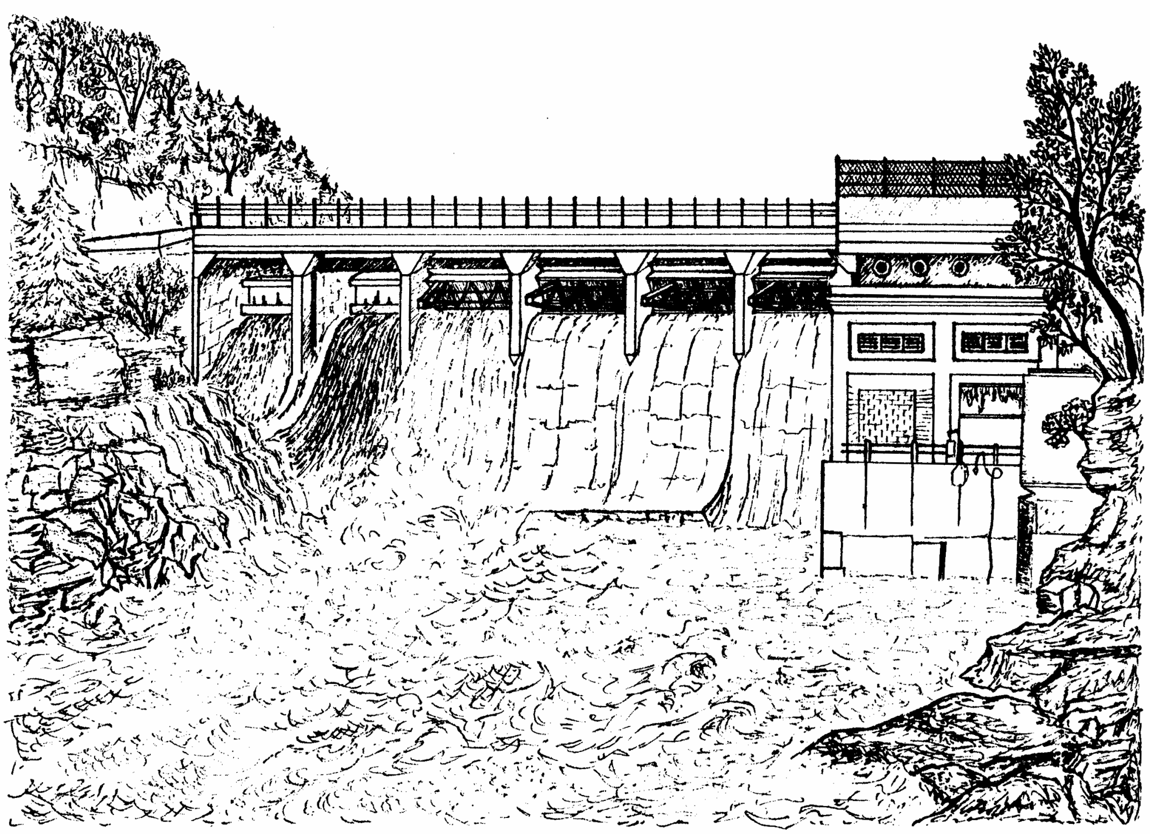
The Rapidan Dam Research Project:
Environmental impacts of converting a run-of-the-river low head hydroelectric dam to a peaking operation.



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Rapidan Dam Hydroelectric Research Project Director
Professor Henry W. Quade

Note: For a more detailed presentation of the Water Chemistry and Macroinvertebrates refer to:

1.) Ruff, Greg. 1987. The Impact of A Non-Stratifying Reservoir and it's Small, Low-Head, Peaking Hydroelectric Dam on the Water Quality and POM Transport of the Blue Earth River, South central Minnesota, M.A. Thesis, Mankato State University, Mankato, Minnesota, 293 pp.
2.) Danks, Marilyn. 1991. Macroinvertebrate Co mmunity Response to Flow Fluctuations Causedly by a Peak-Operated Hydroelectric Dam. M.A. Thesis, Mankato State University, Mankato, Minnesota, 102 pp.

For reports on the fisheries component of the Rapidan Dam stipulation agreement contact Dirk Peterson, Minnesota Department of Natural Resources.

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The full Research Project Report and the Executive Summary are available on the Minnesota River Basin Data Center: Water Resources Center, Minnesota State University Mankato. http://mrbdc.mnsu.edu

INTRODUCTION
Background

At the turn of the 20th century, hydropower met 60% of the nation's electrical power demand. Thirty years later, its role had diminished as inexpensive oil and coal dominated as major energy sources. With the election of President Roosevelt in 1932, the United States embarked on an ambitious program of building the large hydroelectric dams on the Columbia and Colorado Rivers. By 1976, more than 2,000 megawatts of electrical power were being generated from the Columbia basin dams, while 3,200 megawatts were being produced in the Colorado basin (Reisner, 1985).

By the late 1960's, with nearly all the prime hydro sites occupied or found in national parks, with inexpensive oil and vast reserves of coal available, and with the increased use of nuclear power, hydropower's role in the nations economy diminished once again.

The OPEC oil crisis of 1973 spurred a flurry of interest in hydropower. Since most of the available prime hydropower sites were developed earlier in the 20th century, attention was focused on the smaller hydroelectric producers. In 1978, the U.S. Congress passed the Public Utilities Regulatory Policies Act (PURPA), which required both private and public utilities to purchase the electric power produced by small private producers at a per-kilowatt cost. This cost would be equal to what the utility would have to spend to produce the power itself. PURPA, along with other new laws which provided small energy producers with investment tax credits and accelerated depreciation schedules, made small hydropower projects (less than 5 megawatts of potential output) like the Rapidan Dam economically feasible.

In 1864, with a change from subsistence to commercial grain farming in southern Minnesota, the first Rapidan Mill for grinding grain was built. The town of Rapids was built around the mill. An eight foot high, 260 foot long dam was built upstream from the mill with an 800 foot diversion tunnel, seven feet in diameter constructed from the pond to the mill to power the mill. The construction of a large iron bridge in 1878 connecting Rapids to the other side of the river, allowed easy transportation to Mankato. However, the railroad went four miles east of Rapids and the town of Rapidan grew rather than Rapids. With the construction of the hydroelectric dam, the town of Rapids would be underwater and therefore the power company bought 913 acres as far as five miles upstream (Pfaender, J. 1969).

Construction of the Rapidan Dam began in 1910 by the Ambursen Company under supervision of the H.M. Billesby Company of Chicago. Ambursen type dams are hollow-reinforced concrete buttress and slab dams. Construction of the dam lasted 11 months with a total cost of $500,000 for the Consumer Power Company. Consumer Power eventually became Northern States Power Company (NSP). The power house consisted of two 1250 horsepower horizontal Francis-type turbines manufactured by the Pelton Water Wheel Company, each driving a General Electric 750 Kw generator. The maximum potential output of the hydroelectric facility was 1500 Kw. The dam went into operation on March 11, 1911, and supplied power to the towns of Rapidan, Mankato, Lake Crystal, and Kasota. This doubled the existing capacity of Mankato's power supply and was the first electricity brought in from outside of the city (Tim Krohn, 2002).

The Rapidan Dam consisted of an 82-foot high structure extending 435 feet between rocky abutments. It also includes a 252-foot hollow concrete overflow spillway, a 90 foot powerhouse and inclined concrete decks slabs supported on reinforced concrete buttresses founded in sandstone bedrock. Sluice gates were installed to allow silt and sediments to be removed periodically from the upstream base of the dam. The gates failed to operate when first attempted due to sediment accumulation. The sediment then built up quickly to present level. Had the gates functioned, we probably would have had a thermally stratified reservoir.

Over the last 90 years, a series of repairs have been made to the dam. In 1916 and 1920 extensive repair work was needed on the concrete spillway apron due to a large hole scoured in the downstream apron of gate #4. The original apron of 50 feet was extended downstream to its present length of 300 feet. In 1937, concrete repair work was needed on the east bank retaining walls and during the 1950's the spillway pier noses were repaired.

In April of 1965, abnormal early ice break-up and greater than normal rainfall produced a peak flow of 43,100 cfs. The dam was left inoperable due to extensive damage to the dam's tainter gates and powerhouse caused by the record flow of the Blue Earth River. As stated earlier, the status of hydropower in the U.S. during the 1960's was considered bleak, therefore NSP decided against repairing the dam, and eventually presented ownership of the dam to Blue Earth County in 1975. The dam remained abandoned for 18 years until the rehabilitation project began in 1983. During this time the river was unregulated and discharges from the dam were run-of-the-river. The dam began producing electricity in the fall of 1984 after a rehabilitation project, which included the following:

- -Reinforcement of the dam itself.
- -Installation of new tainter gates.
- -Upgrading of the powerhouse with new equipment that would produce a maximum potential output of 5 megawatts.
- -Dredging of reservoir sediment immediately upstream of the turbine intakes.
- -Doubling the surface area of the reservoir to 168 hectares (145 acres).

Rapidan Dam was the first hydroelectric plant in the state to be resurrected (Tim Krohn, 2002). In order to achieve maximum output of electricity, and economic gain, the developer of the dam requested a store and release mode of operation. This required storing water in the reservoir during periods of low electrical demand and the releasing it through the turbines during periods of high electrical demand. This operational scheme of store-and-release is termed “peaking.”

The relicensing of the Rapidan Dam provided an opportunity to study the effects of manipulated flows and its unstratified reservoir on the physical, chemical and biological aspects of the river.

Purpose and Study Components

As part of the relicensing of the Rapidan Dam Hydroelectric Facility, the Blue Earth County Board of Commissioners contracted Professor Henry Quade and his students at Mankato State University to determine “the effects of converting a run-of-the-river, unstratified reservoir, hydroelectric dam into a peaking operation.”

The Rapidan Dam Research Project investigated four river components potentially impacted by the conversion to a peaking operation of the hydroelectric dam during the years of 1983 to 1985. The four components include: water quality, sediment transport, synthetic organics, and aquatic macroinvertebrates.

The Minnesota Department of Natural Resources conducted a separate study pertaining to the affect of the peaking on the downstream fishery.

In order to assess and quantify the potential impacts identified above, the following research was conducted:

1) The establishment of a spring to fall baseline set of data (run-of-the-river) for eleven water quality parameters and four size classifications of particulate organic material in transport within the water column. Three peak power generations in August 1985 were sampled with the data being compared to the baseline data set as well as historic data, impacts down stream, and effects of differences in peaks.
2) The establishment of a peaking season baseline set of data (run-of-the-river) for five sediment in transport parameters. Three peak power generations were sampled and compared to the seasonal baseline data.
3) The characterization of the surficial reservoir sediment by grain size and percent organic. This component also included an initial bed load study and post peaking reservoir sediment grain size comparison.
4) A survey of waters, baseline and peaks, for chlorinated hydrocarbons.
5) The permit for relicensing of the dam specifically required a study of the impact of fluctuating flows on the aquatic invertebrates of the Blue Earth River. Samples were collected over a three-year period beginning in 1983, the year before dam operation, and during dam operation from late 1984 through 1985.

The information gained from this study is intended to identify parameters impacted by the peaking versus “run-of-the-river” operation. The impacts identified, and their magnitude, can be utilized as a component in the decision making process of whether to remove, restore, or modify the dam. The results can further be utilized as input for future research and model development concerning the physical, chemical and biological impacts of small peaking hydroelectric dams on riverine systems.

SITE DESCRIPTION

Study Area

General Description

The study area was located in the north central region of Blue Earth County, in South Central Minnesota (Figure 1). Specific water quality, sediment, and benthic macroinvertebrate parameters were monitored at eight sampling sites, along a 51.8 river kilometer (32.2 river mile) stretch of the Blue Earth River running from the south east corner of Section 6 in Lyra Township (T108N, R27W) to the north central portion of Section 14 in Mankato Township (T108N, R26W) (Figure 2). Three sites were located upstream of the Rapidan Reservoir, one was in the reservoir itself, three downstream of the reservoir, and one site was on the Le Sueur River as a control. The eight sampling sites of this study were all located within the Storden-Comfrey-Lomax soil association.

The Blue Earth River Watershed

The Blue Earth River is a sixth order stream which encompasses a total drainage area of about 9,003 square kilometers (3,476 square miles) (Fasching, 1984). Approximately 8,164 square kilometers (3,152 square miles) of the total drainage area exists in Minnesota while 837 square kilometers (323 square miles) are found in Iowa where the river originates (USDA, 1972), (Figure 3). The mean discharge of the Blue Earth at its mouth is nearly 36.8 cubic meters per second (1,300 cubic feet per second) with maximum flood discharge recorded at 1,699 cubic meters per second (60,000 cubic feet per second) (Waters, 1977). The Blue Earth River can account for over one-half of the flood flow in the Minnesota River, of which the Blue Earth is a major tributary. The length of the Blue Earth River, from its junction with the East Branch of the Blue Earth, is 161 kilometers (100 miles). The river drops 87 meters (285 feet) with a mean slope of 0.6 meters per kilometer (3 feet per mile) upstream of the Rapidan Reservoir, and 0.9 meters per kilometer (5 feet per mile) downstream of the Rapidan Reservoir (Waters, 1977).

The watershed is wider than it is long, giving rise to a fan shape rather than the typical teardrop shape. An explanation for this can be attributed to the past capture of the Le Sueur River, at one time a tributary of the Minnesota River, by the Blue Earth River (Fasching, 1984).

Precipitation and Stream Flow

Blue Earth County is described as having a humid, cool, continental climate with warm summers and cold winters. The area receives a mean annual rainfall of 74 cm (29 inches) and a mean annual snowfall of 94 cm (37 in).

The United States Geological Survey (USGS) maintains water-stage recorder-type gauges on the Blue Earth and Le Sueur Rivers. The Blue Earth River gauge is located 0.3 km (0.2 mi) downstream of the dam. The Le Sueur River gauge is located 183 m (600 ft) downstream from the State Highway 66 bridge.

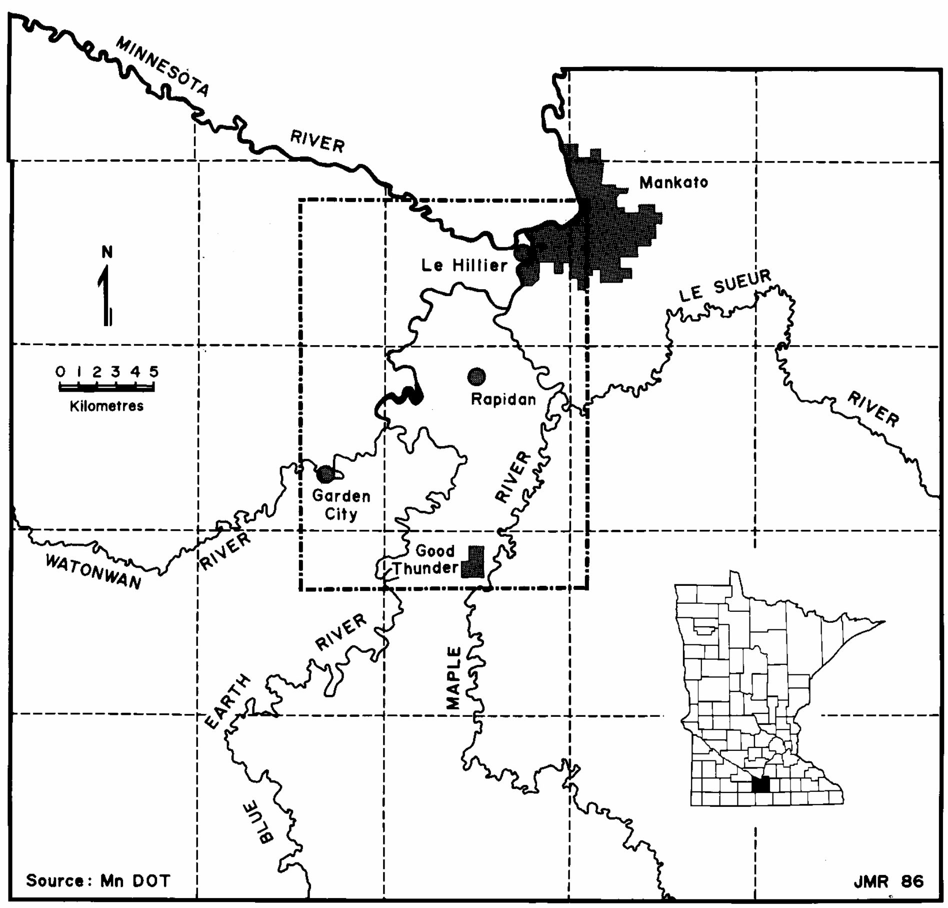


Figure 1. Location of study area in Blue Earth County, Minnesota

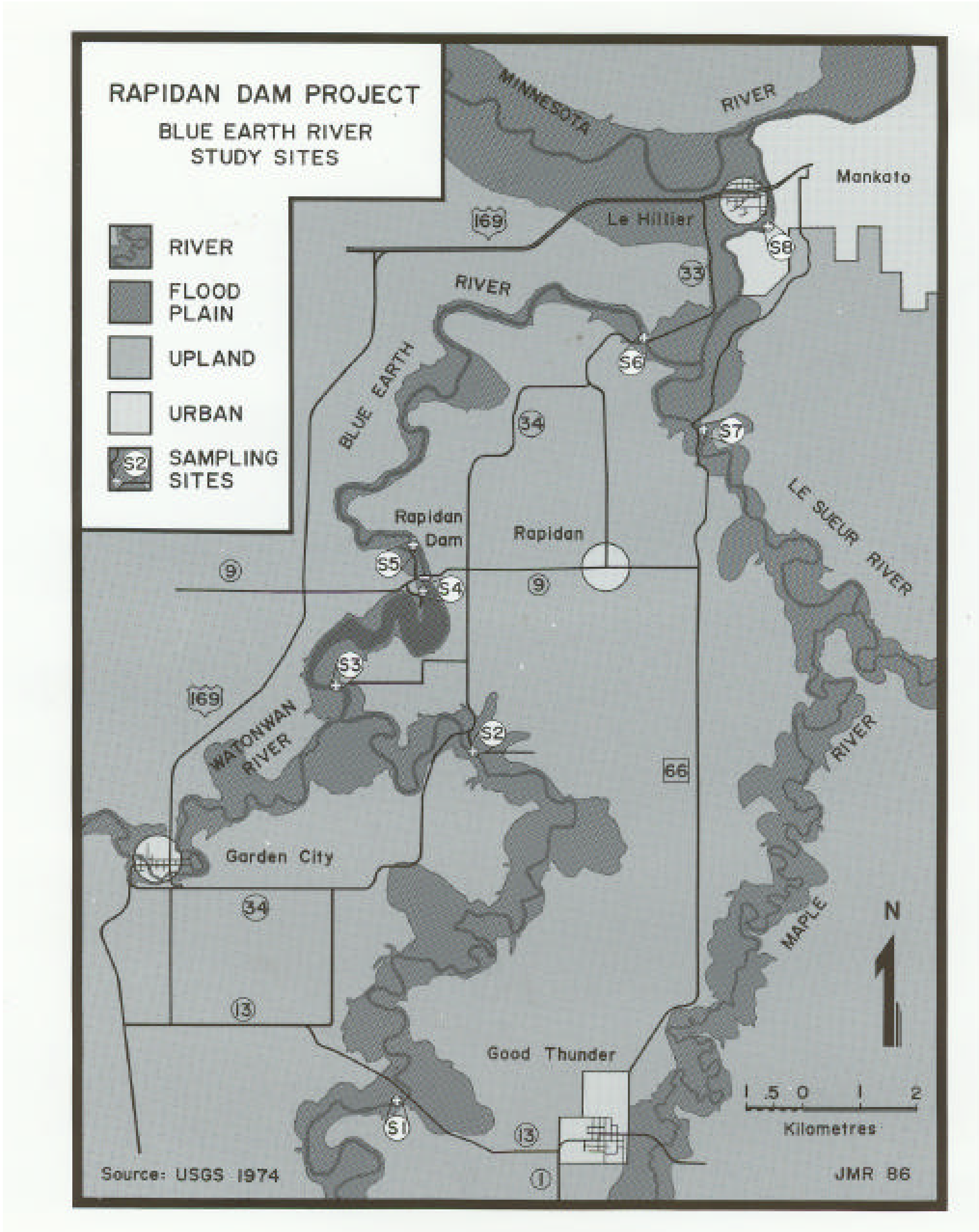


Figure 2. Location of sampling sites in the study area

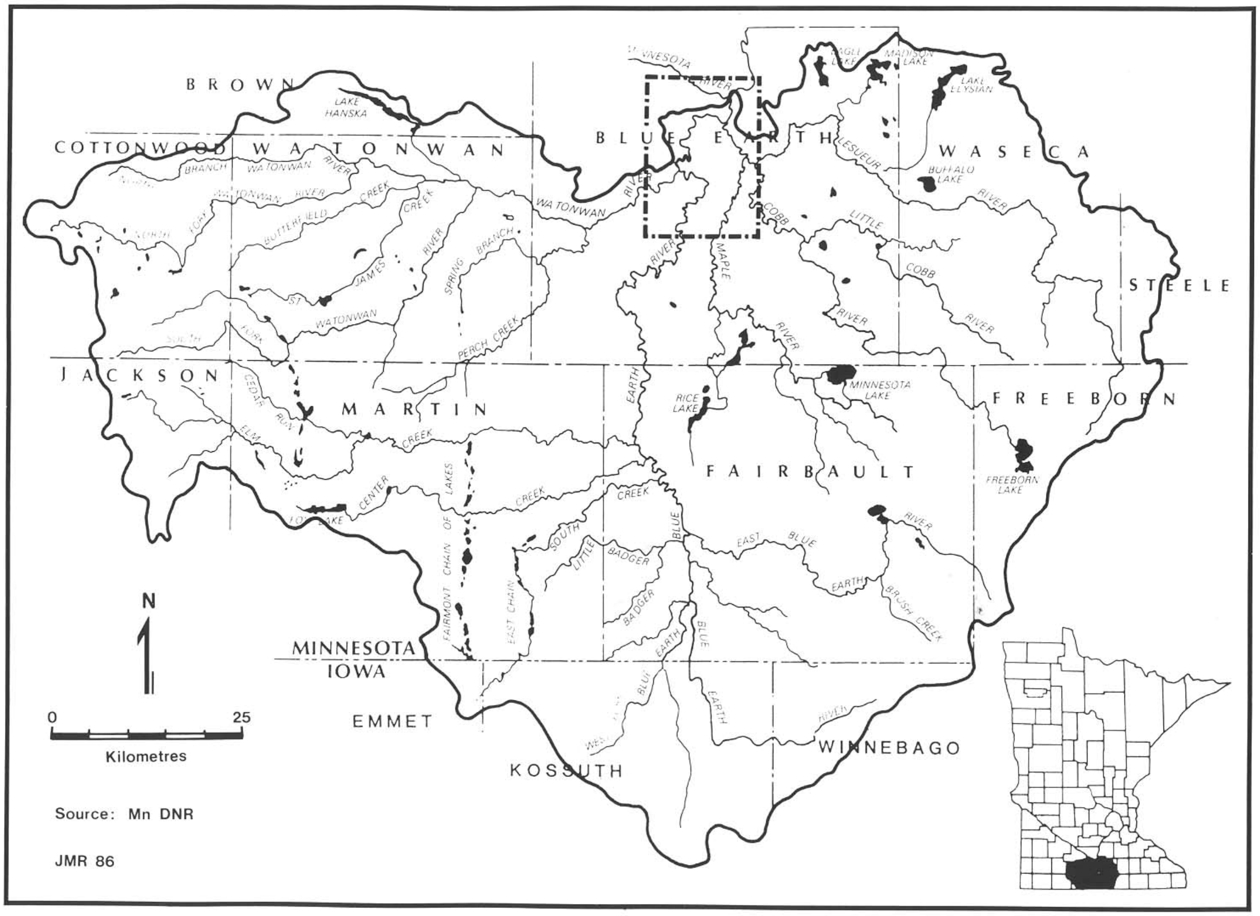


Figure 3. Blue Earth River watershed

The Rapidan Dam and Reservoir

The Rapidan Reservoir is in Rapidan Township (Sec 7 and 8, T107N, R27W and R28W) and is located 2.8 km (1.7 mi) west of Rapidan, MN on BE County Road 9. The Reservoir, with a surface area of 168 hectares (415 acres), has a volume of 1.03×10^7 cubic meters (3.62×10^8 cubic feet), a maximum depth of 9 meters (29.5 feet) and does not exhibit thermal stratification during the summer. The reservoir is contained by a 126-meter (414 foot) wide, 25.1 meter (82.5 foot) high dam (Figure 4). The reservoir is only a maximum of 13 feet deep in the channel at the bridge over the reservoir close to the dam and gets shallower quickly as one moves up reservoir or out of the channel. The dam contains a total of six tainter gates, each 2.7 meters (9 feet) in height, and can be manually or electrically operated. The tainter gate nearest to the east bank of the river, can also be automatically operated by a mechanism which monitors pond elevation. Two Allis-Chalmers, 1750 mm (69 in), Kaplan-type turbines draw reservoir water through 2.7 meter (9 feet) long penstocks located at a depth of 7 meters (23 feet) with outlets located at a depth of 1.7 meters (5.5 feet) below the centerline of the turbines (centerline=811msl). At a normal pool elevation of 266 m above mean sea level (874 msl), a head of 15.2-18.9 meters (50-62 feet) is produced. Each turbine drives a generator rated at 2500 kilowatts for a maximum potential output of 5 megawatts. Water is released during the months of July through September primarily for power generation during peak power demands (approximately 1200-1900 hour, Monday through Sunday). The maximum flow release capacity during a peak power generation is 34 cubic meters per second (cms) (1,200 cubic feet per second (cfs)). Nongeneration flow consists solely of an automated flow release outlet (minimum flow outlet) 91 cm (36 in) in diameter, with an inlet located at a depth of 1.2 meters (4 ft) at normal pool elevation and an outlet located on the east wall of the powerhouse. The minimum flow outlet is in operation if the flow entering the reservoir is less than 2.8 cms (100cfs) and is required by the licensing contract from fisheries (Jordan, 1986). Peaking operation dropped the reservoir (pool) about one foot as a result of a five to six hour event starting at normal pool elevation of 874 msl and 300 cfs flowing over the dam or turbines prior to the event. Since the reservoir is basin shaped, it drops up to two feet per event if the event start up occurs when the pool is already down By 1987 the reservoir had already silted in significantly therefore limiting peaking capacity (Jordan, 2004). Run-of-the-river power generation occurs when the flow entering the reservoir is greater than 2.8 cms and the reservoir is not being filled.

Sampling Sites

Water Chemistry and Sediment Sites

Refer to Figure 2 for the locations of all sites within the study area. Sites 1-4 are upstream of the dam and sites 5-8 are downstream of the dam.

Site 1 (S1)

This site was located in Lyra Township (NE1/4, SE1/4, Sec 6, T106N, R27W) and was the site situated the farthest upstream from the reservoir. The site was located 3 km (2 mi) west of the town of Good Thunder on Blue Earth (BE) County Road 13. Sampling was conducted 46 m (56 yds) upstream of the bridge. Deciduous woods bordered the site upstream right and left, and downstream right and left.

Site 2 (S2)

The site was located in Rapidan Township (SW1/4, SE1/4, Sec 17, T107N, R27W) 91 m (100 yds.) East of BE County Road 34 on BE County Road 126. The site was located 46 m (50 yds) southeast of BE 126, and was bordered by deciduous woods in all four directions.

Site 3 (S3)

This site was located on the D.P. Friederichs farm in Rapidan Township (NW1/4, NW1/4, Sec 18, T107N, R27W). A dramatic change occurred at this site between the July 9th and July 23rd baseline samplings of 1984. During this time span, repairing of the floodgates and reinforcement of the Rapidan Dam was completed. Subsequently, the gates were closed to allow the water level of the recently enlarged reservoir to rise and flooding of S3 occurred. Flow at S3 was reduced to the point where it was no longer visibly detectable and silt deposition occurred quickly. The site was bordered in all four directions by deciduous woods. Cattle grazed upstream left and downstream right portions.

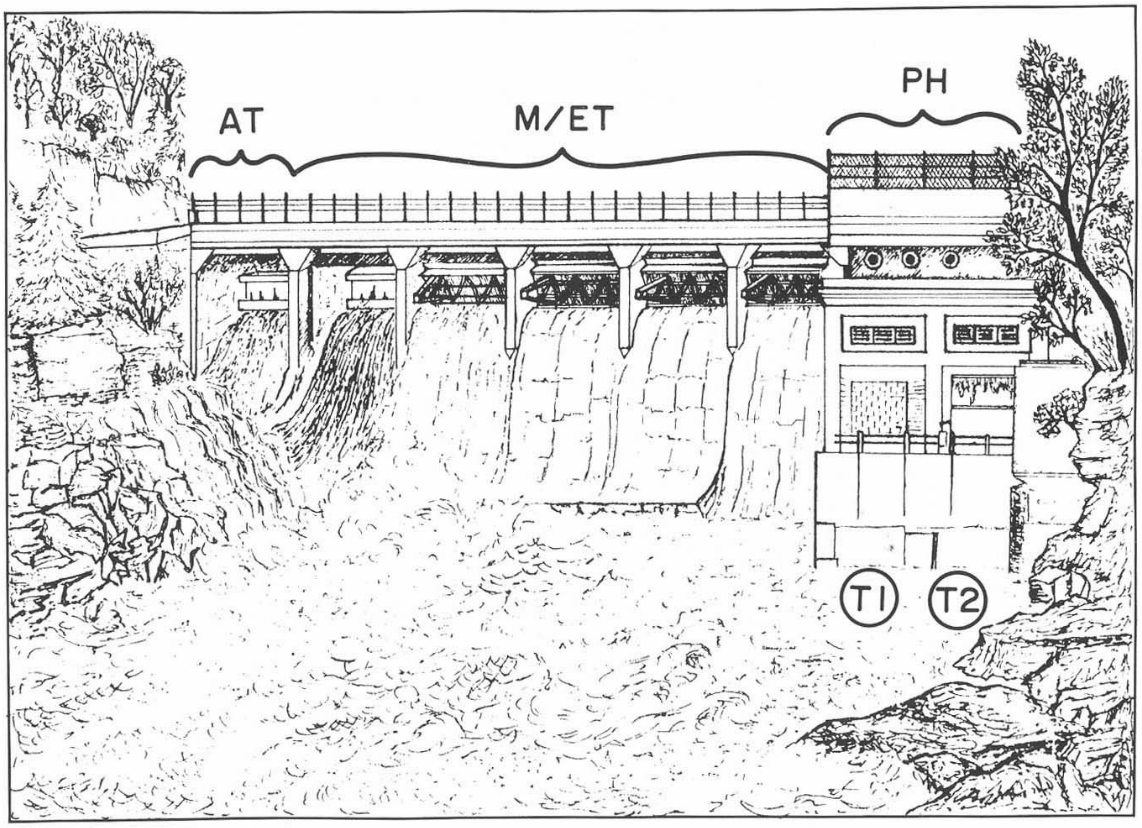


Figure 4. The Rapidan Dam looking south, in an upstream direction (Strom, 1985).
PH: Powerhouse **M/ET: Manually/Electrically controlled tainter gates**
AT: Automated tainter gate **T1: Turbine #1 outlet** **T2: Turbine #2 outlet**

Site 4 (S4)
The site was located in Rapidan Township (SW1/4, NW1/4, Sec 8, T107N, R27W) 0.4 km (0.25 mi) south of BE County Road 9. This site was the lower portion of the Rapidan Reservoir and sampling was conducted at the public boat landing. Deciduous, wooded, sandstone bluffs bordered the site upstream left and downstream right, while deciduous woods bordered upstream right and downstream left.

Site 5 (S5)
This site was the first site immediately downstream of the dam and was located in Rapidan Township (SE1/4, SE1/4, Sec 6, T107N, R27W) 0.4 km (0.25 mi) north of BE County Road 9. Access to the site was accomplished by using the private access road immediately east of The Dam Store, a small café and bait shop, located just west of the dam. Wooded sandstone bluffs bordered downstream right and upstream left. Deciduous woods bordered downstream left and upstream right.

Site 6 (S6)
The site was located in South Bend Township (NW1/4, SE1/4, Sec 27, T107N, R27N) just under 5 km (3 mi) south of U.S. Highway 169 on BE County Road 33. The sampling location was 46 m (50 yds) upstream of the bridge. Deciduous woods bordered the site upstream right and downstream left. Row crop and pasture land bordered upstream left and downstream right.

Site 7 (S7)
This site was on the Le Sueur River, a major tributary of the Blue Earth. It was located in Mankato Township (SW1/4, NW1/4, Sec 35, T108N, R27W) 5 km (3 mi) south of U.S. Highway 169 on Minnesota State Highway 66. Sampling was conducted 46 m (50 yds) upstream of the bridge. A dense stand of willow bordered the site upstream left and downstream right, while private residential land bordered upstream right and downstream left.

Site 8 (S8)
The site was located in Mankato Township (NW1/4, NE1/4, Sec 23, T108N, R27W) and was the site situated the farthest downstream of the reservoir. It was reached by driving to the southeast corner of the town LeHillier, MN, by way of Eleanor Street. The actual sampling site was 46 m (50 yds) beyond the levee in a northeast direction. Deciduous wooded sandstone bluffs bordered the site upstream left and downstream right, while deciduous woods bordered upstream right and downstream left.

See Appendix A for photographs of each site.

Sediment Bedload Sites

Two cliff locations were selected, one on the Blue Earth River and one on the Watonwan River. At each location sites were selected upstream and downstream of the sandstone cliffs.

Blue Earth River:

Site 1 was just downstream (west) of the tall sandstone cliff located downstream of the Hwy 34 bridge over the Blue Earth River in Section 17. Samples sites a and b were on dry riverbed. The river had approximately four to five foot banks on either side here. Site 2 was slightly upstream of the beginning of the sandstone cliff halfway between the cliff and bridge. Sample sites a and b were on dry river bed. Approximately 5-6 foot tall banks were on both sides of the river at this location.

Watonwan River:

Site 3 was near the N.W. corner of Blue Earth County Fairgrounds in Garden City, Minnesota downstream of a very tall stepped sandstone cliff N.E. of the river across from the fairgrounds. Sample site a was on dry river bottom. Facing downstream, west, the left bank was 7 foot tall and the right bank was 3 foot tall. Site 4 was located far upstream of the cliff used as a reference at Site 3. It was downstream, S.S.E., of the Highway 169 bridge over the Watonwan in Garden City. All sampling sites were submerged. The banks on both sides were about 5 foot tall and there was a very large sandbar island located upstream of the bridge.

Macroinvertebrate Sites

The macroinvertebrate study utilized a modified sampling strategy of water quality Sites 1-8. Site 5 was divided into 5 sub-areas stretching 0.2 km (0.125 mi) to 0.8 km (0.5 mi) downstream of the dam. Site 5e is used in this report; see Danks 1991 for other site data on Site 5. Sites 2, 5e, 5d, 5c, 5a, 6 and 7 were chosen for detailed analysis because they represented an upstream reference site (S2), sites that would reflect discharge impacts (S5e, S6) and a control site (S7). Sampling was attempted at two stations within each site. Station 1 was located near-shore in water of slower velocity, whereas Station 2 was located offshore in deeper and faster water. At some sites both habitat types were not present, therefore only one station was sampled. See Danks (1991) for more detailed site and station descriptions.

METHODS

Water Quality

Field Methods

Eleven baseline samples were collected from June 25, 1984 to October 25, 1984 and six baseline samples were collected from June 10, 1985 to September 15, 1985. Samples were horizontally and vertically integrated the entire width of the stream using a Federal Interagency Sedimentation Laboratory model US DH75A, with a two liter integrating water sampler when water levels permitted. A separate two liter sample was taken for suspended sediment using the same method. If water levels did not permit the collection of an integrated sample, a grab sample was taken at mid depth, as far out from the bank as one could safely wade.

