plowing	2.6	7.0	8.8	6.9	5.2	4.3	.6
Total Kjeldahl-Nitrogen							
Spring Run Off	22.1	41.1	19.2	11.6	42.3	53.3	32.2
Growing Season	74.6	56.2	74.8	83.9	53.3	41.2	63.1
Fall Harvest & Plowing	3.3	2.7	6.0	4.5	4.4	5.7	4.7
Nitrate-Nitrogen							
Spring Run Off	27.9	38.7	23.6	20.1	40.6	84.9	64.1
Growing Season	62.4	49.7	66.7	61.5	48.7	12.6	28.9
Fall Harvest & Plowing	9.7	11.6	9.7	18.4	10.6	2.5	7.0
Total Dissolved Solids (Conductivity)							
Spring Run Off	19.9	25.5	18.1	13.9	26.7	50.9	35.4
Growing Season	75.2	69.2	79.7	74.4	65.4	42.6	59.0
Fall Harvest & Plowing	4.9	5.3	2.2	11.7	7.9	6.5	5.6

percent, BE-C-5 at 67.7 percent, LS-C-59 at 64.4 percent, and LS-C-58 at 60.2 percent.

Shanaska Creek had an exception to the general trend of the largest chemical loads being in the same season as the largest percentage flow as nitrate-nitrogen had 64.1 percent of load in the first season, "Spring Runoff".

Ditch Br-J-29 is the only ditch with nearly one-third of flow in each season. It also is the only ditch with large chemical loads in the third season.

The largest percentage load for total orthophosphate-phosphorous is in the second season for the Cannon River and ditch LS-C-59 though both sites recorded the major flow in the first season.

The largest percentage loads for total dissolved solids were nearly equal in the first and second seasons for ditch LS-C-58 and LS-C-59 even though the flow percentages were twice as large in the first season 60.2 percent to 32.9 percent for ditch LS-C-58 and 64.4 percent to 35.6 percent for LS-C-59, respectively.

Sediment Chemistry

Proximate Chemistry--Loss on Ignition. All sediments tested were largely ash (Table XXXIII).

The largest value for percent organic was found in the second order ditch LS-C-59 and it increased slightly from spring to fall. This ditch has a major aquatic macrophyte community (Quade, et. al., 1979). The highest values were seen in second order ditches for percent organic even though all the ditches and all the rivers showed variability. Shanaska Creek revealed a decrease spring to fall as did Br-J-10.

The third order rivers had the highest percent ash values as a group. The Cannon River percent of ash value decreased from spring to fall from 90.0 percent to 78.5 percent.

In the third order ditches the percent of $CaCO_3$ decreased from spring to fall for ditch BE-J-48 while it increased for N-J-1A and N-J-1A*, 11.6 percent and 3.6 percent, respectively.

Total orthophosphate-phosphorous. The highest concentration values for sediment total orthophosphate-phosphorous were found in the second order ditches (Table XXXIV). The smallest concentration was also in the second order ditches, ditch BE-C-56. Ditch N-C-40A, the ditch with no flow had the highest value spring while ditch LS-C-59 had the largest value in the fall for total orthophosphate-phosphorous.

The third order rivers and the third order ditches all had lower concentrations of total orthophosphate-phosphorous in the fall than the spring except for the Little Cobb River which stayed nearly the same. Shanaska Creek revealed an increase in sediment total orthophosphate-

Table XXXIII. Proximate chemistry (L.O.I.) of ditch-river bottom sediments taken spring and fall, expressed by percentage.

		SPRING			FALL		
	Site	% Organic	% $CaCO_3$	% Ash	% Organic	% $CaCO_3$	% Ash
Second Order Ditches	N-C-40A	6.41	18.3	75.3	7.6	14.5	77.9
	N-C-38A	3.15	21.6	75.2	2.6	17.4	79.9
	Br-J-29	7.5	6.3	86.2	7.4	9.3	83.3
	Br-C-5	5.6	12.8	81.6	5.7	13.5	80.8
	Br-J-30	2.2	8.7	89.1	1.7	9.3	89.0
	Br-J-10	9.8	11.8	78.4	5.1	11.9	82.9
	BE-C-56	1.6	2.6	95.8	0.81	2.3	96.9
	BE-C-5	4.9	2.7	92.4	Not sampled due to road construction.		
	LS-C-59	13.6	13.2	73.2	14.4	12.9	72.7
	LS-C-58	5.2	5.2	89.6	7.2	4.4	88.4
Third Order Ditches	BE-J-48	5.0	11.9	83.1	2.4	6.1	91.5
	N-J-1A	1.23	20.3	78.5	.8	31.9	67.3
	N-J-1A*	1.45	21.7	76.8	1.8	25.3	72.9
Third Order Rivers	Br-BE Morgan Creek	1.2	10.9	87.9	0.9	13.9	85.2
	BE-Little Cobb River	4.6	3.1	92.3	5.3	3.3	91.4
	LS-Cannon River	2.25	7.7	90.0	0.9	20.6	78.5
Second Order River	LS-Shanaska Creek	6.1	16.2	77.7	2.9	16.3	80.8

Table XXXIV. Total orthophosphate-phosphorous in ditch-river bottom sediments (mg/g), spring and fall.

		SPRING	FALL
	Site	mg/g-P	mg/g-P
Second Order Ditches	N-C-40A	.591	.523
	N-C-38A	.391	.326
	Br-J-29	.417	.455
	Br-C-5	.239	.357
	Br-J-30	.240	.268
	Br-J-10	.466	.362
	BE-C-56	.082	.093
	BE-C-5	.159	No Sample
	LS-C-59	.476	.665
	LS-C-58	.281	.472
Third Order Ditches	BE-J-48	.246	.206
	N-J-1A	.281	.205
	N-J-1A*	.387	.290
Third Order Rivers	Br-BE Morgan Creek	.344	.218
	BE-Little Cobb River	.222	.216
	LS-Cannon River	.318	.210
Second Order River	LS-Shanaska Creek	.246	.300

phosphorous from spring to fall. Several second order ditches showed increases (i.e., Br-C-5, LS-C-59, and LS-C-58). Other second order ditches stayed the same or decreased as seen especially in Br-J-10.

Total Kjeldahl-nitrogen. The highest concentration values for sediment total Kjeldahl-nitrogen were found in the second order ditches (Table XXXV). The smallest concentration found was in Morgan Creek, a third order river. Ditch LS-C-59 had the highest value both spring and fall.

The third order ditches and third order rivers all had higher values in the fall than the spring except for ditch N-J-1A which decreased slightly. The concentration ot total Kjeldahl-nitrogen in the sediment for Shanaska Creek decreased from spring to fall.

The data for the second order ditches revealed an increase from spring to fall for ditches such as Br-J-29, Br-C-5, Br-J-30, and BE-C-56. Other second order ditches indicated a decrease from spring to fall for total Kjeldahl-nitrogen as in B-C-40A, N-C-38A, and LS-C-59.

Statistics

T-tests. All statistics were run on instantaneous values. T-tests were run on three matched ditch-river pairs broken down by season for total orthophosphate-phosphorous, total Kjeldahl-nitrogen, nitrate-nitrogen, and total dissolved solids. The three matched pairs were ditch BE-C-5 and the Little Cobb River in Blue Earth County, ditch LS-C-59, and the Cannon River in Le Sueur County, and ditch LS-C-58 and Shanaska Creek in Le Sueur County.

The mean values for total Kjeldahl-nitrogen, nitrate-nitrogen, and total dissolved solids were found to be different for the first pair, ditch BE-C-5 and the Little Cobb River, for the "Spring Runoff" season and the "Growing Season" at a 95 percent confidence level (Table XXXVI). The mean values for total orthophosphate-phosphorous could not be demonstrated to be different at the 95 percent confidence level for any of the seasons. T-values could not be calculated due to insufficient sample sizes in the last season when ditches were freezing over.

