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ABSTRACT—Discharge was monitored on 13 agricultural drainage ditches and 4 small rivers in south central Minnesota. Derived data were categorized by response to hydrologic events and stream order. Stream order was found to be the most reliable predictor of hydrologic event response. Peak flows in drainage ditches were found to correspond to peak flows in rivers.

During the last century there has been a massive amount of drainage ditching for agricultural purposes in south central Minnesota. The extent of surface drainage by man-made systems has been documented as 46 percent in Le Sueur County, 46 percent in Brown County, 50 percent in Blue Earth County, and 58 percent in Nicollet County (Dunsmore and Quade, 1979a; Dunsmore, Oelerich and Quade, 1979; Dunsmore and Quade, 1979b; Dunsmore and Quade, 1979c).

There are major questions which still exist as to the effects of these drainage systems. This paper reports 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 the flow in ditches different from those in rivers? Are the characteristics of flow in small ditches different from those in large ditches? Do man-made drainage ditches contribute to flooding of major rivers?

Low Flow Techniques Applied to Determine Flow

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.

Cross sectional area was determined by one of two methods. For some ditches and rivers cross-sectional area maps were developed with transit and rod, and water level measurements were used 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 when compared at a single site were found to be in close agreement.

	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 I. Flow characteristics of rivers versus agricultural drainage ditches.

Velocity of flow also was determined by one of two methods. Whenever possible, velocity was measured 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, as compared by Quade, et al (1979), 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 available methods. Instantaneous discharge rates were derived using the formula:

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

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 it was not possible to take either velocity measurements or Embody measurements. 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

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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.

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

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

Hydrologic Response and Stream Order Utilized for Data Comparison

In comparing hydrologic response and mean total accumulated discharge of rivers to ditches, it was found that the rivers tended to be more flashy than the ditches (Table I). 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 II gives data on three ditch-river combinations 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 III). 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 run-off. In contrast, the third-order ditches showed sustained flow throughout the study period.

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 ice-bound until later. With few exceptions we found that during the high-water period of August, the peaks in the ditches preceded those in the rivers by a few days.

	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%
	LeSueur 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%
	LeSueur 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 II. Flow characteristics of three Ditch-River pairs.

Stream Order Most Significant to Flow

In interpreting these results, it must be understood that it is impossible to categorize absolutely waterways as man-made ditches or "natural" rivers in this study area. 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. It thus seems appropriate to consider ditches and rivers not as rigidly exclusive entities but rather as a continuum.

It was found 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 predominately second-order. When the ditches were broken down into second-order and third-order categories, the results for the third-order ditches corresponded more closely to the rivers. This suggests that river-ditch classification is of less importance than order in determining or predicting flow characteristics.

Because ditches were presumably fed mostly by tile lines while rivers were fed to a greater extent by surface runoff, it was hypothesized that peak discharges in the ditches would lag behind those in rivers. However, it was indicated that peaks occurred simultaneously or the ditches peaked slightly ahead of the rivers, so it may be that ditching contributes to peak flows in the major rivers. Although Moore and Larson (1977) report that the advent of drainage projects has not contributed significantly to flooding in the Minnesota River, this study concludes that the existence of ditches has not ameliorated flooding either.

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	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 III. Comparison of flow in second versus third order drainage ditches.

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