Samples were collected for three peak power generation (peak-event) periods, along with an immediate pre-event sample. Samples were collected on August 9th, August 26th and August 30th, 1985. All samples were collected at midstream and integrated vertically, but sampling water at the air-water and sediment-water interfaces were avoided. Water depth was monitored at a fixed metal post driver into the substrate with a meter stick attached. Parameters analyzed, both baseline and peaks, are shown in Table I.

Washing of bottles and preparation and transportation of samples followed EPA protocol.

Peak-Event Sampling of August 9th

The ascending leg (up leg) and peak plateau of this peak-event were intensely sampled. Water samples were collected during a two hour and twenty-four minute period at S3, 6.5 river km (4.0 river mi) upstream, and S5 0.6 river km (0.4 river mi) downstream of the dam.

The initial sampling plan consisted of collecting water samples at two subsites along a transect at each site. One subsite (B) was located at midstream on the transect, while the other subsite (A) was located approximately one quarter of the width of the stream out from the near bank. It was determined that there were no significant differences in water chemistry between the two subsites, and that mixing was occurring throughout the stream during peak-events. During the remaining peak-event samplings, water samples were only collected at subsite B at all sites involved.

Peak-Event Sampling of August 26th

The entire peak-event, consisting of the ascending leg, peak plateau, and descending leg (down leg) was sampled. Water samples were collected during a six hour period at Sites S3, S5, and in addition S6, which was located 13.1 river km (8.1 river mi) downstream of the reservoir. Site S6 was added to the sampling scheme to determine the distance the peak water-surge traveled downstream, and to observe whether effects on water quality were present farther downstream.

Peak-Event Sampling of August 30th

The entire peak-event was sampled during a nine hour period at S3, S5, S6, and in addition S8, which was located 16.0 river km (9.9 river mi) downstream of the reservoir. Site S8 was added to further test the distance traveled by the peak water-surge and magnification of effects on water quality.

Laboratory Methods

Chemical analyses were conducted within a 24-72 hour time period, depending on the parameter being analyzed. All analyses were accomplished using Standard Methods (APHA, 15th edition, 1980), unless otherwise noted. Confidence in laboratory results was established with the following methods:

1. Analyses were run in triplicate. Some analyses were run in duplicate after comparisons between triplicate samples showed consistency.
2. Additional sample bottles were collected at several sites, chosen randomly, during each sampling date. The different sample bottles from the same site were analyzed for the same parameter, and the results compared for consistency.
3. Quality control samples for the water quality parameters of concern in this study, were obtained from the U.S. Environmental Protection Agency, Environmental Monitoring and Support Laboratory, Cincinnati, Ohio. The quality control samples were analyzed every third to fourth sampling date using identical procedures as the study samples. Concentrations obtained from the analysis of the EPA samples were compared to the actual concentrations provided by the EPA.

Table I: Baseline and peak water parameters analyzed.

		Baseline 1984-85	Peaks 1985	EPA Method
Hydrological	Water Depth	_____*	X	
Water Quality	Ammonia Nitrogen ($N-NH_3$)	_____**	X	350.1
	Organic Nitrogen	X	X	353.2
	Nitrate Nitrogen ($N-NO_3$)	X	X	353.2
	Nitrite Nitrogen ($N-NO_2$)	X	X	353.2
	Total Phosphorus (TP)	X	X	365.1
	Filterable Phosphorus ($P-PO_4$)	_____**	X	365.1
	Total Non-Filterable Residue (TNFR)	X	X	160.2
	Total Volatile Non-Filterable Residue (TVNFR)	X	X	160.4
	Conductivity	X	X	120.1
	pH	X	X	150.1
	Water Temperature	X	X	170.1
Organic Matter	Coarse Particulate Organic Matter (CPOM)	X	X	
	Fine Particulate Organic Matter (FPOM)	X	X	
	Very Fine Particulate Organic Matter (VPOM)	X	X	
	Dissolved Organic Carbon (DOC)	X	X	

* See Flow Tables

** Insufficient number of Data Points (Many were below detection)

EPA quality control samples of the Mineral Series, WP882, were used to test the accuracy of the laboratory technique for determining the following parameters: pH and conductivity. The Nutrient Series, WP 481, was used for the following parameters: Ammonia-Nitrogen, Organic-Nitrogen, and Filterable and Total Phosphorus. The Volatile Residue and Non-Filterable Residue quality control samples, WP184, were used for the following parameters: Total Volatile Non-Filterable Residue and Total Non-Filterable Residue (TVNFR) respectively. EPA quality control samples were not available for the following parameters: Water Temperature, Nitrite-Nitrogen, CPOM, FPOM, and VPOM. However, the procedures to determine the last three parameters mentioned were similar to the procedure for TVNFR.

Water Temperature was taken at mid depth using a standard laboratory, mercury-filled, centigrade thermometer. Specific conductance (conductivity) was measured in the field using a portable, battery operated meter (Lab-Line Instruments, model MC-3) and recorded in umhos/cm. The pH of the samples was determined using a Beckman Expandomatic pH meter in the laboratory.

Total non-filterable residue and total volatile non-filterable residue were determined by using standard procedures including a well mixed 100.0 ml sample, pre-washed and pre-ignited Whatman glass fiber filters, a 105° C drying temperature, and a 550-600° C igniting temperature.

Organic material (OM) size analysis was accomplished by dividing the OM into four size classifications. To facilitate comparison with other studies, we defined coarse particulate organic material (CPOM) as particles >1mm in diameter; fine particulate organic material (FPOM) as >0.53 um<1 mm; very fine particulate organic material (VPOM) as >0.45 um<0.53 um; dissolved organic carbon (DOC), the carbon component of OM <0.45 um (Boling et al., 1975). The water from a well-mixed, two liter integrated sample was filtered through nested 1 mm and 0.53 um sieves. The non-filterable residue in each sieve was rinsed onto a pre-weighed and pre-ignited (600°C, 30 minutes) Whatman glass fiber filter with activated charcoal filtered, deionized, glass distilled water. The filtrate was evenly filtered through two, pre-washed and pre-ignited, 0.45 um Whatman glass fiber filters. All filters were dried for 24 hours at 105°C and weighed to obtain the dry weight of the residue. The total organic material was obtained by igniting the filters at 600°C for 30 minutes. The organic material in the remaining filtrate was determined by wet oxidation with a 0.025 N solution of potassium dichromate (Maciolek, 1962). The dissolved organic material was assumed to be fifty percent dissolved organic carbon (Fisher, 1977).

Statistical Methods

Descriptive statistics, Pearson product-moment correlations, and one-way analysis of variance determinations were generated for the entire sampling periods of 1984 and 1985 as well as an early/late sampling period.

Statistical inference was not carried out on the peak-event data gathered. A sufficient number of cases did not exist for the generation of meaningful, interpretable, statistics.

The statistical analysis results are not presented in this report because of their more academic interest. One is referred to Ruff, Greg, 1987 thesis for coverage of this component.

Sediments

Suspended Sediments

Field

Suspended sediments were collected at the eight baseline sites (Figure 2) during the ice free season, twelve times in 1984 and seven in 1985. The three previously described peak events of 1985 were also sampled to correlate with the chemistry. All collecting utilized one gallon glass jugs mounted in a Paul Fasching designed heavy harness sampler (Figure 5). The sampler was moved up and down in the water column in order to achieve vertical integration. The design of the sampler prevented bottom sediment, even if disturbed, from entering the jugs. Duplicates as well as other vertical transects across the river were taken to determine reproducibility and consistency.

Laboratory

The gallon samples were treated to the following process in the sediment laboratory.

1. Decanted down to 1000 ml.
2. Split with the second half to be used for disaggregated, non-flocculated, determinations. .
3. Put through a 230 sieve screen for use in determining weight of coarse and organic content if sufficient material existed.
4. Brought up to 1000 ml in a graduated cylinder.
5. Pipetted to 50 ml beakers for grain size analysis of fines following Table IV.
6. Pipetted to crucibles for determination of percent organic
7. Grain size samples dried and weighted.
8. Percent organic dried at 105° and then burned at 525° for three hours in a muffle furnace.
9. The other half of the original split followed the above procedures 3-7 except that 10 ml of calgon was added, utilizing a calculating factor, to obtain grain-size distribution of the disaggregated sediment.

All sediment, suspended and deposited, was classified as to grain-size by the classes given in Table II. Breakdown classes were smaller than seen in the table, but the data was lumped into these tabled categories to make the comparisons manageable.

Table II: Suspended sediment, reservoir and bedload grain size classes.

Class	Diameter
Pebble or larger	Greater than 4mm
Gravel	(4mm-2mm)
Sand (VA Tube)	(2mm-0.062mm)
Very Coarse Sand	(2mm-1mm)
Coarse Sand	(1mm-0.5mm)
Medium Sand	(0.5mm-0.25mm)
Fine and Very Fine Sand	(0.25mm-0.06mm)
Silts and Clays (Pipetting)	(less than 0.062 mm)
Coarse and Medium Silt	(0.062mm-0.016mm)
Fine and Very Fine Silt	(0.016mm-0.004mm)
Clay	(less than 0.004mm)

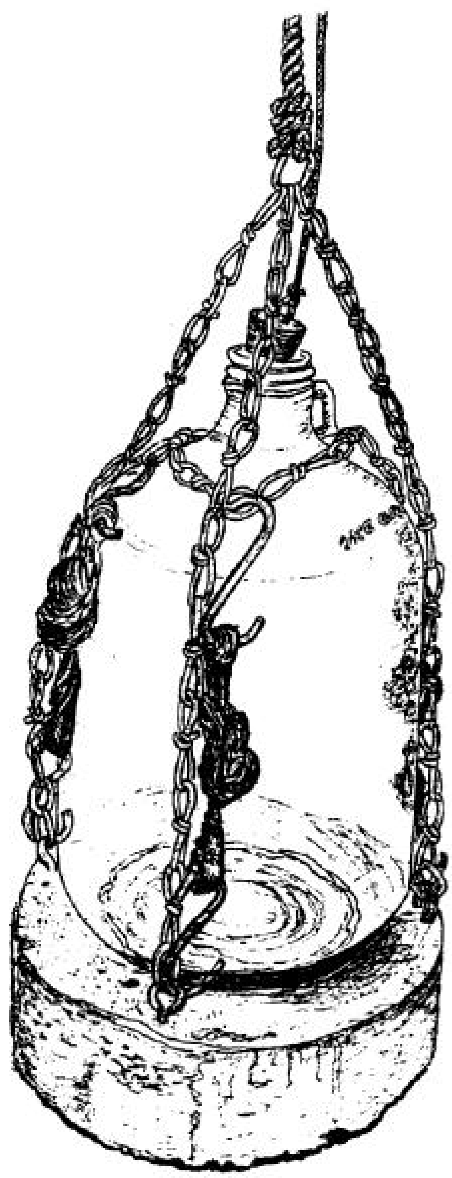


Figure 5. Fasching water sampler.

Reservoir Sediments

Field

Reservoir sediments were collected along 21 transects utilizing a Federal Inter-Agency Sedimentation Project bottom sampler during July of 1985. Representative select sites were again sampled in October. The top two cm's were utilized.

Laboratory

The reservoir sediments were split with a sediment splitter with half used for percent organic determination and half for grain size. The sand fraction of the sediment was analyzed for grain size using a Federal Interagency Visual Apparatus Tube (7 mm) and apparatus. The fines were analyzed by the pipette method as described in the previous section.

Bed Load Sediments

Field

Samples of surface bed material were taken October 12, 1984 (10 samples from the Blue Earth River and 10 samples from the Watonwan River) and measured 2" x 4" x 1". They were taken back to the sediment laboratory and immediately frozen in whirl pacs.

Laboratory

The samples were thawed and the following procedures for analysis were utilized.

1. Splitting with a sediment splitter was used to bring the sample to two 7 to 8 gram subsamples.
2. One portion was wet sieved through a sieve stack of #5, #10, and #1230 mesh with the fines collected also.
3. Sieve contents were dried and weighted.
4. Fines were split and utilized for pipette analysis and burned at 550°C for one hour for organic content.
5. Subsample from 1) above was washed through a #10 sieve, organic material oxidized with hydrogen peroxide and processed with 7mm Visual Accumulation Tube Apparatus, Federal Interagency Sedimentology Laboratory equipment and procedures. Procedure given in U.S.G.S. Handbook Laboratory Analysis Book 5, Chapter C1 Laboratory Theory and Methods for Sediment Analysis by Harold P. Guy.

Synthetic Organics

Field

Water samples were collected with two different methods. The first method employed a Federal Interagency Sediment Laboratory model US DH75A integrating water sampler equipped with a glass bottle for nonpeaking events. This method consisted of wading out into the river with the integrator and obtaining a sample of the water column from one side of the riverbank to the other, the amount taken per sample was approximately one litre. The sample was then placed in a clean glass container, and packed in ice prior to shipment to the laboratory.

The second method was the Fasching Method (Figure 5) and was used only during peaking events. Samples were taken from the middle of the river's water column using a boat as a platform. The sample size was approximately one gallon, which was cooled and divided among the various research teams in the lab. The amount of water that was needed for synthetics testing was approximately one litre.

It should be noted that prior to sampling all containers were cleaned at the lab, to prevent contamination, and also upon arrival at the respective sample sites each container was rinsed three times with water from the river.

Laboratory

Samples were extracted using Standard Method 509A. Prior to sample extraction a turbidity reading was obtained using a turbidity meter. The sample was then agitated for 15 seconds by hand, 500 ml of the river water sample was poured into a 2 litre seporatory funnel.

Extraction of each sample was accomplished by pouring 60 ml of a 15 percent diethyl ether and hexane solution into the separatory funnel and shaking it for 3 minutes. The mixture was allowed to stand for 10 minutes. The water phase was then drained back into a 500 ml flask, and the organic phase was poured into a 2 cm x 10 cm column containing sodium sulfate, {for removal of any water within the organic phase}, which drained into a Kuderna-Danish Evaporative Concentrator. The remaining water phase was then poured back into the 2 litre seporatory funnel and the 500 ml flask was rinsed with another 60 ml portion of the 15 percent diethyl ether and hexane solution and poured into the 2 litre separatory funnel, and the extraction process was repeated. The third and final extraction was done with 60 ml of pure hexane. All three of the extractions were poured into the sodium sulfate column that drained into the Kuderna-Danish Evaporative Concentrator. The addition of 60 ml of hexane was also used as a rinse of the sodium sulfate, giving the total liquid volume of 240 ml.

The Kuderna-Danish Evaporative Concentrator was the fitted with a three-ball snyder column and a 10-ml concentrator tube. The organic phase was reduced to 3 ml in a warm water bath (90-95 degrees centigrade). The reduction by distillation removed the diethyl ether and any other low boiling point materials. The concentrator tube was cooled to room temperature and hexane was added to bring the total volume to 5 ml. The 5-ml sample was then poured into a 7-ml glass vial with a trifluoroethylene screw cap, labeled and stored at 4 degrees centigrade.

After each complete sample extraction all glassware was cleaned and rinsed with double distilled deionized water, hexane and air-dried. The sodium sulfate was replaced to prevent contamination for further samples. All samples were extracted within 24 hours of arrival in the lab and stored within a controlled environment of 4 degrees centigrade.

The samples were first run on a Varian G.C. with a Nickel 63 detector using a 5% OV-210 on 100-120 mesh, dimethyl-dichlorosilane treated diatomaceous earth, in a 2 meter column, and a 1.5% OV-17 and 1.95% QF1 column for confirmatory analysis. Running conditions can be checked and cross-referenced by noting Standard Methods procedure 509A. This method included preparation of standards, column conditioning, column flow, temperature, pressures, sample preparation, and injection amounts.

A representative sample was sent to Minnesota Valley Testing for analysis by G.C. Mass Spectrometry. The instrument used was an Extrel ELQ-400 GC/MS operating in the EI mode and tuned according to EPA protocol (Work Order #: M-K-815, 11-11-86).

The analysis of this sample was performed using a fused silica capillary column (30 meter, 5% phenyl-94% methyl-1% vinyl silicone bonded phase-0.25 um film thickness). The GC conditions were: hold at 30 C for 5 minutes, ramp to 280 C at 8 C/minute and hold for 15 minutes. The splitless injection technique was used for sample introduction into the gas chromatograph.
Because of Minnesota Valley Testing results, a more sensitive detector would be needed for better quantitative results.

A Hewlett Packard HP-5890 with integrator and recorder, and a 5% Phenyl-Methyl Silicone column measuring 25 meters x 0.32 meters x 0.52 micrometers, and a Flame Ionization Detector were used for both qualitative and quantitative analysis. Prior to the runs the machine was calibrated and tested by a representative from Hewlett Packard.

The operating conditions for the HP-5890 were as follows:

1. Total Flow=2.38 ml/min
2. Purge=3.06 ml/min
3. Hydrogen Pressure=28 psi
4. Air=44 psi
5. Auxiliary Gas {Nitrogen}= 40 psi
6. Column Head Pressure=65 Kpa
7. Combined Flow Through Column=75.8 ml/min
8. Injector Temperature=225 degrees Centigrade
9. Detector Temperature=275 degrees Centigrade
10. Ramp Time = Initial temperature at 40 degrees Centigrade, hold 30 seconds, ramp at linear rate of 30 degrees/min to 100 degrees Centigrade, hold for 1 minute, then ramp to 180 degrees at a linear rate of 30 degrees/min
11. Sample injection amount = 2 microlitres

The Run Parameters for the Chart Recorder were as follows:

1. Zero = 10
2. Attenuation 2 = 0.0
3. Chart Speed = 1.0
4. Peak Width 0.01
5. Threshold = 0.0
6. Area Rejected = 0.0
7. No report functions
8. Time table = 3.50 Attenuation 2 = 5, 3.60 Zero = 10, 4.00 Zero = 10, 4.10 Chart Speed= 2.0

Macroinvertebrates

Field

Benthic macroinvertebrates were collected using various sampling methods. The most complete data sets were from Surber samplers and the three-kick sampling and only these data will be presented and discussed.

Surber samplers

The Surber sampler is a quantitative sampler that was used at all sites in triplicate. It was constructed of 80 micron mesh net attached to a brass frame (30 cm x 30 cm). Another brass frame of the same dimensions was attached perpendicular to the net and rested on the substrate when in use. The substrate was disturbed by hand and organisms and finer debris were carried into the net by the current . Samples were preserved in 70% ethanol, labeled, and returned to the laboratory.

Three-kick sampling

The three-kick method involved holding a D-frame dip net firmly against the substrate with the net opening facing upstream. The substrate directly in front of the net was disturbed by kicking it three times. Any dislodged organisms were carried by the current into the net. Sampling was done in triplicate and samples were preserved in 70% ethanol.

Laboratory

Organisms were identified to the Genus level of taxonomy, when possible, or to the Family level when practical. The early instars of various genera of the same Order were pooled and labeled as juveniles.

Due to constraints on time and resources, many of these samples were not used in the analysis. It was decided the artificial substrate samples would not be analyzed at this time due to certain disadvantages as cited by Rosenberg and Resh (1982). Artificial substrates do require relatively long colonization periods during which time fluctuating flows can alter their effectiveness. Changing water levels can expose them to very low flows, to vandalism or loss do to high water levels. These samples are in storage and available for study at another time.

Data Analysis

Data from invertebrate community samples were analyzed in four ways. Total abundance was measured as all macroinvertebrates per sample. Richness was determined by counting all taxa that occurred in a sample. The richness parameter was calculated for insect genera except for the Diptera where families were counted. Diversity of the benthic community was determined using the Shannon-Wiener Diversity Index (Platts, Megahan, and Minshall 1983). Abundance and percent composition of feeding functional groups were calculated after taxa were assigned the functional status defined by Merritt and Cummins (1984). These groups are 1) shredders that use coarse particulate organic material (CPOM) as a food source, 2) collectors that use fine particulate organic material (FPOM) as a food source, 3) scrapers that graze on periphyton and 4) predators that prey on other invertebrates.

RESULTS/DISCUSSION

Hydrology

Rainfall

Monthly precipitation for 1984 and 1985, and monthly deviations based on a twenty-nine year average were obtained from state climatological records for the Winnebago sampling station (the closest National Oceanic and Atmospheric Administration (NOAA) station to Mankato at the time) and are summarized in Table III (NOAA, 1984, 1985). During the 1984 sampling period, the combined months of June and July averaged out to a near normal amount of rainfall while August and September were dry. August and September had a combined negative deviation of 5.46 cm (2.15 in). June and July, of the 1985 sampling period, experienced drought conditions for this part of the county with a combined negative deviation of 11.71 cm (4.61 in). August and September of 1985 were abnormally wet with a combined positive deviation of 19.13 cm (7.53 in).

Daily precipitation for the study periods of 1984 and 1985, including baseline and peak event sampling dates are given in Tables IV and V.

Flow

Monthly mean, maximum, and minimum flow readings for 1984, 1985 (USGS, 1984 and 1985), and the thirty-five year period of record (USGS, 1986) for the Blue Earth River are given in Table VI. Also included in Table VI are the flow readings for each sampling date of the 1985 and 1985 baseline sampling periods. The 1984 flow data indicates that the 1984 sample period began with well above normal flow readings, which was an extended flush (March: 2.3 times mean average flow for 35 year period, April: 2.2 times mean average flow, May: 2.6 times average flow, June: 3.0 times average flow and July: 1.7 times average flow) and ended with well below normal readings. However, although flow during the sampling period was abnormally higher or lower than historic data, a pattern of greater flow in early summer, followed by decreasing flow as the summer progressed on into October is evident. The latter flow pattern is consistent with historic patterns. The flow pattern during the 1985 sampling period, characterized by well below normal flow in early summer, followed by drought conditions and above normal flow to end the period, was completely opposite the historical and 1984 sampling period patterns. The antecedent precipitation conditions are seen to effect flow with often a month offset (Table VI).

Daily flow data for the 1984 and 1985 study periods including baseline and peaking sampling dates are given in Tables VII and VIII.

Water Depth per Peak Event

<u>Peak-Event Sampling of August 9th</u>

Water released between 1215 and 1440 hours during this peak-event increased the river's flow from 2.8 cubic meters per second (cms) or 100 cubic feet per second (cfs) to 17 cms (600 cfs) with one turbine operating. The water level increased 47 cm (19 in) at S5 and decreased 12 cm (5 in) at S3 (Figure 6). The peak plateau at S5 began at 35 minutes following the startup of the turbine. The sample period lasted 145 minutes (2 hours 25 minutes) at S5, and 75 minutes (1hour 15 minutes) at S3.

<u>Peak-Event of August 26th</u>

Water released between 1230 and 1800 hours during the August 26th peak-event increased the river's flow from 17 cms (600 cfs) to 34 cms (1200 cfs) with both turbines operating. Prior to the start of the peak-event, the dam was generating electricity in a run-of-the-river operating mode with one turbine operating, and the minimum flow outlet closed. The peak-event began when the second turbine was placed in operation. The water level increased 25 cm (10 in) at S5, 62 cm (24 in) at S6, and decreased 95 cm (37 in) at S3 (Figure 7).

The peak plateau at S5 began at 48 minutes following the startup of the second turbine and ended with the initiation of the descending leg at 225 minutes (3 hours 45 minutes), lasting for a total of 2 hours 57 minutes. At S6, the plateau began at 262 minutes (4 hours 22 minutes) ending at 292 minutes (4 hours 52 minutes), lasting for 30 minutes.

<u>Peak-Event of August 30th</u>

Water released between 1030 and 1600 hours during the August 30th peak-event increased the river's flow from 17 cms (600 cfs) to 34 cms (1200 cfs) with both turbines operating. Similar to the August 26th peak-event, the dam was generating electricity in a run-of-the-river operating mode with one turbine operating prior to the start of the peak-event. The peak-event began when the second turbine was placed into operation. The water level increased 32 cm (13 in) and decreased 10 cm (4 in) below the original water level after the peak-event ended at S5, increased 62 cm (24 in) at S6, increased 68 cm (27 in) at S8, and decreased 52 cm (20 in) at S3 (Figure 8).

The peak plateau began at 30 minutes after the startup of the second turbine and ended with the beginning of the descending leg at 250 minutes (4 hours), lasting for a total of 3 hours 30 minutes at S5. At S6, the plateau began at 305 minutes (5 hours 5 minutes) after startup of the second turbine and ended at 380 minutes (6 hours 20 minutes), lasting for 1 hour 15 minutes. At S8, the plateau began at 330 minutes (5 hours 30 minutes) and ended at 390 minutes (6 hours 30 minutes), lasting one hour.

In summary, the three 1985 peaking events that were sampled for this study differed as seen in Table IX. The 8/9 event utilized a single turbine, was proceeded by dry conditions and had a short release time, all of which resulted in a minimal 12 cm draw down at Site 3. The 8/26 and 8/30 events both utilized two turbines, started with a background flow of 600 cfs, had similar release time, had precipitation events prior to the events, but differed in their drawdown at Site 3. The reduced drawdown (95 cm during the 8/26 event and 52 cm during the 8/30 event) is hypothesized to be the result of ground saturation and therefore increased runoff by 8/30.

Table III: Monthly precipitation for 1984 and 1985 with monthly deviations based on a 29 year average as recorded in Winnebago, Minnesota (NOAA, 1984, 1985).

Month	Precipitation		Deviation	
1984	(cm)	(in)	(cm)	(in)
January	1.88	0.74	-0.38	-0.15
February	2.92	1.15	0.36	0.14
March	4.06	1.60	-0.56	-0.22
April	10.19	4.01	3.91	1.54
May	9.02	3.55	-0.94	-0.37
June	17.50	6.89	4.93	1.94
July	6.32	2.49	-4.42	-1.74
August	7.37	2.90	-2.13	-0.84
September	4.50	1.77	-3.33	-1.31
October	13.28	5.23	8.43	3.32
November	5.46	2.15	9.93	3.91
December	3.86	1.52	1.24	0.49
Annual Total	86.36	34.00	17.04	6.71
Month	Precipitation		Deviation	
1985	(cm)	(in)	(cm)	(in)
January	1.98	0.78	-0.28	-0.11
February	2.50	1.00	-2.31	-0.91
March	7.47	2.94	2.84	1.12
April	9.65	3.80	3.38	1.33
May	7.29	2.87	-2.69	-1.05
June	6.15	2.42	-6.48	-2.53
July	5.46	2.15	-5.32	-2.08
August	23.04	9.07	13.64	5.33
September	13.41	5.28	5.63	2.20
October	4.93	1.94	0.08	0.03
November	4.70	1.85	1.55	0.61
December	3.81	1.50	1.19	0.47
Annual Total	88.14	34.70	11.23	4.41

Table IV: Precipitation and sampling dates for the 1984 study period (Winnebago sampling station, NOAA, 1984)

		Precipitation				Precipitation	
Date	Sampled	(cm)	(in)	Date	Sampled	(cm)	(in)
6-2		0.23	0.09	7-20		0.08	0.03
6-4		0.38	0.15	7-23	*		
6-5		3.00	1.15	7-26		0.30	0.12
6-6		0.20	0.08	7-28		0.61	0.24
6-8		0.81	0.32	7-30	*		
6-10		0.94	0.37	8-1		0.10	0.04
6-12		3.02	1.20	8-2		3.18	1.25
6-15		1.42	0.56	8-5		T	T
6-17		0.76	0.30	8-6	*		
6-18		1.22	0.48	8-8		2.92	1.15
6-22		4.47	1.76	8-13	*		
6-23		0.91	0.36	8-16		0.56	0.22
6-25	*			8-18		0.36	0.14
6-28		0.10	0.04	8-20	*	0.25	
7-2	*			8-26		1.07	0.10
7-4		0.58	0.23	9-4		0.58	0.42
7-8		1.09	0.43	9-8		0.13	0.23
7-9	*			9-11		2.03	0.05
7-10		0.38	0.15	9-12		0.13	0.80
7-11		1.63	0.64	9-14		0.06	0.05
7-15		0.33	0.13	9-23		0.13	0.02
7-16	*			9-24		0.18	0.05
7-17		1.32	0.52	9-25		0.20	0.07
				9-28	*	0.86	0.08
				10-7		0.51	0.34
				10-8		1.09	0.20
				10-9		0.56	0.43
				10-10		3.43	0.22
				10-15		0.43	1.35
				10-16		2.18	0.17
				10-17		1.52	0.86
				10-19			0.60
				10-25	*	0.41	
				10-26		2.29	0.16
				10-28			0.90

T= Trace precipitation
* = Baseline Sampling

Table V: Precipitation and sampling dates for the 1985 study period (Winnebago sampling station, NOAA, 1985)

		Precipitation				Precipitation	
Date	Sampled	(cm)	(in)	Date	Sampled	(cm)	(in)
6-2		0.13	0.05	8-16		0.61	0.24
6-8		0.25	0.10	8-17		1.80	0.71
6-10	*			8-19	*		
6-11		1.07	0.42	8-22		5.54	2.18
6-12		2.03	0.80	8-23		3.71	1.46
6-15		0.69	0.27	8-25		0.38	0.15
				8-26	**		
6-17	*	0.08		8-29		6.65	2.62
				8-30	**		
6-22		1.77	0.03	9-2		0.18	0.07
6-27		0.05	0.70	9-3		0.56	0.22
6-28		0.08	0.02	9-5		3.51	1.38
6-29			0.03	9-6		0.13	0.05
7-7	*	0.08		9-9		3.12	1.23
7-12		0.23	0.03	9-15	*		
7-13		0.89	0.09	9-17		0.38	0.15
7-15		3.43	0.35	9-18		0.15	0.06
7-25			1.35	9-20		1.02	0.40
7-30	*	0.84		9-22		0.89	0.35
7-31		1.07	0.33	9-23		0.94	0.37
8-9	**	2.39	0.42	9-24		0.74	0.29
8-10		0.89	0.94	9-26		0.08	0.03
8-12			0.35	9-27		0.56	0.22
8-13				9-30		1.17	0.46

T= Trace Precipitation
*= Baseline Sampling
**= Peak Sampling

Table VI: Flow of the Blue Earth River near Rapidan, Minnesota for the 1984 and 1985 calendar years (USGS, 1984, 1985), the historic record (Gunard, 1986) and for each baseline sampling date during the 1984 and 1985 sampling periods (USGS, 1984, 1985). Flow readings are in cfs.

Year 1984	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
mean	261	1042	2857	6286	4044	5184	1870	313	134	193	357	341
max	280	3452	8740	9100	7740	9450	4310	591	315	501	686	658
min	234	206	1260	2970	2200	2150	4761	99	74	61	187	130
Year 1985												
mean	214	149	2362	2735	1634	933	262	159	684	1884*	-	-
max	465	351	7940	5420	3460	1550	658	824	1340	3000*	-	-
min	91	89	115	1320	874	551	111	60	163	856*	-	-
Historic												
mean	161	214	1246	2807	1532	1729	1104	527	449	497*	458	270
Standard deviation	193	348	1316	3136	1224	1202	1041	929	671	905*	631	333
max	967 (1983)	1793 (1983)	6277 (1983)	13230 (1965)	4573 (1960)	5184 (1984)	3725 (1963)	5541 (1979)	8547 (1979)	5121 (1969)	2643 (1983)	1521 (1983)
min	17 (1956)	14 (1959)	92 (1968)	142 (1977)	144 (1976)	110 (1976)	50 (1976)	38 (1976)	22 (1976)	23 (1959)	30 (1956)	16 (1956)
Year 1984												
Flow Deviation Factor	1.6	4.9	2.3	2.2	2.6	3.0	1.7	0.6	0.3	0.4		
Precipitation Deviation Factor	0.8	1.2	0.9	1.6	0.9	1.4	0.6	0.8	1.5	1.5		
Year 1985												
Flow Deviation Factor	1.3	0.7	1.9	1.0	1.1	0.5	0.2	0.3	1.5	3.8		
Precipitation Deviation Factor	0.9	0.5	1.6	1.5	0.7	0.5	0.7	2.4	1.7	1.0		

1984 Sample Period		1985 Sample Period	
Date	Flow	Date	Flow
6-25	9310	6-10	744
7-2	9800	6-17	1520
7-9	1990	7-7	320
7-16	1940	7-30	132
7-23	1360	8-19	82
7-30	476	9-15	401
8-6	484		
8-13	378		
8-20	227		
9-28	74		
10-25	325		

Key:
Historic = 35 year period of record (1950-1985)

* = provisional data
- = data not available
( ) = year flow occurs

Table VII: 1984 Daily flow data (discharge) cfs at USGS gauging station near Site 5 (USGS-1984)

Day	March	April	May	June	July	August	September
1	3580	9080	4130	2620	4310	591	78
2	3460	9080	4980	2420	*3800	340	80
3	3130	9100	5960	2240	3470	547	78
4	2860	8910	6860	2150	3130	459	181
5	2460	8420	7700	2330	2940	425	222
6	2200	7980	7740	2650	2580	*484	222
7	1900	7520	7280	2770	2340	427	315
8	1690	6880	6740	2660	2120	410	248
9	1680	6430	6130	2530	*1990	484	93
10	1670	6370	5560	2980	1920	447	90
11	1630	6430	5010	3400	1870	388	91
12	1580	6430	4510	3330	2090	379	175
13	1480	6540	4160	3480	2200	*378	238
14	1420	7380	3840	4240	2160	362	240
15	1430	8310	6590	4800	2040	221	194
16	1370	8760	3350	5410	*1940	159	111
17	1320	8450	3150	5820	1960	425	107
18	1290	7640	2980	6420	1860	303	110
19	1260	6630	2830	6870	1680	240	107
20	1290	5680	2680	7330	1570	*227	105
21	1290	4930	2530	8120	1500	242	105
22	1310	4370	2420	9220	1010	149	105
23	1320	3980	2330	9450	*1360	99	105
24	1570	3660	2340	9390	1010	132	103
25	2480	3410	2350	*9310	877	209	101
26	3690	3250	2270	8610	826	212	100
27	6500	3100	2200	7650	727	227	83
28	6890	2970	2220	6680	823	256	*74
29	7730	3200	2290	5650	784	199	76
30	8350	3690	2520	5000	*476	164	76
31	8740	---	2700	---	610	107	---
Total	88570	188580	125350	155530	57973	9692	4013
Mean	2857	6286	4044	5184	1870	313	134
Max	8740	9100	7740	9450	4310	591	315
Min	1260	2970	2200	2150	476	99	74

*-Baseline Sampling

Table VIII: 1985 Daily flow data (discharge) cfs at USGS station near Site 5 (USGS-1985)

Day	March	April	May	June	July	August	September
1	360	1520	3460	1100	658	111	826
2	311	1450	3100	1130	617	107	631
3	279	1690	2810	1150	564	97	532
4	213	2280	2500	1280	417	97	483
5	249	3010	2220	989	584	94	421
6	282	3560	2040	775	341	91	555
7	181	3880	1920	622	320	91	804
8	149	3780	1760	830	501	81	1340
9	115	3010	1580	582	389	**146	1240
10	128	2370	1500	*744	216	73	1220
11	251	2230	1410	661	216	74	966
12	1970	2010	1250	693	216	107	1010
13	4020	1870	1240	729	212	141	856
14	5460	1650	1210	850	199	114	748
15	7370	1680	1270	1340	191	127	*401
16	7940	1600	1440	1340	171	114	745
17	6320	1730	1630	*1520	315	90	517
18	4810	1380	1670	1550	187	91	538
19	4280	1410	1660	1350	179	*82	552
20	3800	1430	1650	1210	155	62	363
21	3380	1320	1510	1140	152	60	163
22	2980	1700	1330	932	131	122	326
23	2720	3080	1290	836	132	134	415
24	2340	4560	1240	811	140	167	454
25	2200	5230	1310	744	140	178	485
26	1960	5420	1330	651	142	**418	661
27	1940	5030	1250	610	139	187	780
28	1870	4540	1060	551	136	256	624
29	1940	4080	1020	638	127	152	723
30	1860	3600	1130	644	*132	**450	1040
31	1690	---	874	---	111	824	---
Total	73368	82100	50664	28002	8130	4938	20419
Mean	2367	2737	1634	933	262	159	681
Max	7940	5420	3460	1550	658	824	1340
Min	115	1320	874	551	111	60	163

*-Baseline Sampling
** - Peak Sampling

Table IX: Comparison of hydrologic and water quality characteristics of the three August peaks.