The mean values for total orthophosphate-phosphorous and total dissolved solids were found to be different for the second pair, ditch LS-C-59 and the Cannon River, for all three seasons at a 95 percent confidence level (Table XXXVII). The mean values for nitrate-nitrogen for this pair were found to be different for the "Spring Runoff" season at a 95 percent confidence level. There was no difference for the other parameters and seasons which could be demonstrated at the 95 percent confidence level.

The mean value for nitrate-nitrogen and total dissolved solids were found to be different for the third pair, ditch LS-C-58 and Shanaska Creek, for all three seasons at a 95 percent confidence level (Table XXXVIII). The mean values for total orthophosphate-phosphorous for this pair were found to be different for the last two seasons, "Growing Season"

Table XXXV. Total Kjeldahl-nitrogen in ditch-river bottom sediments (mg/g), spring and fall.

		SPRING	FALL
	Site	mg/g-N	mg/g-N
Second Order Ditches	N-C-40A	3,030	2.911
	N-C-38A	.988	.609
	Br-J-29	2.949	3.202
	Br-C-5	1.409	2.662
	Br-J-30	.718	.947
	Br-J-10	3.234	1.745
	BE-C-56	.529	1.124
	BE-C-5	1.079	No Sample
	LS-C-59	7,122	5.320
	LS-C-58	2.121	2.186
Third Order Ditches	BE-J-48	.923	1.042
	N-J-1A	.487	.420
	N-J-1A*	.457	.815
Third Order Rivers	Br-BE-Morgan Creek	.281	.311
	BE-Little Cobb River	.995	1.209
	LS-Cannon River	.649	.729
Second Order River	LS-Shanaska Creek	2,038	1.304

Table XXXVI. T-tests for the matched pair, ditch BE-C-5 and the Little Cobb River, by season.

Ditch BE-C-5 vs. Little Cobb River

Season	Paried Comparisons	Means (Ditch)	Means (River)	Absolute T-Value
TOTAL ORTHOPHOSPHATE-PHOSPHOROUS				
"Spring Runoff"	15	.168 :	.161	.23
"Growing Season"	18	.195 :	.160	1.46
"Fall Harvest and Plowing"	1	.110 :	.385	---
TOTAL KJELDAHL-NITROGEN				
"Spring Runoff"	15	2.104 :	.812	6.18*
"Growing Season"	18	2.426 :	.962	11.09*
"Fall Harvest and Plowing"	1	2.671 :	1.637	---
NITRATE-NITROGEN				
"Spring Runoff"	15	11.520 :	18.187	2.74*
"Growing Season"	17	6.226 :	17.061	7.14*
"Fall Harvest and Plowing"	1	6.040 :	18.950	---
TOTAL DISSOLVED SOLIDS				
"Spring Runoff"	11	651.385 :	596.946	2.87*
"Growing Season"	17	773.676 :	702.159	2.61*
"Fall Harvest and Plowing"	--	---	581.263	---

* - indicates a significant difference with a 95% confidence interval.

Table XXXVII. T-tests for the matched pair, ditch LS-C-59 and the Cannon River, by season.

Ditch LS-C-59 vs. Cannon River

Season	Paired Comparisons	Means (Ditch)	Means (River)	Absolute T-Value
TOTAL ORTHOPHOSPHATE-PHOSPHOROUS				
"Spring Runoff"	15	.091 :	.143	3.00*
"Growing Season"	18	.127 :	.343	6.78*
"Fall Harvest and Plowing"	3	.046 :	.121	6.71*
TOTAL KJELDAHL-NITROGEN				
"Spring Runoff"	15	2.282 :	2.525	1.50
"Growing Season"	18	2.787 :	2.516	1.53
"Fall Harvest and Plowing"	3	2.303 :	1.878	2.48
NITRATE-NITROGEN				
"Spring Runoff"	15	15.404 :	6.973	2.69*
"Growing Season"	18	4.741 :	1.277	1.95
"Fall Harvest and Plowing"	3	4.927 :	1.725	2.25
TOTAL DISSOLVED SOLIDS				
"Spring Runoff"	11	597.506 :	519.229	5.67*
"Growing Season"	16	576.162 :	402.945	12.26*
"Fall Harvest and Plowing"	2	516.604 :	344.791	125.03*

* - indicates a significant difference with a 95% confidence interval.

Table XXXVIII. T-tests for the matched pair, ditch LS-C-58 and Shanaska Creek, by season.

Ditch LS-C-58 vs. Shanaska Creek

Season	Paired Comparisons	Means (Ditch)		Means (River)	Absolute T-Value
TOTAL ORTHOPHOSPHATE-PHOSPHOROUS					
"Spring Runoff"	15	.128	:	.089	1.22
"Growing Season"	18	.252	:	.058	4.97*
"Fall Harvest and Plowing"	4	.154	:	.002	5.03*
TOTAL KJELDAHL-NITROGEN					
"Spring Runoff"	15	2.101	:	2.086	.04
"Growing Season"	18	2.076	:	2.202	.98
"Fall Harvest and Plowing"	4	1.884	:	1.596	.83
NITRATE-NITROGEN					
"Spring Runoff"	15	28.310	:	5.289	6.06*
"Growing Season"	18	20.619	:	.671	7.82*
"Fall Harvest and Plowing"	4	32.225	:	1.825	6.36*
TOTAL DISSOLVED SOLIDS					
"Spring Runoff"	11	836.652	:	496.677	11.66*
"Growing Season"	16	856.357	:	313.459	25.37*
"Fall Harvest and Plowing"	4	709.954	:	304.143	5.00*

* - indicates a significant difference with a 95% confidence interval.

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and "Fall Harvest and Plowing" at a 95 percent confidence level. There was no difference for the other parameters and seasons which could be demonstrated at the 95 percent confidence level.

Pearson's product-moment correlation. Pearson product-moment correlation values for all instantaneous parameters were calculated and grouped by second order ditches, third order ditches and rivers (Figures 8, 9, 10).

Second order ditches: Flow was negatively correlated to total dissolved solids and to water temperature for five of ten sites, flow was positively correlated for nitrate-nitrogen to one site, LS-C-59, flow was positively correlated for four of the ten sites with total Kjeldahl-nitrogen, and to three sites with total orthophosphate-phosphorous at least at a 95 percent confidence level (Figure 8).

Second order ditches showed a strong positive correlation for total orthophosphate-phosphorous and total Kjeldahl-nitrogen. Total dissolved solids were strongly correlated with water temperature. A strong negative correlation is seen for total orthophosphate-phosphorous and total dissolved solids, while nitrate-nitrogen showed a strong negative correlation for total Kjeldahl-nitrogen and water temperature (Figure 8).

Third order ditches: Flow was negatively correlated to total dissolved solids and water temperature for two of three sites. Flow was positively correlated to total Kjeldahl-nitrogen and total orthophosphate-phosphorous for two sites and three sites, respectively, at least at a 95 percent confidence interval (Figure 9).

Third order ditches showed a positive correlation for two of three sites for total orthophosphate-phosphorous and total Kjeldahl-nitrogen and three for three sites for total dissolved solids and water temperature. A strong negative correlation is seen for all three sites with total orthophosphate-phosphorous and two parameters, total dissolved solids and water temperature.

Rivers: Flow was negatively correlated to total dissolved solids and water temperature for two of four sites. The Cannon River showed a positive correlation between flow and nitrate-nitrogen. Flow was positively correlated with total orthophosphate-phosphorous and total Kjeldahl-nitrogen at two sites, Morgan Creek and the Little Cobb River (Figure 10). All correlations were at least at the 95 percent confidence level.

