THE WATER QUALITY PERFORMANCE OF SELECT URBAN RUNOFF TREATMENT SYSTEMS

PART ONE OF A REPORT TO THE LEGISLATIVE COMMISSION ON MINNESOTA RESOURCES

by
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Judith A. Hartsoe

METROPOLITAN COUNCIL
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METROPOLITAN COUNCIL

The Metropolitan Council coordinates the planning and development of the seven-county Metropolitan Area. The Council is authorized by state and federal laws to plan for highways and transit, sewers, parks and open space, airports, land use, air and water quality, health, housing, aging and arts.

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SUMMARY

The following report presents the findings of a Metropolitan Council study of the water quality effectiveness of five urban runoff treatment facilities. A companion report has also been prepared to address the effects of watershed runoff treatment on lakes. Both reports were funded by the Legislative Commission on Minnesota Resources (LCMR).

The most recent data reported herein are from four sites located in the Ramsey-Washington Metro watershed. The sites and the facilities studied are:

- Lake Ridge detention pond, Woodbury;
- McKnight Basin detention ponds, Maplewood;
- Tanners Lake wetland, Oakdale; and
- Carver Ravine wetland/detention system, Woodbury.

In addition to these four sites, the results of a fifth study that was completed in 1988 will be discussed. The fifth facility is a detention/wetland system tributary to Lake McCarrons in Roseville. This project was funded by the U.S. EPA and the City of Roseville.

The period of data collection for the LCMR portion of the study was very hot and dry. A drought condition existed for most of the sampling period, limiting available rainfall events that could be sampled. It is suspected that the drought resulted in more highly concentrated runoff moving into facilities that contained reduced permanent pools. The Tanners Lake wetland had essentially no permanent pool during most of the sampling period.

Each of the facilities reduced the inflow of pollutants to some degree, and in this respect, they all serve to reduce pollution of receiving waters. The effectiveness of the various systems, however, is quite different. The most effective system is the McCarrons facility, which was designed specifically to improve the quality of water flowing into Lake McCarrons. The tandem approach of pre-settling runoff before discharging it to wetlands seems to work extremely well and will undoubtedly extend the life of the wetland.

The facilities located at Lake Ridge and McKnight Basin also worked well most of the time for most pollutants. The Lake Ridge and McKnight Basin ponds are well designed and perform close to the level of the McCarrons system for all particulate-associated pollutants. These systems, however, do not treat the soluble nutrients as well as McCarrons. The vegetative "polishing" provided by the McCarrons system could well be the reason that this difference occurs.

The Tanners Lake wetland was altered by the addition of "permeable weirs" or small, leaky check dams to slow water down as it flows through the wetland. The system also contains small sediment basins at the head and mouth of the wetland. The Tanners system does a fairly good job of removing particulate material and it removes nutrients quite well at times, but overall nutrient removal is not good. The additional monitoring of this system by the Ramsey-Washington Metro Watershed District will extend the data base beyond the limited amount that we were able to collect.

The main conclusion of the study is that facilities must be designed properly and maintained well in order for them to perform with any level of water quality effectiveness. Placing treatment components in tandem worked extremely well for the McCarrons detention/wetland system and the McKnight double detention ponds, but not well for the Carver Ravine wetland/detention system that was overwhelmed by flow. Simple additions to existing facilities, such as vegetative borders, floatables skimmers, sediment forebays and variable release outflow structures, could improve the water quality effectiveness of existing water quantity facilities.

Lakes in the region have borne the impact of dirty runoff, and, therefore, cannot be expected to rebound rapidly when watershed management programs are instituted. Such programs, however, are an important first step towards reducing the inflow of pollutants to our lakes, and must be pursued, supplemented by in-lake treatment when conditions call for them. Watershed management additionally removes other pollutants , such as sediment and toxic contaminants, that impact receiving waters.

INTRODUCTION

PURPOSE

Since it was designated in 1976 as the areawide water quality planning agency for the Metropolitan Area under section 208 of the Clean Water Act, the Metropolitan Council has been studying the occurrence and control of nonpoint source pollution. As research on nonpoint source pollution proceeded, it became apparent that methods and mechanisms for control were not well understood. Little data existed to evaluate the effectiveness of so-called "best management practices", or BMPs, and optimistic claims were being made with no supporting evidence. Furthermore, there was a poor understanding of the effects of these facilities on mitigating the impacts of runoff on lake water quality.

As a result of this data void, the Council embarked on a program to document the effectiveness of commonly used management practices (this report) and their impact on lakes (Osgood, 1989). In the Metropolitan Area, the two most commonly used techniques for runoff control are detention in ponds and wetland treatment; this is, therefore, where our efforts have been focused. The first Council effort in looking at management practices was in 1982 when the Council joined with the U.S. Geological Survey (USGS) to study the impact of detention and wetland treatment on the quality of lakes (Metropolitan Council 1982). Following this study, the Council published a series of "Surface Water Management" and interpretive lake reports that addressed the facets of good surface water management and water quality control. In 1986, the Council cooperated with the City of Roseville on a water quality study of a combined detention pond/wetland treatment system tributary to Lake McCarrons and the effects of this system on the quality of the lake (Oberts and Osgood, 1988). This system proved to be very effective with respect to runoff treatment, but no definitive conclusions were reached on improvements in the lake. The results of the McCarrons Wetland Treatment System will be further analyzed throughout this report because of their pertinence to the topic being presented.

In 1987, the Council received state funds to obtain further information on specific management practices, namely mainstem detention, wetland treatment/detention (the reverse of the McCarrons system), wetland alteration and well designed detention. Each of these practices are described and evaluated in this report, and conclusions will be drawn on the design and use of facilities to control urban runoff from rainfall and snowmelt events. A companion report (Osgood, 1989) addresses the lake aspects of the study.

SITE DESCRIPTIONS

Data for this study were collected at four management facilities, all located within the Ramsey-Washington Metro Watershed District in the eastern part of the Metropolitan Area (Figure 1 and Table 1). The location of the McCarrons Wetland Treatment System is also shown of Figure 1. Detail descriptions of the watershed physical and demographic features are given in Appendix A. The following text describes each of the facilities and summarizes data collection at each.

Figure 1. LCMR SITE LOCATION MAP

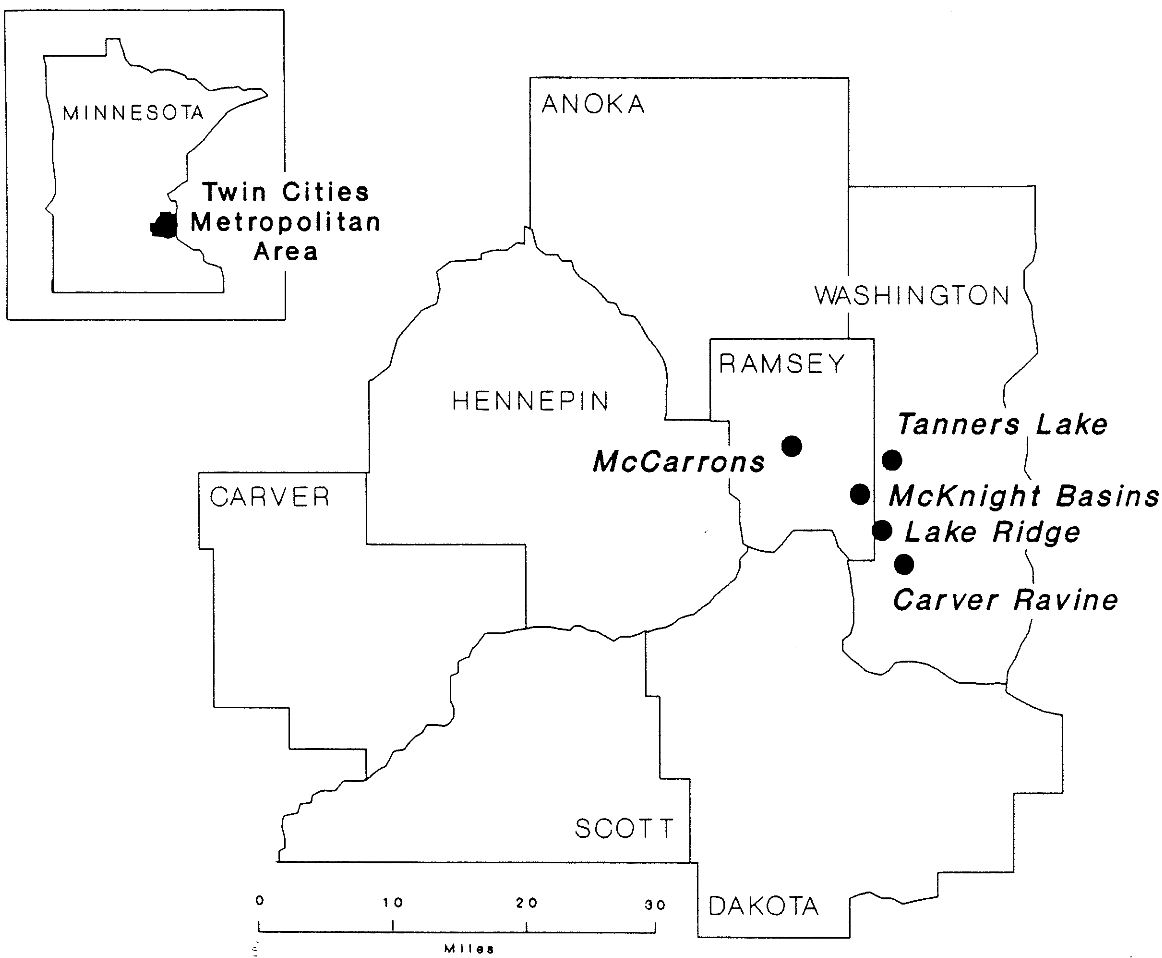


TABLE 1. DESCRIPTION OF LCMR SAMPLING SITES.

Site	Drainage Area (acres)	Effective Drainage Area and Subwatershed Name*	Dominant Land Use	Description
Lake Ridge (inflow)	531 LRI	315 LRIE	grassland/ residential	Treatment system inflow through 48" pipe
Lake Ridge (outflow)	551 LRO	335 LROE	grassland/ residential	Treatment system outflow over weir
McKnight Basin (inflow)	5217 MBI	636 MBIE	grassland/ residential/ wetland	Treatment system inflow over weir
McKnight Basin (outflow)	5671 MBO	725 MBOEN	grassland/ residential/ woodland	Treatment system outflow through 45" X 73" arch pipe
Tanners Lake (inflow)	1134 TLI	413 TLIE	grassland/ wetland/ residential	Treatment system inflow through 48" pipe
Tanners Lake (outflow)	1258 TLO	537 TLOE	grassland/ wetland	Treatment system outflow through 24", 42"and 42" pipes
Carver Ravine (inflow)	170 WRI	170 WRIT	residential	Treatment system inflow through 36" pipe
Carver Ravine Pump	248 WRIP	248 WRIP	grassland/ residential	Pumped inflow through 16" pipe
Carver Ravine (outflow)	184 WRO	432 (with pumped inflow) WROP	grassland/ residential	Treatment system outflow through 15" pipe

* Drainage area when entire watershed not contributing, i.e., part of watershed cutoff from outflow.

Carver Ravine Wetland/Detention Facility (Sites WRI, WRIP and WRO)

The Carver Ravine study site, tributary to Carver Lake, was installed in 1978 by the City of Woodbury. The layout of the treatment facility is shown in Figure 2 and a bathymetric map is contained in Appendix B. The Carver Ravine site was not one included in the initial site selection, but was added in April 1988 after a site in Lakeville was abandoned because of delays in construction of a housing project. As a result, there were fewer data collected at this site than the others (Table 2). Data collection at the Carver Ravine facility began with the April 26-27, 1988 rainfall event and extended through the final monitored rainfall event in April 1989.

The facility consists of a small wetland and detention pond, in-line. The wetland is a marsh approximately 3.9 acres in size, dominated by willows at the point of inflow, and later by cattails and reed canary-grass as flow proceeds downstream. After the rather flat canary-grass stand, a small (0.4 acre), shallow (maximum depth 2.1 feet) detention pond is encountered. The entire area of the combined wetland/detention facility is 4.3 acres. The outflow from the system is via a 15 inch culvert that discharges to Carver Ravine and then to Carver Lake.

Evaluation of this facility is complicated by the fact that there is a pumped discharge into the study watershed when a bordering closed-end detention facility reaches a prescribed elevation. The study facility directly drains a 170 acre watershed. The pumped discharge adds another 262 acres as direct inflow to the wetland/detention system. Without the pumped input, the direct flow between inflow and outflow is only 14 acres. Contributions from the pumped storage appeared to occur quite unpredictably, apparently a function of total rain (usually any amount over 0.33 ") and previous period without pumping (i.e., volume allowed to build in the pond). Further complicating the monitoring was the routine weekly pump testing that contributed a volume of water enough to often qualify as an "event". As a result of the unexpected pumped discharges, sampling at this facility became more labor intensive because of the need to have field staff on-site to record pumping times and subsample inflows for water quality. Further discussion on the site will occur in the results section.

Lake Ridge Detention Pond (Sites LRI and LRO)

The Lake Ridge detention pond was installed in 1981 by the City of Woodbury in conjunction with the construction of the Lake Ridge Condominiums. The facility consists of a 0.94 acre pond (Figure 3), draining a watershed 315 acres in size. An additional 20 acres drains into the pond between the inflow culvert and the outflow. The pond has a permanent storage volume of two acre-feet, and is generally designed according to the recommendations contained in EPA guidelines (Driscoll, 1983) and suggested by Walker (1987). A bathymetric map of the pond is contained in Appendix B.

Lake Ridge was on the original site selection list, and was the first facility equipped in the Fall of 1987. Data collection began with a rainfall event in October 1987 and ended with the early April 1989 rainfall event (Table 2).

Data collection at the site was not without complication. Because of the extremely dry year (1988), the upper 216 acres of the watershed often did not discharge enough to flow out of a mid-watershed wetland. Contributing watershed size has been adjusted for those events when contributing area was reduced.

Figure 2. MAP OF CAVER RAVINE DETENTION SYSTEM SHOWING MONITORING SITES AND SEDIMENT SAMPLE LOCATIONS

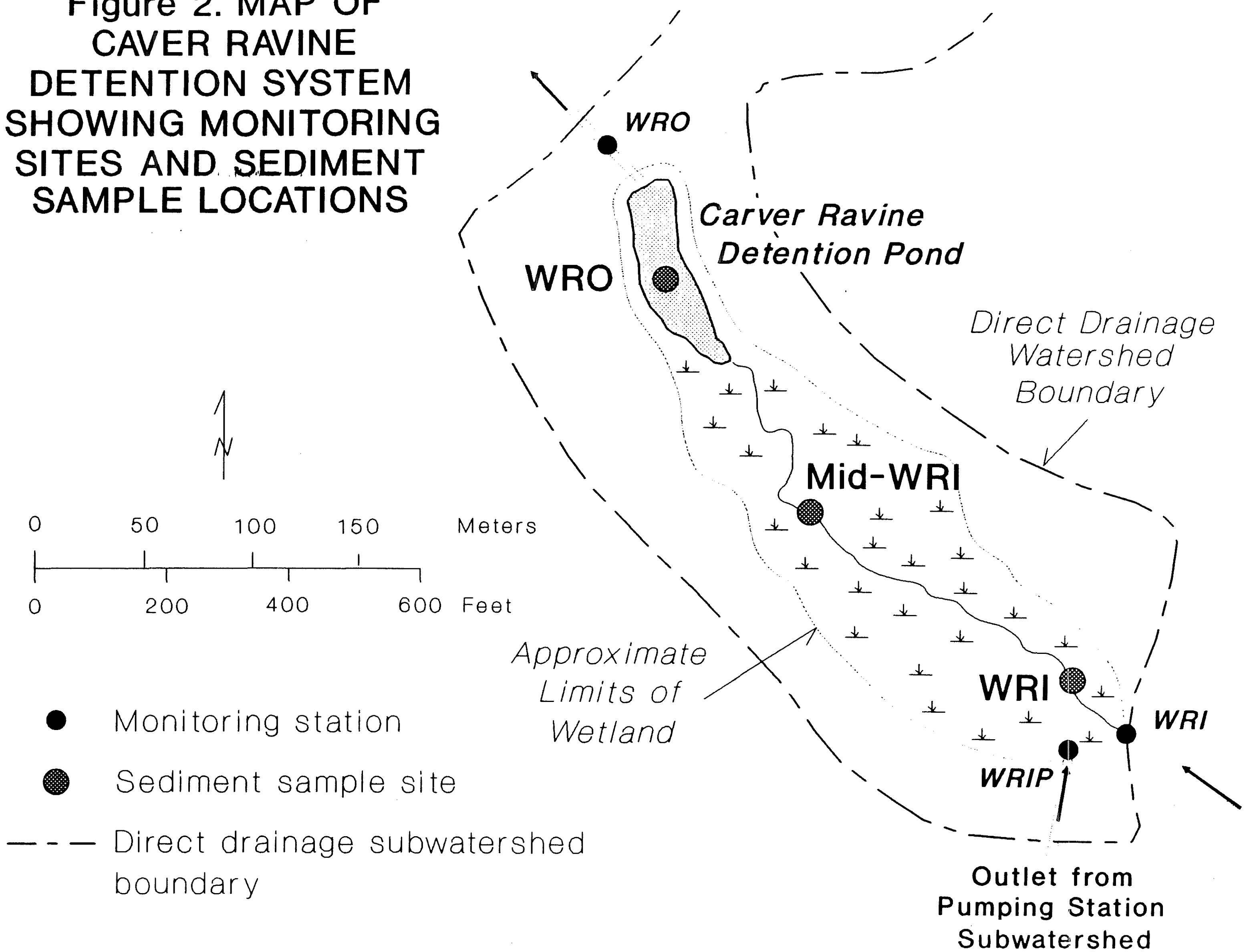


TABLE 2. SAMPLING HISTORY OF THE LCMR SITES.

DATE	COMMENTS	SITES MONITORED
1987		
Oct. 5	Baseflow	MBI,MBO
Oct. 15-16	0.72"	LRI,LRO,MBI,MBO
		TLI and TLO grab samples
Oct. 20	Sediment	LRI,LRO,MBI,MBO,TLI,TLO
Nov. 15-18	0.24"	LRI,LRO,MBI,MBO
1988		
Feb. 18-19 melt	0.40E*	LRI,LRO,MBI,MBO
Feb. 26-27 melt	0.20E	LRI,LRO,MBI,MBO
Feb. 28- March 2 melt	0.10E	LRI,LRO,MBI,MBO
March 3-6 melt	0.10E	LRI,LRO,MBI,MBO
March 8	0.16"	LRI,LRO
March 21	Baseflow	LRI,LRO,MBI,MBO,TLI,TLO
March 24-25	0.77"	LRI,LRO,MBI,MBO
April 2-3	0.26"	LRI,LRO
April 26-27	0.45"	LRI,LRO,WRI,WRO
	0.36"	MBI,MBO
May 8	2.45"	LRI,LRO,MBI,MBO,WRI,WRO,
		WRI pump
May 9	Recess.Limb	LRI,LRO,MBI,MBO
May 13	Construction	TLO
June 2	0.15"	MBI,MBO
July 9	0.18"	TLI,TLO
July 12	Baseflow	All
July 12	Sediment	WRI,WRO
July 13	0.51"	LRI,LRO
	0.52"	MBI,MBO
	0.50"	TLI,TLO,WRI,WRO
July 15-16	0.15"	MBI,MBO
July 20	0.36"	LRI,LRO
	0.61"	MBI,MBO
	0.37"	TLI,TLO
	0.42"	WRI,WRO
Aug. 4-5	1.17"	LRI,LRO
	1.07"	MBI,MBO
	0.93"	TLI,TLO
	1.24"	WRI,WRO,WRI pump
Aug. 7-8	1.40"	WRI,WRO,WRI pump
Aug. 11	0.75"	LRI,LRO
	0.49"	MBI,MBO
	0.50"	TLI,TLO
	0.91"	WRI,WRO,WRIpump

TABLE 2 (continued). SAMPLING HISTORY OF THE LCMR SITES.

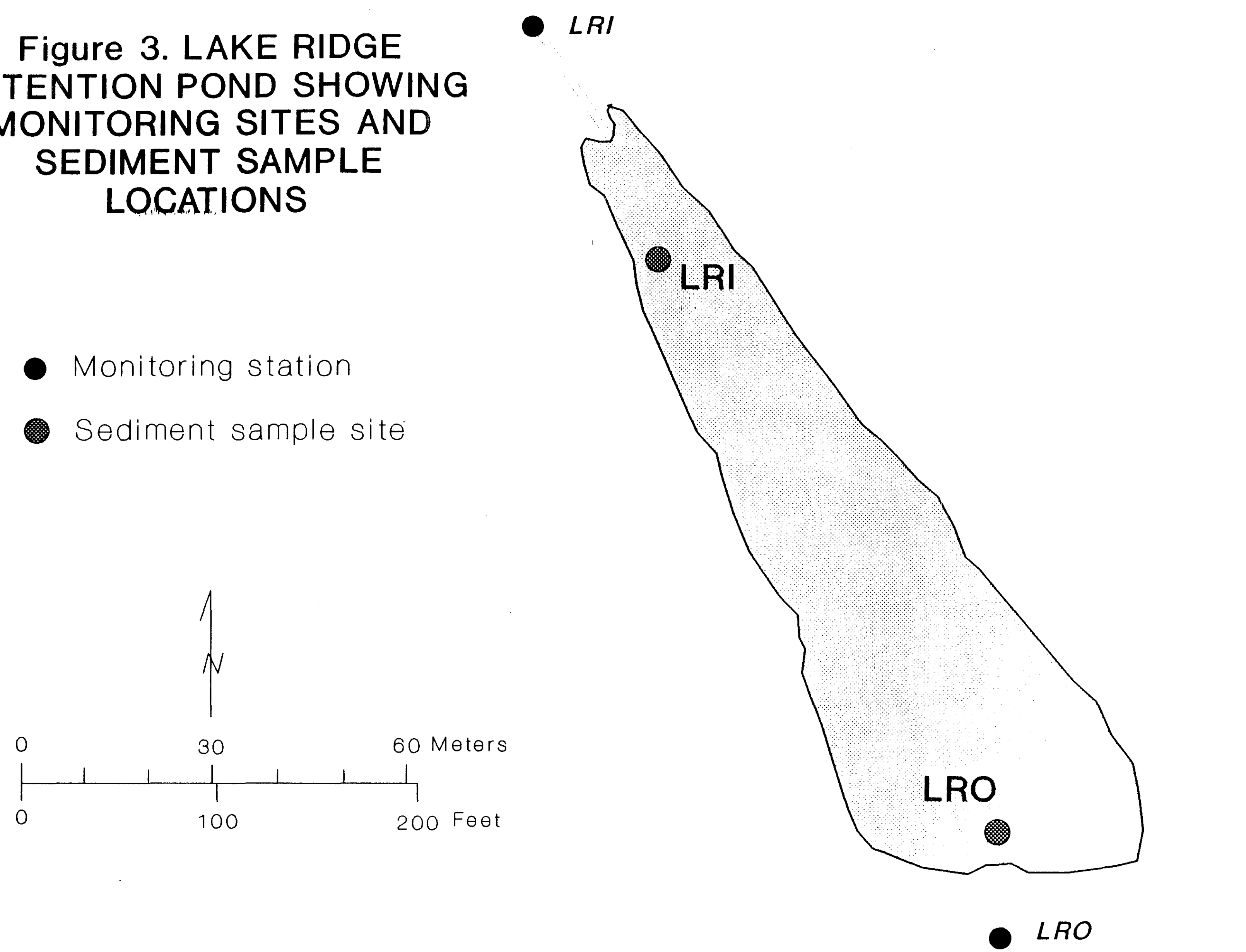
DATE	COMMENTS	SITES MONITORED
Sept. 1	0.45"	LRI,LRO
	0.27"	MBI,MBO
	0.28"	TLI,TLO
	0.45"	WRI,WRO,WRI pump
Sept. 14	Baseflow	LRI,LRO,MBI,MBO,WRI
Sept. 18	0.32"	LRI,LRO
	0.39"	WRI,WRO
Sept. 19-20	1.82"	MBI,MBO
	1.59"	TLI,TLO
Sept. 27	0.55"	LRI,LRO
	0.43"	MBI,MBO,TLI,TLO
	0.50"	WRI,WRO,WRI pump
Oct. 20	0.34"	LRI,LRO
	0.35"	MBI,MBO
	0.38"	TLI,TLO
	0.29"	WRI,WRO
Oct. 2	Baseflow	TLI,TLO
Nov. 4	0.70"	MBI,MBO
	0.65"	WRI,WRO
Nov. 15-16	0.81"	LRI,LRO
	0.77"	MBI,MBO
	0.65"	TLI,TLO
	0.91"	WRI,WRO
Dec. 14	Baseflow	LRI,LRO,MBI,MBO,TLI,WRI
1989		
Feb. 1 melt	0.0E	WRI,WRO
March 9-11 melt	0.4E	LRI,LRO,WRI,WRO
March 20	Baseflow	LRI,LRO,MBI,MBO
March 24-26 melt	0.1E	LRI,LRO,WRI,WRO,WRI pump0.13"
March 26-29 melt	0.5E	LRI,LRO,WRI,WRO,WRI pump
	0.04" rain	
March 23-25 melt	0.1E	MBI,MBO
	0.13" rain	
March 25-28 melt	0.4E	MBI,MBO,MB side
	0.08" rain	
March28-30 melt	0.2E	MBI,MBO,MB side
	0.04" rain	
March 30- April 1 melt	0.03"	MBI,MBO,MB side
April 1-3 melt	0.08"	MBI,MBO
April 3-5 melt	0.46"	MBI,MBO
April 5-11 melt	0"	MBI,MBO

TABLE 2 (continued). SAMPLING HISTORY OF THE LCMR SITES.

DATE	COMMENTS	SITES MONITORED
March 23-25 melt	0.1E 0.13" rain	TLI,TLO
March 25-27 melt	0"	TLI,TLO
March 27-29 melt	0.4E 0.01" rain	TLI,TLO
March 29-31 melt	0.1E 0.07" rain	TLI,TLO
March 31- April 2 melt	0.1E 0.02" rain	TLI,TLO
April 2-4 melt	0.42" rain	TLI,TLO
April 4	0.32"	LRI,LRO
	0.37"	WRI,WRO,WRI pump
April 5 melt	0"	MBI,MBO
April 5	Baseflow	WRI,WRO
April 12	Baseflow	TLI,TLO
April 14 melt	0"	MBI,MBO

* E = equivalent moisture of melt in inches

Figure 3. LAKE RIDGE DETENTION POND SHOWING MONITORING SITES AND SEDIMENT SAMPLE LOCATIONS



McKnight Basin Detention Ponds (Sites MBI and MBO)

The largest facility studied was the three-pond McKnight Basin system installed by the Ramsey County Parks Department and the Ramsey-Washington Watershed District in 1982-83. This facility consists of two primary ponds (1 and 2) and a third pond (3) that seldom overflowed during our study (Figure 4). The facility is a mainstem detention system directly in the channel of the highly erosive Battle Creek. The two primary ponds total 5.5 acres and have a permanent storage volume of 13.2 acre-feet. A bathymetric map of the two primary ponds is contained in Appendix B.

As with some of the other systems, the area draining to the McKnight Basin was not constant for every event. Battle Creek Lake lays upstream of the detention ponds. During a substantial part of 1988, the lake did not have water flowing from it. This in effect cut off the entire upper portion of the Battle Creek watershed from the detention facility. A further watershed adjustment was needed for the third pond, which flowed into the system on rare occasion, adding about another 300 acres of watershed.

The McKnight Basin system was another of the originally selected sites. Data collection began there with baseflow sampling in early October 1987, followed by the October 15-16, 1987 rainfall event and continued throughout the large snowmelt of 1989 (Table 2).

Tanners Lake Wetland (Sites TLI and TLO)

A wetland area tributary to Tanners Lake from the north was altered in 1987-88 in order to detain runoff for a longer period of time. The Ramsey-Washington Metro Watershed District undertook the project because the wetland, with channelized flow, was ineffective in treating runoff coming from the largest single area draining to the lake. The project consists of the installation of two "permeable weirs" or leaky check-dams installed perpendicular to flow (Figure 5). The weirs are constructed of treated timbers that are installed with a small (0.25") gap between them. The entire weir structure is underlain by gravel that filters infiltrating water. A schematic of the weir structure is shown in Figure 6. A bathymetric map of the upper sedimentation basin is contained in Appendix B. There is no permanent storage in the wetland.

Construction of the Tanners Lake wetland facility was delayed slightly at the beginning of the Council's sampling study. The facility was not actually completed and relatively stabilized until the early summer of 1988. At this time, the drought of 1988 was already well established. As a result, the Tanners Lake site was monitored for a period of less than one year (Table 2), plus a baseflow sample in March 1988 and some construction related sampling in May 1988. The Watershed District has continued the monitoring program on the facility as part of a study of Tanners Lake.

As with the Lake Ridge and McKnight Basin sites, dry weather resulted in a decrease in contributing watershed because flow was not sufficient enough to overflow a mid-watershed wetland. The appropriate adjustments have been made in presenting the data.

Figure 4. McKNIGHT DETENTION PONDS SHOWING MONITORING SITES AND SEDIMENT SAMPLE LOCATIONS

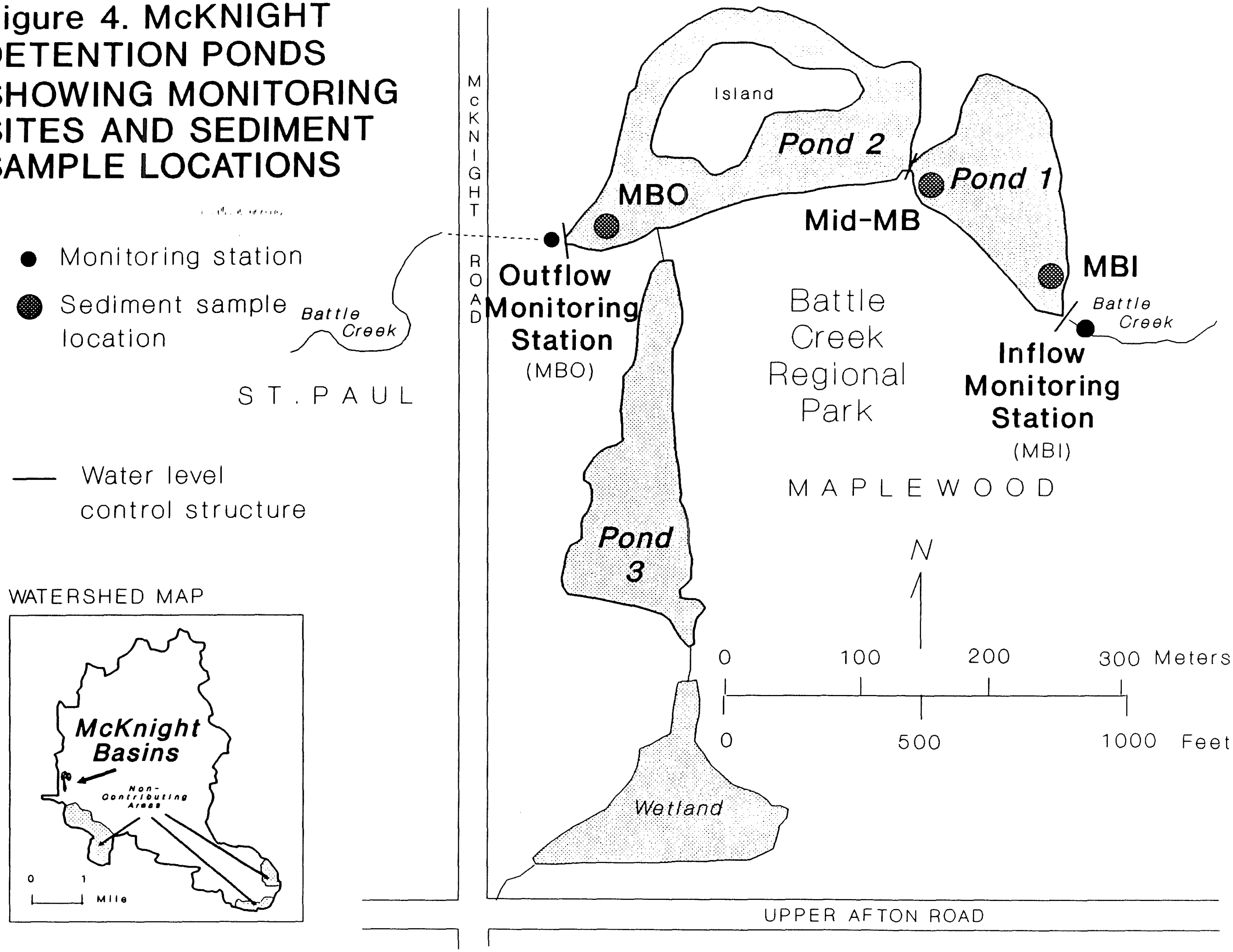


Figure 5. TANNERS LAKE WETLAND TREATMENT SYSTEM SHOWING MONITORING SITES AND SEDIMENT SAMPLE LOCATIONS

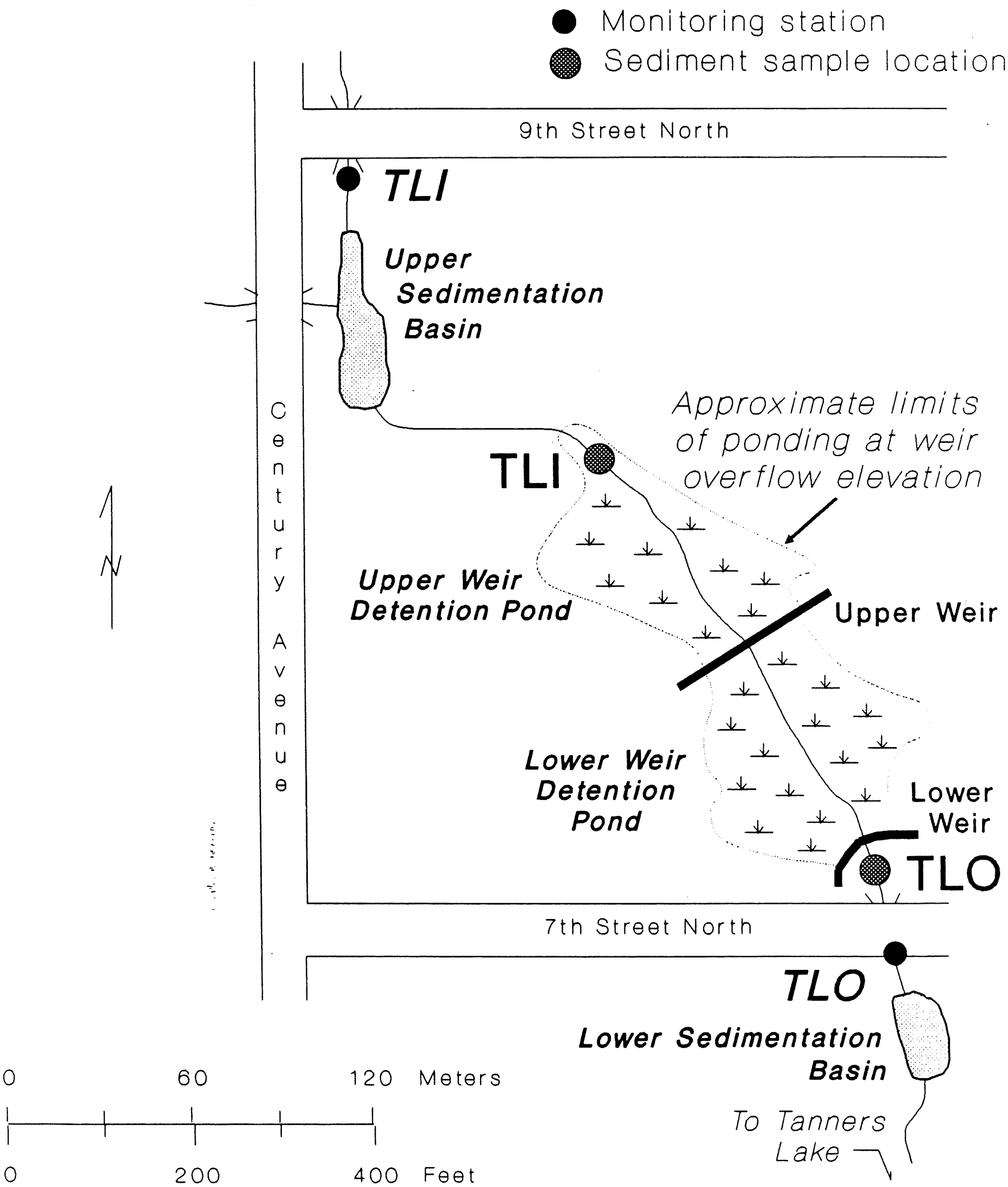
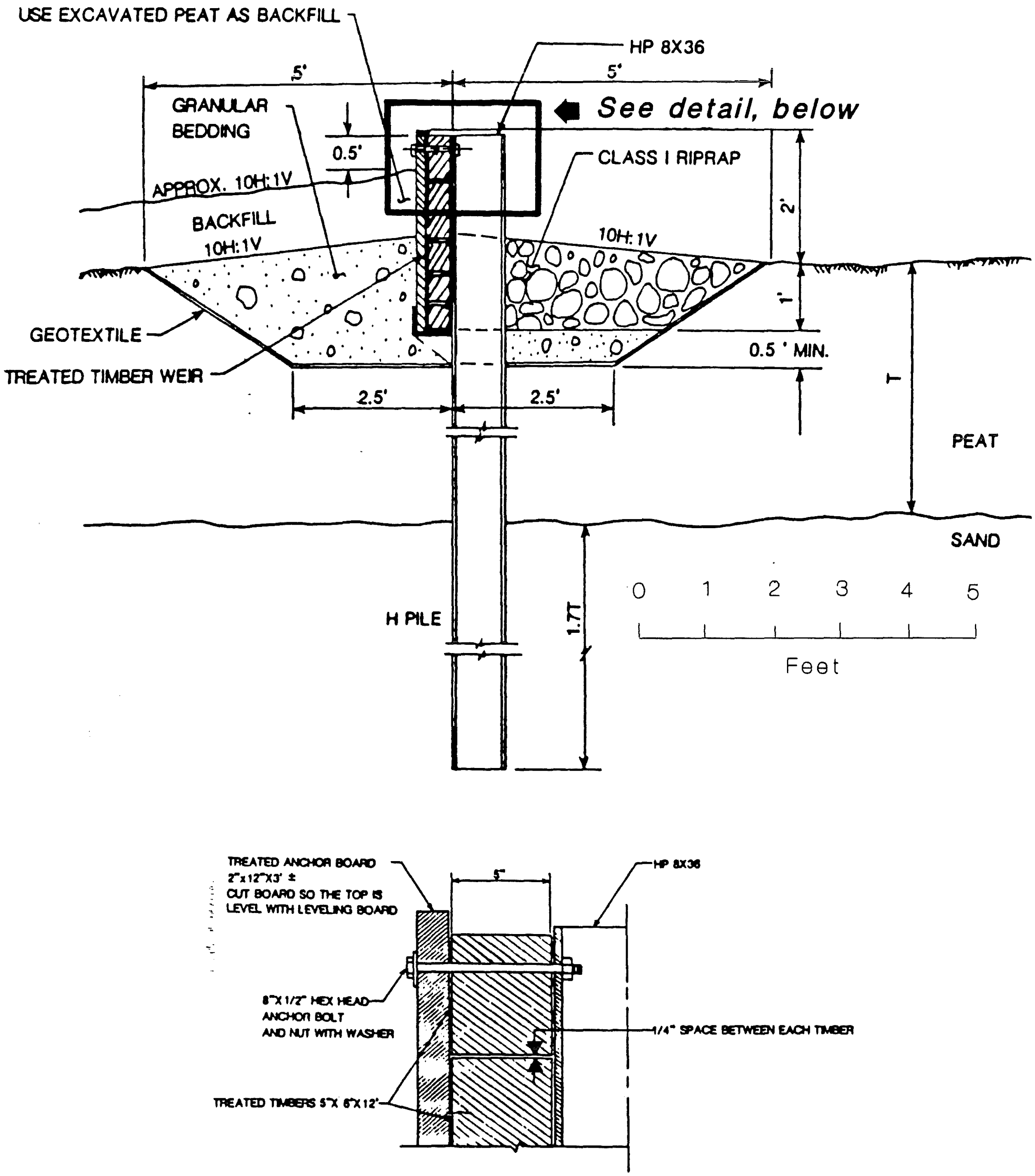


Figure 6. CROSS-SECTION OF TANNERS LAKE WEIR STRUCTURE



Graphic Source: Barr Engineering Co., Minneapolis, Mn.

CLIMATOLOGICAL CONDITIONS

Precipitation during the period of study was well below normal. Slightly above normal precipitation occurred in September and November 1988, while August 1988 had above normal rainfall at the two Woodbury sites (LRI/O and WRI/O); otherwise, the precipitation condition could be considered as drought. Figure 7 compares the precipitation at the four sites with normal conditions at the Minneapolis-St. Paul International Airport as compiled by the U.S. Department of Commerce, National Oceanic and Atmospheric Administration (NOAA), Environmental Data and Information Service, National Climatic Center. The long-term average monthly rainfall is based on data collected at or near the airport since 1891. The snowfall equivalent data is based on data collected from 1939 to present.

Each monitored watershed had one precipitation gauge (tipping bucket rainfall collector). The daily rainfall data for each recording site can be found in Appendix C (Table C1). Table C2 summarizes by month and site the amount of rain that fell during the study. Snowfall is not included in these figures. Figures C1-C4 show the individual rainfall events for each site.

The majority of storms that occurred during the sampling period were associated with fronts that moved from northwest to southeast. These storms generally dissipated and broke apart into small cells as they moved easterly over the central portion of the Twin Cities. The result was that substantial variability exists among the four gauges noted above.

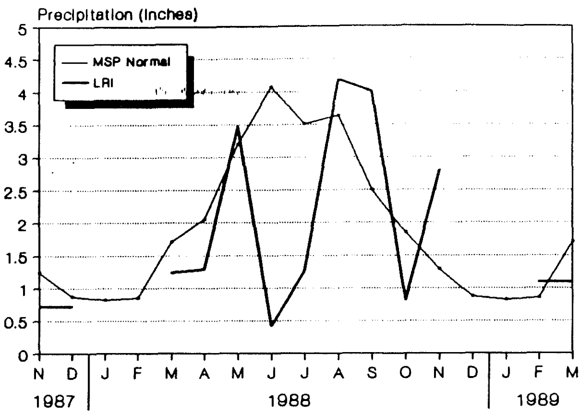
The majority of the rainfall runoff sampling was completed in 1988, when seven of the 12 months had below normal precipitation. The dry year was largely the result of spring and summer months with far less precipitation than normal. The yearly total rainfall at all four sites fell well below the airport average of 26.36 inches. The largest single event of the study occurred on May 7-9, 1988, when an average of 3.33 inches fell over a three day period. The most intense part of this rainfall event occurred on May 8, 1988 when an average of 1.49 inches fell over a two-to-three hour period.

The winter of 1987-1988 was just below normal, with 42.5 inches of snowfall (16.7 cm) recorded at the airport. This is compared to the long-term airport average of 49.9 inches (19.6 cm). The winter of 1988-1989 had 70 inches (27.5 cm) of snowfall.

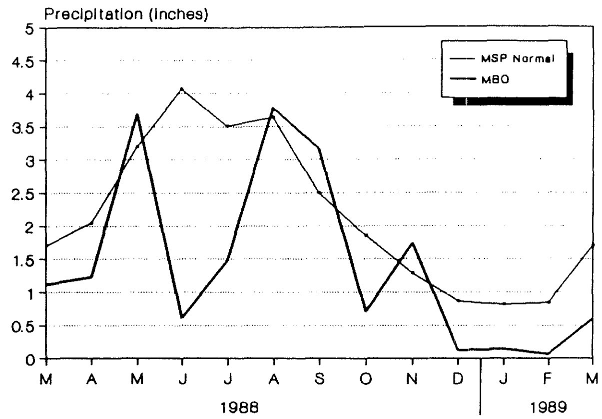
Since the monitoring sites were installed anywhere from October 1987 to June 1988, each had its own range of operation. The number of rainfall events over 0.10 inches (2.5 mm) during the study period was 46 at LRI, 44 at MBO, 37 at TLI and 34 at WRO. Figure 8 is a set of bar graphs comparing the distribution of events that occurred during the sampling period and the number of each range that were sampled at each site. The focus of the study was to collect a variety of events of different magnitude. We were not concerned with sampling at the same frequency as occurrence; rather, we wanted to collect a wide range of events with emphasis on those that were likely to contribute substantial loads. This was accomplished. The hydrologic implications of runoff response during a drought period will be discussed in the "Results" section.

Figure 7. PRECIPITATION AT STUDY SITES COMPARED TO AIRPORT

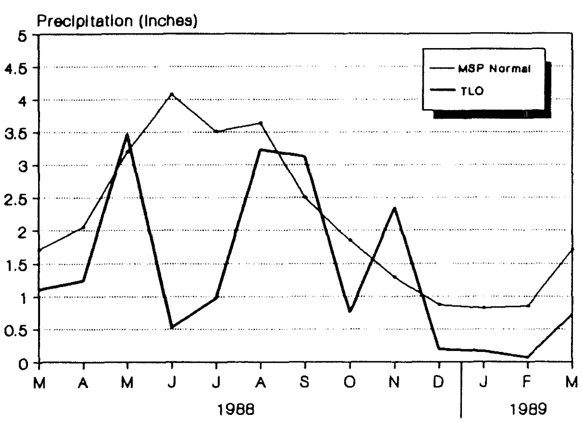
PRECIPITATION AT LRI COMPARED TO MINNEAPOLIS-ST.PAUL NORMAL



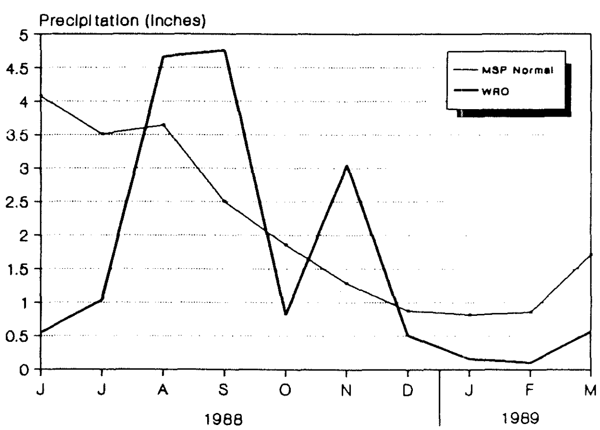
PRECIPITATION AT McKNIGHT COMPARED TO MINNEAPOLIS-ST. PAUL NORMAL



PRECIPITATION AT TANNERS LAKE COMPARED TO MINNEAPOLIS-ST. PAUL NORMAL

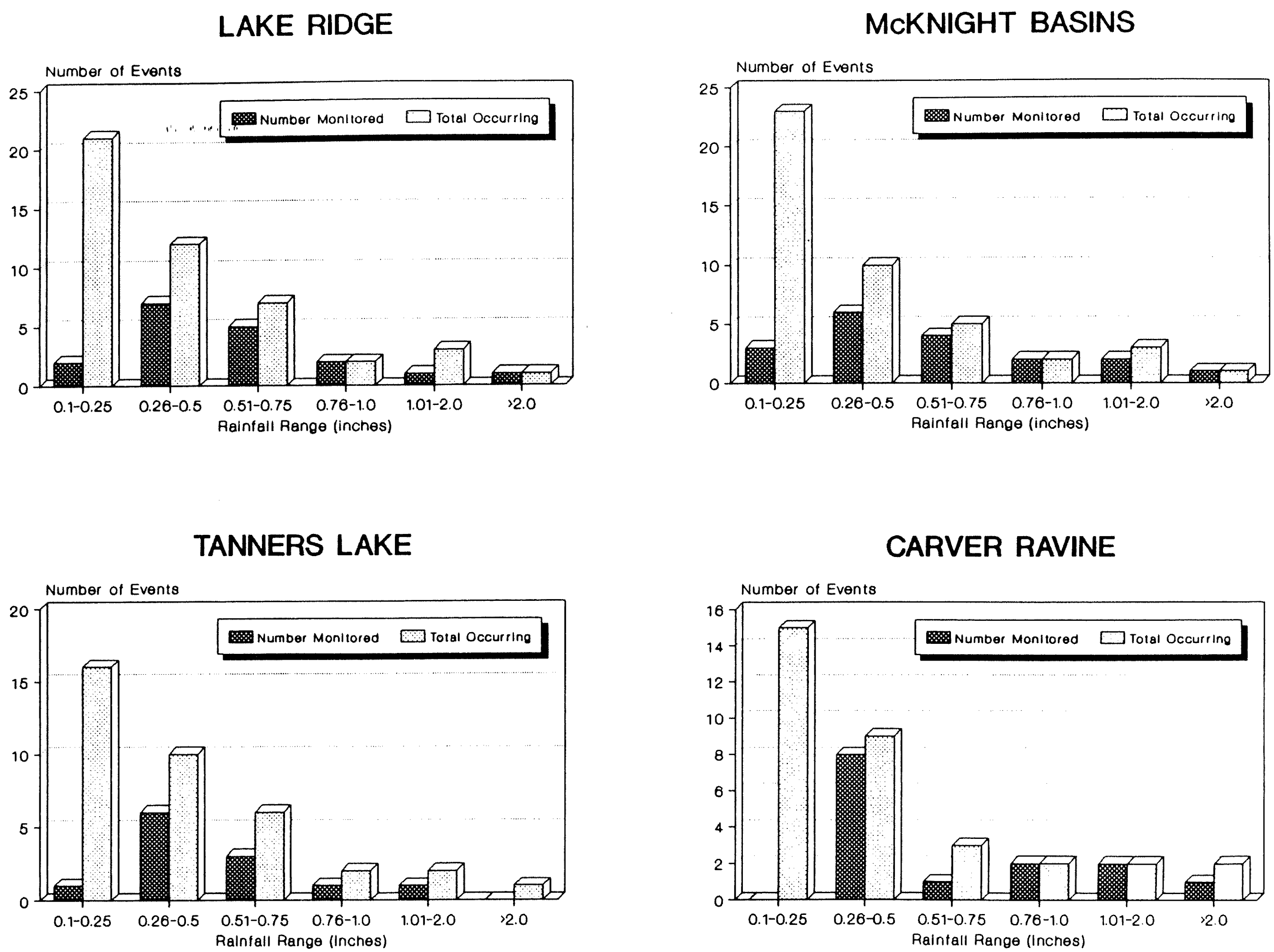


PRECIPITATION AT WRO COMPARED TO MINNEAPOLIS-ST. PAUL NORMAL



Note: Rainfall only; LCMR sites do not include snowfall equivalent.

Figure 8. MONITORED EVENTS AS COMPARED TO TOTAL EVENTS



METHODS

DATA COLLECTION

Collection of surface water data during the study focused on rainfall and snowmelt events in order to determine system performance during periods of high loading. Flow was continually monitored at the eight inflow and outflow sites, and automatically sampled at each site during runoff events. There were brief periods when the pressure transducers were either malfunctioning, or removed for repair or cold weather, explaining the gaps in the daily flow data. Appendix D, Figures D1 through D8 show the daily flow records for the inflow and outflow at each site (Figures 2 through 5). Table 1 describes the inlets and outlets at each of the sites.

The length of study at each site was quite short. Although monitoring commenced at Lake Ridge and McKnight Basin in October 1987, the other two sites were monitored for a considerably shorter time. Event data were not collected until April 26, 1988 for the Carver Ravine system and not until July 9, 1988 for Tanners Lake wetland. This period of monitoring even under normal conditions would be considered short; when coupled with the drought year, it becomes readily apparent that conclusions are drawn on a very limited data base and that they apply only to the short-term. That is, we are not able to draw inferences about the long-term performance of treatment facilities based on one year of data collection.

Flow depth was continually monitored and recorded at the inlet and outlet of all four sites on a Campbell Scientific, Inc. CR10 datalogger. Geokon Pressure Transducers were used to record the head values at each site every 15 minutes. Algorithms were established to convert the head to discharge at each site based on calculated and verified stage-discharge relationships. Algal blooms in standing water, high velocities and short transducer life created several problems with the pressure transducers. Problems were overcome by frequent cleaning of the transducer filter stone during the summer months and by constant vigilance during events to assure that correct stage readings were recorded. This obviously added to the labor required to keep the "automated" stations operable. The CR10 head readings were continually checked by field staff at each site during an event. Each site had its own peculiarities, from the head readings at WRI, which were influenced by pumped inflow, to extremely high velocities at LRI, TLO and WRO, where head readings were higher than recorded readings during periods of high flow. These problems created the need for manual measurements of head levels during events to back up the CR10 recorded head measurements. All event records were closely checked against observations to ensure data reliability. Only verified data are used in this report. Further discussion of quantity limitations is contained in the "Results" section.

Water samples at sites LRI, LRO, MBO, TLI, WRI and WRO were collected with Manning automatic samplers, model S-4050. Samples at MBI and TLI were collected with ISCO automatic samplers, model 2900. Site WRIP was the pumped inflow that was grab-sampled during the period of pumping. The sites with Manning samplers were collected on a time basis and flow-composited. The sites with ISCO samplers were collected on a flow basis and flow-composited. Due to sampler malfunctions and cold weather, manual samples were often collected across hydrographs. Events that were not covered adequately either with the automated equipment or with manual back-up were not sampled.

Baseflow samples were taken six times during the study at MBI and MBO, five times at LRI, LRO, TLI and TLO and four times at WRI and WRO. The results of the baseflow samples are contained in Appendix E. The baseflow samples were used to predict the quality of water moving through the facilities during non-event periods and were used in annual load calculations for lake inflows analyzed in the companion report (Osgood 1989).

Sediment samples were also taken at the inlet and outlet of each site at the beginning of the study. A section that follows discusses the sediment data.

Some series of events were combined into a single large event to reflect the fact that they were all part of a single hydrograph. For example, the Feb.26 - March 6, 1988 melt, the May 7-9,1988 rainfall, and the entire 1989 melt are each considered as a single, large event even separate parts of the event were sampled. The total number of rainfall and snowmelt events monitored to some degree are as follows:

- LRI, LRO = 21
- MBI, MBO = 20
- TLI, TLO = 11
- WRI, WRO = 17 (WRIP = 8).

Rainfall was continually collected in a Sierra-Misco tipping bucket rain gauge, model RG2501. This gauge tipped every 0.01 inch of rain and was recorded by the CR10 datalogger.