1985 Event Date	# of Turbines	Turbine Flow Increase (cfs)	Turbine Release Time (hrs.)	Precipitation prior to event (inches)	Site 3 drawdown (cm)
8/9	1	100-600	2 ½	Dry	12
8/26	2	600-1200	7 ½	3.79 (8/22-8/25)	95
8/30	2	600-1200	7 ½	2.62 (8/29)	52

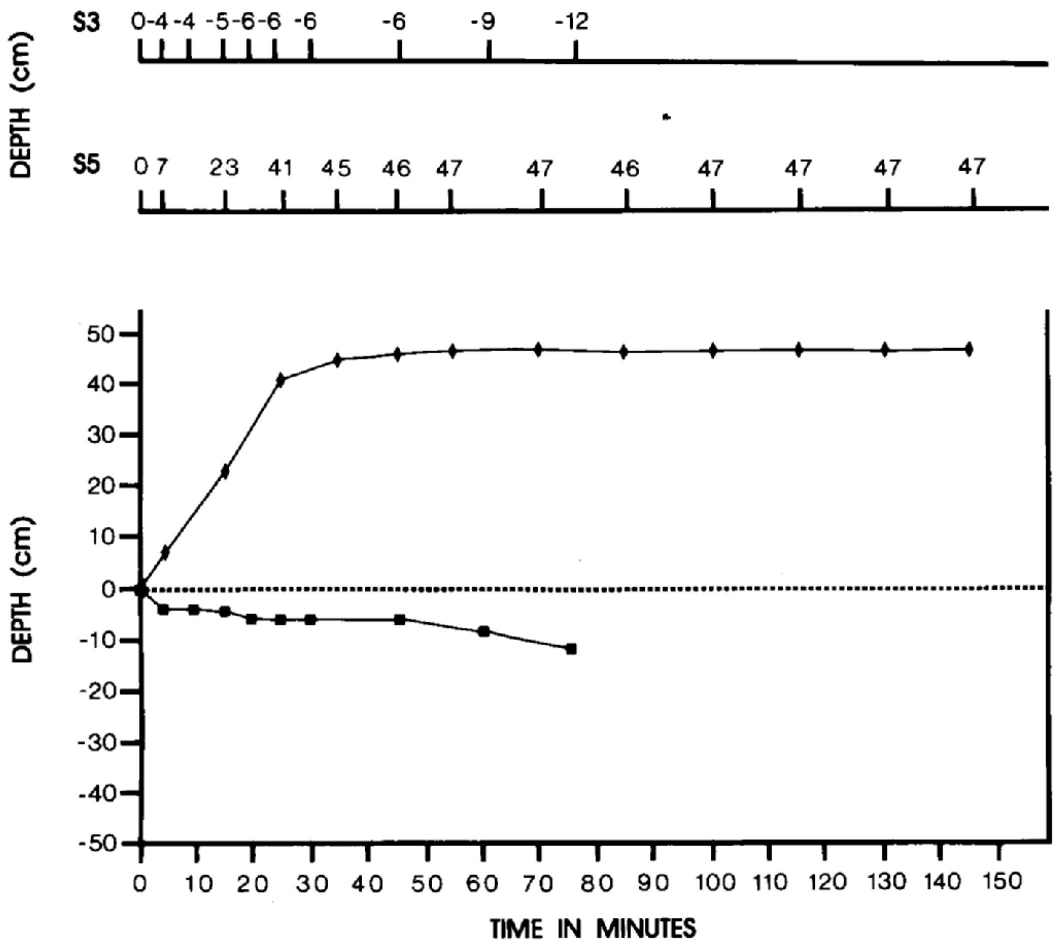


Figure 6. Water Depth for peak event of August 9, 1985 at Sites S3 (■) and S5 (♦).

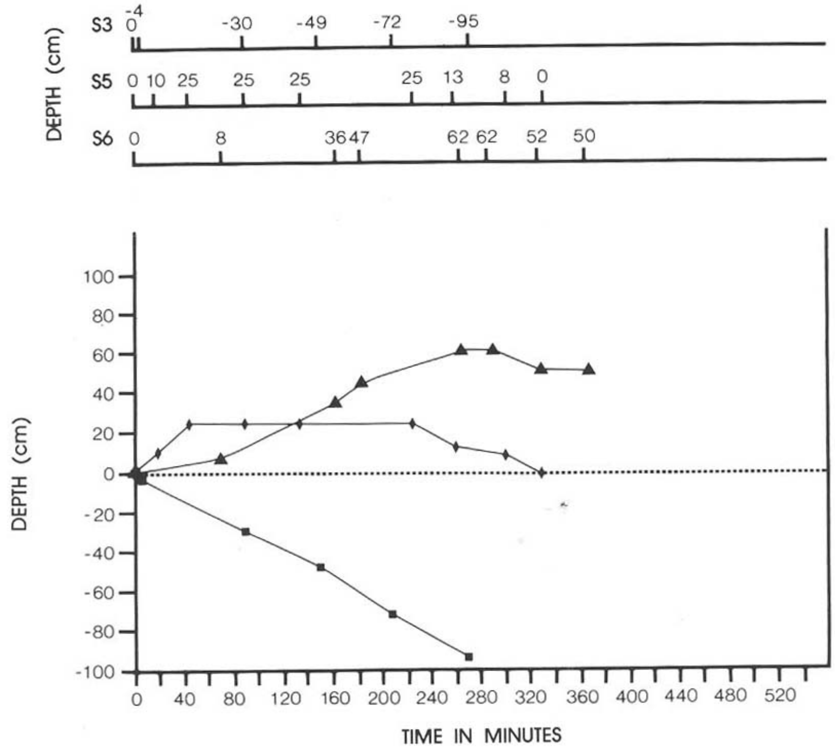


Figure 7. Water Depth for peak event of August 26, 1985 at Sites S3 (■), S5 (♦) and S6 (▲).

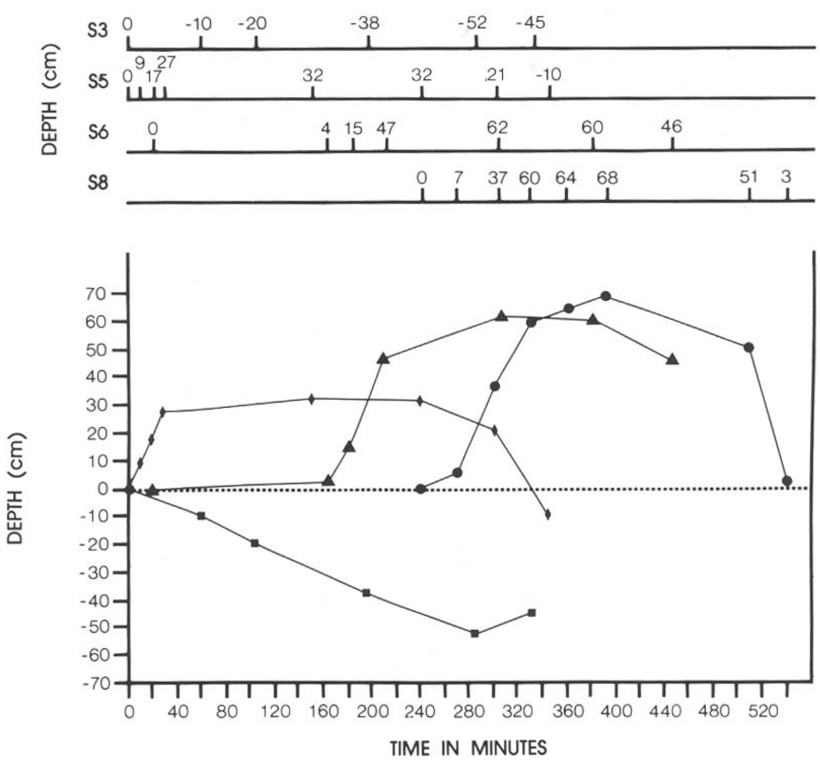


Figure 8. Water Depth for peak event of August 30, 1985 at Sites S3 (■), S5 (♦), S6 (▲) and S8 (●)

Water Quality

Ammonia Nitrogen

Introduction

Ammonia is generated by heterotrophic bacteria as a primary end product of decomposition of organic matter. Although ammonia is a major excretory product of aquatic animals, this is a minor source in comparison to that generated by bacterial decomposition. Ammonia in water is present primarily as NH_4^+ and as un-dissociated NH_4OH, the latter being highly toxic to many organisms, especially fish. The proportions of NH_4^+ to HN_4OH are governed by pH and temperature with the ratio increasing from 3000:1 at pH 6 to 1:1 at pH 9.5 (Wetzel, 1983).

Baseline

Historic baseline data were not available for 1984 and 1985 sampling periods. The 1984 baseline data which were generated showed that concentrations were generally greater in July, possibly due to higher flow, and reduced in August, followed by an increase in September. The increase in concentration that took place in September could have been attributed to the increase in availability of organic matter and the subsequent increase in organic decomposition during the latter portion of summer. At S5 the baseline data that exists for Ammonia-N shows a minimum concentration of 0.08 mg/l , and a maximum of 0.22 mg/l. The reservoir did not appear to impact downstream Ammonia-N. Because of a lack of data points, a graphics baseline was not produced.

Peak 8/9

Concentrations at S5 followed a pattern for all three peak-events with increasing concentration with the onset of the ascending leg, and decreasing but leveling off during the peak plateau and descending leg. The 8-9 peak-event (one turbine) had minimal impact on S5 Ammonia-N when compared to the latter two peak-events. The peak concentration at S5 during the 8-9 event was 0.18 mg/l, which is near the maximum baseline value (Figure 9). (The greatest peak concentration at S5, for all three events, occurred on the 8-26 peak-event with 0.21 mg/l. This level is just below the maximum baseline level of 0.22 mg/l). Pre-sample concentrations at S5 were very similar between the three events (0.08 mg/l, 0.05 mg/l, and 0.07 mg/l respectively). The increase in flow at S3 during the 8-9 event, because of a 12 cm drawdown, may have caused water lower in Ammonia-N from upstream to dilute concentrations at S3. This diluting may have caused the overall decrease in concentration at S3. A “first flush” phenomenon for Ammonia Nitrogen was observed.

Peak 8/26

Preceding the 8/26 peaking event 3.75 inches of rain fell between August 22nd and August 25th (Table V). The peak concentration of 0.6 mg/l, which occurred at S6 during the 8-26 event (two turbines) was ten times greater than the maximum baseline concentration at that site (0.06 mg/l) (Figure 10). This increase can be attributed to the re-suspension of sediments by scouring and first flush as the water level increased with the downstream movement of the initial water surge. Concentrations at S3 during this event remained very low and quite stable, ranging from 0 mg/l to 0.03 mg/l. The lower concentration at S3, compared to the 8-9 event, may have been due to the greater flow and subsequent dilution which was occurring during the 8-26 event.

Peak 8/30

On August 29th, 2.62 inches of precipitation was recorded (Table V). During the 8-30 event (two turbines) the greatest increase in concentration occurred at S6 again, with a peak concentration of 0.26 mg/l (Figure 11). Site S8 did not show a great increase in Ammonia-N, with the pre-sample concentration (0.07 mg/l) being the greatest concentration. This lack of a significant increase in concentration at S8 may have been due to a diluting affect by the Le Sueur River on S8 concentrations. The ten-fold increase in concentration (0.04 mg/l to 0.41 mg/l) which occurred at S3 during the 8-30 event probably represents a “first flush” and also was following a localized storm event on the upstream Blue Earth River which did not impact the Le Sueur River. This concentration was the greatest concentrations occurring during this peak-event for all sites involved.

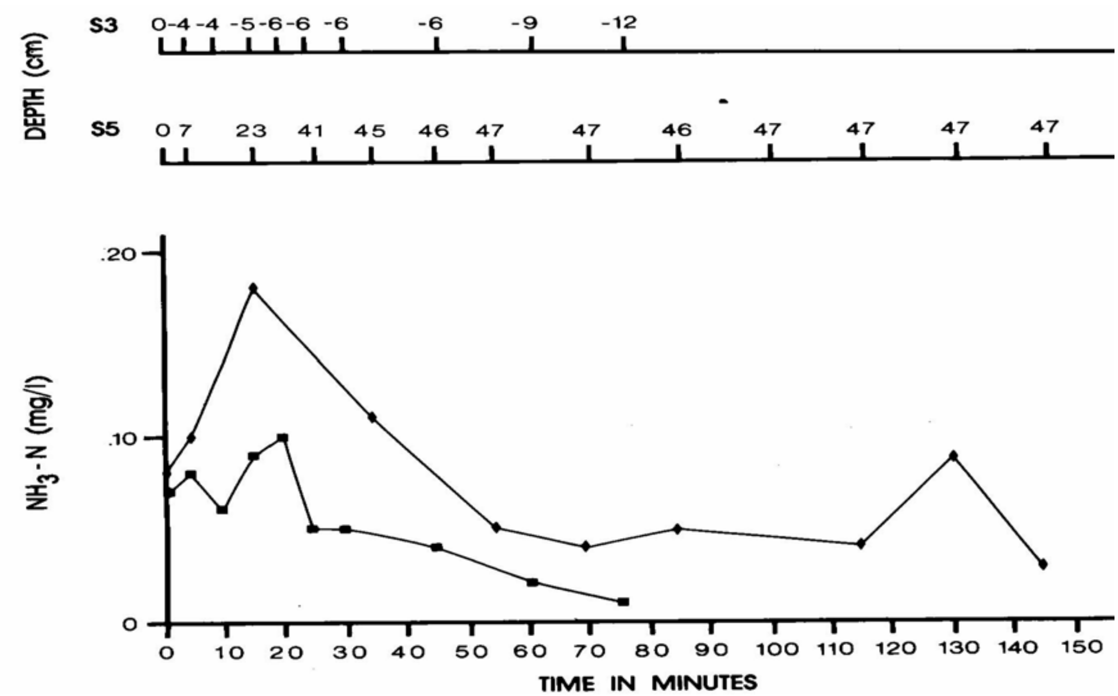


Figure 9. Ammonia-Nitrogen for peak event of August 9, 1985 at Sites S3 (■) and S5 (♦).

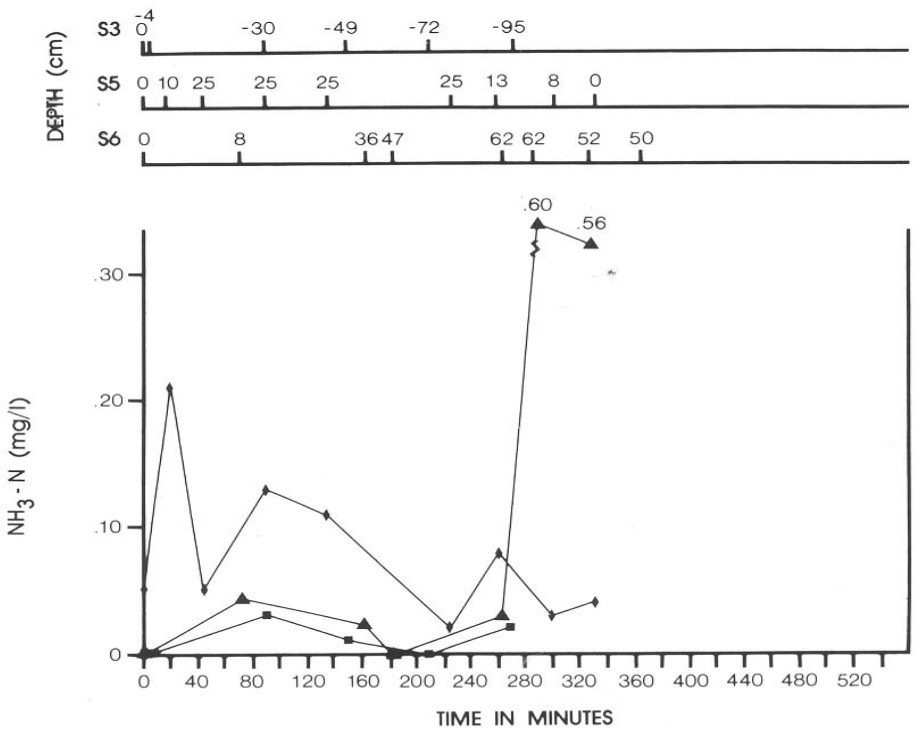


Figure 10. Ammonia-Nitrogen for peak event of August 26, 1985 at Sites S3 (■), S5 (♦) and S6 (▲).

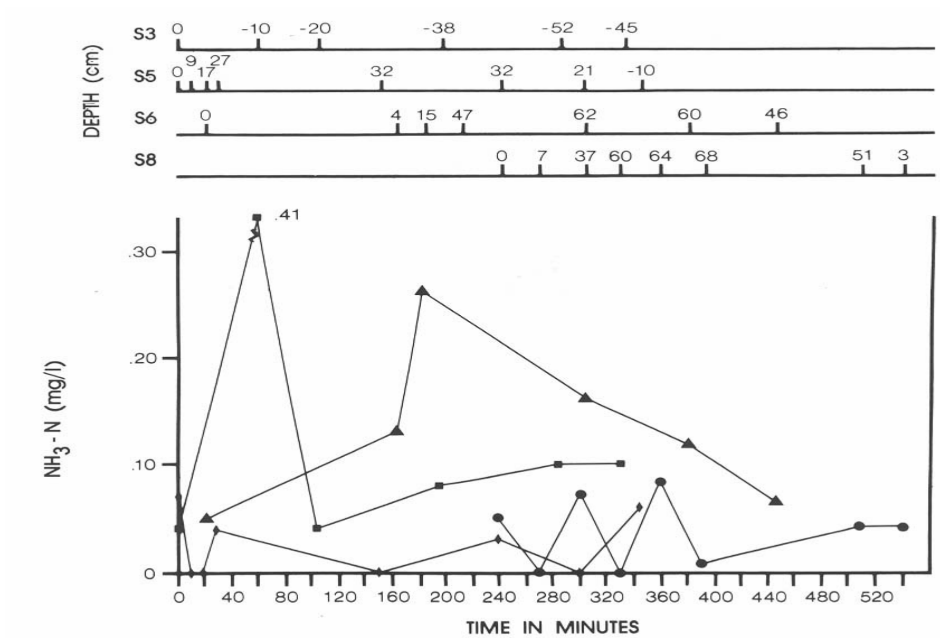


Figure 11. Ammonia-Nitrogen for peak event of August 30, 1985 at Sites S3 (■), S5 (♦), S6 (▲) and S8 (●)

Organic Nitrogen

Introduction

Organic-N is defined as organically bound nitrogen in the tri-negative oxidative state. It does not include all nitrogen compounds such as Ammonia-N, but does include naturally occurring materials such as proteins, peptides, nucleic acids, urea, and numerous synthetic organic materials (APHA, 1980). Dissolved organic nitrogen (DON) often constitutes over 50 percent of the total soluble nitrogen in fresh water and the ratios of DON to particulate organic nitrogen (PON) are usually 5:1 to 10:1 (Wetzel, 1983).

Baseline

Historic Organic-N concentrations at BE-0 were somewhat greater in June, and steadily decreased throughout the summer months on into October (Figure 12). This correlates very well with historic flow patterns (Table VI), where flow is greater in June, and steadily decreases from June to October. The 1984 flow was abnormally higher in June and July, and lower in August through September than historic flow. It was hypothesized that there would be much greater concentrations in June at the mainstem sites due to the abnormally high flow rates, but this did not occur probably because there was abnormally high flow Februarys through May.

In 1985, concentrations were greater than in 1984 at the beginning of the sample period even though flow was much greater in 1984 at that time (5184 cfs in 1984 as compared to 933 cfs in 1985). As the sample period proceeded, concentration patterns resembled the historic data. The 1985 data does differ from the historic data beginning in September when concentrations at all sites began an abrupt increase. This increase can be attributed to abnormally high rainfall occurring at this time and the subsequent increase in flow.

The reservoir does not appear to affect mainstem concentrations

Peaks

Organic-N concentrations at all sites downstream of the dam, during all three peak-events nearly reached or exceeded the maximum baseline concentrations occurring during the entire sampling periods of 1984 and 1985, for their respective sites. However, none of the levels at the downstream sites reached the maximum levels of the historic baseline concentration (2.23 mg/l) for the months of June through October at the Minnesota Pollution Control Agency monitoring station BE-0.

The 8-9 event appeared to have a greater impact on Organic Nitrogen concentrations at S5 than did the 8-26 and 8-30 events (the pre-event concentration to the peak concentration, during the 8-9 event (43% increase) than did the 8-26 event (24%) and the 8-30 event (39%)) (Figures 13, 14, 15). Organic-N at S3 saw an overall decrease during the 8/9 event. The diluting affect from the influx of water from upstream may have caused this decrease, while “first flush” caused the initial peak at S5.

Organic-N concentrations during the 8-26 and 8-30 events did not increase to greater levels at S6 and S8 when compared to S5. Site S3 concentrations during the 8-26 and 8-30 events did not show a consistent decreasing pattern as with the 8-9 event. This may be due to the greater concentrations present, as seen with higher pre-sample readings during the latter two events (1.50 mg/l and 1.46 mg/l), compared to the 8-9 event (1.11 mg/l).

Although peak concentrations at all downstream sites during all three peak events reached or exceeded maximum baseline values, pre-event concentrations for a majority of the sites were already near maximum baseline values. The exception to this was S5 (8-9 event) and S6 (8-26 event), where pre-sample concentrations were within the range of the minimum baseline values for 1984 and 1985. At these two sites, the affects of the peaking operation of the Rapidan Dam on Organic-N resembled early summer high water conditions. The affects on the other downstream sites resembled that of a natural hydrologic event, which could have been produced by approximately one to two inches of rainfall. The increases in concentration at all downstream sites was most likely due to scouring and re-suspension of Organic-N laden detritus and sediment. During the 8-9 event, it is believed that the release of sediment from the reservoir, accumulated during the non-generation days prior to the event in the area of the turbine intakes, was also a contributing source of Organic-N at S5.

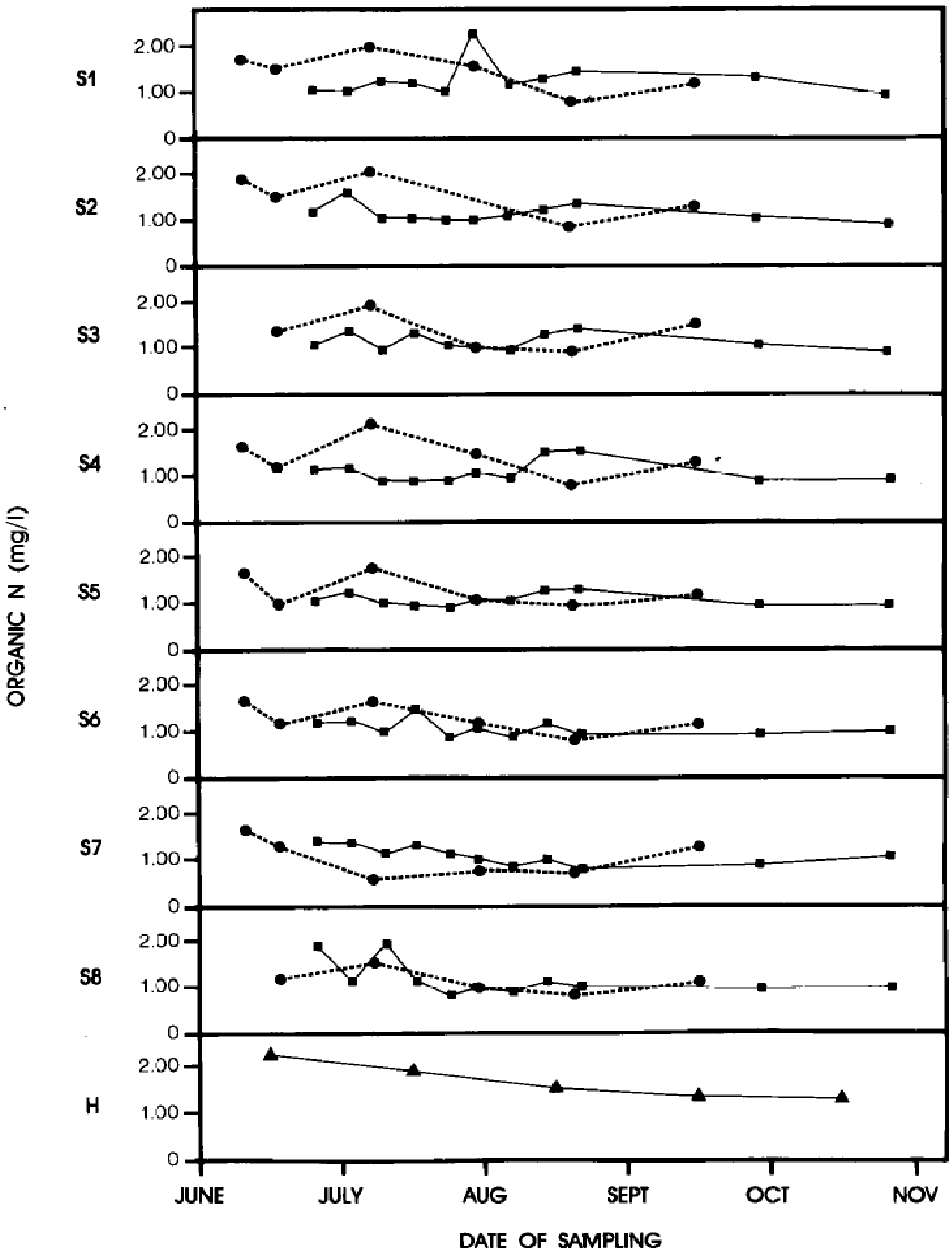


Figure 12. Baseline Organic-Nitrogen for 1984 (■) and 1985 (●) sampling seasons at Sites S1-S8, and historic record for Blue Earth- 0 (▲).

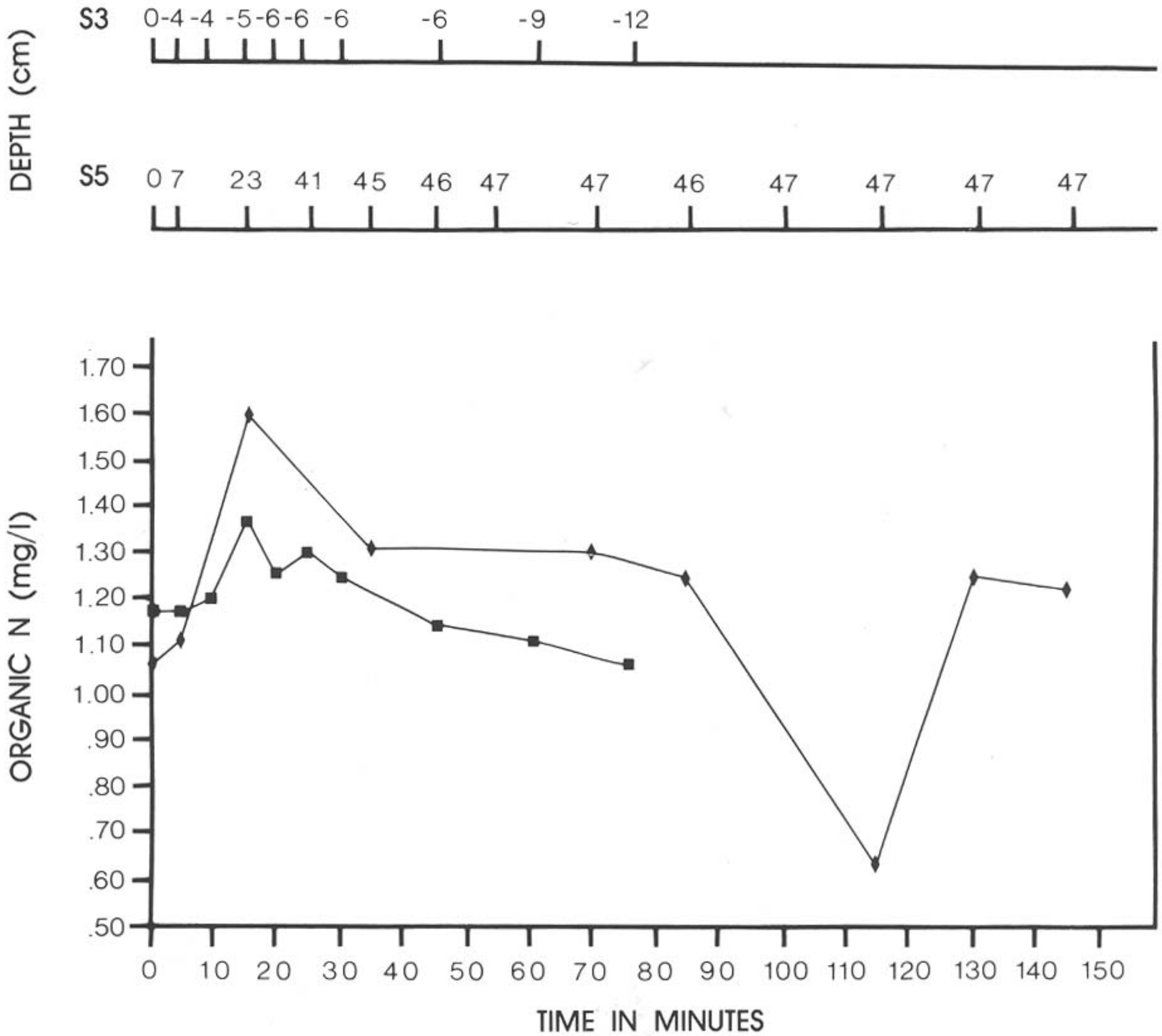


Figure 13. Organic-Nitrogen for peak event of August 9, 1985 at Sites S3 (■) and S5 (♦).

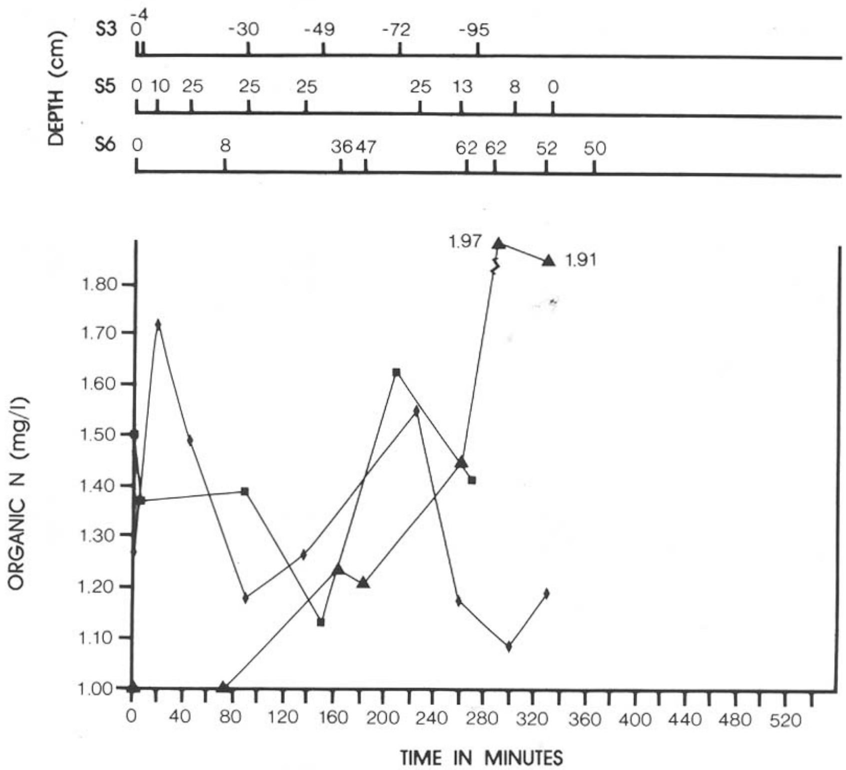


Figure 14. Organic-Nitrogen for peak event of August 26, 1985
at Sites S3 (■), S5 (♦) and S6 (▲).

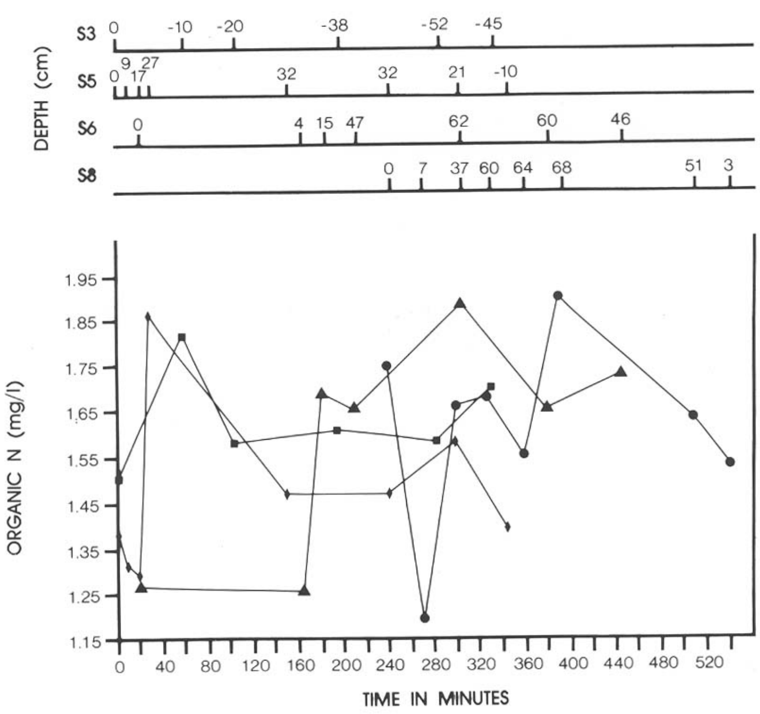


Figure 15. Organic-Nitrogen for peak event of August 30, 1985
At Sites S3 (■), S5 (♦), S6 (▲) and S8 (●) .

Nitrate Nitrogen

Introduction

Nitrate-N is the fully oxidized form of nitrogen, therefore, except under conditions of pollution (reduced environment), will occur naturally in streams (Hynes, 1970). The main sources of Nitrate-N in streams are rainfall, groundwater and the land surface (Hynes, 1970). Nitrate-N is the most readily available form of nitrogen to photosynthetic autotrophs, and in some cases it has been identified as a growth-limiting nutrient (APHA, 1980). The safe drinking water limit is 10 mg/L N-NO_3 and this is exceeded a number of times in our area in the spring and fall. Nitrate-N is very soluble in water and does not attach to soil or sediment very well.

Baseline

Concentrations of N-NO_3 in1984 followed the historic data fairly closely (Figure 16). Greater concentrations occurred in June with a steady decrease as the summer progressed. Minimum concentrations occurred in September followed by increasing concentrations in October. The increase in October and November, during normal low flow, is most likely due to the decomposition of leaf litter and the application of N-NH_3 followed by conversion of some to NO_3.

The increase in concentration, which occurred on the 7-23 sampling date, may be associated with the sampling occurring on the ascending leg of a hydrologic event due to rain fall in the Iowa/Minnesota border stretch of the Blue Earth River. An increase in flow from the previous day was recorded on the sampling date at the USGS flow station just below the Rapidan Dam. Although flow was abnormally high in May, June, and July, concentrations were only slightly greater than historic concentrations for the same months.

In 1985, minimum concentrations occurred much earlier than historic patterns. This is due to the abnormally low flow in July and early August. The increase in concentration, which the historic data depicts as beginning in October, occurs in late August of 1985. This again, is attributed to flow, which was very high in late August.

No impacts by either the reservoir or the two tributaries on mainstem concentrations were observed.