The rivers seemed more variable than the ditches as a group. The only place three of four rivers were correlated was for total orthophosphate-phosphorous and total Kjeldahl-nitrogen, two positively and one negatively correlated. In Shanaska Creek total Kjeldahl-nitrogen was negatively correlated with total orthophosphate-phosphorous and nitrate-nitrogen. Water temperature was positively correlated to total dissolved solids for two sites, Morgan Creek and the Little Cobb River. Other correlations for individual sites can be noted.

Figure 8. Pearson product-moment correlation for water quality parameters for second order ditches.

Second Order Ditches

	Flow	PO_4	TKN	NO_3	Temp
TDS	B- h- C- E- g-	B- h- C- E- G-	B- f-	g	A E i B F J C G D H
Temp	c- J- E- F- i-	A- C- E-		A- j- f- h- I-	
NO_3	I	G- I	C- G- D- H- E- F-		
TKN	B e G J	B F C G d j E			
PO_4	B E G				

LEGEND

A	N-C-40A	F	Br-J-10
B	N-C-38A	G	BE-C-56
C	Br-J-29	H	BE-C-5
D	Br-C-5	I	LS-C-59
E	Br-J-30	J	LS-C-58

Capital = 99% confidence level
Small Case = 95% confidence level
Negative sign indicates an
inverse correlation

Figure 9. Pearson product-moment correlation for water quality parameters for third order ditches.

Third Order Ditches

	Flow	PO_4	TKN	NO_3	Temp
TDS	B- C-	A- b- C-		c	A B C
Temp	B- C-	A- b- C-			
NO_3		c			
TKN	A B	B C			
PO_4	a b c				

LEGEND

A	BE-J-48
B	N-J-1A
C	N-J-1A*

Capital = 99% confidence level
Small case = 95% confidence level
Negative sign indicates an
inverse correlation

Figure 10. Pearson product-moment correlation for water quality parameters for rivers.

Rivers

	Flow	PO_4	TKN	NO_3	Temp
TDS	a- b-	a-	C	b- C	A B
Temp	b- c-	c	A	C- D-	
NO_3	C	D	D-		
TKN	A B	A B d-			
PO_4	A B				

LEGEND

- A Br-BE-Morgan Creek
- B BE-Little Cobb River
- C LS-Cannon River
- D LS-Shanaska Creek

Capital = 99% confidence level
Small Case = 95% confidence level
Negative sign indicates an
inverse correlation

Discussion

Water Quality Compared

The year 1979 was a very wet year with the collection period rainfall total greater than the average for all three rainfall stations in the four counties. Anderson, 1977, and others in the literature found a direct increase in nitrate-nitrogen concentration (mg/l) and total orthophosphate-phosphorous concentration (mg/l) corresponding to rainfall events. In this study this also was found to be the case. Heavy rain fell July 11 and 13 in New Ulm, 1.08 inches and 1.43 inches, respectively, and ditches N-C-38A, N-J-1A, N-J-1A* just east of New Ulm showed a large increase in concentration of total orthophosphate-phosphorous and nitrate-nitrogen. Several ditches west of New Ulm in line with the storm also showed the dramatic increase. Higher than average rainfall on October 19, 1979 for the entire four county area showed an increase for most of the sites in nitrate-nitrogen and total orthophosphate-phosphorous. The sites which did not increase already were at high concentration or may have not received the rainfall.

Nitrate is a very soluble anion which does not form insoluble complexes as phosphate ion does and therefore nitrate ion is easily leached from the soil into drainage systems. Quade, et. al., 1979, states "Microbial fixation and consequent nitrification by the soil microflora is a major source of nitrogen entering natural waters. Nitrification is the process by which nitrogen forms in the reduced state are oxidized to nitrite and nitrate (NO_2- and NO_3-)." Nitrite is quickly oxidized to nitrate in natural systems. The data in this study reveals the leaching of nitrate by rain from a major rainfall event.

Phosphate does not exhibit the variety of forms in fresh water that nitrate does and orthophosphate (PO_4-) is the only biologically important form found which is readily available for utilization by aquatic organisms. Phosphate in the orthophosphate form is poorly soluble as it forms electrostatic bonds with soil particles and is not easily leached from the soil. The question must then be asked, "What accounts for the rise in total orthophosphate-phosphorous concentration after a major storm event?"

Anderson, 1977, found the loss of phosphorous in surface runoff from one of the fields he tested in a 4 to 5 day period in 1974 approached the total loss of phosphorous from three tile systems he was monitoring during the entire three year period 1972-1974. Anderson found phosphate in other forms than just orthophosphate present. The importance of surface runoff during 1979 was probably very significant since the soil in the collection area was saturated for the entire collecting period according to Earl Kuenhast, State Climatologist (personal communication).

It also is possible that orthophosphate-phosphorous was flushed from the sediments of the ditch-river beds during greater water input.

Anderson, 1977, hypothesized that "since the concentration of phosphates in most waters is limited by the slight solubility of the orthophosphate, one would expect the concentration to rise with temperature."

He was not able to demonstrate this in his data. This study revealed the Cannon River as the only site which had a positive correlation between water temperature and total orthophosphate-phosphorous concentration. Quade, et. al., 1979, found a strong positive correlation between temperature and total phosphate in ditch LS-C-59 for 1976. They found no correlation between temperature and total phosphate for the Cannon River.

Jones, et. al., 1976, after monitoring 34 watersheds in N.W. Iowa lake district stated, "Although livestock were the only factor that could be correlated with P and NH_3-N input to the lakes, they were not the sole source of these nutrients. Runoff from grasslands, cultivated lands, and urban lands had high nutrient concentrations. The nutrients attributable to feedlot livestock accounted for less than one-sixth of the P and one-tenth of the NH_3-N carried in the inflows from the watersheds. This is a reflection of the high background nutrient levels that could not be attributed to a specific source."

McGregor, et. al., 1975, found that soil management and different crops could influence nutrient leaching from fields. The crop most heavily fertilized, especially corn were not responsible for the highest concentrations of NO_3-N in the seventeen drainage ditches they sampled from 1969-1971.

McGregor, et. al., 1975, stated that soil drainage itself contributes to nitrate concentrations independent of crop and fertilization factors. Drainage apparently increases the soil temperature, which increases biological decomposition of organic matter releasing the soluble materials to the drainage systems.

In this study total orthophosphate-phosphorous concentration ranged from .000 mg/l to .674 mg/l which was higher than Anderson, 1977, double the values of McGregor, et. al., 1975, and within the range of Jones, et. al., 1976. A possible explanation of this was McGregor, et. al., 1975, only sampled a portion of the ice free season.

Nitrate-nitrogen ranged from .00 mg/l to 121.00 with a more realistic maximum for the ditches with flowing water at 53.50 mg/l. This was higher than the values found by Jones, et. al., 1976 and Anderson, 1977, but within the range of McGregor, et. al., 1975, except for the 121.00 mg/l value at ditch N-C-40A. Ditch N-C-40A was the ditch which had no flow for the entire study period.

Total Kjeldahl-nitrogen ranged from .124 mg/l to 5.090 mg/l which was greater than the values Anderson, 1977, found but within the range of NH_3-N found by Jones, et. al., 1976.

Anderson was working with one ditch and three tile lines. Tile lines were found to have the lowest phosphate concentration and NH_3-N concentration for all runoff types by Jones, et. al., 1976.

Anderson, 1976, reported a peak in June for nitrate-nitrogen and a peak in spring of phosphate with a second peak in the fall due to rainfall events.

This study found no seasonal distribution of maximum values for nitrate-nitrogen probably due to the large amount of rainfall and high solubility of nitrate-nitrogen making it very susceptible to leaching into the drainage water system. Maximum total orthophosphate-phosphorous was generally during early spring runoff probably due to flushing out of concentrated reserves of phosphate released by decomposition of organic matter under the ice and snow of winter.