LABORATORY PROCESSING

Following each sampled event, the discrete samples were emptied from the automatic samplers, and flow-composited (that is, placed in a single sample proportionately based on flow rate at the time of sampling) at the Metropolitan Waste Control Commission (MWCC) laboratory. The samples were filtered and placed in proper containers for subsequent analysis by MWCC laboratory staff. The methods used by the MWCC laboratory are all U.S. EPA-approved. The samples were analyzed for the following constituents:

- total suspended solids (TSS);
- volatile suspended solids (VSS);
- total phosphorus (TP);
- total dissolved phosphorus (DP);
- total Kjeldahl nitrogen (TKN);
- nitrate nitrogen (NO3);
- total lead (TPb);
- soluble lead (SPb); and
- ortho-phosphate (OTP).

Total nitrogen (TN) is reported as the sum of NO3 and TKN. SPb samples were taken infrequently to ascertain the portion of Pb in the dissolved phase. OTP samples for several events were collected during a runoff event, usually at the peak. These OTP samples were filtered and processed as soon as possible after they were collected. For the snowmelt samples, OTP was flow-composited, filtered and processed along with the other samples. Sample bottles were washed with phosphorus-free soap and rinsed with distilled water prior to use.

DATA MANAGEMENT

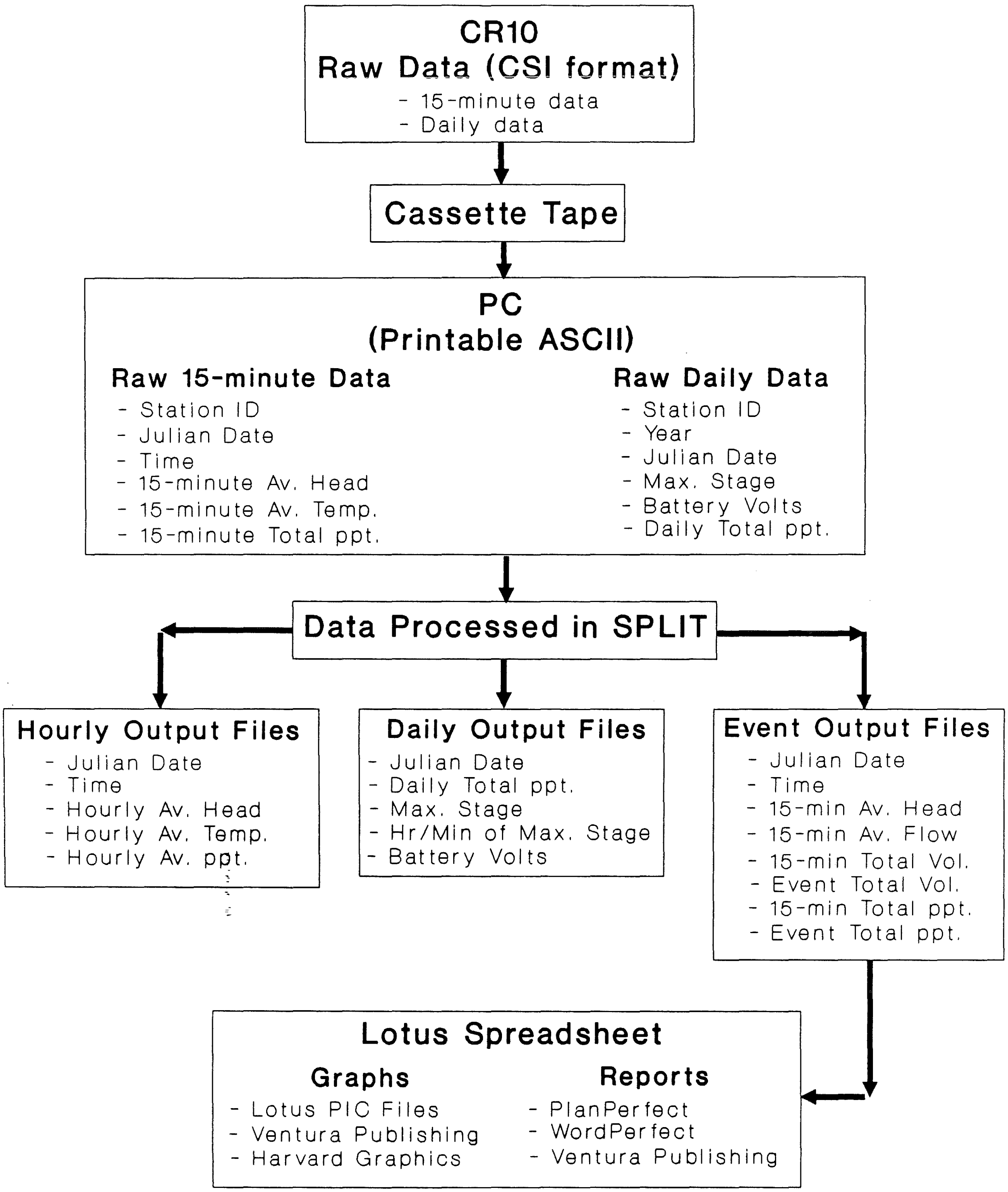
As described above, each site was equipped with a datalogger that recorded water level. Rainfall was also recorded at either the inlet or outlet for each site. Flow rates were recorded every 15 minutes throughout the study period. Flow rates for each respective site were recorded as follows:

- LRI October 1987 - April 1989;
- LRO April 1988 - April 1989;
- MBI November 1987, April 1988 - April 1989;
- MBO November 1987, May 1988 - April 1989;
- TLI June 1988 - April 1989;
- TLO December 1987, April 1988 - April 1989;
- WRI June 1988 - April 1989; and
- WRO August 1988 - April 1989.

These records are fairly continuous with the exception of small gaps where data were not recorded due to malfunctions or freeze-up. TLI and TLO were inoperable from January to March of 1989. WRO and MBI were inoperable from January to February of 1989.

The data were processed according to the scheme shown in Figure 9. The recorders were debriefed every two weeks and after events, and down-loaded onto an IBM-PC for processing with a Campbell Scientific, Inc. (Logan, UT) software program called SPLIT. In SPLIT, the data files were run through weekly programs to make calculations and to format the files for storage. The first program converted 15 minute head data into 15 minute discharge data. Algorithms were developed for each site using either Manning's equation or weir formulae depending on the site type. The 15 minute discharge data program was run, processed and stored in Julian dates to make it possible to run further programs and calculations at a later date. The second program converted the 15 minute data into hourly data and produced hourly average head, hourly average discharge, hourly volume totals, hourly average temperatures, hourly precipitation totals and daily flow volume totals. The third program determined daily flow volumes, which were later used to produce the daily flow volume graphs. The fourth program determined daily maximum head and daily precipitation totals. A fifth program was run to produce data for the rain and snowmelt events. Event data included 15 minute head data, 15 minute discharge data, 15 minute volume data, event volume data, 15 minute precipitation data and event precipitation totals. Graphs were produced for all of the events. A running total of all of the data sets was stored on the mainframe IBM 3270. Any further analyses or calculations were done by transferring the 15 minute data files back to the PC.

Figure 9. METROPOLITAN COUNCIL DATA MANAGEMENT SCHEMATIC



RESULTS

HYDROLOGY

Climatologic Setting

As noted in the previous section on climatologic conditions, 1988 was a drought year, characterized by extremely hot and dry conditions during the portion of the year when most precipitation should occur. The total amount of precipitation during 1988 was 19.08" at the airport, as compared to a normal of 26.36". However, June, July, and August set a record for the hottest summer, and May, June, and July set a record for the driest May through July period at the airport, where only 3.09" fell. Typically, this period receives over 40% of normal annual precipitation, but in 1988 only 16% of the annual precipitation occurred. June, normally the month with the greatest monthly total precipitation (4.07"), was the driest on record (0.22") (NOAA data for Minneapolis-St. Paul International Airport).

This period of drought had some dramatic effects on the runoff from the study watersheds. The prolonged lack of rain lowered the shallow groundwater table, dried-up baseflow, and decreased the volume of permanent pool water stored in the ponds. The low rainfall and high temperatures resulted in the loss of nearly all surface and subsurface soil moisture. This, in turn, resulted in the pervious (unpaved) portion of the watershed effectively acting as a sponge for all precipitation that did occur. With little or no runoff coming from the pervious portions of the watershed, the watersheds essentially reflected runoff from impervious surfaces only. Typical hydrographs for storm events in August and July show recession limbs as steep as rising limbs - an indication of runoff generated from a completely impervious surface. The most telling statistic may be total runoff volume. For example, total storm event runoff volume at McKnight Basin for the eight month period between April and November 1988 was exceeded (one and one-half times) by the snowmelt volume of 20 days in March and April 1989. Over half of the storm event runoff volume of 1988 was generated by a three day storm in early May.

Obtaining accurate flow data was a continual problem throughout the study. During few storm events did both inflow and outflow pressure transducers read accurately at any site. This resulted in an inability to verify runoff other than by on-site observation during the event. Typically, each site had a transducer that read accurately and would subsequently be used to fill-in the missing or inaccurate data from the other transducer. Examination of some recorded hydrographs shows hydraulic inconsistencies and hydrologic improbabilities with the recorded data; examples include peak outflow occurring before peak inflow, and maximum rainfall intensity occurring after peak inflow. In addition, because of the extremely dry conditions, relating precipitation to total runoff was extremely difficult. The sampling error introduced because of equipment difficulty and unusual precipitation conditions introduced the potential for disproportionately large error with respect to the small flows that were measured. This required constant attention and on-site presence to verify actual field conditions. The on-site presence and verification of recorded data are thought to have adequately overcome the equipment malfunctions. Events when this was not the case are not used in facility analysis.

The daily flow that occurred at each of the eight sites is shown on Figures D1-D8 in Appendix D and a summary table of rainfall event hydrologic characteristics is included in Appendix G. Following this table are Figures G1-G4 showing the relationship of rainfall to flow volume at each of the sites.

An analysis of the maximum peak flows and volumes at the sites shows how peak and volume are not always at maximum levels for the same event. By far the largest volumes that were recorded in the study occurred during the long snowmelt of 1989. Figures D1-D8 show the high daily volumes of runoff that occurred over the event. The length of the melt event was different at each of the sites, depending upon upstream conditions. That is, LRI, with a watershed that is quite impervious, experienced all of its snowmelt input over a period of six days, while MBI, with Battle Creek Lake just upstream, received melt-influenced runoff for 20 days. Table 3 shows how the maximum volume and peak flows of the 1989 snowmelt compare to the same figures for rainfall events.

TABLE 3. MAXIMUM PEAK FLOWS AND VOLUMES FOR EVENTS.

Site	Event Type	Peak Discharge,cfs (date)	Volume,Ac-ft (date)
LRI	Rain	70.8 (5/8/88)	23.0 (5/8/88)
	Snowmelt	25.0 (3/27/89)	73.3 (3/24-29/89)
LRO	Rain	18.5 (5/5/88)	25.1 (5/8/88)
	Snowmelt	25.0 (3/27/89)	67.2 (3/24-29/89)
MBI	Rain	232.5 (8/7/88)	75.9 (5/8/88)
	Snowmelt	50.0 (4/3/89)	627 (3/23-4/11/89)
MBO	Rain	118.5 (5/8/88)	81.3 (5/8/88)
	Snowmelt	115.0 (3/28/89)	699 (3/23-4/11/89)
TLI*	Rain	30.2 (8/7/88)	10.3 (11/15/88)
	Snowmelt	15.0 (3/27/89)	100 (3/23-4/4/89)
TLO*	Rain	14 (11/15/88)	11.3 (9/19/88)
	Snowmelt	Not recorded	108 (3/23-4/4/89)
WRI	Rain	43.0 (5/8/88)	13.5 (11/15/88)
	Snowmelt	29.0 (3/27/89)	54.0 (3/24-30/89)
WRO	Rain	13.6 (8/4/88)	25.4 (5/8/88)
	Snowmelt	12.2 (3/24/89)	100 (3/24-30/89)

*Site not installed for 5/8/88 event

Water Quantity Analysis

The following discussion addresses those hydrologic events that were sampled for water quality plus some events that were not sampled. Because of the dry conditions, essentially every event that occurred was analyzed relative to flow in an attempt to better understand the relationship between rainfall/snowmelt and runoff. The discussion focuses on April 1988 to April 1989. Two distinct hydrologic seasons are examined: a storm season extending from April to November 1988, plus a single event in April 1989, and a snowmelt season extending from the end of March to the first week in April 1989. These rainfall and snowmelt seasons are separated by a dormant winter season during which the watersheds were frozen.

During the 1988-89 hydrologic year the four watersheds underwent drastic changes due to extreme variability in climate. Beginning in February 1988, the areas under study began receiving significantly less than normal precipitation. The lack of rain continued through July with records set for the hottest June through August and the driest May through July. This period of drought dried-up baseflow and removed nearly all surface and subsurface soil moisture. The very dry ground acted as a sponge when rain did occur. This had the effect of "shrinking" the watersheds since pervious areas generated little or no runoff. Typical hydrographs (plots of discharge versus time) for storm events in July and August show recession limbs as steep as rising limbs, an indication of runoff generated from a completely impervious surface (Figures 10 and 11). These figures also show the hyetograph (plot of rainfall versus time) that generated the runoff. In contrast to the events with only impervious runoff, Figure 12 shows a McKnight Basin hydrograph that reflects contributions from the entire, large watershed. Note the difference in the receding limb, where hydrograph recession is slowly drawn-out over several days because of upper watershed contributions and shallow groundwater contributions from pervious areas.

Dry conditions began to ease by August (Figure 7), but November 1988 was the first month of significantly above normal rainfall (+1.57" at the airport). Most of this November precipitation, however, fell on frozen ground or occurred as snow. The winter of 1988-89 continued with average snowfall and below normal temperatures. In March 1989, 22.7" of snow fell, setting the stage for a good spring snowmelt. Total volumes of 1989 snowmelt were large, especially when compared to the total storm volumes seen the previous year. McKnight Basin, for example, had 421 acre-feet of storm runoff for April through November, 1988. The 20 day snowmelt of late March - early April 1989 produced 621 acre-feet of runoff (Figure 13) from the snowmelt plus 0.77" of rain. Hydrographs such as those shown in Figures 10-13 were typical of each of the sites for those particular events.

The hydrograph analysis above and the fact that the upper portions of each watershed at times did not contribute flow because of upper watershed storage clearly show that different areas within each watershed were contributing flow during the dry summer of 1988 as opposed to the late 1988 rainfall/1989 melt seasons. For purposes of analysis, therefore, the watersheds were divided into "effective" drainage basins that reflected more accurately the area that contributed runoff for a particular event. The effective watershed sizes were noted in Table 1 for both the inflow and outflow sites. The Carver Ravine outflow site (WROP) reflects the addition of pumped inflow from an adjacent watershed.

Figure 10. HYDRO/HYETOGRAPH FOR McKNIGHT BASIN, JULY 20, 1988

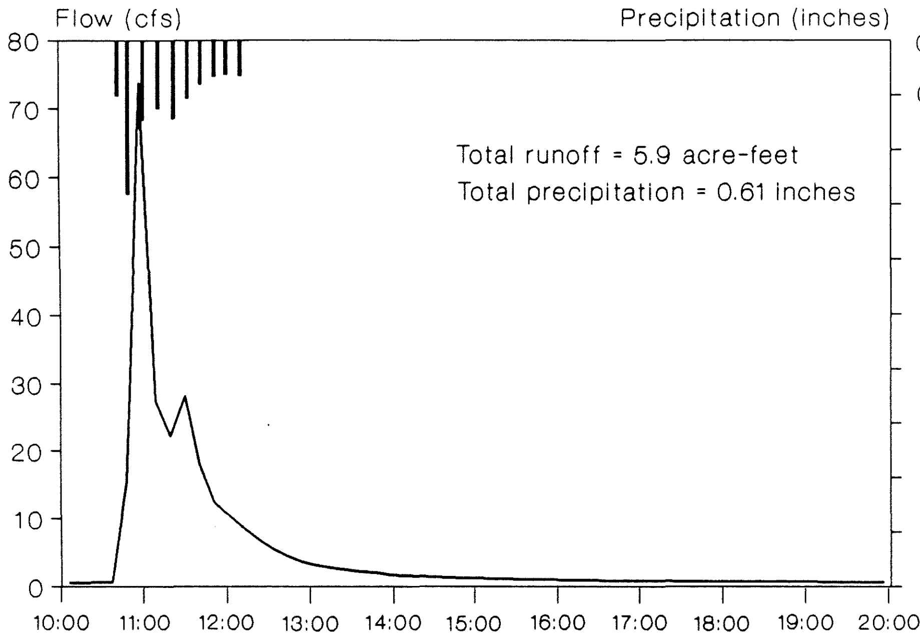


Figure 11. HYDRO/HYETOGRAPH FOR McKNIGHT BASIN, AUGUST 7-8, 1988

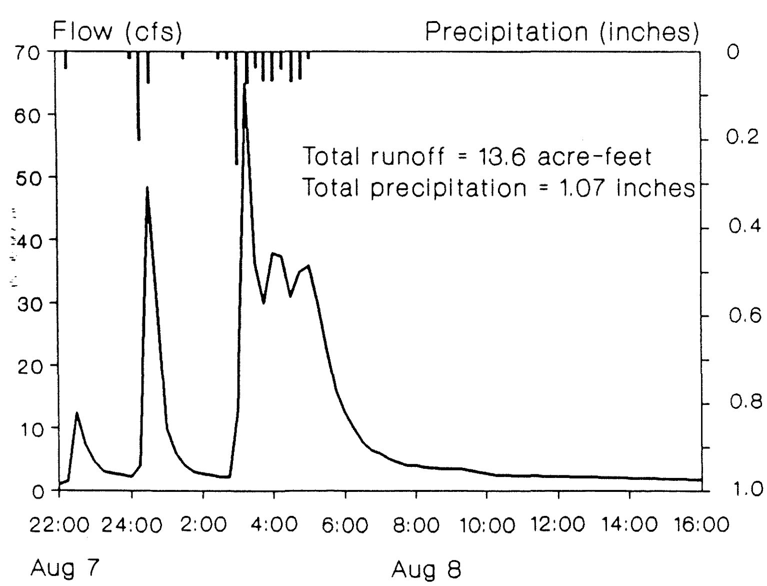


Figure 12. HYDRO/HYETOGRAPH FOR McKNIGHT BASIN, MAY 7-13, 1988

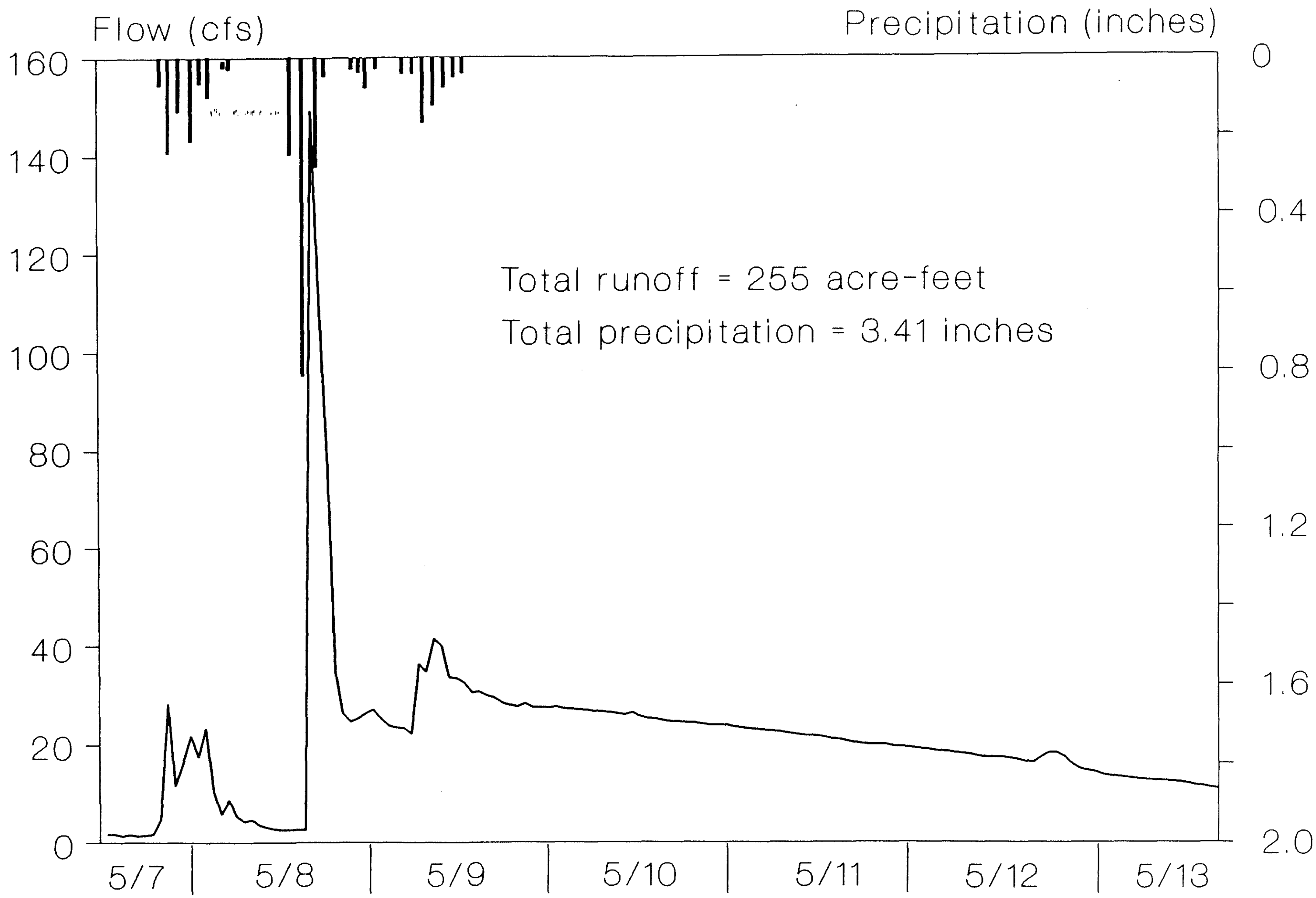
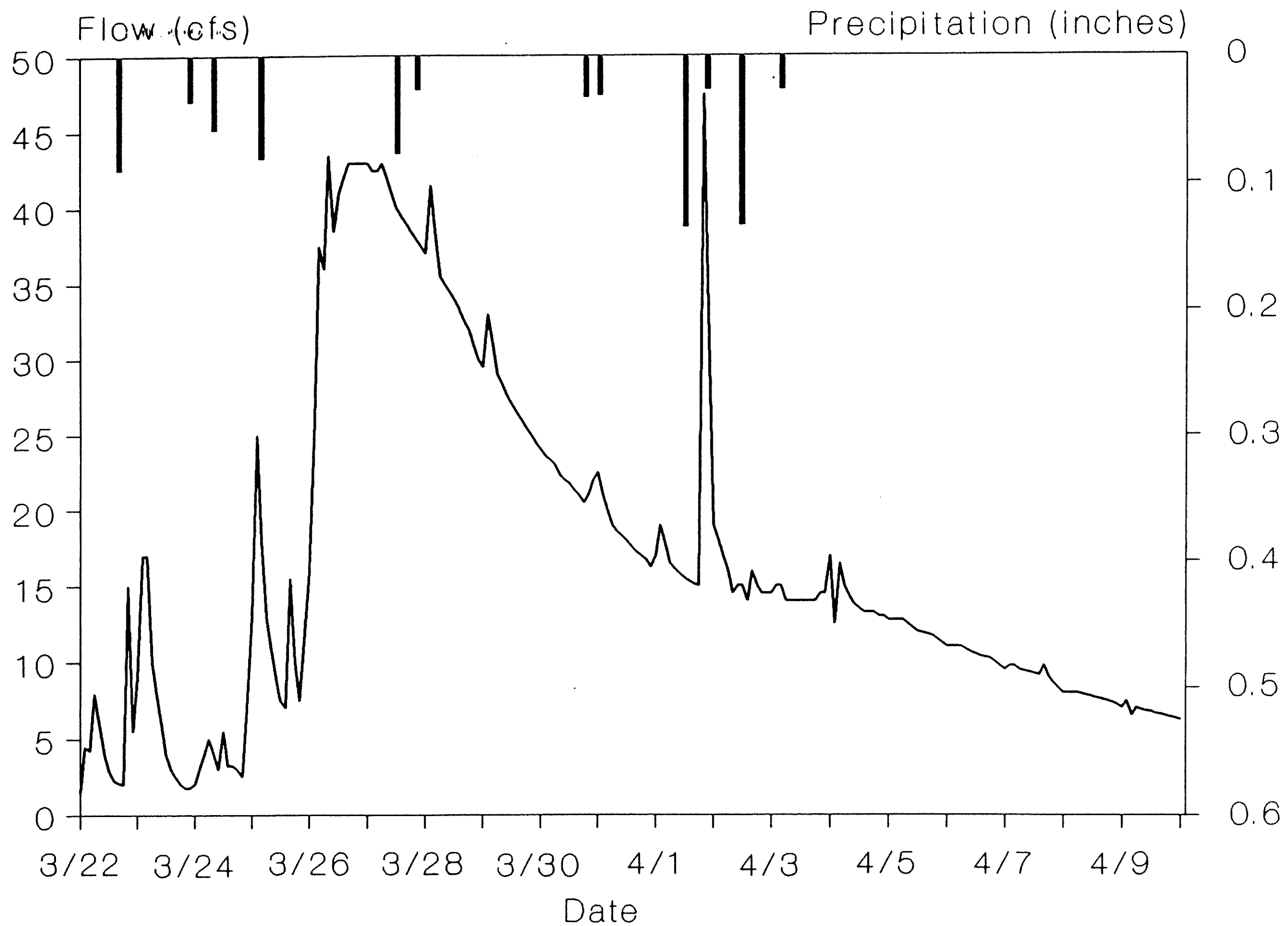


Figure 13. HYDRO/HYETOGRAPH FOR 1989 SNOWMELT FOR McKNIGHT BASIN (March22 - April 10)



Total runoff = 621 acre-feet; total precip. = 0.77 inches

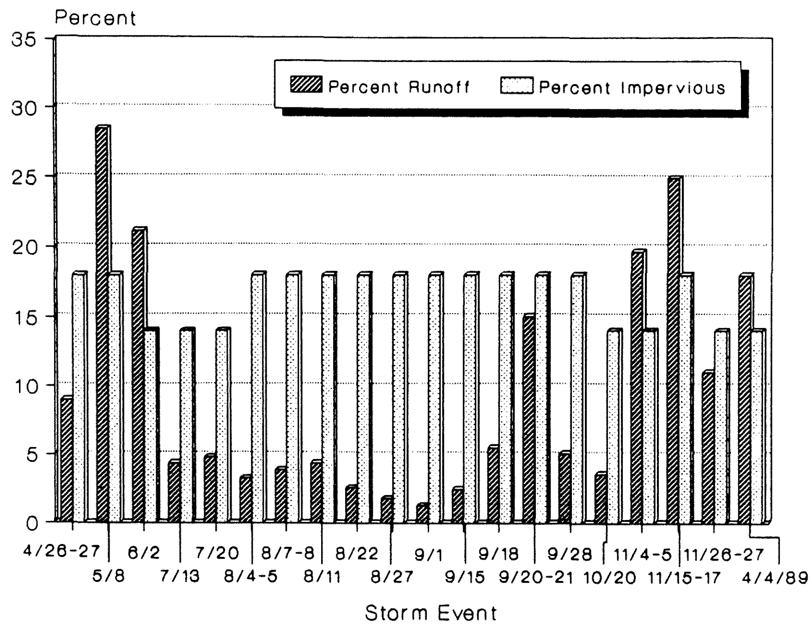
Small effective watersheds contributed during many of the monitored storm events. Figures 14-17 display the percent of runoff for 1988-89 rainfall events versus the percent of effective impervious area for that event. The bar graphs show whether flow occurs beyond that expected from impervious areas. The early 1988 events receive runoff from the entire watershed because they occurred in late spring when surface moisture was close to normal. The early May event was the only large storm in 1988 in terms of both total precipitation and total runoff. Close to half of the monitored storm event runoff for each site came from this three day event.

Figures 14-17 show that for the majority of events, percent runoff was well below the percent imperviousness of the watersheds. The runoff was below the actual percent of imperviousness due to "abstractions" or retention of water in such places as small depressions and canopy cover. At most sites, the percent of runoff approached or exceeded the percent impervious only during high total volume events (May 7-9 and Sept. 20-21) or during November when the pervious portion of the contributing area was frozen.

Figures 18-21 show the results of a simplistic runoff model that was used to validate the fact that little runoff comes from pervious areas during most events of a drought period. The model predicts total event runoff by computing only the total precipitation over the impervious portion of the contributing watershed area, subtracting abstractions which can be deducted as a constant portion of the rainfall. In Figures 18-21, the bar graphs depict substantial agreement between predicted and actual runoff event total volumes for the events of June 1988 through mid-September 1988, when soil moisture begins to increase and some pervious areas begin to contribute runoff. The above analysis illustrates that the effective watershed area often differs from the total watershed area and also shows that during periods of extended dry weather, watersheds can respond to rainfall from a very limited portion of the drainage basin.

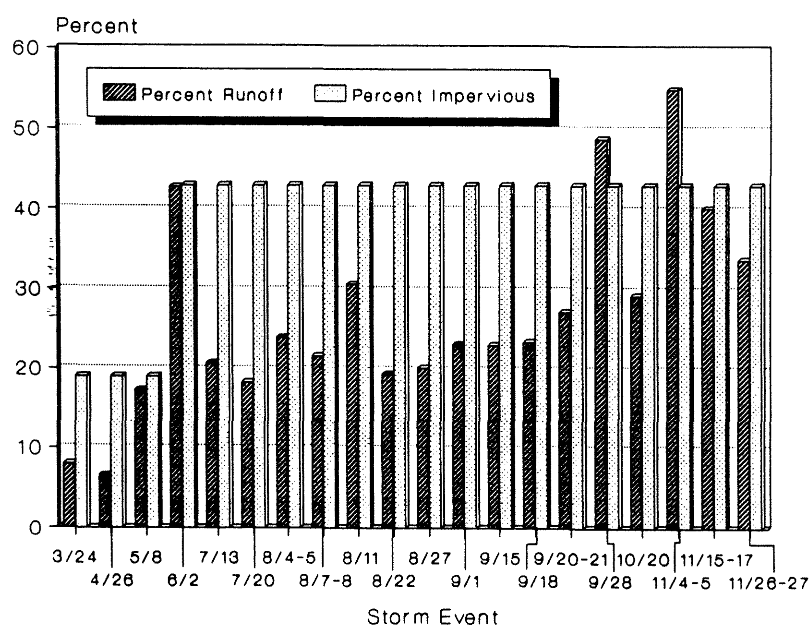
Watershed response to rainfall, of course, becomes much more complicated when the pervious portion of a watershed begins to contribute runoff. The dynamic performance in terms of runoff from the pervious portion of our watersheds can be illustrated by looking at three closely spaced storm events in August and comparing percent runoff for these storms with percent runoff for three events of November. The Carver Ravine site is not included in this analysis because of complications due to pumped inflow. The early August events represent the first break in the drought. Substantial rainfall occurred for both the August 4-5 (0.93-1.17") and August 7-8 events (1.17-1.49") and a moderate amount for the August 11 event (0.49-0.75"). The percent runoff generated from these events (Figure 22) increased slightly over the events, but did not substantially change. According to Soil Conservation Service Methods (TR-55), our watersheds should have "moved" from dry to moist antecedent moisture conditions based on previous five day total rainfall (USDA-SCS, 1986). In actuality, the watersheds did not receive enough moisture to change the extremely dry ground and therefore pervious runoff was still absent from the August 11 storm. November, on the other hand, is the month when the ground and streams begin to freeze. The November 4-5 (0.65-0.70"), November 15-17 (0.64-0.81") and the November 26-27 (0.55-0.61") events were all similar in total precipitation. However, the differences seen in Figure 22 show that the effects of pervious watershed freezing and the effects of precipitation freezing and not running off can be substantial.

Figure 14. PERCENT RUNOFF VS. PERCENT IMPERVIOUS AREA, LAKE RIDGE WATERSHED



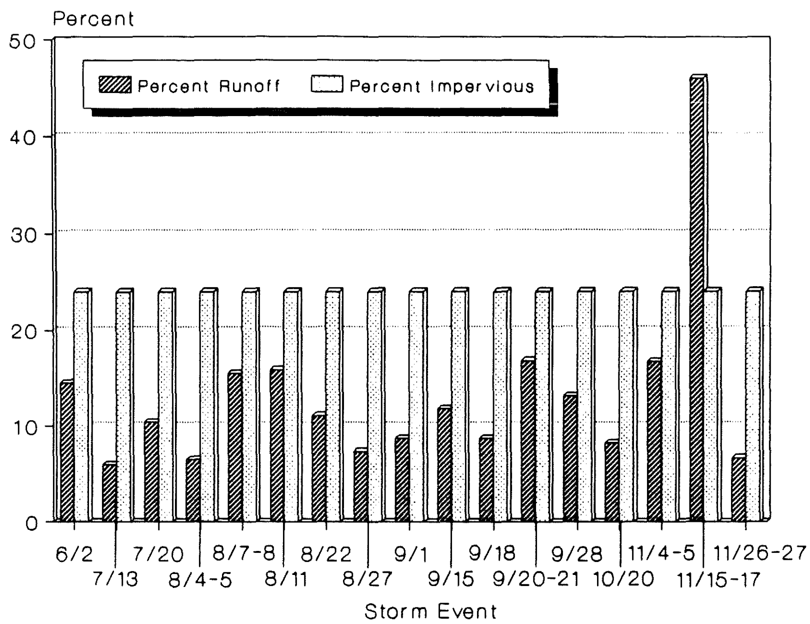
n=20; 18% impervious area = effective watershed only

Figure 15. PERCENT RUNOFF VS. PERCENT IMPERVIOUS AREA, McKNIGHT BASIN WATERSHED



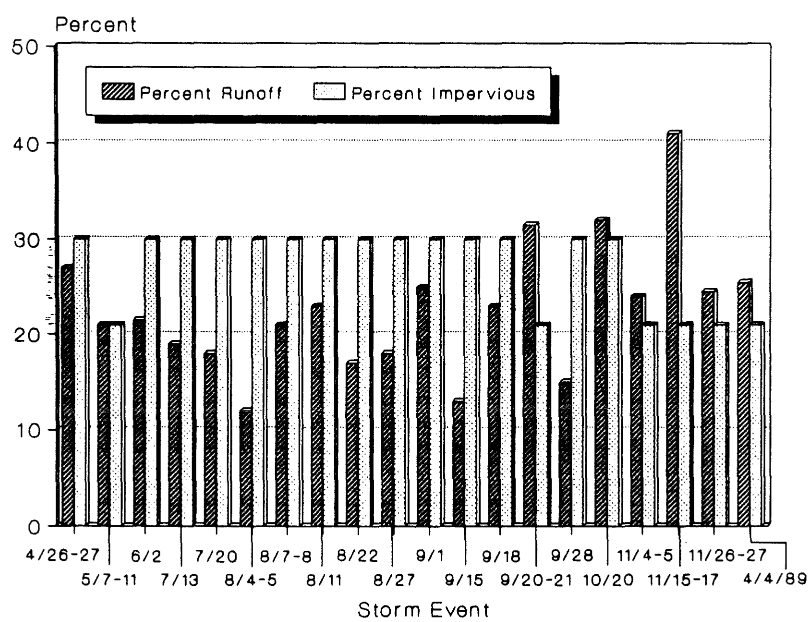
n=20; effective watershed area only after May 8 event

Figure 16. PERCENT RUNOFF VS. PERCENT IMPERVIOUS AREA, TANNERS LAKE WATERSHED



n=17; effective watershed area only

Figure 17. PERCENT RUNOFF VS. PERCENT IMPERVIOUS AREA, CARVER RAVINE WATERSHED



n=20; effective watershed area only
WSHD=170; %IMP=30. PumpWSHD=432; %IMP=21

Figure 20. ACTUAL VS. PREDICTED RUNOFF TANNERS LAKE WATERSHED

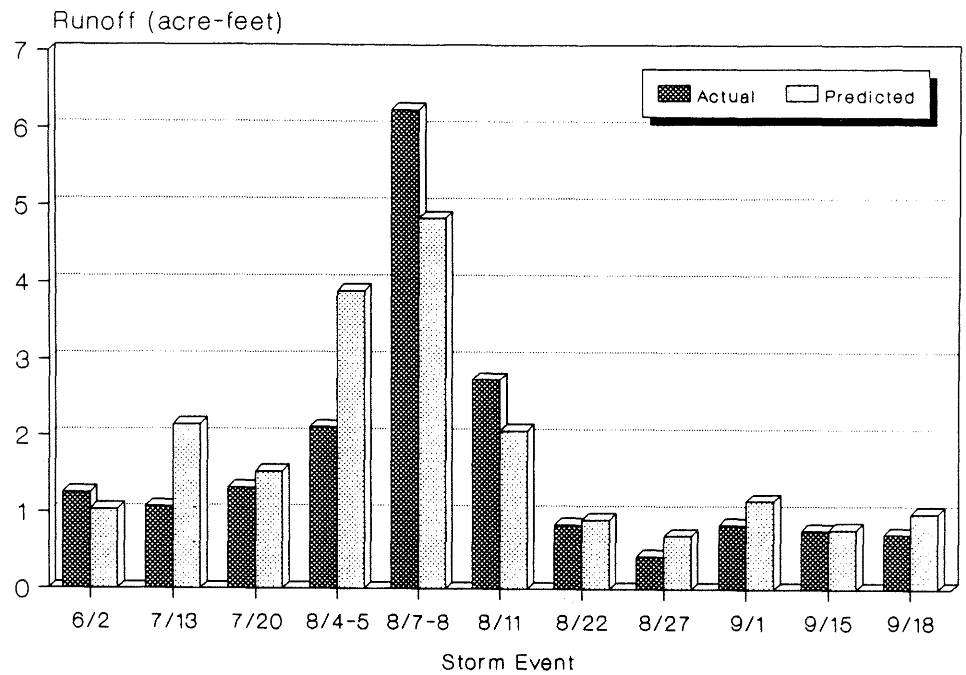


Figure 21. ACTUAL VS. PREDICTED RUNOFF CARVER RAVINE WATERSHED

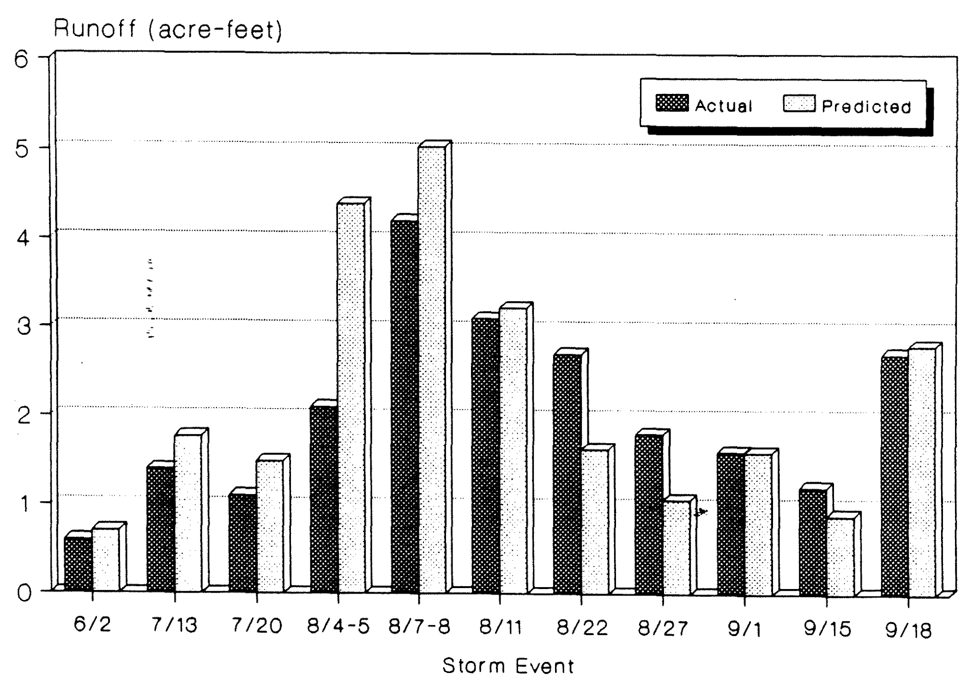


Figure 18. ACTUAL VS. PREDICTED RUNOFF LAKE RIDGE WATERSHED

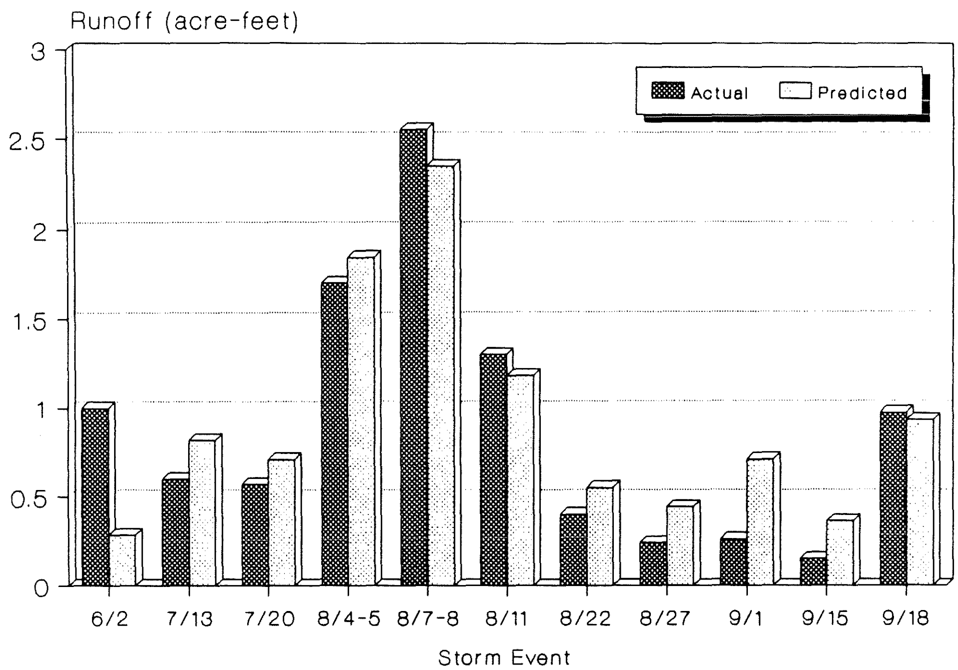


Figure 19. ACTUAL VS. PREDICTED RUNOFF McKNIGHT BASIN WATERSHED

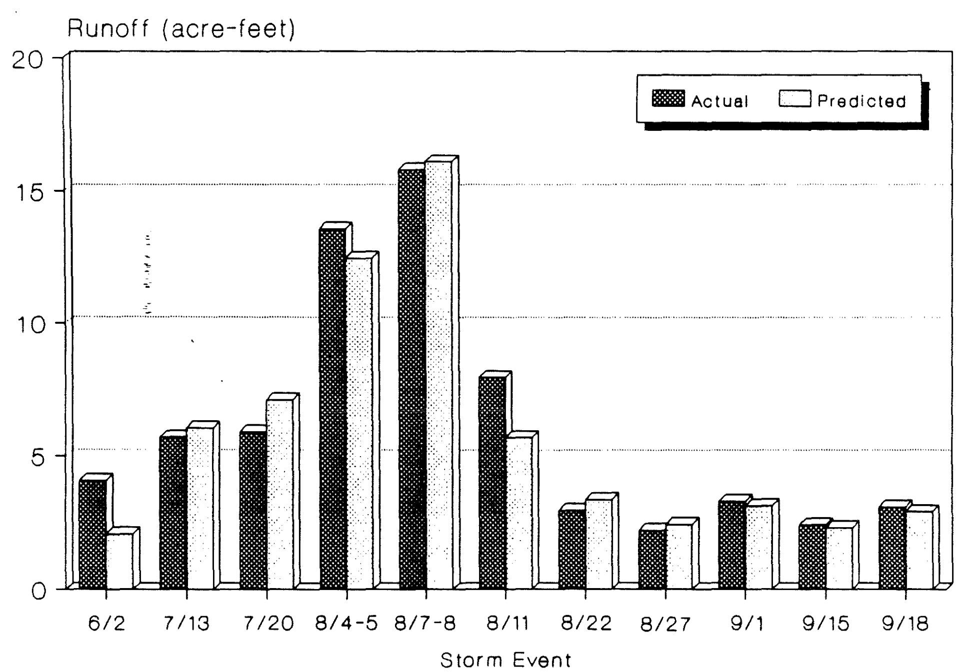
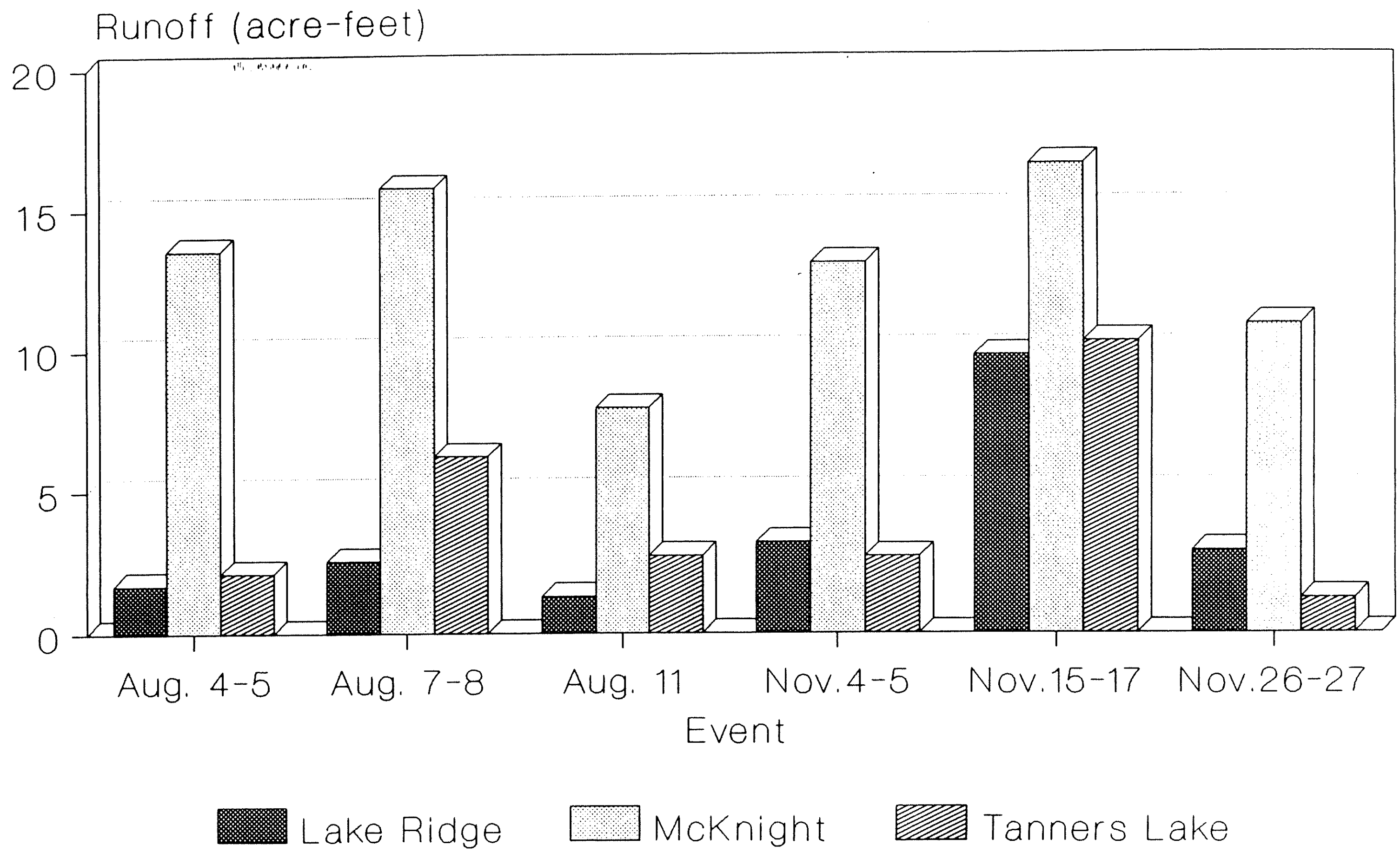


Figure 22. AUGUST AND NOVEMBER 1988 PERCENT RUNOFF FOR LAKE RIDGE McKNIGHT BASIN AND TANNERS LAKE



Relationship to Water Quality

The hydrologic behavior of a watershed can have a significant impact on the water quality performance of a treatment facility. The relationship between water quantity and water quality can best be seen during extreme hydrologic events - drought and flood - both of which occurred during the study.

During the period of drought, the effective size of each watershed decreased because of infiltration in pervious areas. Runoff, therefore, came from impervious surfaces - parking lots, streets, driveways, and rooftops - where runoff quickly moves pollutants deposited on urban surfaces to receiving waters. High velocities associated with impervious runoff also causes erosion of ditches and stream banks, and scouring of deposited material from streams and drainage pipes. Runoff from pervious surfaces, on the other hand, is detained by grasses and vegetation, and allowed to drop its load of pollutants before reaching a receiving water. The water also can infiltrate into the dry soil and move through the shallow groundwater system before entering a receiving water body; this allows for further filtration and cleaning. Runoff from pervious areas is, therefore, generally less polluted that urban surface wash-off and has the effect of diluting the impervious runoff. As seen in the previous discussion, runoff from pervious surfaces was largely absent from the events monitored during much of 1988. We can, therefore, expect pollutant concentrations to be higher than in a normal rainfall year.

Total runoff volume was low in 1988 because of the drought. Total runoff volume is one of the primary factors affecting pond performance. The most important mechanism operating in a treatment system is sedimentation. Sedimentation of a particle will take place if its settling velocity is greater than its flow-through velocity. Settling velocity is a function of particle and fluid properties, while flow-through velocity is a function of pond and runoff properties. Quiescent settling occurs between storm events and plays as significant a role as dynamic settling that occurs during storm events (Driscoll 1983). One can envision this treatment process by thinking of the permanent pool of water as treated water that is pushed out by "dirty" storm water. The total treatment of inflowing runoff, then, is a function of the quiescent treatment that the displaced water has received and the treatment of water as it passes through the system during the event. By decreasing runoff volume, permanent pool volume becomes larger in comparison and less of the untreated water flows out of the system. The treatment efficiencies reported later in this report are determined on this basis.

The permanent pool volumes and several other design hydrologic characteristics of the four LCMR sites plus the McCarrons detention pond are listed in Table 4. The first three facilities have the best design features when compared to those recommended by Driscoll (1983) and Walker (1987). This fact will become important when water quality loads are discussed in the following section.

The numbers in Table 4 can be used to see how flows are impacted during rainfall events as they move through each facility. The specifics of performance for the McCarrons system are discussed in the completion report for that project (Oberts and Osgood, 1988). Runoff volumes exceeded permanent pool volumes for about half of the rainfall and snowmelt events at Lake Ridge and McKnight Basin, but runoff exceeded permanent storage for every event at Tanners Lake and Carver Ravine because of their limited storage. It should be noted that most pollutants are only temporarily trapped and can become physically or chemically resuspended and flushed out of the pond. Large storm events and spring snowmelts that exceed the volume of permanent storage can easily supply this needed turbulence and energy.

TABLE 4. HYDROLOGIC CHARACTERISTICS OF TREATMENT FACILITIES.

	SITE				
	McCARRONS POND	LAKE RIDGE	McKNIGHT BASIN	TANNERS LAKE*	CARVER RAVINE**
DESIGN					
Permanent Pool Vol.(acre-feet)	2.8	2.0	13.2	0.1	1.0
Maximum Depth (feet)	2.6	4.8	4.9	3.0	2.0
Average Depth (feet)	1.2	2.0	2.5	1.4	1.1
Surface Area (acres)	2.4	0.94	5.53	0.07	0.37
Pond Area/ Max.Watershed Area (%)	0.4	0.2	0.3	>0.1	>0.1
Pond Area/ Effective Watershed Area (%)	0.7	0.3	2.1	>0.1	0.2
Volume Ratio***					
Max.Watershed	1.5	0.6	0.4	0.02	0.1
Eff.Watershed	2.5	1.3	1.7	0.04	0.3

* Tanners Lake Upper Sediment Basin; no permanent storage in wetland
** Carver Ravine detention pond; no permanent storage in wetland
*** VR = Perm. Pool Vol./ Mean June-Sept.Storm Runoff Vol.

The ability of a facility to store and subsequently remove material during quiescent periods between storm events can be determined by looking at a Volume Ratio (VR), which is the ratio of the permanent pool volume to the runoff from the mean June-Sept. storm (Driscoll 1983). The mean June-Sept. storm at the Minneapolis-St. Paul Airport for the period of record is 0.34", with an average duration of 4.5 hours (U.S. Weather Service data and SYNOP data management program). VR for the various sites is contained in Table 4. Rainfall was converted to runoff by a modified Rational Equation for each site. A volume ratio of 2.5 is suggested by Driscoll to obtain a long term sediment removal rate of 75%. Table 4 shows that the LCMR sites are substantially undersized for water quality purposes, primarily because they were designed for water quantity purposes to decrease peak flows. The water quality performance of the facilities is discussed in the following section.

WATER QUALITY

Water quality results report herein are based on the rainfall and snowmelt events previously referenced. The actual concentration and load data for each event sampled are contained in Appendix H. Table 5A lists the total monitored loads and flow-weighted mean concentrations for the rainfall events, and Table 5B lists the same numbers for the set of all events (rainfall and snowmelt). Figure 23 graphically displays through box plots the concentration range, median value, and 10% and 90% concentration quantiles for each site for all events.

Some system effectiveness results become apparent by looking at the concentration data in Table 5 and Figure 23. The concentrations, particularly at the inflow sites, are quite variable, typical of urban runoff. Reductions in the concentration of solids and associated pollutants (TSS, VSS, TPb) are very apparent. The same cannot be said for the nutrients, where reductions are seen, but not near the magnitude of the solids. Still, every site can be said to lower the concentration of nutrients. This picture might not be as clear when flow is incorporated into the analysis for individual site events in the section that follows.

The volume of snowmelt recorded at each site substantially exceeds the volume from rainfall events only, which is not an uncommon phenomenon in areas with snowfall. This is further accentuated, however, by the very dry period of monitoring. Comparison of Tables 5A and 5B show that when snowmelt volumes are considered, overall volumes are approximately two to three times the rainfall event volumes for the Lake Ridge (LR) and Carver Ravine (WR) sites, and from four to five times for the McKnight Basin (MB) and Tanners Lake (TL) sites. The flow-weighted mean concentration changes that result from adding in snowmelt are not uniform for all sites and pollutants. There is some consistency for the solids and associated pollutants (TSS, VSS, TPb), which all decrease in flow-weighted mean concentration with the addition of snowmelt. The melt flowing through the facilities is not as highly concentrated as stormwater, and the high volumes help to dilute the concentrations at each of the sites.