Peaks

Nitrate-N concentrations followed flow very closely. Concentrations at S5 did not appear to be significantly different when comparing all three peak-events (Figures 17,18,19). Site S3 concentrations during the 8-30 peak-event were much greater than the other three sites involved, and cannot be explained at this time. As the initial water surge moved downstream, concentrations at S6 (8-26 event), and S6 and S8 (both of the 8-30 event), show significant increases in Nitrate-N. Recruitment from bank storage and scouring of stream sediments can be attributed to these increases in concentration.

The increases of Nitrate-N at sites S6 and S8 may appear to be significant, but when compared to the baseline data they actually are not. The minimum baseline concentration for the entire sampling periods of 1984 and 1985 at sites S5, S6, and S8 were approximately equal to the maximum concentrations occurring at these sites during each peak-event. Baseline maximums at these three sites during the entire sampling periods of 1984-1985 ranged between 10.00 mg/l to 13.99 mg/l N-NO_3. Peak concentrations at S5, S6, and S8 during all three peak events, did not reach or exceed the minimum historic baseline concentration of 0.43 mg/l during the months of June through October. Therefore, it can be concluded that the peaking operation of the dam was not affecting Nitrate-N concentration to any significant degree.

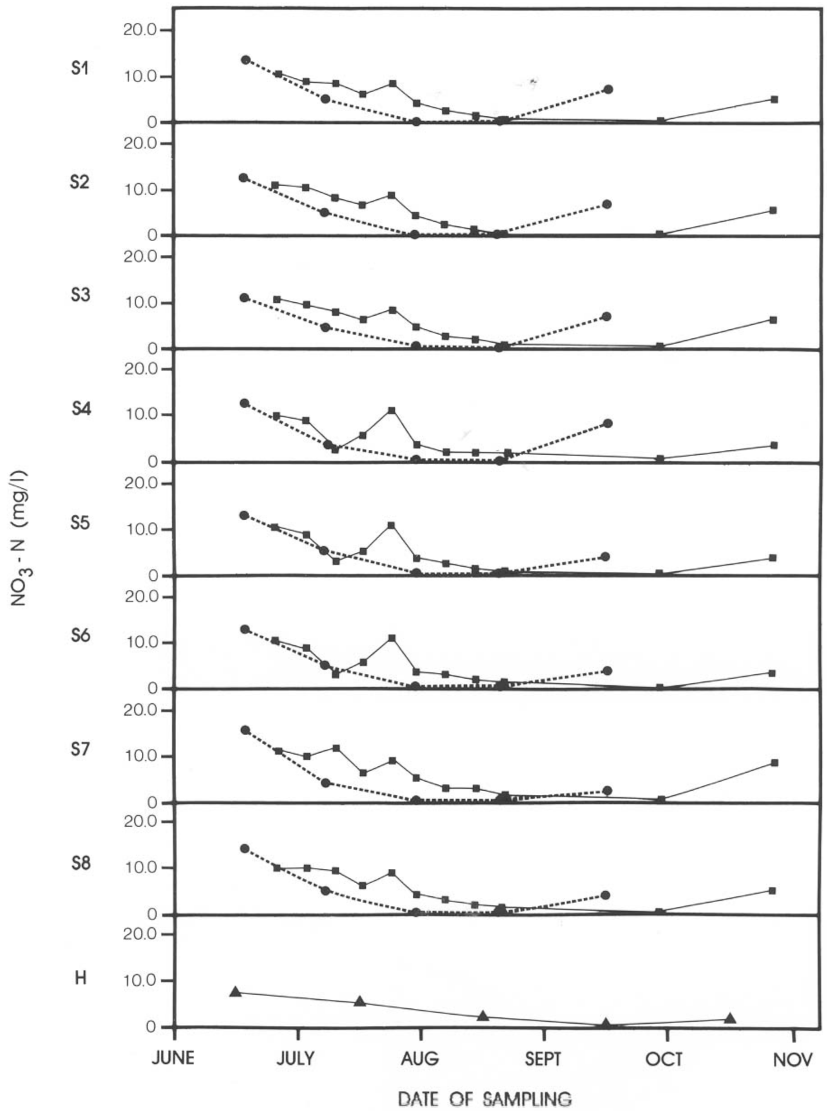


Figure 16. Baseline Nitrate-Nitrogen for 1984 (■) and 1985 (●) sampling seasons at Sites S1-S8, and historic record for Blue Earth – 0 (▲).

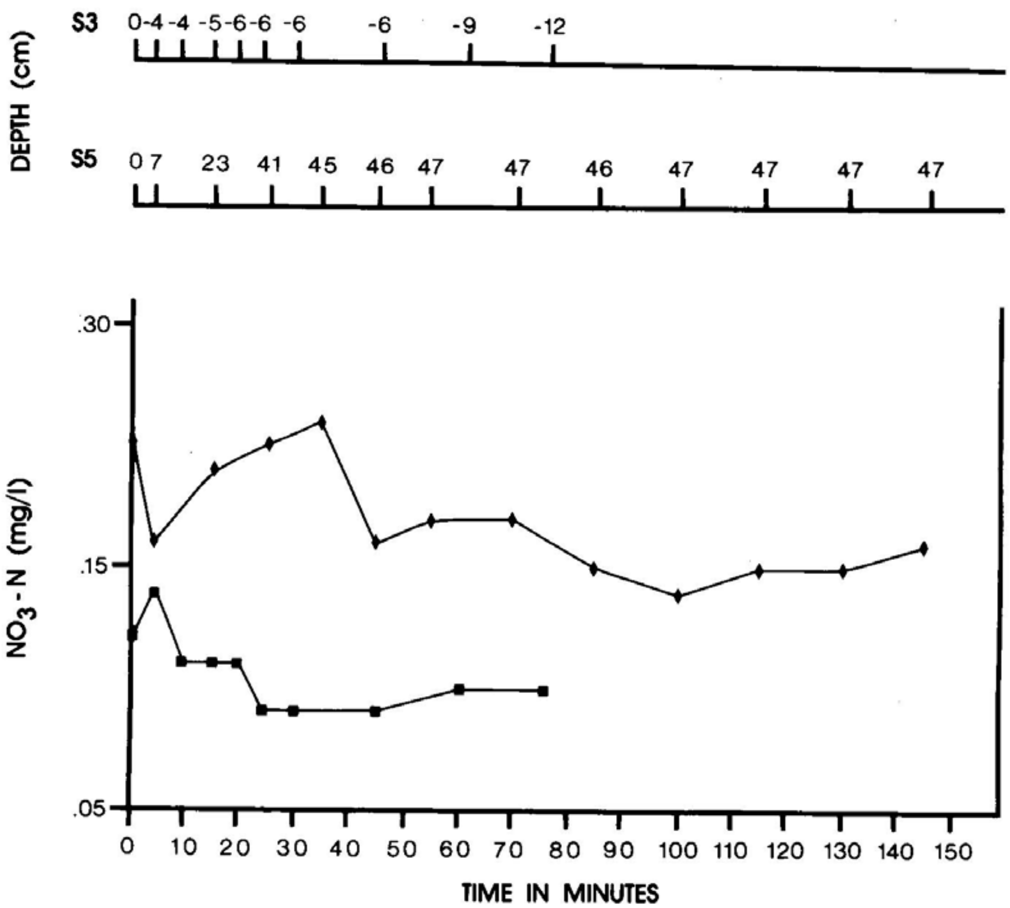


Figure 17. Nitrate-Nitrogen for peak event of August 9, 1985 at Sites S3 (■) and S5 (♦).

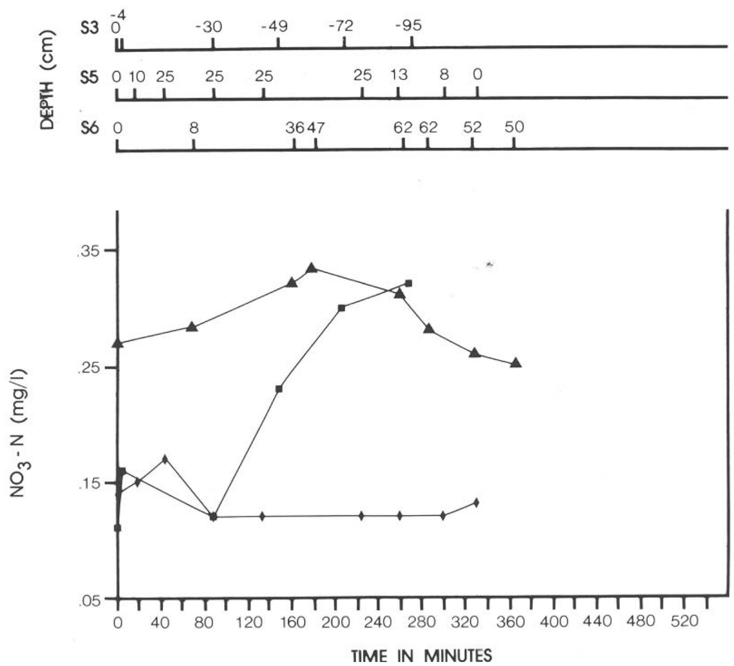


Figure 18. Nitrate-Nitrogen for peak event of August 26, 1985 at Sites S3 (■), S5 (♦) and S6 (▲).

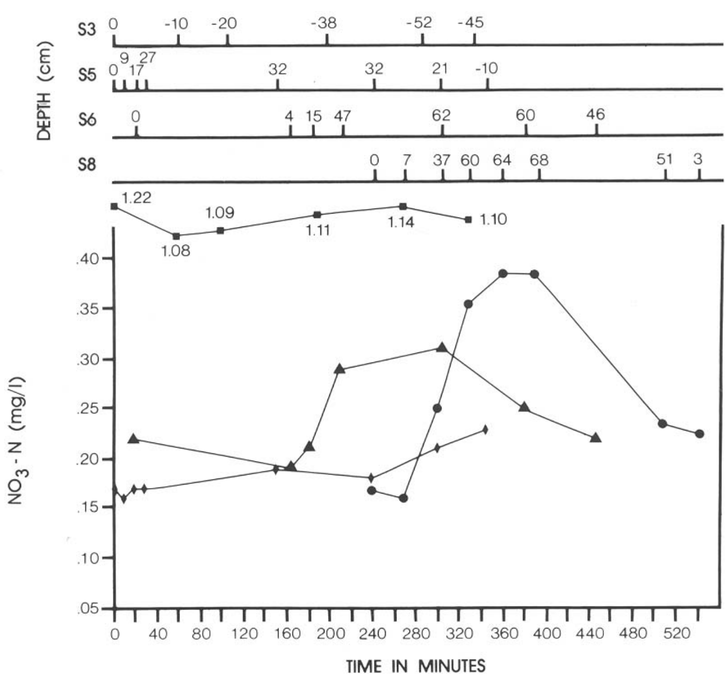


Figure 19. Nitrate-Nitrogen for peak event of August 30, 1985 at Sites S3 (■), S5 (♦), S6 (▲) and S8 (●) .

Nitrite-Nitrogen

Introduction

Nitrite-N is an intermediate oxidation state of nitrogen, both in the oxidation of ammonia to Nitrite, and in the reduction of nitrate (APHA, 1976). Concentrations of nitrite are usually very low unless organic pollution is high such as in the interstitial waters of sediments in eutrophic lakes (Wetzel, 1983). This could be the case in the interstitial waters (hyporheic zone) of nutrient laden rivers.

Baseline

Concentrations (in units of ppb) in 1984 followed historic data patterns closely except for a sharp increase at all sites in October (Figure 20). An increase in Nitrite-N during August was especially evident at sites S4 through S8. Increased rates of decomposition may have been occurring within the reservoir, thereby producing the higher concentrations of Nitrite-N than at sites upstream of the reservoir.

There does not appear to be any consistent impact by the tributaries on mainstem concentrations, however the reservoir does appear to impact mainstem concentrations by increasing them in its tailwaters during the months of August in 1984, and July in 1985.

Peaks

Concentrations at S3 during the 8-26 peak-event followed a very similar pattern, as did Nitrate-N, where an increase was seen throughout the decrease in water level at the site. Concentrations were also very high at S3 during the 8-30 event. The high concentrations could have been due to nitrification occurring at the site (Figures 21, 22, 23).

The peaks in concentration at sites S6 and S8 during the 8-26 and 8-30 events did not show the increases that were seen with Nitrate-N, however, less dramatic increases were present at these sites.

The greatest concentration which occurred downstream of the reservoir during all three peak-events was 1.91ug/l at S5 during the 8-9 event (a 65% increase). A decrease of 83% in concentration occurred with the onset of the peak plateau. This concentration was much lower than the maximum concentrations occurring during the entire sampling period of 1984-1985 at S5, S6, and S8. The range of maximum baseline concentrations at these three sites was 11.00 ug/l to 28.00 ug/l. The minimum, historic baseline monthly mean concentration at BE-0, for the months of June through October was 18 ug/l. Therefore, the maximum peak event concentration of 1.91 ug/l is insignificant. It can be concluded that the peaking operation of the Rapidan Dam has no significant impact on downstream Nitrite-N concentrations.

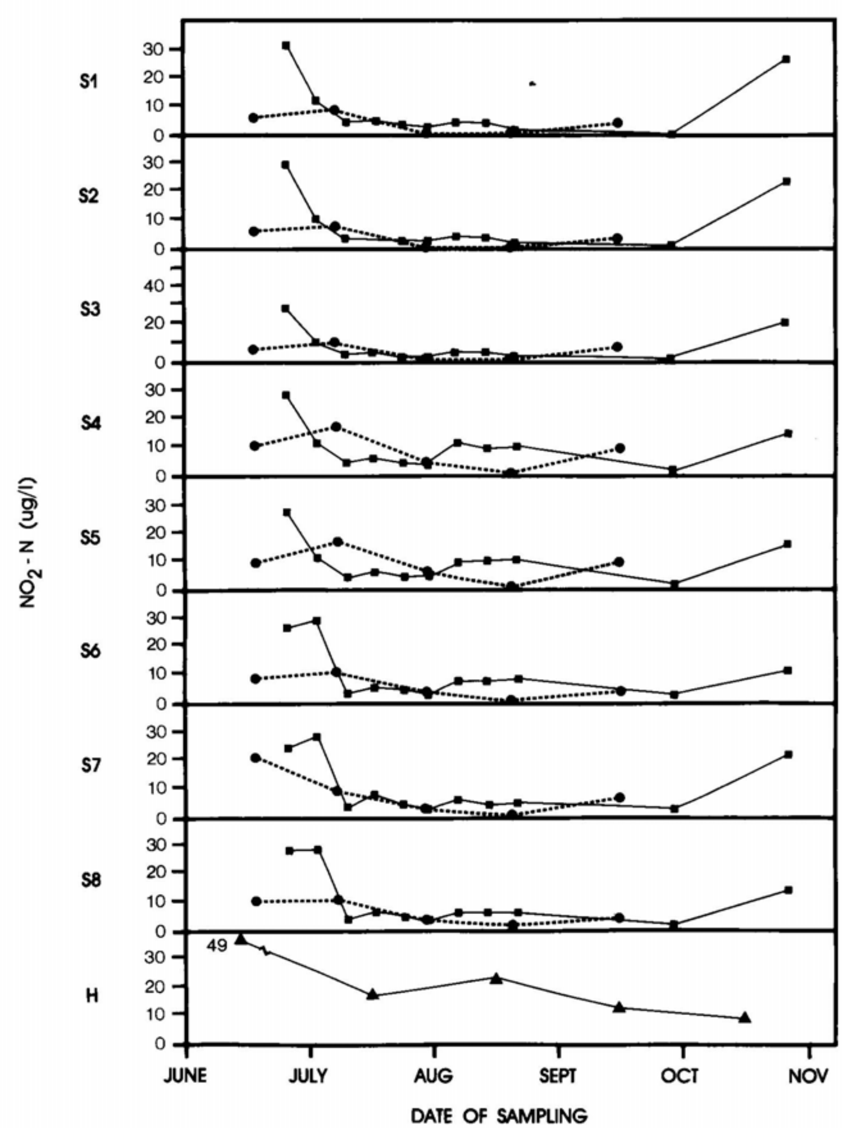


Figure 20. Baseline Nitrite-Nitrogen for 1984 (■) and 1985 (●) sampling seasons at Sites S1-S8, and historic record for Blue Earth – 0 (▲).

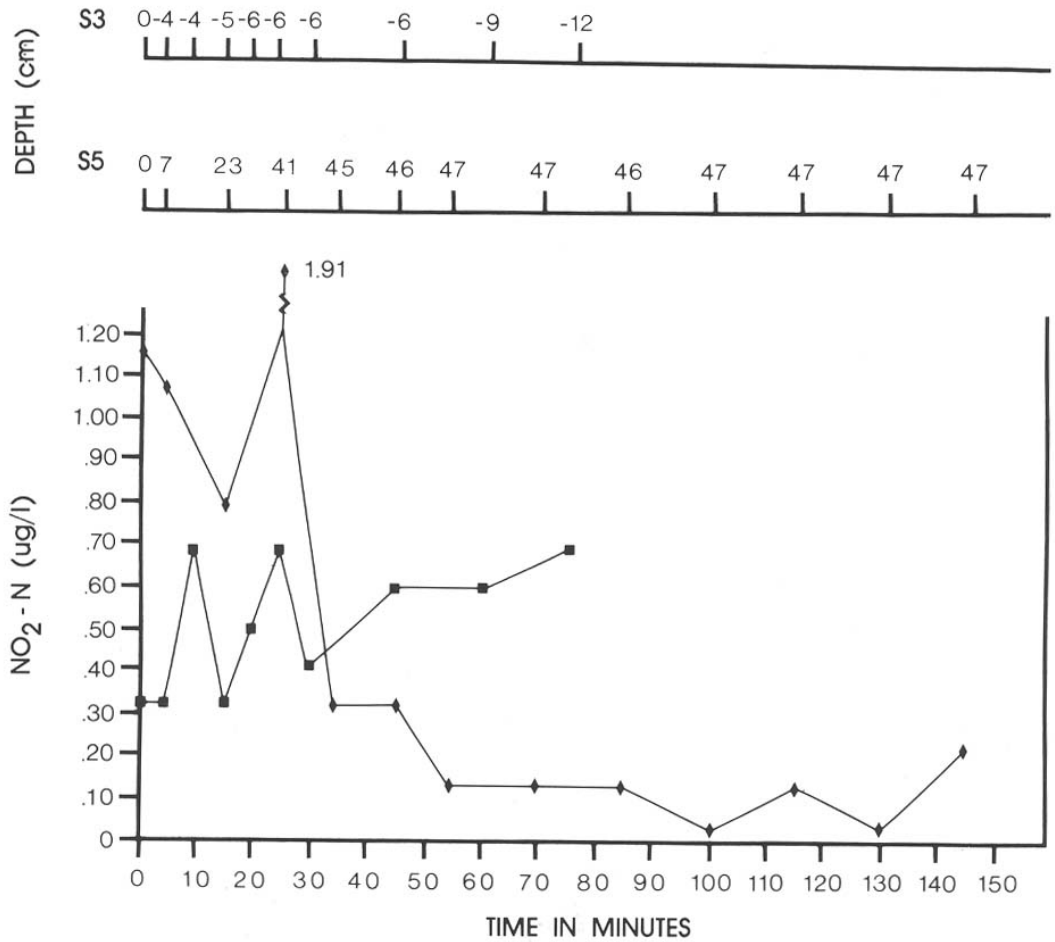


Figure 21. Nitrite-Nitrogen for peak event of August 9, 1985 at Sites S3 (■) and S5 (♦).

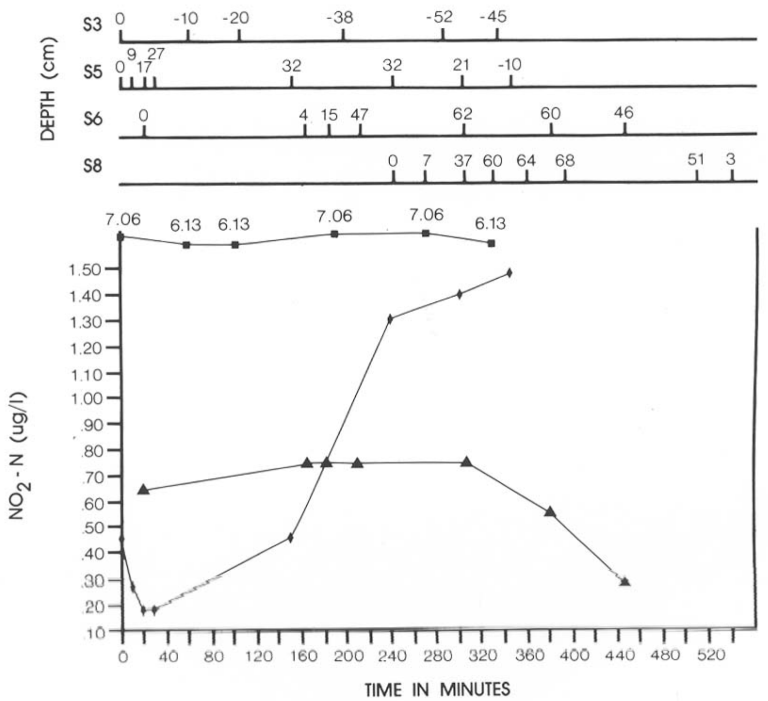


Figure 22. Nitrite-Nitrogen for peak event of August 26, 1985 at Sites S3 (■), S5 (♦) and S6 (▲).

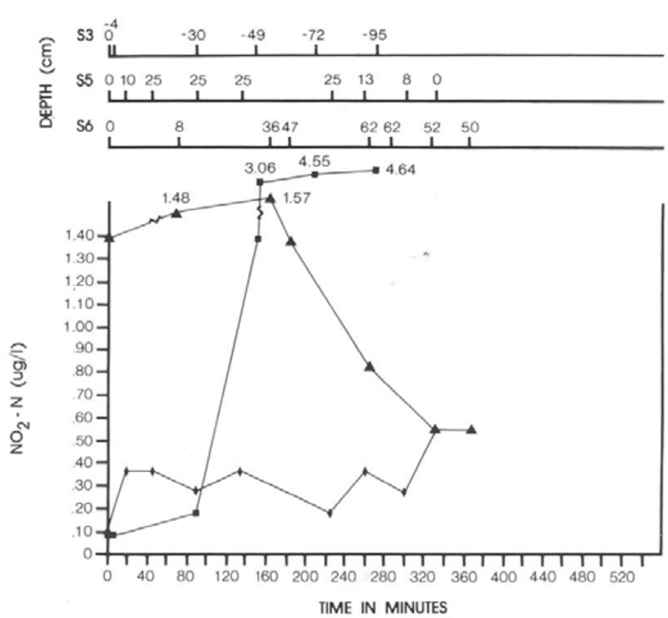


Figure 23. Nitrite-Nitrogen for peak event of August 30, 1985 at Sites S3 (■), S5 (♦), S6 (▲) and S8 (●) .

Total Phosphorus

Introduction

Phosphorus can be found in natural systems as inorganic forms and incorporated into organic compounds (APHA, 1980), both of which can be precipitated out of the water column within a reservoir.

Baseline

Historic Total-P at BE-0 was high in June and gradually decreased throughout the summer months, and continued to decrease into the month of October (Figure 24). Surprisingly, concentrations during June of 1984 were lower at most sites than historic values, despite the very high flow rates occurring at this time. Total-P in 1984 did follow historic patterns rather well in terms of a gradual decrease throughout summer. However, the decrease did lead to below historic concentrations. Concentrations did begin to increase to historic levels in October at all sites.

Despite a relatively normal flow year up until the month of June in 1985 concentrations began the sample period in June lower than historic means. Total-P at all sites except S4, followed the usual decrease as the summer progressed to below normal concentrations. Concentrations at S4 increased slightly between June and August. This increase could be attributed to the drought conditions occurring during July and early August, and the subsequent concentrating of Total-P due to evaporation within the reservoir, and/or high rates of decomposition within the reservoir. Total-P between the 7/30 and 9/15 sampling dates, did increase to greater than historic concentrations. This increase is most likely due to the abnormally high rainfall and subsequent increasing overland flow causing more runoff and an increased amount of TSS. Also if dissolved oxygen levels in the reservoir became limiting, phosphorus would have been released by the sediments.

The reservoir did show evidence of acting as a trap for Total-P by lowering mainstem concentrations downstream during a majority of the sampling dates.

Peaks

Total phosphorus concentrations reached or exceeded baseline maximums during all three peak-events at various downstream sites, but did not reach the mean monthly historic maximum for June through October at BE-0 at 0.51 mg/l.

August 9: Total-P concentrations at S5 saw an increase during the ascending leg of 80% (Figure 25). Concentrations decreased with the onset of the peak plateau. Concentrations at S3 showed an initial decrease during the ascending leg and then a rise with a gradual rise through the remaining peak plateau.

August 26: Pre sample concentrations were very similar at all sites (Figure 26). Total Phosphorus concentrations at S5 increased 23%, at S6-138% and at S3-43%.

August 30: Pre sample concentrations were fairly similar. Total Phosphorus concentrations at S5 increased 18%, at S6-160%, and at S8-125% and decreased 19% at S3 (Figure 27).

One must keep in mind that flow rates in the Blue Earth River were on the increase, beginning approximately one week prior to the 8-26 event, and continued into the 8-30 peak-event with record rainfall occurring for the month of August in 1985. This may account for the greater concentrations during the 8-30 event when compared to the 8-26 peak-event.

The initial downstream surge of water released from the turbine outlets produced an increase in Total-P comparable to a natural hydrologic event caused by approximately one to two inches of rainfall. However, the significant increases in Total-P were seen 13.1 river km to 16.0 river km (8.1 river mi to 9.9 river mi) downstream with insignificant increases occurring 0.6 river km (0.4 river mi) downstream of the dam. The greater concentrations occurring downstream of S5 may have been attributed to sources including scouring of sediments and recruitment from bank storage as downstream water levels increased.

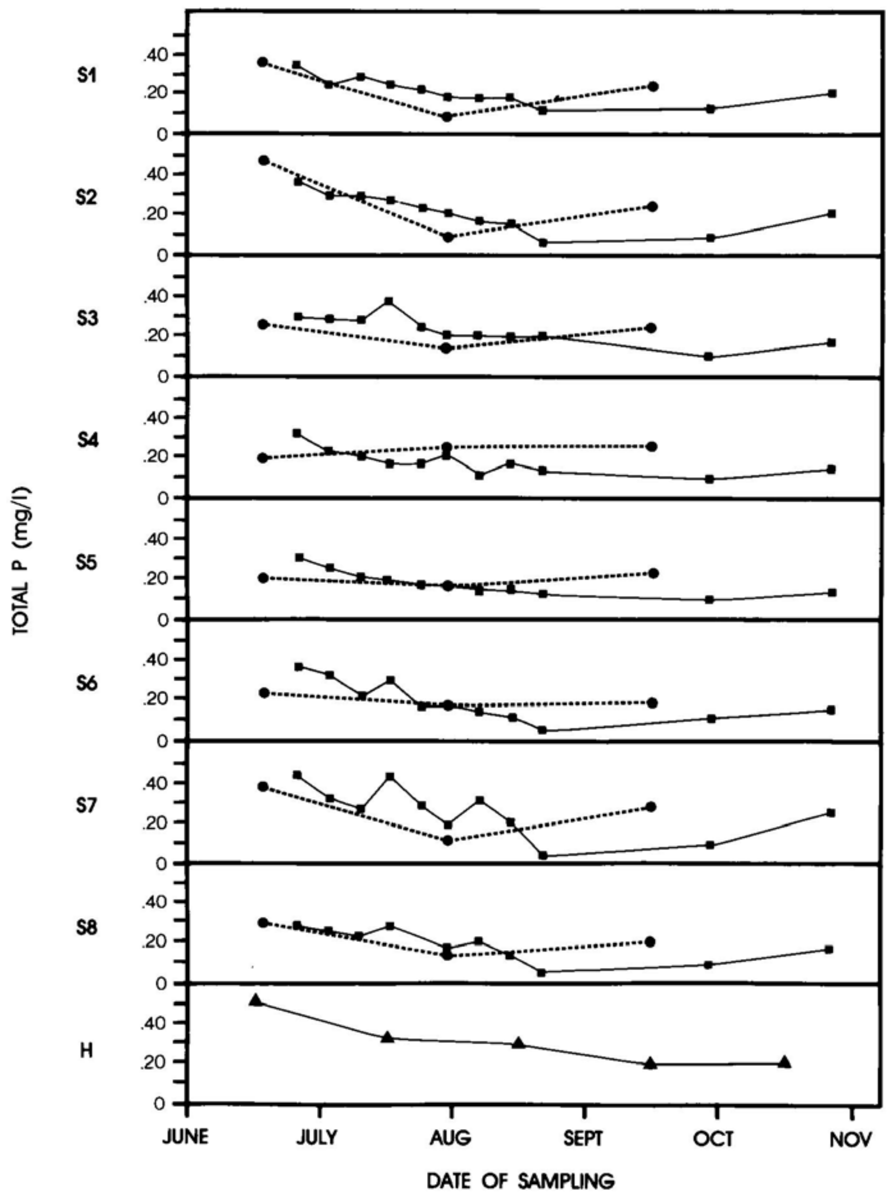


Figure 24. Baseline Total Phosphorus for 1984 (■) and 1985 (●) sampling seasons at Sites S1-S8, and historic record for Blue Earth- 0 (▲).

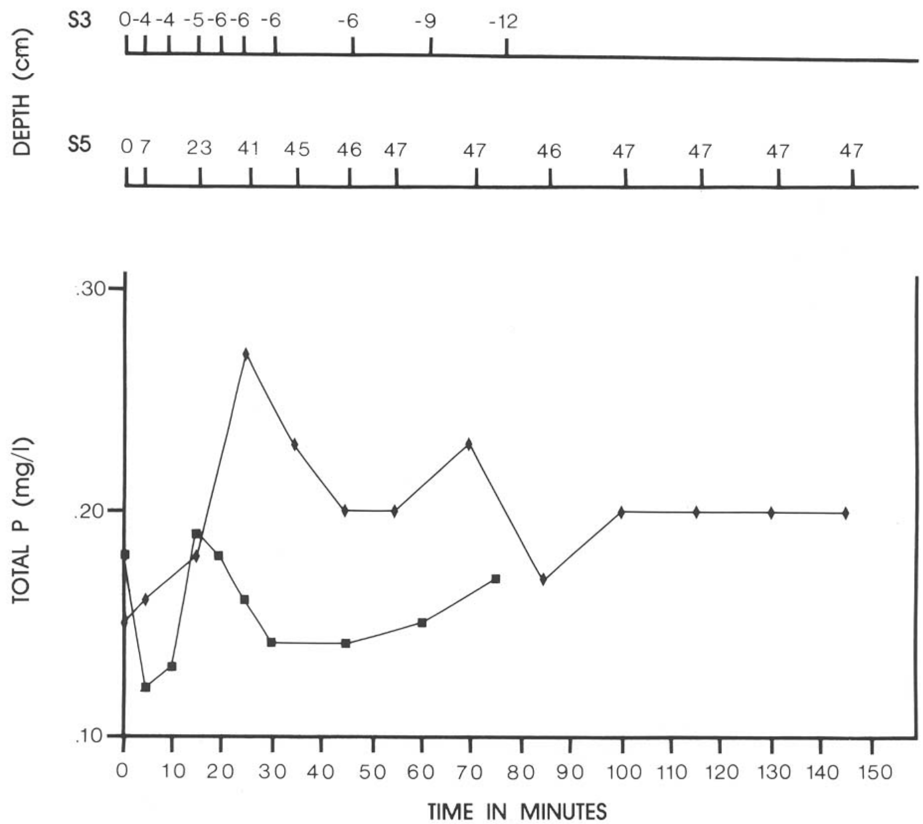


Figure 25. Total Phosphorus for peak event of August 9, 1985 at Sites S3 (■) and S5 (♦).

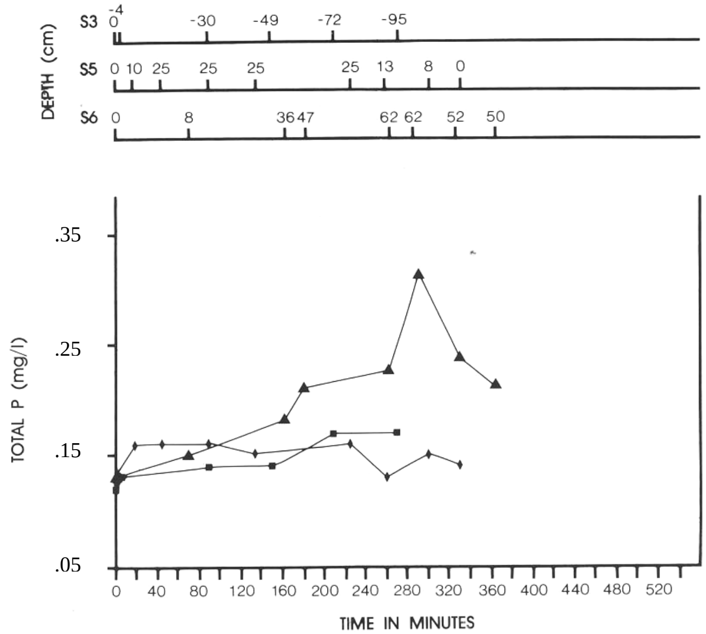


Figure 26. Total Phosphorus for peak event of August 26, 1985 at Sites S3 (■), S5 (♦) and S6 (▲).

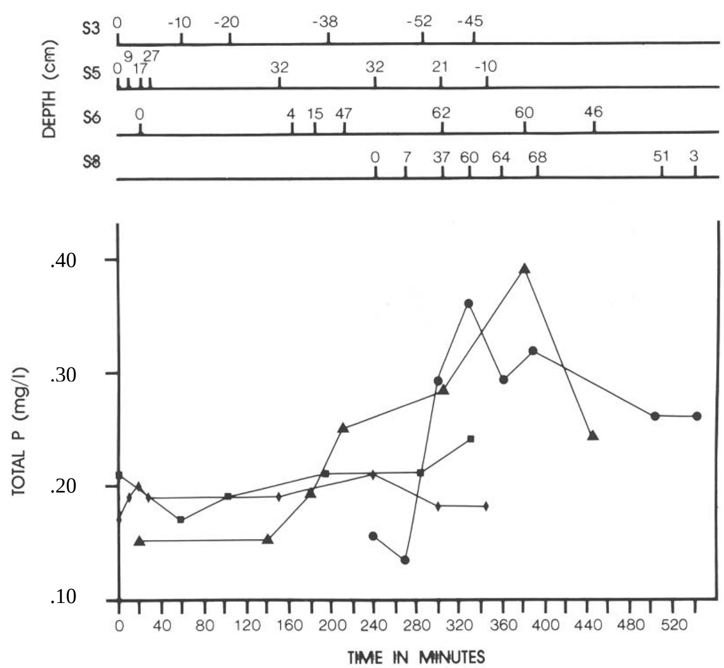


Figure 27. Total Phosphorus for peak event of August 30, 1985 at Sites S3 (■), S5 (♦), S6 (▲) and S8 (●) .

Filterable Phosphorus

Introduction

Filterable Phosphorous (Orthophosphate PO_4^{3-}) is the only directly utilizable from of soluble inorganic phosphorous. Phosphate is extremely reactive and interacts with Fe and Ca, under oxidizing conditions, to from insoluble compounds. Filterable phosphate is also reduced by adsorption to inorganic colloids and particulate compounds such as clays, carbonates and hydroxides (Wetzel, 1983). Algae can at time remove almost all Filterable Phosphorous from the water. Filterable phosphorus concentrations are usually expressed in parts per billion (ug/l) because 10 ug/L is the Minnesota Pollution Control Agency Action level for P- PO_4^{3-}. The reader should be cautious when reading this section that there is 1000 fold difference between parts per million (mg/l) used to express Total Phosphorus and parts per billion (ug/L) used to express levels of P- PO_4^{3-}. For example 1 mg/l (part per million) equals 1000 ug/l (parts per billion)

Baseline

The limited baseline data (many samples below detection) that exists for Filterable-P shows a minimum concentration of 40 ug/l (0.040 mg/l) and a maximum concentrations of 120 ug/l (0.120 mg/l) , at S5.