The maximum to minimum ratios tabulated in this study indicated a relationship between chemical load and total flow that was not in equal proportion for each chemical parameter sampled.

The fact that the solubility of the orthophosphate ion was far different than that of the nitrate ion or the ammonimum ion may be one reason the ratios are not the same.

Quade, et. al., 1979, found evidence of nutrient up take by ditch macrophytes in LS-C-59 which inactivated considerable amounts of nutrients in the waters in which they grew. Ditch algae also can inactivate nutrients. Some of the ditches in the study area had emergent and submerged vegetation in the river bed and this perhaps influenced the nutrient levels and indicates why the values were so low at that site for most of the year.

Jones, et. al., 1976, and others indicate that nutrients, such as orthophosphate-phosphorous tend to decrease in concentration due to forces within the watershed itself. Soils and sediments scavenge phosphorous even within the tributary. The velocity of the flow would have to be a factor in soil adsorption of total orthophosphate-phosphorous.

Another point important in this study is that nutrient input is unlikely to be equal from all parts of the watershed, many hydrological and chemical processes occur as the water travels through the watershed. In this study some samples were taken at the bottom of the watershed while other samples were taken high up in the watershed.

Third order ditches and rivers are less affected by nutrient inactivation or local changes in nutrient concentration because of the larger absolute volume of water as flow. The larger total flow was due to larger drainage areas serviced by the third order ditches and rivers. Also, possibly even more important is that the water in third order ditches and rivers have already gone through chemical and biological processing in the second order tributaries.

For both the second order ditches and the third order ditches in this study the site in each group with the maximum total flow also had the maximum total load for each chemical parameter. The site in each group with the minimum total flow also had the minimum total chemical load. This was not the case for the third order rivers.

Ditches do not exhibit the individual characteristics each river exhibits. The ditches with the largest flow probably drain the largest area and therefore have the largest reservoir of possible nutrient load.

The Little Cobb River lacked the riffle-pool configuration witnessed in Morgan Creek while the Cannon River passed through several lakes before being sampled. Shanaska Creek samping site was very close to the outlet of Lake Washington. The ditches all physically looked pretty much the same, straight, non-meandering, with high banks and agricultural land use.

The water in the rivers travel through varied geomorphic types while each ditch is generally confined to one geomorphic type.

It is very possible that ditch Br-J-10, near Hanska, Minnesota, has been contaminated by animal wastes. A biological indicator of sewage pollution, commonly called the rat tailed maggot, a dipteran, was found in the ditch in early spring. The ditch had a low flow for the season, but had the highest instantaneous concentration (mg.1) for total orthophosphate-phosphorous, the highest concentration (mg/l) for nitrate-nitrogen other than N-C-40A which had no flow at all, and the second highest total Kjeldahl-nitrogen concentration (mg/l) for second order ditches, even though total dissolved solids were quite low.

Cannon River and Ditch LS-C-59 compared to 1975-1976 and 1979

The Cannon River and ditch LS-C-59 were sampled in 1975 and 1976. The 1976 season was considered to be a year of drought conditions by Quade, et. al., 1979. Their sites F and H were the same sites sampled in this (1979) study as LS-C-59 and the Cannon River, respectively.

When total load values for the chemical parameters and flow were calculated as a ratio of river to ditch it was interesting to find that the flow was nine times greater in the Cannon River than in the ditch for both Quade's 1975-1976 data and for this study's data, 1979. All ratios for Quade, et. al., 1979 data were recalculated from the total load values found at the sites F and H rather than sites further downstream as in their (1975-1976) study. So even with fives times as much water passing through the drainage system in 1979, the ditch to river ratio is the same for both sampling studies.

Total orthophosphate-phosphorous was determined by standard methods using the Stannous Chloride Procedure in both studies but Quade, et. al, 1979, filtered the sample through a 45 u filter while in this study the sample was not filtered before the chemical determination. The river to ditch ratio determined by total load values was twice as large during the low flow by Quade as in 1979, 31.5 and 15.6, respectively. Instantaneous concentrations were higher for Quade in the low flow study with the Cannon River means at .518 mg/l and at .238 mg.1 for this study of higher flow. Concentrations of total orthophosphate-phosphorous for the ditch were more similar with Quade's mean value at .126 mg/l and this study's at .105 mg/l. The maximum value in the river was higher at 1.533 mg/l for Quade and .600 mg/l in this study.

The methods for nitrate-nitrogen were not the same but both studies reported reproducibility of results were good when compared to standard NO_3-N solutions. The river to ditch ratio was more than twice as large for Quade's low flow determination as in this study determination at 8.4 and 3.2, respectively. However, the actual concentrations (mg/l) of nitrate-nitrogen were found to be much higher in this study. In both studies the ditch had higher concentrations than the river with a range from .30 mg/l to 18.4 mg/l with a mean of 3.34 mg/l for Quade and in this study the range was .22 mg/l to 52.50 mg/l with a mean of 9.20 mg/l. The Cannon River ranged from .23 mg/l to 6.30 mg/l with a mean of 2.56 mg/l for the dry year study while in this study a range of .20 mg/l to 16.00 mg/l with a mean of 3.64 mg/l was found.

The fact that total orthophosphate-phosphorous concentration was higher in the river for both studies with the dry year of Quade having the highest values compared to the nitrate-nitrogen concentration having been higher in the ditch for both studies with the wet year of this study having the highest values indicates a relationship of nutrient loading with flow. Nitrate-nitrogen is highly soluble in water and this probably is the reason during the higher flow study nitrate-nitrogen concentrations were so much higher than during the dry year. In this study flow and nitrate-nitrogen were found positively correlated for both ditch and river at the 99 percent confidence level. Total orthophosphate-phosphorous has a low solubility in water and the concentrations seen in the wet year of 1979 may be due to a dilution effect of the greater volume of water.

The fact that nitrate-nitrogen concentration was higher in the ditch for both studies and that total orthophsophate-phosphorous concentration was higher in the river for both studies indicates there are many more factors than flow which influence nutrient loading including land use of the drainage area, fertilizer and crop selection, hydrologic and chemical processing within the river or ditch itself, and vegetation in the body of water.

The ratio of river to ditch of total dissolved solids is quite similar for load and instantaneous concentration (mg/l) are also comparable for the two different studies.

Water temperature was slightly higher during the dry year period of Quade. In this study a negative correlation between flow and water temperature for both ditch and river above the 95 percent confidence level was found.

Total load was greater for all parameters for both the ditch and river during the wet year, 1979 than during the dry period, 1975-1976.

Pearson Product-Moment Correlation Coefficients Compared

Quade, et. al., 1979, found orthophosphate-phosphorous and water temperature positively correlated for both ditch LS-C-59 and the Cannon River at a 99 percent confidence level. They found water temperature and nitrate-nitrogen to be inversely (negatively) correlated at a 99 percent confidence level in the ditch.

In this study total orthophosphate-phosphorous and water temperature were found to be positively correlated in the Cannon River at a 99 percent confidence level. Water temperature and nitrate-nitrogen were negatively correlated for both ditch and river at a 99 percent confidence level. Flow was negatively correlated to water temperature in both ditch and river, while flow was found to be strongly correlated to nitrate-nitrogen in both ditch and river at 99 percent confidence level. This supports the idea that nitrate-nitrogen concentration was higher in 1979 in both ditch and river because of increased flow.

Quade found flow negatively correlated to orthophosphate-phosphorous for both ditch and river from April 3, 1976 to June 22, 1976 at a 95 percent confidence level and flow negatively correlated to nitrate-nitrogen in the ditch at a 95 percent confidence level for the same period. He accounts for this due to rapid biological turnover and release of nutrients at the same time flow decreased leading to drought conditions later in the season.

The literature supports the findings in this study but Quade seems to have found some interesting variations on ditch nutrient dynamics during dry or drought conditions.