Nutrient concentrations behave differently than solids. Both TP and TKN concentrations at Lake Ridge and McKnight Basin decrease in inflow concentrations and increase in outflow concentrations with the addition of snowmelt. This behavior indicates that inflows are diluted by the large melt flows and that treatment in the two facilities is not as good during the melt events as it is during rainfall events. Some discussion of the performance of the systems during snowmelt occurs later in the report. TKN concentrations at both the inflows and the outflows at Tanners Lake and Carver Ravine, and TP concentrations at the Carver Ravine inflow and outflow increase with the addition of snowmelt relative to the values seen for rainfall events only. TP at the Tanners Lake inflow and outflow decrease with the addition of snowmelt. The snowmelt appears to overwhelm the small design capacities of Tanners Lake wetland and Carver Ravine detention pond, although some reduction in TP concentration does occur in the Tanners Lake wetland.

All sites show an increase in nitrate (NO3) levels when snowmelt is added to the flow-weighted mean calculations. Nitrate levels in snowmelt tend to be high because of the limited biological and chemical processes that alter nitrogen forms in the cold weather.

Changes in the behavior of DP with the addition of snowmelt are negligible for the Lake Ridge, McKnight Basin and Tanners Lake sites. Carver Ravine shows a small increase in flow-weighted mean concentration of the total event values when compared to the rainfall only values at both the inflow and outflow. The soluble nature of this form of phosphorus makes it difficult to reduce its levels as it moves through treatment facilities, whether the water entering the system is from rain or snowmelt.

Table 5. SITE LOADS AND FLOW-WEIGHTED MEAN CONCENTRATIONS
A) MONITORED RAINFALL EVENTS ONLY

TOTAL LOAD in POUNDS
FLOW-WEIGHTED MEAN CONCENTRATION in MG/L

SITE	EVENTS	VOL*	TSS	VSS	TP	DP	OP	TKN	NO3	TN	TPB	SPB
LRI	17	65.81	132036	15241	104.11	33.9	3.666	404.59	117.14	521.84	3.3	0.406
			738	85	0.58	0.19	0.059	2.26	0.66	2.92	0.018	0.003
LRO	16	71.12	13145	4898	42.9	32.24	3.14	214.2	110.36	324.6	0.94	0.109
			68	25	0.22	0.17	0.050	1.11	0.57	1.68	0.005	0.001
MBI	17	203.07	120925	19650	223.76	103.93	4.718	1047.8	203.3	1251.17	15.162	0.398
			219	36	0.43	0.20	0.019	2.03	0.39	2.42	0.027	0.003
MBO	17	239.34	21791	7657	138.42	104.48	1.706	855.31	177.8	1033.16	6.022	0.428
			34	12	0.23	0.17	0.006	1.40	0.29	1.69	0.009	0.003
TLI	10	32.48	16737	3177	58.04	19.74	4.87	141.47	35.03	176.6	2.409	0.006
			190	36	0.66	0.22	0.084	1.60	0.40	2.00	0.027	0.001
TLO	10	33.59	7359	1743	50.05	20.62	4.119	99.48	28.59	128.1	1.037	0.005
			81	19	0.55	0.23	0.074	1.09	0.31	1.40	0.011	0.001
WRI	13	53.05	8262	1681	61.19	49.68	19	190.95	55.67	246.7	0.515	0.041
			57	12	0.47	0.38	0.254	1.48	0.43	1.91	0.004	0.001
WRIP**	7	27.43	7859	1109	28.34	12.4	2.8	112.02	9.51	121.52	0.402	0.068
			105	15	0.38	0.17	0.083	1.50	0.13	1.63	0.005	0.002
WRO	13	80.37	8921	1964	71.46	50.97	10.05	273.8	57.4	331.33	0.618	0.078
			41	9	0.35	0.25	0.096	1.34	0.28	1.62	0.003	0.001

*Volume in acre-feet
** Based on grab samples

Table 5, continued
SITE LOADS AND FLOW-WEIGHTED MEAN CONCENTRATIONS
B) ALL MONITORED EVENTS

TOTAL LOAD in POUNDS
FLOW-WEIGHTED MEAN CONCENTRATION in MG/L

SITE	EVENTS	VOL*	TSS	VSS	TP	DP	OP	TKN	NO3	TN	TPB	SPB
LRI	23	170.07	195149	23541	203.11	85.93	28.023	892.01	419.94	1312.44	5.437	0.406
			422	51	0.44	0.19	0.105	1.93	0.91	2.84	0.012	0.003
LRO	22	174.02	30852	7988	132.34	81.36	29.698	656.95	355.5	1013.35	2.7	0.109
			65	17	0.28	0.17	0.111	1.39	0.75	2.14	0.006	0.001
MBI	22	966.94	442585	45938	902.44	411.98	229.76	4204.5	1169.7	5374.3	34.269	0.398
			168	17	0.35	0.16	0.118	1.62	0.45	2.07	0.013	0.003
MBO	22	1076.34	69485	22201	739.62	514.83	255.323	4351.3	1207.5	5558.8	14.13	0.428
			24	8	0.26	0.18	0.117	1.51	0.42	1.93	0.005	0.003
TLI	11	157.48	55410	12860	181.74	81.46	39.416	701.77	443.03	1145.69	9.41	0.006
			129	30	0.42	0.19	0.099	1.64	1.04	2.68	0.022	0.001
TLO	11	169.62	15549	4621	166.45	95.58	32.669	688.79	474.59	1163.24	3.756	0.005
			34	10	0.36	0.21	0.077	1.49	1.03	2.52	0.008	0.001
WRI	16	114.9	10638	2846	146.57	119.79	62.11	523.47	158.97	682.75	1.27	0.041
			34	9	0.49	0.41	0.280	1.76	0.53	2.30	0.004	0.001
WRIP**	8	78.03	13306	2347	73.73	38.98	28.28	307.35	68.68	376.03	0.952	0.068
			63	11	0.35	0.18	0.165	1.45	0.32	1.77	0.004	0.002
WRO	16	189.07	17564	4811	215.48	158.31	96.265	883.3	196.7	1080.5	1.882	0.078
			34	9	0.43	0.32	0.259	1.77	0.39	2.16	0.004	0.001

*Volume in acre-feet
** Based on grab samples

Figure 23. CONCENTRATION BOX PLOTS

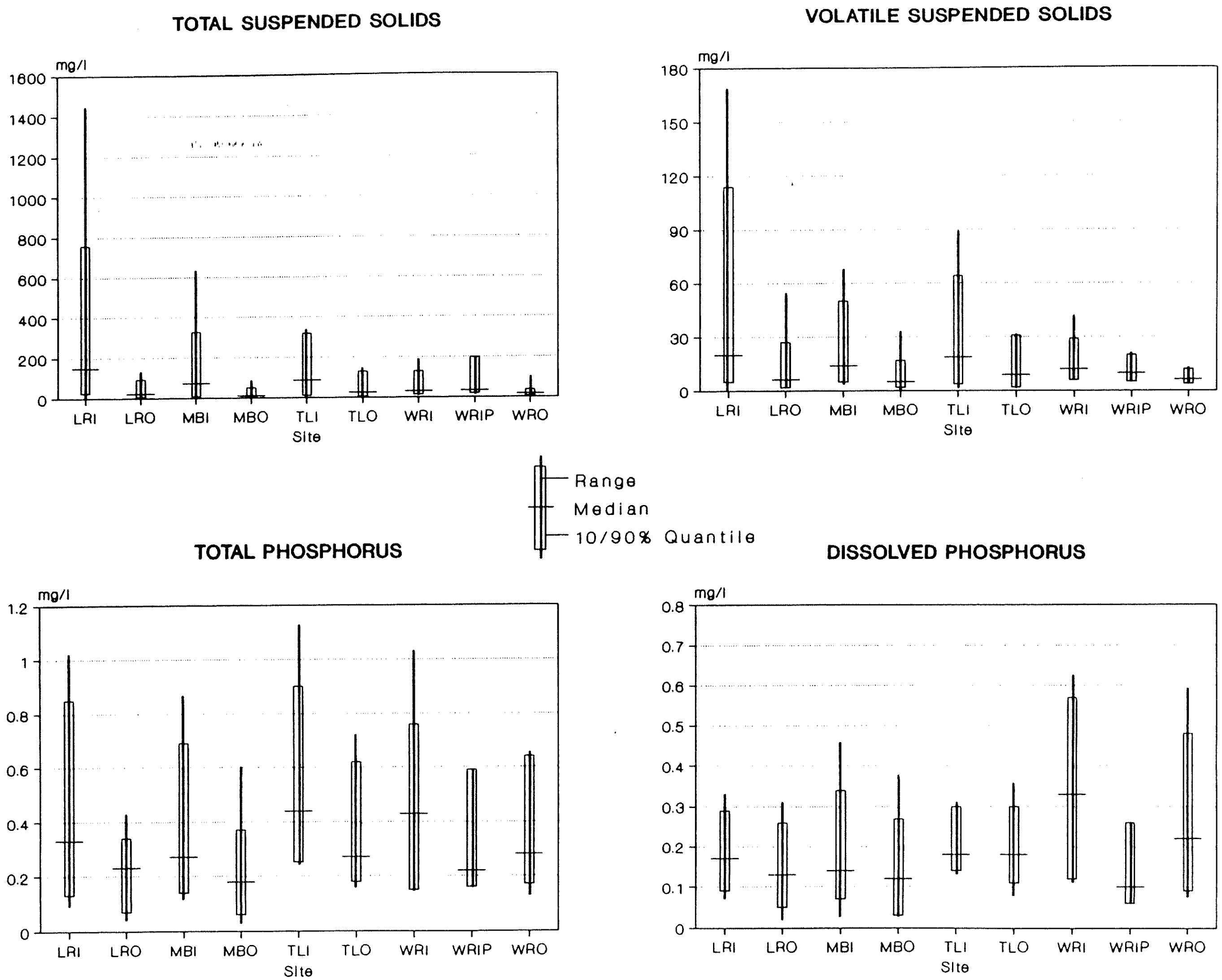
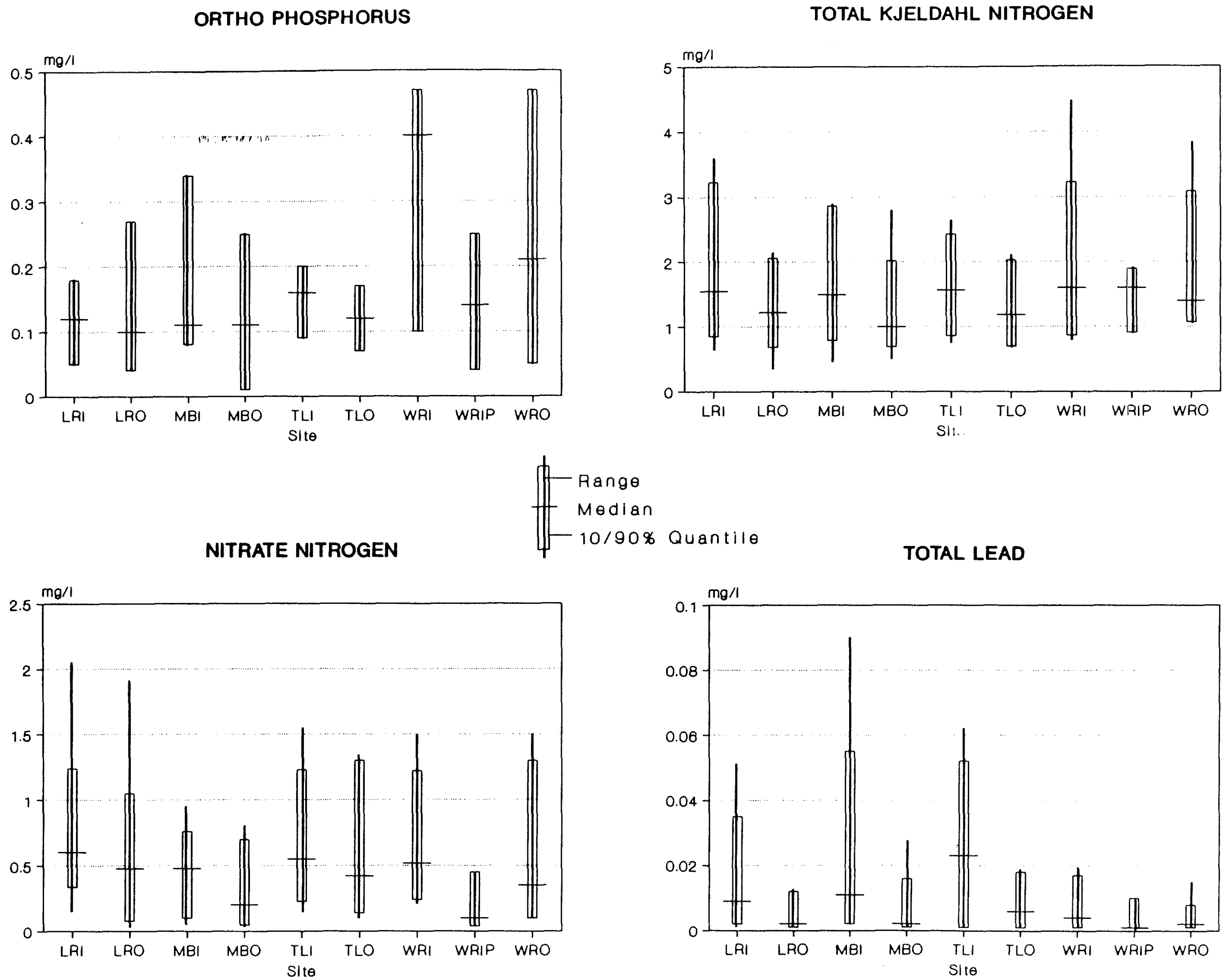


Figure 23, continued. CONCENTRATION BOX PLOTS



SEDIMENT

Sediment samples were taken at each of the four treatment facilities at the beginning of the study. These samples were taken from the upper six inches of soil to determine background levels of organic content, TP, TPb, total iron (TFe) and total aluminum (TAl) in the soils close to the inflow and outflow of each facility and at the mid-points of the McKnight Basin and Carver Ravine facilities. The samples were collected at Lake Ridge, McKnight Basin and Tanners Lake in October, 1987. An extra sample was taken at McKnight Basin just above the weir located midway through the detention facility and at Carver Ravine in the middle of the wetland part of the system. Sediment samples at Carver Ravine were collected in June of 1988 because this site was a replacement for the previously dropped Lakeville site. The location of sediment sampling is shown on the site maps (Figures 2-5).

The results of the sediment sampling are shown in Table 6. As discussed in the McCarrons Wetland Treatment System completion report (Oberts and Osgood, 1988), phosphorus retention can be enhanced through geochemical adsorption by extractable aluminum and iron minerals in wet soils (Richardson, 1985). Patterns of TP association with TAl and TFe among the samples in Table 6 are not apparent. Patterns of TPb association are similarly absent. Exceptions to these are the high levels of TP and TPb associated with high TAl and TFe at MBI(mid) and the two TL sites. Contrary to the above relationship is the very high level of TP associated with the lowest observed level of TFe at WR(mid).

The sediment data do indicate for the McKnight Basin that material is settling behind the weir located mid-way through the facility. Levels of both TP and TPb are markedly higher behind the weir where the sample was taken than at the inflow or outflow sites. Conclusions on TP behavior for the Carver Ravine sites and comparison of these sites to the others are difficult to make because total solids and total volatile solids analyses were inadvertently left off of the laboratory request form, meaning that dry weight concentrations for the three sites were not run. The wet weight totals do show a more highly concentrated TP sample was drawn from the middle of the system, where particulates tend to accumulate.

Table 6. SEDIMENT ANALYSES

Site*	Date	Percent of Total: Total Solids	Percent of Total: Tot.Vol. Solids	Concentration (mg/kg dry weight): Total P	Total Fe	Total Al	Total Pb
LRI	10/20/87	66.4	9.4	294	11000	7030	8.8
LRO		54.1	6.7	397	13700	8280	8.5
MBI	10/20/87	76.4	1.0	105	8305	4165	11.2
MBI(mid)		53.3	2.5	563	14400	9330	54
MBO		70.4	1.4	199	9590	6540	10.9
TLI	10/20/87	21.2	9.0	1014	15800	6270	29
TLO		37.2	5.4	1048	26800	9930	81.8
WRI	6/12/88	**	**	28***	13400	5070	8.1
WRI(mid)				324	4460	4620	5.3
WRO				19	10360	4790	5

*See Appendix D for site specific sampling locations
** Solids analysis not completed
***All TP values at WR sites are for wet weight

DISCUSSION

The purposes of this study are to quantify the pollutant load reductions that occurred over the time interval during which samples were taken and to propose design considerations that might lead to more effective long-term pollutant reductions. This section of the report will include a discussion on pollutant reductions in runoff facilities. This discussion will also include findings from the recently completed study of the McCarrons Wetland Treatment System, as reported in Oberts and Osgood (1988). Recommendations on the various systems studied will follow in the next major section.

LOAD REDUCTIONS

For each of the five sites (four LCMR plus McCarrons), total loads entering and leaving the facilities for a suite of events have been documented. To assess pollution reduction efficiency, the load in plus indirect loads between the inflow and the outflow are compared to the total load leaving the facility, as defined by the following equation for each separate facility and each pollutant being considered:

$$R_e = \sum_{N=i} \frac{(L_{in} + L_d) - L_o}{(L_{in} + L_d)} * 100$$

where R_e = reduction efficiency for any pollutant (%),
L_{in} = inflow load via tributaries (lbs.),
L_d = direct (overland and precip.) load between inflow and outflow (lbs.),
L_o = outflow load (lbs.), and
i = the number of events sampled.

These event totals have been summed for the total amount of events sampled and overall load reductions determined. It must be emphasized here that this method of analysis has some limits and must be used in the proper context. The number of events sampled represents a very good portion (close to half) of the total events that occurred during the study (Figure 8), but it does not include inter-event sampling to quantify "quiescent" period additions (or deletions) from overall event efficiency. It is also important to keep in mind that the period of study for all five sites was very dry and that long-term detention of runoff did not occur. Typically, the facilities filled to a certain level during an event and immediately went back to base levels of permanent storage shortly after the event ended. Appendix G lists all of the hours of outflow for each rainfall event. For snowmelt events, the period of melt-affected outflow can extend well beyond the actual snowmelt because of slow release from shallow groundwater and upper watershed storage. For example, MBO flowed at greater than baseflow for a period of almost three weeks, two of which were past the most active snowmelt (Figure 13). Unfortunately, ice exists on the facilities during much of this time and treatment can be minimal, as discussed later.

The treatment efficiencies for each of the four recently studied sites, and for the McCarrons detention pond (the uppermost component in the McCarrons system) and for the entire McCarrons Wetland Treatment System (pond and wetland chambers) are listed in Table 7A for all monitored events and in Table 7B for rainfall events only. Figures 24A and 24B show the reductions graphically for the pollutants that are common to both studies and Figures 25A and 25B for those pollutants unique to each study. These bar graphs show total pollutant reductions

Table 7A. PERCENT POLLUTANT REMOVAL EFFICIENCY FOR LCMR AND McCARRONS, ALL MONITORED RAINFALL AND SNOWMELT EVENTS

Percent Load Reduction
Percent Regression Efficiency
Number of Events

	Lake Ridge	McKnight Basin	Tanners Lake	Carver Ravine	McCarrons Pond	McCarrons System
TSS	85	85	63	20	90	96
	86	85	63	21	91	94
	20	20	11	16	23	23
VSS	67	57	50	1	92	95
	64	52	48	-31	94	94
	20	20	11	16	23	23
TP	37	34	7	1	73	78
	37	30	-1	-12	73	78
	20	19	11	15	23	23
DP	8	12	-14	1	52	56
	3	9	-23	-6	43	65
	20	19	11	14	23	23
TKN	28	15	7	-10	70	76
	25	10	-5	-26	85	84
	20	19	11	15	23	23
NO3	17	11	1	9	52	63
	19	9	-1	8	46	64
	20	19	11	15	23	23
TN	24	14	5	-6	68	74
	19	9	-3	-19	81	81
	20	19	11	15	23	23
TPb	52	63	59	6	78	90
	54	58	57	-8	75	89
	20	20	11	16	23	23
SPb*	--	--	--	--	--	--
	75	18	71	66	--	--
	3	5	2	3	--	--
Ortho-P	-5	34	20	-3	--	--
	-11	33	12	-10	--	--
	10	9	8	8	--	--
COD	--	--	--	--	82	89
	--	--	--	--	88	93
	--	--	--	--	23	23

* SPb 'N' too small to run regressions

Table 7B. PERCENT POLLUTANT REMOVAL EFFICIENCY FOR LCMR AND McCARRONS, MONITORED RAINFALL EVENTS ONLY

Percent Load Reduction
Percent Regression Efficiency
Number of Events

	Lake Ridge	McKnight Basin	Tanners Lake	Carver Ravine	McCarrons Pond	McCarrons System
TSS	90	85	62	46	93	97
	90	86	56	38	91	96
	16	17	10	13	19	19
VSS	70	67	52	32	94	96
	67	72	46	13	95	96
	16	17	10	13	19	19
TP	61	48	24	24	78	77
	66	55	26	27	77	78
	16	16	10	12	19	19
DP	11	13	10	21	58	48
	9	28	17	31	57	53
	16	16	10	12	19	19
TKN	50	31	40	14	78	78
	58	37	38	11	87	85
	16	16	10	12	19	19
NO3	10	24	23	18	63	64
	-5	13	21	21	60	63
	16	16	10	12	19	19
TN	41	30	36	15	76	76
	45	33	34	12	85	82
	16	16	10	12	19	19
TPb	73	67	63	42	88	93
	76	63	57	41	85	90
	16	17	10	13	19	19
SPb*	--	--	--	--	--	--
	75	18	71	66	--	--
	3	5	2	3	--	--
Ortho-P	22	50	26	27	--	--
	-4	57	19	43	--	--
	9	8	7	7	--	--
COD	--	--	--	--	88	89
	--	--	--	--	90	93
	--	--	--	--	19	19

* SPb 'N' too small to run regressions

Figure 24A. LOAD REDUCTIONS ALL MONITORED EVENTS

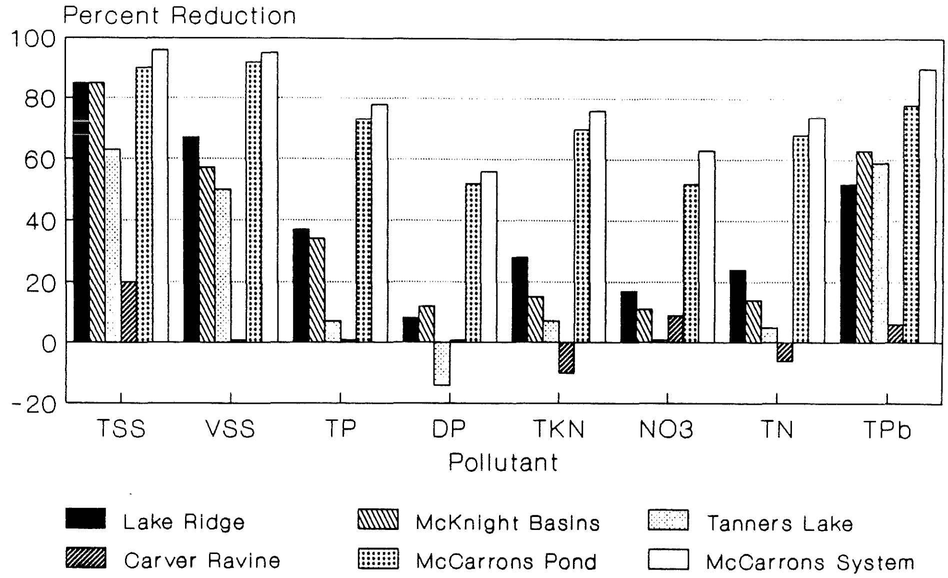
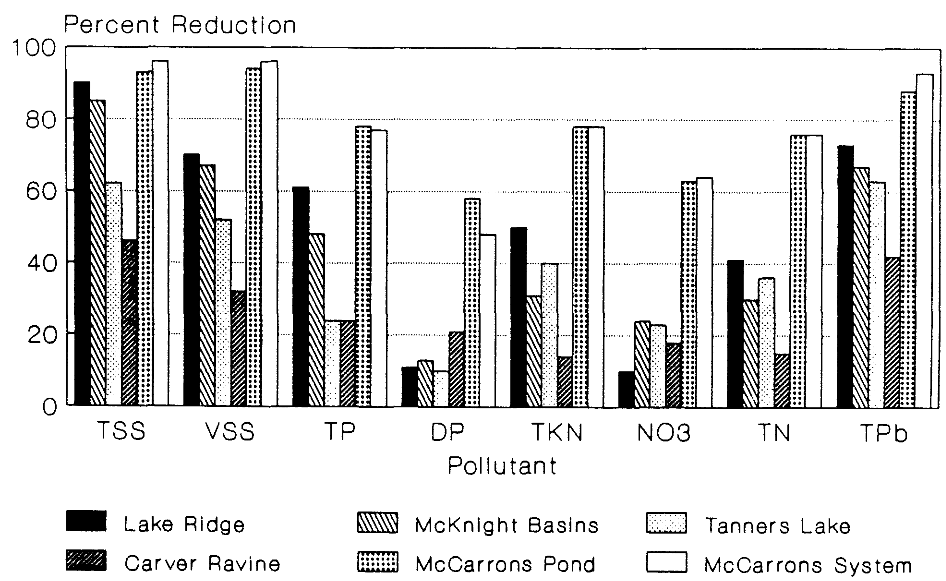


Figure 24B. LOAD REDUCTIONS RAINFALL EVENTS ONLY



Based on Sampled Loads

Figure 25A. OTHER LOAD REDUCTIONS ALL EVENTS

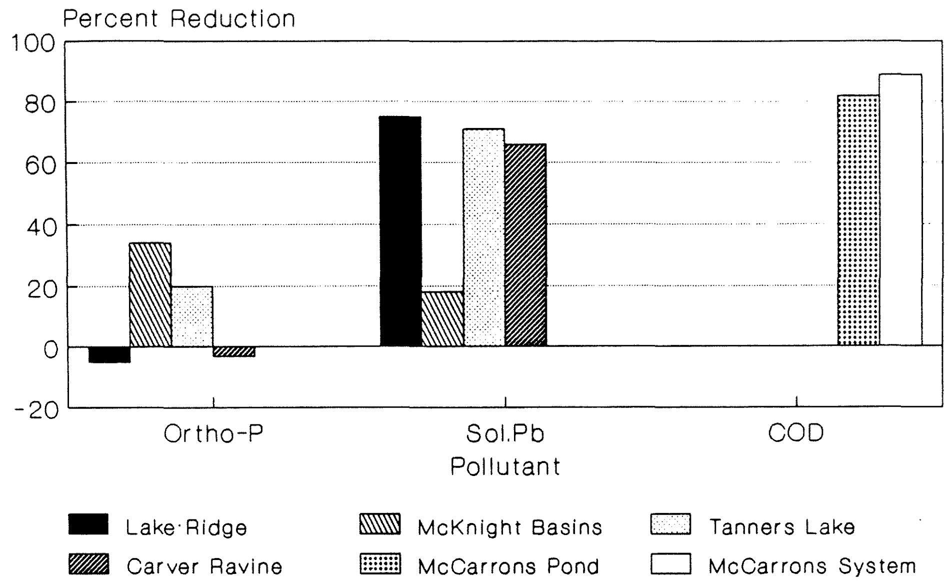
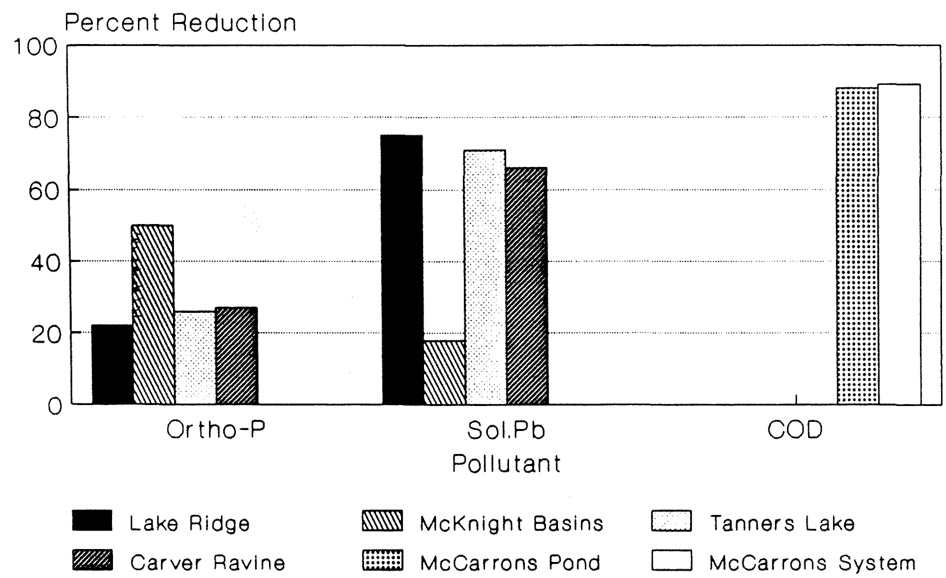


Figure 25B. OTHER LOAD REDUCTIONS RAINFALL EVENTS ONLY



Based on Sampled Loads

for each pollutant evaluated at each site.

The most dramatic conclusion from viewing the Figures 24A and 24B is the dominance of the McCarrons pond and system in treatment efficiency relative to the other facilities. The McCarrons Wetland Treatment System, as described in the previously referenced analytical report, operates particularly well because of the combined detention and wetland treatment. Following close behind McCarrons for the solids and solids-associated TPb are Lake Ridge, McKnight Basin and Tanners Lake. Carver Ravine shows markedly lower reduction efficiencies for these pollutants.

The McCarrons pond and system also performed surprisingly well in reducing nutrient loads. The runoff into the treatment facility contained a large proportion of particulate nutrient load, which tended to settle in the pond and follow-up wetland chambers. Reference to Figures 24A and 24B shows that the Lake Ridge detention facility performed quite well in reducing TP, TKN and TN during rainfall events, and the McKnight Basin detention ponds were fairly efficient in removing TP from these same events; performance of these facilities was not good, however, for the soluble nutrients, DP and NO3. Tanners Lake wetland was fair in removing TKN, but this site and Carver Ravine performed poorly for the other nutrients during rainfall events, likely due to the lack of adequate settling time.

Figure 26 shows the ratio of dissolved-to-total phosphorus entering and leaving the treatment facilities. A similar plot for the McCarrons detention pond and wetland is contained in the McCarrons system report (Oberts and Osgood 1988), but is not repeated here because of the number of tributaries that were analyzed. The results, however, show that the particulate portion of phosphorus flowing into the detention pond is quite high at more than 80%, indicating the likelihood of good treatment in the pond through settling of particulates. The percentage of particulate phosphorus in the runoff decreases to about 55% by the time it leaves the wetland treatment system. The ratios for both Lake Ridge and McKnight Basin indicate that the facilities are more efficient at settling particulate phosphorus, reducing it from inflowing levels of about 60% to outflowing levels in the 30% range. The Tanners Lake wetland, on the other hand, reduces the inflowing particulate P by only about 10% for both rainfall and all events. Carver Ravine inflow from the WRI watershed is quite limited in particulate P (<20%), whereas the pumped inflow (WRIP) is about 50% particulate.

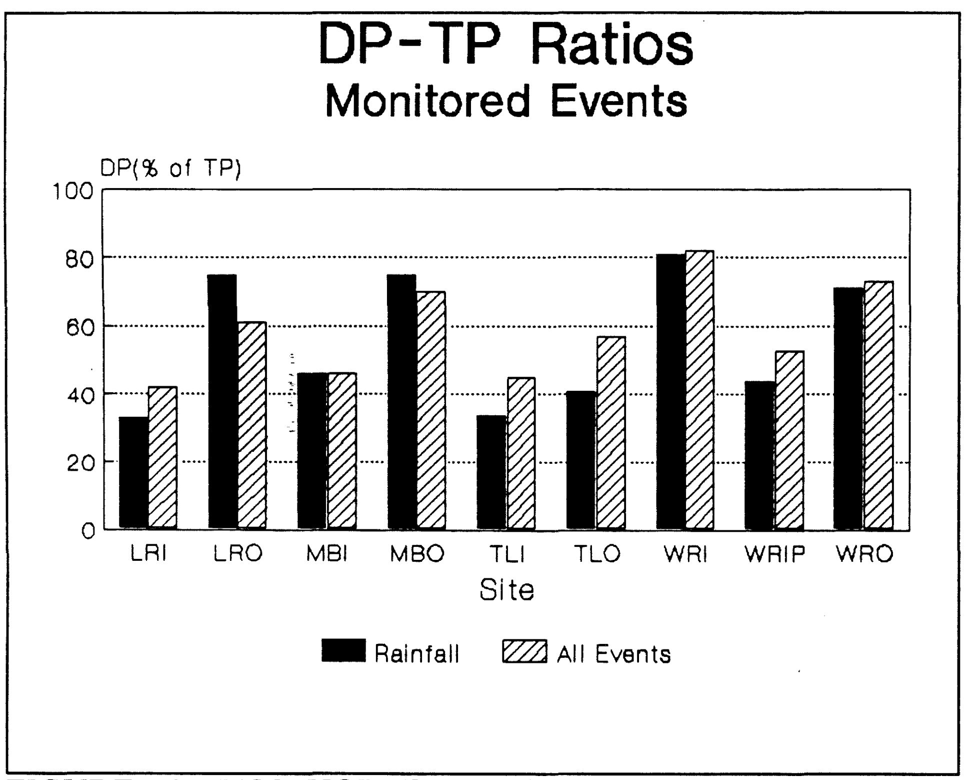


FIGURE 26. PHOSPHORUS RATIOS.

The outflow (WRO) levels are between the WRI and WRIP ratios. Further discussion on the settling abilities of the various facilities will occur when the individual sites are discussed.

Comparison of Figures 24A and 24B shows that reduction levels for the solids and associated TPb remain essentially the same for rainfall and all events for Lake Ridge, McKnight Basin, Tanners Lake and the McCarrons sites. Carver Ravine, however, showed much reduced levels of treatment when the snowmelt loads are considered.

Nutrient treatment levels at McCarrons pond and system remain fairly consistent between the rainfall events and all events. The other sites, however, all suffer reductions in treatment efficiency during snowmelt. The only exception to this is NO3 at Lake Ridge, which is more efficiently treated in the all events category. The performance of the McCarrons system is again thought to be a function of the size of the facility and the combined detention and wetland treatment. This approach appears to be successful and should be considered when the design options are available.

Treatment efficiencies can also be tested to ascertain whether changes are statistically different between inflows and outflows from the individual facilities. Flow-weighted mean inflow concentration of all analyzed pollutants were compared against outflow concentrations to test the assumption that change occurs in the treatment facilities. The data were analyzed through various procedures available in statistical packages from the SAS Institute, Inc. (Cary, N.C.). The first step in the process was to test for normality of the concentrations to see if parametric tests could be run on non-transformed data. Shapiro-Wilk Statistic (W), stem leafs, box-plots, and normal probability plots all showed the data to be log-normal, meaning that either non-parametric tests or parametric tests on log-transformed data has to be run. A Mann-Whitney Statistic (T) non-parametric test was selected because of its relative "power" over parametric tests. Table 8 shows the results of the significance tests.

Each of the sites was tested to see if there was a significant difference between all of the system inflows, including tributary inflow, overland flows and atmospheric deposition, and treatment system outflow. Overland flow values were determined from U.S. Department of Agriculture, Soil Conservation Service (SCS) flow equations (USDA-SCS 1986) coupled with inflow water quality to obtain loads. Atmospheric values were derived from previous Metropolitan Council studies (1982) and recorded precipitation.

Results of the significance tests run on the complete data sets for each site show that at the 95% confidence level, TSS, VSS and TPb, that is, the solids and associated TPb, are significantly different (lower) at the outflows compared to the inflows. Unfortunately, there is not a large enough data base to run similar statistics on a seasonal basis. The analysis of the total event set, however, shows that McCarrons pond and Lake Ridge pond do a very good job of removing essentially everything that enters them, with the exception of OP at Lake Ridge; recall that OP was not collected as frequently as the other pollutants and that its solubility makes it difficult to remove by conventional treatment. McKnight Basin performed fairly well, although the soluble nutrients did not appear to be lowered significantly in the large, lake-like system. The McCarrons system, as described in Oberts and Osgood (1988) does not significantly remove DP, TKN or TN, again because the soluble phosphorus and nitrogen (that is, dissolved organic N and ammonia) move through the system and are sometimes even added as water moves through

TABLE 8. RESULTS OF MANN-WHITNEY NON-PARAMETRIC SIGNIFICANCE TEST.

Null Hypothesis H_0: Inflow concentration = Outflow concentration
(Alternate hypothesis H_1: Inflow > Outflow)

	Accept H_0	Reject H_0
Carver Ravine	OP, TP, DP	TSS, VSS, TPb TKN, NO3, TN
Lake Ridge	OP	TSS, VSS, TP, DP TKN, NO3, TN, TPB
McCarrons Pond	None	TSS, VSS, COD, TP, DP, TKN, NO3, TN, TPb
McCarrons System	DP, TKN, TN	TSS, VSS, COD, TP, NO3, TPb
McKnight Basin	OP, DP, NO3*	TSS, VSS, TP, TKN TN, TPb
Tanners Wetland	OP*, DP, NO3,	TSS, VSS, TP, TKN, TN TPb

* Critical values equal-- no reason to reject H_o

the wetland component of the system. Tanners Lake wetland appears to have the same soluble nutrient problem. The Carver Ravine wetland/detention facility is so overwhelmed with flow and contains such a small permanent storage volume that treatment is limited only to coarse-grained particulates; most of the sampled nutrients moved right through the Carver Ravine system and into Carver Lake. Detailed analysis of each of these systems occurs under the next section.

CONTRIBUTING FACTORS

There are a number of watershed and hydrologic factors that contribute to the loads entering treatment facilities and to the effectiveness of those facilities. In order to evaluate which factors are most important, stepwise regression techniques can be used. Statistical methods available through SAS procedures allow a large number of independent physical, demographic and hydrologic variables to be examined relative to their importance in determining watershed loads and treatment facility effectiveness. The results of these statistical procedures are not intended to provide quantitative techniques for prediction; rather, they are intended to give a first-cut impression of those factors that are likely contributing to a set of dependent variables.

The first stepwise regression models were run to evaluate factors influencing loads entering facilities during rainfall events. Management of snowmelt runoff will be discussed as a separate topic later in this report. These contributing factors will be important in future management decisions intended to control nonpoint pollution from urban surfaces. The independent variables considered in this evaluation can be grouped into two major categories as follow:

Land Use/Cover Percentages -
- SFR = single family residential
- MFR = multi-family residential
- WET = wetland
- CI = commercial plus industrial
- GRS = grassland plus vacant land
- WOD = woodland
- POS = parks and open space
- WTR = open water
- MISC = transportation and utility corridors, construction, and aggregate (mining) operations

Hydrologic Factors -
- IMP = imperviousness of effective watershed area
- VOL = volume of runoff
- PPT = depth of precipitation
- DUR = duration of precipitation
- IAVE = average intensity of precipitation
- IMAX = maximum intensity of precipitation
- ICTR = intensity during period of greatest continuing precipitation
- QPk = peak discharge into facility
- EFFDA = effective drainage area
- DA = total drainage area

In order to "normalize" the analysis or put it on a per unit basis, the total loads to the facility being considered were divided by the effective drainage area, which was then removed as an independent variable in the regression analysis. Also, the number of independent variables in the final equation was limited to two to avoid long equations that usually do not add much to the descriptive abilities. Table 9 gives the results of the stepwise regression analysis, listing the first and second selected independent variables and the coefficient of determination (R^2) for each pollutant analyzed at each LCMR site. A similar exercise is contained in the McCarrons report. OP and SPb were not analyzed because of the low number of samples.

Table 9. RESULTS OF STEPWISE REGRESSION ANALYSIS OF LOADING FACTORS

FIRST SELECTED INDEPENDENT VARIABLE
SECOND SELECTED INDEPENDENT VARIABLE
COEFFICIENT OF DETERMINATION (R-SQUARE)

SITE	N	TSS	VSS	TP	DP	TKN	NO3	TN	TPb	VOL
LRI	17	IMAX	IMAX	IMAX	IMAX	IMAX	IMAX	IMAX	IMAX	QPk
		-WOD	-WOD	-WOD	DUR	-WOD	DUR	DUR	-WOD	POS
		0.49	0.50	0.47	0.48	0.51	0.41	0.52	0.50	0.90
LRO	16	IMAX	IMAX	IMAX	IMAX	IMAX	IMAX	IMAX	IMAX	PPT
		-MFR	-WOD	DUR	DUR	DUR	DUR	DUR	DUR	-CI
		0.46	0.46	0.53	0.49	0.57	0.47	0.54	0.39	0.87
MBI	17	IMAX	IMAX	IMAX	DUR	MFR	WOD	IMAX	IMAX	PPT
		DUR	DUR	DUR	WOD	IMAX	DUR	DUR	MISC	WET
		0.81	0.80	0.86	0.79	0.92	0.83	0.89	0.73	0.94
MBO	17	DUR	DUR	IMAX	IMAX	DUR	DUR	DUR	DUR	QPk
		IMAX	IMAX	DUR	POS	IMAX	POS	IMAX	WET	DUR
		0.80	0.80	0.50	0.30	0.83	0.65	0.81	0.74	0.98
TLI	10	IMAX	DUR	DUR	DUR	IMAX	IMAX	IMAX	DUR	QPk
		DUR	IMAX	IMAX	IMAX	DUR	DUR	DUR	IMAX	-IMAX
		0.43	0.40	0.37	0.50	0.55	0.48	0.54	0.44	0.98
TLO	10	IMAX	DUR	DUR	DUR	IMAX	DUR	IMAX	DUR	QPk
		DUR	IMAX	IMAX	IMAX	DUR	IMAX	DUR	IMAX	PPT
		0.38	0.37	0.43	0.43	0.60	0.48	0.58	0.39	0.95
WRI	13	DUR	MFR	DUR	DUR	DUR	SFR	DUR	DUR	QPk
		IMAX	DUR	IMAX	IMAX	IMAX	DUR	IMAX	GRS	-IMAX
		0.54	0.63	0.55	0.44	0.76	0.61	0.73	0.50	0.90
WRO	13	DUR	DUR	DUR	DUR	DUR	DUR	DUR	DUR	PPT
		-CI	-CI	-WTR	-MISC	IMAX	CI	IMAX	IMAX	-IMP
		0.57	0.69	0.72	0.65	0.82	0.60	0.79	0.63	0.88

The most obvious result of this exercise is the dominance of IMAX (maximum precipitation intensity) in determining the dependent variables for load and volume. In fact, when the stepwise regression models were first run, all of the independent variables selected were intensity factors, indicating a cross-correlation among intensity factors. The most commonly chosen first intensity variable was IMAX, so ICTR and IAVE were eliminated from subsequent runs. The most commonly selected second independent variable is DUR (rainfall duration). QPk and PPT dominate the determination of volume. The complete set of sites was combined into one large data set and the same stepwise regression run. The coefficients of determination for each of the pollutants in the data set never exceeded 0.30, indicating that no clear-cut results for all sites could be obtained; further analysis was dropped. Hydrologic factors related to the rate and duration of rainfall are, therefore, shown by the factors analysis to be very important in the mobilization and movement of pollutants from urban surfaces. These factors seem to be more important than the differences among the type of land use or land cover. Because we were not monitoring homogeneous land use/cover, these factors were not "strong" enough to surface as dominant independent variables. From a management standpoint, the regression results tell us that methods must be instituted to effectively capture the runoff that results from storms since we cannot do anything to manage the rate or duration of the rainfall. Also, treatment facilities have to be designed considering the peak flow that occurs, as well as the total volume of runoff.

The stepwise regression approach can also be used to evaluate the importance of hydrologic and system design factors in pollutant reduction efficiency. In addition to the hydrologic factors noted previously, the system efficiency also looked at the following:

Design and Wash-off Factors - LAST = days since last rainfall over 0.1"
HYDR = hydraulic detention time
STOR = permanent storage volume of facility
ZMAX = maximum depth of permanent storage pool
OUTFL = hours of event-influenced outflow

The results of this analysis are contained in Table 10. It appears as though design-related features, such as storage volume, maximum depth and hydraulic detention time, are more important than hydrologic factors, although IAVE and IMAX do appear in the matrix a number of times in both positive and negative relationships. The positive relationships seem to indicate, as they did in a similar exercise with the McCarrons data (Oberts and Osgood 1988), that higher intensity events wash more pollutants into the facilities. The treatment systems can then show a higher degree of removal from dirtier water than from clean water from less intense events. That is, it is easier to show substantial reductions if there is more material to remove. Similar inferences can be made from Table 10 for almost any of the entries; however, speculating on the meaning is not as important as our original purpose of seeing which factors might be important. The conclusion of this undertaking is that design conditions do markedly influence the effectiveness of treatment facilities.

The most often occurring factors in Table 10 are ZMAX and HYDR, indicating the importance of a permanent storage pool of adequate depth and volume to detain runoff for a period of time. The relatively large number of negative hours of outflow (-OUTFL) reflects the fact that larger storms cause the facility to operate at event conditions for longer periods. The negative OUTFL variable and HYDR would seem to indicate opposite phenomenon, except OUTFL is a

Table 10. RESULTS OF STEPWISE REGRESSION ANALYSIS OF POLLUTANT REMOVAL EFFICIENCY FACTORS

FIRST SELECTED INDEPENDENT VARIABLE
SECOND SELECTED INDEPENDENT VARIABLE
COEFFICIENT OF DETERMINATION (R-SQUARE)

SITE	N	TSS	VSS	TP	DP	TKN	NO3	TN	TPb	VOL
Lake Ridge	14	ZMAX	ZMAX	ZMAX	-OUTFL	STOR	HYDR	ZMAX	ZMAX	-OUTFL
(detention)		-LAST	-LAST	-OUTFL	ZMAX	-HYDR	IAVE	-LAST	-OUTFL	STOR
		0.93	0.88	0.84	0.68	0.78	0.79	0.86	0.70	0.43
McKnight Basin	15	STOR	STOR	HYDR	LAST	HYDR	IAVE	HYDR	STOR	IMAX
(detention)		-DUR	-DUR	LAST	-IAVE	-OUTFL	HYDR	-DUR	-DUR	-OUTFL
		0.92	0.91	0.47	0.14	0.58	0.54	0.62	0.94	0.57
Tanners Lake	10	ZMAX	ZMAX	IMAX	-OUTFL	ZMAX	LAST	ZMAX	ZMAX	IMAX
(wetland)		-QPk	HYDR	HYDR	ZMAX	LAST	-OUTFL	LAST	LAST	LAST
		0.98	0.96	0.73	0.56	0.94	0.81	0.92	0.98	0.57
Carver Ravine	10	ZMAX	HYDR	HYDR	HYDR	LAST	HYDR	LAST	HYDR	-IMAX
(wetland/		-OUTFL	IAVE	-LAST	-IAVE	IAVE	-IMAX	HYDR	-LAST	STOR
detention)		0.81	0.64	0.69	0.42	0.35	0.80	0.46	0.77	0.56

temporal variable and HYDR incorporates storage volume, inflow volume and time. Both variables point to the importance of not overloading a treatment facility with large volumes of runoff that have to pass through quickly. The two variables seem to be indicating that to make the best use of the treatment facility, it should be designed to accommodate frequently occurring events, rather than high volume, low frequency events and it should provide adequate storage for good hydraulic detention.

Based on these findings, we would certainly agree with the recommendations of NURP/Walker that a permanent pool should be part of any well designed water quality management facility. The LCMR sites that worked the best from a water quality standpoint (Lake Ridge and McKnight Basin) had maximum permanent pool depths over four feet (Table 4). McCarrons pond, which had the best overall water quality treatment of the sites evaluated, had a maximum permanent pool depth of only 2.6 feet, but the small (12") outlet meant that the effective depth of storage increased rapidly and decreased slowly as a storm would pass through the pond. Under conditions where a depth over four feet cannot be provided, such as an area of limited impermeable substrata or an area where safety precludes deeper water, the McCarrons approach of limiting outflow rate could be a viable option to providing permanent pool depth. This approach has an added benefit of extending detention times.

In summary, a comparison of the pollutant removal efficiencies (Tables 7A and 7B), the hydrologic design characteristics of the various facilities (Table 4) and the factors contributing to treatment efficiency (Table 10) shows the importance of design in the attainment of good pollutant removal percentages. The best performing systems were McCarrons, Lake Ridge, and McKnight Basin. Tanners Lake performed marginally well for solids, but the lack of adequate storage seemed to detract from its ability to treat nutrients. Finally, Carver Ravine performs poorly for each of the pollutants evaluated because of its small size.

SNOWMELT CONSIDERATIONS

Before each of the sites are reviewed, a word needs to be said about snowmelt. As was apparent in the load reduction graphics and tables, snowmelt markedly reduces the overall efficiency of treatment. The McCarrons report discussed this, but it bears repeating. The frozen nature of Minnesota winters results in a thick layer of ice being formed on all water surfaces during most winters. This ice creates a barrier to treatment for two basic reasons: first, the ice prevents full circulation of runoff into the permanent pool. Water typically "dives" under the ice until the capacity of the sub-ice volume is reached. At this point it appears as though the water might even be pressurized, as evidenced by its turbulent and upwelling character at the ice edge near outflow. Very turbid water flows from under the ice and appears at times to be eroding and mobilizing the bottom sediments and the pollutants associated with them. This condition was seen at the McCarrons sites and at every one of the LCMR sites where ice formed. Figure 27 is an adaptation of a graphic that appeared in the McCarrons report. This figure portrays schematically what has been observed at the sites above.

The second thing that ice does during snowmelt is limit the storage depth available. The available volume under the ice is limited and quickly fills. This results in a portion of the melt water running over the top of the ice. The ice, in essence, then provides an almost impermeable surface over which the runoff flows. Runoff initially flows in sheets over the top of ice, but eventually cuts channels into the ice. In both the sheet flow and the ice-channel flow, very little settling can occur because of the very shallow depth and total lack of storage volume. Other functions inhibited by ice cover and cold weather include vegetative/biological activity, the rate of chemical reaction and physical entrapment.

In order to better understand the conditions that occur under ice, some data were collected at the McKnight Basin during two periods of melt in 1989. The condition that was sampled was one first noted at the McCarrons outflow sites and at MBO in 1988. At the beginning of melt, flow from under the ice contains "plumes" of clear and turbid water, distinctly separate. It is suspected that the clarity differences are due to circulation patterns and/or density differences under the ice that prevent total mixing of the relatively clear pond water with the inflowing, dirty meltwater. The data are reported in Table 11, but no attempt will be made to explain the results because the data are not clear. That is, the turbid samples in the first event show better water quality for most pollutants than the clear sample. In the second event, the clear samples are "cleaner", which was the expected result. We cannot explain the reason for the first set of data being anomalous, but suspect that a mix-up occurred at some point in processing the samples at the lab. Even though we are not able to draw conclusions on the data, it can certainly be said that ice cover inhibits the total mixing that optimizes treatment capacity.

There are some design options that can be considered to avoid or minimize the problems with ice. Any standing water should be deep enough to prevent pressurized, turbulent under ice flow from scouring previously deposited sediments. If the entire pond cannot be kept deep, the area around the outflow should be deepened so that water that flows to it under the ice does not encounter shallow water and easily eroded sediments as it concentrates at a single outflow point. An option to deepened outflow design is dewatering of the facility in the fall, with installation of a winter low flow channel that would move water through the facility and out without allowing it to accumulate and freeze. This design requires an adequate velocity to prevent icing in the low flow channel and will likely require a flexible discharge outlet that can be lowered in the fall to dewater the facility. All culverts, conduits and channels associated with a treatment facility should be designed so that baseflow water is encouraged to move rather than slow down and freeze, eventually accumulating and further inhibiting treatment when the snow melts.

Figure 27. SCHEMATIC OF FLOW CREATED UNDER PARTIAL ICE COVER, McCARRONS DETENTION POND

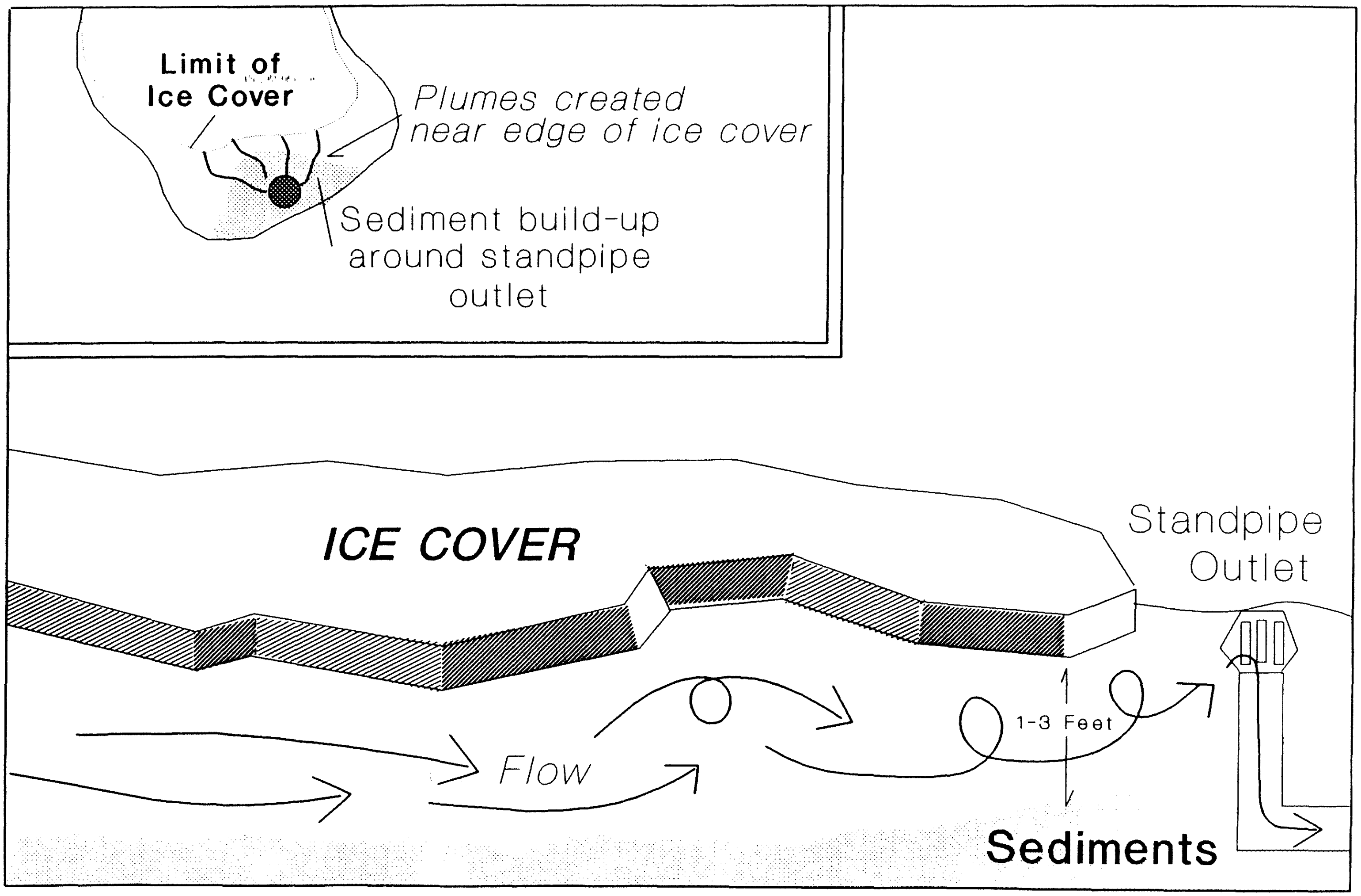


Table 11. UNDER ICE STUDY - WATER QUALITY DATA

EVENT	PRECIP.	SITE	TSS	VSS	TP	DP	ORTHO-P	TKN	NO3	TN	TPb	Degree C
890311	Melt grab	MB(clear)	31	13	0.66	0.09	0.067	2.49	0.20	2.69	0.002	1.25
		MB(turb.)	17	11	0.39	0.10	0.049	2.45	0.35	2.80	0.004	0.75
890327	Melt grab	MB(clear)	23	10	0.90	0.75	0.728	3.50	0.60	4.10	0.004	0.50
		MB(turb.)	39	16	0.53	0.39	0.398	2.27	0.55	2.82	0.014	1.25

Another option to avoid ice problems is diversion around the facility until the ice melts. This option is usually not good from a water quality standpoint because the melt runoff could be the highest loading event of the year; however, in some years , if a by-pass option is available, small melt flows diverted around an ice-covered pond or frozen wetland might mean better water quality.