Peaks

During the 8-9 event, the pre sample concentration at S5 (58 ug/l) was greater than the minimum baseline value (Figure 28). However, the peak concentration (74 ug/l) at S5 during the same peak-event did not reach the maximum baseline value. The great increase in Filterable-P at S5 (857 ug/l) during the 8-26 event was due to oil, suspended within the water column, passing through the site. The oil resulted from an oil spill at the dam. The peak concentration at S3 (49 ug/l) was below the minimum baseline concentration of 60 ug/l for this site.

Peak concentrations during the 8-26 and 8-30 events at S6 (49 ug/l and 75 ug/l respectively) and S8 (44 ug/l), resembled an increase in concentration one would normally expect following one to two inches of rainfall (Figure 29, 30). These peak concentrations did not reach the maximum baseline values of 110 ug/l and 130 ug/l at S6 and S8 respectively. The affect of the peaking operation of the dam was magnified as you moved farther downstream, but only as far as S6 (13./1 river km, 8.1 river mi downstream of the dam). The peak concentrations at S8 were much lower than at S6. This could have been due to a diluting affect by the Le Sueur River on S8 Filterable-P concentrations. Similar to the 8-9 event, peak concentrations at S3 during the 8-26 and 8-30 events (42 ug/l and 49 ug/l respectively) never reached the minimum baseline concentration for the site (60 ug/l). The peak concentrations for the latter two events were actually the pre-sample concentrations. Filterable-P possessed an overall decrease during both events, possibly indicating dilution from upstream as flow increased.

The lack of a sufficient number of data points for Filterable-P gives an unclear picture as to the baseline characteristics of this parameter. However, when looking at existing baseline data, Filterable-P did not appear to be impacted as significantly, nor as consistently, as was Total-P downstream of the Rapidan Reservoir due to the peaking operation of the dam.

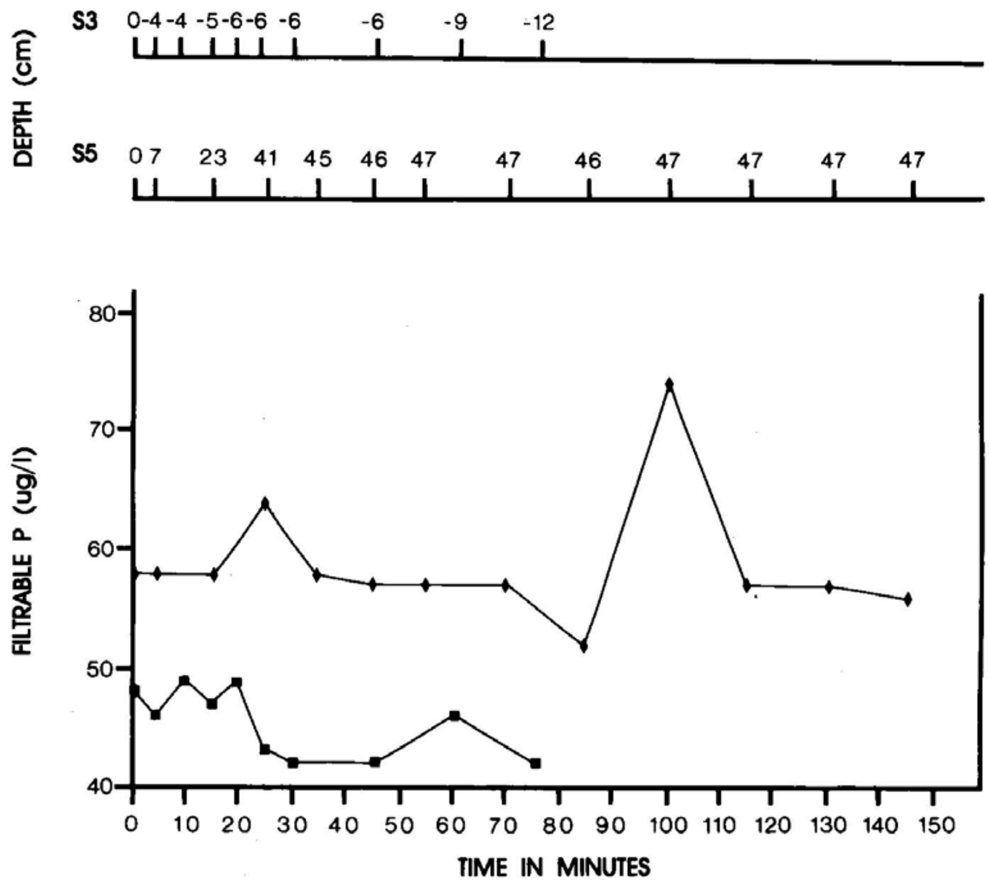


Figure 28. Filterable Phosphorus for peak event of August 9, 1985 at Sites S3 (■) and S5 (♦)

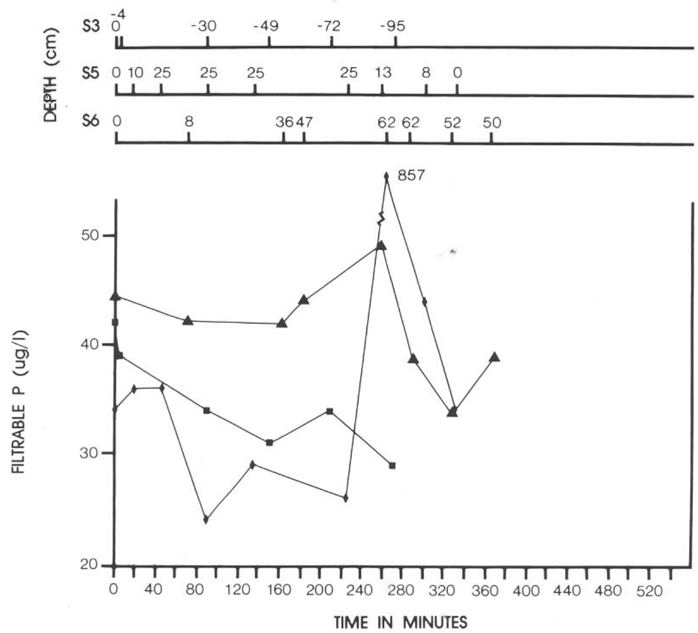


Figure 29. Filterable Phosphorus for peak event of August 26, 1985 at Sites S3 (■), S5 (♦) and S6 (▲)

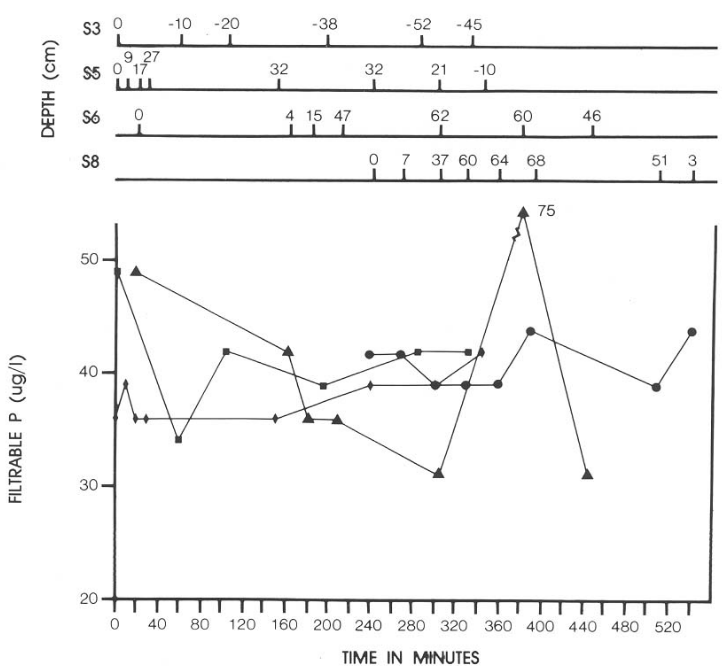


Figure 30. Filterable Phosphorus for peak event of August 30, 1985 at Sites S3 (■), S5 (♦), S6 (▲) and S8 (●).

Total Non-Filterable Residue (TNFR)

Introduction

The term "residue" refers to solid material, organic or inorganic, suspended or dissolved in water. The phrase "total non-filterable residue" refers to the solid material (organic or inorganic) which will not filter through a 0.45 um glass-fiber filter, and therefore becomes trapped in the fibers of the filter (suspended solid material), (APHA, 1980). Turbidity and TNFR are closely correlated, but measured differently. At times of low flow, most streams are normally less turbid than during hydrologic events when large amounts of TNFR may be carried in the water column (Hynes, 1970). Today, TNFR is referred to as Total Suspended Solids or TSS. The relationship between TSS and flow is a fairly well documented phenomenon. Lakes or reservoirs on the course of a stream allow great amounts of TNFR to settle out by reducing the velocity of the stream, thus clarifying the water (Symons et al., 1964).

Baseline

Historic data at BE-0 demonstrates the relationship between flow and TSS very well (Figure 31). TNFR concentrations were greater in June with high flow, gradually decreasing with flow through the months of July and August, and remaining low with flow into October.

In 1984, concentrations were lower at all sites than the historic data, even though flow was above historic records on the 6-25 sampling date. The lower concentrations could be attributed to the fact high flows in March through May resulted in a scouring and flush of the stream resulting in lower TNFR in June. Looking at TNFR concentrations a week later further strengthens this hypothesis. On the 7-2 sampling date, flow decreased and TNFR increased at all sites except S3. Site S3 TNFR increases again on the 7-16 sampling which correlates well with the closing of the dam's tainter gates to flood the reservoir. The reservoir did show evidence of acting as a trap for TNFR, because sites upstream of the reservoir had greater concentrations than did the sites downstream.

In 1985, TNFR reduced considerably within the reservoir on the first sampling in June. The reservoir appeared to stabilize TNFR at S5 and S6 throughout the entire sample period. Concentrations at all sites began to increase in late August/early September, contrary to historic patterns. This is believed to have occurred due to the abnormally high flow occurring at this time.

The Le Sueur River did contribute elevated TNFR to mainstem concentrations in the Blue Earth River during the entire 1984 and the early season of 1985. This did not happen throughout the 1985 sampling period because of the abnormally low flows. .

Peaks

Overall impacts on TNFR caused by the initial downstream surge of water resembled a natural hydrologic event. Increases in TNFR at S5 were more pronounced during the 8-9 event than the 8-26 and 8-30 peak-events (Figures 32, 33, 34). The maximum baseline concentrations at S5 were 226 mg/l and 84 mg/l in 1984 and 1985 respectively. The historic maximum mean monthly concentration, during June through October, at BE-0 was 274 mg/l. The peak concentration at S5 during the 8-9 event (142 mg/l), was approximately one-half the historic maximum. Peak concentrations at S5 during the 8-26 (46 mg/l) and 8-30 (73 mg/l) events were considered insignificant. The pre-sample concentrations at this site during all three peak-events, were fairly similar (49 mg/l, 38 mg/l, and 57 mg/l respectively), and were less than the mean historic reading at BE-0 for the month of August. Site S3 concentrations tended to decrease during the event from pre-sample of 75 mg/l, which was also the peak concentration. Baseline maximums for this site were 229 mg/l and 108 mg/l in 1984 and 1985 respectively.

The affects of a power generation water release on downstream water quality after many consecutive days of no power generation, compared to a water release preceded by a run-of-the-river operating mode, is evident when comparing the peak TNFR concentrations for the three peak-events. The increase in TNFR during the 8-9 event is much more abrupt than the 8-26 and 8-30 events, and the peak concentration is much greater (142 mg/l compared to 46 mg/l and 73 mg/l respectively). The increase in TNFR at S5 during the 8-9 event could be contributed to three possible sources, scouring of the substrate between the dam and S5, recruitment of sediment from bank storage, and the re-suspension of sediments believed to have been deposited immediately upstream of the dam, within the reservoir, near the turbine intakes.

As seen with the parameter Total-P, TNFR peak concentrations at S6 during the 8-26 and 8-30 events (157 mg/l and 150 mg/l respectively), and S8 during the 8-30 event (310 mg/l) were much greater than at S5 (46 mg/l, 73 mg/l) during the same peak-events. Peak concentrations at S6, during the 8-26 and 8-30 events, resembled that of the peak concentration occurring at S5 during the 8-9 event. Similar to the S5 peak concentration, the S6 concentration resembled an increase one would expect to see with a natural hydrologic event produced by one to two inches of precipitation. Concentrations at S3 during the 8-26 event tended to increase with a peak concentration of 62 mg/l, again well below the baseline maximums. The 8-30 event at S3 peaked at 63 mg/l with an overall decrease for the sampling period.

The increase of TNFR at S8 during the 8-30 event (peak concentration of 310 mg/l), resembles concentrations one would observe during early summer high water levels. Site S8 concentrations could be a culmination of the scouring of the streambed along a 16.0 river km (9.9 river mi) stretch downstream of the dam by the initial water surge, the recruitment of suspended sediment from bank storage along the stretch, and loading of TNFR from the Le Sueur River which possessed high maximum baseline values during 1984 and1985.

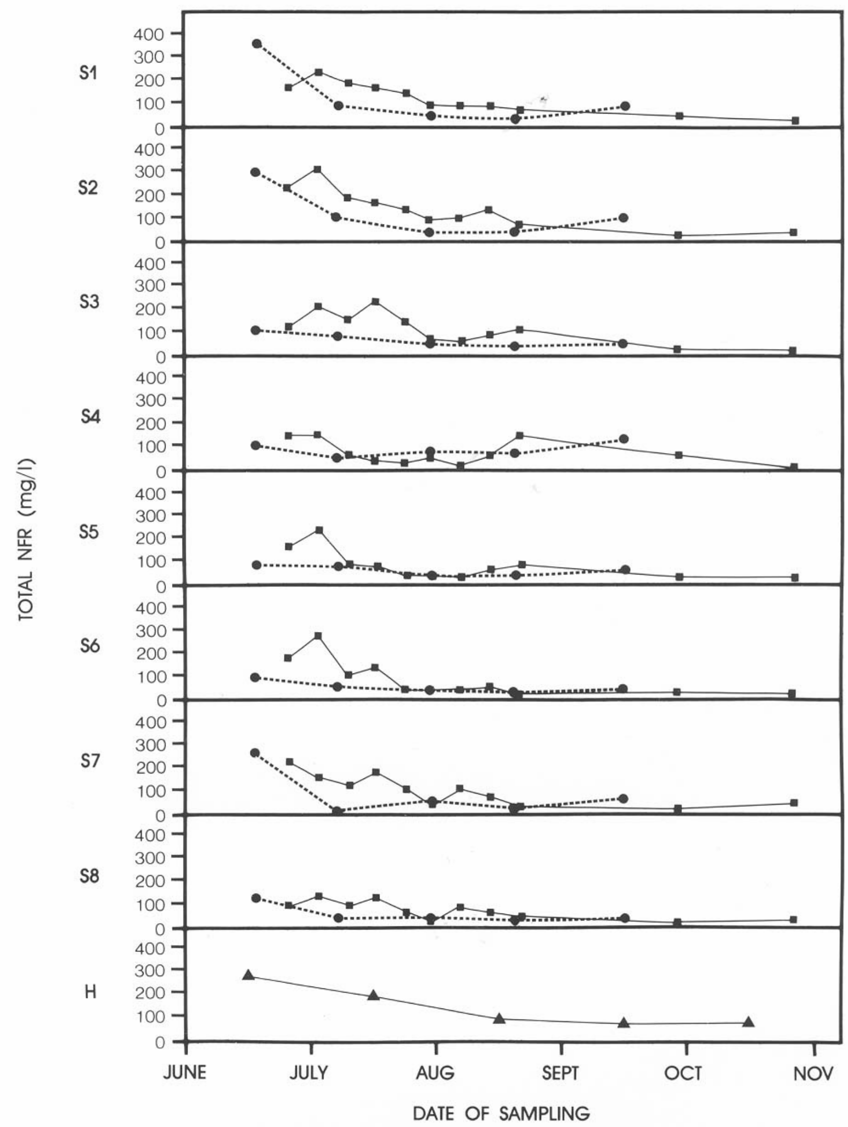


Figure 31. Baseline Total Non-Filterable Residue for 1984 (■) and 1985 (●) sampling seasons at Sites S1-S8, and historic record for Blue Earth – 0 (▲).

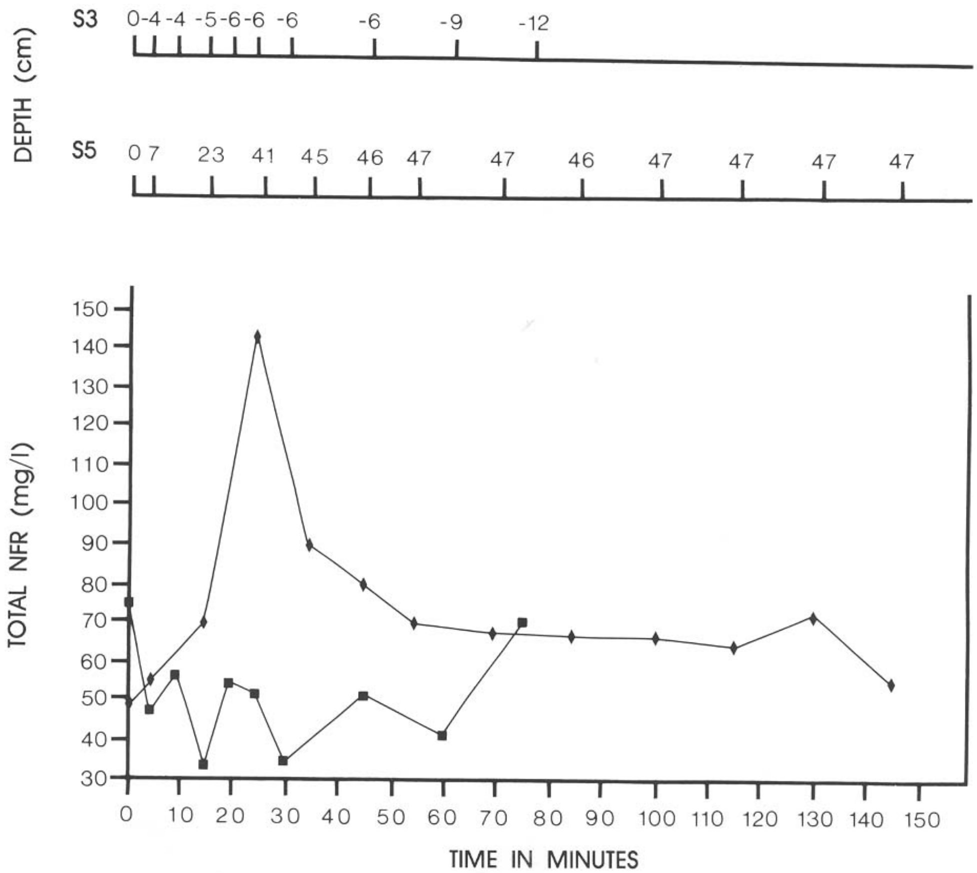


Figure 32. Total Non-Filterable Residue for peak event of August 9, 1985 at Sites S3 (■) and S5 (♦)

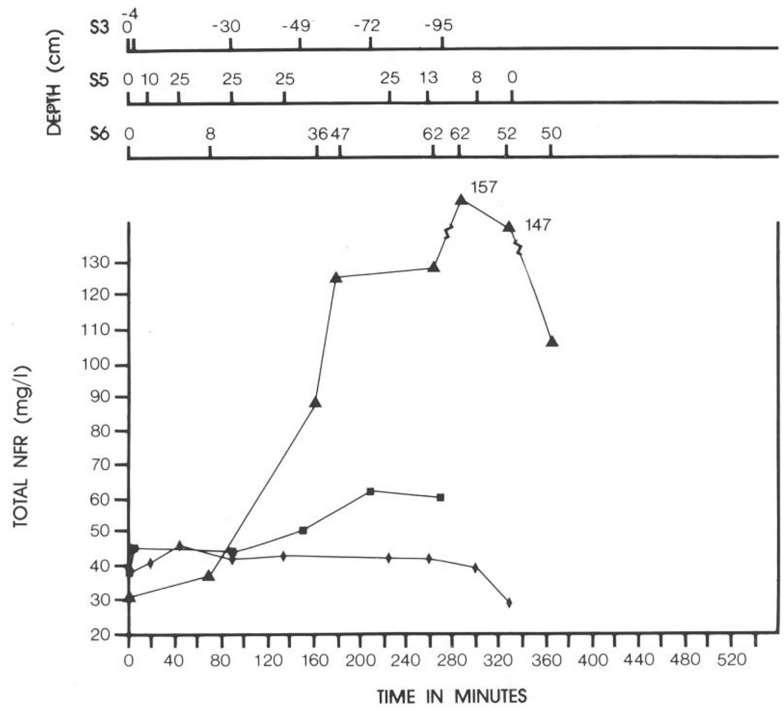


Figure 33. Total Non-Filterable Residue for peak event of August 26, 1985 at Sites S3 (■), S5 (♦) and S6 (▲)

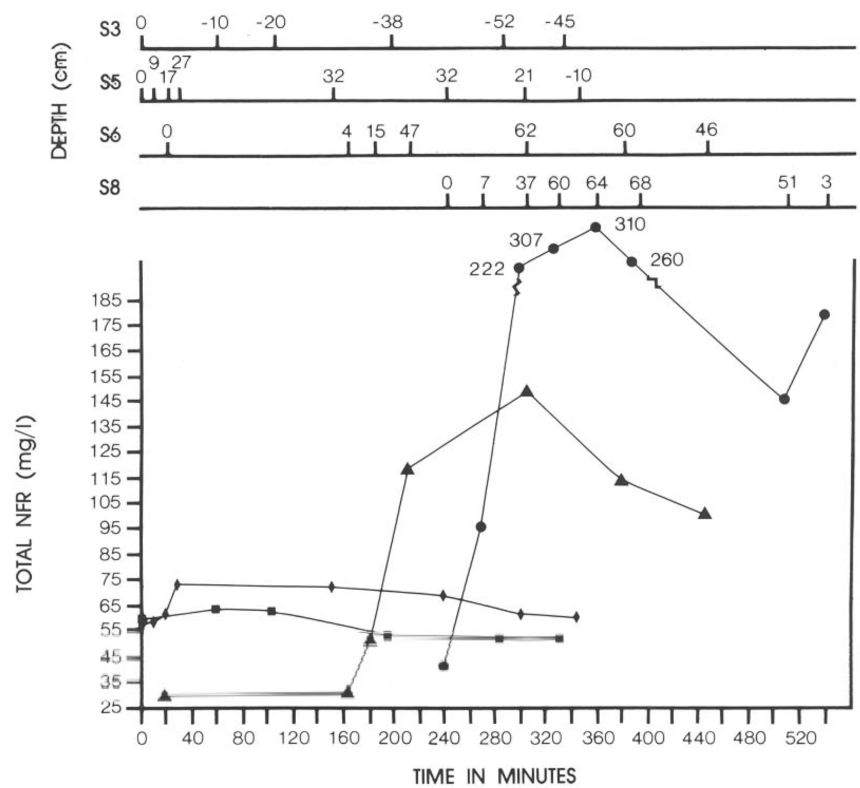


Figure 34. Total Non-Filterable Residue for peak event of August 30, 1985 at Sites S3 (■), S5 (♦), S6 (▲) and S8 (●) .

Total Volatile Non-Filterable Residue

Introduction

Most of the organic carbon (TVNFR) in running-water ecosystems in is the dissolved form rather than the particulate (6:1 to 10:1) (Wetzel, 1983). Further, living particulate organic carbon (POC) constitutes a very small portion of the total POC. However, POC is important in mediating carbon fluxes. The phrase "total volatile non-filterable residue" refers to that portion of TNFR which is solely organic in composition. Today TNFR is usually referred to as Total Suspended Volatile Solids (TSVS).

Baseline

Historical trends at BE-0 show TVNFR increasing in July, then decreasing and leveling out through October (Figure 35). This increase in July can be attributed to an increase in productivity that may have occurred within the river due to lower flow, increased water clarity, and increasing water temperature. Baseline TVNFR graphs appear similar to TNFR baseline graphs in terms of increases and decreases in concentration throughout the sampling period. Similar to TNFR, concentrations for the first sampling date of 1984 were lower than the sampling occurring one week later. The increase in TVNFR during July was observed at all sites except S4, the reservoir, which would be expected due to the settling basin affect. Similar to TNFR, increase in concentration is seen in late August at sites S3, S4, and S5. Concentrations then steadily decreased into October.

In 1985, as with TNFR, concentrations are greater at sites upstream of the reservoir than downstream, and S7 was increasing mainstem concentrations. Concentrations remained low due to the low flow occurring at this time, and began to increase during the latter part of August into September. This increase is believed to have been caused by an increase in flow.

The trapping affect of the reservoir on TVNFR is evident, but is far more subtle than for TNFR

Peaks

The historic baseline, maximum monthly mean at BE-0 was 44 mg/l, while the minimum was 20 mg/l. The peak concentration at S5 during the 8-9 event was 19 mg/l (Figure 36). During the 8-26 and 8-30 peak events, peak concentrations at S5 repeated this pattern with near minimum historic concentrations (Figures 37, 38).

The increase in concentration at S5 during the 8-9 event was greater in magnitude than during the latter two events, however it still was considered insignificant. When comparing these observations with the TNFR peak-event data, it can be concluded that the sediment re-suspended by the initial water surge was primarily inorganic in composition. The peak concentration at S3 (23 mg/l) was greater than the maximum baseline concentration of 20 mg/l at this site. However, the maximum historic concentration of 44 mg/l, and the maximum baseline concentration of 40 mg/l, demonstrates the insignificance of concentration. The normal concentration, as indicated by historic data, for August, at BE-0 was 25 mg/l.

Site S3 concentrations during the 8-26 and 8-30 events were greater than at S5. This may have been due to the reservoir acting a trap for TVNFR during these two events, and thereby decreasing concentrations at S5. Sites S6 and S8 once again demonstrated the magnification affect as the water surge moved farther downstream from the dam. This is evident by the greater peak concentration at 56 and S8, than at S5, during the 8-26 and 8-30 events. Peak concentrations at S6 during the latter two events (35 mg/l and 37 mg/l respectively), which exceeded maximum baseline concentrations for 1984 (32 mg/l) and 1985 (21 mg/l), can be compared to increases in concentration on may observe during a natural hydrologic event produced by approximately one to two inches in rainfall. The peak concentration at S8 (54 mg/l) (170% increase) did exceed the baseline maximums for 1984 (30 mg/l) and 1985 (21 mg/l) for the site, and the historic maximum for BE-0. As the water surge moved towards S8, it may have re-suspended large amounts of organic material both from the streambed and bank storage. It can also be assumed that the Le Sueur River may have contributed a proportion of S8's TVNFR during the peak-events.

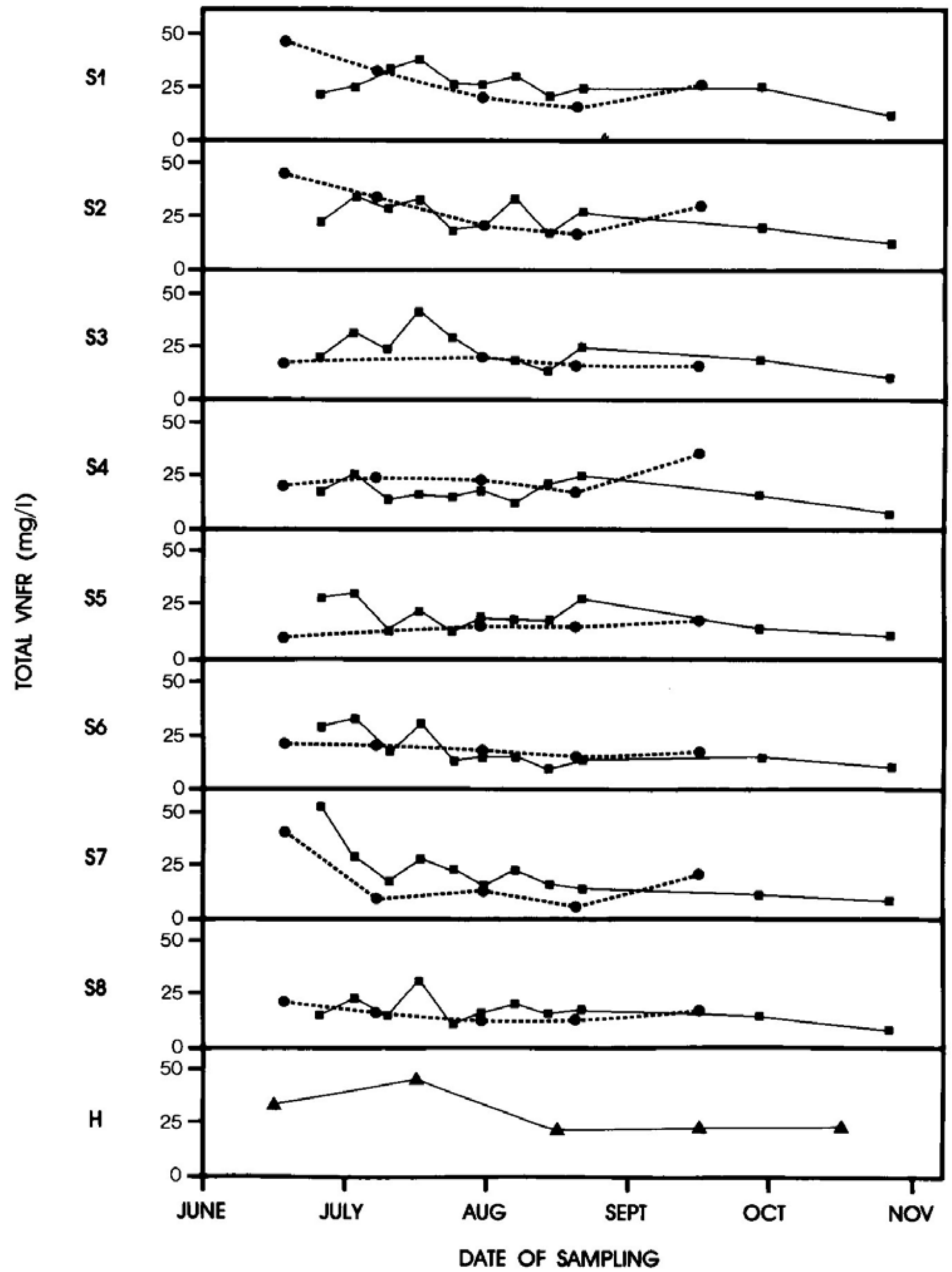


Figure 35. Baseline Total Volatile Non-Filterable Residue for 1984 (■) and 1985 (●) sampling seasons at Sites S1-S8, and historic record for Blue Earth – 0 (▲).

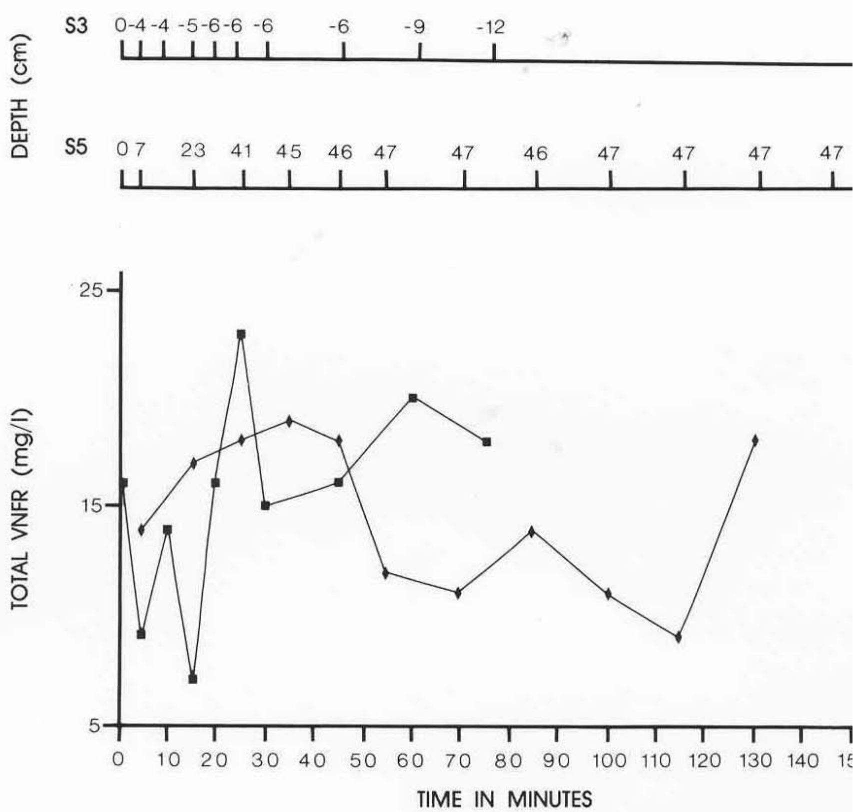


Figure 36. Total Volatile Non-Filterable Residue for peak event of August 9, 1985 at Sites S3 (■) and S5 (♦)

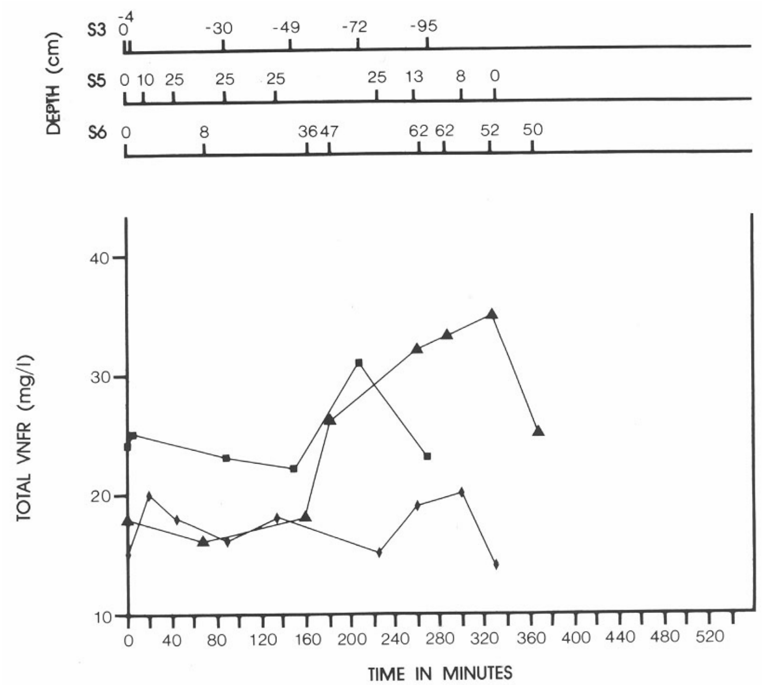


Figure 37. Total Volatile Non-Filterable Residue for peak event of August 26, 1985 at Sites S3 (■), S5 (♦) and S6 (▲)

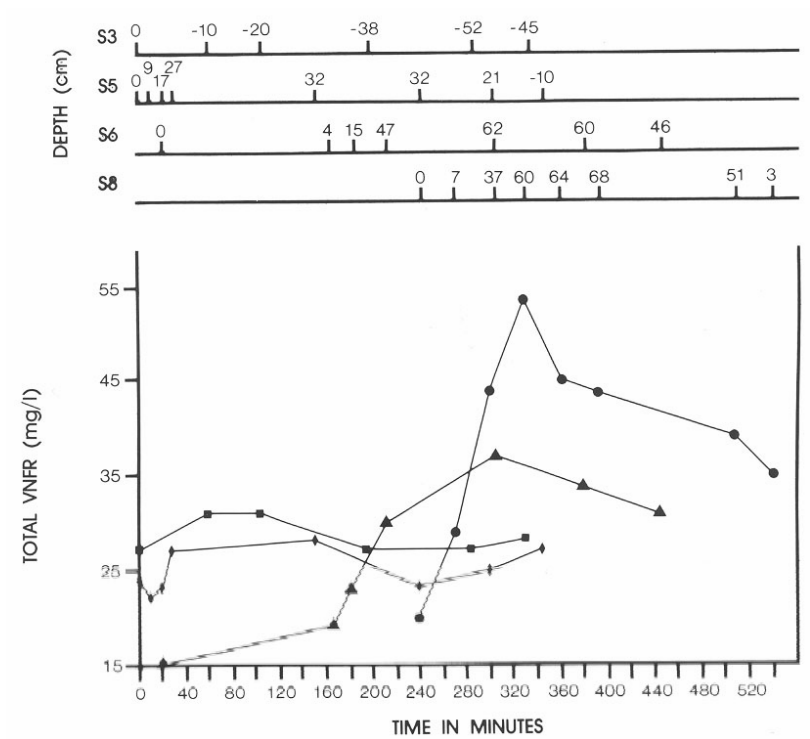


Figure 38. Total Volatile Non-Filterable Residue for peak event of August 30, 1985 at Sites S3 (■), S5 (♦), S6 (▲) and S8 (●).