Conclusion

The year 1979 was a very wet year and the quality of water sampled in each ditch and river was unique and responded to rainfall, vegetation, and internal chemical variations independently. The ditches and rivers could not easily be grouped into discrete groups because each had its own unique characteristics physically as well as chemically.

Second order ditches showed more variability in water quality for all parameters than third order ditches or rivers. The actual total volume of flow was less for second order ditches and the second order river than third order ditches and third order rivers. As indicated in the data in this study the water in third order ditches and rivers was less affected by nutrient inactivation and local nutrient variations because of the larger absolute volume of water as flow and the biological and chemical processing in the second order tributaries prior to entering the third order ditches and rivers.

Flow was seen to influence chemical load but in unequal proportions for each chemical parameter tested. In this study, the second order ditch with the maximum flow had the miximum total chemical load for all parameters. This also was the same situation for the third order ditches. Flow was directly related to total chemical load in the ditches while this was not the case for the rivers tested. The Cannon River had the largest total volume of flow and the largest total chemical load for total orthophosphate-phosphorous and total Kjeldahl-nitrogen but the smallest chemical load of nitrate-nitrogen. This river is very lake influenced however.

Chemical load showed high concentrations during high spring runoff and also in August-September during high water levels due to summer rains. Nitrate-nitrogen concentrations showed less seasonality than the other chemical paramters. There was no great temperature difference for any of the ditch or river sample sites.

When the data from Quade for ditch LS-C-59 and the Cannon River from 1975 and 1976 were compared to this study, nitrate-nitrogen was higher in the ditch for both studies and the river was higher in total orthophosphate-phorphorous for both studies. Total load was greater for all paramters in the wet year 1979 for both ditch and river.

When the data for the Cannon River and ditch LS-C-59 were compared to the other rivers and ditches in this study, the conclusion was that the Cannon River should not be used as a baseline for all rivers in South Central Minnesota and ditch LS-C-59 was only one ditch which could not by itself represent water quality of drainage ditch systems in South Central Minnesota.

Anderson, 1979, and others found an increase in nitrate-nitrogen concentration and total orthophosphate-phosphorous concentration corresponding to rainfall as this study found. Concentrations of total orthophosphate-phosphorous, total Kjeldahl-nitrogen, and nitrate-nitrogen were higher than some of the values in the literature, Anderson, 1977, for example, but within the range of McGregor, et. al., 1975 and Jones, et. al., 1976.

Nutrient loading of ditches within our region varied tremendously by season, which clearly demonstrated the need for multiple cross season sampling to obtain an adequate limnological base for water quality interpretation.

FLOW

This section reports on a preliminary investigation of the relationship between flow in natural waterways and flow in drainage ditches. Some of the questions considered include: Are the characteristics of flow in ditches different from those in rivers? Are the characteristics of flow in small ditches different from those in large ditches? Can differences in flow characteristics of ditches be explained or predicted by geomorphic parameters? Do man-made drainage ditches contribute to flooding of major rivers?

Methods

Flow measurements were taken from March 21, 1979 to November 17, 1979 at thirteen drainage ditches and four small rivers. Some ditches could not be measured until later than March 21 due to lingering ice cover. An interval of four to five days between measurements was maintained during spring runoff and during the remainder of the study period an approximate seven to eight day interval was used. A set order of measurement was followed assuring that the measurements were taken at similar times of day at each site. All work was done near road crossings for access purposes.

The water level was determined by a measurement between the water surface and marked locations on the bridges. If no bridge was available, water depth was measured at a location marked by a stake.

We determined cross sectional area by one of two methods. For some ditches and rivers we developed cross-sectional area maps with transit and rod which were used with the water level measurements to determine cross-sectional area. Ditches that were shallow and easily wadeable throughout the study period were measured for cross-sectional area directly at each time of flow measurement. The two methods were compared at a single site and were in close agreement.

Velocity of flow was also determined by one of two methods. Whenever possible we measured velocity with a Kahl Scientific Instrument Corporation pygmy meter using the "six-tenths-depth" method outlined in Buchanan and Somers (1969). Sometimes it was necessary due to existing conditions, temporary equipment malfunction, or safety precaution to use the Embody method for measuring velocity. These two methods have been compared by Quade, et. al. (1979) and were found to agree closely. Nearly all of our measurements were made under what are called "low flow conditions" where accuracy is known to be limited when using the methods available to us.

Instantaneous discharge rates were derived using the formula:

$$D = wdav$$

where D - discharge, w = width, d = mean depth, a = bed roughness coefficient (.8 if rough, .9 if smooth), and v = mean velocity. When using the Embody (float) method the formula used was:

$$D = \frac{wdal}{t}$$

where l = distance travelled by the float in time t.

The instantaneous rates were extrapolated halfway back to the preceeding measurement date and halfway forward to the succeeding measurement date generating period-flow data. Addition of successive period flows constituted the total accumulated discharge for the particular ditch or river and from these data were gleaned seasonal percentages of the total.

Occasionally we were unable to take either velocity measurements or Embody measurements and in order to obtain instantaneous rates for these instances, rating curves were plotted of discharge versus water level from previous data. Under these circumstances only water level data were necessary to obtain an estimate of discharge.

Hydrographs of each ditch or river were transposed onto graphs of rainfall from the nearest weather station. From these they were subjectively classified into two categories of hydrologic response, flashy and unresponsive, based on the magnitude of jumps in discharge and the timing of these jumps in relation to rainfall in the area.

Quantitative geomorphological data were obtained from Silis (1979) and considered for the ditches we studied. Mean values for each geomorphological parameter, by each hydrologic response category, were tabulated. Although these data were not ideally suited for statistical treatment due to small sample size, t-values were calculated and the means of the two categories were tested for significant difference.

Stream order of all ditches and rivers was determined according to Strahler (1957), using United States Geological Survey 7½ minute topographic maps.

The following percentages of days in the study period by season are to be compared with seasonal discharge percentages. The spring runoff season accounted for 29.6% of the days, the growing season accounted for 55.8% of the days, and the fall harvest and plowing season accounted for 14.6% of the days.

Results

In comparing hydrologic response and mean total accumulated discharge of rivers to ditches we found that the rivers tended to be more flashy than the ditches (Table XXXIX). Further, the discharge of the rivers averaged twice that of the ditches. Comparison of mean seasonal discharge percentages between rivers and ditches showed slight differences but any possible relationship became unclear when the comparison was made between ditches and the larger rivers in the study area that were measured by the United States Geological Survey. The seasonal percentages of the ditches were nearly identical to those of the larger rivers.

Table XL gives data on three ditch-river comparisons that were so paired because of proximity. The ditches were all second-order and the rivers third-order except for Shanaska Creek which was second-order. In all cases the rivers had much higher total accumulated discharge than the respective ditches. The ditches were unresponsive to hydrologic events and showed disproportionately high percentages of discharge during the spring runoff season. The rivers were flashy and tended to have more sustained flow throughout the study period with the exception of Shanaska Creek, which is an outlet of a lake. This small river was very unresponsive to hydrologic events and showed extreme constancy of flow throughout the study period.

In comparing second-order ditches to third-order ditches, mean total accumulated discharge was four times greater in the latter (Table XLI). Second-order ditches tended to be unresponsive to hydrologic events whereas all the third-order ditches were flashy. The second-order ditches exhibited disproportionately high flow during spring runoff. In contrast, the third-order ditches showed sustained flow throughout the study period.

Table XLII shows mean values for total accumulated discharge and sixteen quantitative geomorphological parameters from Silis (1979) broken down by the two hydrologic response categories. Differences between means of drainage density, length of overland flow, length of main stream, longest basin length, ditch gradient, and channel maintenance were found to be significant at the 95% level. Channel maintenance is the inverse of drainage density.