SITE SPECIFIC FINDINGS

Carver Ravine Wetland/Detention Facility

As noted in the introduction, this detention facility drains a residential area in Woodbury tributary to Carver Lake. Complicating the situation is a pumped inflow from an adjacent drainage basin, adding 262 acres to the original 170 acres. Figure 2 in the introductory section shows the system configuration.

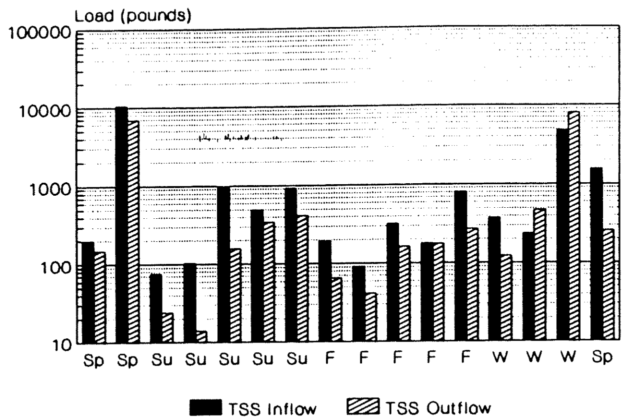
Flow enters the treatment system shortly after inflow from the normal watershed (WRI, 170 acres), with or without the additional pumped inflow (WRIP, 262 acres). Flow proceeds through a wetland complex comprised of a willow stand, followed by a cattail stand and a wet sedge meadow. This small wetland complex of 3.9 acres is partially channelized and does not appear to add significantly to the treatment capabilities of the overall system. The cattails do provide an effective screening for litter, which is trapped in the vegetation as flow weaves its way through. Flow rapidly passes through the wetland and proceeds to the very small (0.4 acre, 0.4 acre-feet) detention pond. The pond seemed to be overwhelmed in most events because of its small size relative to the size of the watershed it drains, with or without the pumped input. Runoff could be seen to pass quickly through the shallow (maximum 2.1 feet) pond and immediately out the outlet. The percentage of pond size relative to watershed size when only WRI contributes is 0.2%; when WRIP is added, this percentage drops to 0.09% (Table 4). This ratio and the shallow depth are substantially short of the recommended values suggested by U.S. EPA as a result of the Nationwide Urban Runoff Program (NURP) research and by Walker (1987), who has also studied the minimal requirements for successful runoff detention. These studies suggest a pond surface equal to approximately 2% of watershed size and a permanent pool depth of 6-10 feet. In order for the pond to meet the watershed size ratio, it would need to be 3.4 acres.

Figure 28 shows inflow/outflow bar graphs for each of the monitored events during the period of study. The graphs show that most events other than those from the winter of 1989 do result in net pollutant reductions. The reductions when they occur, however, are generally quite small. The winter events for each of the pollutants shown are negative for two of the three melt events (DP was evaluated in only two events). This poor performance in the melt is explained by the small system size and the treatment inhibiting character of the ice cover, as previously described. Summer DP levels show little or no reduction in loading when the lake is most sensitive to phosphorus.

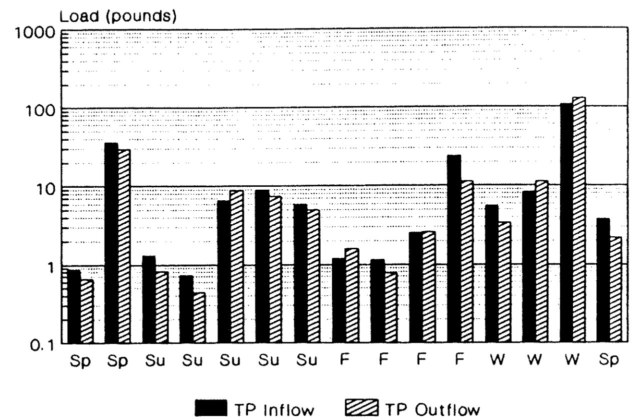
The City of Woodbury could improve the treatment abilities of the Carver Ravine system by increasing both the areal size and the depth of the detention pond. Extending the pond to available land to the west or even into the sedge area could reasonably increase its size. Increasing the permanent pool storage depth of the pond to approximately six feet would help the pond dissipate runoff energy and would provide a location for the permanent removal of settleable material that now passes through. The addition of some permanent storage would also allow for more detention time, which will aid in the reduction of nutrients. Increasing the depth would likely require fencing or, more preferably, the installation of a tall vegetative stand on a shallow shelf (1-3') ringing the permanent pool. Wetland species that are very tolerant of fluctuating water levels (cattails, rushes) could be used to prevent children from venturing into the water and would also use some of the nutrients retained by the pond.

Figure 28. CARVER RAVINE INFLOW-OUTFLOW LOADS

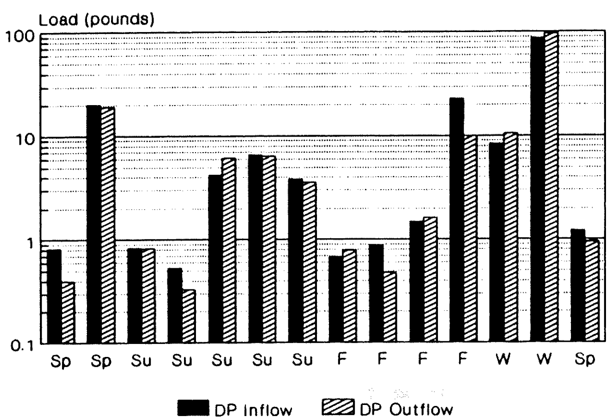
TSS - MONITORED EVENTS



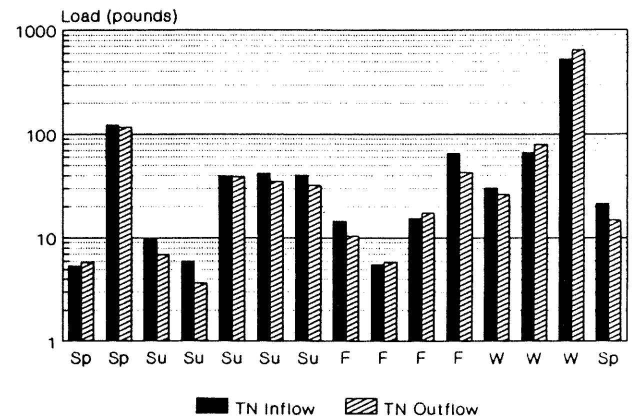
TP - MONITORED EVENTS



DP - MONITORED EVENTS



TN - MONITORED EVENTS



The area between the inflow pipes at York Avenue and the footbridge immediately upstream of the wetland could serve a better function if it operated as a catchment area for the tremendous bedload of coarse-grained particulates that move through that channel. The scope of this project did not allow us to quantify the bedload to the wetland, but it was very apparent that an extremely large amount of sandy material is carried into the system via this channel. The worst loads of the coarse material occurred with the snowmelt and the first spring events when the material used for anti-skid protection on the street surfaces washed off. The city should consider the possibility of converting this small channel area into a "forebay" or easily accessible, possibly cement-lined, sump area where grit is collected and routinely removed with a backhoe, mud-cat or shovel. The access from the road and the path make this an ideal location to trap sediments before entering the wetland.

If the coarse-grained material is removed by a forebay, a low head earthen berm could be installed at the downstream side of the wetland complex in order to provide some detention time in the wetland. Built with a flow diffuser to spread the flow out, this would allow physical treatment processes such as settling to occur in combination with the biological treatment processes ordinarily occurring in wetlands. Currently, it does not appear as though either suite of processes is successful.

The final suggestion for this system involves the inflow pipe that drains Carver Lake Road into the pond. This pipe drains to the pond about five feet from the system outflow pipe. As a result, flow from this pipe, which is substantial at times, "short-circuits" the pond and immediately flows out. In order to divert this inflowing water to the pond, some sort of structural solution is needed to turn the water away from the outflow and toward the pond. Field staff repeatedly attempted to divert this flow with the large rip-rap available around the outflow, but this never succeeded because of high impact velocity and inability to get a tight rip-rap wall. Structural solutions to this problem could include a pipe extension to outlet flow further into or along the edge of the pond; a concrete, metal, or wooden barrier between the inflowing water and the outlet pipe barrier; or elimination of the street input altogether. We suggest the extension as the best solution from a water quality standpoint.

Lake Ridge Detention Pond

The detention pond at the Lake Ridge condominiums in Woodbury drains an area very similar in land use to the Carver Ravine site. The detention pond at Lake Ridge, however, is built closer to the NURP/Walker guidelines and was, therefore, expected to show better treatment than the Carver Ravine site (Table 4). The Lake Ridge detention pond has a permanent pool approximately one acre in size. The pool has an average depth of 2.0 feet, with a maximum depth of 4.8 feet. The shape of the pond is triangular as suggested in the design guidance and grades from shallow at the inflow to its deepest point near the outflow. The exact design specifications on this facility are not quite up to NURP/Walker levels, but they are typical of ponds installed in the region.

As with the Carver Ravine site, the Lake Ridge watershed drained different areas at different parts of the year. For four of the 17 events monitored, flow from the upper 216 acres in the watershed did not escape a large wetland at its downstream end. This effectively cut off a fully developed portion of the drainage basin, resulting in proportionately lower inflows to the detention pond. The lower portion of the watershed, although containing a major highway corridor and some high runoff from commercial and multi-family land uses, also contains some vacant land that held back water from the pond. This vacant land, however, is likely to develop within the next several years, increasing the amount of runoff to the pond.

Another feature of the Lake Ridge pond that helps its performance is an outlet structure that releases flow in rough proportion to inflow; that is, at low inflow the outlet weir is at its most constricted width (4.0 feet). As water levels in the pond rise and the need increases to pass water at a higher rate, the weir width increases in steps, going from the initial 4.0 feet to 16 feet in three steps. The net effect of this structure is that low flows and the beginning stages of an event can be held at low outflow rates so that enhanced treatment can occur. This type of variable flow outflow structure can be used with a permanent pool to maximize treatment.

Figure 29 shows that all of the events monitored yielded net reductions for TSS and TN. TP and DP in two melt events, and DP in two fall events increase slightly as flow passes through the pond. The winter events are influenced by the ice cover phenomenon described previously. The fall events are likely the result of biological senescence of plankton in the pond. Summer reduction of TP is very good, and DP reductions are moderate. This DP behavior during the most sensitive period for the lake is beneficial.

Recommendations for improvement to the Lake Ridge pond are not extensive. It works well in reducing pollutants during most of the events, and is effective at reducing DP loads during the most critical time of the year. The only immediate suggestion would be to deepen the pond to an average of six feet. To provide a measure of safety if this is done, there should be a three foot wide vegetative strip around the periphery of the pool, as suggested for Carver Ravine. Also, this pond receives a large load of coarse-grained material and needs to be cleaned out regularly to maintain the design shape and depths. Perhaps the installation of a forebay at the point of inflow to the pond could also effectively reduce bedload.

McKnight Basin Detention Ponds

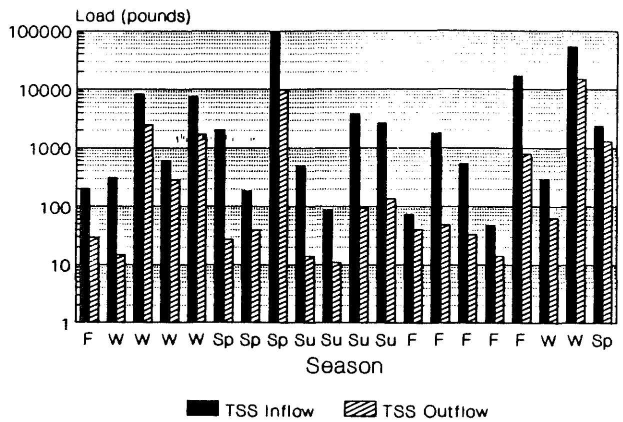
The McKnight Basin system (Figure 4) is a mainstem (Battle Creek) detention facility consisting of three detention ponds, two of which are considered primary treatment facilities. The third pond contributed flow to the system only during the largest rainfall or snowmelt events. The detention system was installed to control the rate of flow on Battle Creek. Most discussion will focus on the two primary ponds.

The primary McKnight ponds total 5.53 acres at the permanent pool level (Table 4). There are 13.2 acre-feet of storage in these ponds, with a maximum depth in Pond #1 of 4.3 feet and in Pond #2 of 4.9 feet. The watershed contributing to the ponds changed depending upon the size of the event, as noted for other sites. During the summer of 1988, the watershed upstream of Battle Creek Lake did not contribute because outflow from the lake did not occur. There are several possible combinations of contributing watershed depending upon whether the upper watershed and the third pond contribute. The maximum area with all possible areas flowing into the ponds is 5671 acres; this occurred in the spring of 1988 and during periods of the snowmelt in 1989. For most of the monitored rainfall events, the watershed above Battle Creek Lake and the third pond did not contribute, resulting in a contributing area of 725 acres.

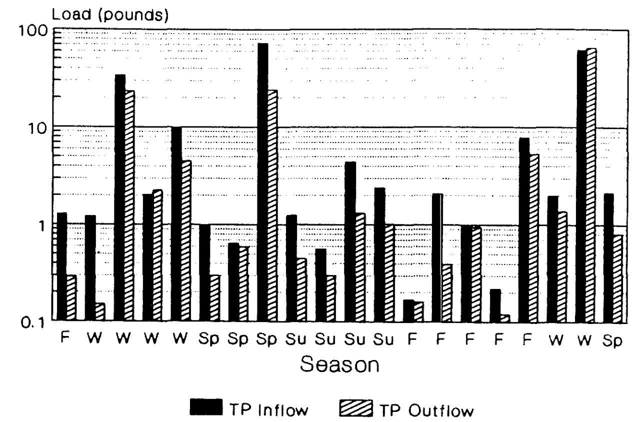
The most substantial difference related to the contributing watersheds is the difference in imperviousness (see Appendix A also). For most monitored rainfall events, the effective imperviousness of the area draining to the ponds was 43%, largely due to the contributions from

Figure 29. LAKE RIDGE INFLOW-OUTFLOW LOADS

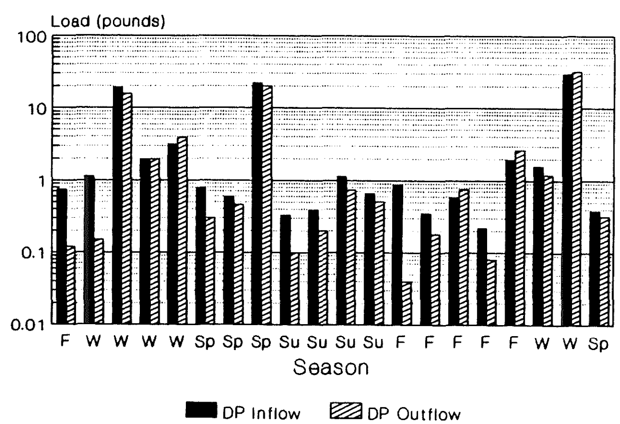
TSS - MONITORED EVENTS



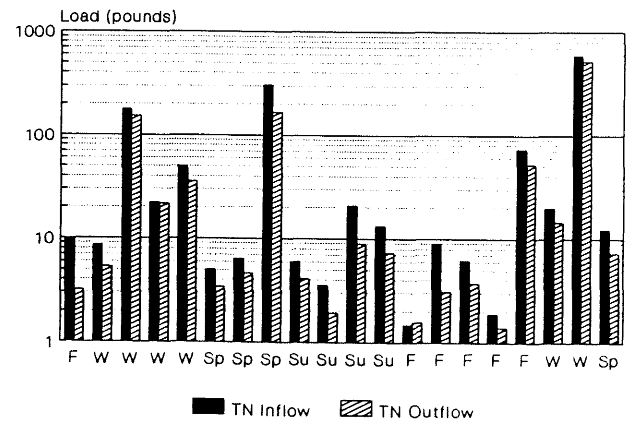
TP - MONITORED EVENTS



DP - MONITORED EVENTS



TN - MONITORED EVENTS



the 160 acre 3M complex north of Interstate 94, which discharges approximately one-quarter mile upstream of the basin inflow at MBI. When the larger area upstream of Battle Creek Lake contributes, the imperviousness decreases to 18%. These changes very much affect the hydrologic response from the watershed and hence the ability of the treatment ponds to reduce pollution. As a result of the usual high degree of imperviousness, MBI tended to be very "flashy" or quick to respond to rainfalls. Increases in discharge from 0 to 100 cubic feet per second were not uncommon over a 15 minute period (Figure 12). When the entire watershed above Battle Creek Lake contributes, the pond percentage of watershed equals 0.3%; however, when the larger watershed is cut off by the lake, the percentage increases to 2.1%. This latter figure is approximately the recommended NURP/Walker figure.

An analysis of system effectiveness as a function of contributing watershed size, however, shows that the McKnight Basin ponds perform as well with a large watershed contributing as with a small one. The likely reason for this is that the flow leaving Battle Creek Lake has been essentially pre-treated and is much cleaner than the direct runoff flowing in from the smaller, highly impervious drainage area. This phenomenon is similar to that occurring at the McCarrons system, where the pond pretreats runoff before discharging it to the wetland.

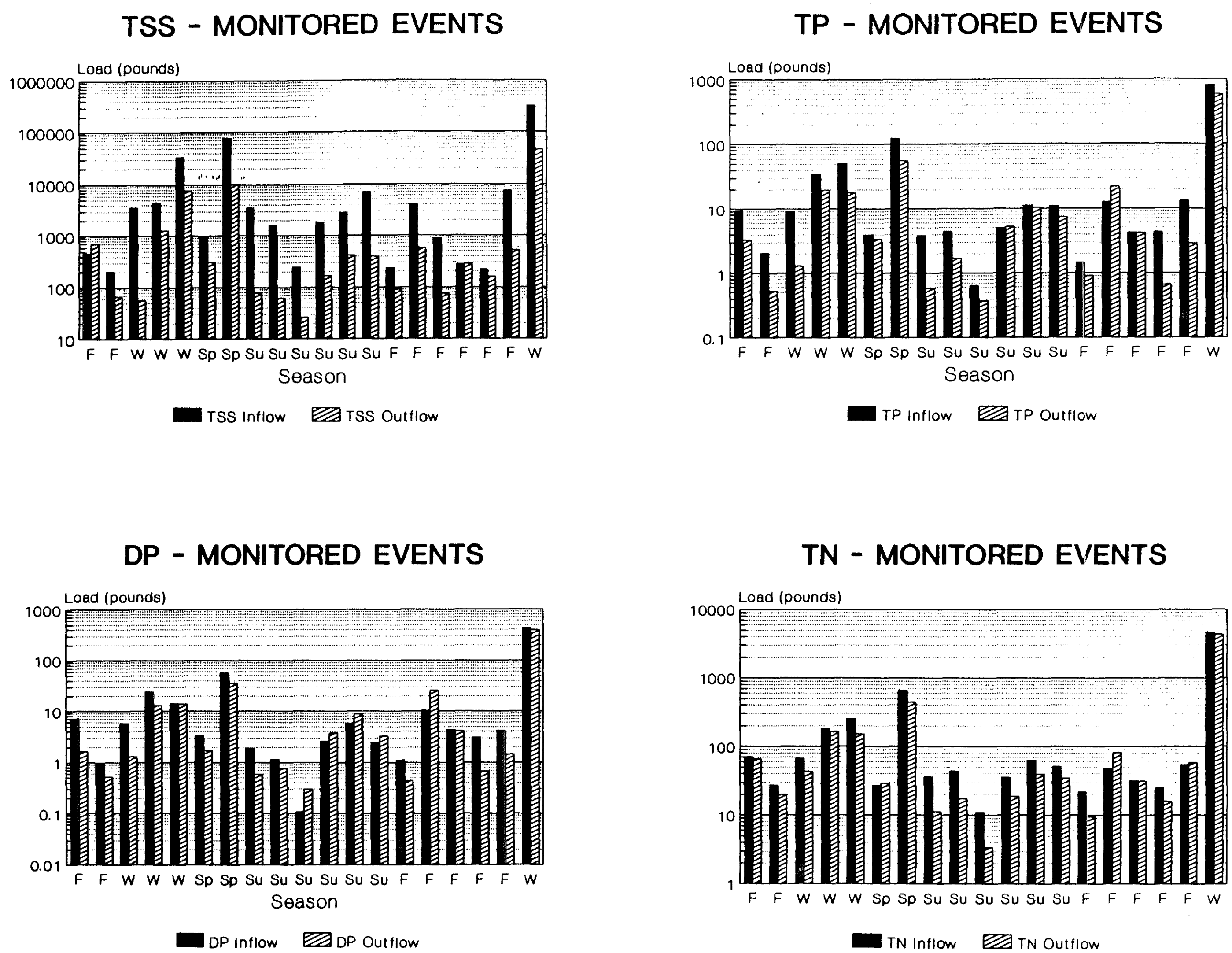
Figure 30 shows the McKnight Basin events. Substantial TSS reductions are seen for all but two small events when outflow TSS concentration slightly exceeded that of inflow. The sediment data collected as part of this study (Table 6) seem to indicate that TP and TPb are concentrating (that is, settling out) in the sediment at the mid-point of the two pond system. The concept of a tandem detention pond system seems to work very well for the removal of particulates. TP levels for two events and DP levels for five events are greater in the outflow than the inflow. Four of these DP events occur in the mid- to late-summer when phosphorus loading is most critical; plankton die-off appears to be adding DP into the water and out of the system. TN outflow levels for three sporadic events exceed inflow, but not by a large amount.

Reference to Table 7A and 7B shows that system effectiveness decreases markedly for the nutrients and VSS when the snowmelt events are added to the overall system effectiveness determinations. Again, detention systems under ice cover are partially inhibited and do not perform as well as they do without this cover.

The McKnight Basin detention system is the single example of a mainstream facility for which data were collected. The system proved to be very effective in treating runoff from both its large watershed and smaller, yet highly imperviousness, watershed. Such a system could be considered when a "regional" approach to watershed management is needed. This could occur when small facility sites are not available or when a watershed level plan calls for routing water through a single facility rather than through numerous local facilities. The important thing to remember is that the regional facility must be adequately designed.

Specific recommendations for the McKnight Basin ponds address primarily maintenance. The upper part of Pond #1 still contains a large amount of sediment that was deposited during the "super storm" of July, 1987. This material should be removed. The outflow structure of the system continually clogged with debris, resulting in an increase in pond depth and a net loss in available storage volume. This loss was not critical in any of the events monitored, but could be for larger events in the future. We suggest the installation of a well maintained floatables skimmer just upgradient from the outflow grate. The skimmer should be designed to be effective for small-to-moderate events, but topped by large events when it becomes necessary to move water through the facility to meet design specifications. This skimmer would have the added feature of collecting nutrient rich material and litter that otherwise makes its way downstream in Battle Creek.

Figure 30. McKNIGHT BASIN INFLOW-OUTFLOW LOADS



The bedload along Battle Creek at the inflow to the ponds is very high. Capturing the sediment again by some sort of sump or forebay would be beneficial. Such an area already exists under the footbridge at the inflow. A weir on the downstream side of the concrete inlet structure would trap a large amount of sediment that could subsequently be removed by a backhoe operating from the side of the structure.

Finally, the county should consider the idea of biomanipulation to control the algae in the ponds. The ponds were notably algae rich during the summer. During this period, DP load increases as runoff passes through and flushes the ponds. Algal levels during this period might be influenced by manipulation of the aquatic life in the ponds.

Tanners Lake Wetland

Construction of the Tanners Lake wetland alteration project ran behind schedule and precluded data collection for more than 11 events spread over ten months. The Tanners Lake site also was impacted severely by the drought (vegetative stabilization) and by nearby construction (Century Avenue). These events are unfortunate because the efficiency results have to be discussed based on a small data set. The expected result is lower efficiency than long-term monitoring would likely show. Fortunately, the Ramsey-Washington Metro Watershed District will continue monitoring this system in conjunction with a restoration project on Tanners Lake.

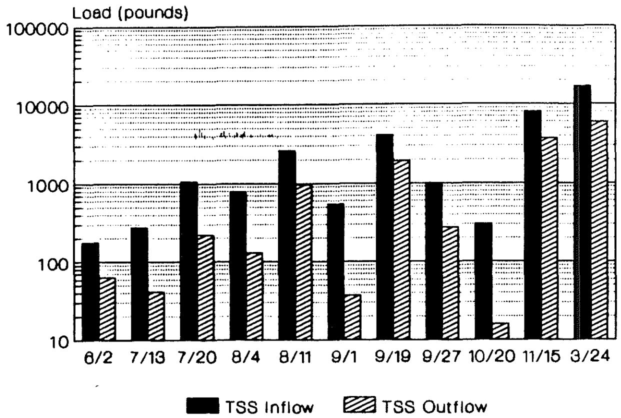
Figure 5 shows that this 2.1 acre wetland tributary to the north side of Tanners Lake has been altered by the installation of two wooden, permeable weirs to partially detain water. The weir structures (Figure 6) are built of stacked timbers, separated by 0.25 inch, through which water seeps. The weirs are also underlain by gravel so that baseflow or a portion of event flow can seep under the structures. The net effect of this design is that there is no permanent storage pool (Table 4); the wetland system effectively dewaters itself after every event. The detention times, therefore, are close to the actual hours of outflow in Appendix G. At maximum storage, the wetland weirs hold back a capacity of about 3.1 acre-feet, releasing continually even while stored volumes increase. At no time during the study did we see flow over the weirs, but a large storm or rapid melt event could certainly do so.

Figure 31 displays the events that were sampled during the limited study of Tanners Lake wetland. The system reduces TSS quite well for each of the events. The small sediment basin on the upper side of the system, and the detention and filtering through, and under, the weirs likely provides this removal. TN is also reduced for all but the 1989 melt event, but the levels of reduction are not high. Two TP events and three DP events resulted in net increases in outflow load. This is not surprising for the 1989 melt event, when the wetland system was in a frozen state. During the winter, the baseflow and first meltwaters to move through the wetland established a channel to, and subsequently under, the upstream weir; the downstream weir appeared to operate well, spreading out the meltwater as it approached the weir.

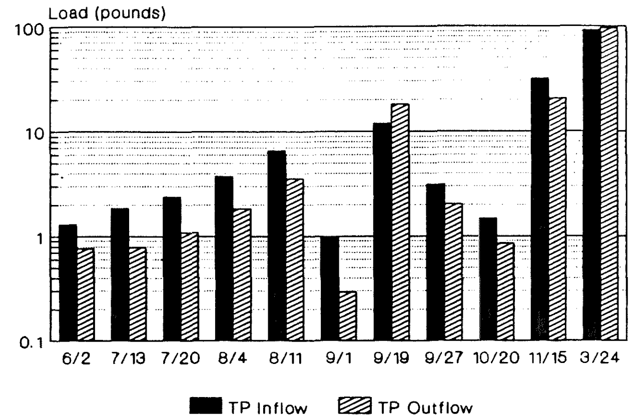
Tables 7A and 7B show that the single snowmelt event has a tremendous impact on the overall ability of the wetland system to treat nutrients in runoff. Again, it must be emphasized that the data are limited, but the melt event overwhelmed the rest of the year as far as nutrient reduction is concerned. In fact, in the data set collected during our study, more DP flowed out of the wetland system than into it and TN was decreased by only 5%. The Ramsey-Washington Metro Watershed District is continuing an evaluation of this wetland system and further data might indicate better long-term performance. In spite of the rather poor nutrient performance seen during the study, the Tanners Lake wetland system does remove a large amount of solids

Figure 31. TANNERS LAKE INFLOW-OUTFLOW LOADS

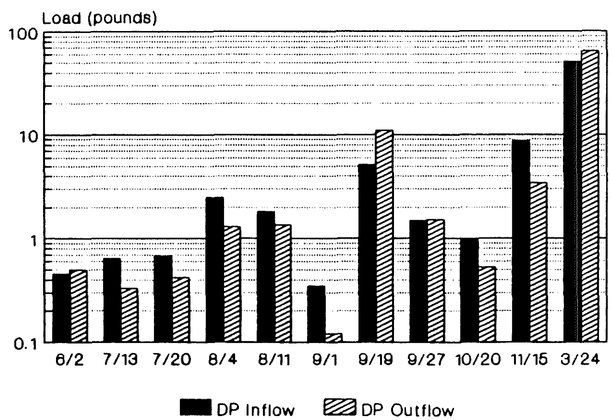
TSS - MONITORED EVENTS



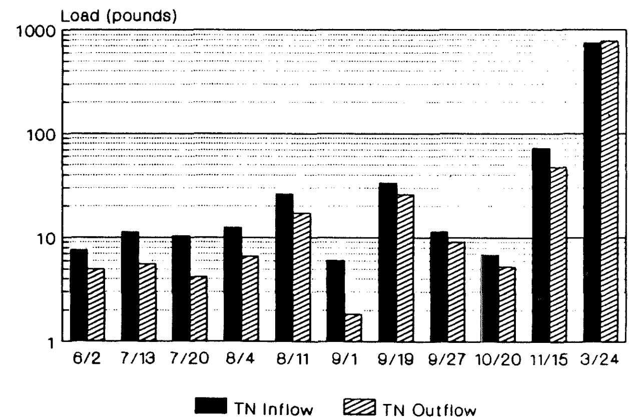
TP - MONITORED EVENTS



DP - MONITORED EVENTS



TN - MONITORED EVENTS



and it does reduce nutrients quite well during the summer when the lake is most sensitive and responsive to nutrient inputs. The lake is certainly better off having the wetland system in place than not having a treatment system in this watershed.

Recommendations for improving the wetland system are difficult to make, given the small number of events that were evaluated. The system does appear to dewater very quickly. At no time in the course of viewing the system perform during an event, did field staff see water approach the top of the weirs. The weirs could possibly be "tightened" slightly to hold water longer during events; they will still dewater between events because of the gravel under the weirs. The upper sediment basin visibly lost capacity during the brief period of study because of slope failure adjacent to the basin from the Century Avenue construction and because a high bedload of solids flows into the basin from upstream. Figure 32 shows the design and the current (June 1989) permanent pool volume of the basin. Assuming the basin was built as designed, the permanent pool volume has been reduced by 60% in approximately one year. This amount of in-fill is exceptionally high, but it is indicative of the types of loads that a sediment basin is forced to handle. The basin appears to have worked well as a coarse sediment trap and will have to be maintained well to continue to do so.

The bottom sediment basin was also checked to determine the amount of storage lost during the period of study. Figure 33 shows that 20% of the permanent pool storage was lost, again assuming that the basin was built as designed. Storage losses such as those seen in the two sediment basins are critical in a system short of storage to begin with. Every attempt should be made to reestablish design conditions and maintain the basins on a routine schedule.

The inflows into the top and bottom sediment basins from the road culverts did cause some erosion damage. These should be stabilized and watched, since the potential exists for continual problems due to high velocities and volumes.

McCarrons Wetland Treatment System

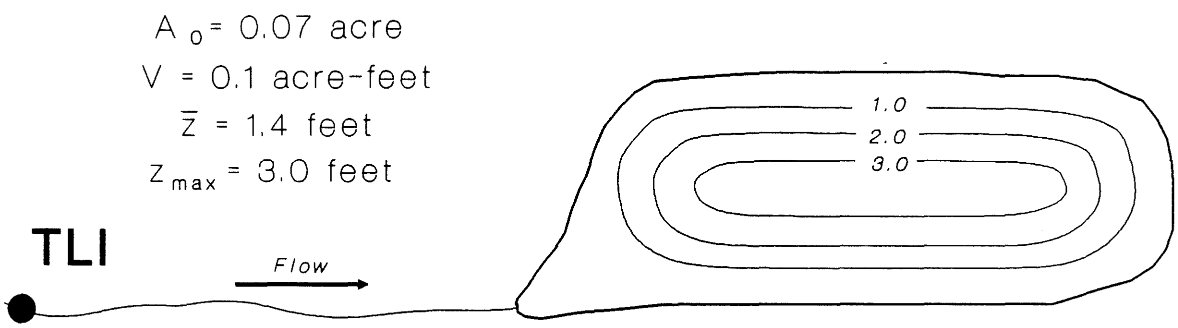
From a pollutant reduction viewpoint, the McCarrons detention/wetland system out-performs all of the other four facilities. The water quality benefits of wetlands described by Hemond and Benoit (1988) are clearly in operation in this system. This is not unintentional, since the facility was designed to specifically address water quality. A detailed analysis of the McCarrons system will not be repeated here since a separate completion report exists for that project. The findings, however, will be highlighted.

The McCarrons configuration is shown in Figure 34. The system drains a 636 acre watershed in Roseville when one of the three pond tributaries overtops a storage facility, or 423 acres when this facility is not overtopped (the common occurrence for most storms). The watershed contains residential and commercial land uses, with major transportation corridors. The upper part of the treatment system consists of a 2.4 acre (permanent pool) detention pond, with a capacity to store 9.6 acre-feet of runoff at overflow elevation (Table 4). The pond area is 0.7% of the limited drainage basin area, and 0.4% of the larger basin.

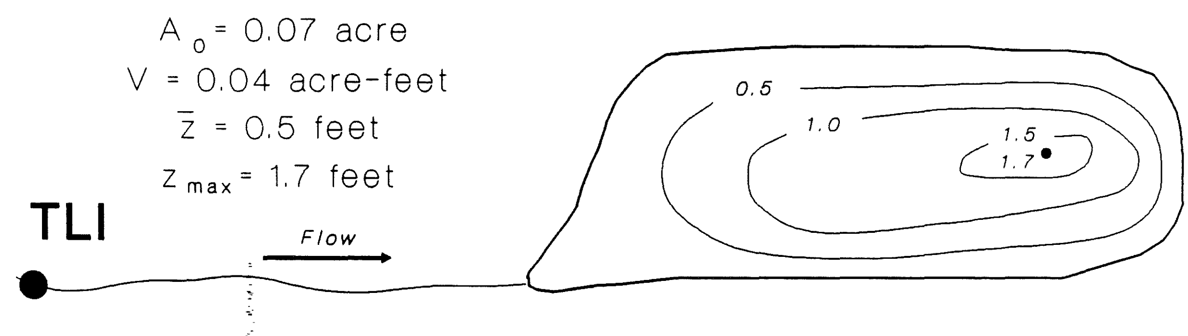
The detention pond outflow proceeds through a series of five small, bermed wetland chambers totaling 3.8 acres. These wetlands serve to "polish" the pond outflow and treat the inflow from a fourth tributary of 60.5 acres, as well as the overland runoff entering the wetlands. Outflow from the system discharges to Lake McCarrons.

Figure 32. TANNERS LAKE WETLAND TREATMENT SYSTEM UPPER SEDIMENTATION BASIN VOLUME COMPARISON

As Designed



As Surveyed 6 June 1989



Contour lines in feet, and represent base flow conditions

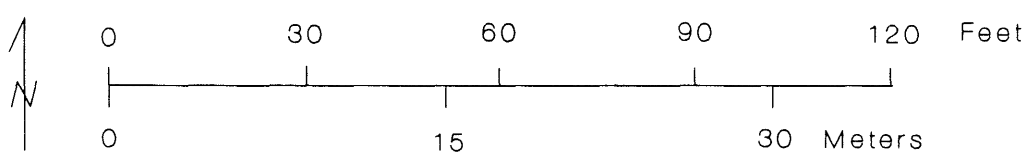
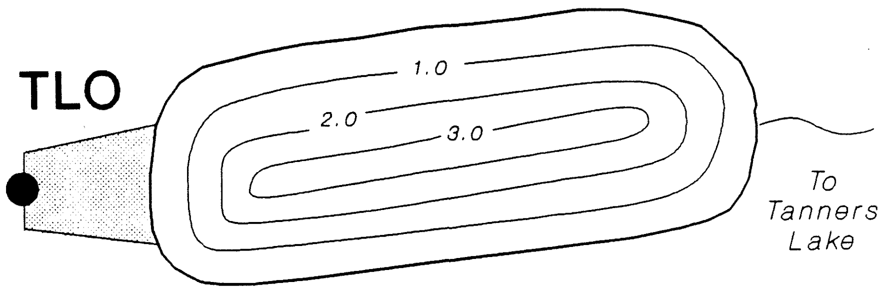


Figure 33. TANNERS LAKE WETLAND TREATMENT SYSTEM LOWER SEDIMENTATION BASIN VOLUME COMPARISON

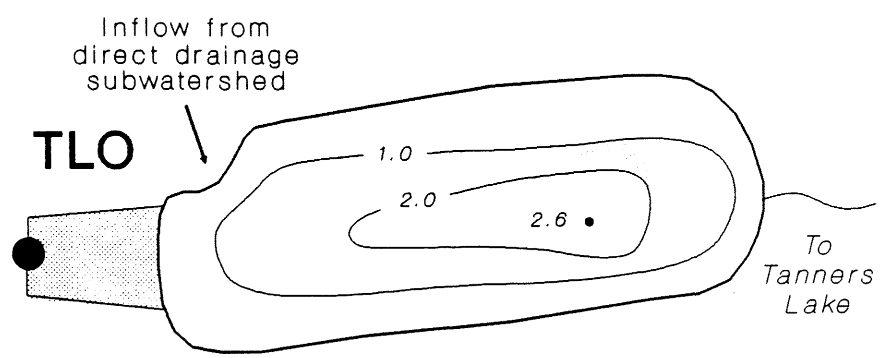
As Designed

A_0 = 0.07 acre
V = 0.10 acre-feet
$\bar{z}$ = 1.4 feet
z_{max} = 3.0 feet



As Surveyed 6 June 1989

A_0 = 0.06 acre
V = 0.08 acre-feet
$\bar{z}$ = 1.3 feet
z_{max} = 2.6 feet



Contour lines in feet, and represent base flow conditions

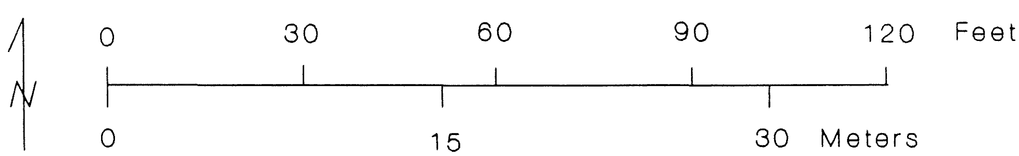
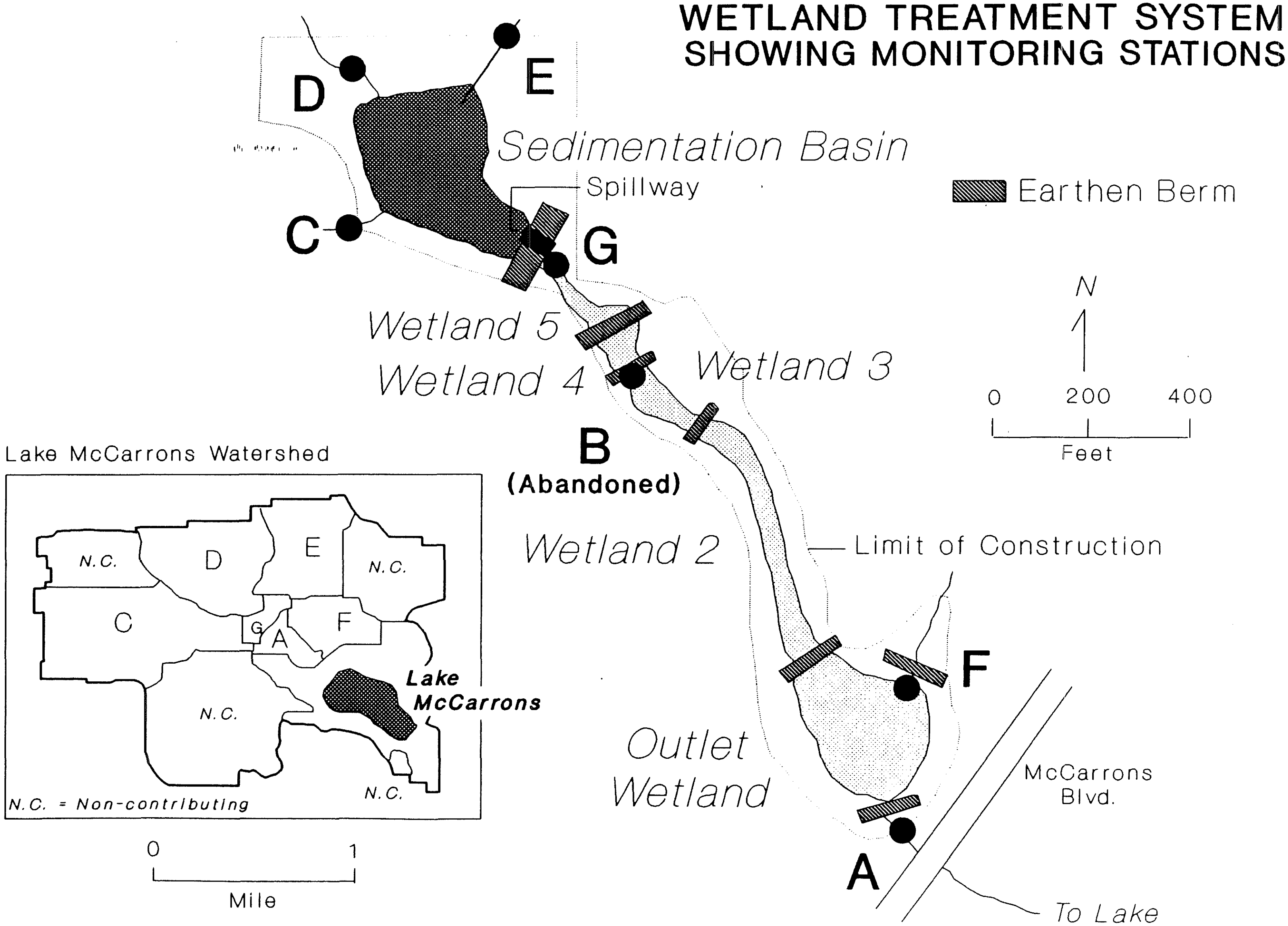


Figure 34. LAKE McCARRONS WETLAND TREATMENT SYSTEM SHOWING MONITORING STATIONS



The McCarrons system was studied for a period of 21 months from September 1986 through May 1988. A total of 19 rainfall and four snowmelt events were monitored. Results of this study showed that the system was very effective in the removal of pollutants from runoff. Even though the design of the detention pond does not meet the suggested criteria of NURP/Walker, the pond works very well and accounts for most of the treatment that occurs in the system. The treatment success of the pond is likely due to diffuse inflow from the three tributaries, from the high percentage of coarse-grained, easily settleable solids, and good phosphorus adsorption on soils. The dominant hydrologic variables affecting performance of the pond are rainfall intensity and detention time in the fall; the previous two plus time since last 0.1" rainfall for the summer; and total precipitation and time since last rainfall in the spring. The treatment of snowmelt at the pond suffered from the previously discussed problems with ice cover.

The wetland portion of the system did not show treatment percentages as high as the pond, most likely the result of the pre-treatment provided by the pond; that is, concentration levels were lower coming into the wetland, thus precluding high removal percentages. Solids and associated pollutants were removed very efficiently by the wetlands, and nutrients, particularly the soluble portion, were less easily removed, although overall reductions were good when compared to the four LCMR sites. The wetland system froze during the two winters of study, minimizing its treatment abilities relative to snowmelt. The first rainfalls after melt seem to flush stored material out of the previously frozen system.

Statistical evaluation of the system indicated a significant difference between pond inflow and outflow for each of the pollutants evaluated. There was a significant difference in the wetland between inflow and outflow for TSS, VSS, TP, COD, NO3 and TPb. There was no difference, however, for DP, TKN, or TN. In short, the wetland did contribute by polishing the pre-treated pond outflow and inflows to the system below the pond. The configuration and performance of the system was excellent and seems to be ideal for treating highly loaded urban runoff.

One problem with the McCarrons system is the propensity of the system to erode, largely due to the peat in which the system is built and the large volume of quickly moving water that passes through. During the study length of 21 months, erosion of several of the berms and the major tributary to the pond constantly added a solids load. The accumulation of sediment and debris in detention facilities is something to be expected, since the facilities are designed to do so. Routine, scheduled maintenance of such facilities is essential to their continued effective operation. Maintenance will usually include removal of bottom material, cleaning of conduits, litter and floatables removal, and vegetation cutting/replanting.

RELATIONSHIP TO LAKE IMPROVEMENT AND RECEIVING WATERS

In addition to this report on treatment facilities, the Metropolitan Council has prepared a companion report for LCMR on lake water quality and management (Osgood 1989). Data from this report on runoff were used in the companion report to evaluate short-term and long-term results of watershed management on lake water quality. The lakes report, briefly, found that typically designed urban runoff treatment facilities do not do much to improve the short-term quality of lakes into which they drain. The reason for this is that most facilities do not remove sufficient enough phosphorus at the proper time to limit the growth of algae in the lake. As pointed out in this report, most detention ponds and wetlands are not capable of removing large amounts of phosphorus, particularly in the dissolved from, and, therefore, cannot influence the overall phosphorus availability that triggers algal growth.

Over the longer-term, however, phosphorus reduction at the levels seen in successful treatment facilities such as McCarrons, may gradually begin to break the cycle of high external-high internal loading. If external loads are reduced by the amounts seen at the McCarrons system, and the lake relies on its internal load, eventually a situation may be reached wherein phosphorus availability in the lake will be limited. We cannot say with any certainty the point at which this can occur, and we cannot say that this effect has been documented, but limiting one of the primary factors in the mass balance of a lake loading scheme inherently leads to changes on the use side of the equation. Hopefully, our continued lake sampling program will eventually show that a specific lake has responded to decreased external loading. The big problem with this, of course, is that few lake watersheds have extensive and effective treatment facilities in place. Our hopes for documenting the McCarrons Wetland Treatment System effect on the lake are not high given the condition the treatment system has fallen into. The advent of watershed management programs in the Metropolitan Area, however, might provide some examples of lake improvement in the future. At a minimum, we suspect that successful watershed management will maintain the status quo for lakes in the watershed and prevent them from degrading any further. When combined with in-lake treatment methods, water quality in well managed lakes stands a chance of improvement.

In order to achieve long-term water quality improvement goals for our lakes, the runoff treatment systems being installed will have to operate for an equally long term. The experience with the McCarrons pond and Tanners Lake sediment basin loss of storage volume, and the general experience we have gained in dealing with detention structures for several years, indicates that the unmaintained life of a successful detention facility in an urban area is probably less than five years. After this time, enough solids have probably accumulated in the ponds to eliminate any water quality effectiveness. Treatment systems that become ineffective after such a short period of time cannot ever be counted upon to yield water quality improvements in lake that may take over a decade to respond.

There are certainly other reasons for runoff treatment than phosphorus reduction and lake protection. The most substantial reductions that were seen in the five treatment systems studied were for solids. Keeping organic and inorganic debris out of any receiving water is certainly reason enough to install an urban runoff control structure. In addition to the solids mass, there are commonly pollutants such as metals and nutrients that are associated with the solids. Reduction of these inputs to receiving waters can be accomplished through a program of effective watershed management using well designed treatment facilities.

Methods to control urban runoff do not necessarily have to include an engineered structure. Wetlands can perform very well in polishing runoff on its way to a receiving water. Runoff should, however, be settled for a short period of time before introduction to a wetland. Long-term studies on the ecological health of runoff impacted wetlands are not available, but one has only to view one of these to realize the impact. Sediment deltas at the end of stormsewers emptying to wetlands are commonplace. Wetlands with much reduced biologic diversity as a result of contaminated runoff and vastly fluctuating water levels are all too common. Even minimal periods of settling in any sump area will serve to protect our wetlands for the longer term.

CONCLUSIONS AND RECOMMENDATIONS

A total of 185 site-events for this study and 116 site-events for a previous study of the McCarrons Wetland Treatment System were evaluated to ascertain the water quality treatment effectiveness of five urban runoff management facilities. The results of the LCMR-funded study of four urban runoff treatment facilities plus the results of the McCarrons Wetland Treatment System study (Roseville) clearly point to the need for proper design in the construction of facilities that might be expected to reduce pollutant loads being carried in the runoff. Small capacity, poorly maintained facilities might slow water down for a time, but long-term, reliable water quality improvements will not be seen.

Four of the five facilities evaluated reduced solids and associated TPb by greater than 50% during the rainfall events that were monitored. The fifth site, Carver Ravine, contains such a small capacity relative to its drainage area, that runoff detention time is too limited to allow for much treatment. Solids are washed through the Carver Ravine facility by the high energy runoff and the fact that essentially no permanent storage areas are available in the system. The construction of forebays to collect coarse-grained particulate material at the inflow of a treatment facility is a design feature that should be considered when a heavy bedload exists.

Nutrient reduction effectiveness of the five systems depends upon the particular nutrient and the amount of storage available. TP removals for Lake Ridge, McKnight Basin and McCarrons are at or above 50% for rain events; Tanners Lake wetland and Carver Ravine remove about one-quarter of the TP entering those facilities. The only facility that performs reasonably well for the reduction of DP is McCarrons; the other sites are all at or below 20% reduction. TKN reductions at the McCarrons facility approach 80%, while Lake Ridge and Tanners Lake are 50% and 40%, respectively. The only facility to treat NO3 to any extent is the McCarrons system, at about 80%. All other sites lower NO3 level at, or less than, 20%. Nitrate, like DP, is soluble and tends to move easily through treatment facilities. When the sum of all of the nitrogen species is considered, McCarrons still tops the others at over 75% removal, while Carver Ravine is less than 20%. Floatables skimmers should be considered when the organic debris load or litter, leaving or entering a facility appears to be high. The skimmers must, however, be routinely maintained to remove accumulated debris.

TPb acts in a manner similar to the solids because it associates closely with them through adsorption. Lead levels in the bottom sediments of the four recently sampled sites do not reach single location levels as high as were seen at McCarrons, but relatively concentrated levels were sampled at the mid-point of the McKnight system and near the outlet of the Tanners Lake wetland.

The performance of urban runoff control facilities is complex and not easily explained by a single, or even a universal few, factors. An analysis of independent variables influencing the water quality effectiveness of the five facilities for each pollutant studied resulted in mixed results. The independent variables evaluated included rainfall intensity, duration, and depth; time since last event over 0.1"; storage volume and maximum depth of the permanent storage pool; hydraulic detention time; hours of event-influenced outflow; and peak rate of inflow to the facility. Every one of these factors appeared at least once for some pollutant, at some site (Table 10). The analysis of factors affecting pollutant removal do point to the importance of a permanent storage pool over four feet in maximum depth and with a ratio of permanent pool volume to average storm volume over 1.0 to detain runoff for an adequate period of time.

Facilities designed for water quality treatment should not be overloaded with a large volume of quickly moving runoff, as the Carver Ravine site is. The facilities should be designed for frequently occurring events, rather than for large volume, low frequency events. If the maximum depth of a permanent pool cannot exceed four feet, provision should be made to limit outflow in such a way that water levels rise fast and decrease slowly.

A design manual prepared by the Metropolitan Washington Council of Governments (Schueler 1987), based on prior work by their organization and U.S. EPA, recommends maintaining a permanent storage pool 2.5 times the volume of runoff generated from the mean summer storm over the watershed area to achieve a 75% long-term removal of sediment and a 55% removal of total phosphorus. McCarrons, Lake Ridge and McKnight all achieved this level of treatment, but only McCarrons, with a limited effective watershed, met the design recommended above (Table 4). It appears as though a ratio over 1.0 is sufficient to obtain a good level of treatment, but the 2.5 figure would likely result in more consistent treatment and longer facility life.

The design figures presented in Table 4 and the water quality performance figures in Tables 7A and 7B indicate that the five systems evaluated perform better than would be expected. There are several reasons why this likely occurs. Pre-settling of runoff prior to wetland discharge at the McCarrons site proved to be extremely effective. For the McCarrons system, the inflow into the detention pond comes from three equally spaced tributaries, thus spreading the inflow and dissipating the energy usually associated with urban runoff. The inflows to the pond are also highly concentrated with particulates, which adsorb nutrient and metals and are readily settleable. The detention pond and wetland also are very new and appear to have a high adsorption capacity for phosphorus. The four LCMR sites were monitored during a period of drought and therefore are thought to have performed better from a percentage reduction standpoint than they would during a normal year. The hydrologic effects seen during a drought mean that rainfall events are infrequent and of low intensity and volume; that washoff is primarily from pervious surfaces only, resulting in highly concentrated inflow; and that the relative ratio of permanent pool volume to event volume is high, enhancing both event and inter-event (quiescent) treatment. The tandem ponds at McKnight Basin provide a very effective detention system that works well for water quality.

Water quality design of structures in Minnesota's climate should consider the problems associated with ice cover and frozen conditions. Provision could be made for deepening water levels under ice, dewatering facilities and passing baseflow through quickly, routing water around frozen pond and wetlands until they thaw, and building a variable discharge outlet structure that gives flexibility depending upon a particular winter's conditions.