Conductivity

Introduction

Conductivity is a numerical expression which describes the ability of an aqueous solution to conduct an electric current. This ability depends on the presence of ions in the solution, their total concentration, their mobility, valence, and the temperature of the solution (APHA, 1980). Solutions containing primarily inorganic salts are relatively good conductors and would possess a high conductivity reading, while molecules of organic compounds, which do not disassociate in aqueous solution, are poor conductors possessing low conductivity readings.

Baseline

Lower Conductivity readings in 1984 than in 1985, could have been caused by the abnormally high flow during the months of April through June in 1984 (Figure 39). The high flow during this time could have had a dilution affect on Conductivity.

In 1985, despite drought conditions in the latter part of June, the entire month of July and the first half of August, Conductivity followed historic patterns closely. The onset of the above normal flow in August may have caused Conductivity to increase earlier in the season than historic data does. The increase in flow at this time probably produced, with subsequent scouring of the streambed and banks, may have caused an influx of high concentrations of inorganic salts from overland flow plus scouring of stream banks... This influx may have lead to greater Conductivity readings. A more gradual increase in flow followed by sustained high flow over several months (similar to the early period of 1984) would tend to dilute Conductivity causing lower readings.

Impacts by the reservoir or the two tributaries on mainstem Conductivity were not apparent.

Peaks

Low flow and high water temperatures could have contributed to a pre-sample reading of 751 at S5 during the 8-9 peak-event (Figure 40). This reading is comparable to the maximum baseline readings at S5 in 1984 and 1985 of 750 umhos/cm and 740 umhos/cm respectively. The maximum historic, mean monthly conductivity reading at BE-0 during June through October was 759 umhos/cm. During the 8-26 and 8-30 events, the range of conductivity observed was lower than the 8-9 event at S5 (Figure 41, 42). Significant changes in conductivity at S5 for all three peak-events were not observed. Site S8 readings showed no significant differences from readings at S5. Conductivity at S3 during the 8-9 event was not available. Site S3 Conductivity during the 8-26 event decreased sharply. This may be due to dilution from upstream as flow increased. Conductivity was not impacted consistently, or to any great degree, by the peaking operation of the Rapidan Dam.

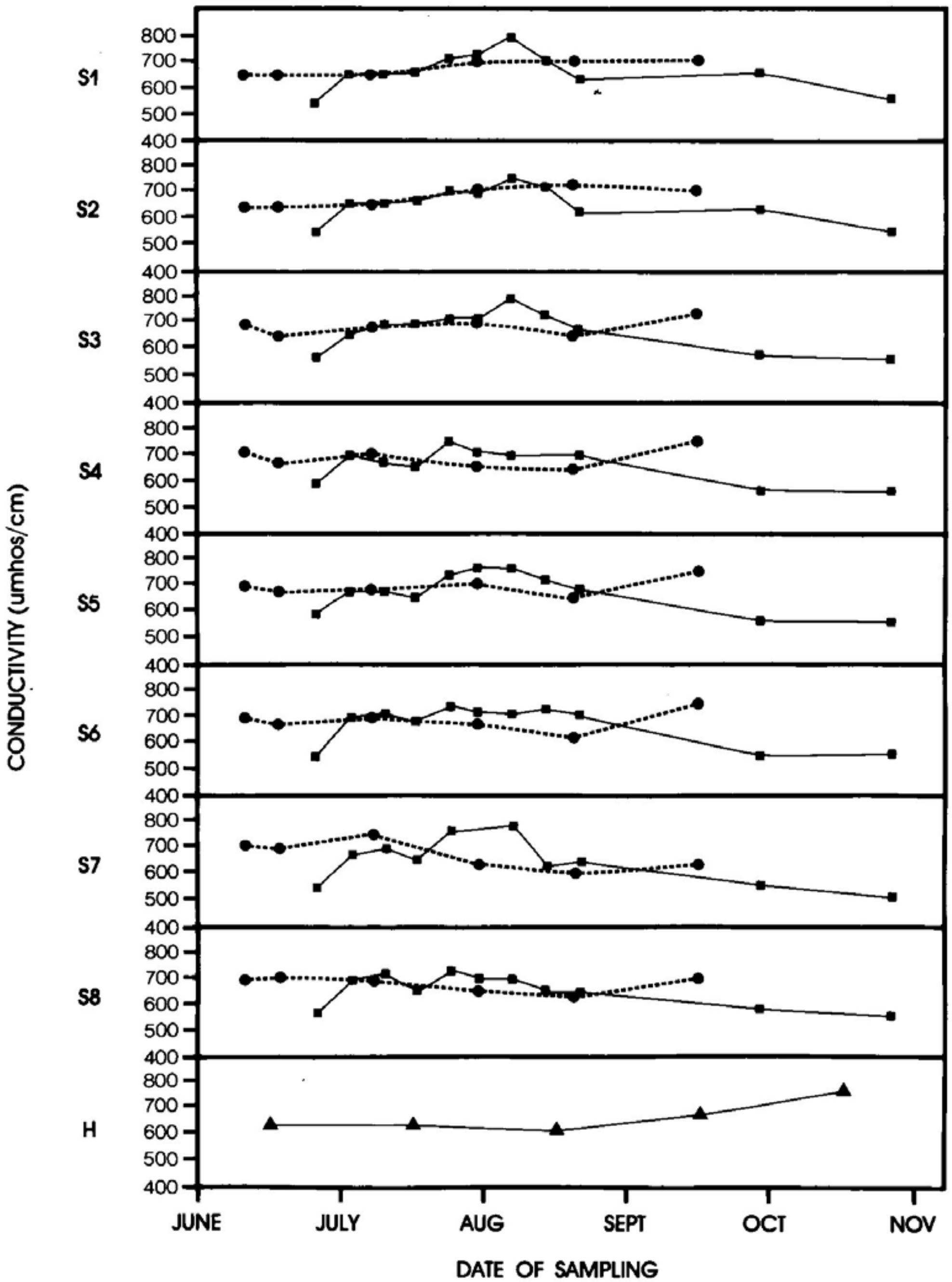


Figure 39. Baseline Conductivity for 1984 (■) and 1985 (●) sampling seasons at Sites S1-S8, and historic record for Blue Earth – 0 (▲).

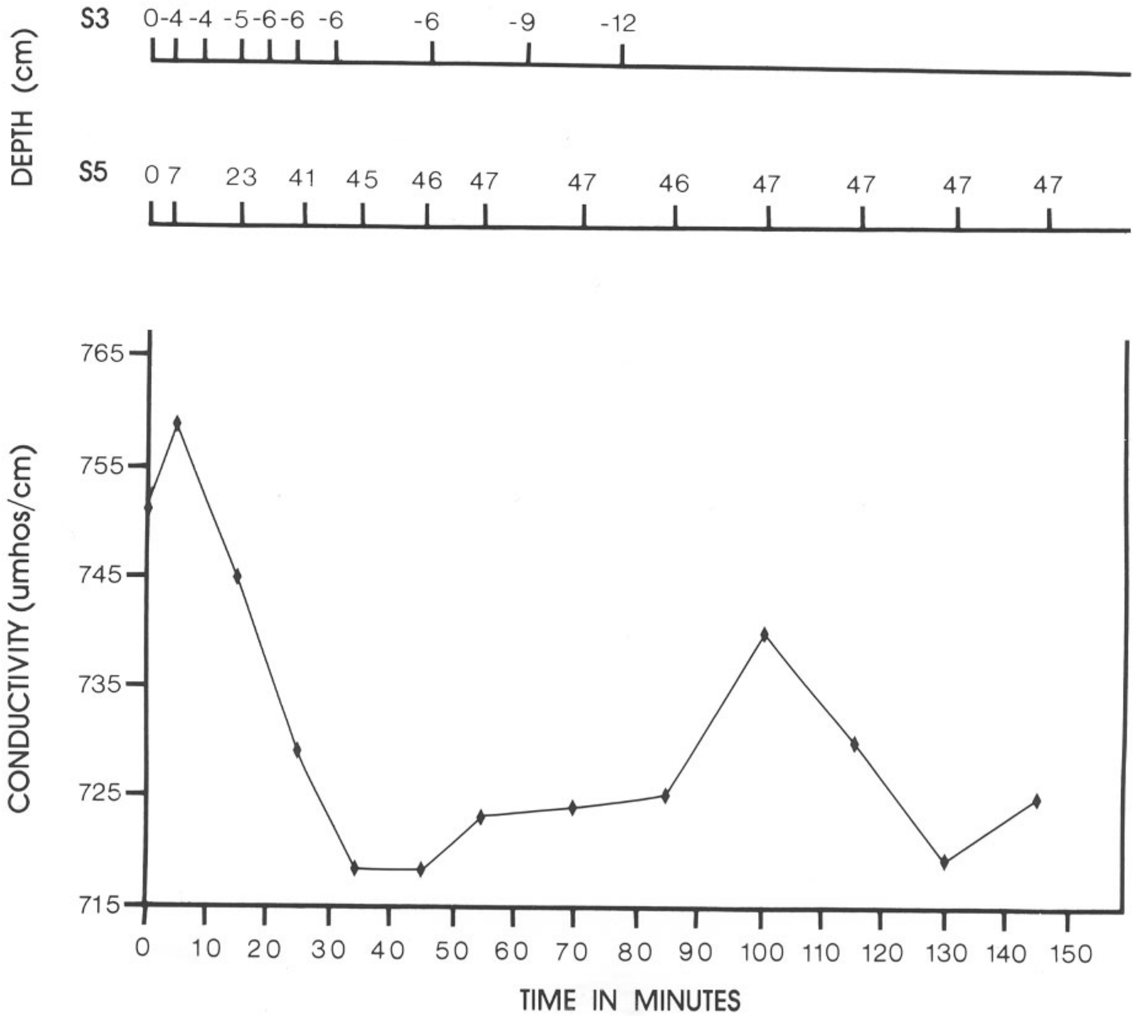


Figure 40. Conductivity for peak event of August 9, 1985 at Site S5 (♦)

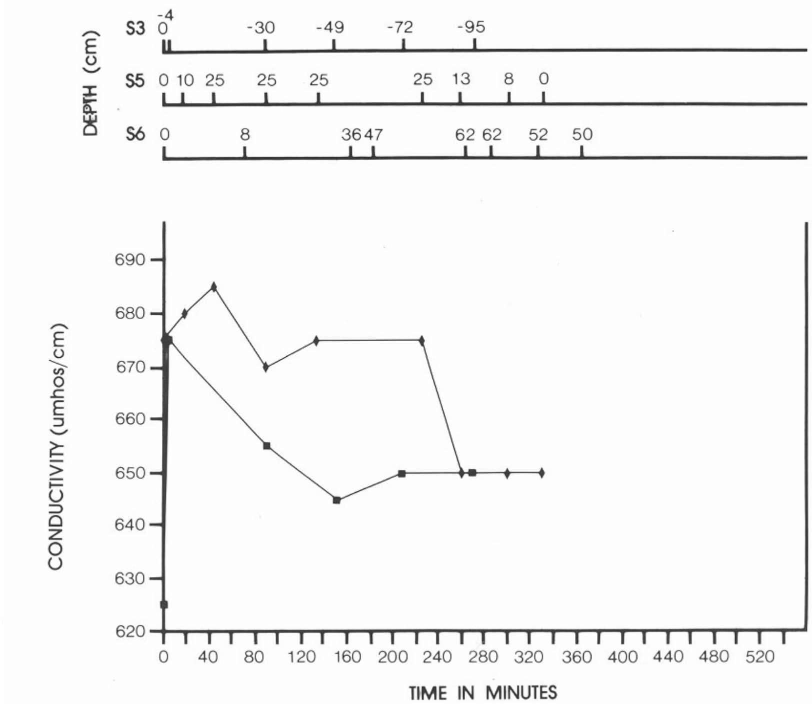


Figure 41. Conductivity for peak event of August 26, 1985 at Sites S3 (■), S5 (♦)

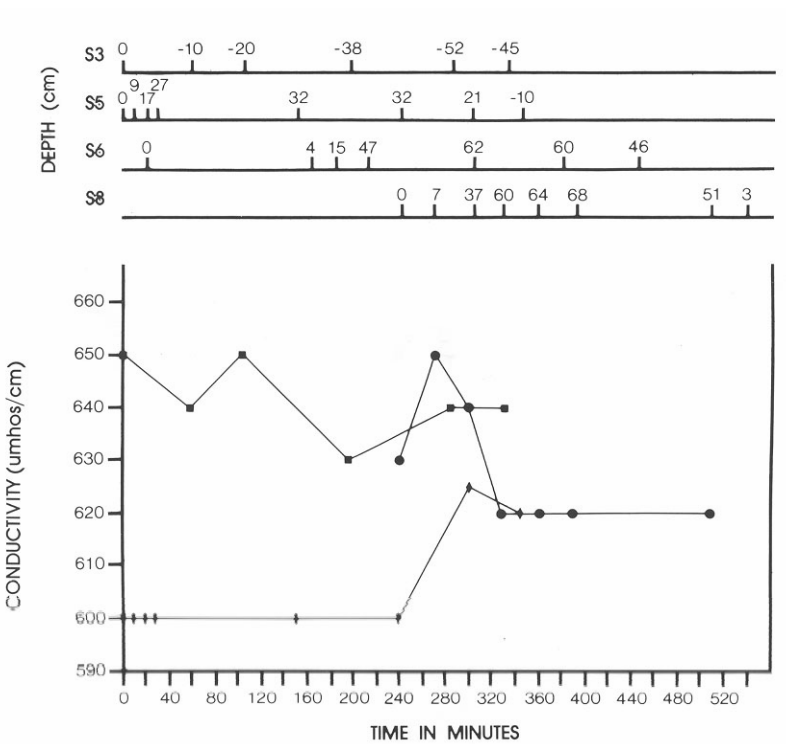


Figure 42. Conductivity for peak event of August 30, 1985 at Sites S3 (■), S5 (♦) and S8 (●)

pH

Introduction

The measurement of pH is one of the most important and frequently used tests in water chemistry. At a given temperature, the intensity of the acidic or basic character of a solution is indicated by the pH or hydrogen ion activity (APHA, 1980). Natural waters have pH values in the range of 4 to 9, and most are slightly basic due to the presence of bicarbonates and carbonates (APHA, 1980). The concept of pH is important in that all living organisms are very sensitive to hydrogen ion concentration, and need to maintain it at a constant level (Mader, 1985).

Baseline

Historic pH trends at BE-0 throughout the months of June through November, remained relatively stable which can be due to the presence of bicarbonates and carbonates, an effective buffering mechanism against large changes in pH. In 1984, pH levels followed historic trends closely in terms of remaining relatively constant throughout the sample period (Figure 43). The pH readings were slightly lower than historic data suggests. The increase at all sites on the 7-23 sampling (not as pronounced at S4) correlates with the closing of the tainter gates and the subsequent filling of the reservoir. The pH in 1984 demonstrated a consistent increase as one moved downstream from S1 to S8. This increase in pH may have been caused by the loss of equilibrium carbon dioxide as you move downstream, which is required to retain calcium bicarbonate (a buffer against changes in pH) in solution (Hynes, 1980). The greater readings during the early sampling period than the late sampling period could be attributed to greater flow during the former.

Readings in 1985 were greater during the late sampling period when flow was greater. Readings were fairly stable throughout the sample period but lower than historic readings at BE-0. Similar to 1984, readings increased as you moved downstream.

The reservoir did not appear to impact downstream pH.

Peaks

The pH at S5 during the 8-9 event, fluctuated between 7.33 to 8.00 which was within the range observed for baseline data during 1984 and 1985 (Figure 44). This fluctuation could be attributed to the particular sediment composition suspended in the water column as it passed through the site. The pH at S3 during the 8-9 event was not available. Site S3 pH during the 8-26 and 8-30 peak-events was much greater than at S5 (8-26) and S5 and S6 (8-30) (Figure 45, 46). An initial increase was seen shortly into both events at S3 followed by a stabilization for the remainder of the sample period. This initial increase may have been due to a concentrating affect as draw-down began at the site. The 8-26 and 8-30 events possessed greater pre-sample readings and peak pH readings at S5 than did the 8-9 event. Higher water levels with greater flow could have been re-suspending calcareous laden sediment, resulting in higher pH readings. Significant changes in pH were not evident during either peak event, however pH did follow the ascending leg, peak plateau, and descending leg with a corresponding increase, leveling off, and decrease respectively at all downstream sites. This study has concluded that pH is not impacted to any significant degree by the peaking operation within the Rapidan Dam’s downstream reaches.

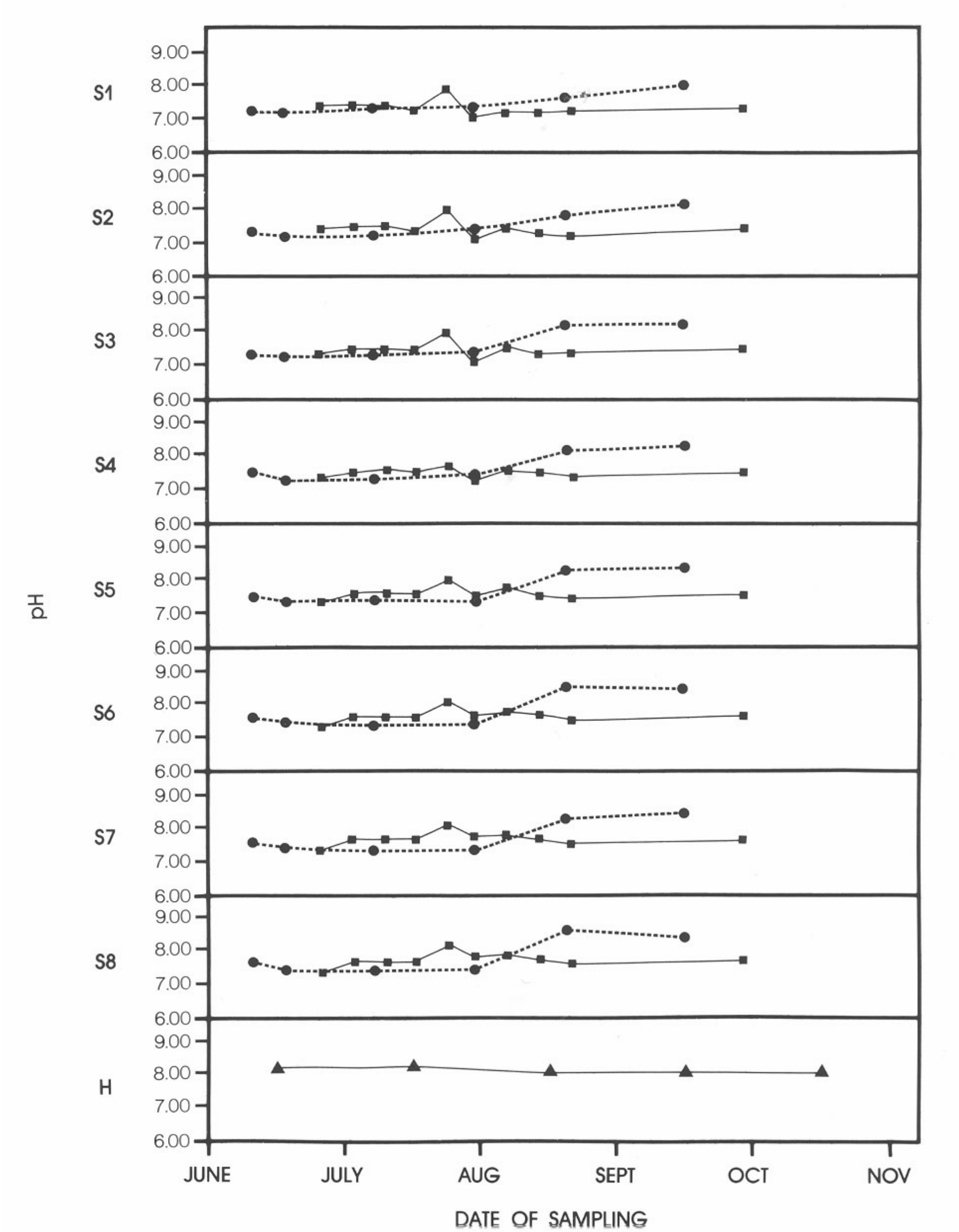


Figure 43. Baseline pH for 1984 (■) and 1985 (●) sampling seasons at Sites S1-S8, and historic record for Blue Earth – 0 (▲)

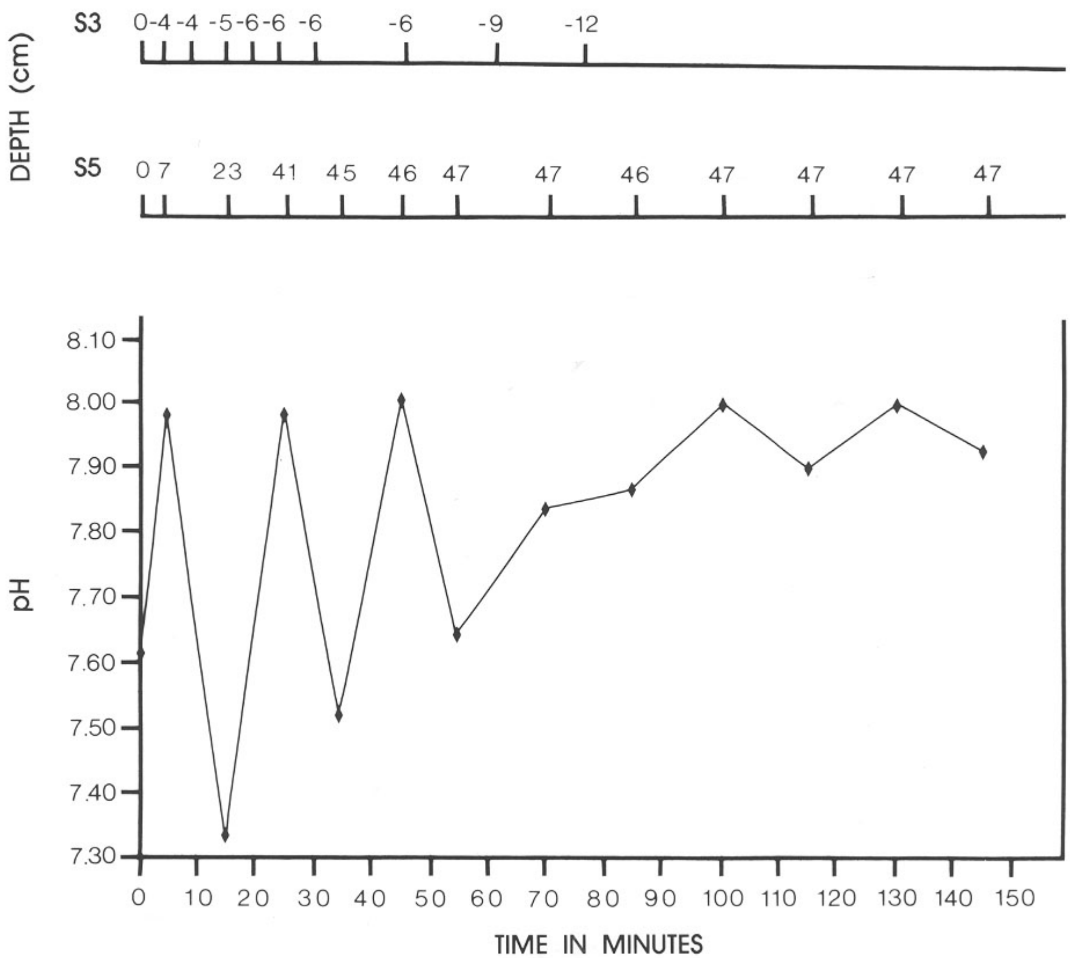


Figure 44. pH for peak event of August 9, 1985 at Site S5 (♦)

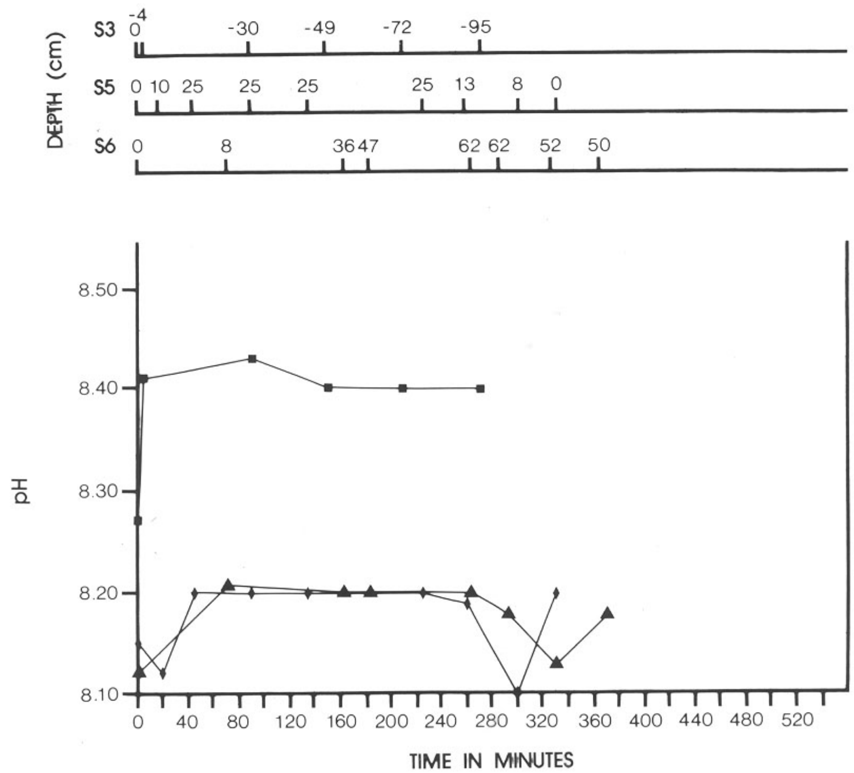


Figure 45. pH for peak event of August 26, 1985 at Sites S3 (■), S5 (♦) and S6 (▲)

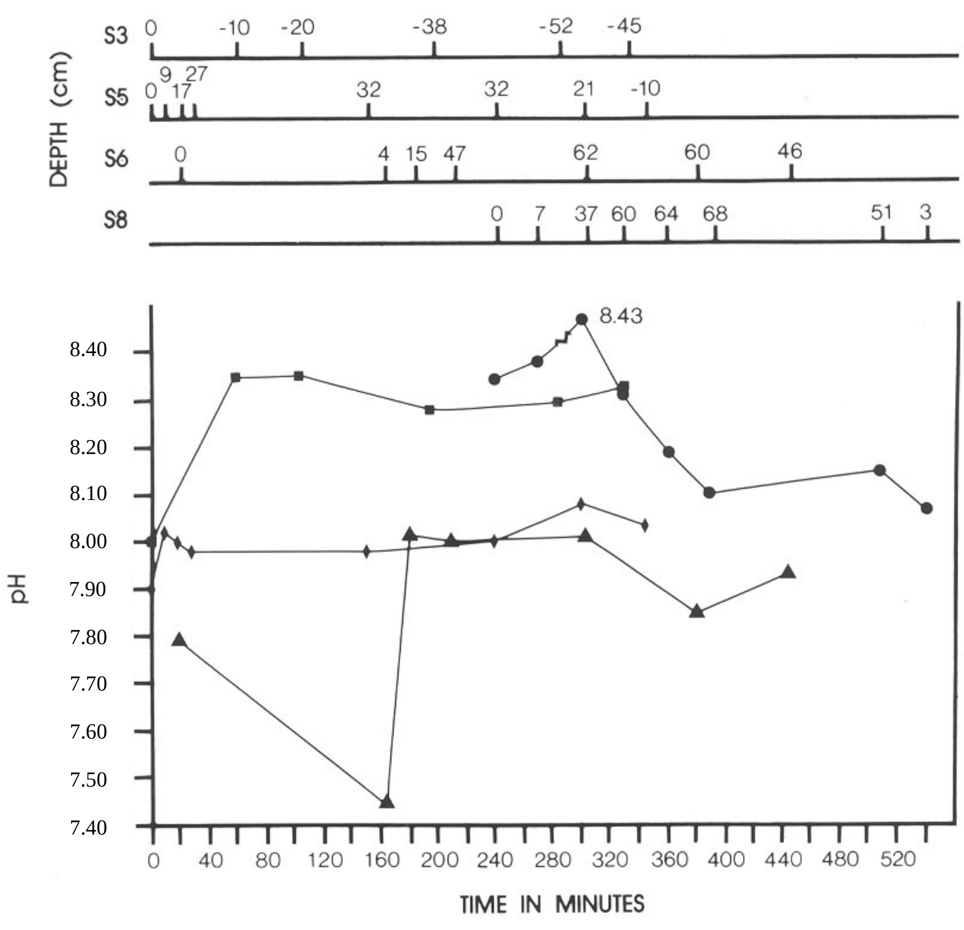


Figure 46. pH for peak event of August 30, 1985 at S3 (■), S5 (♦), S6 (▲) and S8 (●)

Water Temperature

Introduction

The temperature of an aquatic ecosystem has numerous impacts on the biotic and abiotic components of that ecosystem. The water temperature regime will determine the types of aquatic fauna and flora found, and will affect viscosity of the water, the solubility of gases and the suspension of sediments within the water column (Hynes, 1980).

Baseline

Historic data at BE-0 suggests that water temperatures steadily increase throughout the months of June and July, peak in August, and steadily decrease throughout September and October, (Figure 47). In 1984, water temperatures followed historic trends closely, peaking on the 8-6 sampling date along the 51.8 river km stretch of the river within the study area. A river may continue to receive groundwater along its length and its temperature will remain fairly constant for a long distance (Hynes, 1980).

In 1985, as in 1984, fairly stable temperatures between S1` and S8 were evident. Water temperatures peaked one week earlier in 1985 (7-30 sampling) than in 1984 (8-7 sampling). Greater mean water temperatures during the late sampling period of 1985, than the same sampling period of 1984, may be due to the fact that the 1985 sampling period did not extend into October as in 1984. Therefore, the lower temperatures of October were not calculated into the means for the late sampling period of 1985.

The reservoir did not appear to impact downstream water temperature.

Peak

The historic baseline, mean monthly water temperature for August is 23.9°C (75.0°F). The pre-sample temperature at S5 during the 8-9 peak-event was 26.0°C (78.8°F)(Figure 48). The very low flow conditions and high air temperatures preceding this peak-event, may have caused the greater than normal water temperature. The 1.5°C (2.7°F) decreases in water temperature at S5 within the first 25 minutes of the 8-9 event could have been attributed to the inflow of the slightly cooler water from the reservoir into the turbine inlets. The turbine inlets are located at a depth of 7 meters (23 feet) below the surface of the reservoir at normal pool elevation. Whether this drop in water temperature is significant enough to have affected aquatic fauna in the reservoir’s tail waters cannot be determined by this study. Water temperature data was not available for S3.

Water temperatures throughout the 8-26 and 8-30 events for all sites except S8 saw near normal water temperatures (Water temperature data was not available at S6 for the 8-30 event) (Figures 49, 50). Site S8, during the 8-30 event, possessed a peak water temperature of 25.0°C (77.0°F) with a pre-sample reading of 23.5°C (74.3°F), compared to pre-sample readings of 21.0°C and 20.5°C at S5 and S3 respectively. Sampling at S8 began much later in the day than at the other sites, and occurred where the river flowed across a large sandbar with a maximum depth of 30 cm (12 in). These two factors could have contributed to considerable warming of the water.

A feature that does stand out in terms of the impacts of the peaking operation on water temperature in the dam’s downstream reaches is the increase in water temperature of 1.5°C during the 8-30 event at S8. The increase in conductivity observed during the same time was most likely attributed to this increase in temperature. The initial water surge, as it approached S8, was 1.5°C warmer than the water immediately downstream of it.

Another feature that stands out is the fluctuation of water temperature at S3 during the 8- 26 event. An initial increase of 1.5°C, from 21.5°C to 23.0°C, during the first 90 minutes of the event, was followed by a decrease of 2.0°C towards the end of the event. The initial increase may have been due to the draw-down, i.e. less water to distribute solar gain. The decrease of 2.0°C may be related to increased groundwater impact.