The peak flows of the drainage ditches were found to correspond closely to those of the major rivers in the area. During spring runoff we found ditches that were open and flowing to have peaks occurring simultaneously with the peaks in the rivers. There were a few ditches, however, that remained icebound until later. With few exceptions we found that during the high-water period of August, the peaks in the ditches preceeded those in the rivers by a few days.

Discussion

In the interpretation of our results it must be understood that in our area it is impossible to absolutely categorize waterways as man-made

Table XXXIX. Flow characteristics of rivers versus agricultural drainage ditches.

	Rivers (4)			Ditches (12)		
Mean Total Accumulated Discharge	33,995,289 m^3			15,218,199 m^3		
Hydrologic Response	Flashy 3	Unresponsive 1		Flashy 5	Unresponsive 7	
Mean Seasonal Discharge Percentage	Spring Runoff 36.0%	Growing Season 54.9%	Fall Harvest & Plowing 9.1%	Spring Runoff 42.6%	Growing Season 49.1%	Fall Harvest & Plowing 8.3%

Table XL. Flow characteristics of three ditch-river pairs.

	Blue Earth C-5			Little Cobb River		
Total Accumulated Discharge	7,829,986			30,339,426		
Hydrologic Response	Unresponsive			Flashy		
Seasonal Percentages	67.7%	31.1%	1.2%	40.9%	48.5%	10.5%
	Le Sueur C-59			Cannon River		
Total Accumulated Discharge	5,894,501			52,871,011		
Hydrologic Response	Unresponsive			Flashy		
Seasonal Percentages	64.4%	35.6%	0.0%	49.8%	42.7%	7.4%
	Le Sueur C-58			Shanaska Creek		
Total Accumulated Discharge	1,772,064			4,516,647		
Hydrologic Response	Unresponsive			Unresponsive		
Seasonal Percentages	60.2%	32.9%	6.9%	32.0%	61.8%	6.2%

Table XLI. Comparison of flow in second versus third order drainage ditches.

	Second-Order Ditches (9)			Third-Order Ditches (3)		
Mean Total Accumulated Discharge	8,325,848 m^3			35,895,252 m^3		
Hydrologic Response	Flashy 2	Unresponsive 7		Flashy 3	Unresponsive 0	
Mean Seasonal Discharge Percentage	Spring Runoff 46.2%	Growing Season 45.6%	Fall Harvest & Plowing 8.2%	Spring Runoff 31.6%	Growing Season 59.7%	Fall Harvest & Plowing 8.7%

Table XLII. Hydrologic response breakdown for quantitative geomorphic parameters.

	Mean Total Accumulated Flow (m^3)	Drainage Area (mi^2)	Drainage Density Flow (mi)	Length of Overland (mi)	Length of Main Stream (mi)	Longest Basin Length (mi)	Longest Basin Width (mi)	Ditch Gradient Slope (ft/mi)	Ditchshed Gradient (ft/mi)
Flashy (8)	15,388,652	14.67	2.20	33.14	8.38	6.25	3.55	2.78	8.85
Unresponsive (8)	5,165,517	11.26	.90	9.53	5.46	4.92	3.63	5.91	13.35

	Texture Ratio (mi)	Channel Maintenance (mi^2)	Form F	Shape S_1	Shape S_2	Circularity Ratio C	Elongation Ratio E	Leminscate Ratio K
Flashy (8)	1.12	.48	.37	2.69	1.83	.42	.65	.50
Unresponsive (8)	1.24	1.16	.46	2.34	1.69	.53	.76	.58

ditches or "natural" rivers. Many ditches are merely straightened streams and the rivers all have tile lines feeding them and have ditches as part of their network of tributaries. With this in mind it would seem appropriate to consider ditches and rivers not as rigidly exclusive species, but rather as a continuum. Our research supports this idea.

We found, as stated earlier, that small rivers tend to discharge approximately twice the amount of water that the ditches discharged, and that the rivers tended to be flashier than the ditches. The rivers under study were mostly third-order while the ditches were predominantly second-order. When the ditches were broken down into second-order and third-order categories, the results for the third-order ditches very closely corresponded to those for the rivers we studied. This suggests that river-ditch classification is of less importance than order in determining or predicting flow characteristics.

Our examination of quantitative geomorphological data shows that the drainage density of the ditch-shed and the length of the ditch are likely predictors of response to hydrologic events, with flashiness apparently linked to greater length and density. Longer ditches and higher density seem to be intuitively related to higher stream order.

We originally hypothesized that, because ditches were presumably fed mostly by tile lines and rivers were fed to a greater extent by surface runoff, peak discharges in the ditches would lag behind those in rivers. However, as we found the peaks to be occurring simultaneously or the ditches to be peaking slightly ahead of the rivers we speculate that ditching contributes to peak flows in the major rivers. Although Moore and Larson (1977) report that the advent of drainage projects have not contributed significantly to flooding in the Minnesota River, we conclude that they have not ameliorated flooding either.

BED AND SUSPENDED SEDIMENT

Bed and suspended sediment samples were taken at each water quality monitoring site in order to ascertain differences between and within ditches and rivers. This information should give an idea of the nature and extent of erosion (load) from ditches versus rivers.

Grain Size Analysis of Bed Material

Bed samples were taken from the study ditches and rivers during the spring of 1979 and in the fall of 1979. Sieving and settling velocity were employed to determined grain size distribution.

Methods

Three equally spaced samples of the upper four centimeters of bed material were taken on each date from a representative cross section of the waterway. These samples were taken with a United States Geological Survey bed material sampler, the US BMH-53. The three samples were composited to give a cross sectional representation.

The portion of the sample of size larger than one millimeter was removed by sieving. This constitutes the gravel fraction. The remainder of the sample was washed into the sedimentation chamber of a US VATSA-58 visual accumulation tube size analyzer, an apparatus developed by the U.S.G.S. and the United States Army Corps of Engineers. Material that had settled after seven minutes was withdrawn and, as this portion contained the sand fraction, was size-analyzed with the US VATSA-58 according to procedure outlined in Report K, IACWR (1958). Material still suspended upon completion of size analysis of the sands was combined with the material that remained unsettled at the original seven minute splitting. This constitutes the fine fraction. The three fractions were each dried and weighed to obtain percentages of the total.

Results

The results of the bed grain size analysis for spring and fall are given in Tables XLIII and XLIV and are summarized in Tables XLV and XLVI. Second order ditches revealed bed material generally much finer than third order ditches or rivers. It appears that flow was key as to bed load grain size as significant differences occurred within the second order ditches. Also, some significant changes occurred between spring and fall as seen in BE-C-56 although in general the relative proportions remained fairly constant.

Table XLIII. Bed grain size analysis for spring of 1979 in percent.

	Second Order Ditches									
Site #	N-C-40A	N-C-38A	Br-J-29	Br-C-5	Br-J-30	Br-J-10	BE-C-56	BE-C-5	LS-C-59	LS-C-58
% coarser than 1mm (gravel)	0	43.7	0	7.1	11	6.1	1.9	2.9	0	6
% finer than 1mm	100	56.3	100	92.9	89	93.9	98.1	97.1	100	94
% finer than .7mm	100	55	100	92	84	92	94	96	99	92
% finer than .5mm	99	52	100	89	62	88	83	93	98	89
% finer than .35mm	98	50	97	84	34	85	68	82	97	86
% finer than .25mm	97	48	92	80	25	80	43	73	95	83
% finer than .175mm	95	44	84	73	23	76	21	65	92	78
% finer than .125mm	92	41	78	68	22	65.7	17	57	88	73
% finer than .088mm	87	37	71	62	21	--	14	51	78	64
% finer than .0625mm (fine)	72.3	33.5	64.1	51.8	20.6	--	10.4	43.9	68.5	54.8

	Third Order Ditches			Third Order Rivers			Second Order River
Site #	BE-J-48	N-J-1A	N-J-1A*	Br-BE Morgan Creek	BE-Little Cobb River	LS-Cannon River	LS-Shanaska Creek
% coarser than 1mm (gravel)	2	38.7	49	26.7	2.6	44	45.5
% finer than 1mm	98	61.3	51	73.3	97.4	56	54.5
% finer than .7mm	97	58.0	45	71	95	45	53
% finer than .5mm	94	38	35	62	80	33	52
% finer than .35mm	92	17	30	40	67	24	51
% finer than .25mm	87	9	23	25	57	18	50
% finer than .175mm	82	8	17	17	49	13	48
% finer than .125mm	78	8	13	15	46	11	47
% finer than .088mm	74	8	11	14	42	10	44
% finer than .0625mm (fine)	49.4	7.4	9.3	13.1	37.3	8.4	32.5

Table XLIV. Bed grain size analysis for fall of 1979 in percent.