The implementation of watershed management programs that can effectively control the movement of polluted runoff into receiving waters is a worthy endeavor. Our lakes have borne the impact of urban runoff for years and cannot be expected to recover and improve in the short-term. However, undertaking efforts to reduce phosphorus loading to lakes will impact the external/internal load cycle and may prove effective in the long-term. In order for this to happen, however, maintenance of the treatment facilities is essential. After five years of use, it appears as though the water quality treatment efficiency of a treatment system will be hindered. Periodic (less than once every five years) removal of accumulated sediments must be done to assure continuing capacity and reintroduction of previously removed material.

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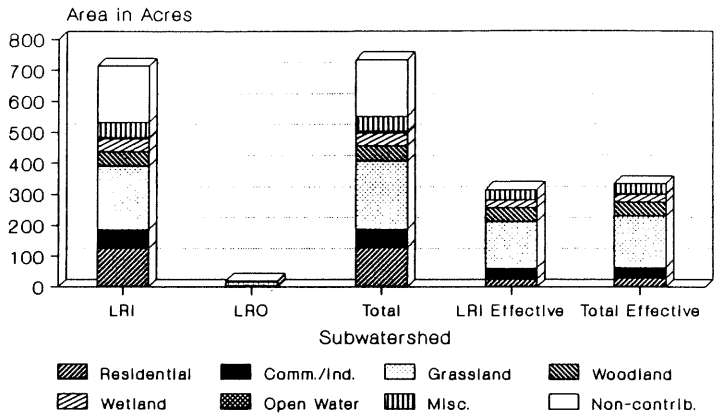
APPENDIX A

WATERSHED DESCRIPTIONS

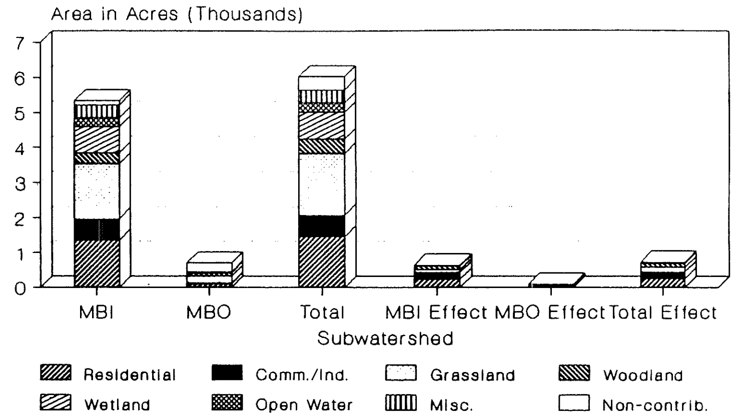
APPENDIX A, TABLE A1. WATERSHED DESCRIPTIONS.

Watershed/ Subwatershed	SFR	MFR	WET	CI	GRS	WOD	POS	WTR	MISC	DA (Acres)	IMP
	LAND USE (%)										
Lake Ridge											
LRI Total	20.7	0.0	7.7	11.5	36.0	8.9	2.8	0.0	12.4	531	18
LRI Effective	7.9	0.0	7.9	11.4	47.9	14.0	0.0	0.0	10.8	315	14
LRO Total	20.0	0.5	7.4	11.1	37.2	8.9	2.7	0.2	12.0	551	17
LRO Effective	7.5	0.9	7.5	10.7	49.2	13.7	0.0	0.3	10.1	335	13
McKnight Basin											
MBI Total	24.3	1.6	14.2	11.8	25.5	6.0	4.3	4.9	7.2	5217	19
MBI Effective	35.4	1.4	0.0	30.2	3.5	16.2	9.4	0.6	3.3	636	43
MBO Total	24.0	8.0	13.5	11.1	25.9	7.3	5.1	4.7	6.6	5671	18
MBO Effective	33.2	1.2	0.3	26.9	3.3	16.3	14.2	1.7	2.9	725	39
Tanners Lake											
TLI Total	25.2	2.6	22.3	11.1	21.1	3.5	2.5	1.2	10.0	1134	16
TLI Effective	37.0	2.7	15.7	14.0	23.5	4.4	2.7	0.0	0.0	413	24
TLO Total	26.6	2.4	20.6	11.9	19.0	3.6	5.5	1.1	9.0	1258	16
TLO Effective	37.6	2.0	13.2	15.3	18.1	4.3	9.7	0.0	0.0	537	23
Carver Ravine											
WRI Total	84.7	1.8	0.0	1.8	11.8	0.0	0.0	0.0	0.0	170	30
WRO Total	81.0	1.6	0.5	1.6	13.6	1.1	0.0	0.5	0.0	183	29
WRO Pump	49.5	5.8	1.4	0.7	21.8	3.2	4.6	1.4	11.0	432	21

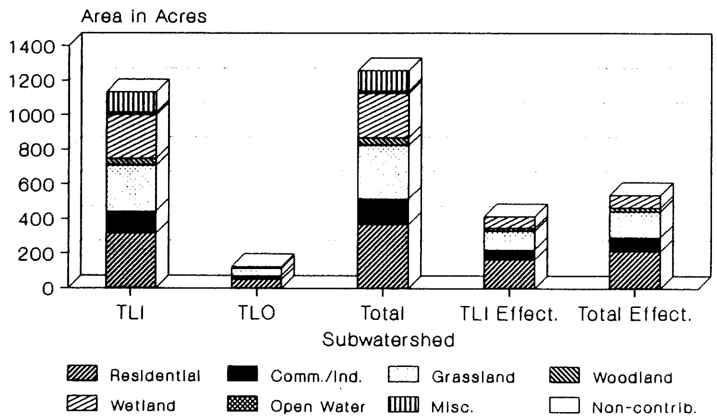
1988 LAND USE
LAKE RIDGE WATERSHED



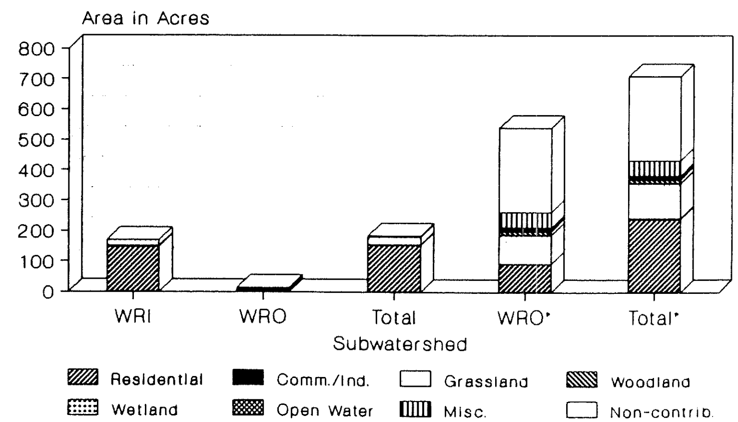
1988 LAND USE
McKNIGHT BASINS WATERSHED



1988 LAND USE
TANNERS LAKE WATERSHED



1988 LAND USE
WOODBURY BASIN



* Includes Pumping Station subwatershed

APPENDIX B

BATHYMETRIC MAPS OF DETENTION FACILITIES

BATHYMETRIC MAP OF LAKE RIDGE BASIN

Contour lines in feet

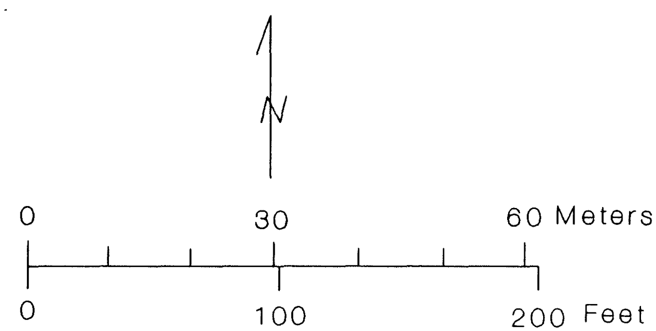
Contours represent base flow conditions

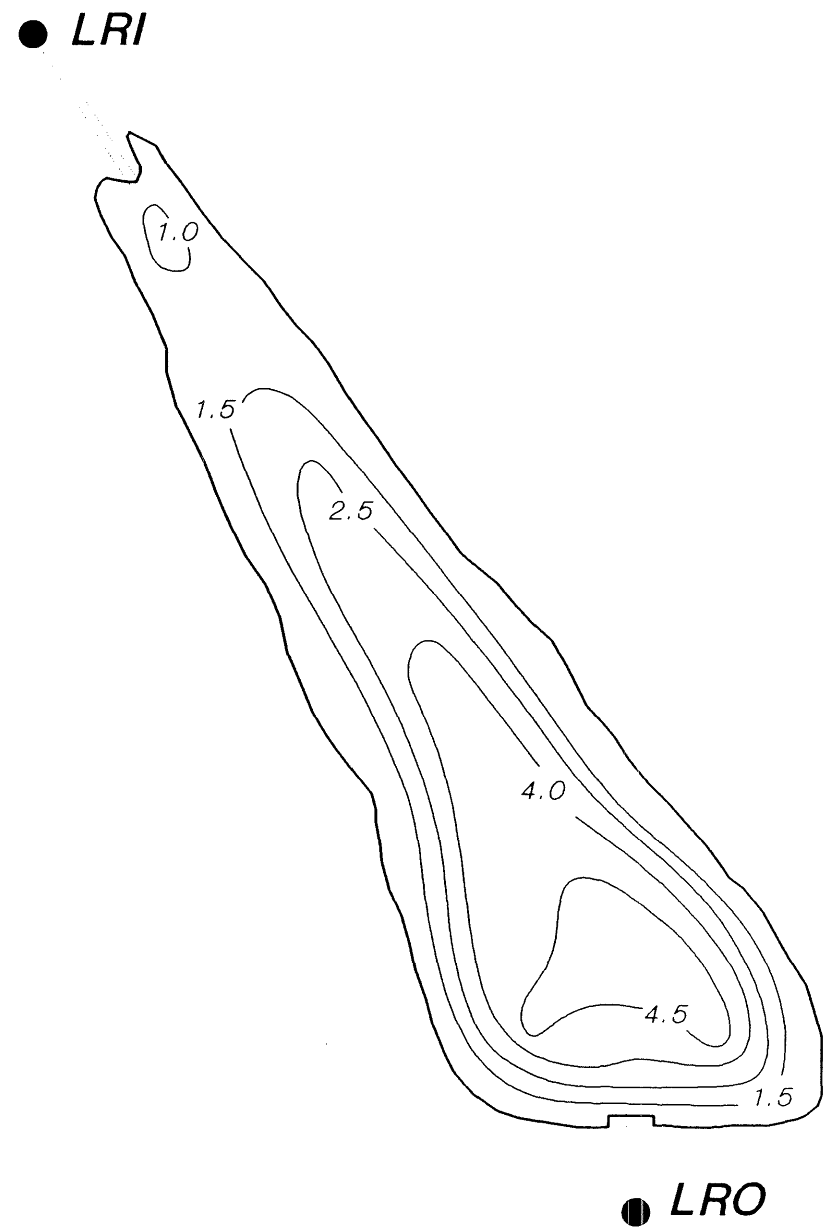
$A_0 = 0.94$ acres

$Z_{max} = 4.8$ ft

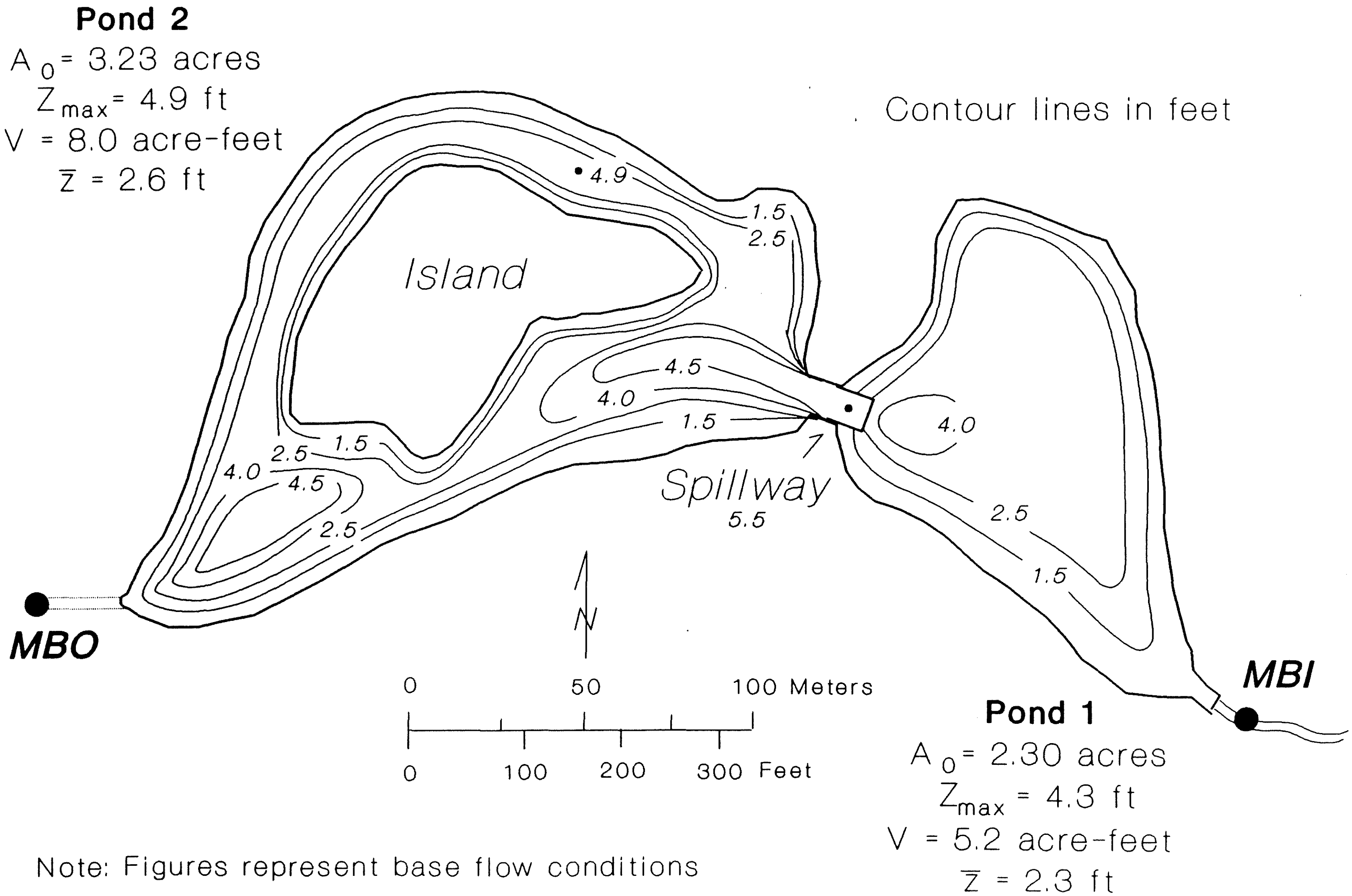
$V = 2.0$ acre-feet

$\bar{z} = 2.0$ ft



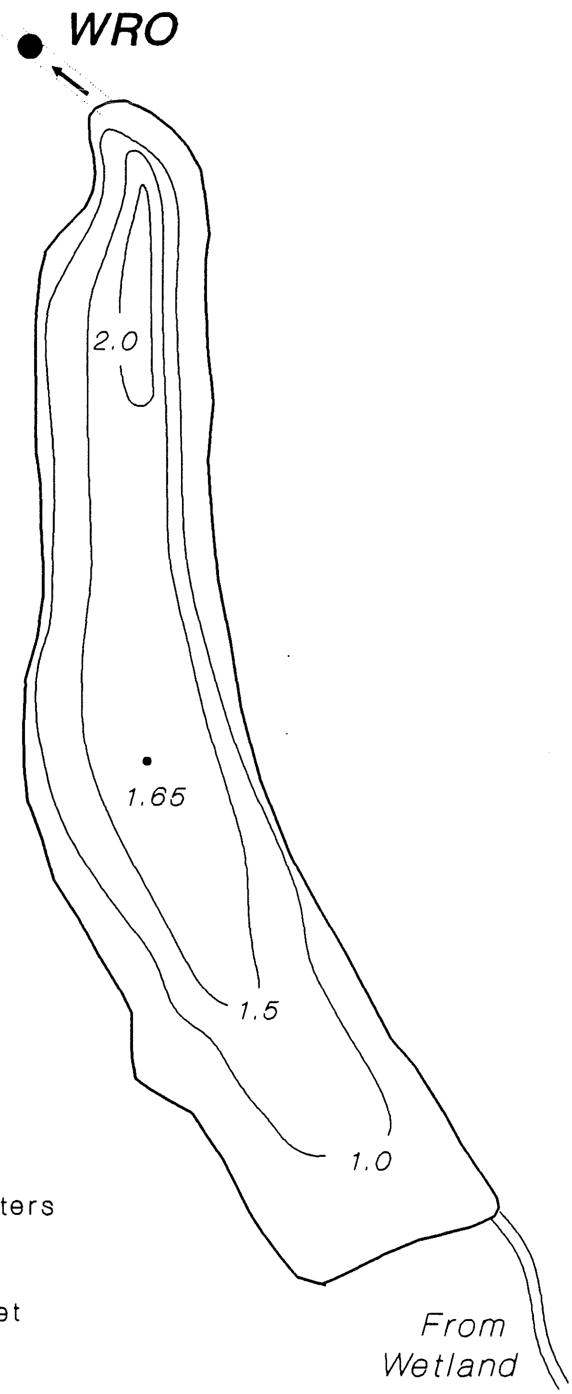


BATHYMETRIC MAP OF McKNIGHT BASINS
Showing Monitoring Site Locations



Note: Figures represent base flow conditions

BATHYMETRIC MAP OF CARVER RAVINE DETENTION POND



A_0 = 0.37 acre

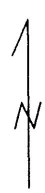
Z_{max} = 2.1 ft

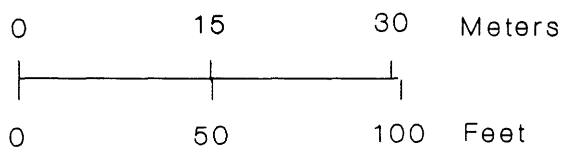
V = 0.4 acre-feet

$\bar{Z}$ = 1.1 ft

Contour lines in feet

Contours represent base flow conditions





APPENDIX C

PRECIPITATION DATA

TABLE C1.
DAILY RAINFALL TOTALS

LRI/O RAINFALL DATA (does not include snowfall equivalent)

DAY	10-87	11-87	3-88	4-88	5-88	6-88	7-88	8-88	9-88	10-88	11-88	12-88	1-89	2-89	3-89	4-89
1		0.01	0	0	0	0	0	0	0.45	0	0	0	0	0	0	0.07
2		0.02	0	0.26	0	0.13	0	0.19	0.02	0	0	0.04	0	0	0	0
3		0.01	0	0.08	0	0	0	0.03	0.01	0	0	0	0	0	0	0.43
4		0	0	0	0	0	0	1.16	0	0	0.57	0	0	0	0	0.04
5		0	0	0.01	0	0	0	0.01	0	0	0.1	0	0	0	0	0
6		0	0	0	0	0	0	0	0.01	0	0.02	0	0	0	0.1	0
7		0.01	0.16	0	0.57	0	0	1.36	0	0	0	0	0.01	0	0	0
8		0.03	0.01	0	1.95	0	0.05	0.13	0	0	0	0	0	0	0	0.01
9		0	0	0	0.72	0.01	0.06	0	0	0	0	0	0	0	0	0
10		0	0.04	0	0	0	0	0	0	0	0	0	0	0	0	0
11		0	0.07	0	0	0	0	0.76	0	0	0	0	0	0	0	0
12		0	0.01	0	0	0	0	0.1	0.01	0	0.26	0.02	0	0	0	0
13		0	0	0	0	0	0.52	0.04	0	0	0.19	0	0	0.09	0.02	0
14		0	0	0.01	0.05	0.04	0	0	0	0	0	0	0.02	0	0.3	0
15	0.54	0.06	0.03	0.03	0	0	0.07	0	0.06	0	0.61	0	0.01	0	0.04	0
16	0.18	0.18	0.01	0	0	0.02	0	0	0.2	0.04	0.31	0	0.01	0	0	0.03
17	0.01	0.34	0	0	0	0.07	0	0	0	0.19	0.05	0	0	0	0	Project
18	0	0.07	0	0	0	0	0.01	0	0.59	0.01	0.02	0	0	0	0.09	Complete
19	0	0	0.01	0	0.05	0.15	0	0	1.89	0	0	0	0	0	0.02	
20	0.04	0	0	0	0	0	0.47	0	0.09	0.34	0	0.16	0.01	0.01	0	
21	0	0	0	0	0	0	0.02	0	0	0.04	0	0.01	0	0	0	
22	0.03	0	0.01	0.26	0	0	0	0.32	0	0.03	0	0.02	0	0	0	
23	0	0	0	0.17	0	0	0	0.03	0	0.03	0	0.03	0	0	0	
24	0.07	0	0.77	0	0	0	0	0	0	0	0	0	0	0	0.19	
25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.02	
26	0	0	0	0.44	0	0	0	0	0.1	0	0.57	0	0.02	0	0.02	
27	0	0	0	0.03	0.14	0	0	0.04	0	0.13	0.04	0	0.09	0	0.23	
28	0	0	0.08	0	0	0	0	0	0.55	0	0	0	0.01	0	0.01	
29	0	0	0.04	0	0	0	0	0.01	0.03	0	0.07	0	0.01		0.04	
30	0	0	0	0	0	0	0	0	0	0	0	0.04	0		0.02	
31	0		0		0		0.06	0		0		0	0		0	
TOTAL	0.87	0.73	1.24	1.29	3.48	0.42	1.26	4.18	4.01	0.81	2.81	0.32	0.19	0.1	1.1	0.58

MBI/O RAINFALL DATA (does not include snowfall equlivalent)

DAY	11-87	3-88	4-88	5-88	6-88	7-88	8-88	9-88	10-88	11-88	12-88	1-89	2-89	3-89	4-89
1	0	0	0	0	0.05	0	0	0.11	0	0	0	0	0	0	0.06
2	0.01	0	0.2	0	0.18	0	0.18	0	0	0	0.01	0	0	0	0
3	0	0	0.21	0	0	0	0.11	0.14	0	0	0	0	0	0	0.39
4	0	0	0	0	0	0	1.01	0	0	0.45	0	0	0	0	0.01
5	0	0	0	0	0	0	0	0	0	0.06	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0	0	0.05	0
7	0.02	0.17	0	0.74	0	0	1.29	0	0	0	0	0.06	0	0	0
8	0.02	0.1	0	1.9	0	0	0.09	0	0	0	0	0	0	0	0.01
9	0	0	0	0.77	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0.05	0	0	0	0	0.49	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0.08	0	0	0.22	0	0	0	0	0
13	0	0	0	0	0	0.75	0.03	0	0	0	0	0	0.02	0	0
14	0	0	0	0.06	0.06	0	0	0.01	0	0	0	0	0	0.22	0
15	0.08	0	0	0	0	0.11	0	0.02	0	0.62	0	0	0	0	0
16	0.13	0	0	0	0	0	0	0.15	0.04	0.16	0	0	0	0	0.03
17	0.32	0	0	0	0	0	0	0	0.13	0.01	0	0	0	0	0
18	0	0	0	0	0	0	0	0.18	0	0	0	0	0	0	0.02
19	0	0.01	0	0.02	0.24	0	0	1.89	0	0	0	0	0	0.07	0
20	0	0	0	0	0	0.61	0	0.08	0.31	0	0.06	0	0.05	0	Project
21	0	0	0	0	0	0	0	0	0.04	0	0	0	0	0	Complete
22	0	0	0.22	0	0.01	0	0.3	0	0.04	0	0.01	0	0	0.01	
23	0	0	0.13	0	0	0	0	0	0.02	0	0.05	0	0	0	
24	0	0.78	0	0	0	0	0	0.01	0	0	0	0	0	0.13	
25	0	0.01	0	0	0	0	0	0	0	0	0	0	0	0.04	
26	0	0	0.37	0	0.01	0	0	0.15	0	0.16	0	0	0	0	
27	0	0	0.1	0.21	0	0	0.21	0	0.13	0.04	0	0.09	0	0.04	
28	0	0	0	0	0	0	0	0.43	0	0	0	0	0	0	
29	0	0	0	0	0	0	0	0	0	0.03	0	0		0.04	
30	0	0	0	0	0.06	0	0	0	0	0	0	0		0	
31		0		0		0.01	0		0		0	0		0	
TOTAL	0.58	1.12	1.23	3.7	0.61	1.48	3.79	3.17	0.71	1.75	0.13	0.15	0.07	0.6	0.52

TLI/O RAINFALL DATA (does not include snowfall equivalent)

DAY	3-88	4-88	5-88	6-88	7-88	8-88	9-88	10-88	11-88	12-88	1-89	2-89	3-89	4-89
1	0	0	0	0.01	0	0	0.28	0	0	0	0	0	0	0.02
2	0	0.19	0	0.24	0	0.05	0	0	0	0.04	0	0	0	0
3	0	0.16	0	0.01	0	0.11	0.14	0	0	0	0	0	0	0.42
4	0	0	0	0	0	0.85	0	0	0.45	0	0	0	0	0
5	0	0	0	0.01	0	0	0	0	0.06	0	0	0	0	0
6	0	0.01	0	0	0	0	0	0	0.01	0	0	0	0.05	0
7	0.11	0	0.68	0	0	1.1	0	0	0	0	0.01	0	0	0
8	0	0	1.96	0.01	0	0.08	0	0	0	0	0	0	0	0
9	0	0	0.69	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0.01	0	0	0	0	0.5	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0.1	0	0	0.05	0	0	0	0	0
13	0	0	0	0	0.6	0.03	0	0	0.53	0	0	0.02	0	0
14	0	0	0.03	0.04	0	0	0	0	0	0	0	0	0.25	0.02
15	0	0	0	0	0	0	0.05	0	0.51	0	0	0	0	0
16	0.04	0	0	0	0	0	0.19	0.03	0.16	0	0	0	0	0.04
17	0	0	0	0	0	0	0	0.13	0.02	0	0	0	0	0
18	0	0	0	0	0	0	0.24	0.01	0.02	0	0	0	0	0
19	0.01	0	0	0.21	0	0	1.64	0	0	0	0.07	0	0.07	Project
20	0	0	0	0	0.37	0	0.07	0.33	0	0.06	0	0.05	0	Complete
21	0.01	0	0	0	0	0	0	0.07	0	0	0	0	0	
22	0	0.14	0	0	0	0.23	0	0.03	0	0.03	0	0	0.01	
23	0	0.33	0	0	0	0	0	0.02	0	0.05	0	0	0	
24	0.79	0	0	0	0	0	0.01	0	0	0	0	0	0.15	
25	0.02	0	0	0	0	0	0	0	0	0	0	0	0.04	
26	0	0.39	0	0	0	0	0.08	0	0.48	0	0	0	0	
27	0	0.02	0.12	0	0	0.19	0	0.14	0.05	0	0.09	0	0.1	
28	0.12	0	0	0	0	0	0.43	0	0	0	0	0	0	
29	0	0	0	0	0	0	0	0	0.02	0	0		0.07	
30	0	0	0	0	0	0	0	0	0	0.02	0		0	
31	0		0		0.01	0		0		0	0		0	
TOTAL	1.11	1.24	3.48	0.53	0.98	3.24	3.13	0.76	2.36	0.2	0.17	0.07	0.74	0.5

WRI/O RAINFALL DATA (does not include snowfall equivalent)

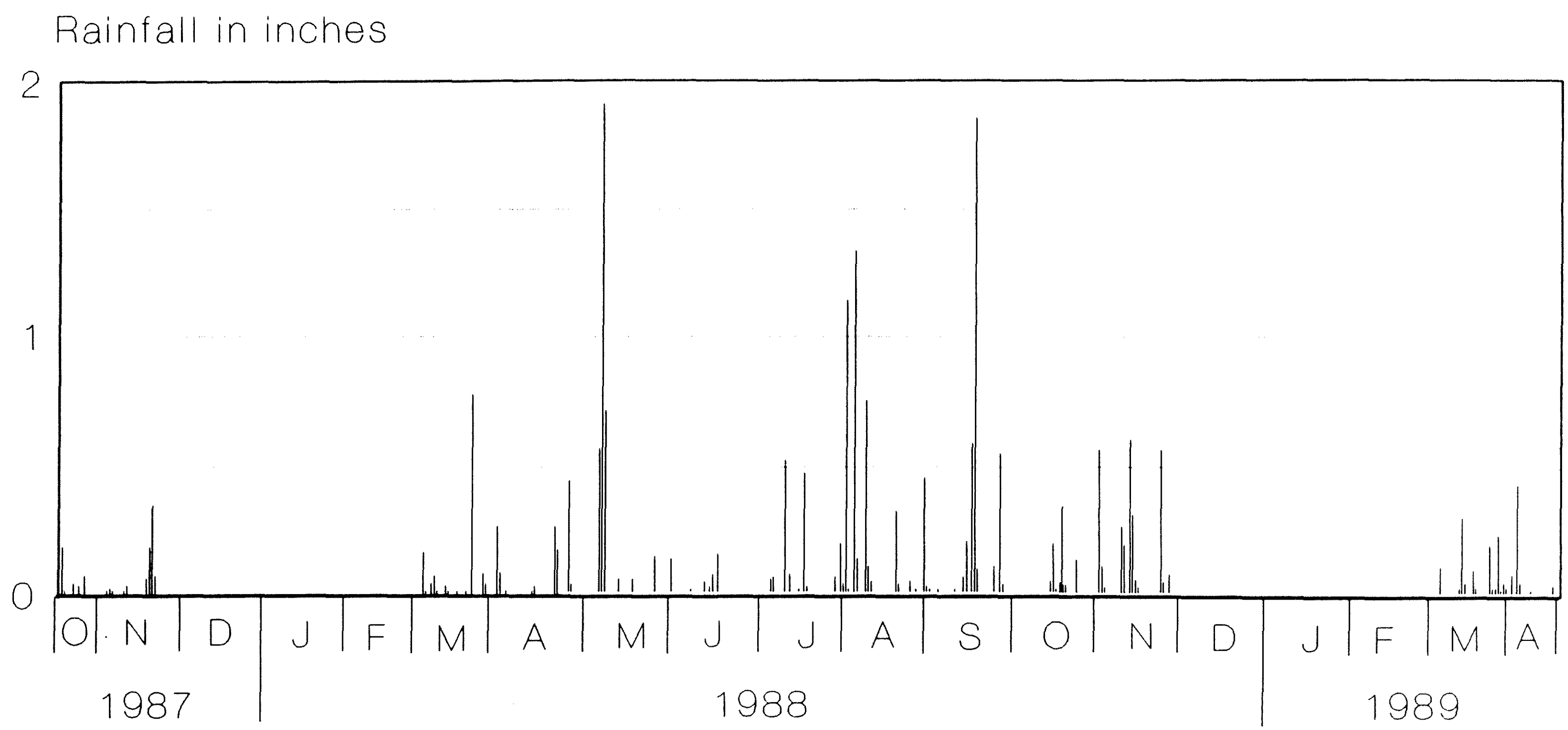
DAY	6-88	7-88	8-88	9-88	10-88	11-88	12-88	3-89	4-89
1	0	0	0	0.45	0	0	0	0	0.07
2	0.13	0	0.18	0.02	0	0	0.21	0	0
3	0	0	0.03	0.12	0.01	0	0	0	0.4
4	0	0	1.24	0.01	0	0.62	0	0	0.01
5	0	0	0	0	0	0.12	0	0	0
6	0	0	0	0	0.01	0.17	0	0	0
7	0	0	1.31	0	0	0.01	0	0	0
8	0	0	0.11	0	0	0	0	0	0.03
9	0.17	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0
11	0	0	0.91	0	0	0	0	0	0
12	0	0	0.09	0.01	0	0.32	0.01	0	0
13	0	0.5	0.04	0	0	0	0.01	0	0
14	0.05	0	0	0	0	0	0	0	0
15	0	0.04	0	0.06	0	0.69	0	0.05	0
16	0	0	0	0.25	0.05	0.24	0	0.01	0.04
17	0	0	0	0.01	0.19	0	0	0	Project
18	0	0.02	0	0.79	0.02	0.2	0.01	0.01	Complete
19	0.2	0	0	2.3	0.01	0.02	0.03	0.02	
20	0	0.42	0	0.11	0.27	0	0.19	0.02	
21	0	0	0	0	0.03	0	0	0	
22	0	0	0.53	0	0.03	0	0.02	0.02	
23	0	0	0.01	0	0.05	0	0.03	0	
24	0	0	0	0	0	0	0	0.17	
25	0	0	0	0	0	0	0	0.03	
26	0	0	0	0.13	0	0.57	0	0.01	
27	0	0	0.22	0	0.14	0.09	0	0.2	
28	0	0	0	0.5	0.01	0	0	0	
29	0	0	0	0	0	0	0	0.03	
30	0	0	0	0	0	0	0	0	
31		0.06	0		0		0	0	
TOTAL	0.55	1.04	4.67	4.76	0.82	3.05	0.51	0.57	0.55

TABLE C2.
MONTHLY PRECIPITATION TOTALS

SITE/YEAR	JAN	FEB	MARCH	APRIL	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	TOTAL
LRI													
1987											0.73		
1988			1.24	1.29	3.48	0.42	1.26	4.18	4.01	0.81	2.81		19.5
1989			1.1	*0.59									
MBO													
1987											0.58		
1988			1.12	1.23	3.7	0.61	1.48	3.79	3.17	0.71	1.75		17.56
1989			0.6	*0.52									
TLI													
1988			1.11	1.24	3.48	0.53	0.98	3.24	3.13	0.76	2.36		16.83
1989			0.74	*0.50									
WRO													
1988						0.55	1.04	4.67	4.76	0.82	3.05		14.89
1989			0.57	*0.55									
NORMAL (MSP)	0.82	0.85	1.71	2.05	3.2	4.07	3.51	3.64	2.5	1.85	1.29	0.87	26.36

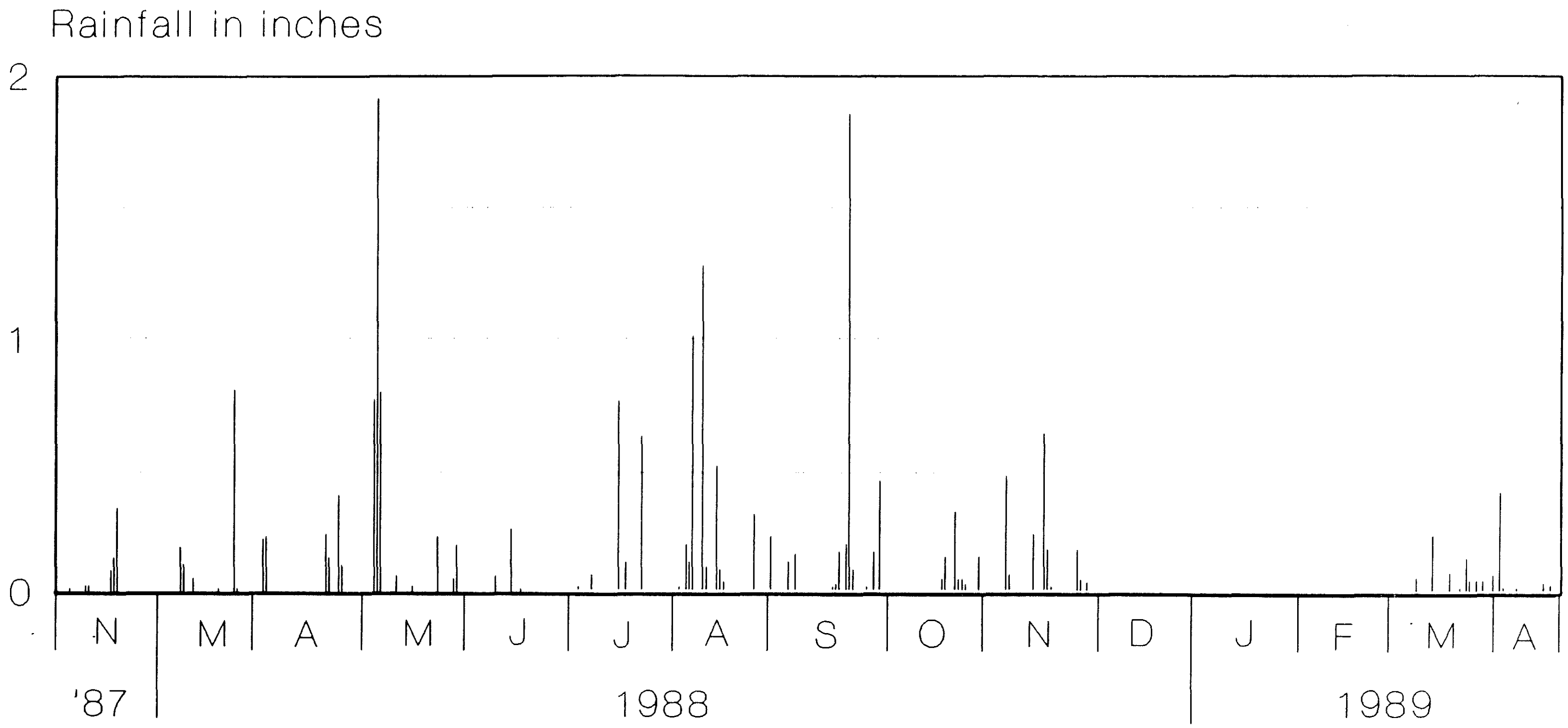
* includes rainfall up to April 15
** totals are for months with data only
*** snowfall data is not included

LRI RAINFALL
OCTOBER 1987 - APRIL 1989



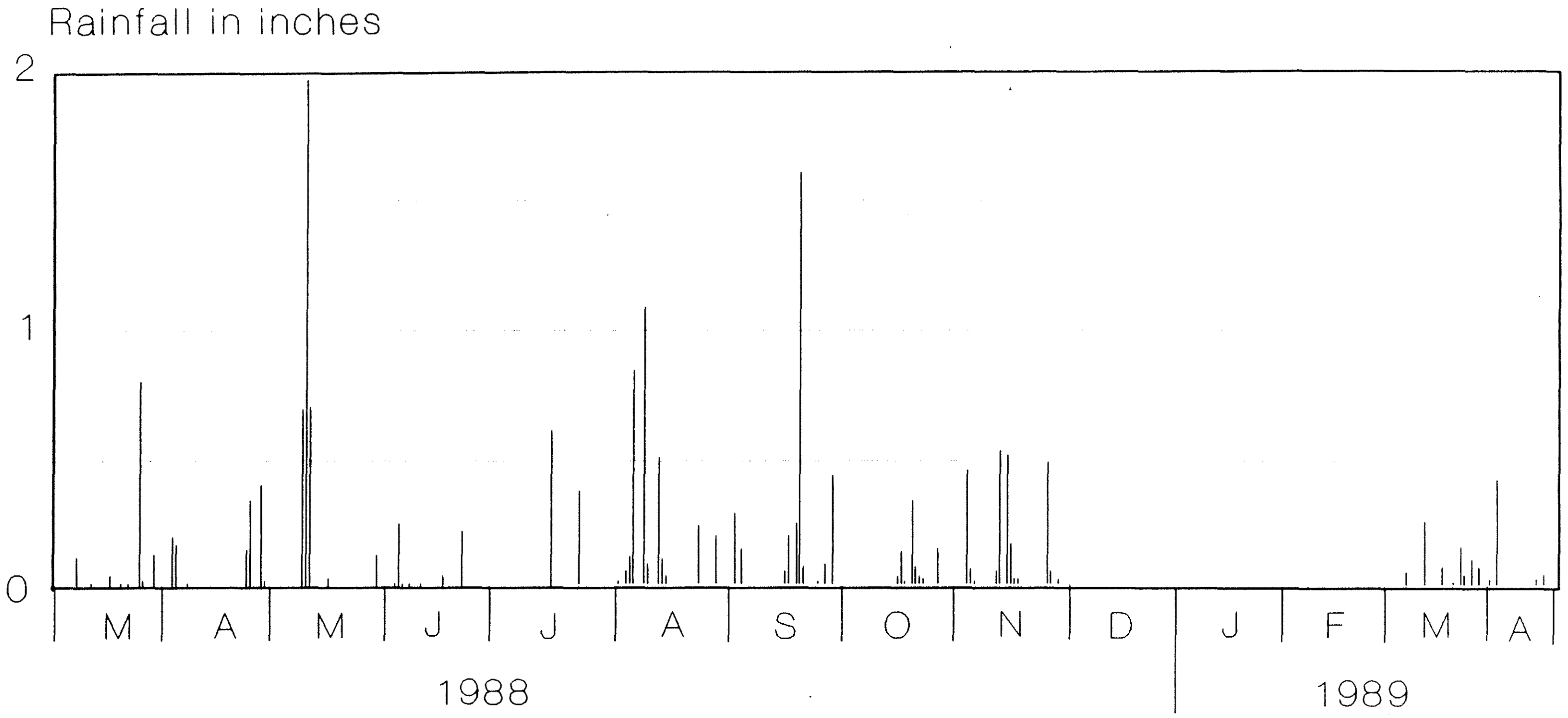
Note: Rainfall only; does not include
snowfall equivalent

MBO RAINFALL
NOVEMBER 1988 - APRIL 1989



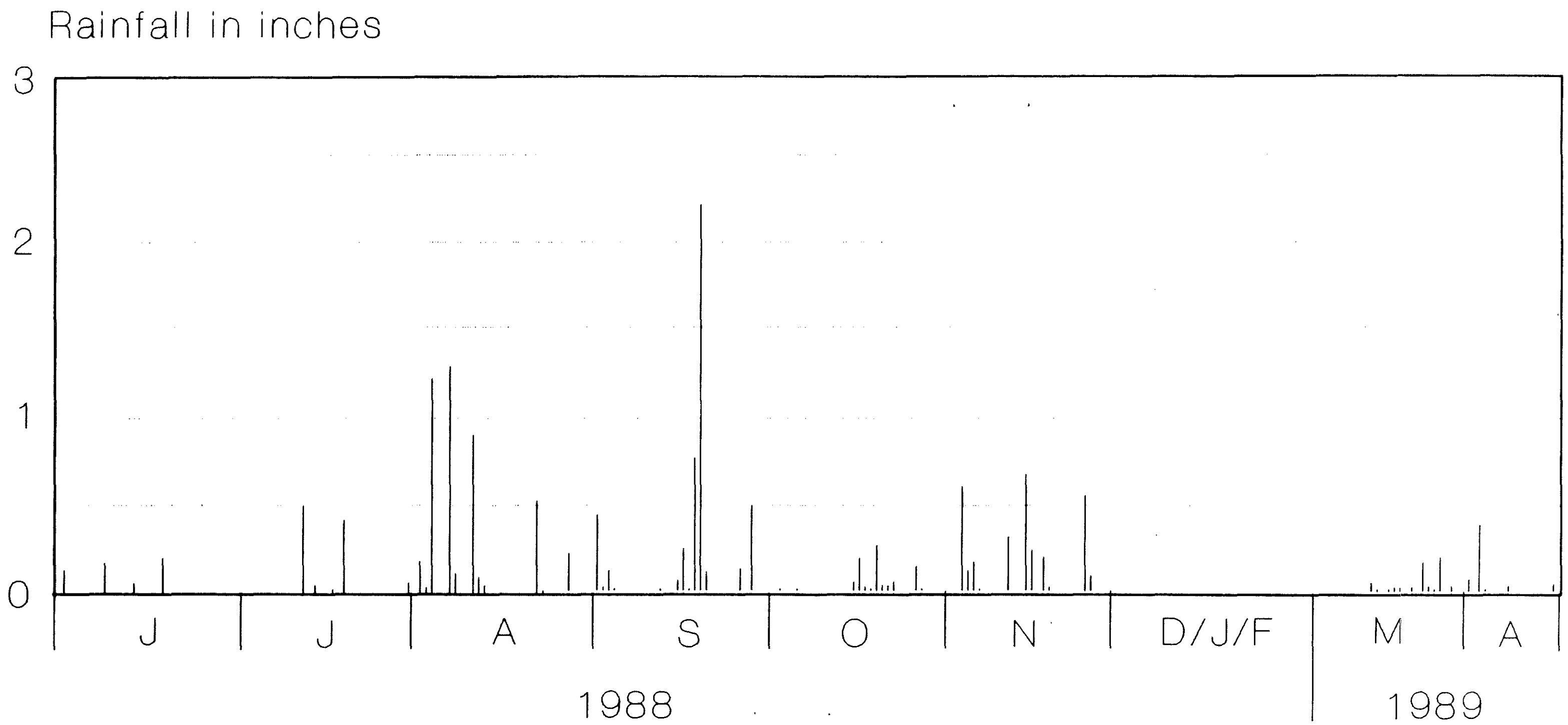
Note: Rainfall only; does not include
snowfall equivalent

TLI RAINFALL
MARCH 1988 - APRIL 1989



Note: Rainfall only; does not include
snowfall equivalent

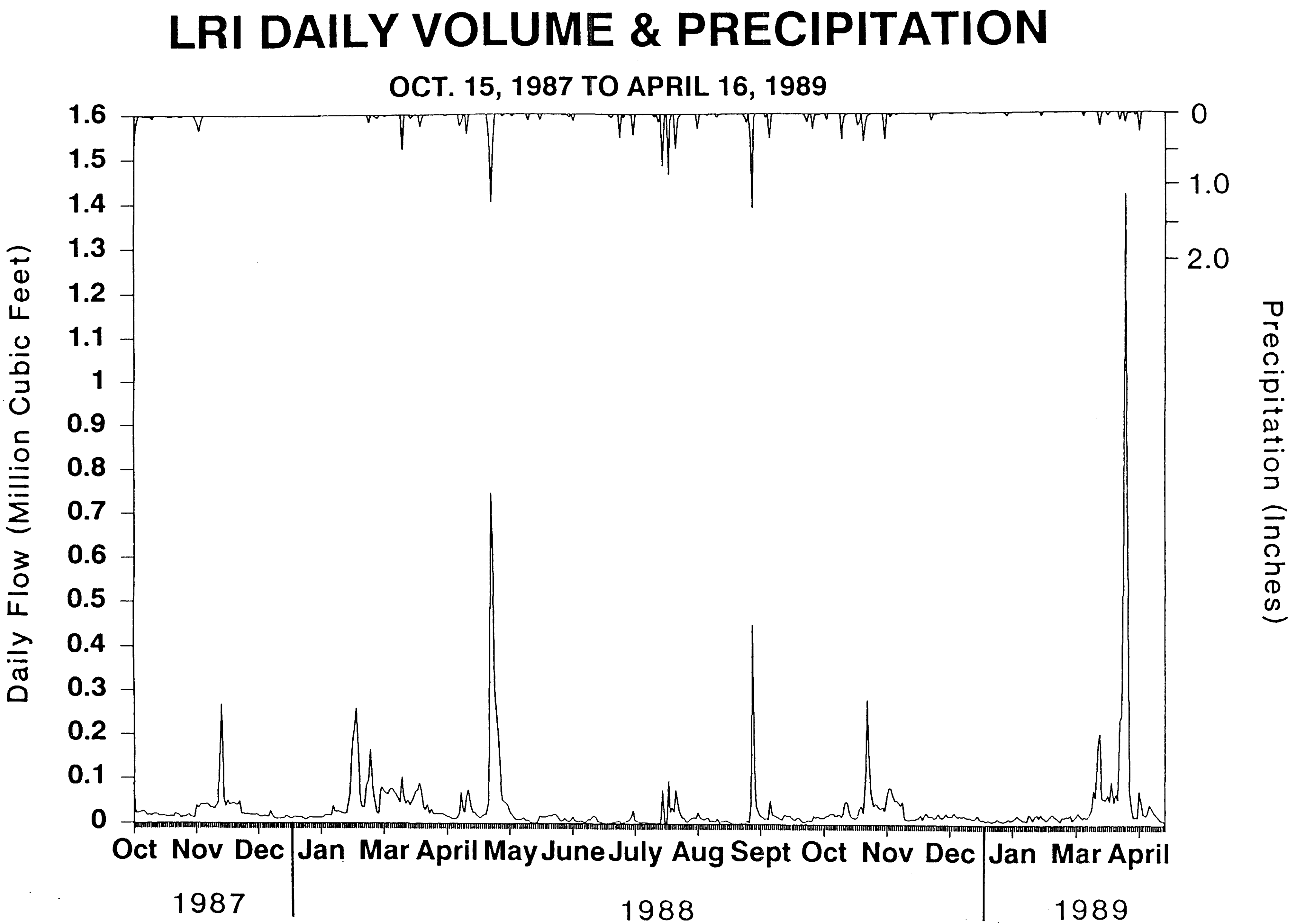
WRO RAINFALL
JUNE 1988 - APRIL 1989



Note: Rainfall only; does not include
snowfall equivalent

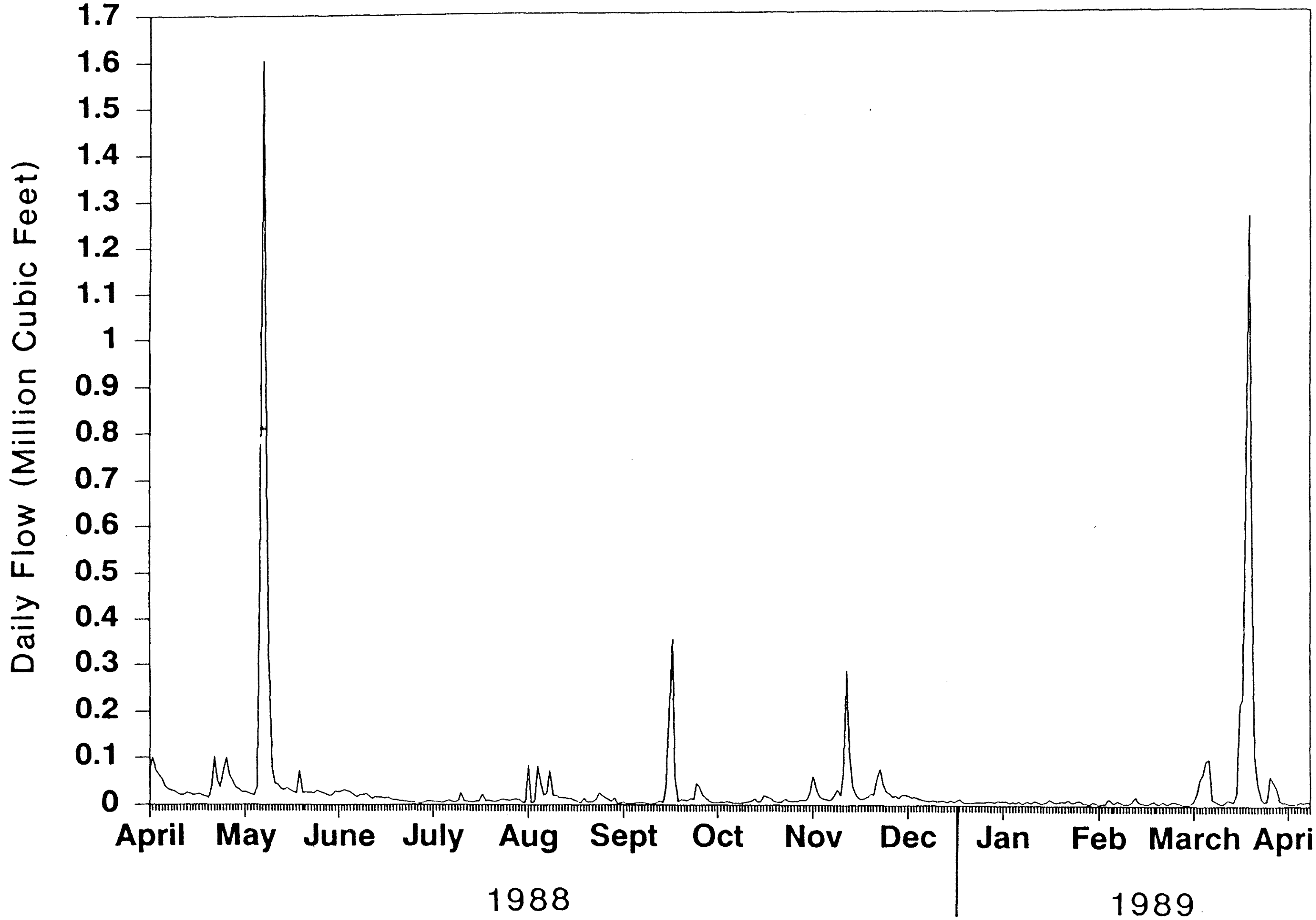
APPENDIX D

DAILY FLOW DATA


LRI DAILY VOLUME & PRECIPITATION
OCT. 15, 1987 TO APRIL 16, 1989
Daily Flow (Million Cubic Feet)
Precipitation (Inches)
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
1.0
2.0
Oct
Nov
Dec
Jan
Mar
April
May
June
July
Aug
Sept
Oct
Nov
Dec
Jan
Mar
April
1987
1988
1989