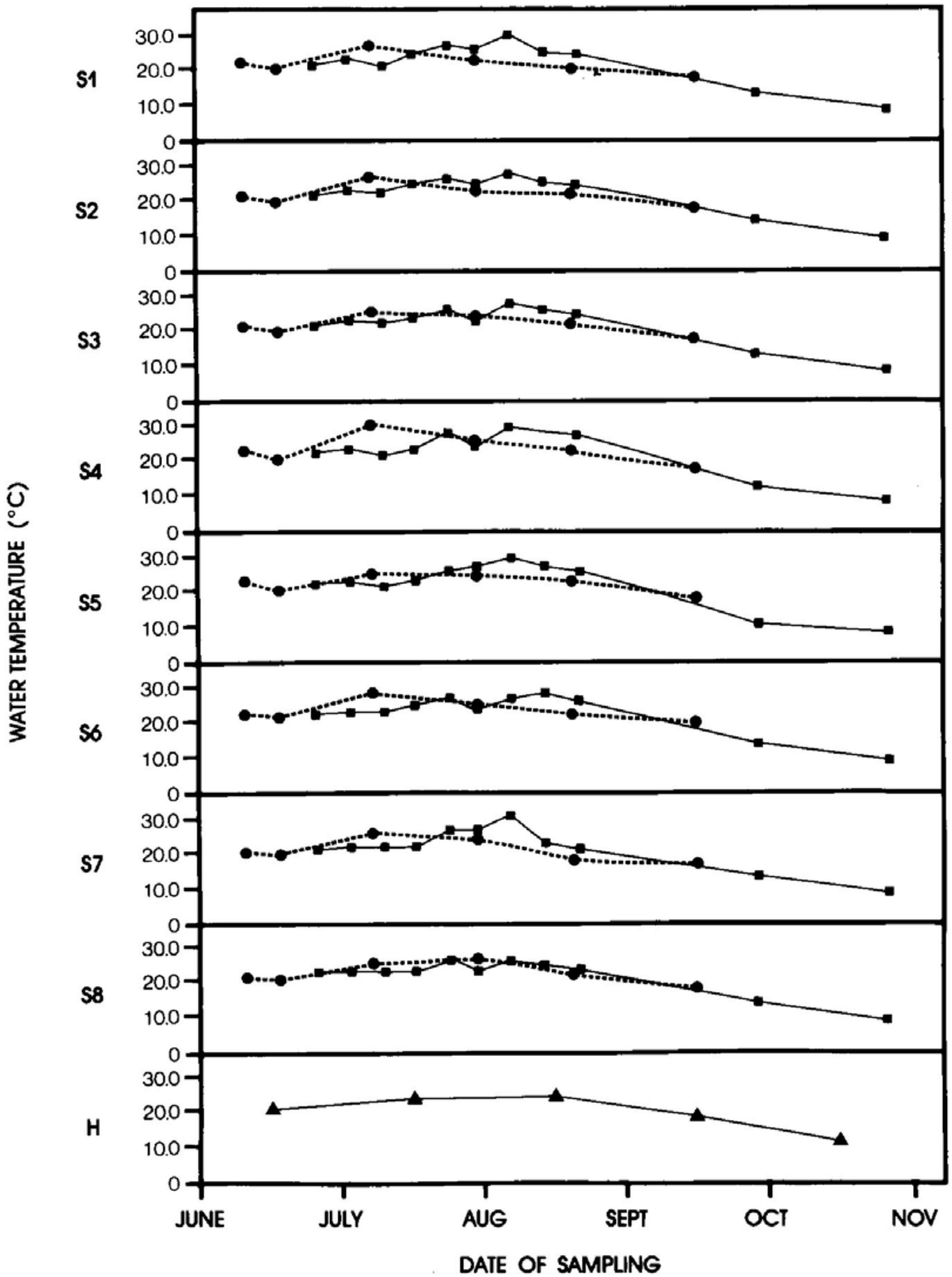


Figure 47. Baseline Water Temperature for 1984 (■) and 1985 (●) sampling seasons at Sites S1-S8, and historic record for Blue Earth – 0 (▲)

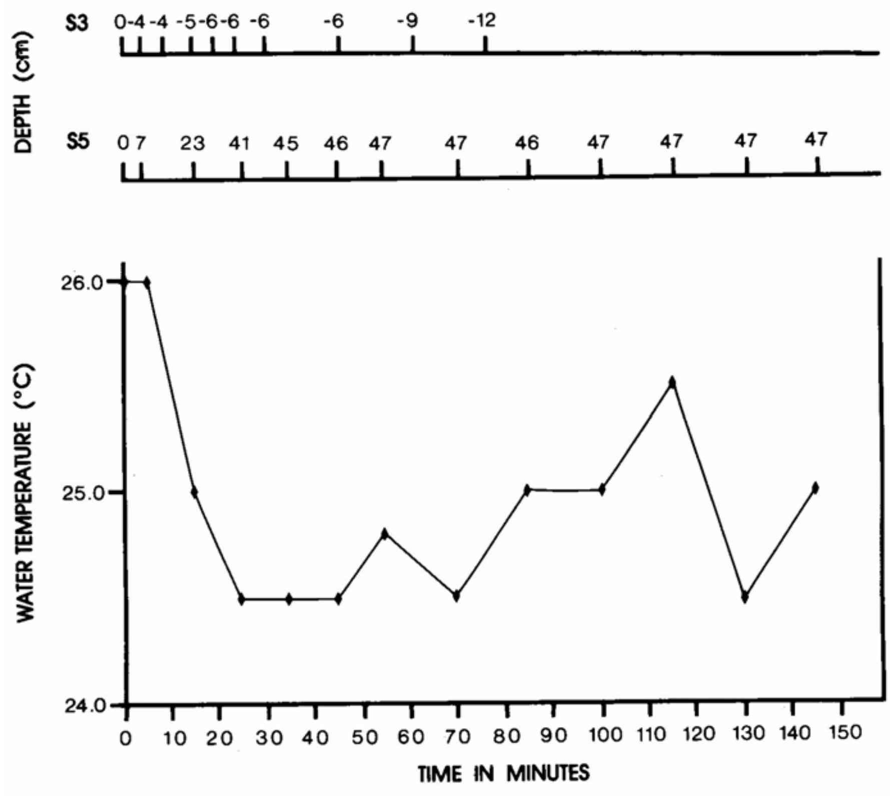


Figure 48. Water Temperature for peak event of August 9, 1985 at Site S5 (♦)

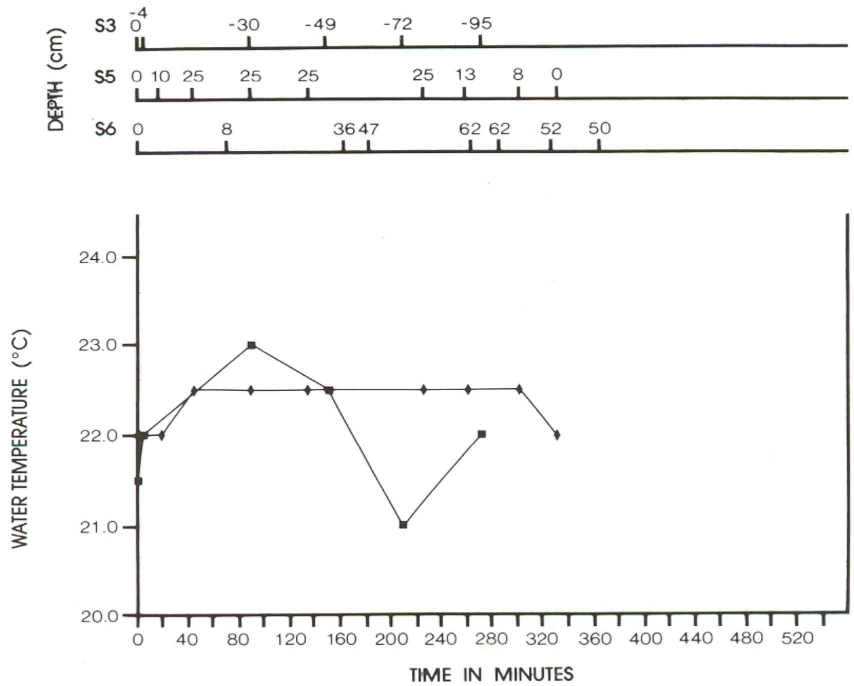


Figure 49. Water Temperature for peak event of August 26, 1985 at Sites S3 (■) and S5 (♦)

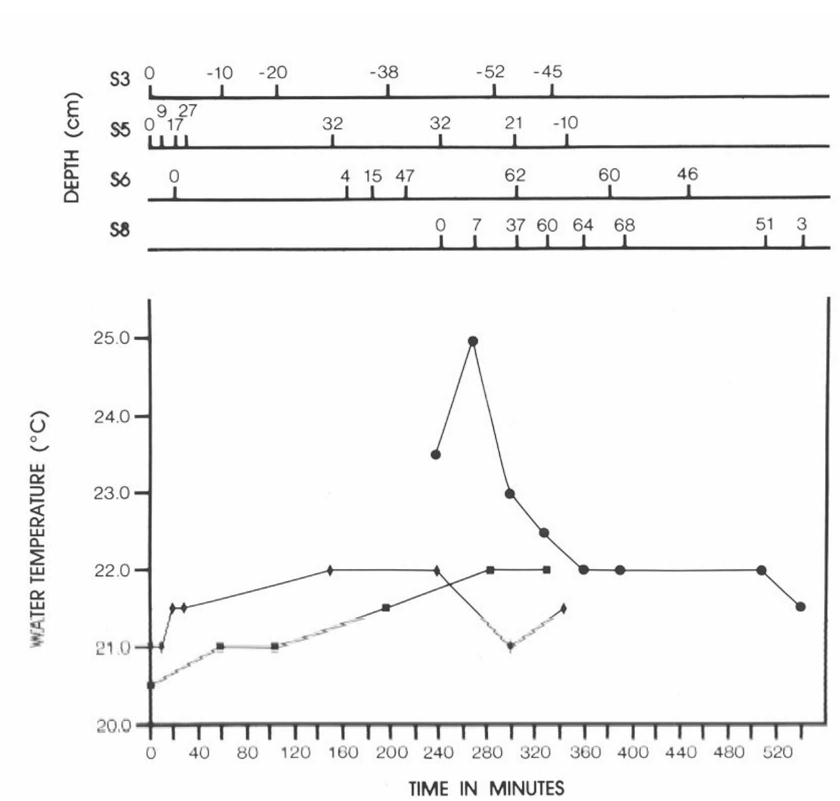


Figure 50. Water Temperature for peak event of August 30, 1985 at Sites S3 (■), S5 (♦) and S8 (●).

<u>Organic Matter</u>

Introduction

Rivers have been called the "gutters down which flow the ruins of continents" (Leopold <u>et al.,</u> 1964). Streams transport large quantities of dissolved and particulate material, and in doing so alter the geomorphology of the land. Stream systems, from small headwaters to large rivers, import, produce, process, and store organic material (Vannote <u>et al.,</u> 1980). The processing and partial release of organic nutrients from one stream reach to the next has been characterized as processing along a continuum (Vannote <u>et al,</u> 1980). Stream systems also provide habitat to highly specialized biological communities which transform, utilize, and release materials being transported. As a result of their activities, the physical and chemical composition of materials exported at the mouth of a stream, may be quite different from the materials entering the watershed. Streams and rivers are no longer viewed as open export systems for terrestrial products, but rather as sites of production and processing of organic material (Hynes, 1980; Whitton, 1975).

The term "seston" can be defined as all organic and inorganic material suspended in water (Ruttner, 1963). The organic fraction of seston, both living and nonliving, is generally referred to as organic material (OM). A number of studies over the last twenty-five years have demonstrated the importance of OM to the energetics of aquatic ecosystems. The sources of OM can be autochthonous, produced within the stream (live, senescent, on dead algae, microbes, and other organic detritus), or allocthonous, originating from terrestrial sources (non-living detritus such as wood or leaves, etc.) (Liaw <u>et al</u>., 1977). The transport of OM within streams in important to the aquatic invertebrates as a food source (Cummins, 1974).

Coarse Particulate Organic matter (CPOM)

<u>Introduction</u>

Coarse particulate organic matter has been defined in this study as OM >1mm in size. CPOM may be allocthonous in origin (leaves, wood, bark, flowers, terrestrial insect grass, etc.) or autochthonous (aquatic macrophytes, filamentous, algae, certain aquatic invertebrates, etc.), (Bird <u>et al</u>., 1981). In a stream the size of the Blue Earth River (sixth order), the importance of allocthonous input of CPOM diminishes as the affects of the riparian vegetation becomes less important (Vannote <u>et al</u>., 1980), and as abiotic-biotic processing is completed (Cummins, 1975).

<u>Baseline</u>

CPOM in 1984, began the sample period in June with lower concentrations than in 1985 (Figure 51). The very high flow occurring during the preceding months of February through May of 1984 may have scoured a majority of the CPOM from the watershed. As flow decreased, the CPOM levels dropped to near 0 mg/l for the remainder of the sample period. It seems reasonable to assume that concentrations did not increase substantially again until the onset of the spring floods of the following year. The greater concentrations in June of 1985 can be due to a more normal flow regime during the months of March through June, resulting in normal scour and suspension of CPOM within the water column. CPOM concentrations began to increase in the latter portion of August and continued into September with increasing flow.

No apparent impacts on mainstem CPOM concentrations due to the reservoir or tributaries were observed.

The percentage of total OM comprised by CPOM remained relatively small but stable during the entire early and late sampling periods of 1984 with 0.5%, 0.6%, and 0.3 respectively (Table X). In 1985, CPOM comprised 1.7%, 2.%, and 1.0% total OM in transport during the entire, early and late periods respectively. The slightly greater percentages can be due to fewer data points than in 1984. The relatively stable percentage of CPOM during both years indicates that although CPOM increased or decreased in concentration in relation to flow, its percentage of total OM remained constant. This was observed with the other three size classifications as well (Table X).

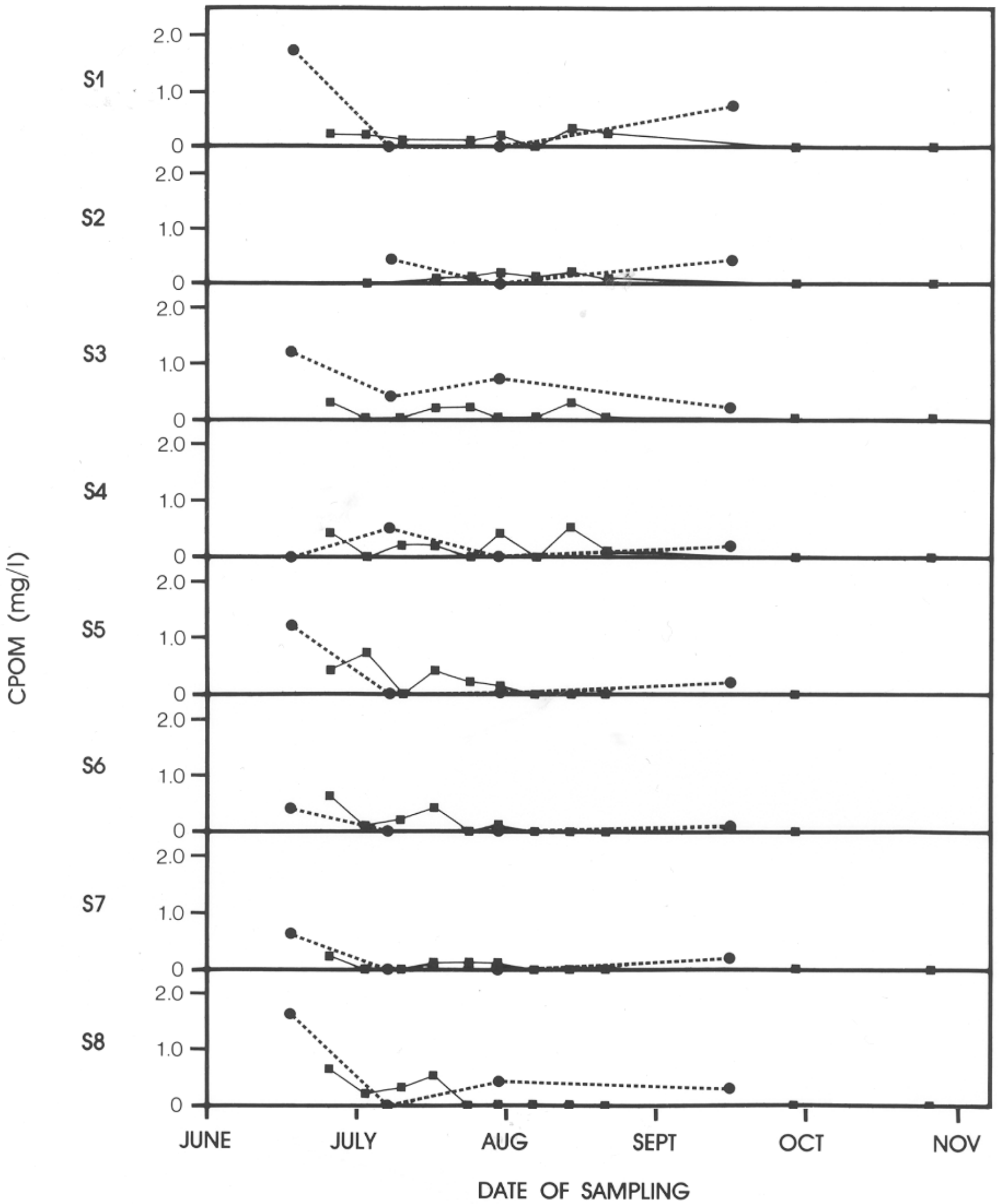


Figure 51. Baseline Coarse Particulate Organic Matter for 1984 (■) and 1985 (●) sampling seasons at Sites S1-S8.

Table X: Percent composition, by grain size, of the total OM in transport during the entire, early and late sampling periods of 1984 and 1985

1984	Entire	Early*	Late**
Coarse Particulate Organic Matter (CPOM) > 1mm	0.5%	0.6%	0.03%
Fine Particulate Organic Matter (FPOM) > 53um to < 1mm	6.2%	5.4%	8.0%
Very Fine Particulate Organic Matter (VPOM) > 0.45um to < 53um	64.7%	67.5%	58.0%
Dissolved Organic Carbon (DOC) < 0.45 um	28.6%	26.5%	33.7%
1985			
Coarse Particulate Organic Matter (CPOM) > 1mm	1.7%	2.1%	1.2%
Fine Particulate Organic Matter (FPOM) > 53um to < 1mm	8.1%	9.6%	6.1%
Very Fine Particulate Organic Matter (VPOM) > 0.45um to < 53um	66.2%	68.4%	63.4%
Dissolved Organic Carbon (DOC) < 0.45 um	23.9%	19.9%	29.3%

* 6/1/84-7/30/84 and 6/24/85 – 7/22/85
** 8/8/84 – 9/28/84 and 8/7/85 – 9/27/85

Peaks

Site S3 and S5 experienced peak CPOM concentrations comparable to early season high water concentrations during the 8-9 peak-event. Site S5 CPOM increased to 0.6 mg/l, while S3 CPOM peaked at 0.5mg/l (Figure 52). The maximum baseline concentrations at S3 for 1984 and 1985 were 0.50 mg/l and 1.20 mg/l respectively. The increase in CPOM at both sites was due to an increase in flow, and the subsequent scour and re-suspension of sediments.

The 8-26 and 8-30 events were similar in that peak concentrations were comparable to June high water concentrations, but the events were different in that the pre-event sample concentrations during the 8-26 event were greater for all upstream and downstream sites than during the 8-30 event (Figure 53, 54). The one exception was site S6, during the 8-30 peak-event, which possessed a very high pre-sample concentration of 0.8 mg/l. This cannot be explained at this time. The greater pre event sample concentrations of the 8-26 event can be attributed to the increasing flow due to abnormally high precipitation levels preceding the event. Prior to the 8-26 event, the NOAA climatological station at Winnegabo, Minnesota recorded 9.63 cm (3.79 in) of precipitation between the dates 8-22 and 8-25 after a prolonged dry period. On 8-29, one day before the 8-30 peak-event sampling, another 6.65 cm (2.62 in) of precipitation occurred. The constant high flow and subsequent scouring of the streambed could have caused the lower pre-sample concentrations during the 8-30 event.

Affects due to the watershed and initial water surge moving downstream were not magnified as with other parameters except at S8 during the 8-30 event. During this event, site S8 possessed the greatest peak concentration of all the sites involved with 1.0 mg/l. Site S3 concentrations increased significantly during the 8-30 event (from 0.3 mg/l to 1.0 mg/l) during the first 40 minutes of the event. This could be attributed to an increase in flow and the possible re-suspension of sediments due to this increase.

The peaking operation of the dam did impact downstream CPOM concentrations by elevating CPOM to concentrations observed during early June high water.

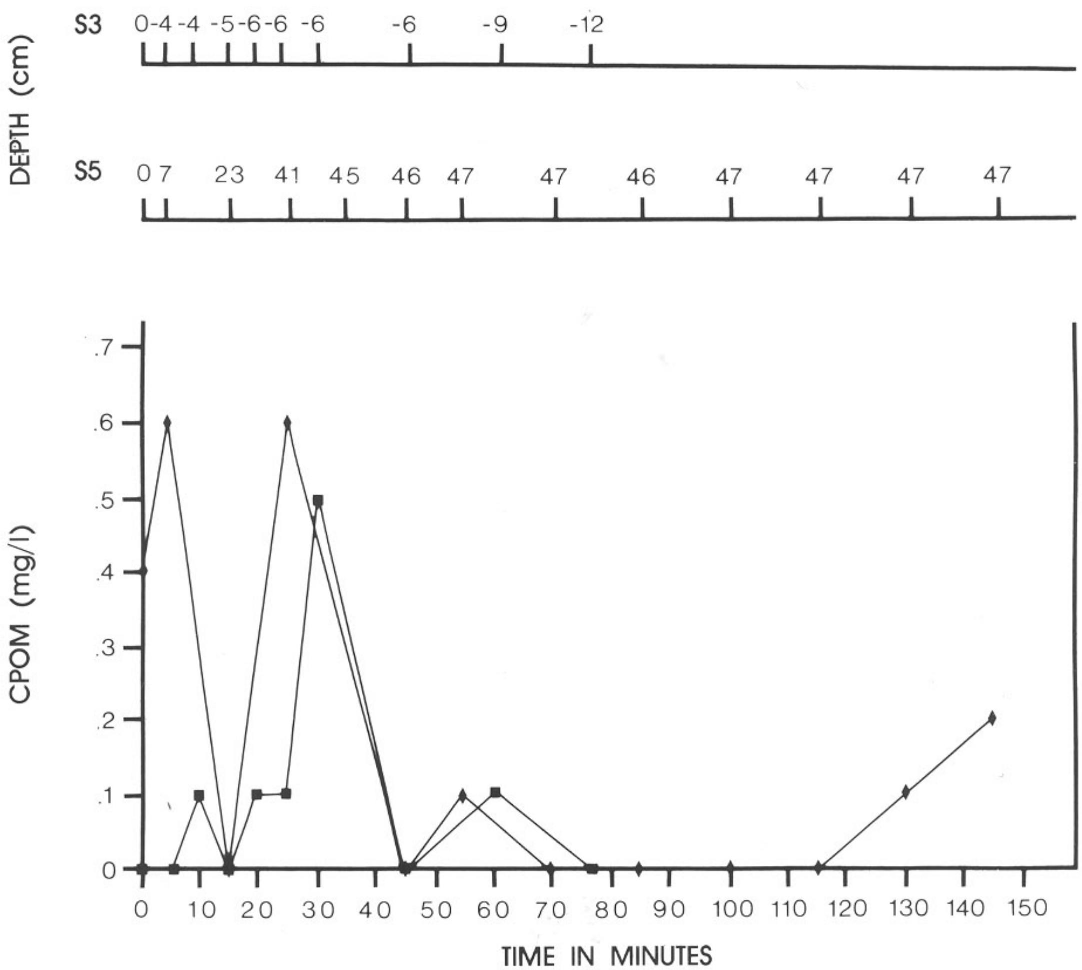


Figure 52. Coarse Particulate Organic Matter for peak event of August 9, 1985 at Sites S3 (■) and S5 (♦)

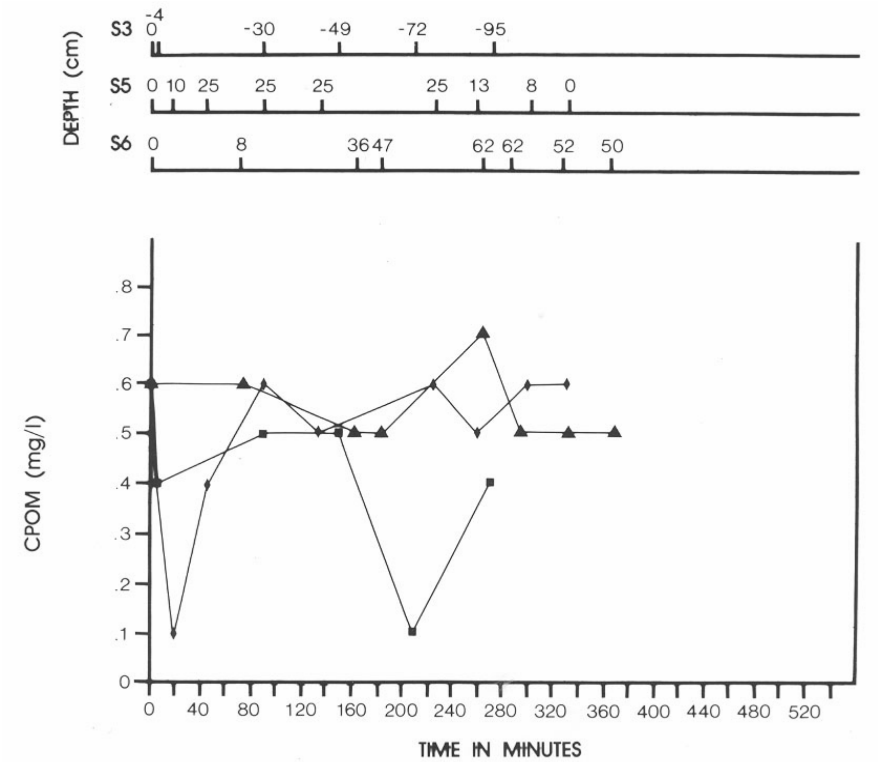


Figure 53. Coarse Particulate Organic Matter for peak event of August 26, 1985 at Sites S3 (■), S5 (♦) and S6 (▲)

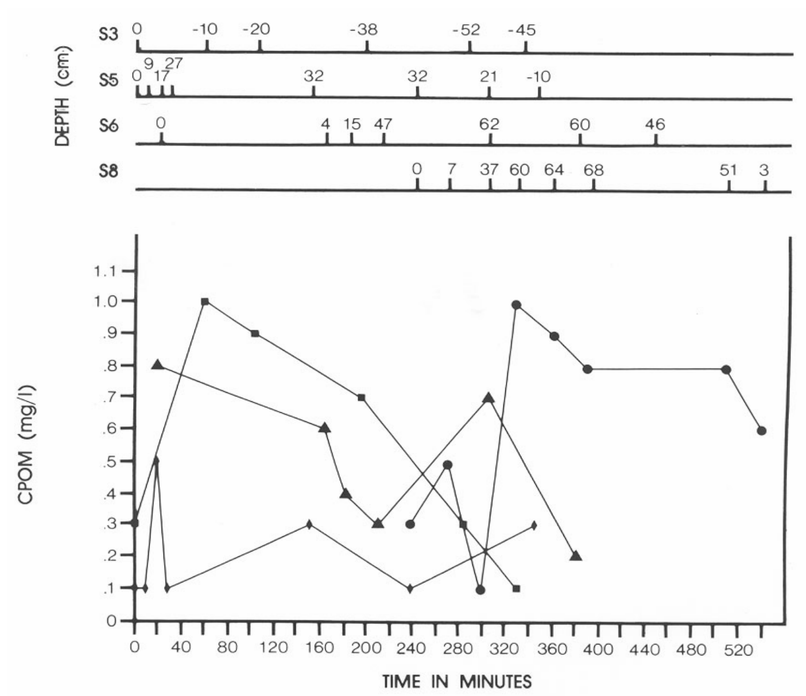


Figure 54. Coarse Particulate Organic Matter for peak event of August 30, 1985 at Sites S3 (■), S5 (♦), S6 (▲) and S8 (●)

Fine Particulate Organic Matter (FPOM)

Introduction

Fine particulate organic matter was defined in this study as OM <1 mm but >53 um in size. CPOM, both autochthonous and allocthonous, undergoes heterotrophic-mediated biological and mechanical degradation within the stream (Kausnik et al., 1968). Microbes and shredding macroinvertebrates reduce the CPOM to FPOM. FPOM is more easily transported by a stream than CPOM because of its smaller size. Therefore, FPOM will be exported downstream while CPOM may become trapped in organic debris dams (Cummins, 1975). Collecting macroinvertebrates, such as clams and Trichoptera, utilize FPOM for feeding purposes (Cummins, 1979). In a sixth order stream such as the Blue Earth River, FPOM should be relatively low in concentration and contribute a small proportion to the total OM in transport. This hypothesis can be stated because of the low concentrations of CPOM, and the minimal impact of riparian FPOM contributions, both of which are needed for the generation of FPOM.

Baseline

Mean FPOM concentrations were greatest at S1 during 1984 and 1985, and decreased as one moved downstream to S8 (Figure 55). This downstream reduction in concentrations may be due to the further processing of FPOM to smaller size classifications or changes in slope. The reservoir did not demonstrate a consistent pattern of trapping FPOM, however it did reduce downstream concentrations on certain sampling dates.

It was found that FPOM concentration were greater than CPOM (Table X). Vannotes River Continuum Theory predicts CPOM: FPOM will decrease as stream order increases (Vannote et. al. 1980). In 1984, FPOM comprised 6.2%, 5.4%, and 8.0% of total OM during the entire, early, and late sampling periods. In 1985, it comprised 8.1%, 9.6%, and 6.1% during the same sampling periods. When comparing the early and late sampling periods, FPOM possessed a greater percentage of total OM during the late period of 1984 and the early period of the 1985. Flow was low during these two sampling periods and may indicate that FPOM is greater in percentage of total OM during periods of lower flow.

Peaks

The impacts on FPOM concentrations in the Rapidan Dam's tailwaters was similar to the impacts observed for Total Phosphorus. FPOM concentrations reached or exceeded, by as much as five times, the maximum baseline concentration for the same sites in 1984 and 1985.

The 8-9 event (Figure 56) increased S5 FPOM to a peak concentration of 4.1 mg/l from a pre-sample concentration of 1.4 mg/l (193% increase in 25 minutes). Maximum baseline concentrations at S5 in 1984 and 1985 were 2.60 mg/l and 2.30 mg/l respectively. During the 8-26 and 8-30 peak-events, (Figures 57, 58), concentrations at S5 were 3.7 mg/l (3.7 mg/l pre-sample) and 2.8 mg/l (1.7 mg/l) pre-sample), demonstrating the greater impact of the 8-9 event. Concentrations at S3 were very stable during this event, and near the minimum baseline concentration for 1985 (1.10 mg/l).

During the 8-26 and 8-30 events, the water surge magnified the affects of FPOM as it moved farther downstream Site S6 (8-26 event) FPOM peaked at 5.7 mg/l (a 380% increase) and possessed baseline maximum concentrations of 3.0 mg/l and 5.4 mg/l in 1984 and 1985 respectively. Site S8 (8-30 event) FPOM peaked at 10.4 mg/l (increased 329% during the ascending leg) and possessed baseline maximum concentrations of 1.2 mg/ l and 2.3 mg/l in 1984 and 1985 respectively. The peak concentration at S6 during the 8-30 event reached 3.1 mg/l. Site S3 concentrations peaked at 3.4 mg/l (8-26 event) which is near the maximum baseline value for 1984 (3.7 mg/l). The 8-30 event saw S3 FPOM remain basically stable and similar to S5 concentrations.

The peaking operation did impact downstream FPOM concentrations by increasing them to early summer high water levels.

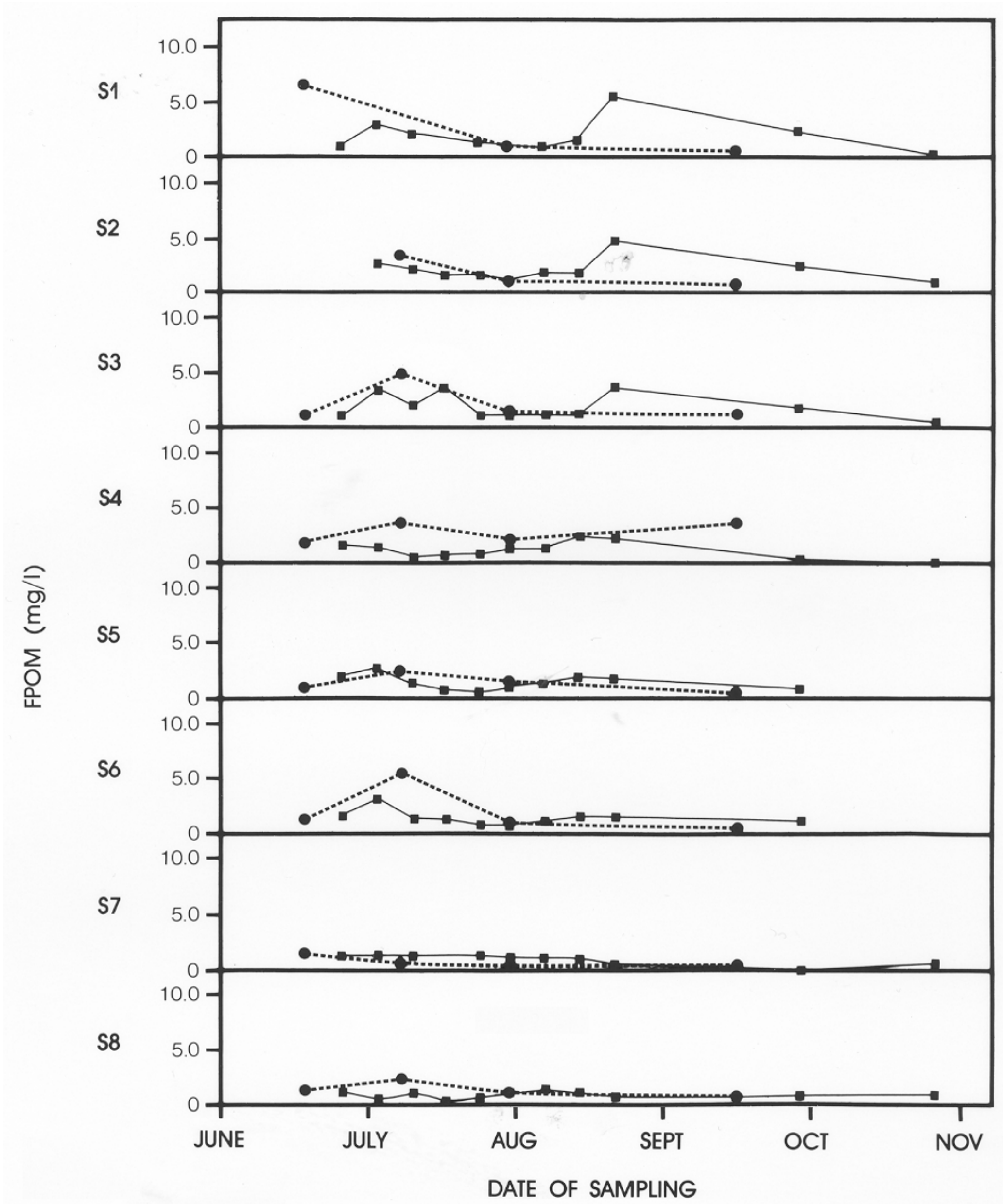


Figure 55. Baseline Fine Particulate Organic Matter for 1984 (■) and 1985 (●) sampling seasons at Sites S1-S8.