	Second Order Ditches									
	N-C-40A	N-C-38A	Br-J-29	Br-C-5	Br-J-30	Br-J-10	BE-C-56	BE-C-5	LS-C-59	LS-C-58
% coarser than 1mm (gravel)	0	52.9	0	10	14.7	4.2	32	--	0	5.3
% finer than 1mm	100	47.1	100	90	85.3	95.8	68	--	100	94.7
% finer than .7mm	100	46	99	89	81	92	57	--	98	94
% finer than .5mm	98	44	98	88	69	90	44	--	97	93
% finer than .35mm	97	42	97	84	52	88	37	--	96	92
% finer than .25mm	95	39	96	82	47	84	32	--	95	89
% finer than .175mm	92	37	93	76	43	77	29	--	91	85
% finer than .125mm	87	34	88	67	41	70.4	27	--	87	80
% finer than .088mm	80	32	82	57	40	--	26	--	78	74
% finer than .0625mm (fine)	67.2	29.8	71.8	45.2	39.3	--	24.9	--	64.4	68.8

	Third Order Ditches			Third Order Rivers			Second Order River
	BE-J-48	N-J-1A	N-J-1A*	Br-BE Morgan Creek	BE-Little Cobb River	LS-Cannon River	LS-Shanaska Creek
% coarser than 1mm (gravel)	14.2	36.7	42.9	18.6	9.2	42.6	36.9
% finer than 1mm	85.8	63.3	57.1	81.4	90.8	57.4	63.1
% finer than .7mm	84	56	53	59	87	46	61
% finer than .5mm	82	40	47	30	77	28	57
% finer than .35mm	78	22	39	16	64	16	55
% finer than .25mm	74	15	32	10	53	12	54
% finer than .175mm	69	12	26	9	49	9	52
% finer than .125mm	65	11	22	7	45	8	50
% finer than .088mm	59	11	20	7	39	7	45
% finer than .0625mm (fine)	46.1	10.9	19.5	6.1	30.9	5.2	39.5

Table XLV. Summary of bed grain size analysis by sediment category for spring of 1979.

Site	% Fine	% Sand	% Gravel
N-C-40A	72.3	27.7	0
N-C-38A	33.5	22.8	43.7
Br-J-29	64.1	35.9	0
Br-C-5	51.8	41.1	7.1
Br-J-30	20.6	68.4	11.0
Br-J-10	65.7	28.2	6.1
BE-C-56	10.4	87.7	1.9
BE-C-5	43.9	53.2	2.9
LS-C-59	68.5	31.5	0
LS-C-58	54.8	39.2	6.0
BE-J-48	49.4	48.6	2.0
N-J-1A	7.4	53.9	38.7
N-J-1A*	9.3	41.7	49.0
Br-BE Morgan Creek	13.1	60.2	26.7
BE-Little Cobb River	37.3	60.1	2.6
LS-Cannon River	8.4	49.7	41.9
LS-Shanaska Creek	32.5	22.0	45.5

Table XLVI. Summary of bed grain size analysis by sediment category for fall of 1979.

Site	% Fine	% Sand	% Gravel
N-C-40A	67.2	32.8	0
N-C-38A	29.8	17.3	52.9
Br-J-29	71.8	28.2	0
Br-C-5	45.2	44.8	10.0
Br-J-30	39.3	46.0	14.7
Br-J-10	70.4	25.4	4.2
BE-C-56	24.9	45.1	30.0
BE-C-5	(not sampled due to road construction)		
LS-C-59	64.4	35.6	0
LS-C-58	68.8	25.9	5.3
BE-J-48	46.1	39.7	14.2
N-J-1A	10.9	52.4	36.7
N-J-1A*	19.5	37.6	42.9
Br-BE Morgan Creek	6.1	75.3	18.6
BE-Little Cobb River	30.9	59.9	9.2
LS-Cannon River	5.2	52.2	42.6
LS-Shanaska Creek	39.5	23.6	36.9

Suspended Load Analysis

Methods

Flow and cross-section integrated water samples were collected at each site at each water quality sampling period for a total of 472 samples. The water samples from each site (and sampling period) were concentrated from their original volume of one to two liters down to approximately 25-30 ml through a series of 24 hour decantations. After each water sample was condensed to 25-30 ml it was transferred to a preweighted drying tin. The tins were heated in a drying oven for 24 hours at 95° C.

The mean, median, and high-low density values for each site were determined as well as a load determination for each sampling period (for each site). This load determination was calculated by multiplying the density (mg/liter) by the flow value (for each of the sampling periods per site). These values were then multiplied by .001 to convert to kilograms. The numbers were still extremely large and so they were further divided by a factor of 10^2.

Samples from the 1st, 32nd, 33rd, and last sampling periods were missing. Data from the first and last periods can be omitted from this segment of the study but adjustments had to be made for those samples which would have resulted from the 32nd and 33rd periods. In order to come up with an "average" estimated load for the various sites at these time periods, the flow values for the 32nd and 33rd sampling periods were averaged (added together and divided by 2) then this average value was added onto both the flow values for the 31st and 34th sampling periods. These "adjusted" flow values for periods 31 and 34 were then used normally to determine load for the various sampling sites within these sampling periods (flow x density (for each site)). In this way, compensation was made for the time that had elapsed and the flow that had passed during that time.

Results

A summary of the results are given in Table XLVII. Within the second order ditches there is a large range of variation in total load. However, closer examination indicates that load and flow show a close relationship. This is further born out by the similarity of means. Ditch LS-C-58 seems to be the exception. The high of 242.6 mg/l indicates the cause of its individuality. Third order ditches and third order rivers (exclusive of LS-Cannon) are higher in load, flow, and mean perhaps reflecting overland runoff. The two rivers which are influenced by lakes (LS-Cannon and LS-Shanaska) are both extremely low in mean load which is to be expected.

Table XLVII. Suspended sediment load analysis by site.