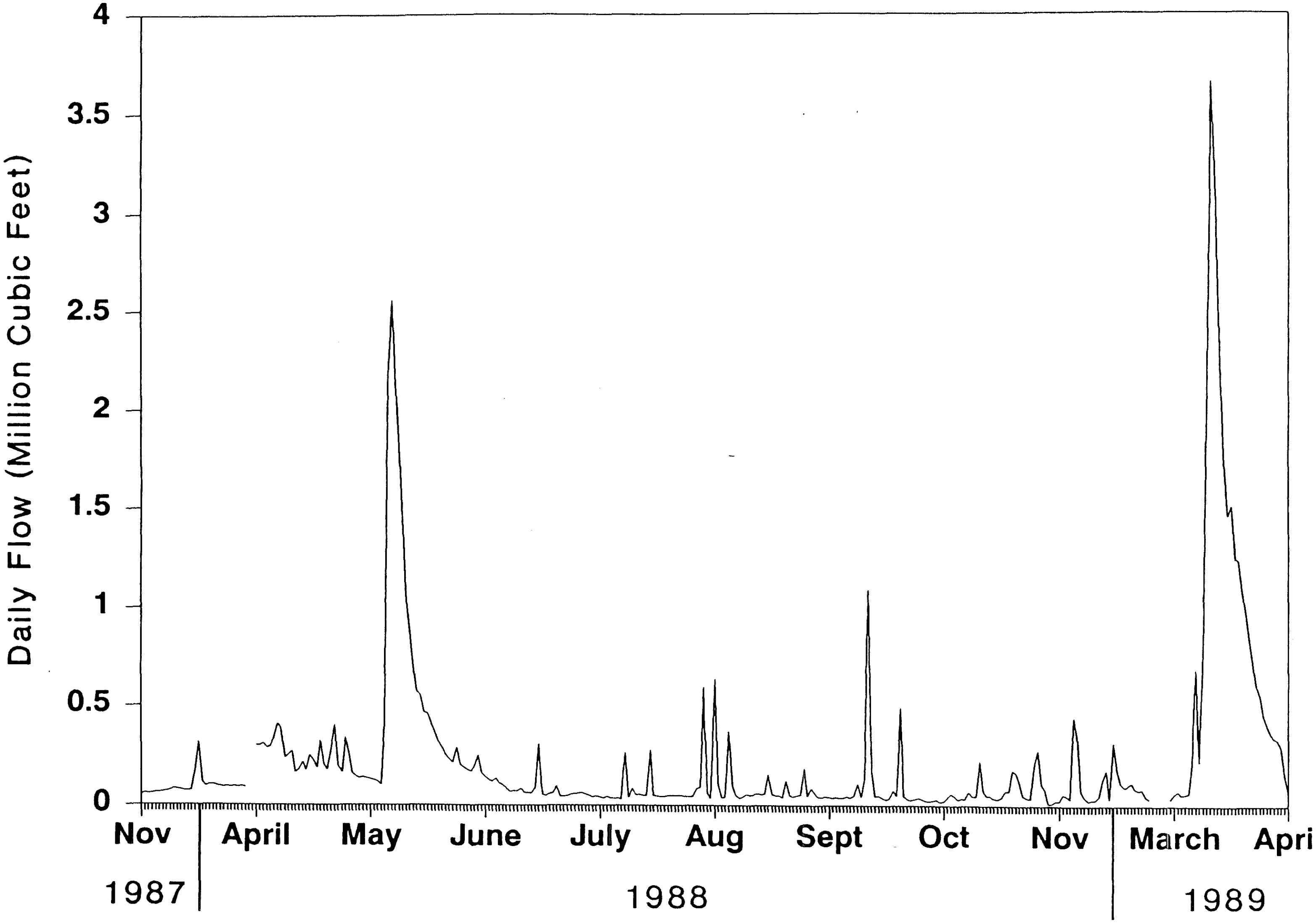
LRO DAILY VOLUME & PRECIPITATION

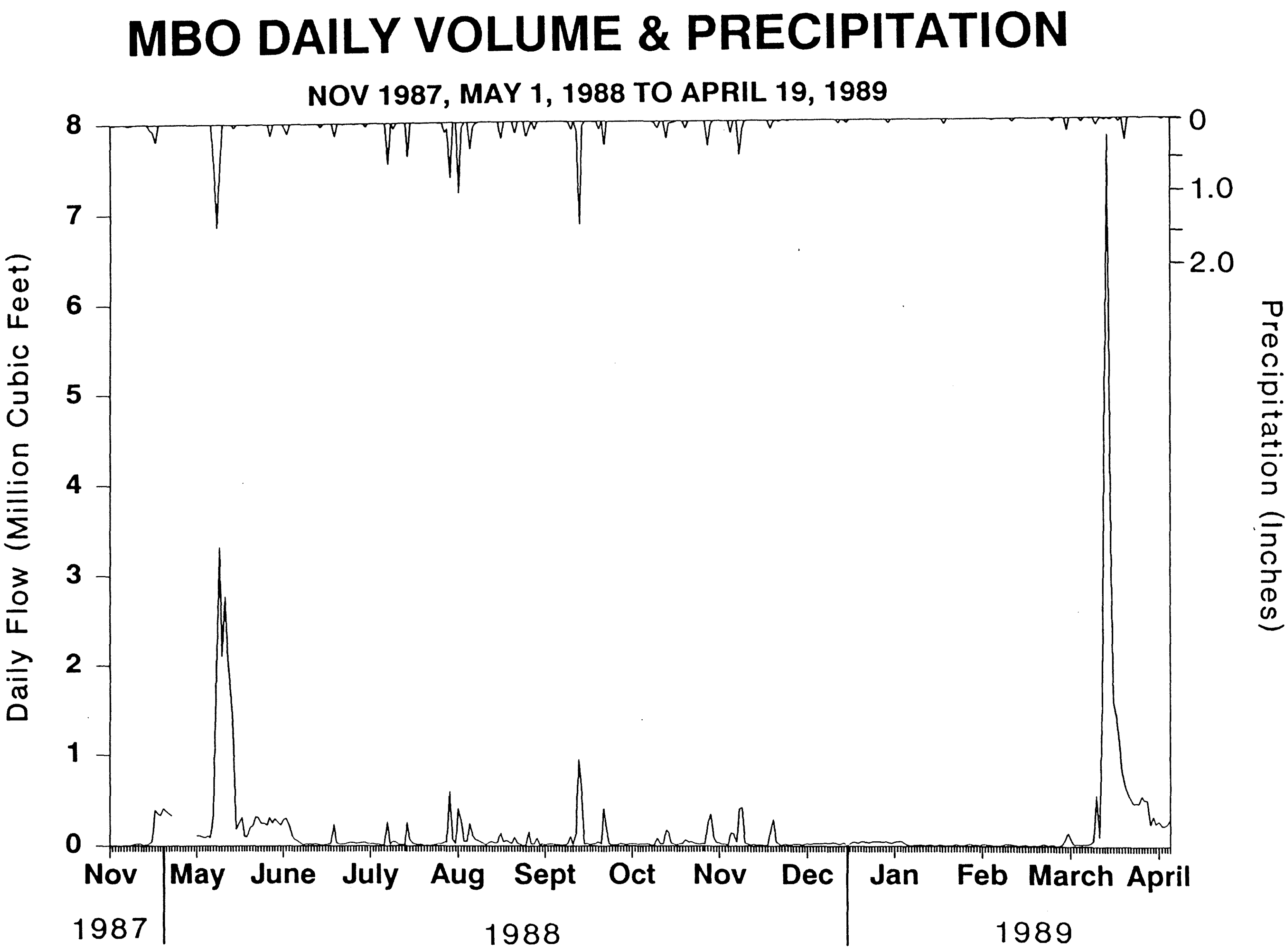
APRIL 2, 1988 TO APRIL 16, 1989



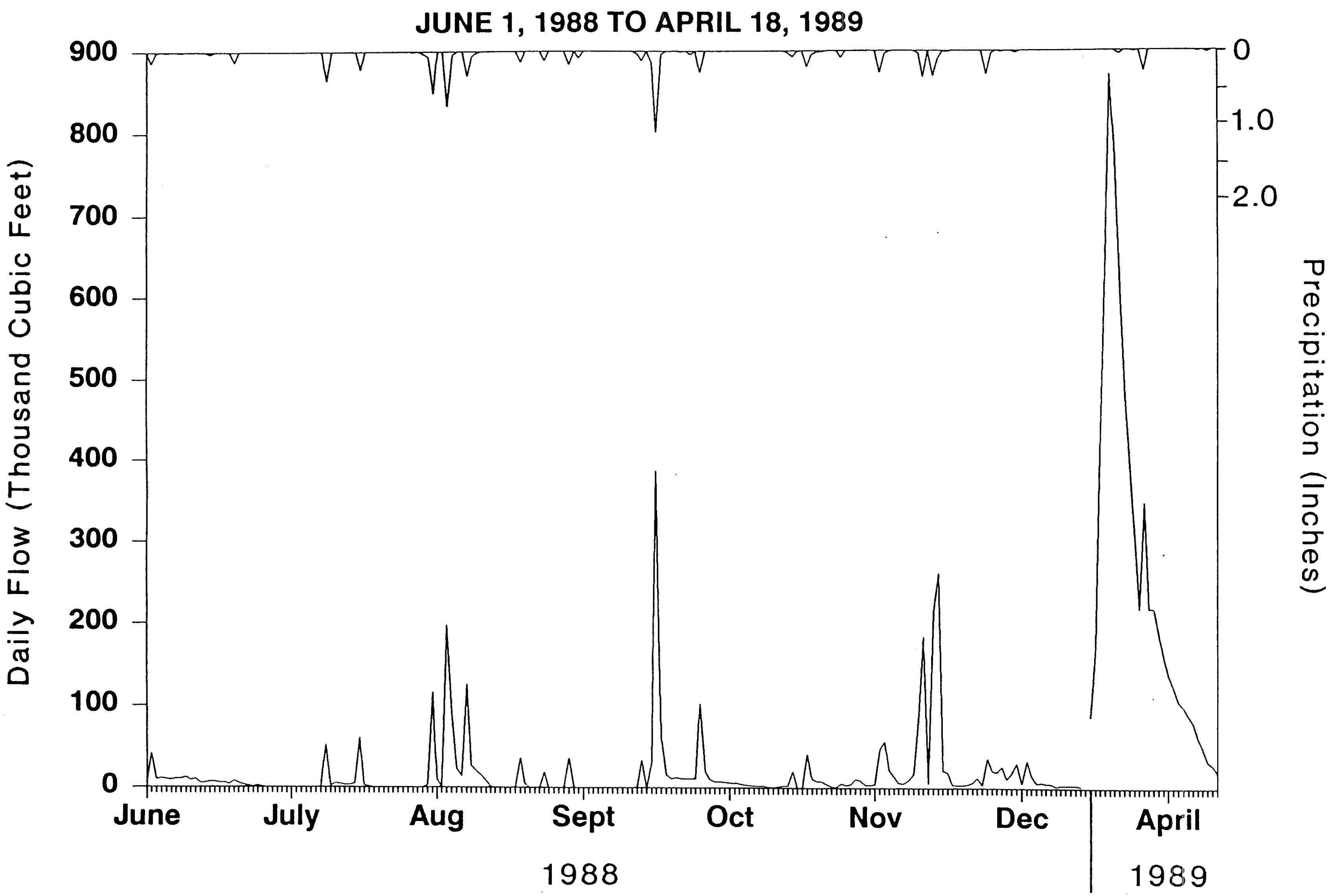
MBI DAILY VOLUME & PRECIPITATION

NOV 1987, APRIL 1988 TO APRIL 19, 1989



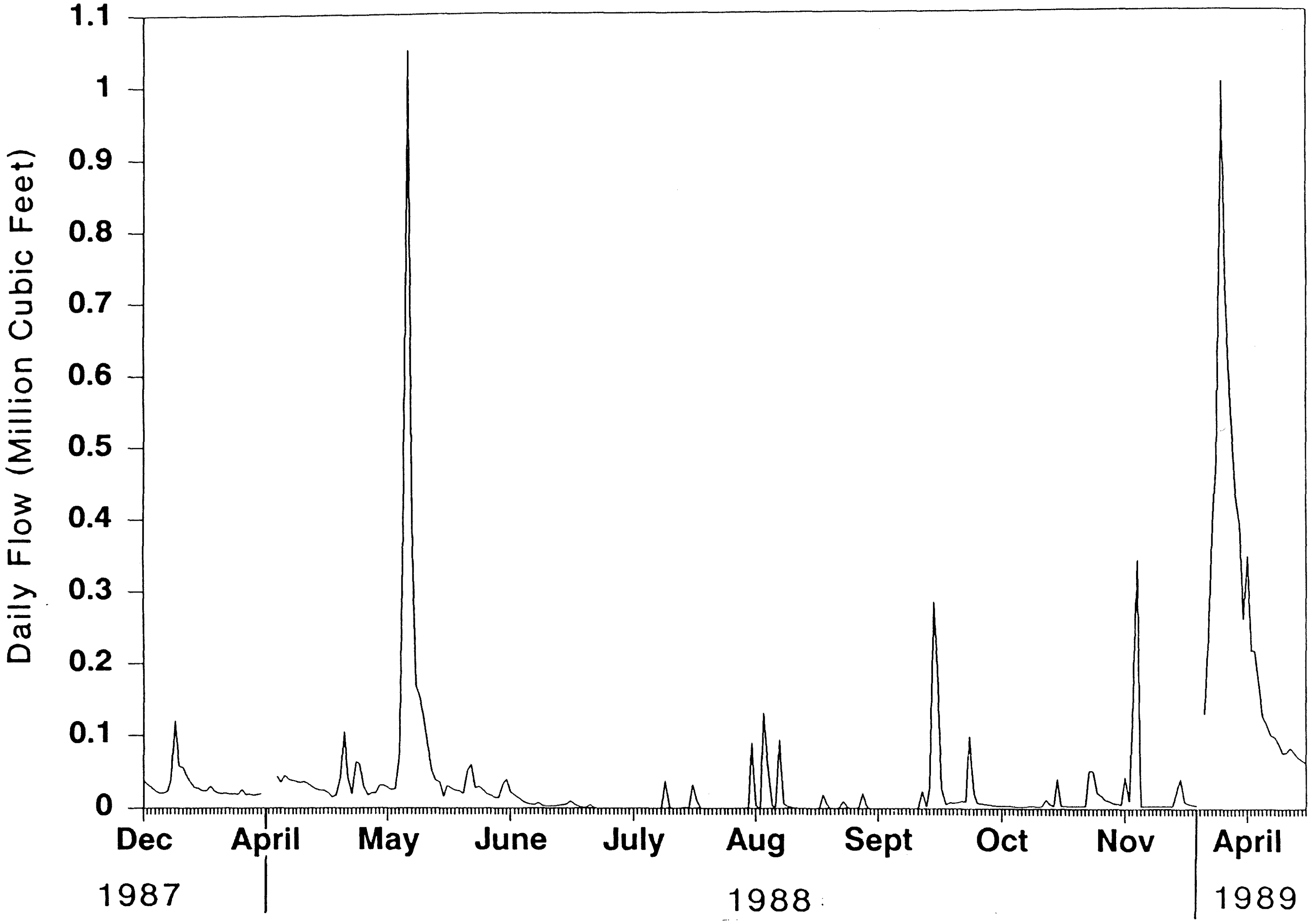

MBO DAILY VOLUME & PRECIPITATION
NOV 1987, MAY 1, 1988 TO APRIL 19, 1989
Daily Flow (Million Cubic Feet)
0
1
2
3
4
5
6
7
8
Precipitation (Inches)
0
1.0
2.0
Nov
May
June
July
Aug
Sept
Oct
Nov
Dec
Jan
Feb
March
April
1987
1988
1989

TLI DAILY VOLUME & PRECIPITATION



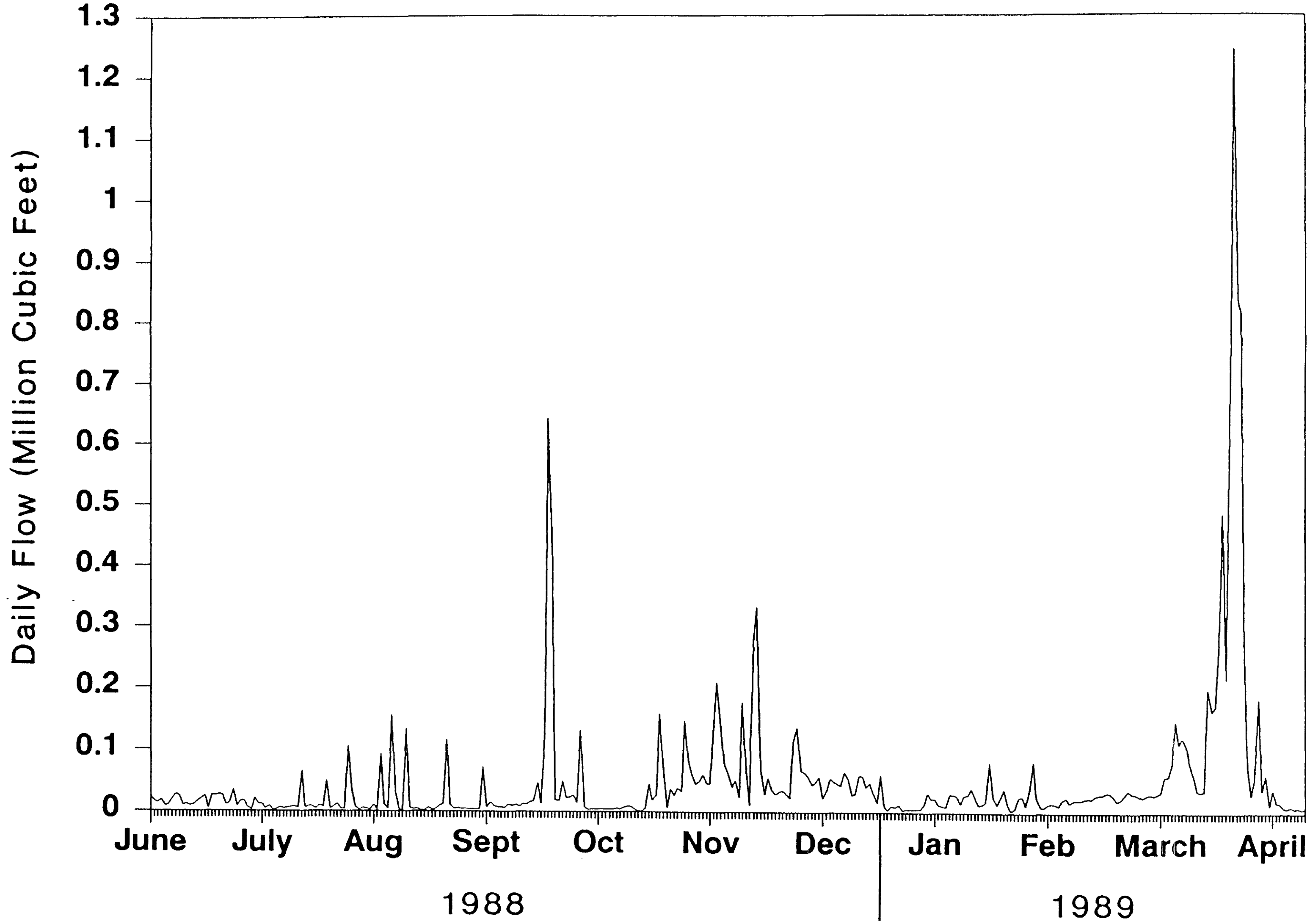
TLO DAILY VOLUME & PRECIPITATION

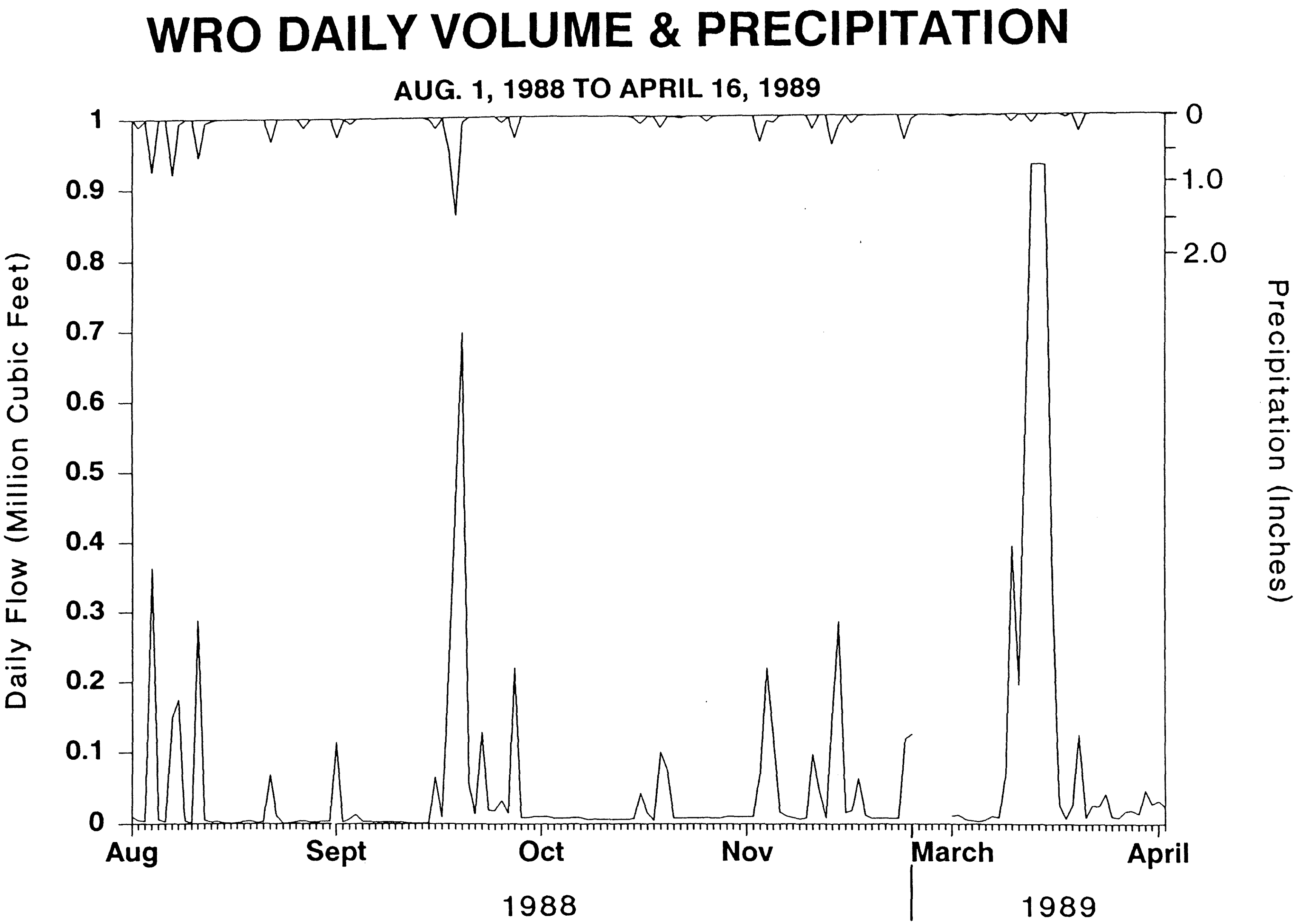
DEC 1987, APRIL 1988 TO APRIL 18, 1989



WRI DAILY VOLUME & PRECIPITATION

JUNE 1, 1988 TO APRIL 16, 1989





WRO DAILY VOLUME & PRECIPITATION
AUG. 1, 1988 TO APRIL 16, 1989
Daily Flow (Million Cubic Feet)
Precipitation (Inches)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
1.0
2.0
Aug
Sept
Oct
Nov
March
April
1988
1989

APPENDIX E

BASEFLOW WATER QUALITY DATA

APPENDIX E. BASEFLOW WATER QUALITY DATA

EVENT	PRECIP.	SITE	TSS	VSS	TP	DP	ORTHO-P	TKN	NO3	TN	TPb
871005	Baseflow	MBI	2	1	0.05	0.03	0.055	0.40	0.55	0.95	0.001
		MBO	7	6	0.04	0.02	0.010	1.05	0.20	1.25	0.001
880322	Baseflow	LRI	4	2	0.07	0.07		0.50	0.49	0.99	0.001
		LRO	4	3	0.06	0.04		0.60	0.44	1.04	0.001
		MBI	5	4	0.08	0.08		0.85	0.09	0.94	0.001
		MBO	2	2	0.06	0.06		0.75	0.19	0.94	0.001
		TLI	4	3	0.07	0.07		0.75	0.58	1.33	0.001
		TLO	5	2	0.06	0.06		0.75	0.78	1.53	0.001
880513	Const.baseflow	TLO	8	4	0.16	0.16		1.50	0.10	1.60	0.002
880609	Baseflow	LRI	5	2	0.06	0.06		0.30	0.45	0.75	0.001
		LRO	8	3	0.07	0.07		0.65	0.10	0.75	0.001
		MBI	6	2	0.10	0.08		1.00	0.20	1.20	0.001
		MBO	9	5	0.08	0.08		1.05	0.15	1.20	0.001
		TLI	9	3	0.19	0.17		1.00	0.10	1.10	0.001
		TLO	6	3	0.22	0.18		1.15	0.05	1.20	0.001
		WRI	13	4	0.13	0.13		0.80	2.05	2.85	0.001
		WRO	115	18	0.23	0.19		1.90	0.05	1.95	0.001
880914	baseflow	LRI	1	1	0.10	0.11		0.45	0.45	0.90	0.001
		LRO	6	4	0.08	0.06		0.75	0.10	0.85	0.002
		MBI	1	1	0.13	0.14		1.10	0.60	1.70	0.001
		MBO	8	5	0.48	0.43		0.80	0.10	0.90	0.001
		TLI(dry)									
		TLO(dry)									
		WRI	9	7	0.23	0.21		1.30	2.10	3.40	0.001
		WRO(dry)									
881026	baseflow	TLI	1	1	0.12	0.07		1.12	0.05	1.17	0.001
		TLO	5	2	0.09	0.06		0.65	0.05	0.70	0.003

881026	baseflow	TLI	1	1	0.12	0.07	1.12	0.05	1.17	0.001
		TLO	5	2	0.09	0.06	0.65	0.05	0.70	0.003
881214	baseflow	LRI	4	2	0.04	0.05	0.35	0.90	1.25	0.001
		LRO	10	7	0.07	0.04	0.41	0.85	1.26	0.001
		MBI	8	4	0.10	0.09	2.40	1.30	3.70	0.008
		MBO	5	2	0.09	0.05	0.92	1.10	2.02	0.001
		TLI	17	6	0.13	0.05	2.10	0.35	2.45	0.004
		TLO(frz.)								
		WRI	19	7	0.07	0.06	0.35	3.50	3.85	0.001
		WRO(frz.)								
890320	baseflow	LRI	9	3	0.10	0.08	1.33	1.40	2.73	0.004
		LRO	10	3	0.17	0.13	1.10	1.30	2.40	0.002
		MBI	27	9	0.11	0.07	1.85	0.80	2.65	0.006
		MBO	18	7	0.27	0.15	2.14	0.90	3.04	0.006
		TLI(frz.)								
		TLO(frz.)								
		WRI(frz.)								
		WRO(frz.)								
890405	baseflow	WRI	13	3	0.19	0.11	0.99	1.25	2.24	0.001
		WRO	23	6	0.18	0.06	0.98	0.40	1.38	0.001
890412	baseflow	TLI	4	2	0.06	0.04	1.27	0.45	1.72	0.001
		TLO	6	3	0.06	0.04	1.25	0.30	1.55	0.001

APPENDIX F

EVENT HYDROLOGIC DATA

RAINFALL DATA FOR EVENTS

Event	Site	Precip. (inches)	Duration (hours)	Ave.Intens. (Inches/Hr.)	Max.Intens. (Inches/Hr.)	Ctr.Intens. (Inches/Hr.)	Pk.Flow (cfs)	Volume (Acre-Ft.)	Runoff Coeff.	Outfl. Hrs.	Det.Time Hrs.*
871015	LRI	0.68	29	0.023	0.11	0.042	0.28	2.09	6.9		
	LRO	-	-	-	-	-	-	2.13	6.8	30	28.2
	MBI	-	-	-	-	-	10.7	18.54	51.4		
	MBO	0.68	29	0.023	0.11	0.042	-	20.07	48.9	40	26.3
871115	LRI	0.24	29	0.008	0.07	0.032	1.52	0.94	8.9		
	MBI	-	-	-	-	-	10.5	4.65	48.7		
	MBO	0.18	7.25	0.025	0.12	0.053	1.4	4.86	44.7	17	46.2
880308	LRI	0.17	9	0.019	0.09	0.032	3.45	4.15	55.2		
	LRO	-	-	-	-	-	-	4.18	53.5	24	11.5
880324	LRI	0.77	7	0.11	0.43	0.11	3.1	5.9	17.3		
	LRO	-	-	-	-	-	7.33	6.15	17.4	23	7.5
	MBI	-	-	-	-	-	67.1	27.85	8.3		
	MBO	0.77	7	0.11	0.43	0.11	-	31.86	8.8	23	9.5
880402	LRI	0.26	3	0.09	0.2	0.115	3.58	1.06	9.2		
	LRO	-	-	-	-	-	1.83	1.12	9.4	9	16.1
880426	LRI	0.45	9.25	0.049	0.16	0.072	1.64	1.92	9.6		
	LRO	-	-	-	-	-	1.79	2.43	11.8	41	33.7
	MBI	-	-	-	-	-	13.04	9.58	6.1		
	MBO	0.36	9.25	0.039	0.08	0.062	20.13	10.29	6.0	24	30.8
	WRI	-	-	-	-	-	1.64	1.72	27.0		
	WRO	0.45	10	0.045	0.16	-	1.79	1.84	26.7	14	7.6
880508 (first part of 3 day event)	LRI	2.45	22	0.111	1.8	0.54	70.76	22.96	21.2		
	LRO	-	-	-	-	-	18.5	25.13	22.3	22	1.8
	MBI	-	-	-	-	-	197.98	75.89	7.1		
	MBO	2.45	21.25	0.115	1.84	0.53	118.5	81.34	7.0	23	3.7
	WRI	-	-	-	-	-	43	11.46	46.8		
	WRI(pump)	-	18(pump)	-	-	-	-	12.52	-		
	WRO	1.73	21.5	0.113	1.82	0.53	10.7	25.4	40.8	31.5	1.2

880602	MBI	-	-	-	-	-	33.54	4.08	51.3		
	MBO	0.18	0.5	0.3	0.56	0.3	16.65	3.57	39.4	10	37.0
	TLI	0.18	0.5	0.36	0.48	0.24	3.06	0.94	5.5		
	TLO	-	-	-	-	-	0.88	1.03	5.5	19	**
880713	LRI	0.51	2.25	0.23	0.84	0.39	3.18	0.56	4.2		
	LRO	-	-	-	-	-	1.58	0.64	4.5	11	34.4
	MBI	-	-	-	-	-	54.11	5.72	20.8		
	MBO	0.52	1.5	0.33	0.74	0.36	8.94	5.62	17.9	9	21.1
	TLI	0.5	1.5	0.33	0.74	0.36	3.51	1.07	2.3		
	TLO	-	-	-	-	-	2.47	0.82	1.6	12	**
	WRI	-	-	-	-	-	13.78	1.42	20.0		
	WRO	0.5	1.5	0.33	0.64	0.33	3.48	1.11	14.5	9	8.1
880716	MBI	-	-	-	-	-	14.22	1.29	22.1		
	MBO	0.11	0.5	0.22	0.4	0.22	2.53	1.37	20.6	11	106.0
880720	LRI	0.36	6.75	0.053	0.4	0.13	4.41	0.55	5.8		
	LRO	-	-	-	-	-	0.79	0.44	4.4	10	45.5
	MBI	-	-	-	-	-	73.72	6.39	19.8		
	MBO	0.61	1.75	0.348	1.08	0.47	9.7	6.94	18.8	22.5	42.8
	TLI	0.37	1.75	0.211	0.76	0.28	8.48	1.45	4.1		
	TLO	-	-	-	-	-	1.31	0.86	2.2	6.5	**
	WRI	-	-	-	-	-	10.45	1.13	19.0		
	WRO	0.42	6	0.07	0.36	0.24	3.48	0.86	13.4	8	9.3
880804	LRI	1.17	13.75	0.085	1.32	0.43	8.52	1.73	3.3		
	LRO	-	-	-	-	-	6.05	1.92	3.6	15	15.6
	MBI	-	-	-	-	-	65.33	14.85	26.2		
	MBO	1.07	7	0.153	1	0.26	20.25	15.4	23.8	37	31.7
	TLI	0.93	10.5	0.089	0.64	0.21	6.24	1.93	2.2		
	TLO	-	-	-	-	-	3.2	2.18	2.2	23.5	**
	WRI	-	-	-	-	-	10.78	2.18	12.4		
	WRI(pump)	-	5.5(pump)	-	-	-	-	7.46	-		
	WRO	1.24	7.75	0.216	0.84	0.49	13.56	9.77	21.9	24	2.5

880807	LRI	1.49	16.25	0.092	2.64	0.52	18.67	2.55	3.9		
	LRO	-	-	-	-	-	8.35	2.7	3.9	20.25	15.0
	MBI	-	-	-	-	-	232.47	15.8	21.6		
	MBO	1.38	11	0.125	2.92	0.62	66.06	16.11	19.3	16	13.1
	TLI	1.17	11	0.106	2.72	0.43	30.25	6.24	5.6		
	TLO	-	-	-	-	-	11.97	4.29	3.5	16.75	**
	WRI	-	-	-	-	-	25.47	4.25	21.4		
	WRI(pump)	-	4.25(pump)	-	-	-	-	2.56	-		
	WRO	1.4	10.5	0.133	2.2	0.45	10.75	7.42	14.7	29	3.9
880811	LRI	0.75	2.25	0.333	1.16	0.58	9.32	1.45	4.4		
	LRO	-	-	-	-	-	5.86	1.57	4.6	14.5	18.5
	MBI	-	-	-	-	-	105.35	8.69	33.5		
	MBO	0.49	1	0.49	1.64	0.49	22.61	8.56	28.9	26	40.1
	TLI	0.5	1	0.5	1.32	0.5	9.78	2.73	5.8		
	TLO	-	-	-	-	-	7.05	2.21	4.2	24	**
	WRI	-	-	-	-	-	28.56	3.07	23.8		
	WRI(pump)	-	5(pump)	-	-	-	-	3.02	-		
	WRO	0.91	2.25	0.4	2.28	1.78	10.75	6.62	20.2	16.25	2.5
880822	LRI	0.35	13	0.027	0.08	0.03	0.96	0.41	2.6		
	LRO	-	-	-	-	-	0.6	0.31	1.9	18.5	119.4
	MBI	-	-	-	-	-	14.58	2.98	19.4		
	MBO	0.29	6.25	0.046	0.24	0.07	5.07	3.17	18.1	22.25	92.6
	TLI	0.22	5.25	0.042	0.16	0.07	3.3	0.84	4.0		
	TLO	-	-	-	-	-	0.81	0.52	2.3	23.75	**
	WRI	-	-	-	-	-	9.55	2.68	42.0		
	WRI(pump)		?								
	WRO	0.45	5.25	0.086	0.32	0.08	3.11	1.67	10.3	23.75	14.2
880827	LRI	0.3	2.75	0.109	0.2	0.1	0.56	0.24	1.8		
	LRO	-	-	-	-	-	0.48	0.49	3.6	18	73.5
	MBI	-	-	-	-	-	15.6	2.24	21.1		
	MBO	0.2	2.75	0.073	0.2	0.07	4.7	2.31	19.1	25	142.9
	TLI	0.17	2.75	0.062	0.2	0.2	1.54	0.43	2.7		
	TLO	-	-	-	-	-	0.25	0.23	1.3	27	**

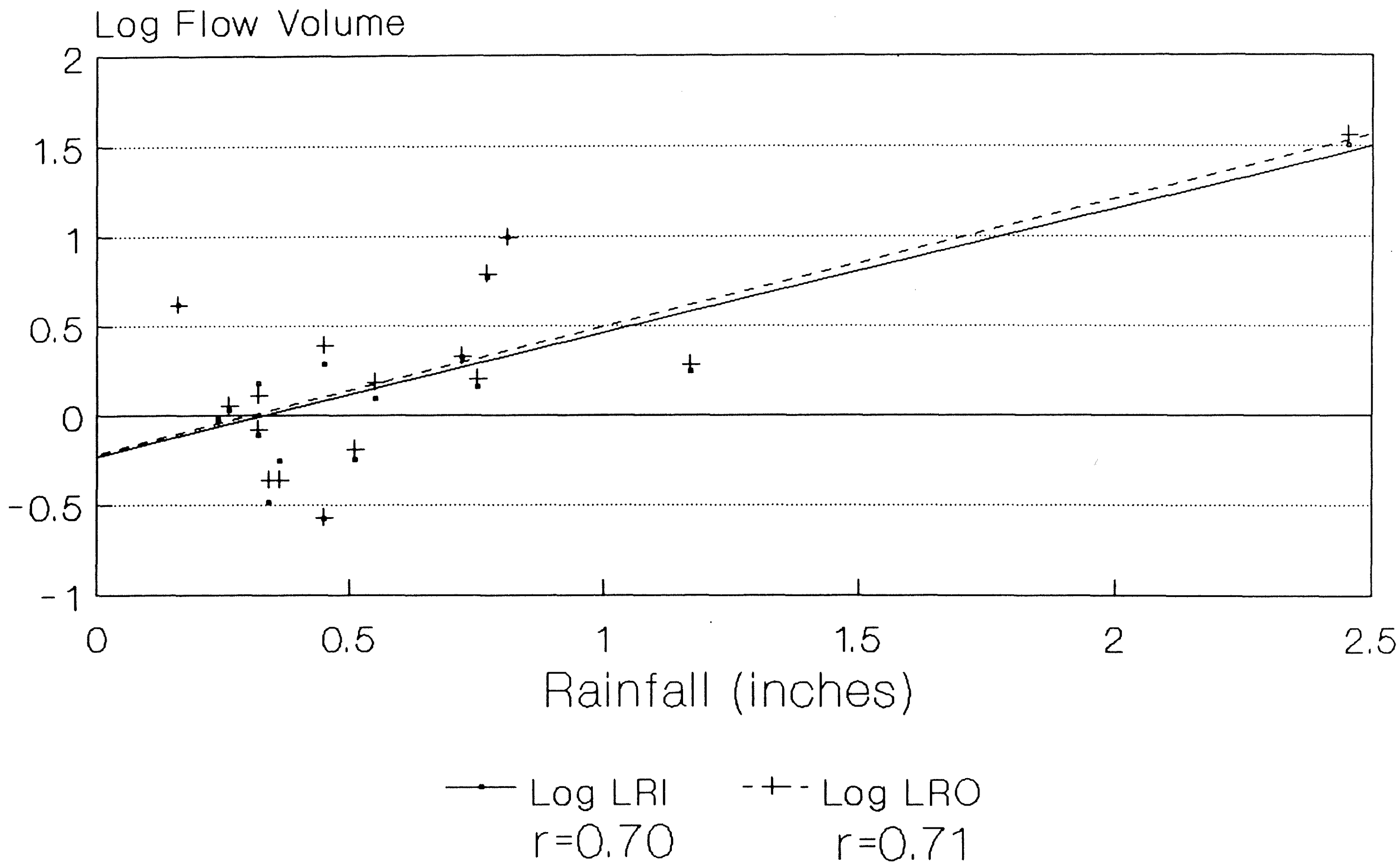
880901	LRI	0.45	5	0.09	0.16	0.1	1.49	0.26	1.3		
	LRO	-	-	-	-	-	0.89	0.27	1.3	10.5	77.8
	MBI	-	-	-	-	-	16.58	3.31	23.1		
	MBO	0.27	2.75	0.098	0.16	0.12	4.8	4.09	25.1	28	90.4
	TLI	0.28	5	0.056	0.16	0.1	2.43	0.84	3.2		
	TLO	-	-	-	-	-	1.11	0.53	1.8	25.25	**
	WRI	-	-	-	-	-	6.87	1.6	25.1		
	WRI(pump)	-	2(pump)	-	-	-	-	1.24	-		
	WRO	0.45	3.75	0.12	0.36	0.15	6.84	2.65	16.4	12.75	4.8
880918	LRI	0.32	2.75	0.12	1.08	0.4	3.34	0.78	5.5		
	LRO	-	-	-	-	-	2.9	0.84	5.7	10.75	25.6
	WRI	-	-	-	-	-	9.8	1.12	20.3		
	WRO	0.39	2.5	0.156	1.44	0.74	10.2	1.18	16.4	10	8.5
880919	MBI	-	-	-	-	-	61.4	26.19	27.2		
	MBO	1.82	11.75	0.155	0.56	0.155	47.8	35.56	32.3	27.25	10.1
	TLI	1.59	11.75	0.135	0.48	0.135	17.6	9.23	6.1		
	TLO	-	-	-	-	-	13.1	11.29	6.8	57.5	**
880928	LRI	0.55	7	0.079	0.28	0.12	4.41	1.24	5.1		
	LRO	-	-	-	-	-	1.37	1.52	6.0	27	35.5
	MBI	-	-	-	-	-	37.2	11.12	48.8		
	MBO	0.43	7	0.06	0.24	0.08	13.1	14	53.9	42	39.6
	TLI	0.43	7	0.06	0.32	0.09	4.87	1.94	4.8		
	TLO	-	-	-	-	-	3.31	2.24	5.0	21.5	**
	WRI	-	-	-	-	-	14.6	3.02	42.6		
	WR(pump)	-	2(pump)	9.12cfs	-	-	-	1.51	-		
	WRO	0.5	6.5	0.077	0.28	0.08	10.2	5.03	27.9	16.75	3.3
881020	LRI	0.34	7	0.048	0.12	0.07	0.83	0.32	3.6		
	LRO	-	-	-	-	-	0.72	0.44	4.6	13.5	61.4
	MBI	-	-	-	-	-	9.79	6.25	33.7		
	MBO	0.35	17	0.02	0.08	0.05	5.3	8.08	38.2	36	58.8
	TLI	0.38	17	0.02	0.12	0.057	2.16	1.08	3.0		
	TLO	-	-	-	-	-	1.49	1.5	3.8	34	**
	WRI	-	-	-	-	-	6.87	3.39	92.0		
	WRO	0.26	6.75	0.038	0.08	0.043	7.68	2.63	66.0	17.25	6.6

881104	MBI	-	-	-	-	-	4.11	13.08	35.3		
	MBO	0.7	18.75	0.024	0.08	0.026	8.14	14.87	35.2	48	6.5
	WRI	-	-	-	-	-	7.37	5.54	60.2		
	WRO	0.65	21	0.03	0.08	0.035	7.79	5.04	50.6	44	8.7
881115	LRI	0.81	9.75	0.083	0.48	0.085	11.53	9.82	27.4		
	LRO	-	-	-	-	-	5.53	9.71	26.1	42.75	8.8
	MBI	-	-	-	-	-	65.8	16.6	40.7		
	MBO	0.77	7.75	0.099	0.72	0.244	34.4	17.6	37.8	24	18.0
	TLI	0.64	8.5	0.075	0.6	0.2	20.6	10.3	17.0		
	TLO	-	-	-	-	-	14	10.6	15.8	24	**
	WRI	-	-	-	-	-	28.36	13.48	104.6		
	WRO	0.91	8.5	0.107	0.48	0.11	11.1	9.99	50.6	30.5	3.1
890404	LRI	0.32	4.5	0.07	0.2	0.09	12.1	1.5	17.9		
	LRO	-	-	-	-	-	2	1.3	14.6	13.5	20.8
	WRI	-	-	-	-	-	11.6	3.4	64.9		
	WRO	0.37	5	0.074	0.28	0.11	7.1	2.8	21.0	12.75	4.6

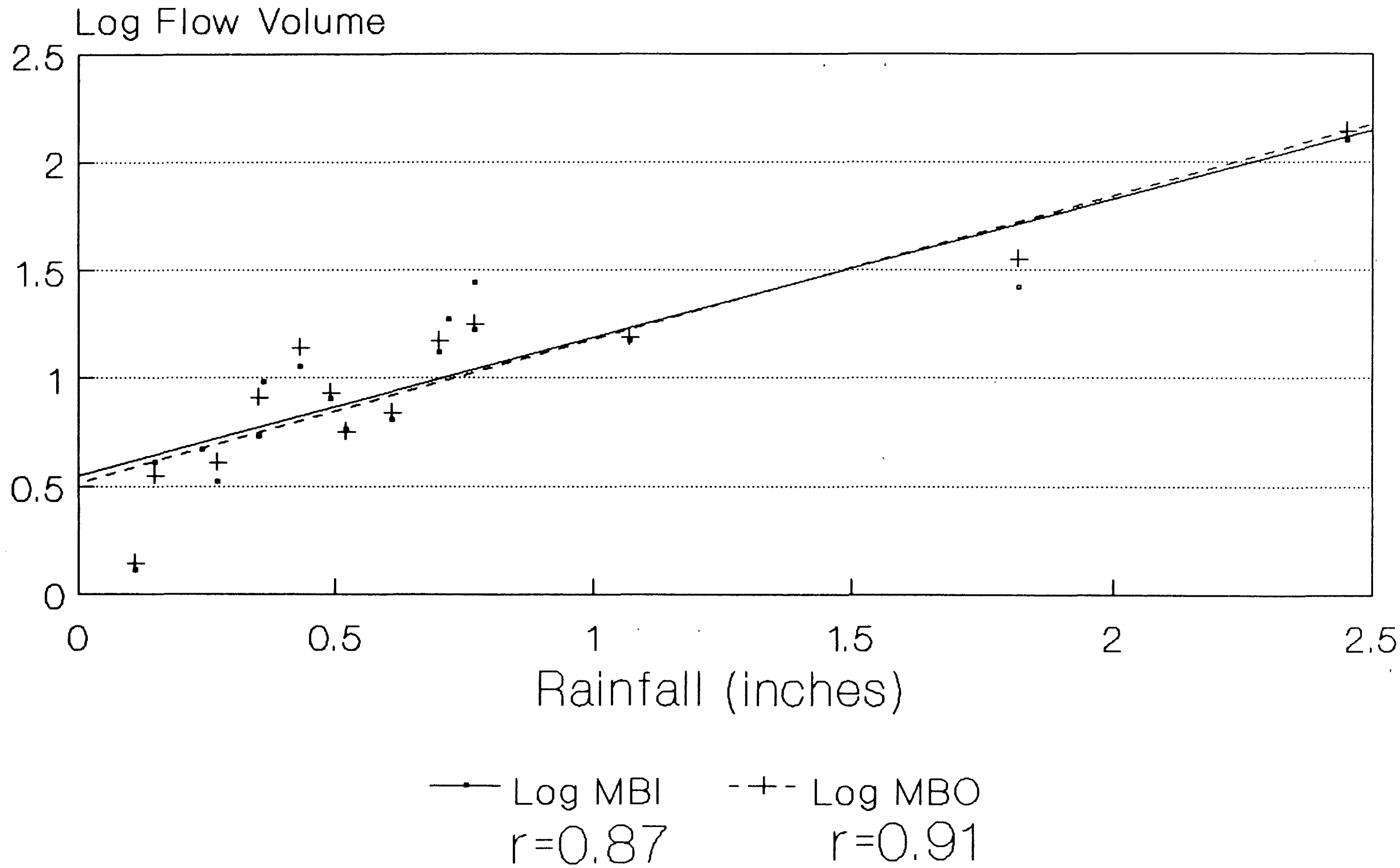
* Hyd.Det.Time= Perm.storage/(Inflow vol./Time of outflow)

** Tanners Lake Wetland has no permanent storage so detention time equals hours of outflow

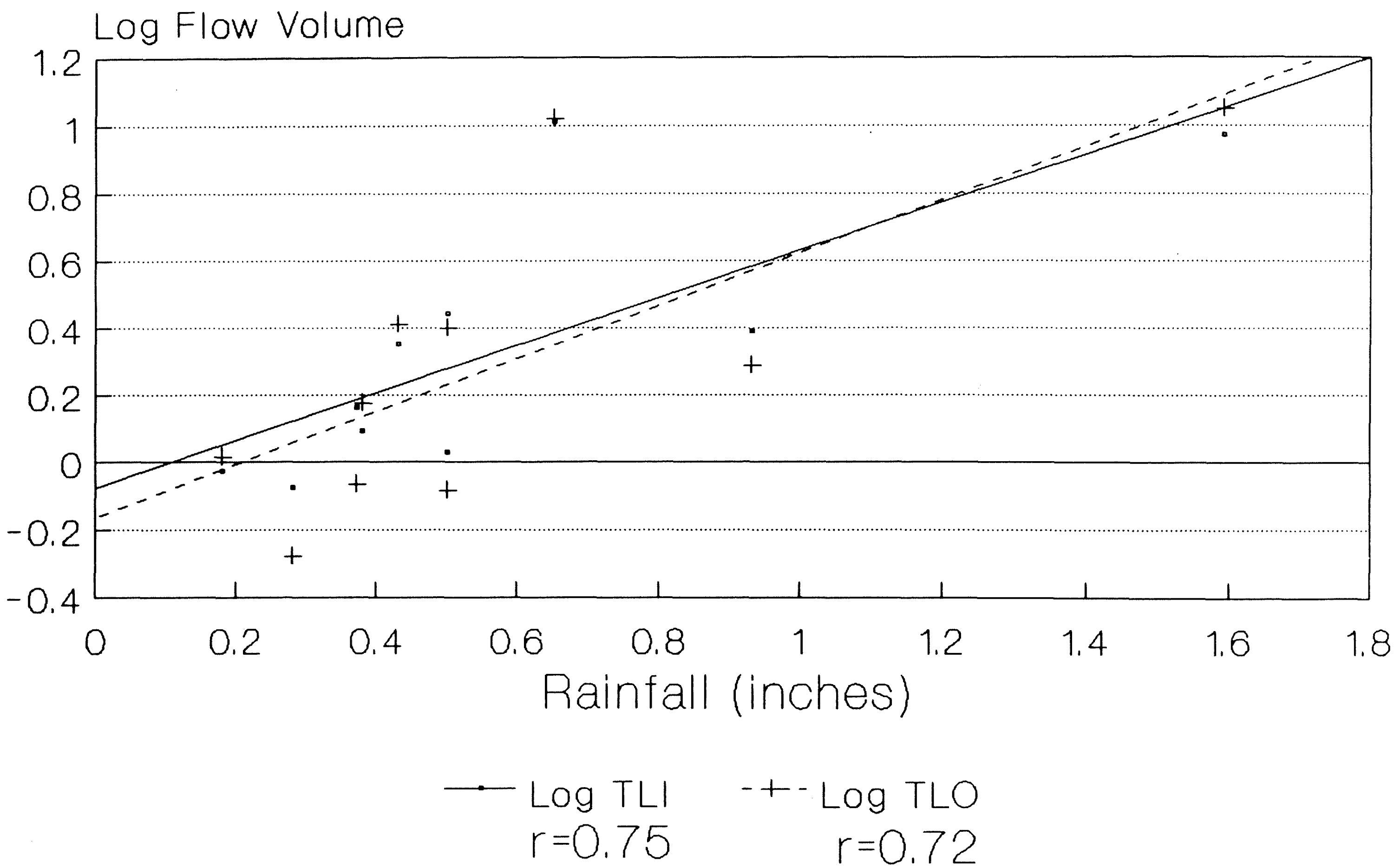
LR Flow Analysis
LRI and LRO Comparison

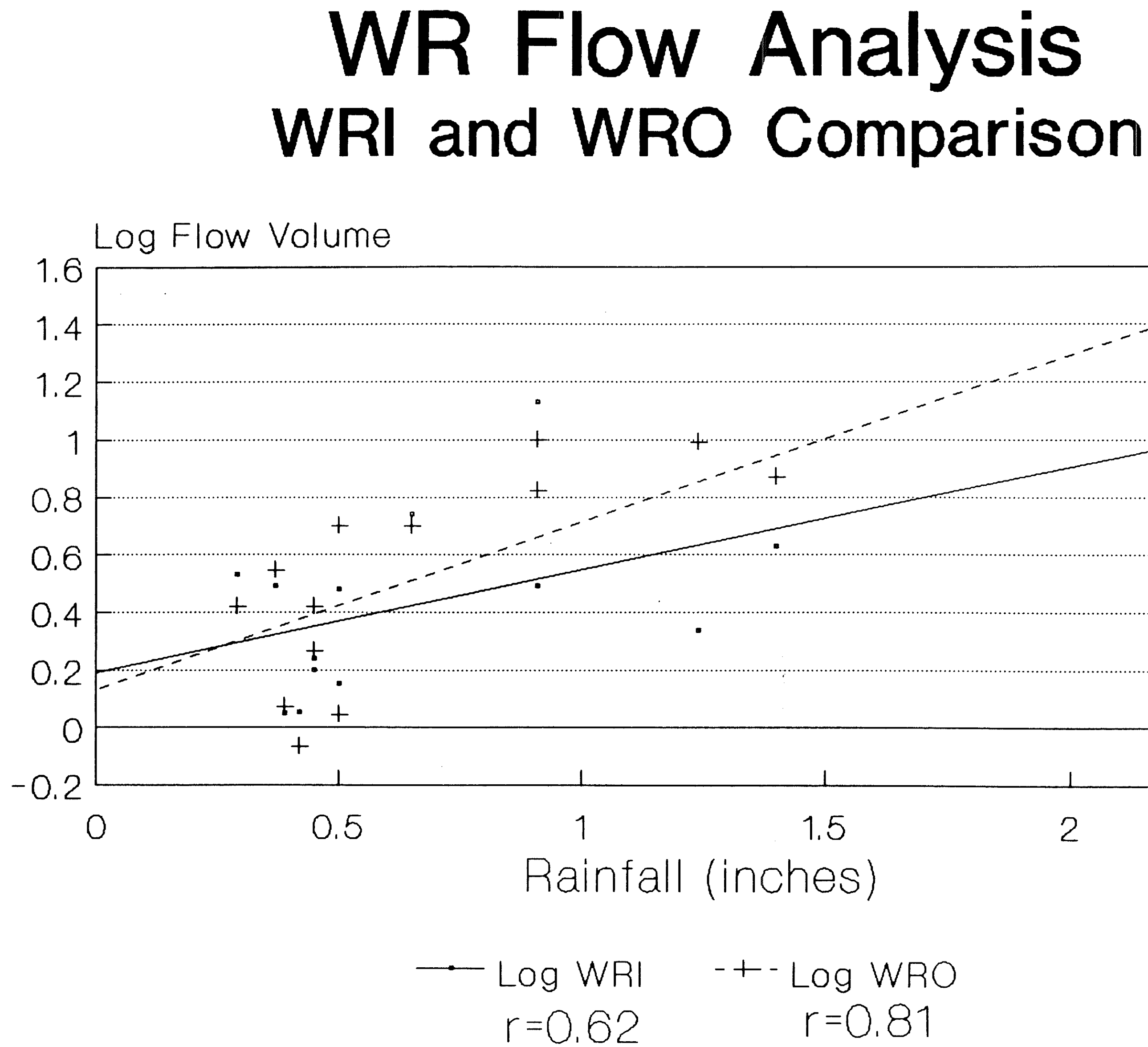


MB Flow Analysis
MBI and MBO Comparison



TL Flow Analysis
TLI and TLO Comparison




WR Flow Analysis
WRI and WRO Comparison
Log Flow Volume
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
0
0.5
1
1.5
2
2.5
Rainfall (inches)
Log WRI
r=0.62
Log WRO
r=0.81

APPENDIX G

EVENT WATER QUALITY DATA

1987 LCMR Water Quality Concentration and Load Summary

Event: Oct.15-16, 1987

LR Precip: 0.72 — Duration: 29 hours (0.02"/hr)

MB Precip: - — Last event: 25 days

TL Precip: -

CONCENTRATION in MG/L

SITE	TSS	VSS	TP	DP	ORTHO-P	TKN	NO3	TN	TPb	QWATER(A')	COMMENTS
LRI	34	11	0.21	0.12	-	0.75	0.85	1.60	0.001	2.09	-Event mean concentration (EMC)
LRO	5	2	0.05	0.02	-	0.35	0.20	0.55	0.001	2.13	-EMC
MBI	9	6	0.18	0.14	-	0.85	0.50	1.35	0.004	18.54	-EMC
MBO	13	10	0.06	0.03	-	0.90	0.30	1.20	0.002	20.07	-EMC for WQ; modeled flow
TLI	32	12	0.32	0.17	-	0.90	0.35	1.25	0.025	-	-Grab
TLO	13	7	0.27	0.18	-	0.70	0.85	1.55	0.005	-	-Grab