	Second Order Ditches									
Site #	N-C-40A	N-C-38A	Br-J-29	Br-C-5	Br-J-30	Br-J-10	BE-C-56	BE-C-5	LS-C-59	LS-C-58
Mean (mg/l)	49.9	55.4	52.3	37.1	50.5	51.7	43.0	54.5	32.3	77.4
Median (mg/l)	41.0	39.0	44.7	30.8	40.65	40.4	37.1	17.9	23.0	70.3
High (mg/l)	101.9	180.0	206.3	124.1	170.8	226.0	118.8	199.0	153.7	242.6
Low (mg/l)	5.3	9.8	14.3	2.5	6.5	5.6	12.0	5.6	7.3	9.5
# of Samples	14	30	31	14	32	27	31	25	19	28
Load (kg x 10^2)	0.0	3,694.5	3,406.1	100.4	7,693.9	3,423.8	4,265.0	2,653.1	947.7	1,005.8
Flow (100,000 m^3)	0.0	93.9	75.7	5.8	242.0	70.0	107.0	78.3	58.9	17.7

	Third Order Ditches			Third Order Rivers			Second Order River
Site #	BE-J-48	N-J-1A	N-J-1A*	Br-BE(Morgan)	BE-Little Cobb	LS-Cannon	LS-Shanaska
Mean (mg/l)	61.5	65.3	56.0	105.6	53.4	19.1	11.3
Median (mg/l)	47.5	49.7	41.6	90.2	34.6	13.7	9.1
High (mg/l)	365.3	182.8	172.2	272.3	148.9	79.9	23.1
Low (mg/l)	16.2	9.2	6.3	27.1	13.0	5.8	3.9
# of Samples	39	30	29	29	30	31	29
Load (kg x 10^2)	16,472.4	21,231.0	12,456.0	61,629.4	9,711.8	9,499.2	481.5
Flow (100,000 m^3)	260.8	535.3	280.8	482.5	303.4	528.7	45.2

CONCLUSION

The first objective of this study was to determine the extent and location of public drainage in our four county South Central Minnesota study area. This was an essential first step in that this data served both as a factor in selecting water quality sampling sites and as a data base for quantitative geomorphology determinations. It is clear from this study that important decisions regarding wetlands, public waters, water resource planning and agricultural practices are presently being made on a grossly and significantly inadequate and erroneous data base as regards the extent of drainage. Further, the extent of public drainage within South Central Minnesota, as determined in this study, certainly must result in public drainage systems being the dominant surface hydrologic feature.

The second objective, that of documenting the causes and legal history of drainage in Minnesota with emphasis on wet lands status has been completed and is presented in a Minnesota Water Resources Research Center Circular, separate from this report (King, 1979). Drainage law has been traced from 1858 to present showing the interweaving of constitutionality of drainage, public waters, riparian rights, and Minnesota State Statutes Chapter 106.

The objective of determining the quantitative geomorphic nature of public drainage systems has resulted in both a quantification of the geomorphic effects of man's drainage and some guidelines for future quantitative analysis and modeling.

Conclusions drawn from this component of our study are as follows:

1) It was found that 78.8 percent of the drainage ditches in the four counties terminate into rivers and that they more than double the length of the surface fluvial systems.

2) It was found that 28.6 percent of the ditches originated from lakes or lake-marsh environments which indicates a loss of lakes and lakesheds to the fluvial systems.

3) This study has found that artificial drainage ditches are best classified within the second or third order categories of Strahler (1957) and that tile lines probably fit the first order. Further, the closeness of fit of drainage ditch systems to second order natural systems strongly suggests that man has taken an immature lake-marsh environment and within 100 years achieved a geomorphically mature fluvial landscape.

4) Since some ditches are tributary to other ditches it is important to follow Strahler's classification scheme when comparing ditches

or attempting to model effects. This mainly involves a determination as to whether a particular drainage ditch is a second or third-order system.

The survey of the botanical nature of the created riparian strip associated with open drainage ditches found that although there were some significant differences in the drainage ditch morphology of some counties the most important factor was county ditch management policy. Given the linear extent of open ditches, as documented in Chapter 1 of this report, it does seem reasonable that the management of the riparian zone should be for agriculture, wildlife, and water quality improvement. At present it is managed strictly for agriculture. As a rule limited and monotinous vegetation is maintained by herbicides. Further research is needed here.

The assessment of the effects of agricultural drainage on water quality and quantity of the receiving bodies of water involved the close monitoring of 17 sites during the ice free season of 1979. Ten of the sites were second order ditches, three were third order ditches, three were third order rivers and one was a second order river. Utilizing four Minnesota Pollution Control Agency water quality monitoring stations (BE-0, Mi-133, CO-0.5, and Mi-88) from WRRC Circular by Feind, Braaten, and Quade (1979) one concludes the following:

1) The organic nitrogen levels in the Minnesota and Blue Earth Rivers range in monthly means from about 1.2 to 2.0 mg/liter. However, ditches range from 1.1 to 2.5, rivers with lakes from 2 to 2.5, and rivers without lakes are around 0.9 mg/liter. Certain ditches and rivers with lakes tend to be higher. Interestingly the concentration of organic nitrogen changes little from the source of the Minnesota River to the end indicating an equilibrium.

2) Nitrate nitrogen exhibits the opposite of the above with regards to rivers. The rivers with lakes have a mean of 3 mg per liter whereas those without lakes are close to 20 mg per liter. Drainage ditches show variation and the seasonal means range from 8 to 25. Within the Minnesota and Blue Earth Rivers the seasonal means within our study area range from 0.9 to 5.8 mg per liter. Within the major Minnesota River system there is a definite increase in nitrate nitrogen as one proceeds down river. A major increase is observed on entering South Central Minnesota from the west with the Blue Earth River from the south being a second major source (Feind, et. al., 1979).

3) Total orthophosphate in mg per liter reveal similar concentrations between ditches and rivers (0.1 to 0.24). The greatest variation is seen between the second order river from a lake (0.064) and a third order river from a series of lakes (0.238). Total phosphate in the Minnesota River system reveals a great deal of flashiness from site to site but an overall equilibrium from upper to lower reach (Feind, et. al., 1979).

The degree of variation from ditch to ditch and ditch to river for water quality revealed that flow influenced chemical load but not uniformly between chemical parameters. Flow was more directly related to total chemical load in ditches than in the rivers sampled. The Cannon River had the largest total volume of flow and the largest chemical load for total orthophosphate-phosphorous and total Kjeldahl-nitrogen but the smallest chemical load for rivers for nitrate-nitrogen. Further, nitrate-nitrogen concentrations showed less seasonality than the other chemical parameters.

Nutrient loading of ditches within our region varied tremendously by season, which clearly indicated the need for sampling during all seasons to obtain a limnological appreciation of the system.

When the data from Quade for ditch LS-C-59 and the Cannon River from 1975 and 1976 were compared to this study, nitrate-nitrogen was higher in the ditch for both studies and the river was higher in total orthophosphate-phosphorous for both studies. Total load was greater for all parameters in the wet year 1979 for both ditch and river.

When the data for the Cannon River and ditch LS-C-59 were compared to the other rivers and ditches in this study, the conclusion was that the Cannon River should not be used as a baseline for all rivers in South Central Minnesota and ditch LS-C-59 was only one ditch which could not by itself represent water quality of drainage ditch systems in South Central Minnesota.

The objectives of establishing management guidelines and creating predictive models of the effects of agricultural drainage on the water quality of receiving bodies is still in an embryonic stage. The degree of variation among similar order ditches and rivers has resulted in a lack of predictability. It is our opinion that the "stream-order" system and its associated topographic characteristics is the most limnologically meaningful approach to follow.

The six most significant findings of this study which should impact on needed follow up studies are:

1) That at present public drainage systems have approached what would be expected under natural systems given time (stream order quantitative geomorphology analysis). An interesting question is the potential impact of pushing drainage beyond this point.

2) That the present extent of drainage information is grossly inadequate for research and planning.

3) That the vegetation along drainage ditches is monotonous and limited botanically due to county management.

4) That the water quality conclusions from a previous single ditch-river study (Quade, et. al., 1979) are not applicable to the region as a whole.

5) That individual drainage systems show a great deal of variability with regards to nutrient concentrations, loads, flow, and seasonality of loading. This requires each ditch system at present to be considered unique.

6) That the most significant nutrient loading chemical parameter to the Minnesota River is nitrate-nitrogen. This loading appears to be from both ditches and those tributary rivers without lakes. Organic nitrogen shows little variation and downstream impact. Total phosphate, although showing a great deal of flashiness has little overall downstream impact due to an apparent overall equilibrium. Finally, as regards flow some ditches are flashy in response to a storm event and some are more conservative. The cause of this difference is unknown at present.

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