LOAD in POUNDS

SITE	TSS	VSS	TP	DP	ORTHO-P	TKN	NO3	TN	TPb	TWATER(A')
LRI	193	63	1.19	0.68	-	4.26	4.83	9.10	0.006	2.09
LR(Qdir.)	13	4	0.08	0.05	-	0.29	0.33	0.62	0.000	0.14
LR(Atmos.)	-	-	0.01	0.01	-	0.22	0.12	0.34	0.002	0.12
LR(Inflow)	206	67	1.29	0.74	-	4.77	5.28	10.05	0.008	2.35
LRO	29	12	0.29	0.12	-	2.03	1.16	3.19	0.006	2.13
%Reduct.	86	83	77	84	-	57	78	68	30	9
MBI	454	303	9.08	7.06	-	42.86	25.21	68.08	0.202	18.54
MB(Qdir.)	14	9	0.27	0.21	-	1.28	0.75	2.03	0.006	0.55
MB(Atmos.)	-	-	0.04	0.04	-	0.87	0.50	1.37	0.009	0.48
MB(Inflow)	467	312	9.39	7.31	-	45.01	26.46	71.48	0.217	19.57
MBO	710	546	3.28	1.64	-	49.13	16.38	65.51	0.109	20.07
%Reduct.	-52	-75	65	78	-	-9	38	8	50	-3

Event: Nov.15-18, 1987

LR Precip:	0.24	Duration: 29 hours (0.01"/hr)
MB Precip:	-	Last event: 30 days
TL Precip:	-	

CONCENTRATION in MG/L

SITE	TSS	VSS	TP	DP	ORTHO-P	TKN	NO3	TN	TPb	QWATER(A')	COMMENTS
LRI	12	2	0.09	0.08	-	0.65	1.00	1.65	0.002	0.94	-EMC
LRO	-	-	-	-	-	-	-	--	-	-	-Not monitored; construction
MBI	16	5	0.16	0.07	-	1.50	0.60	2.10	0.004	4.65	-EMC
MBO	5	2	0.04	0.04	-	0.80	0.70	1.50	0.001	4.86	-EMC for WQ; modeled flow

LOAD in POUNDS

SITE	TSS	VSS	TP	DP	ORTHO-P	TKN	NO3	TN	TPb	TWATER(A')
LRI	31	5	0.23	0.20	-	1.66	2.56	4.22	0.005	0.94
LR(Qdir.)	0	0	0.00	0.00	-	0.02	0.03	0.06	0.000	0.01
LR(Atmos.)	-	-	0.00	0.00	-	0.07	0.04	0.11	0.001	0.04
LR(Inflow)	31	5	0.24	0.21	-	1.76	2.63	4.39	0.006	0.99
LRO	-	-	-	-	-	-	-	-	-	-
%Reduct.	-	-	-	-	-	-	-	-	-	-
MBI	202	63	2.02	0.89	-	18.97	7.59	26.56	0.051	4.65
MB(Qdir.)	2	1	0.02	0.01	-	0.20	0.08	0.28	0.001	0.05
MB(Atmos.)	-	-	0.01	0.01	-	0.29	0.17	0.46	0.003	0.16
MB(Inflow)	204	64	2.06	0.91	-	19.46	7.83	27.29	0.054	4.86
MBO	66	26	0.53	0.53	-	10.58	9.25	19.83	0.013	4.86
%Reduct.	68	59	74	42	-	46	-18	27	76	0

1988 LCMR Water Quality Concentration and Load Summary

Event: Feb.18-19, 1988 melt
Equiv.Moist. : 0.40 (4" snow loss)

CONCENTRATION in MG/L

SITE	TSS	VSS	TP	DP	ORTHO-P	TKN	NO3	TN	TPb	QWATER(A')	COMMENTS
LRI	90	22	0.35	0.33	-	1.55	0.90	2.45	0.040	1.23	-EMC
LRO	4	2	0.04	0.04	-	0.75	0.65	1.40	0.007	1.39	-EMC
MBI	208	55	0.53	0.33	-	2.90	0.95	3.85	0.090	6.25	-EMC
MBO	3	3	0.07	0.07	-	1.60	0.70	2.30	0.002	6.90	-EMC for WQ; modeled flow

LOAD in POUNDS

SITE	TSS	VSS	TP	DP	ORTHO-P	TKN	NO3	TN	TPb	TWATER(A')
LRI	301	74	1.17	1.10	-	5.19	3.01	8.20	0.134	1.23
LR(Qdir.)	10	2	0.04	0.04	-	0.17	0.10	0.28	0.005	0.04
LR(Atmos.)	-	-	0.01	0.01	-	0.12	0.07	0.19	0.001	0.07
LR(Inflow)	311	76	1.22	1.15	-	5.48	3.18	8.66	0.140	1.34
LRO	15	8	0.15	0.15	-	2.84	2.46	5.29	0.026	1.39
%Reduct.	95	90	88	87	-	48	23	39	81	-4
MBI	3536	935	9.01	5.61	-	49.30	16.15	65.45	1.530	6.25
MB(Qdir.)	91	24	0.23	0.14	-	1.26	0.41	1.68	0.039	0.16
MB(Atmos.)	-	-	0.02	0.02	-	0.48	0.28	0.76	0.005	0.27
MB(Inflow)	3627	959	9.26	5.78	-	51.05	16.84	67.89	1.574	6.68
MBO	56	56	1.31	1.31	-	30.03	13.14	43.17	0.038	6.90
%Reduct.	98	94	86	77	-	41	22	36	98	-3

Event: **Feb.26-27, 1988 melt**
Equiv.Moist. : 0.20 (2" snow loss)
Beginning of several day event

CONCENTRATION in MG/L

SITE	TSS	VSS	TP	DP	ORTHO-P	TKN	NO3	TN	TPb	QWATER(A')	COMMENTS
LRI	117	17	0.51	0.27	-	2.20	0.45	2.65	0.020	2.57	-EMC
LRO	33	3	0.28	0.19	-	1.45	0.46	1.91	0.010	2.55	-EMC
MBI	107	27	0.71	0.37	-	2.80	0.38	3.18	0.051	2.94	-EMC
MBO	30	11	0.24	0.12	-	1.75	0.64	2.39	0.011	3.20	-EMC for WQ; modeled flow

LOAD in POUNDS

SITE	TSS	VSS	TP	DP	ORTHO-P	TKN	NO3	TN	TPb	TWATER(A')
LRI	818	119	3.57	1.89	-	15.38	3.15	18.52	0.140	2.57
LR(Qdir.)	3	0	0.01	0.01	-	0.05	0.01	0.06	0.000	0.01
LR(Atmos.)	-	-	0.00	0.00	-	0.06	0.03	0.09	0.001	0.03
LR(Inflow)	820	119	3.58	1.90	-	15.49	3.19	18.68	0.141	2.61
LRO	229	21	1.94	1.32	-	10.06	3.19	13.25	0.069	2.55
%Reduct.	72	83	46	30	-	35	0	29	51	2
MBI	856	216	5.68	2.96	-	22.39	3.04	25.43	0.408	2.94
MB(Qdir.)	9	2	0.06	0.03	-	0.23	0.03	0.26	0.004	0.03
MB(Atmos.)	-	-	0.01	0.01	-	0.24	0.14	0.38	0.002	0.13
MB(Inflow)	865	218	5.75	3.00	-	22.87	3.21	26.07	0.415	3.10
MBO	261	96	2.09	1.04	-	15.23	5.57	20.80	0.096	3.20
%Reduct.	70	56	64	65	-	33	-74	20	77	-3

Event: Feb.28-March 2, 1988 melt
Equiv.Moist. : 0.10 (1" snow loss)
Middle of several day event

CONCENTRATION in MG/L

SITE	TSS	VSS	TP	DP	ORTHO-P	TKN	NO3	TN	TPb	QWATER(A')	COMMENTS
LRI	150	11	0.58	0.32	-	2.25	0.56	2.81	0.008	18.28	-EMC
LRO	47	4	0.43	0.28	-	2.00	0.51	2.51	0.006	17.26	-EMC
MBI	98	14	0.68	0.46	-	2.50	0.35	2.85	0.035	12.56	-EMC
MBO	24	6	0.36	0.24	-	2.00	0.51	2.51	0.015	12.67	-EMC for WQ; modeled flow

LOAD in POUNDS

SITE	TSS	VSS	TP	DP	ORTHO-P	TKN	NO3	TN	TPb	TWATER(A')
LRI	7458	547	28.84	15.91	-	111.87	27.84	139.72	0.398	18.28
LR(Qdir.)	0	0	0.00	0.00	-	0.01	0.00	0.01	0.000	0.00
LR(Atmos.)	-	-	0.00	0.00	-	0.03	0.02	0.05	0.000	0.02
LR(Inflow)	7459	547	28.84	15.91	-	111.91	27.86	139.77	0.398	18.30
LRO	2207	188	20.19	13.15	-	93.89	23.94	117.84	0.282	17.26
%Reduct.	70	66	30	17	-	16	14	16	29	6
MBI	3348	478	23.23	15.72	-	85.41	11.96	97.37	1.196	12.56
MB(Qdir.)	1	0	0.01	0.00	-	0.02	0.00	0.03	0.000	0.00
MB(Atmos.)	-	-	0.01	0.01	-	0.12	0.07	0.19	0.001	0.07
MB(Inflow)	3349	478	23.24	15.73	-	85.55	12.03	97.58	1.197	12.63
MBO	827	207	12.41	8.27	-	68.92	17.58	86.50	0.517	12.67
%Reduct.	75	57	47	47	-	19	-46	11	57	0

ent: March 3-6, 1988 melt
uiv.Moist. : 0.10 (1" snow loss)
d of several day event

CENTRATION in MG/L

SITE	TSS	VSS	TP	DP	ORTHO-P	TKN	NO3	TN	TPb	QWATER(A')	COMMENTS
LRI	14	4	0.14	0.12	-	1.00	0.53	1.53	0.002	4.65	-EMC
LRO	6	3	0.11	0.11	-	1.00	0.68	1.68	0.001	4.57	-EMC
MBI	9	4	0.14	0.14	-	1.40	0.08	1.48	0.003	15.12	-EMC
MBO	5	4	0.13	0.09	-	1.25	0.13	1.38	0.001	15.23	-EMC for WQ; modeled flow

AD in POUNDS

SITE	TSS	VSS	TP	DP	ORTHO-P	TKN	NO3	TN	TPb	TWATER(A')
LRI	177	51	1.77	1.52	-	12.65	6.70	19.35	0.025	4.65
R(Qdir.)	0	0	0.00	0.00	-	0.00	0.00	0.00	0.000	0.00
(Atmos.)	-	-	0.00	0.00	-	0.03	0.02	0.05	0.000	0.02
(Inflow)	177	51	1.77	1.52	-	12.68	6.72	19.40	0.026	4.67
LRO	75	37	1.37	1.37	-	12.43	8.45	20.88	0.012	4.57
Reduct.	58	26	23	10	-	2	-26	-8	51	2
MBI	370	165	5.76	5.76	-	57.58	3.29	60.87	0.123	15.12
3(Qdir.)	0	0	0.00	0.00	-	0.01	0.00	0.01	0.000	0.00
(Atmos.)	-	-	0.01	0.01	-	0.12	0.07	0.19	0.001	0.07
(Inflow)	370	165	5.76	5.76	-	57.71	3.36	61.07	0.125	15.19
MBO	207	166	5.39	3.73	-	51.78	5.39	57.17	0.041	15.23
Reduct.	44	-1	7	35	-	10	-60	6	67	0

ELT SUMMARY LOAD IN POUNDS - Feb.26 to March 6, 1988

SITE	TSS	VSS	TP	DP	ORTHO-P	TKN	NO3	TN	TPb	TWATER(A')
LRI	8453	716	34.17	19.32	-	139.90	37.69	177.59	0.563	25.50
LR(Qdir.)	3	0	0.01	0.01	-	0.06	0.01	0.07	0.000	0.01
.R(Atmos.)	-	-	0.01	0.01	-	0.12	0.07	0.19	0.001	0.07
.R(Inflow)	8456	717	34.19	19.33	-	140.08	37.77	177.85	0.565	25.58
LRO	2510	246	23.50	15.83	-	116.38	35.59	151.97	0.363	24.38
%Reduct.	70	66	31	18	-	17	6	15	36	5
MBI	4574	859	34.67	24.43	-	165.38	18.29	183.66	1.727	30.62
MB(Qdir.)	10	2	0.07	0.04	-	0.27	0.04	0.31	0.005	0.04
IB(Atmos.)	-	-	0.02	0.02	-	0.48	0.28	0.76	0.005	0.27
IB(Inflow)	4584	861	34.76	24.49	-	166.13	18.60	184.73	1.736	30.92
MBO	1295	468	19.88	13.04	-	135.94	28.53	164.47	0.654	31.10
%Reduct.	72	46	43	47	-	18	-53	11	62	-1

Event: March 8, 1988

LR Precip:	0.16	Duration: 9 hours (0.02"/hr)	
MB Precip:	0.15	Last event: melt	
TL Precip:	-		

CONCENTRATION in MG/L

SITE	TSS	VSS	TP	DP	ORTHO-P	TKN	NO3	TN	TPb	QWATER(A')	COMMENTS
LRI	54	7	0.18	0.17	-	1.25	0.72	1.97	0.003	4.15	-EMC
LRO	25	5	0.20	0.17	-	1.25	0.66	1.91	0.002	4.18	-EMC

LOAD in POUNDS

SITE	TSS	VSS	TP	DP	ORTHO-P	TKN	NO3	TN	TPb	TWATER(A')
LRI	610	79	2.03	1.92	-	14.11	8.13	22.24	0.034	4.15
LR(Qdir.)	1	0	0.00	0.00	-	0.01	0.01	0.02	0.000	0.00
LR(Atmos.)	-	-	0.00	0.00	-	0.05	0.03	0.08	0.000	0.03
LR(Inflow)	610	79	2.04	1.92	-	14.17	8.16	22.34	0.034	4.18
LRO	284	57	2.27	1.93	-	14.21	7.50	21.72	0.023	4.18
%Reduct.	53	28	-12	0	-	0	8	3	34	0

Event: **March 24-25, 1988**

LR Precip:	0.77	Duration: 7 hours (0.11"/hr)	
MB Precip:	-	Last event: 16.5 days	
TL Precip:	-		

CONCENTRATION in MG/L (OP use grab ratio)

SITE	TSS	VSS	TP	DP	ORTHO-P	OP/TP	TKN	NO3	TN	TPb	QWATER(A'	COMMENTS
LRI	460	72	0.60	0.19	0.036	-	2.40	0.60	3.00	0.032	5.90	-EMC
LRO	104	31	0.27	0.23	0.01	-	1.55	0.58	2.13	0.012	6.15	-EMC for WQ; modeled flow
MBI	400	68	0.60	0.17	0.15	-	2.50	0.48	2.98	0.090	27.85	-EMC
MBO	88	33	0.21	0.16	0.059	-	1.45	0.33	1.78	0.027	31.86	-EMC for WQ; modeled flow
LRI(OP)	-	-	4.50	-	0.253	0.06	-	-	-	-	-	-Grab; early event
LRO(OP)	-	-	0.17	-	0.063	0.37	-	-	-	-	-	-Grab; early event
MBI(OP)	-	-	0.88	-	0.151	0.17	-	-	-	-	-	-Grab; early event
MBO(OP)	-	-	0.12	-	0.059	0.49	-	-	-	-	-	-Grab; early event

LOAD in POUNDS

SITE	TSS	VSS	TP	DP	ORTHO-P	TKN	NO3	TN	TPb	TWATER(A')
LRI	7382	1155	9.63	3.05	0.58	38.52	9.63	48.14	0.514	5.9
LR(Qdir.)	203	32	0.26	0.08	0.02	1.06	0.26	1.32	0.014	0.16
LR(Atmos.)	-	-	0.01	0.01	0.01	0.23	0.13	0.37	0.002	0.13
LR(Inflow)	7585	1187	9.90	3.14	0.60	39.80	10.03	49.83	0.530	6.19
LRO	1740	519	4.52	3.85	0.17	25.93	9.70	35.63	0.201	6.15
%Reduct.	77	56	54	-22	72	35	3	28	62	1
MBI(large)	30301	5151	45.45	12.88	11.36	189.38	36.36	225.74	6.818	27.85
MB(Qdir.)	3799	646	5.70	1.61	1.42	23.75	4.56	28.30	0.855	3.49
MB(Atmos.)	-	-	0.04	0.04	0.04	0.93	0.53	1.46	0.009	0.51
MB(Inflow)	34100	5797	51.19	14.54	12.83	214.05	41.45	255.51	7.682	31.86
MBO	7626	2860	18.20	13.87	5.11	125.66	28.60	154.25	2.340	31.86
%Reduct.	78	51	64	5	60	41	31	40	70	0

/ent: April 2-3, 1988

R Precip: 0.26 Duration: 3 hours (0.09"/hr)

B Precip: - Last event: 8 days

L Precip: -

)NCENTRATION in MG/L

SITE	TSS	VSS	TP	DP	ORTHO-P	TKN	NO3	TN	TPb	QWATER(A')	COMMENTS
LRI	710	19	0.33	0.27	-	1.35	0.33	1.68	0.006	1.06	-EMC
LRO	9	4	0.10	0.10	-	0.70	0.42	1.12	0.002	1.12	-EMC

)AD in POUNDS

SITE	TSS	VSS	TP	DP	ORTHO-P	TKN	NO3	TN	TPb	TWATER(A')
LRI	2047	55	0.95	0.78	-	3.89	0.95	4.84	0.017	1.06
.R(Qdir.)	30	1	0.01	0.01	-	0.06	0.01	0.07	0.000	0.02
R(Atmos.)	-	-	0.00	0.00	-	0.08	0.04	0.12	0.001	0.04
R(Inflow)	2077	56	0.97	0.79	-	4.03	1.01	5.04	0.018	1.12
LRO	27	12	0.30	0.30	-	2.13	1.28	3.41	0.006	1.12
%Reduct.	99	78	69	62	-	47	-27	32	67	0

Event: April 26-27, 1988

LR Precip: 0.45 Duration:9.25hours(0.05"/hr)

MB Precip: 0.36 Duration:9.5 hours(0.04"/hr)

WR Precip: 0.45 Last event: 3.25 days

CONCENTRATION in MG/L

SITE	TSS	VSS	TP	DP	SOL.Pb	SPb/TPb	TKN	NO3	TN	TPb	QWATER(A'	COMMENTS
LRI	34	6	0.12	0.11	0.001	0.50	1.00	0.15	1.15	0.002	1.92	-EMC
LRO	6	2	0.09	0.07	0.001	0.25	0.65	0.05	0.70	0.004	2.43	-EMC
MBI	34	6	0.14	0.12	0.001	0.10	0.80	0.15	0.95	0.010	9.58	-EMC
MBO	11	4	0.12	0.06	0.001	0.33	1.00	0.05	1.05	0.003	10.29	-EMC for WQ; flow modeled
WRI	42	12	0.18	0.17	0.001	0.13	0.90	0.20	1.10	0.008	1.72	-EMC
WRO	30	13	0.13	0.08	0.001	0.50	1.05	0.10	1.15	0.002	1.84	-EMC

LOAD in POUNDS

SITE	TSS	VSS	TP	DP	SOL.Pb	TKN	NO3	TN	TPb	TWATER(A')
LRI	178	31	0.63	0.57	0.005	5.22	0.78	6.01	0.010	1.92
LR(Qdir.)	5	1	0.02	0.02	0.000	0.15	0.02	0.17	0.000	0.05
LR(Atmos.)	-	-	0.01	0.01	0.001	0.14	0.08	0.21	0.001	0.08
LR(Inflow)	183	32	0.65	0.60	0.007	5.50	0.88	6.39	0.012	2.05
LRO	40	13	0.59	0.46	0.007	4.30	0.33	4.63	0.026	2.43
%Reduct.	78	59	9	22	2	22	63	28	-118	-19
MBI(large)	886	156	3.65	3.13	0.026	20.85	3.91	24.75	0.261	9.58
MB(Qdir.)	65	11	0.27	0.23	0.002	1.52	0.29	1.81	0.019	0.70
MB(Atmos.)	-	-	0.02	0.02	0.004	0.43	0.25	0.68	0.004	0.24
MB(Inflow)	951	168	3.93	3.38	0.032	22.80	4.44	27.24	0.284	10.52
MBO	308	112	3.36	1.68	0.028	27.99	1.40	29.39	0.084	10.29
%Reduct.	68	33	15	50	14	-23	69	-8	70	2
WRI	196	56	0.84	0.80	0.005	4.21	0.94	5.15	0.037	1.72
WR(Qdir.)	5	1	0.02	0.02	0.000	0.10	0.02	0.12	0.001	0.04
WR(Atmos.)	-	-	0.00	0.00	0.001	0.07	0.04	0.11	0.001	0.04
WR(Inflow)	201	57	0.87	0.82	0.005	4.38	1.00	5.37	0.039	1.80
WRO	150	65	0.65	0.40	0.005	5.26	0.50	5.76	0.010	1.84
%Reduct.	25	-13	25	51	9	-20	50	-7	74	-2

Total Event: May 8-10, 1988
Tot.Precip.= 3.24"   NOTE: 3.24" for 5/8-10 but sites sampled only for portions; see comments
TL, MB and WR LU needs input to eqs.

Event 1: May 8, 1988
LR Precip: 2.45   Duration: 22 hours (0.11"/hr)
MB Precip: 2.45   Duration: 21.25hr ((0.11"/hr)
WR Precip: 2.45   Last event: 0.5 days

CONCENTRATION in MG/L

SITE	TSS	VSS	TP	DP	SOL.Pb	SPb/TPb	TKN	NO3	TN	TPb	QWATER(A'	COMMENTS
LRI	1440	168	1.02	0.26	0.006	0.20	3.60	0.50	4.10	0.030	22.96	-EMC for 2.45"
LRO	124	54	0.29	0.23	0.001	0.17	1.20	0.60	1.80	0.006	25.13	-EMC for 2.45"
MBI	238	35	0.38	0.14	0.001	0.06	1.65	0.15	1.80	0.018	75.89	-EMC for 2.45"
MBO	38	8	0.18	0.09	0.001	0.09	1.05	0.20	1.25	0.011	81.34	-EMC for 2.45"
WRI	118	10	0.48	0.34	0.001	0.17	1.60	0.25	1.85	0.006	11.46	-EMC for 1.73" applied to whole event
WRI(pump)	197	19	0.59	0.26	0.002	0.20	1.60	0.15	1.75	0.010	12.52	-Grabbed 2 hrs. into 18 hrs. of pumping
WRO	99	16	0.43	0.28	0.001	0.20	1.50	0.20	1.70	0.005	25.40	-EMC for 2.45"

LOAD in POUNDS

SITE	TSS	VSS	TP	DP	SOL.Pb	TKN	NO3	TN	TPb	TWATER(A')
LRI	89930	10492	63.70	16.24	0.375	224.82	31.23	256.05	1.874	22.96
LR(Qdir.)	5222	609	3.70	0.94	0.022	13.06	1.81	14.87	0.109	1.33
LR(Atmos.)	-	-	0.03	0.03	0.008	0.74	0.42	1.16	0.008	0.41
LR(Inflow)	95152	11101	67.43	17.22	0.404	238.62	33.46	272.08	1.990	24.70
LRO	8476	3691	19.82	15.72	0.068	82.02	41.01	123.04	0.410	25.13
%Reduct.	91	67	71	9	83	66	-23	55	79	-2
MBI	49128	7225	78.44	28.90	0.206	340.59	30.96	371.56	3.716	75.89
MB(Qdir.)	19265	2833	30.76	11.33	0.081	133.56	12.14	145.70	1.457	29.76
MB(Atmos.)	-	-	0.14	0.14	0.030	2.96	1.69	4.65	0.030	1.63
MB(Inflow)	68393	10058	109.34	40.37	0.317	477.11	44.80	521.91	5.203	107.28
MBO	8407	1770	39.82	19.91	0.221	232.31	44.25	276.56	2.434	81.34
%Reduct.	88	82	64	51	30	51	1	47	53	24
WRI	3678	312	14.96	10.60	0.031	49.87	7.79	57.67	0.187	11.46
WR(Qdir.)	318	27	1.30	0.92	0.003	4.32	0.67	4.99	0.016	0.99
WR(Atmos.)	-	-	0.02	0.02	0.004	0.37	0.21	0.58	0.004	0.20
WRI(pump)	6709	647	20.09	8.85	0.068	54.49	5.11	59.60	0.341	12.52
WR(Inflow)	10705	986	36.37	20.39	0.106	109.05	13.79	122.84	0.548	25.18
WRO	6840	1105	29.71	19.34	0.069	103.63	13.82	117.45	0.345	25.40
%Reduct.	36	-12	18	5	35	5	0	4	37	-1

Event 2: May 9, 1988
Precipitation: 0.00 (receding portion of hydrograph)

CONCENTRATION in MG/L

SITE	TSS	VSS	TP	DP	SOL.Pb	SPb/TPb	TKN	NO3	TN	TPb	QWATER(A'	COMMENTS
LRI	160	20	0.22	0.21	0.001	0.50	1.00	0.45	1.45	0.002	8.58	-EMC for receding part of hydrograph
LRO	40	5	0.14	0.14	0.001	0.50	0.85	0.50	1.35	0.002	11.36	-EMC for receding part of hydrograph
MBI	79	8	0.12	0.12	0.001	0.25	1.00	0.05	1.05	0.004	49.63	-EMC for receding part of hydrograph
MBO	12	5	0.11	0.11	0.001	0.33	1.00	0.10	1.10	0.003	55.24	-EMC for receding part of hydrograph

LOAD in POUNDS

SITE	TSS	VSS	TP	DP	SOL.Pb	TKN	NO3	TN	TPb	TWATER(A')
LRI	3734	467	5.13	4.90	0.023	23.34	10.50	33.84	0.047	8.58
LR(Qdir.)	0	0	0.00	0.00	0.000	0.00	0.00	0.00	0.000	0.00
LR(Atmos.)	-	-	0.00	0.00	0.000	0.00	0.00	0.00	0.000	0.00
LR(Inflow)	3734	467	5.13	4.90	0.023	23.34	10.50	33.84	0.047	8.58
LRO	1236	154	4.33	4.33	0.031	26.26	15.45	41.71	0.062	11.36
%Reduct.	67	67	16	12	-32	-13	-47	-23	-32	-32
MBI	10664	1080	16.20	16.20	0.135	134.99	6.75	141.74	0.540	49.63
MB(Qdir.)	0	0	0.00	0.00	0.000	0.00	0.00	0.00	0.000	0.00
MB(Atmos.)	-	-	0.00	0.00	0.000	0.00	0.00	0.00	0.000	0.00
MB(Inflow)	10664	1080	16.20	16.20	0.135	134.99	6.75	141.74	0.540	49.63
MBO	1803	751	16.53	16.53	0.150	150.25	15.03	165.28	0.451	55.24
%Reduct.	83	30	-2	-2	-11	-11	-123	-17	17	-11

/ent Total: May 8-9, 1988
·ecipitation: 2.45 (total event monitored)

)AD in POUNDS

SITE	TSS	VSS	TP	DP	SOL.Pb	TKN	NO3	TN	TPb	TWATER(A')
LRI	93664	10959	68.83	21.14	0.398	248.16	41.73	289.89	1.920	31.54
.R(Qdir.)	5223	609	3.70	0.94	0.022	13.06	1.81	14.87	0.109	1.33
R(Atmos.)	-	-	0.03	0.03	0.008	0.74	0.42	1.16	0.008	0.41
R(Inflow)	98887	11568	72.57	22.12	0.427	261.96	43.97	305.92	2.037	33.28
LRO	9712	3846	24.15	20.05	0.099	108.29	56.46	164.75	0.472	36.49
%Reduct.	90	67	67	9	77	59	-28	46	77	-10
MBI	59793	8305	94.64	45.10	0.341	475.59	37.71	513.30	4.256	125.52
1B(Qdir.)	19265	2833	30.76	11.33	0.081	133.56	12.14	145.70	1.457	29.76
B(Atmos.)	-	-	0.14	0.14	0.030	2.96	1.69	4.65	0.030	1.63
B(Inflow)	79057	11138	125.54	56.57	0.452	612.10	51.55	663.65	5.743	156.91
MBO	10210	2521	56.35	36.44	0.371	382.56	59.27	441.83	2.884	136.58
%Reduct.	87	77	55	36	18	38	-15	33	50	13
WRI	3678	312	14.96	10.60	0.031	49.87	7.79	57.67	0.187	11.46
JR(Qdir.)	318.41	27	1.30	0.92	0.003	4.32	0.67	4.99	0.016	0.99
R(Atmos.)	-	-	0.02	0.02	0.004	0.37	0.21	0.58	0.004	0.20
JRI(pump)	6709	647	20.09	8.85	0.068	54.49	5.11	59.60	0.341	12.52
R(Inflow)	10705	986	36.37	20.39	0.106	109.05	13.79	122.84	0.548	25.18
WRO	6840	1105	29.71	19.34	0.069	103.63	13.82	117.45	0.345	25.40
%Reduct.	36	-12	18	5	35	5	0	4	37	-1

Event: **June 2, 1988**

MB Precip. 0.15 Duration: 0.5 hour (0.30"/hr)

TL Precip. 0.18 Duration: 0.5 hour (0.36"/hr)

Last event: 6.5 days

CONCENTRATION in MG/L

SITE	TSS	VSS	TP	DP	SOL.Pb	SPb/TPb	TKN	NO3	TN	TPb	QWATER(A'	COMMENTS
MBI	319	47	0.34	0.17	0.001	0.05	2.85	0.40	3.25	0.020	4.08	-EMC
MBO	8	5	0.06	0.06	0.001	1.00	1.05	0.10	1.15	0.001	3.57	-EMC
TLI	62	19	0.45	0.16	0.001	0.10	2.25	0.45	2.70	0.010	0.94	-EMC
TLO	23	11	0.27	0.18	0.001	0.33	1.60	0.20	1.80	0.003	1.03	-EMC

LOAD in POUNDS

SITE	TSS	VSS	TP	DP	SOL.Pb	TKN	NO3	TN	TPb	TWATER(A')
MBI(small)	3540	522	3.77	1.89	0.011	31.63	31.63	63.26	36.067	4.08
MB(Qdir.)	12	2	0.01	0.01	0.000	0.11	0.01	0.12	0.001	0.01
MB(Atmos.)	-	-	0.01	0.01	0.002	0.18	0.10	0.28	0.002	0.10
MB(Inflow)	3552	523	3.79	1.90	0.013	31.92	31.75	63.66	36.070	4.19
MBO	78	49	0.58	0.58	0.010	10.20	0.97	11.17	0.010	3.57
%Reduct.	98	91	85	69	25	68	97	82	100	15
TLI	159	49	1.15	0.41	0.003	5.75	1.15	6.90	0.026	0.94
TL(Qdir.)	20	6	0.15	0.05	0.000	0.73	0.00	0.73	0.003	0.12
TL(Atmos.)	-	-	0.00	0.00	0.000	0.00	0.00	0.00	0.000	0.00
TL(inflow)	179	55	1.30	0.46	0.003	6.49	1.15	7.64	0.029	1.06
TLO	64	31	0.76	0.50	0.003	4.48	0.56	5.04	0.008	1.03
%Reduct.	64	44	42	-9	3	31	51	34	71	3

Event: July 13, 1988

LR Precip. 0.51 Duration:2.25 hour(0.23"/hr)

MB Precip. 0.52 Last event: 3.75 days

TL Precip. 0.50

WR Precip. 0.50

CONCENTRATION in MG/L

SITE	TSS	VSS	TP	DP	SOL.Pb	SPb/TPb	TKN	NO3	TN	TPb	QWATER(A'	COMMENTS
LRI	294	32	0.73	0.19	0.001	0.07	2.75	0.65	3.40	0.014	0.56	-EMC
LRO	8	6	0.26	0.06	0.001	1.00	2.15	0.20	2.35	0.001	0.64	-EMC
MBI	100	19	0.27	0.07	0.001	0.07	1.95	0.70	2.65	0.014	5.72	-EMC
MBO	4	4	0.11	0.05	0.001	1.00	0.95	0.20	1.15	0.001	5.62	-EMC
TLI	73	15	0.49	0.17	0.001	0.04	2.30	0.90	3.20	0.028	1.07	-EMC
TLO	19	6	0.35	0.15	0.001	0.09	2.00	0.50	2.50	0.011	0.82	-EMC
WRI	19	8	0.33	0.21	0.001	0.33	1.80	0.60	2.40	0.003	1.42	-EMC
WRO	8	4	0.27	0.27	0.001	0.50	1.70	0.60	2.30	0.002	1.11	-EMC

LOAD in POUNDS

SITE	TSS	VSS	TP	DP	SOL.Pb	TKN	NO3	TN	TPb	TWATER(A')
LRI	448	49	1.11	0.29	0.002	4.19	0.99	5.18	0.021	0.56
LR(Qdir.)	56	6	0.14	0.04	0.000	0.52	0.12	0.65	0.003	0.07
LR(Atmos.)	-	-	0.01	0.01	0.002	0.15	0.09	0.24	0.002	0.09
LR(Inflow)	504	55	1.26	0.33	0.003	4.87	1.20	6.07	0.026	0.71
LRO	14	10	0.45	0.10	0.002	3.74	0.35	4.09	0.002	0.64
%Reduct.	97	81	64	69	47	23	71	33	93	10
MBI(small)	1556	296	4.20	1.09	0.016	30.34	10.89	41.23	0.218	5.72
MB(Qdir.)	77	15	0.21	0.05	0.001	1.50	0.54	2.04	0.011	0.28
MB(Atmos.)	-	-	0.03	0.03	0.006	0.63	0.36	0.99	0.006	0.35
MB(Inflow)	1633	310	4.44	1.17	0.023	32.46	11.79	44.25	0.235	6.35
MBO	61	61	1.68	0.76	0.015	14.52	3.06	17.58	0.015	5.62
%Reduct.	96	80	62	35	33	55	74	60	93	11
TLI	212	44	1.43	0.49	0.003	6.69	2.62	9.31	0.081	1.07
TL(Qdir.)	66	14	0.44	0.15	0.001	2.09	0.82	2.90	0.025	0.33
TL(Atmos.)	-	-	0.00	0.00	0.000	0.00	0.00	0.00	0.000	0.00
TL(inflow)	279	57	1.87	0.65	0.004	8.78	3.44	12.21	0.107	1.40
TLO	42	13	0.78	0.33	0.002	4.46	1.12	5.58	0.025	0.82
%Reduct.	85	77	58	48	42	49	68	54	77	42
WRI	73	31	1.27	0.81	0.004	6.95	2.32	9.27	0.012	1.42
WR(Qdir.)	3	1	0.05	0.03	0.000	0.25	0.08	0.33	0.000	0.05
WR(Atmos.)	-	-	0.00	0.00	0.001	0.08	0.04	0.12	0.001	0.04
WR(Inflow)	76	32	1.32	0.84	0.005	7.28	2.40	9.60	0.012	1.47
WRO	24	12	0.82	0.82	0.003	5.13	1.81	6.94	0.006	1.11
%Reduct.	68	62	38	3	37	29	25	28	50	25

Event: July 15-16, 1988

MB Precip. 0.11 Duration: 0.5 hour (0.22"/hr)

Last event: 2 days

CONCENTRATION in MG/L (OP use grab ratio)

SITE	TSS	VSS	TP	DP	SOL.Pb	ORTHO-P	TKN	NO3	TN	TPb	QWATER(A'	COMMENTS
MBI	69	22	0.18	0.03	0.001	0.065	2.30	0.75	3.05	0.012	1.29	-EMC
MBO	7	3	0.10	0.08	0.001	0.019	0.75	0.15	0.90	0.001	1.37	-EMC
					ORTHO-P	OP/TP						
MBI(sub)	-	-	0.29	-	0.103	0.36	2.45	-	-	-	-	-Grab
MBO(sub)	-	-	0.28	-	0.054	0.19	1.20	-	-	-	-	-Grab

LOAD in POUNDS

SITE	TSS	VSS	TP	DP	SOL.Pb	TKN	NO3	TN	TPb	TWATER(A')	ORTHO-P
MBI(small)	242	77	0.63	0.11	0.004	8.07	2.63	10.70	0.042	1.29	0.228
MB(Qdir.)	1	0	0.00	0.00	0.000	0.03	0.01	0.04	0.000	0.00	0.001
MB(Atmos.)	-	-	0.01	0.01	0.001	0.13	0.08	0.21	0.001	0.07	0.01
MB(Inflow)	243	77	0.64	0.11	0.005	8.23	2.72	10.95	0.044	1.37	0.24
MBO	26	11	0.37	0.30	0.004	2.79	0.56	3.35	0.004	1.37	0.071
%Reduct.	89	86	42	-166	24	66	79	69	91	0	70

Event: July 20, 1988

LR Precip. 0.36 Duration: 6.75 hrs (0.05"/hr)

MB Precip. 0.61 1.75 (0.35"/hr)

TL Precip. 0.37 1.75 (0.21"/hr)

WR Precip. 0.42 Last event: 5 days

CONCENTRATION in MG/L (OP use grab ratio)

SITE	TSS	VSS	TP	DP	ORTHO-P	OP/TP	TKN	NO3	TN	TPb	QWATER(A'	COMMENTS
LRI	55	12	0.35	0.24	0.052	-	1.30	0.85	2.15	0.004	0.55	-EMC
LRO	9	8	0.25	0.17	0.062	-	1.45	0.10	1.55	0.001	0.44	-EMC
MBI	101	22	0.27	0.14	-	-	1.35	0.55	1.90	0.017	6.39	-EMC
MBO	9	7	0.28	0.20	-	-	0.95	0.05	1.00	0.001	6.94	-EMC
TLI	231	21	0.52	0.15	0.161	-	1.80	0.55	2.35	0.039	1.45	-EMC
TLO	94	17	0.46	0.18	0.060	-	1.40	0.40	1.80	0.016	0.86	-EMC
WRI	33	10	0.23	0.17	0.170	-	1.45	0.45	1.90	0.004	1.13	-EMC
WRO	6	4	0.19	0.14	0.104	-	1.25	0.35	1.60	0.001	0.86	-EMC
LRI	-	-	0.80	-	0.121	0.15	3.70	-	-	-	-	-Grab
LRO	-	-	0.36	-	0.089	0.25	1.65	-	-	-	-	-Grab
MBI	-	-	-	-	-	-	-	-	-	-	-	
MBO	-	-	-	-	-	-	-	-	-	-	-	
TLI	-	-	0.71	-	0.219	0.31	1.95	-	-	-	-	-Grab
TLO	-	-	0.48	-	0.062	0.13	1.45	-	-	-	-	-Grab
WRI	-	-	0.22	-	0.165	0.75	1.10	-	-	-	-	-Grab
WRO	-	-	0.22	-	0.121	0.55	1.30	-	-	-	-	-Grab

LOAD in POUNDS

SITE	TSS	VSS	TP	DP	ORTHO-P	TKN	NO3	TN	TPb	TWATER(A')
LRI	82	18	0.52	0.36	0.08	1.94	1.27	3.22	0.006	0.55
LR(Qdir.)	5	1	0.03	0.02	0.00	0.12	0.08	0.19	0.000	0.03
LR(Atmos.)	-	-	0.01	0.01	0.01	0.11	0.06	0.17	0.001	0.06
LR(Inflow)	87	19	0.56	0.39	0.09	2.17	1.41	3.58	0.007	0.64
LRO	11	10	0.30	0.20	0.07	1.74	0.12	1.86	0.001	0.44
%Reduct.	88	50	47	47	15	20	92	48	84	32
MBI(small)	1755	382	4.69	2.43	-	23.46	9.56	33.02	0.295	6.39
MB(Qdir.)	108	24	0.29	0.15	-	1.45	0.59	2.04	0.018	0.39
MB(Atmos.)	-	-	0.03	0.03	-	0.74	0.42	1.16	0.007	0.41
MB(Inflow)	1864	406	5.02	2.62	-	25.65	10.57	36.22	0.321	7.19
MBO	170	132	5.29	3.78	-	17.93	0.94	18.88	0.019	6.94
%Reduct.	91	67	-5	-44	-	30	91	48	94	3
TLI	911	83	2.05	0.59	0.63	7.10	2.17	9.27	0.154	1.45
TL(Qdir.)	155	14	0.35	0.10	0.11	1.21	0.37	1.58	0.026	0.25
TL(Atmos.)	-	-	0.00	0.00	0.000	0.00	0.00	0.00	0.000	0.00
TL(inflow)	1066	97	2.40	0.69	0.74	8.31	2.54	10.85	0.180	1.70
TLO	220	40	1.08	0.42	0.14	3.27	0.94	4.21	0.037	0.86
%Reduct.	79	59	55	39	81	61	63	61	79	49
WRI	101	31	0.71	0.52	0.52	4.46	1.38	5.84	0.012	1.13
WR(Qdir.)	3	1	0.02	0.02	0.02	0.14	0.04	0.18	0.000	0.03
WR(Atmos.)	-	-	0.00	0.00	0.00	0.06	0.04	0.10	0.001	0.04
WR(Inflow)	105	32	0.73	0.54	0.54	4.59	1.43	6.02	0.013	1.16
WRO	14	9	0.44	0.33	0.24	2.92	0.82	3.74	0.002	0.86
%Reduct.	87	70	39	39	55	36	43	38	82	26

Event: August 4-5, 1988

LR Precip.	1.17	Duration:	14 hours (0.08"/hr)
MB Precip.	1.07		7.25hours(0.15"/hr)
TL Precip.	0.93		7.25hours(0.13"/hr)
WR Precip.	1.24		5 hours (0.25"/hr)

Last event: 1.5 days

CONCENTRATION in MG/L (OP use grab ratio)

SITE	TSS	VSS	TP	DP	ORTHO-P	OP/TP	TKN	NO3	TN	TPb	QWATER(A'	COMMENTS
LRI	680	126	0.78	0.20	0.140	-	3.05	0.55	3.60	0.019	1.73	-EMC
LRO	18	14	0.25	0.14	0.072	-	1.55	0.15	1.70	0.001	1.92	-EMC
MBI	65	14	0.26	0.13	0.062	-	1.00	0.40	1.40	0.012	14.85	-EMC
MBO	10	6	0.25	0.21	0.080	-	0.85	0.10	0.95	0.002	15.40	-EMC
TLI	96	18	0.45	0.30	0.234	-	1.25	0.25	1.50	0.019	2.45	-EMC
TLO	25	10	0.35	0.25	0.192	-	0.95	0.30	1.25	0.005	1.93	-EMC
WRI	81	21	0.42	0.33	0.323	-	1.55	0.40	1.95	0.005	2.18	-EMC
WRI(pump)	22	10	0.19	0.10	0.100	-	1.20	0.10	1.30	0.001	7.46	-Grab; 5.5 hours at 16.42cfs
WRO	6	6	0.33	0.23	0.230	-	1.25	0.20	1.45	0.002	9.77	-EMC
LRI	-	-	0.74	-	0.135	0.18	2.75	-	-	-	-	
LRO	-	-	0.20	-	0.058	0.29	1.35	-	-	-	-	
MBI	-	-	0.17	-	0.040	0.24	0.80	-	-	-	-	
MBO	-	-	0.09	-	0.029	0.32	0.75	-	-	-	-	
TLI	-	-	0.28	-	0.146	0.52	0.85	-	-	-	-	
TLO	-	-	0.29	-	0.159	0.55	0.80	-	-	-	-	
WRI	-	-	0.35	-	0.268	0.77	1.05	-	-	-	-	
WRO	-	-	0.39	-	0.286	0.73	1.20	-	-	-	-	

LOAD in POUNDS

SITE	TSS	VSS	TP	DP	ORTHO-P	TKN	NO3	TN	TPb	TWATER(A')
LRI	3200	593	3.67	0.94	0.66	14.35	2.59	16.94	0.089	1.73
LR(Qdir.)	669	124	0.77	0.20	0.14	3.00	0.54	3.54	0.019	0.36
LR(Atmos.)	-	-	0.02	0.02	0.02	0.35	0.20	0.56	0.004	0.20
LR(Inflow)	3869	717	4.45	1.15	0.81	17.71	3.33	21.04	0.112	2.29
LRO	94	73	1.31	0.73	0.38	8.09	0.78	8.88	0.005	1.92
%Reduct.	98	90	71	37	54	54	76	58	95	16
MBI(small)	2625	565	10.50	5.25	2.50	40.39	16.16	56.55	0.485	14.85
MB(Qdir.)	213	46	0.85	0.43	0.20	3.28	1.31	4.59	0.039	1.20
MB(Atmos.)	-	-	0.06	0.06	0.06	1.29	0.74	2.03	0.013	0.71
MB(Inflow)	2838	611	11.41	5.74	2.77	44.96	18.21	63.17	0.537	16.77
MBO	419	251	10.47	8.80	3.35	35.60	4.19	39.79	0.084	15.40
%Reduct.	85	59	8	-53	-21	21	77	37	84	8
TLI	640	120	3.00	2.00	1.56	8.33	1.67	10.00	0.127	2.45
TL(Qdir.)	162	30	0.76	0.51	0.39	2.11	0.42	2.53	0.032	0.62
TL(Atmos.)	-	-	0.00	0.00	0.00	0.00	0.00	0.00	0.000	0.00
TL(inflow)	802	150	3.76	2.51	1.95	10.44	2.09	12.53	0.159	3.07
TLO	131	52	1.84	1.31	1.01	4.99	1.57	6.56	0.026	1.93
%Reduct.	84	65	51	48	48	52	25	48	83	37
WRI	480	125	2.49	1.96	1.92	9.19	2.37	11.56	0.030	2.18
WR(Qdir.)	67	17	0.34	0.27	0.27	1.27	0.33	1.60	0.004	0.30
WRI(pump)	446	203	3.86	2.03	2.03	24.35	2.03	26.38	0.020	7.46
WR(Atmos.)	-	-	0.01	0.01	0.01	0.19	0.11	0.29	0.002	0.10
WR(Inflow)	993	345	6.70	4.27	4.22	35.00	4.84	39.84	0.056	10.05
WRO	159	159	8.77	6.11	6.11	33.22	5.31	38.53	0.053	9.77
%Reduct.	84	54	-31	-43	-45	5	-10	3	5	3

Event: **August 7-8, 1988**

WR Precip. 1.40 Duration:10.5hours(0.13"/hr)

Last event: 3.3 days

CONCENTRATION in MG/L

SITE	TSS	VSS	TP	DP	ORTHO-P	TKN	NO3	TN	TPb	QWATER(A')	COMMENTS
WRI	22	7	0.58	0.47	-	1.85	0.60	2.45	0.002	4.25	-EMC
WRI(pump)	32	9	0.25	0.10	-	1.45	0.10	1.55	0.004	2.56	-Grab; pump 4.25hr at 7.3cfs
WRO	17	5	0.37	0.32	-	1.40	0.35	1.75	0.004	7.42	-EMC

LOAD in POUNDS

SITE	TSS	VSS	TP	DP		TKN	NO3	TN	TPb	TWATER(A')
WRI	254	81	6.70	5.43	-	21.39	6.94	28.32	0.023	4.25
WR(Qdir.)	23	7	0.59	0.48	-	1.90	0.61	2.51	0.002	0.38
WR(Atmos.)	-	-	0.01	0.01	-	0.21	0.12	0.33	0.002	0.12
WR(pump)	223	63	1.74	0.70	-	10.10	0.70	10.79	0.028	2.56
WR(Inflow)	500	151	9.05	6.62	-	33.59	8.37	41.96	0.055	7.30
WRO	343	101	7.47	6.46	-	28.26	7.06	35.32	0.081	7.42
%Reduct.	31	33	17	2	-	16	16	16	-46	-2

vent: August 11, 1988

R Precip. 0.75 Duration:2.25hours(0.33"/hr)

B Precip. 0.49

L Precip. 0.50 1 hour (0.50"/hr)

R Precip. 0.91 2.25 (0.4"/hr)

Last event: 3 days

ONCENTRATION in MG/L (OP use grab ratio)

SITE	TSS	VSS	TP	DP	ORTHO-P	OP/TP	TKN	NO3	TN	TPb	QWATER(A'	COMMENTS
LRI	622	102	0.55	0.15	0.150	-	2.30	0.65	2.95	0.014	1.45	-EMC
LRO	32	12	0.24	0.12	0.048	-	1.55	0.15	1.70	0.001	1.57	-EMC
MBI	316	50	0.49	0.11	0.088	-	1.80	0.45	2.25	0.028	8.05	-EMC
MBO	17	8	0.32	0.14	0.051	-	1.40	0.10	1.50	0.001	8.56	-EMC
TLI	316	54	0.80	0.22	0.112	-	2.65	0.50	3.15	0.024	2.73	-EMC
TLO	140	31	0.52	0.20	0.130	-	2.10	0.45	2.55	0.011	2.50	-EMC
WRI	62	14	0.47	0.38	0.301	-	2.10	0.65	2.75	0.002	3.07	-EMC
WRI(pump)	47	20	0.22	0.06	0.060	-	1.85	0.10	1.95	0.001	3.02	-Grab during pump operation; 5hr @7.3cfs
WRO	23	7	0.28	0.20	0.151	-	1.40	0.40	1.80	0.001	6.62	-EMC
LRI	-	-	1.30	-	0.610	0.47	9.00	-	-	-	-	
LRO	-	-	0.23	-	0.046	0.20	1.25	-	-	-	-	
MBI	-	-	0.29	-	0.053	0.18	1.60	-	-	-	-	
MBO	-	-	0.24	-	0.038	0.16	1.15	-	-	-	-	
TLI	-	-	0.89	-	0.128	0.14	2.65	-	-	-	-	
TLO	-	-	0.43	-	0.109	0.25	1.55	-	-	-	-	
WRI	-	-	0.22	-	0.141	0.64	1.10	-	-	-	-	
WRO	-	-	0.29	-	0.156	0.54	1.20	-	-	-	-	

.OAD in POUNDS

SITE	TSS	VSS	TP	DP	ORTHO-P	TKN	NO3	TN	TPb	TWATER(A')
LRI	2453	402	2.17	0.59	0.59	9.07	2.56	11.63	0.055	1.45
LR(Qdir.)	260	43	0.23	0.06	0.06	0.96	0.27	1.23	0.006	0.15
LR(Atmos.)	-	-	0.01	0.01	0.01	0.23	0.13	0.36	0.002	0.13
LR(Inflow)	2713	445	2.41	0.66	0.66	10.26	2.97	13.22	0.063	1.73
LRO	137	51	1.02	0.51	0.20	6.62	0.64	7.26	0.004	1.57
%Reduct.	95	88	57	23	69	35	78	45	93	9
MBI(small)	6919	1095	10.73	2.41	1.93	39.41	9.85	49.27	0.613	8.05
MB(Qdir.)	214	34	0.33	0.07	0.06	1.22	0.30	1.52	0.019	0.25
MB(Atmos.)	-	-	0.03	0.03	0.03	0.59	0.34	0.93	0.006	0.33
MB(Inflow)	7133	1129	11.09	2.51	2.01	41.22	10.50	51.72	0.638	8.63
MBO	396	186	7.45	3.26	1.19	32.60	2.33	34.92	0.023	8.56
%Reduct.	94	83	33	-30	41	21	78	32	96	1
TLI	2346	401	5.94	1.63	0.83	19.68	3.71	23.39	0.178	2.73
TL(Qdir.)	287	49	0.73	0.20	0.10	2.40	0.45	2.86	0.022	0.33
TL(Atmos.)	-	-	0.00	0.00	0.00	0.00	0.00	0.00	0.000	0.00
TL(inflow)	2633	450	6.67	1.83	0.93	22.08	4.17	26.25	0.200	3.06
TLO	952	211	3.54	1.36	0.88	14.28	3.06	17.34	0.075	2.50
%Reduct.	64	53	47	26	5	35	27	34	63	18
WRI	518	117	3.92	3.17	2.51	17.54	5.43	22.96	0.017	3.07
WR(Qdir.)	28	6	0.22	0.17	0.14	0.96	0.30	1.26	0.001	0.17
WR(Atmos.)	-	-	0.01	0.01	0.01	0.14	0.08	0.22	0.001	0.08
WR(pump)	386	164	1.81	0.49	0.49	15.20	0.82	16.02	0.008	3.02
WR(Inflow)	932	288	5.95	3.85	3.15	33.83	6.63	40.46	0.027	6.33
WRO	414	126	5.04	3.60	2.72	25.21	7.20	32.41	0.018	6.62
%Reduct.	56	56	15	6	14	25	-9	20	34	-5

Event: Sept.1, 1988

LR Precip. 0.45 Last event: 9.25 days

MB Precip. 0.27

TL Precip. 0.28

WR Precip. 0.45

CONCENTRATION in MG/L (OP use grab ratio)

SITE	TSS	VSS	TP	DP	ORTHO-P	TKN	NO3	TN	TPb	QWATER(A')	OP/TP	COMMENTS
LRI	88	20	0.19	0.09	0.090	0.92	0.57	1.49	0.003	0.26	-	-EMC
LRO	56	23	0.22	0.06	0.019	2.11	0.03	2.14	0.001	0.27	-	-EMC
MBI	26	9	0.16	0.12	0.071	1.64	0.70	2.34	0.008	3.31	-	-EMC
MBO	8	3	0.08	0.04	0.024	0.82	0.04	0.86	0.001	4.09	-	-EMC
TLI	236	38	0.43	0.15	0.090	1.98	0.64	2.62	0.049	0.84	-	-EMC
TLO	26	8	0.20	0.08	0.032	0.94	0.32	1.26	0.006	0.53	-	-EMC
WRI	30	12	0.15	0.11	0.082	1.16	0.67	1.83	0.003	1.60	-	-EMC
WRI(pump)	18	7	0.16	0.06	0.060	1.90	0.04	1.94	0.001	1.21	-	-Grab; pump on 2hr at 7.3cfs
WRO	9	5	0.22	0.11	0.110	1.16	0.28	1.44	0.001	2.65	-	-EMC
LRI	-	-	0.14	-	0.091	1.17	-	-	-	-	0.65	
LRO	-	-	0.14	-	0.012	1.03	-	-	-	-	0.09	
MBI	-	-	0.19	-	0.084	2.85	-	-	-	-	0.44	
MBO	-	-	0.04	-	0.012	0.57	-	-	-	-	0.30	
TLI	-	-	0.88	-	0.184	3.99	-	-	-	-	0.21	
TLO	-	-	0.42	-	0.067	1.20	-	-	-	-	0.16	
WRI	-	-	0.30	-	0.164	2.47	-	-	-	-	0.55	
WRO	-	-	0.15	-	0.085	1.45	-	-	-	-	0.57	

LOAD IN POUNDS

SITE	TSS	VSS	TP	DP	ORTHO-P	TKN	NO3	TN	TPb	TWATER(A')
LRI	62	14	0.13	0.06	0.06	0.65	0.40	1.05	0.002	0.26
LR(Qdir.)	13	3	0.03	0.01	0.01	0.13	0.08	0.22	0.000	0.05
LR(Atmos.)	-	-	0.01	0.01	0.01	0.14	0.08	0.21	0.001	0.08
LR(Inflow)	75	17	0.17	0.08	0.08	0.92	0.56	1.48	0.004	0.39
LRO	41	17	0.16	0.04	0.01	1.55	0.02	1.57	0.001	0.27
%Reduct.	45	1	4	47	83	-68	96	-6	81	31
MBI(small)	234	81	1.44	1.08	0.64	14.77	6.30	21.07	0.072	3.31
MB(Qdir.)	5	2	0.03	0.02	0.01	0.29	0.12	0.41	0.001	0.06
MB(Atmos.)	-	-	0.02	0.02	0.02	0.33	0.19	0.51	0.003	0.18
MB(Inflow)	239	83	1.48	1.12	0.67	15.38	6.61	21.99	0.077	3.55
MBO	89	33	0.89	0.44	0.27	9.12	0.44	9.57	0.011	4.09
%Reduct.	63	60	40	60	60	41	93	56	86	-15
TLI	539	87	0.98	0.34	0.21	4.52	1.46	5.99	0.112	0.84
TL(Qdir.)	6	1	0.01	0.00	0.00	0.05	0.00	0.05	0.001	0.01
TL(Atmos.)	-	-	0.00	0.00	0.00	0.00	0.00	0.00	0.000	0.00
TL(inflow)	545	88	0.99	0.35	0.21	4.57	1.46	6.04	0.113	0.85
TLO	37	12	0.29	0.12	0.05	1.36	0.46	1.82	0.009	0.53
%Reduct.	93	87	71	67	78	70	68	70	92	38
WRI	131	52	0.65	0.48	0.36	5.05	2.92	7.96	0.013	1.60
WR(Qdir.)	3	1	0.02	0.01	0.01	0.13	0.07	0.20	0.000	0.04
WR(Atmos.)	-	-	0.00	0.00	0.00	0.07	0.04	0.11	0.001	0.04
WR(Pump)	59	23	0.53	0.20	0.20	6.25	0.13	6.38	0.003	1.21
WR(Inflow)	193	77	1.20	0.69	0.57	11.50	3.16	14.66	0.017	2.89
WRO	65	36	1.59	0.79	0.79	8.36	2.02	10.38	0.007	2.65
%Reduct.	66	53	-32	-15	-40	27	36	29	58	8

Event: Sept.18, 1988

LR Precip. 0.32 Last event: 2 days

MB Precip. -

TL Precip. -

WR Precip. 0.39

CONCENTRATION in MG/L

SITE	TSS	VSS	TP	DP	ORTHO-P	TKN	NO3	TN	TPb	QWATER(A')	COMMENTS
LRI	830	106	0.96	0.16	-	3.50	0.55	4.05	0.051	0.78	-EMC
LRO	21	7	0.17	0.08	-	1.10	0.25	1.35	0.002	0.84	-EMC
WRI	29	13	0.37	0.28	-	1.35	0.40	1.75	0.002	1.12	-EMC
WRO	13	8	0.24	0.15	-	1.45	0.35	1.80	0.001	1.18	-EMC

LOAD IN POUNDS

SITE	TSS	VSS	TP	DP		TKN	NO3	TN	TPb	TWATER(A')
LRI	1761	225	2.04	0.34	-	7.43	1.17	8.59	0.108	0.78
LR(Qdir.)	57	7	0.07	0.01	-	0.24	0.04	0.28	0.003	0.03
LR(Atmos.)	-	-	0.00	0.00	-	0.10	0.06	0.15	0.001	0.05
LR(Inflow)	1818	232	2.11	0.35	-	7.76	1.26	9.02	0.113	0.86
LRO	48	16	0.39	0.18	-	2.51	0.57	3.08	0.005	0.84
%Reduct.	97	93	82	49	-	68	55	66	96	2
WRI	88	40	1.13	0.85	-	4.11	1.22	5.33	0.006	1.12
WR(Qdir.)	2	1	0.03	0.02	-	0.11	0.03	0.14	0.000	0.03
WR(Atmos.)	-	-	0.00	0.00	-	0.06	0.03	0.09	0.001	0.03
WR(Pump)	-	-	-	-	-	-	-	-	-	-
WR(Inflow)	91	41	1.16	0.88	-	4.28	1.28	5.56	0.007	1.18
WRO	42	26	0.77	0.48	-	4.65	1.12	5.78	0.003	1.18
%Reduct.	54	37	34	45	-	-9	13	-4	53	0

ent: Sept.19-20, 1988

Precip. 1.82 Last event: 2 days

Precip. 1.59

NCENTRATION in MG/L

SITE	TSS	VSS	TP	DP	ORTHO-P	TKN	NO3	TN	TPb	QWATER(A')	COMMENTS
MBI	52	10	0.16	0.13	-	0.45	0.10	0.55	0.006	26.19	-EMC
MBO	6	3	0.23	0.27	-	0.70	0.15	0.85	0.001	35.56	-EMC
TLI	105	19	0.30	0.13	-	0.75	0.15	0.90	0.016	9.23	-EMC
TLO	63	12	0.59	0.36	-	0.70	0.15	0.85	0.008	11.29	-EMC

AD IN POUNDS

SITE	TSS	VSS	TP	DP		TKN	NO3	TN	TPb	TWATER(A')
I(small)	3704	712	11.40	9.26	-	32.06	7.12	39.18	0.427	26.19
3(Qdir.)	455	87	1.40	1.14	-	3.93	0.87	4.81	0.052	3.21
(Atmos.)	-	-	0.10	0.10	-	2.20	1.26	3.45	0.022	1.21
(Inflow)	4159	800	12.90	10.50	-	38.19	9.26	47.44	0.502	30.62
MBO	580	290	22.25	26.12	-	67.71	14.51	82.21	0.097	35.56
Reduct.	86	64	-72	-149	-	-77	-57	-73	81	-16
TLI	2636	477	7.53	3.26	-	18.83	3.77	22.60	0.402	9.23
L(Qdir.)	1554	281	4.44	1.92	-	11.10	0.00	11.10	0.237	5.44
(Atmos.)	-	-	0.00	0.00	-	0.00	0.00	0.00	0.000	0.00
(inflow)	4190	758	11.97	5.19	-	29.93	3.77	33.70	0.639	14.67
TLO	1935	369	18.12	11.06	-	21.50	4.61	26.10	0.246	11.29
Reduct.	54	51	-51	-113	-	28	-22	23	62	23

Event: Sept.27, 1988

LR Precip. 0.55 Last event: 1.5 days

MB Precip. 0.43

TL Precip. 0.43

WR Precip. 0.50

CONCENTRATION in MG/L

SITE	TSS	VSS	TP	DP	ORTHO-P	TKN	NO3	TN	TPb	QWATER(A')	COMMENTS
LRI	152	34	0.27	0.16	0.165	1.27	0.40	1.67	0.009	1.24	-EMC
LRO	8	3	0.23	0.18	0.102	0.76	0.15	0.91	0.003	1.52	-EMC
MBI	29	8	0.14	0.14	0.080	0.76	0.25	1.01	0.005	11.12	-EMC
MBO	2	1	0.11	0.11	0.062	0.63	0.20	0.83	0.001	13.96	-EMC
TLI	155	26	0.48	0.23	0.208	1.50	0.30	1.80	0.023	2.26	-EMC
TLO	39	12	0.29	0.22	0.176	1.05	0.25	1.30	0.010	2.56	-EMC
WRI	29	12	0.15	0.15	0.132	0.80	0.30	1.10	0.002	3.02	-EMC
WRI(pump)	19	12	0.31	0.06	0.054	1.35	0.15	1.50	0.001	1.51	-Grab; pump on 2hr at 9.12 cfs;WQ fr.statis.
WRO	12	7	0.19	0.12	0.104	1.08	0.20	1.28	0.001	5.03	-EMC

LOAD IN POUNDS

SITE	TSS	VSS	TP	DP	ORTHO-P	TKN	NO3	TN	TPb	TWATER(A')
LRI	513	115	0.91	0.54	0.56	4.28	1.35	5.63	0.030	1.24
LR(Qdir.)	34	8	0.06	0.04	0.04	0.28	0.09	0.37	0.002	0.08
LR(Atmos.)	-	-	0.01	0.01	0.01	0.17	0.10	0.26	0.002	0.09
LR(Inflow)	547	122	0.98	0.58	0.60	4.73	1.53	6.27	0.034	1.41
LRO	33	12	0.95	0.74	0.42	3.14	0.62	3.76	0.012	1.52
%Reduct.	94	90	3	-28	30	34	60	40	64	-8
MBI(small)	877	242	4.23	4.23	2.42	22.99	7.56	30.55	0.151	11.12
MB(Qdir.)	15	4	0.07	0.07	0.04	0.39	0.13	0.52	0.003	0.19
MB(Atmos.)	-	-	0.02	0.02	0.02	0.52	0.30	0.82	0.005	0.29
MB(Inflow)	892	246	4.33	4.33	2.49	23.89	7.99	31.88	0.159	11.59
MBO	76	38	4.18	4.18	2.35	23.92	7.59	31.52	0.038	13.96
%Reduct.	91	85	4	4	5	0	5	1	76	-20
TLI	953	160	2.95	1.41	1.28	9.22	1.84	11.06	0.141	2.26
TL(Qdir.)	58	10	0.18	0.09	0.08	0.56	0.00	0.56	0.009	0.14
TL(Atmos.)	-	-	0.00	0.00	0.00	0.00	0.00	0.00	0.000	0.00
TL(inflow)	1011	170	3.13	1.50	1.36	9.78	1.84	11.63	0.150	2.40
TLO	272	84	2.02	1.53	1.23	7.31	1.74	9.05	0.070	2.56
%Reduct.	73	51	35	-2	10	25	6	22	54	-7
WRI	238	99	1.23	1.23	1.08	6.57	2.46	9.04	0.016	3.02
WR(Qdir.)	4	2	0.02	0.02	0.02	0.11	0.04	0.15	0.000	0.05
WR(Atmos.)	-	-	0.00	0.00	0.00	0.08	0.04	0.12	0.001	0.04
WR(Pump)	78	49	1.27	0.25	0.22	5.54	0.62	6.16	0.004	1.51
WR(Inflow)	320	150	2.53	1.50	1.33	12.30	3.16	15.47	0.022	4.62
WRO	164	96	2.60	1.64	1.42	14.78	2.74	17.51	0.014	5.03
%Reduct.	49	36	-3	-9	-7	-20	14	-13	37	-9

vent: Oct.20, 1988
R Precip. 0.34 Last event: 3 days
B Precip. 0.35
L Precip. 0.38
R Precip. 0.29 Note: dead mouse in WRI so threw out sample

ONCENTRATION in MG/L

SITE	TSS	VSS	TP	DP	ORTHO-P	TKN	NO3	TN	TPb	QWATER(A')	COMMENTS
LRI	50	32	0.23	0.23	0.181	1.46	0.35	1.81	0.002	0.32	-EMC
LRO	12	4	0.10	0.07	0.040	1.01	0.15	1.16	0.003	0.44	-EMC
MBI	16	12	0.25	0.18	0.147	1.02	0.40	1.42	0.005	6.25	-EMC
MBO	13	10	0.03	0.03	0.012	0.52	0.20	0.72	0.002	8.08	-EMC
TLI	86	40	0.42	0.28	0.185	1.54	0.40	1.94	0.021	1.23	-EMC
TLO	4	2	0.21	0.13	0.096	0.89	0.40	1.29	0.006	1.50	-EMC
WRI	-	-	-	-	-	-	-	-	-	3.39	-Dead mouse, no sample
RI(pump)	-	-	-	-	-	-	-	--	-	-	-Pumps not operating
WRO	10	4	0.18	0.11	0.102	1.25	0.40	1.65	0.002	2.63	-EMC

LOAD IN POUNDS

SITE	TSS	VSS	TP	DP	ORTHO-P	TKN	NO3	TN	TPb	TWATER(A')
LRI	44	28	0.20	0.20	0.16	1.27	0.30	1.58	0.002	0.32
LR(Qdir.)	4	3	0.02	0.02	0.01	0.11	0.03	0.14	0.000	0.03
LR(Atmos.)	-	-	0.00	0.00	0.00	0.10	0.06	0.16	0.001	0.06
LR(Inflow)	47	30	0.22	0.22	0.18	1.49	0.39	1.88	0.003	0.41
LRO	14	5	0.12	0.08	0.05	1.21	0.18	1.39	0.004	0.44
%Reduct.	70	84	46	62	73	19	54	26	-22	-8
MBI(small)	272	204	4.25	3.06	2.50	17.34	6.80	24.14	0.085	6.25
MB(Qdir.)	5	4	0.08	0.06	0.05	0.33	0.13	0.46	0.002	0.12
MB(Atmos.)	-	-	0.02	0.02	0.02	0.42	0.24	0.66	0.004	0.23
MB(Inflow)	277	208	4.35	3.14	2.57	18.09	7.17	25.26	0.091	6.60
MBO	286	220	0.66	0.66	0.26	11.43	4.40	15.82	0.044	8.08
%Reduct.	-3	-6	85	79	90	37	39	37	52	-22
TLI	288	134	1.41	0.94	0.62	5.15	1.34	6.49	0.070	1.23
TL(Qdir.)	18	8	0.09	0.06	0.04	0.32	0.00	0.32	0.004	0.08
TL(Atmos.)	-	-	0.00	0.00	0.00	0.00	0.00	0.00	0.000	0.00
TL(inflow)	305	142	1.49	0.99	0.66	5.47	1.34	6.81	0.075	1.31
TLO	16	8	0.86	0.53	0.39	3.63	1.63	5.26	0.024	1.50
%Reduct.	95	94	43	47	40	34	-22	23	67	-15
WRI	-	-	-	-	-	-	-	-	-	3.39
WR(Qdir.)	-	-	-	-	-	-	-	-	-	0.02
WR(Atmos.)	-	-	0.00	0.00	-	0.04	0.03	0.07	0.000	0.02
WR(Pump)	-	-	-	-	-	-	-	-	-	-
WR(Inflow)	-	-	-	-	-	-	-	-	-	3.43
WRO	72	29	1.29	0.79	0.73	8.94	2.86	11.80	0.014	2.63
%Reduct.	-	-	-	-	-	-	-	-	-	23

Event: Nov.4, 1988

LR Precip. -　　　Last event: 7.5 days
MB Precip. 0.70
TL Precip. -
WR Precip. 0.65　　　(NOTE: samples kept too long to run nuts.)

CONCENTRATION in MG/L

SITE	TSS	VSS	TP	DP	ORTHO-P	TKN	NO3	TN	TPb	QWATER(A')	COMMENTS
MBI	6	4	-	-	-	-	-	-	0.003	13.10	-EMC
MBO	4	2	-	-	-	-	-	-	0.003	14.90	-EMC
WRI	12	6	-	-	-	-	-	-	0.001	5.50	-EMC
WRI(pump)	-	-	-	-	-	-	-	-	-	-	-Pumps not operating
WRO	13	6	-	-	-	-	-	-	0.001	5.00	-EMC

LOAD IN POUNDS

SITE	TSS	VSS	TP	DP	ORTHO-P	TKN	NO3	TN	TPb	TWATER(A')
MBI(small)	214	143	-	-	-	-	-	-	0.107	13.10
MB(Qdir.)	9	6	-	-	-	-	-	-	0.004	0.52
MB(Atmos.)	-	-	-	-	-	-	-	-	0.009	0.47
MB(Inflow)	222	148	-	-	-	-	-	-	0.120	14.09
MBO	162	81	-	-	-	-	-	-	0.122	14.90
%Reduct.	27	45	-	-	-	-	-	-	-2	-6
WRI	180	90	-	-	-	-	-	-	0.015	5.50
WR(Qdir.)	3	1	-	-	-	-	-	-	0.000	0.09
WR(Atmos.)	-	-	-	-	-	-	-	-	0.001	0.05
WR(Pump)	-	-	-	-	-	-	-	-	-	-
WR(Inflow)	182	91	-	-	-	-	-	-	0.016	5.64
WRO	177	82	-	-	-	-	-	-	0.014	5.00
%Reduct.	3	11	-	-	-	-	-	-	16	11

lov.15-16, 1988
LR Precip. 0.81 Last event: 2.25 days
MB Precip. 0.77
TL Precip. 0.65
WR Precip. 0.91

ONCENTRATION in MG/L

SITE	TSS	VSS	TP	DP	ORTHO-P	TKN	NO3	TN	TPb	QWATER(A')	SPb	COMMENTS
LRI	635	39	0.29	0.07	0.070	1.38	1.30	2.68	0.014	9.82	<0.001	-EMC
LRO	30	8	0.20	0.10	0.098	0.93	1.05	1.98	0.006	9.71	<0.001	-EMC
MBI	163	30	0.29	0.09	0.090	0.88	0.25	1.13	0.019	16.58	-	-EMC
MBO	11	5	0.06	0.03	0.030	0.70	0.50	1.20	0.003	17.63	-	-EMC
TLI	288	58	1.13	0.31	0.136	2.01	0.55	2.56	0.040	10.28	-	-EMC
TLO	128	32	0.72	0.12	0.120	1.19	0.45	1.64	0.018	10.57	-	-EMC
WRI	22	8	0.65	0.62	0.470	1.31	0.45	1.76	0.004	13.48	<0.001	-EMC
WRI(pump)	-	-	-	-	-	-	-	--	-	-	-	-Pumps not operating
WRO	10	4	0.42	0.37	0.323	1.17	0.40	1.57	0.002	9.99	<0.001	-EMC

LOAD IN POUNDS

SITE	TSS	VSS	TP	DP	ORTHO-P	TKN	NO3	TN	TPb	TWATER(A')
LRI	16961	1042	7.75	1.87	1.87	36.86	34.72	71.58	0.371	9.82
LR(Qdir.)	309	19	0.14	0.03	0.03	0.67	0.63	1.30	0.007	0.18
LR(Atmos.)	-	-	0.01	0.01	0.01	0.24	0.14	0.38	0.002	0.14
LR(Inflow)	17270	1061	7.90	1.92	1.92	37.78	35.50	73.27	0.381	10.13
LRO	792	211	5.28	2.64	2.59	24.56	27.73	52.29	0.151	9.71
%Reduct.	95	80	33	-38	-35	35	22	29	60	4
MBI(small)	7351	1353	13.08	4.06	4.06	39.69	11.27	50.96	0.857	16.58
MB(Qdir.)	281	52	0.50	0.15	0.15	1.51	0.43	1.94	0.033	0.63
MB(Atmos.)	-	-	0.04	0.04	0.04	0.93	0.53	1.46	0.009	0.51
MB(Inflow)	7631	1405	13.62	4.26	4.26	42.13	12.24	54.37	0.899	17.73
MBO	527	240	2.88	1.44	1.44	33.57	23.98	57.54	0.125	17.63
%Reduct.	93	83	79	66	66	20	-96	-6	86	1
TLI	8053	1622	31.60	8.67	3.80	56.20	15.38	71.58	1.118	10.28
TL(Qdir.)	89	18	0.35	0.10	0.04	0.62	0.00	0.62	0.012	0.11
TL(Atmos.)	-	-	0.00	0.00	0.00	0.00	0.00	0.00	0.000	0.00
TL(inflow)	8142	1640	31.95	8.76	3.84	56.83	15.38	72.20	1.131	10.39
TLO	3679	920	20.69	3.45	3.45	34.20	12.93	47.13	0.517	10.57
%Reduct.	55	44	35	61	10	40	16	35	54	-2
WRI	807	293	23.84	22.74	17.24	48.04	16.50	64.55	0.147	13.48
WR(Qdir.)	10	4	0.30	0.28	0.22	0.60	0.21	0.81	0.002	0.17
WR(Atmos.)	-	-	0.01	0.01	0.01	0.14	0.08	0.22	0.001	0.08
WR(Pump)	-	-	-	-	-	-	-	-	-	-
WR(Inflow)	817	297	24.14	23.03	17.46	48.78	16.79	65.57	0.150	13.73
WRO	272	109	11.41	10.05	8.77	31.78	10.86	42.64	0.065	9.99
%Reduct.	67	63	53	56	50	35	35	35	57	27

|989 LCMR Water Quality Concentration and Load Summary

:vent: Feb.1, 1989 melt

IR Precip. 0.00

:ONCENTRATION in MG/L

;ITE	TSS	VSS	TP	DP	ORTHO-P	TKN	NO3	TN	TPb	QWATER(A')	COMMENTS
IRI	69	26	1.03	-	-	4.47	1.10	5.57	0.016	2.00	-Small melt
IRO	24	11	0.66	-	-	3.86	1.25	5.11	0.007	1.90	-Small melt

.OAD IN POUNDS

;ITE	TSS	VSS	TP	DP	ORTHO-P	TKN	NO3	TN	TPb	TWATER(A')
IRI	375	141	5.60	-	-	24.32	5.98	30.30	0.087	2.00
IR(Qdir.)	0	0	0.00	-	-	0.00	0.00	0.00	0.000	0.00
IR(Atmos.)	-	-	-	-	-	-	-	-	-	-
IR(Pump)	-	-	-	-	-	-	-	-	-	1.90
IR(Inflow)	375	141	5.61	-	-	24.32	5.99	30.30	0.087	3.90
IRO	124	57	3.41	-	-	19.95	6.46	26.41	0.036	1.90
;Reduct.	67	60	39	-	-	18	-8	13	58	51

Event: March 11-12, 1989
MB snow loss 3/9 to 3/11 = 4"(0.4" equiv.water)

CONCENTRATION in MG/L

SITE	TSS	VSS	TP	DP	ORTHO-P	TKN	NO3	TN	TPb	QWATER(A')	COMMENTS
LRI	49	15	0.33	0.26	-	2.01	1.20	3.21	0.016	2.20	-EMC
LRO	13	11	0.28	0.24	-	1.91	1.05	2.96	0.013	1.80	-EMC
WRI	15	9	0.53	0.53	-	2.70	1.50	4.20	0.012	5.80	-EMC
WRI(pump)	-	-	-	-	-	-	-	-	-	-	-Pumps not operating
WRO	26	12	0.63	0.59	-	2.89	1.50	4.39	0.015	6.60	-EMC

LOAD IN POUNDS

SITE	TSS	VSS	TP	DP	ORTHO-P	TKN	NO3	TN	TPb	TWATER(A')
LRI	293	90	1.97	1.56	-	12.03	7.18	19.21	0.096	2.20
LR(Qdir.)	6	2	0.04	0.03	-	0.23	0.14	0.36	0.002	0.04
LR(Atmos.)	-	-	0.01	0.01	-	0.12	0.07	0.19	0.001	0.07
LR(Inflow)	299	91	2.02	1.59	-	12.38	7.39	19.76	0.099	2.31
LRO	64	54	1.37	1.18	-	9.35	5.14	14.49	0.064	1.80
%Reduct.	79	41	32	26	-	24	30	27	36	22
WRI	237	142	8.36	8.36	-	42.60	23.66	66.26	0.189	5.80
WR(Qdir.)	1	1	0.05	0.05	-	0.23	0.13	0.36	0.001	0.03
WR(Atmos.)	-	-	0.00	0.00	-	0.06	0.03	0.09	0.001	0.03
WR(Pump)	-	-	-	-	-	-	-	-	-	-
WR(Inflow)	238	143	8.41	8.41	-	42.89	23.83	66.71	0.191	5.86
WRO	467	215	11.31	10.59	-	51.88	26.93	78.81	0.269	6.60
%Reduct.	-96	-51	-34	-26	-	-21	-13	-18	-41	-13

1989 Melt - Lake Ridge

Event #1: March 24, 11:00 to March 26, 7:00
Early part of melt (0.1" equiv.water) plus 0.13" rain
NOTE: check direct shed area

CONCENTRATION in MG/L

SITE	TSS	VSS	TP	DP	ORTHO-P	TKN	NO3	TN	TPb	QWATER(A')	COMMENTS
LRI	82	15	0.23	0.14	0.113	1.62	2.05	3.67	0.01	10.92	-EMC
LRO	53	11	0.35	0.31	0.270	1.69	1.90	3.59	0.011	10.41	-EMC

LOAD IN POUNDS

SITE	TSS	VSS	TP	DP	ORTHO-P	TKN	NO3	TN	TPb	TWATER(A')
LRI	2436	446	6.83	4.16	3.36	48.12	60.89	109.01	0.297	10.92
LR(Qdir.)	8	2	0.02	0.01	0.01	0.17	0.21	0.38	0.001	0.04
LR(Atmos.)	-	-	0.00	0.00	0.00	0.07	0.04	0.11	0.001	0.04
LR(Inflow)	2444	447	6.86	4.18	3.37	48.35	61.14	109.49	0.299	11.00
LRO	1501	311	9.91	8.78	7.65	47.85	53.80	101.65	0.311	10.41
%Reduct.	39	30	-44	-110	-127	1	12	7	-4	5

Event #2: March 26, 8:00 to March 29, 16:00
Peak and recession of melt (.5" equiv.) plus .04" rain
NOTE: check direct shed area

CONCENTRATION in MG/L

SITE	TSS	VSS	TP	DP	ORTHO-P	TKN	NO3	TN	TPb	QWATER(A')	COMMENTS
LRI	304	41	0.32	0.15	0.132	1.62	1.10	2.72	0.01	62.38	-EMC
LRO	85	15	0.33	0.14	0.130	1.61	0.90	2.51	0.006	56.79	-EMC

LOAD IN POUNDS

SITE	TSS	VSS	TP	DP	ORTHO-P	TKN	NO3	TN	TPb	TWATER(A')
LRI	51581	6957	54.30	25.45	22.40	274.87	186.64	461.51	1.018	62.38
LR(Qdir.)	186	25	0.20	0.09	0.08	0.99	0.67	1.67	0.004	0.23
LR(Atmos.)	-	-	0.01	0.01	0.010	0.13	0.08	0.21	0.001	0.09
LR(Inflow)	51767	6982	54.50	25.55	22.49	276.00	187.39	463.39	1.023	62.70
LRO	13130	2317	50.97	21.63	20.08	248.69	139.02	387.72	0.927	56.79
%Reduct.	75	67	6	15	11	10	26	16	9	9

Event #3: March 29, 16:00 to April 2, 16:00

End of melt- storage outflow from pond; LRI use 3/20 baseflow, LRO estimate 1/2 conc. from event #2

CONCENTRATION in MG/L

SITE	TSS	VSS	TP	DP	ORTHO-P	TKN	NO3	TN	TPb	QWATER(A')	COMMENTS
LRI	9	3	0.10	0.08	0.070	1.33	1.40	2.73	0.004	2.03	-No samples collected
LRO	22	7	0.16	0.07	0.060	0.80	0.45	1.25	0.003	8.13	-No samples collected

LOAD IN POUNDS

SITE	TSS	VSS	TP	DP	ORTHO-P	TKN	NO3	TN	TPb	TWATER(A')
LRI	50	17	0.55	0.44	0.39	7.34	7.73	15.07	0.022	2.03
LR(Qdir.)	0	0	0.00	0.00	0.00	0.00	0.00	0.00	0.000	0.00
LR(Atmos.)	-	-	0.00	0.00	0.000	0.00	0.00	0.00	0.000	0.00
LR(Inflow)	50	17	0.55	0.44	0.39	7.34	7.73	15.07	0.022	2.03
LRO	486	155	3.54	1.55	1.33	17.69	9.95	27.64	0.066	8.13
%Reduct.	-879	-834	-541	-250	-243	-141	-29	-83	-200	-300

SUMMARY OF MELT EVENTS

LOAD IN POUNDS

SITE	TSS	VSS	TP	DP	ORTHO-P	TKN	NO3	TN	TPb	WATER
LRI	54066	7419	61.68	30.05	26.14	330.33	255.26	585.59	1.34	75.33
LR(Qdir.)	195	27	0.22	0.11	0.09	1.16	0.88	2.04	0.00	0.26
LR(Atmos.)	---	---	0.01	0.01	0.01	0.20	0.12	0.32	0.00	0.13
LR(Inflow)	54261	7445	61.91	30.17	26.25	331.69	256.26	587.95	1.34	75.72
LRO	15117	2783	64.42	31.95	29.05	314.24	202.77	517.01	1.30	75.33
%Reduct.	72	63	-4	-6	-11	5	21	12	3	1

1989 Melt - McKnight Basin

Event #1: March 23, 12:00 to March 25, 12:00 (SSS1)

Early part of melt (0.1" equiv.) plus 0.13" rain

CONCENTRATION in MG/L

SITE	TSS	VSS	TP	DP	ORTHO-P	TKN	NO3	TN	TPb	QWATER(A')	COMMENTS
MBI	135	31	0.48	0.22	-	2.46	0.80	3.26	0.038	22.00	-EMC
MBO	55	22	0.39	0.24	-	2.12	0.80	2.92	0.028	22.00	-EMC

LOAD IN POUNDS

SITE	TSS	VSS	TP	DP	ORTHO-P	TKN	NO3	TN	TPb	TWATER(A')
MBI(small)	8078	1855	28.72	13.16	-	147.21	47.87	195.08	2.274	22.00
MB(Qdir.)	62	14	0.22	0.10	-	1.13	0.37	1.50	0.018	0.17
MB(Atmos.)	-	-	0.01	0.01	-	0.28	0.16	0.44	0.003	0.15
MB(Inflow)	8141	1869	28.96	13.28	-	148.62	48.40	197.02	2.294	22.32
MBO	3291	1316	23.34	14.36	-	126.86	47.87	174.73	1.676	22.00
%Reduct.	60	30	19	-8	-	15	1	11	27	1

Event #2: March 25, 12:00 to March 28, 8:30 (SSS2)

Peak part of melt (.4" equiv.) plus .08" rain

NOTE: So. pond inflowing: MB(side) put into MBdirect calcs.

CONCENTRATION in MG/L

SITE	TSS	VSS	TP	DP	ORTHO-P	TKN	NO3	TN	TPb	QWATER(A')	COMMENTS
MBI	620	43	0.87	0.32	0.320	2.89	0.55	3.44	0.026	97.00	-EMC
MB(side)	25	9	0.94	0.80	0.778	3.61	0.75	4.36	0.003	30.00	-Grab; Q=MBO-MBI
MBO	48	16	0.60	0.38	0.256	2.79	0.50	3.29	0.007	127.00	-EMC

LOAD IN POUNDS

SITE	TSS	VSS	TP	DP	ORTHO-P	TKN	NO3	TN	TPb	TWATER(A')
MBI(large)	163581	11345	229.54	84.43	84.43	762.50	145.11	907.61	6.860	97.00
MB(Qdir.)	2040	734	76.70	65.28	65.28	294.58	61.20	355.78	0.245	30.00
MB(Atmos.)	-	-	0.03	0.03	0.03	0.58	0.33	0.91	0.006	0.32
MB(Inflow)	165621	12080	306.27	149.74	149.74	1057.65	206.64	1264.30	7.111	127.32
MBO	16581	5527	207.26	131.27	88.43	963.78	172.72	1136.50	2.418	127.00
%Reduct.	90	54	32	12	41	9	16	10	66	0

Event #3: March 28, 8:30 to March 30, 8:30 (SSS3)

Immediately past melt peak (.2" equiv.) plus .04" rain

NOTE: So.pond inflowing; MB(side) used in MBdirect calcs.

CONCENTRATION in MG/L

SITE	TSS	VSS	TP	DP	ORTHO-P	TKN	NO3	TN	TPb	QWATER(A')	COMMENTS
MBI	261	14	0.46	0.16	0.152	1.81	0.60	2.41	0.008	152.00	-EMC
MB(side)	25	9	0.94	0.80	0.778	3.61	0.75	4.36	0.003	36.00	-Grab; Q=MBO-MBI
MBO	31	6	0.23	0.23	0.188	1.86	0.50	2.36	0.003	186.00	-EMC

LOAD IN POUNDS

SITE	TSS	VSS	TP	DP	ORTHO-P	TKN	NO3	TN	TPb	TWATER(A')
MBI(large)	107908	5788	190.18	66.15	62.84	748.33	248.06	996.39	3.308	152.00
MB(Qdir.)	2448	881	92.04	78.34	76.18	353.49	73.44	426.93	0.294	36.00
MB(Atmos.)	-	-	0.01	0.01	0.01	0.29	0.17	0.46	0.003	0.16
MB(Inflow)	110356	6669	282.24	144.50	139.04	1102.11	321.67	1423.78	3.604	188.16
MBO	15684	3036	116.36	116.36	95.11	941.01	252.96	1193.97	1.518	186.00
%Reduct.	86	54	59	19	32	15	21	16	58	1

Event #4: March 30, 8:30 to April 1, 8:30 (SSS4)

Receding melt peak plus .03" rain

NOTE: So. pond flow now minor; use MS(side) for WQ and Qdir calcs.

CONCENTRATION in MG/L

SITE	TSS	VSS	TP	DP	ORTHO-P	TKN	NO3	TN	TPb	QWATER(A')	COMMENTS
MBI	68	7	0.30	0.18	0.127	1.43	0.55	1.98	0.003	100.00	-EMC
MB(side)	25	9	0.94	0.80	0.778	3.61	0.75	4.36	0.003	(est.1cfs)	-Grab
MBO	16	5	0.30	0.20	0.146	1.36	0.55	1.91	0.002	81.00	-EMC

LOAD IN POUNDS

SITE	TSS	VSS	TP	DP	ORTHO-P	TKN	NO3	TN	TPb	TWATER(A')
MBI(large)	18496	1904	81.60	48.96	34.54	388.96	149.60	538.56	0.816	100.00
MB(Qdir.)	270	97	10.15	8.64	8.40	38.98	8.10	47.08	0.032	3.97
MB(Atmos.)	-	-	0.00	0.00	0.00	0.04	0.02	0.06	0.000	0.02
MB(Inflow)	18766	2001	91.75	57.60	42.95	427.98	157.72	585.70	0.849	103.99
MBO	3525	1102	66.10	44.06	32.17	299.64	121.18	420.81	0.441	81.00
%Reduct.	81	45	28	24	25	30	23	28	48	22

Event #5: April 1, 8:45 to April 3, 6:00 (SSS5)

Receding melt peak plus .08" rain

NOTE: So. pond still flowing; use now MBI for so. pond inflow WQ

CONCENTRATION in MG/L

SITE	TSS	VSS	TP	DP	ORTHO-P	TKN	NO3	TN	TPb	QWATER(A')	COMMENTS
MBI	27	5	0.26	0.18	0.104	1.35	0.55	1.90	0.002	68.00	-EMC
MBO	12	3	0.34	0.27	0.127	1.44	0.55	1.99	0.002	64.00	-EMC

LOAD IN POUNDS

SITE	TSS	VSS	TP	DP	ORTHO-P	TKN	NO3	TN	TPb	TWATER(A')
MBI(large)	4994	925	48.09	33.29	19.24	249.70	101.73	351.42	0.370	68.00
MB(Qdir.)	0	0	0.00	0.00	0.00	0.02	0.01	0.03	0.000	0.01
MB(Atmos.)	-	-	0.00	0.00	0.00	0.10	0.06	0.15	0.001	0.05
MB(Inflow)	4994	925	48.10	33.30	19.24	249.81	101.79	351.60	0.371	68.06
MBO	2089	522	59.19	47.00	22.11	250.68	95.74	346.42	0.348	64.00
%Reduct.	58	44	-23	-41	-15	0	6	1	6	6

Event #6: April 3, 6:00 to April 5, 12:00 (SSS6)

Receding melt peak plus .46" rain

NOTE: So. pond still flowing at about 1cfs; use MBI for WQ

CONCENTRATION in MG/L

SITE	TSS	VSS	TP	DP	ORTHO-P	TKN	NO3	TN	TPb	QWATER(A')	COMMENTS
MBI	45	9	0.28	0.15	0.089	1.40	0.50	1.90	0.010	70.00	-EMC
MBO	18	5	0.32	0.22	0.106	1.45	0.50	1.95	0.004	49.00	-EMC

LOAD IN POUNDS

SITE	TSS	VSS	TP	DP	ORTHO-P	TKN	NO3	TN	TPb	TWATER(A')
MBI(large)	8568	1714	53.31	28.56	16.95	266.56	95.20	361.76	1.904	70.00
MB(Qdir.)	504	101	3.14	1.68	1.00	15.69	5.60	21.29	0.112	4.12
MB(Atmos.)	-	-	0.03	0.03	0.03	0.55	0.32	0.87	0.006	0.31
MB(Inflow)	9072	1814	56.48	30.27	17.97	282.80	101.12	383.92	2.022	74.43
MBO	2399	666	42.65	29.32	14.13	193.26	66.64	259.90	0.533	49.00
%Reduct.	74	63	24	3	21	32	34	32	74	34

Event #7: April 5, 12:00 to April 11, 24:00 (unmonitored tail of melt)

Receding melt; water quality collected 4/14; MB(side) minor

NOTE: MBO trash-rack cleaned; previously stored water released

CONCENTRATION in MG/L

SITE	TSS	VSS	TP	DP	ORTHO-P	TKN	NO3	TN	TPb	QWATER(A')	COMMENTS
MBI	6	3	0.01	0.01	0.034	1.18	0.45	1.63	0.001	118.00	-Recorded flow w/ assumed WQ
MBO	6	4	0.14	0.03	0.006	1.20	0.50	1.70	0.001	170.00	-MBO cleaned and stored water relea

LOAD IN POUNDS

SITE	TSS	VSS	TP	DP	ORTHO-P	TKN	NO3	TN	TPb	TWATER(A')
MBI(large)	1926	963	3.21	3.21	10.91	378.73	144.43	523.16	0.321	118.00
MB(Qdir.)	0	0	0.00	0.00	0.00	0.00	0.00	0.00	0.000	0.00
MB(Atmos.)	-	-	0.00	0.00	0.00	0.00	0.00	0.00	0.000	0.00
MB(Inflow)	1926	963	3.21	3.21	10.91	378.73	144.43	523.16	0.321	118.00
MBO	2774	1850	64.74	13.87	2.77	554.88	231.20	786.08	0.462	170.00
%Reduct.	-44	-92	-1917	-332	75	-47	-60	-50	-44	-44

SUMMARY OF MELT - March 23 to April 11, 1989

SITE	TSS	VSS	TP	DP	ORTHO-P	TKN	NO3	TN	TPb	TWATER(A')
MBI	313551	24494	635	278	229	2942	932	3874	15.852	627
MB(Qdir.)	5325	1828	182	154	151	704	149	853	0.701	74
MB(Atmos.)	-	-	0.1	0.1	0.1	1.8	1.1	2.9	0.019	1.0
MB(Inflow)	318876	26322	817	432	380	3648	1082	4729	16.571	702
MBO	46343	14019	580	396	255	3330	988	4318	7.396	699
%Reduct.	85	47	29	8	33	9	9	9	55	0

1989 Melt - Tanners Lake Wetland

Event #1: March 23-25, 1989

Early part of melt (0.1" equiv.) plus 0.13" rain

CONCENTRATION in MG/L

SITE	TSS	VSS	TP	DP	ORTHO-P	TKN	NO3	TN	TPb	QWATER(A')	COMMENTS
TLI	326	88	0.50	0.17	-	2.33	1.00	3.33	0.062	6.00	-EMC
TLO	30	12	0.26	0.14	-	2.01	1.35	3.36	0.019	8.00	-EMC

LOAD IN POUNDS

SITE	TSS	VSS	TP	DP	ORTHO-P	TKN	NO3	TN	TPb	TWATER(A')
TLI	5320	1436	8.16	2.77	-	38.03	16.32	54.35	1.012	6.00
TL(Qdir.)	232	63	0.36	0.12	-	1.66	0.00	1.66	0.044	0.26
TL(inflow)	5552	1499	8.52	2.90	-	39.68	16.32	56.00	1.056	6.26
TLO	653	261	5.66	3.05	-	43.74	29.38	73.11	0.413	8.00
%Reduct.	88	83	34	-5	-	-10	-80	-31	61	-28

Event #2: March 25-27, 1989

NOTE: no data collected but used MB:TL relationship to predict volumes
and used WQ data from event #1

CONCENTRATION in MG/L

SITE	TSS	VSS	TP	DP	ORTHO-P	TKN	NO3	TN	TPb	QWATER(A')	COMMENTS
TLI	326	88	0.50	0.17	-	2.33	1.00	3.33	0.062	25.00	-Estimates of vol. and W
TLO	30	12	0.26	0.14	-	2.01	1.35	3.36	0.019	28.00	-Estimates of vol. and W

LOAD IN POUNDS

SITE	TSS	VSS	TP	DP	ORTHO-P	TKN	NO3	TN	TPb	TWATER(A')
TLI	22168	5984	34.00	11.56	-	158.44	68.00	226.44	4.216	25.00
TL(Qdir.)	20	5	0.03	0.01	-	0.14	0.00	0.14	0.004	0.02
TL(inflow)	22188	5989	34.03	11.57	-	158.58	68.00	226.58	4.220	25.02
TLO	2285	914	19.80	10.66	-	153.08	102.82	255.90	1.447	28.00
%Reduct.	90	85	42	8	-	3	-51	-13	66	-12

Event #3: March 27, 10:00 to March 29, 9:00

Peak part of melt (.4" equiv.) plus .01" rain

CONCENTRATION in MG/L

SITE	TSS	VSS	TP	DP	ORTHO-P	TKN	NO3	TN	TPb	QWATER(A')	COMMENTS
TLI	66	12	0.37	0.18	0.171	1.60	1.55	3.15	0.008	38.00	-EMC
TLO	35	10	0.45	0.29	0.133	1.74	1.30	3.04	0.004	46.00	-EMC

LOAD IN POUNDS

SITE	TSS	VSS	TP	DP	ORTHO-P	TKN	NO3	TN	TPb	TWATER(A')
TLI	6822	1240	38.24	18.60	17.67	165.38	160.21	325.58	0.827	38.00
TL(Qdir.)	165	30	0.92	0.45	0.43	4.00	0.00	4.00	0.020	0.92
TL(inflow)	6987	1270	39.17	19.05	18.10	169.37	160.21	329.58	0.847	38.92
TLO	4379	1251	56.30	36.28	16.64	217.71	162.66	380.36	0.500	46.00
%Reduct.	37	2	-44	-90	8	-29	-2	-15	41	-18

Event #4: March 29, 9:00 to March 31, 9:00

End of melt (.1" equiv.) plus 0.07" rain

CONCENTRATION in MG/L

SITE	TSS	VSS	TP	DP	ORTHO-P	TKN	NO3	TN	TPb	QWATER(A')	COMMENTS
TLI	19	4	0.26	0.17	0.169	1.38	1.10	2.48	0.003	25.00	-EMC
TLO	3	2	0.27	0.20	0.131	1.26	1.05	2.31	0.001	25.00	-EMC

LOAD IN POUNDS

SITE	TSS	VSS	TP	DP	ORTHO-P	TKN	NO3	TN	TPb	TWATER(A')
TLI	1292	272	17.68	11.56	11.49	93.84	74.80	168.64	0.204	25.00
TL(Qdir.)	6	1	0.09	0.06	0.06	0.46	0.00	0.46	0.001	0.12
TL(inflow)	1298	273	17.77	11.62	11.55	94.30	74.80	169.10	0.205	25.12
TLO	204	136	18.36	13.60	8.91	85.68	71.40	157.08	0.068	25.00
%Reduct.	84	50	-3	-17	23	9	5	7	67	0

Event #5: March 31, 9:00 to April 2, 22:00
End of melt (.1" equiv.) plus 0.02" rain

CONCENTRATION in MG/L

SITE	TSS	VSS	TP	DP	ORTHO-P	TKN	NO3	TN	TPb	QWATER(A')	COMMENTS
TLI	13	5	0.24	0.19	0.115	1.17	1.15	2.32	0.001	20.00	-EMC
TLO	6	4	0.19	0.14	0.084	1.12	1.10	2.22	0.002	17.00	-EMC

LOAD IN POUNDS

SITE	TSS	VSS	TP	DP	ORTHO-P	TKN	NO3	TN	TPb	TWATER(A')
TLI	707	272	13.06	10.34	6.26	63.65	62.56	126.21	0.054	20.00
TL(Qdir.)	2	1	0.03	0.02	0.01	0.14	0.00	0.14	0.000	0.04
TL(inflow)	709	273	13.08	10.36	6.27	63.79	62.56	126.35	0.055	20.04
TLO	277	185	8.79	6.47	3.88	51.79	50.86	102.65	0.092	17.00
%Reduct.	61	32	33	38	38	19	19	19	-70	15

Event #6: April2, 22:00 to April 4, 12:00
End of melt (no equiv. water) plus 0.42" rain

CONCENTRATION in MG/L

SITE	TSS	VSS	TP	DP	ORTHO-P	TKN	NO3	TN	TPb	QWATER(A')	COMMENTS
TLI	79	16	0.42	0.23	0.093	1.37	0.90	2.27	0.023	11.00	-EMC
TLO	12	4	0.23	0.15	0.075	1.14	0.90	2.04	0.006	12.00	-EMC

LOAD IN POUNDS

SITE	TSS	VSS	TP	DP	ORTHO-P	TKN	NO3	TN	TPb	TWATER(A')
TLI	2364	479	12.57	6.88	2.78	40.99	26.93	67.92	0.688	11.00
TL(Qdir.)	207	42	1.10	0.60	0.24	3.59	0.00	3.59	0.060	0.96
TL(inflow)	2571	521	13.67	7.48	3.03	44.58	26.93	71.51	0.748	11.96
TLO	392	131	7.51	4.90	2.45	37.21	29.38	66.59	0.196	12.00
%Reduct.	85	75	45	35	19	17	-9	7	74	0

MELT SUMMARY (WITH APRIL 4 EVENT) - March 23 to April 4

NOTE: Ortho-P only 4 events

SITE	TSS	VSS	TP	DP	ORTHO-P	TKN	NO3	TN	TPb	TWATER(A')
TLI	38673	9683	123.71	61.72	38.21	560.32	408.82	969.14	7.001	125.00
TL(Qdir.)	632	142	2.53	1.26	0.74	9.98	0.00	9.98	0.129	2.33
TL(inflow)	39305	9825	126.23	62.98	38.95	570.30	408.82	979.12	7.131	127.33
TLO	8190	2878	116.42	74.96	31.88	589.21	446.49	1035.69	2.717	136.00
%Reduct.	79	71	8	-19	18	-3	-9	-6	62	-7

MELT SUMMARY (WITHOUT APRIL 4 EVENT) - March 23 to March 25, and March 27 to April 4

SITE	TSS	VSS	TP	DP	ORTHO-P	TKN	NO3	TN	TPb	TWATER(A')
TLI	16505	3699	89.71	50.16	38.21	401.88	340.82	742.70	2.785	100.00
TL(Qdir.)	612	136	2.50	1.25	0.74	9.84	0.00	9.84	0.125	2.31
TL(inflow)	17117	3836	92.20	51.41	38.95	411.72	340.82	752.54	2.911	102.31
TLO	5905	1964	96.61	64.30	31.88	436.12	343.67	779.80	1.270	108.00
%Reduct.	66	49	-5	-25	18	-6	-1	-4	56	-6

1989 Melt - Carver Ravine

Event #1: March 24, 8:00 to March 26, 8:00
Early part of melt (0.1" equiv.) plus 0.13" rain

CONCENTRATION in MG/L

SITE	TSS	VSS	TP	DP	ORTHO-P	TKN	NO3	TN	TPb	QWATER(A')	COMMENTS
WRI	12	6	0.44	0.42	0.420	1.92	0.75	2.67	0.005	15.84	-EMC
WRI(pump)	-	-	-	-	-	-	-	-	-	-	-Pump not operating
WRO	27	12	0.50	0.44	0.44	2.33	0.90	3.23	0.006	15.08	-EMC

LOAD IN POUNDS

SITE	TSS	VSS	TP	DP	ORTHO-P	TKN	NO3	TN	TPb	TWATER(A')
WRI	517	259	18.96	18.10	18.10	82.72	32.31	115.04	0.215	15.84
WR(Qdir.)	1	0	0.03	0.03	0.03	0.14	0.06	0.20	0.000	0.03
WR(Atmos.)	-	-	0.00	0.00	0.00	0.03	0.02	0.05	0.000	0.02
WR(Pump)	-	-	-	-	-	-	-	-	-	-
WR(Inflow)	518	259	18.99	18.13	18.13	82.90	32.39	115.29	0.216	15.89
WRO	1107	492	20.51	18.05	18.05	95.57	36.92	132.49	0.246	15.08
%Reduct.	-114	-90	-8	0	0	-15	-14	-15	-14	5

Event #2: March 26, 9:00 to March 28, 7:00
Peak part of melt (0.4" equiv.) plus 0.08" rain
Pump shed all flow through WRI(pump), not WR(Qdir)

CONCENTRATION in MG/L

SITE	TSS	VSS	TP	DP	ORTHO-P	TKN	NO3	TN	TPb	QWATER(A')	COMMENTS
WRI	12	6	0.51	0.42	0.402	1.76	0.40	2.16	0.001	47.73	-EMC
WRI(pump)	50	11	0.41	0.26	0.256	1.68	0.45	2.13	0.006	7.25	-Pump operating at 4.5cfs
WRO	30	9	0.47	0.34	0.331	1.91	0.30	2.21	0.003	40.88	-EMC

LOAD IN POUNDS

SITE	TSS	VSS	TP	DP	ORTHO-P	TKN	NO3	TN	TPb	TWATER(A')
WRI	1558	779	66.21	54.53	52.19	228.49	51.93	280.42	0.130	47.73
WR(Qdir.)	4	2	0.18	0.15	0.14	0.62	0.14	0.76	0.000	0.13
WR(Atmos.)	-	-	0.00	0.00	0.00	0.07	0.04	0.11	0.001	0.04
WR(Pump)	986	217	8.09	5.13	5.05	33.13	8.87	42.00	0.118	7.25
WR(Inflow)	2548	998	74.48	59.81	57.38	262.32	60.99	323.30	0.249	55.15
WRO	3336	1001	52.26	37.81	36.81	212.38	33.36	245.74	0.334	40.88
%Reduct.	-31	0	30	37	36	19	45	24	-34	26

Event #3: March 28, 8:00 to March 30, 11:00

End of week melt (0.1" equiv.)

Quality estimated using WR(pump) averaged from above and 4/3/89 event and WRO from above and WRI from event #2

CONCENTRATION in MG/L

SITE	TSS	VSS	TP	DP	ORTHO-P	TKN	NO3	TN	TPb	QWATER(A')	COMMENTS
WRI	12	6	0.51	0.42	0.402	1.76	0.40	2.16	0.001	0.83	-Small residual flow
WRI(pump)	35	8	0.29	0.16	0.150	1.29	0.42	1.71	0.003	17.81	-Pumps operating at 4.5cfs
WRO	30	9	0.47	0.34	0.331	1.91	0.30	2.21	0.003	43.97	-EMC

LOAD IN POUNDS

SITE	TSS	VSS	TP	DP	ORTHO-P	TKN	NO3	TN	TPb	TWATER(A')
WRI	27	14	1.15	0.95	0.91	3.97	0.90	4.88	0.002	0.83
WR(Qdir.)	4	2	0.18	0.15	0.14	0.62	0.14	0.76	0.000	0.13
WR(Atmos.)	-	-	0.00	0.00	0.00	0.02	0.01	0.02	0.000	0.01
WR(Pump)	1696	388	14.05	7.75	7.27	62.49	20.35	82.84	0.145	17.81
WR(Inflow)	1727	403	15.38	8.85	8.32	67.10	21.40	88.50	0.148	18.78
WRO	3588	1076	56.21	40.66	39.59	228.43	35.88	264.31	0.359	43.97
%Reduct.	-108	-167	-265	-360	-376	-240	-68	-199	-142	-134

MELT SUMMARY - 3/24 to 3/30

SITE	TSS	VSS	TP	DP	ORTHO-P	TKN	NO3	TN	TPb	TWATER(A')
WRI	2102	1051	86.32	73.57	71.19	315.19	85.15	400.34	0.348	64.40
WR(Qdir.)	9	5	0.39	0.33	0.32	1.39	0.34	1.73	0.001	0.29
WR(Atmos.)	-	-	0.01	0.01	0.01	0.12	0.07	0.19	0.001	0.07
WR(Pump)	2682	604	22.13	12.88	12.31	95.62	29.22	124.84	0.264	25.06
WR(Inflow)	4793	1660	108.85	86.78	83.83	412.32	114.78	527.10	0.613	89.81
WRO	8031	2569	128.98	96.52	94.44	536.38	106.15	642.54	0.938	99.93
%Reduct.	-68	-55	-18	-11	-13	-30	8	-22	-53	-11

Event: April 4, 1989

.R Precip. 0.32 Last event: last part of melt 2 days previous

4B Precip.

TL Precip.

JR Precip. 0.37 WRI(pump) grabbed at 11:30 4/3

CONCENTRATION in MG/L

SITE	TSS	VSS	TP	DP	ORTHO-P	TKN	NO3	TN	TPb	QWATER(A')	COMMENTS
.RI	590	100	0.52	0.09	0.059	2.14	0.80	2.94	0.027	1.50	-EMC
.RO	37	10	0.23	0.09	0.041	1.20	0.85	2.05	0.006	1.30	-EMC
4BI	(included in extended melt event)										
4BO											
TLI	(included in extended melt event)										
TLO											
JRI	180	42	0.41	0.13	0.105	1.61	0.65	2.26	0.019	3.10	-EMC
JRI(pump)	20	5	0.17	0.07	0.043	0.91	0.40	1.31	0.001	0.66	-2hrs.@4cfs
JRO	27	4	0.23	0.10	0.056	1.11	0.45	1.56	0.003	3.50	-EMC

.OAD IN POUNDS

SITE	TSS	VSS	TP	DP	ORTHO-P	TKN	NO3	TN	TPb	TWATER(A')
.RI	2407	408	2.12	0.37	0.24	8.73	3.26	12.00	0.110	1.50
.R(Qdir.)	40	7	0.04	0.01	0.00	0.15	0.05	0.20	0.002	0.03
.R(Atmos.)	-	-	0.00	0.00	0.00	0.10	0.06	0.15	0.001	0.05
.R(Inflow)	2448	415	2.16	0.38	0.25	8.97	3.37	12.35	0.113	1.58
.RO	131	35	0.81	0.32	0.14	4.24	3.01	7.25	0.021	1.30
%Reduct.	95	91	62	16	42	53	11	41	81	18
JRI	1518	354	3.46	1.10	0.89	13.58	5.48	19.06	0.160	3.10
JR(Qdir.)	13	3	0.03	0.01	0.01	0.12	0.05	0.16	0.001	0.03
JR(Atmos.)	-	-	0.00	0.00	0.00	0.06	0.03	0.09	0.001	0.03
JR(Pump)	36	9	0.31	0.13	0.08	1.63	0.72	2.35	0.002	0.66
JR(Inflow)	1567	366	3.79	1.23	0.97	15.38	6.28	21.66	0.164	3.82
JRO	257	38	2.19	0.95	0.53	10.57	4.28	14.85	0.029	3.50
%Reduct.	84	90	42	23	45	31	32	31	83	8