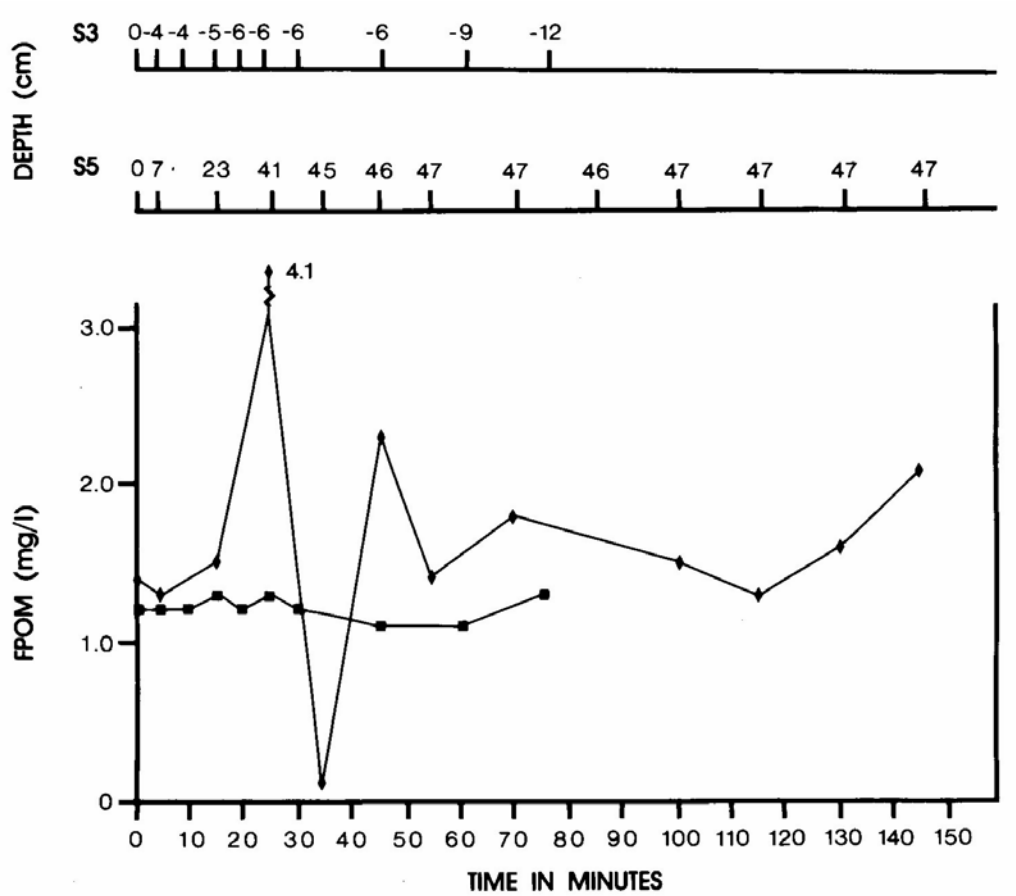


Figure 56. Fine Particulate Organic Matter for peak event of August 9, 1985 at S3 (■) and S5 (♦)

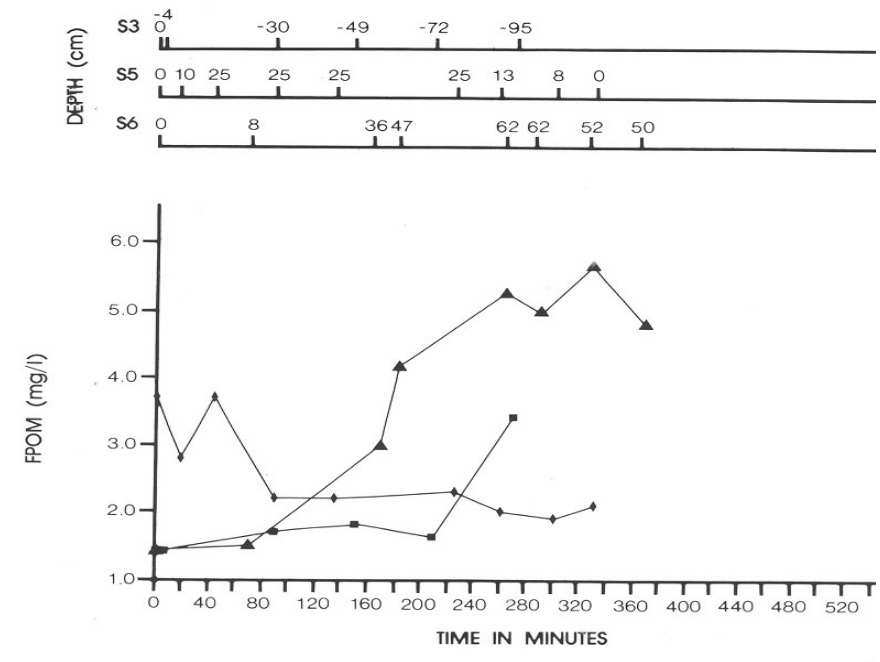


Figure 57. Fine Particulate Organic Matter for peak event of August 26, 1985 at Sites S3 (■), S5 (♦) and S6 (▲)

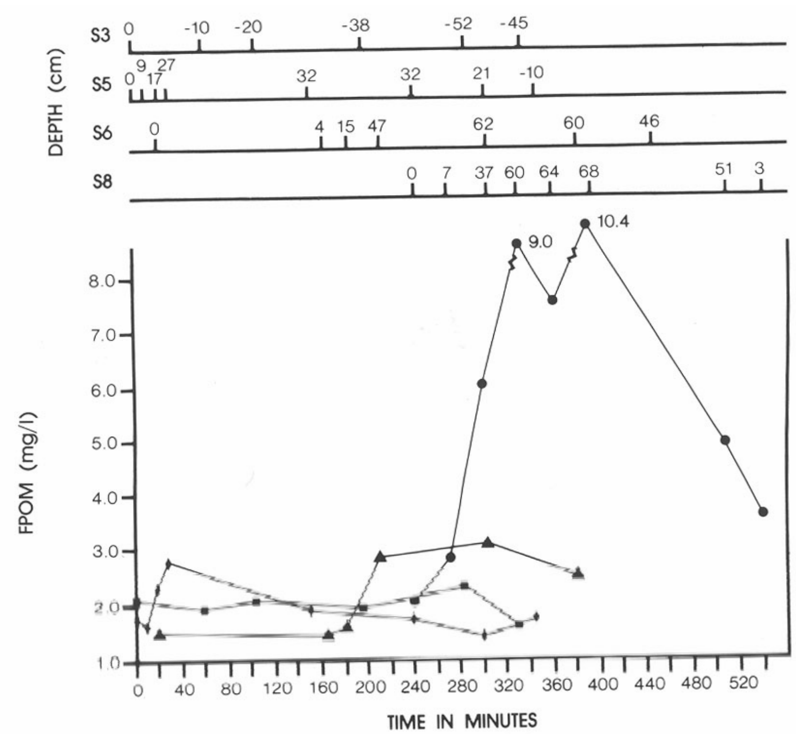


Figure 58. Fine Particulate Organic Matter for peak event of August 30, 1985 at Sites S3 (■), S5 (♦), S6 (▲) and S8 (●)

Very Fine Particulate Organic Matter (VPOM)

Introduction

Very fine particulate organic matter was defined in this study as OM <53 um but >0.45 um in size. VPOM in the Blue Earth River contributed the greatest proportion to the total OM in transport. Naimen and Sedell (1979) found that VPOM possessed the greatest proportion of total OM transported by four streams in Oregon ranging in order from first to seventh. They hypothesized that higher order streams transport mostly VPOM because it can be generated very rapidly from CPOM, FPOM and dissolved organic material. Wallace et al. (1977), and Maciolek and Tunzi (1968), demonstrated that particle sizes are selectively utilized by the aquatic fauna. Their studies also indicated the importance of VPOM to downstream communities.

Baseline

Although flow patterns were completely opposite in 1984 and 1985, VPOM concentrations followed very similar trends for the two years. The similar patterns, regardless of flow, strengthens the hypothesis that VPOM is generated rapidly and is abundant. The very high concentration of 71.5 mg/l at S3 on the 7-16-84 sampling date, correlates with the closing of the tainter gates of the dam to fill the reservoir (Figure 59).

Similar to FPOM, the reservoir did not demonstrate a trapping affect on VPOM. The small particle size may have allowed VPOM to remain suspended within the water column.

VPOM comprised the greatest percentage of total OM with 64.7%, 67.5%, and 58.0% in 1984, and 66.2%, 68.4%, and 63.4% in 1985, during the entire, early and late sampling periods respectively (Table VII). VPOM did possess a slightly greater percentage of total OM during the early sampling periods of both years. This cannot be attributed to flow since flow was very high during this time in 1984, but lower in 1985.

Throughout the sampling periods, concentrations at each site were initially high, and steadily decreased during the summer and on into fall. A consistent impact by the reservoir or the tributaries on mainstem concentrations is not evident.

Peaks

VPOM concentrations during all three peak-events reached or exceeded maximum baseline concentrations at all tailwater sites. Peak concentrations were again greater as the initial surge moved downstream beyond S5 (Figures 60, 61, 62).

Similar to CPOM and FPOM, VPOM concentrations followed the peak-events ascending leg, peak plateau, and descending leg closely with a respective increase, leveling off, and decrease. Sites S5, S6, and S8 possessed fairly similar pre-sample concentrations, both between sites and between events.

Site S5 experienced its greatest peak concentration during the 8-30 event with 21.0mg/l, as compared to 15.4mg/l, and 15.2 mg/l during the latter two peak-events. The maximum baseline concentrations at S5 for 1984 and 1985 were 20.2 mg/l and 15.4 mg/l respectively. The 8-9 peak-event did not appear to have a greater impact on S5 concentrations than did the 8-26 and 8-30 events.

The peak concentrations at S6 during the 8-26 (a 92% increase) and 8-30 (a 63% increase) events were 22.5 mg/l and 26.2 mg/l respectively. The maximum baseline concentrations at this site were 24.0 mg/l and 18.5 mg/l in 1984 and 1985 respectively.

Site S8 saw a peak concentration of 26.1 mg/l during the 8-30 event, with a baseline maximum of 18.0 mg/l and 13.2 mg/l in 1984 and 1985 respectively.

Site S3 saw VPOM steadily increase to peak at 21.8 mg/l (a 31% increase) from a pre-sample of 16.6 mg/l during the 8-26 event. This peak concentration was well below the maximum baseline concentration in 1984 (71.5 mg/l), but greater than the maximum in 1985 (17.1 mg/l). This increase could have been due to a concentrating effect due to the draw-down occurring at the site.

The peaking operation of the dam had the same impact on downstream VPOM concentrations as early summer floods. The impacts on concentration were magnified as the initial sure moved downstream. The increases in concentration are no doubt due to scour and recruitment from bank storage sources.

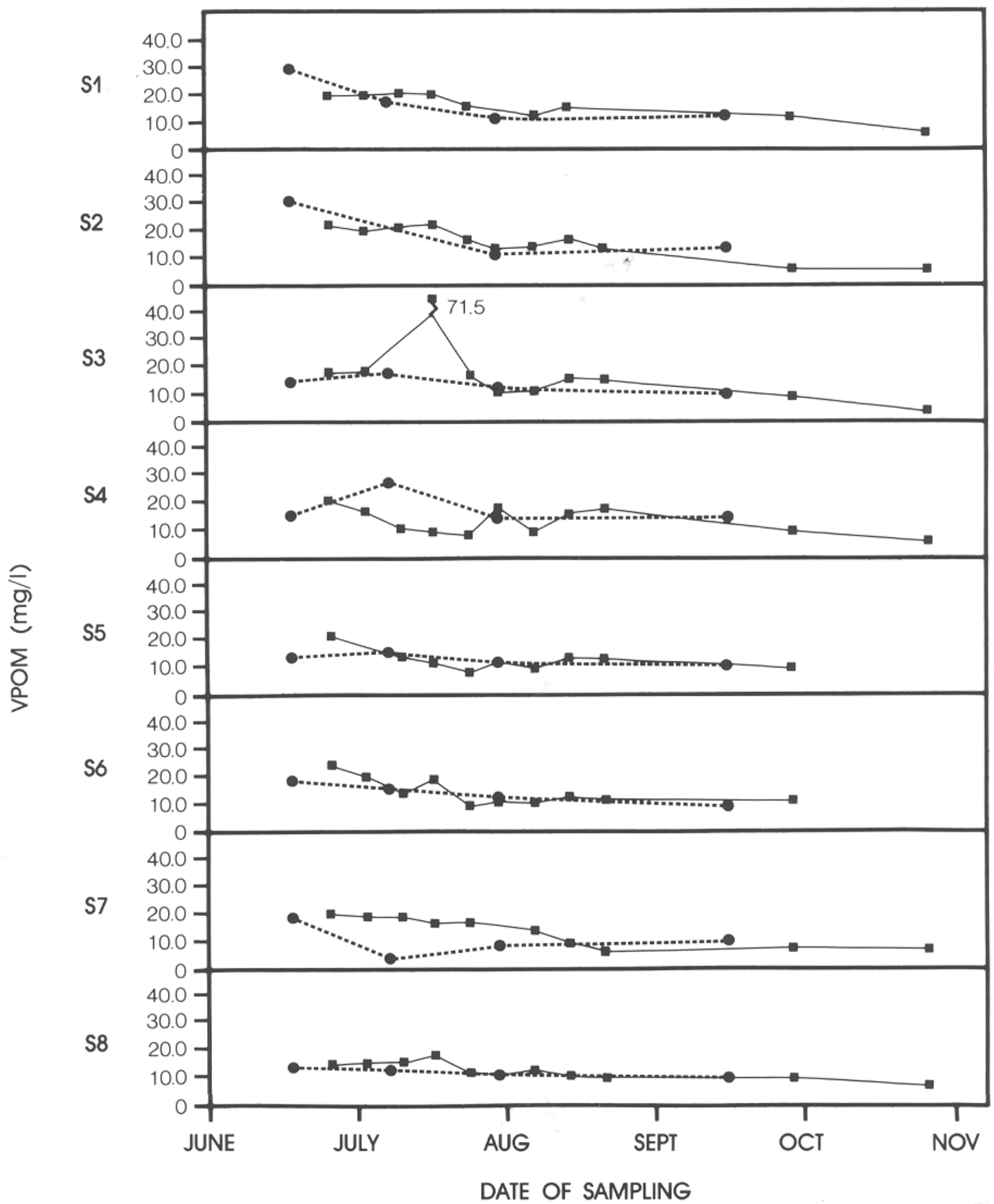


Figure 59. Baseline Very Fine Particulate Organic Matter for 1984 (■) and 1985 (●) sampling seasons at Sites S1-S8.

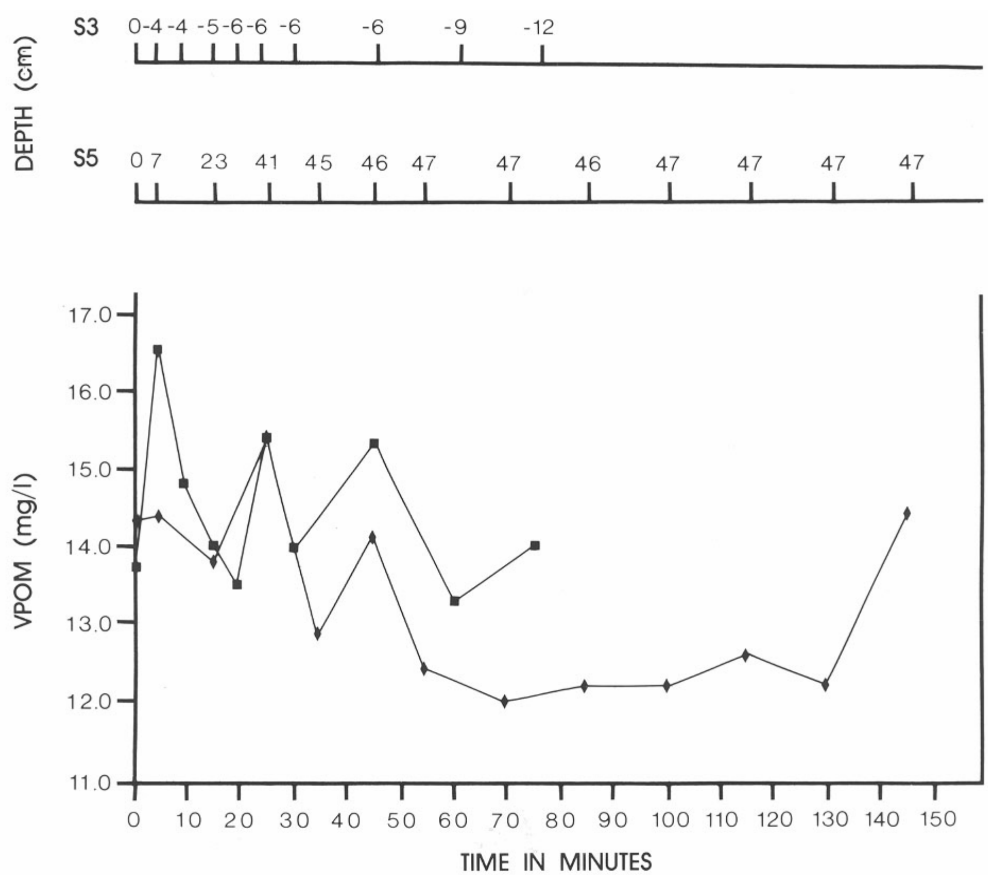


Figure 60. Very Fine Particulate Organic Matter for peak event of August 9, 1985 At Sites S3 (■) and S5 (♦)

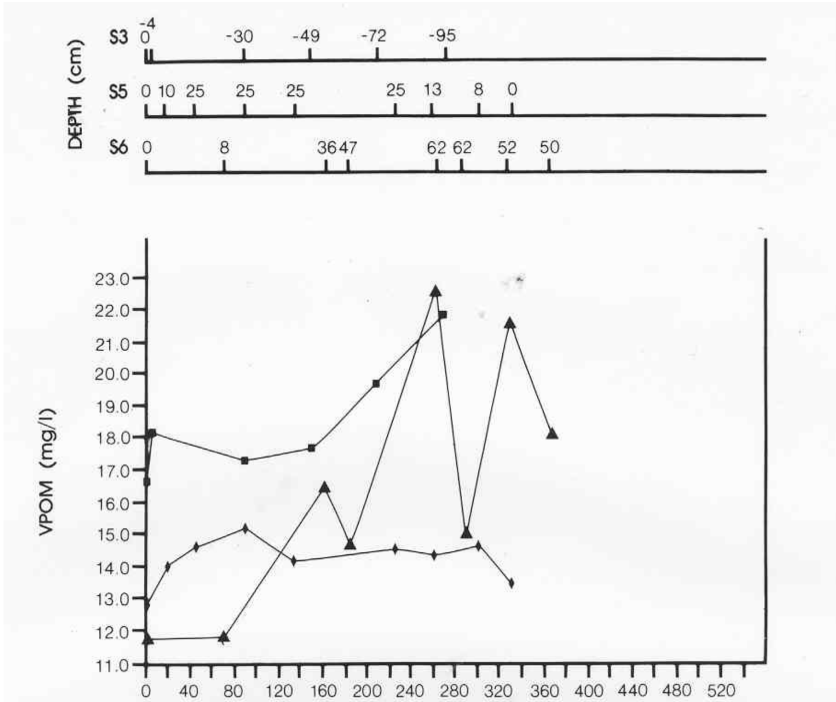


Figure 61. Very Fine Particulate Organic Matter for peak event of August 26, 1985 at Sites S3 (■), S5 (♦) and S6 (▲)

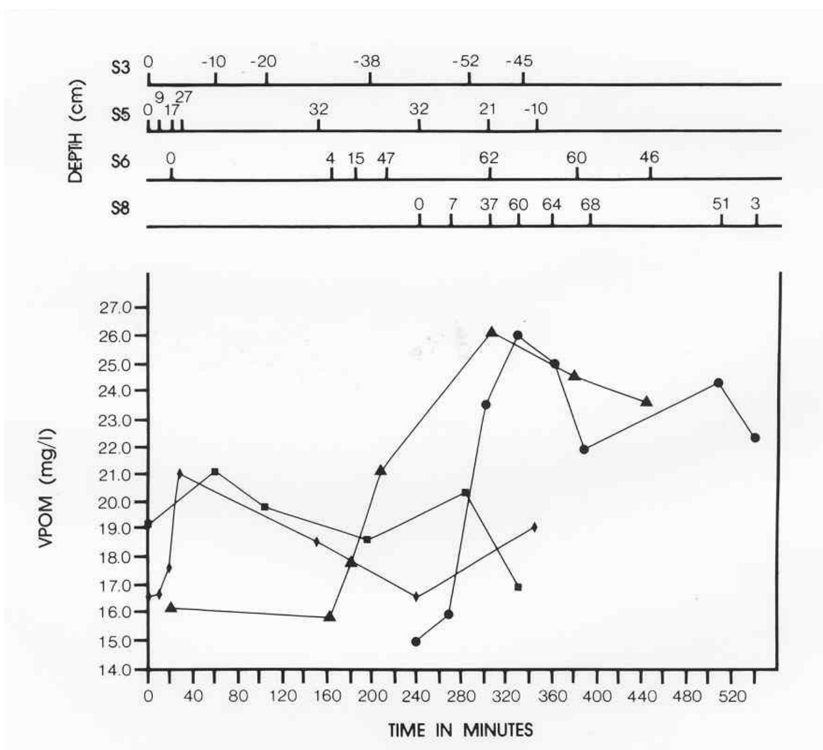


Figure 62. Very Fine Particulate Organic Matter for peak event of August 30, 1985 at Sites S3 (■), S5 (♦), S6 (▲) and S8 (●)

Dissolved Organic Carbon

Introduction

Dissolved organic carbon (DOC) was defined in this study as the carbon component of organic material <0.45 um in size. DOC enters riverine ecosystems throughout their length from upstream, OM degradation, groundwater, producer/consumer exudates and excretions (Cummins, 1979). DOC is utilized solely by bacteria as a direct food source since there is no functional macroinvertebrate group capable of feeding directly on DOC (Cummins, 1979).

Baseline:

During both the1984 and 1985 sampling periods (Figure 63) there is a consistent diluting of mainstem DOC downstream of the confluence of the Watonwan and Blue Earth Rivers (S2). The Le Sueur River (S7) tended to have greater concentrations than at S6, but did not appear to impact mainstem concentrations a great distance downstream. This is evident because DOC mean concentrations at S8 were lower than or the same as at S6. Concentration means during the early and late sampling periods of 1984 and 1985, show very little variation for their respective years. One can therefore conclude that similar to VPOM, DOC is not correlated with flow since both years were very different in regard to flow, similar to VPOM. Several studies have reported weak positive correlations between DOC and flow (Lewis and Tyburczy, 1974; Fisher and Likens, 1973; Larson, 1978), while others have found weak negative correlations (Fisher, 1977). When looking at sampling date concentrations, there does not appear to be any significant changes in DOC throughout the sampling periods of both 1984 and 1985.

DOC does not contribute as large a proportion to total OM in transport as does VPOM, however it is greater in proportion that CPOM and FPOM. The percentage of total OM in the DOC size classification was 28.6%, 67.5%, and 33.7% in 1984, and 23.0%, 19.9%, and 29.3% in 1985 during the entire, early and late sampling periods respectively (Table VII). DOC was slightly greater as a percentage of total OM during the late sampling periods of 1984 and 1985. This may have been caused by the greater rates of productivity and metabolism expected to occur during the late summer period.

The reservoir did not appear to impact downstream DOC concentrations.

Peaks:

DOC concentrations during the peak-events reached maximum baseline concentrations at certain downstream sties. The 8-9 event did not appear to have a greater impact on downstream , when compared to the latter two events, as was evident with the other size classifications of OM (Figure 64).

Contrary to what has been observed with a majority of the parameters analyzed, DOC concentrations did not appear to be greater at S6 and S8 than S5 concentrations during the 8-26 and 8-30 events (Figures 65, 66). Site S3 possessed lower concentrations than S5 during the 8-9 event, but had greater concentrations during the latter two events. Site S6 possessed lower concentrations than S5 during the 8-26 peak-event, and possessed a lower peak concentration (5.8 mg/l) than did S5 (8.0 mg/l) during the 8-30 event. However, site S8 did demonstrate the usual pattern, as with most parameters, of a greater peak concentration than at sites S5 and S6 during the 8-30 peak event. Although the peak concentration at S8 was only 0.6 mg/l greater than the peak concentration at S5, S8 possessed a 59% increase from the pre-sample while S5 possessed a 16% increase from its pre-sample reading to its peak concentration.

The peaking operation of the dam appeared to resemble a natural hydrologic event of one to two inches in rainfall, but cannot be concluded to resemble early season high water conditions due to the lack of consistent increases to maximum baseline concentrations.

During the 8-9 event, DOC concentrations at S5 peaked as the ascending leg gave way to the peak plateau, but also peaked for a second time at 100 minutes into the peak-event. This second peak in concentration also appears with the parameter Filterable Phosphorus during the same peak-event, at the same 100-minute sample time. The two parameters were linked to one another in some way during this particular event. The two parameters had one characteristic in common in that they were both in the dissolved state, and therefore could not have been directly associated with suspended detritus or seston. This association was not observed during the latter two peak-events. An explanation of the significance of the association between these two parameters during the particular event, other than what has been stated, cannot be given at this time.

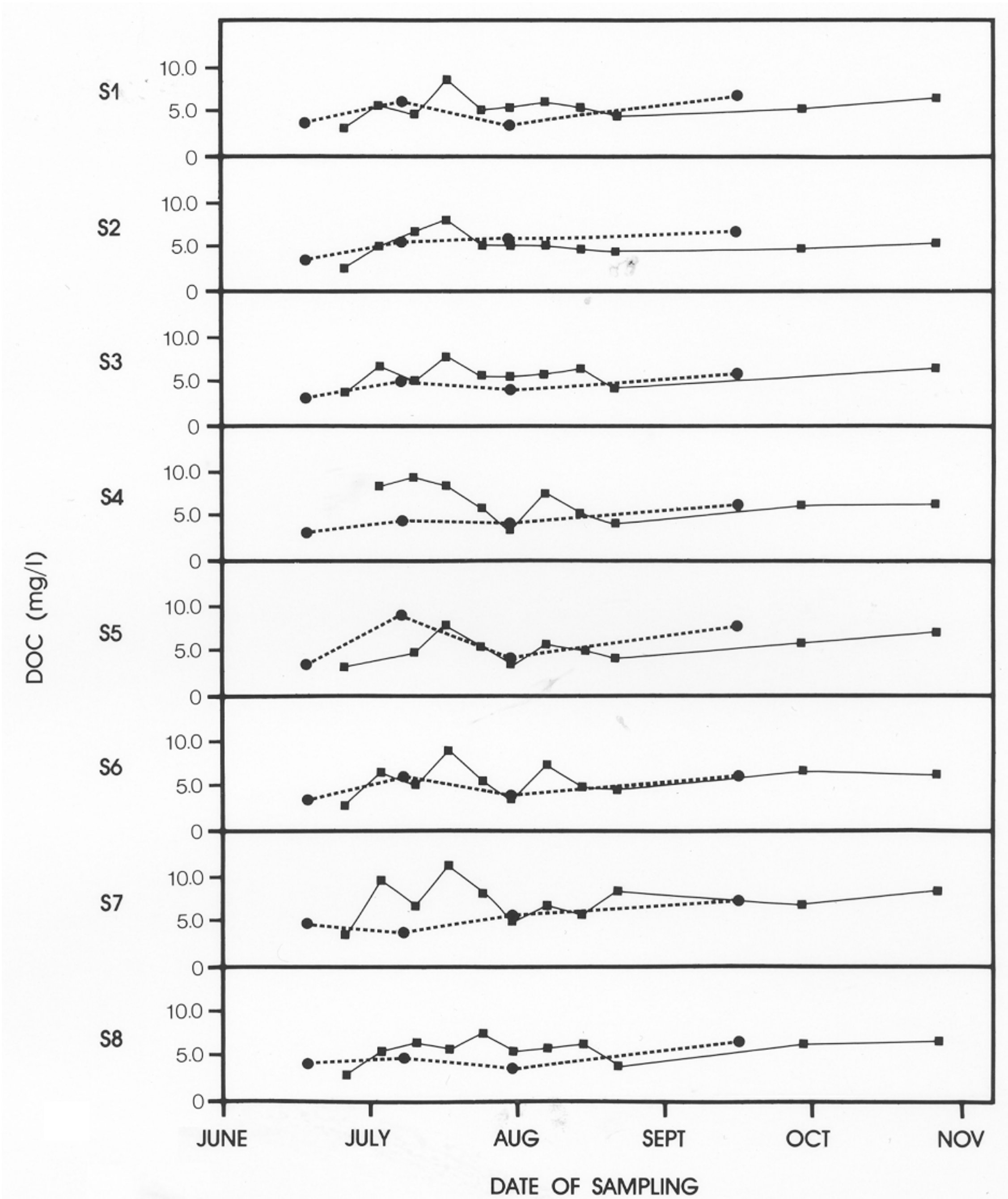


Figure 63. Baseline Dissolve Organic Carbon for 1984 (■) and 1985 (●) sampling seasons at Sites S1-S8.

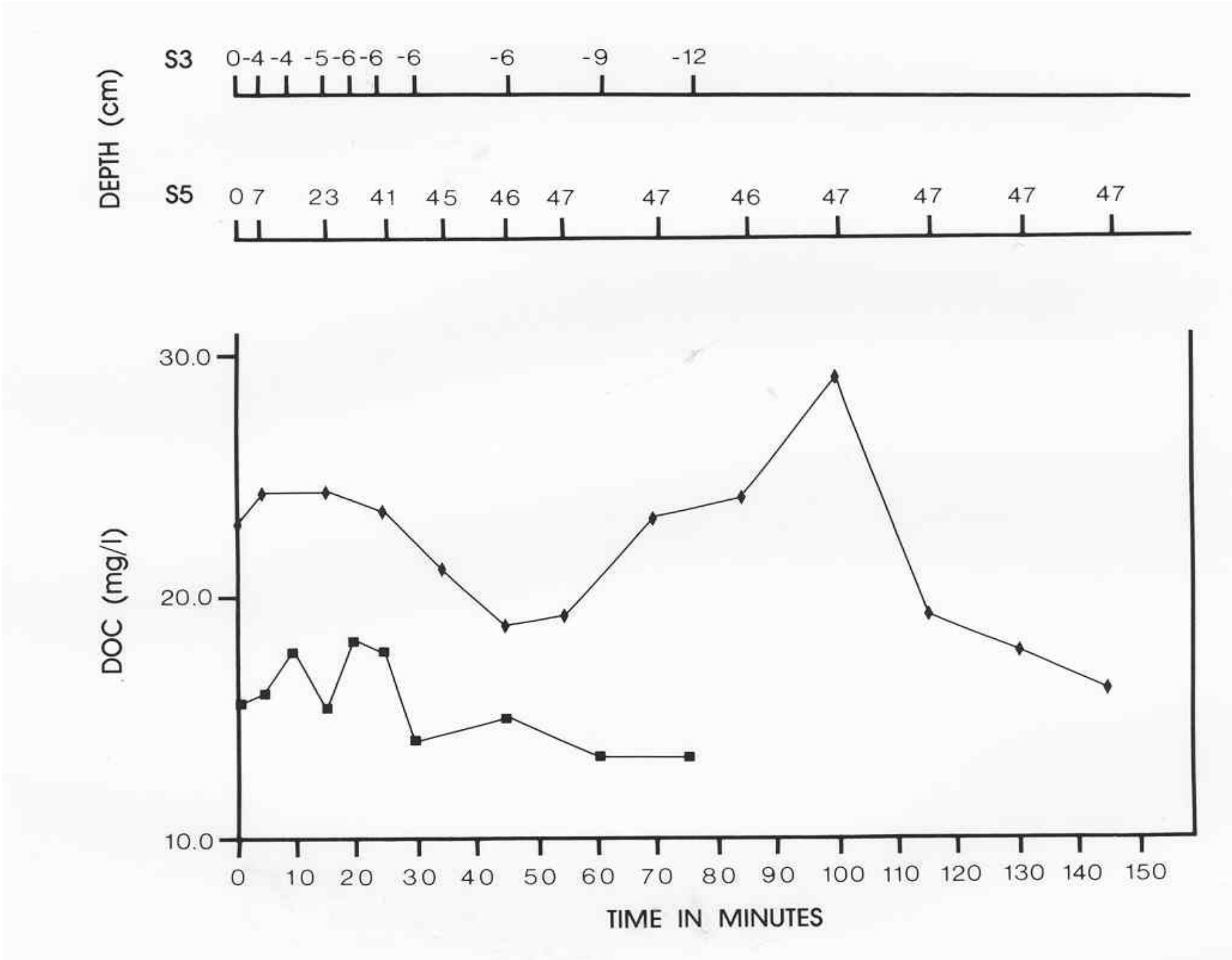


Figure 64. Dissolved Organic Carbon for peak event of August 9, 1985 at Sites S3 (■) and S5 (♦)

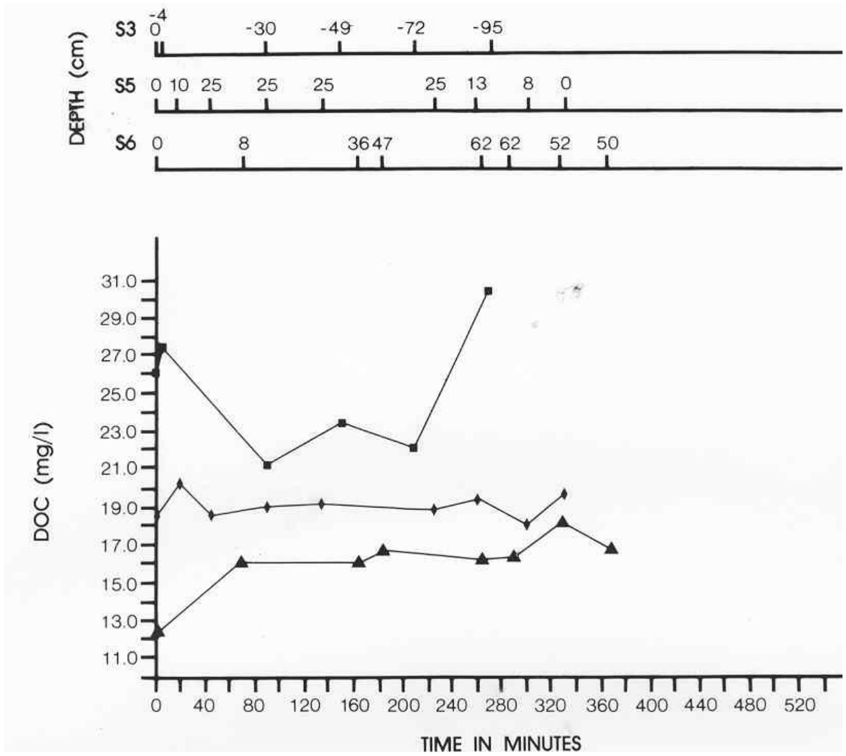


Figure 65. Dissolved Organic Carbon for peak event of August 26, 1985 at Sites S3 (■), S5 (♦) and S6 (▲).

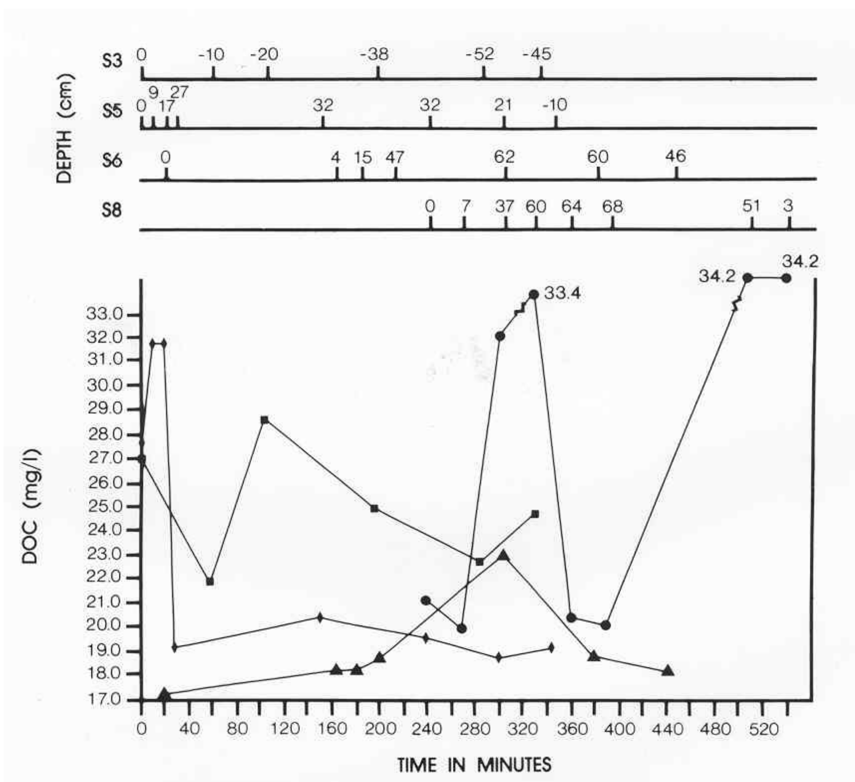


Figure 66. Dissolved Organic Carbon for peak event of August 30, 1985 at Sites S3 (■), S5 (♦), S6 (▲) and S8 (●) .

Sediments

Suspended Sediments

Introduction

The suspended sediments grain size data for both baseline and peaks are first treated as a whole and then broken down and discussed individually for coarse and medium silt (0.062 mm-0.016 mm), fine and very fine silt (0.016 mm-0.004 mm), and clay (less than 0.004 mm). Data for percent organic content of suspended sediments are treated both as percent organic matter silt and clay combined (everything less than 0.062 mm, also known as fines) and as percent organic matter clay (everything less than 0.004 mm).

Total Suspended Sediments

Baseline:

Integrated suspended sediment sample data at all sites for 1984 and 1985 are shown in Table XI and Figure 67. The mean suspended sediment data for each wet and dry period of 1984 and 1985 are shown in Table XII. In both 1984 and 1985 the early (June-July) to late (August to September) period showed almost a 50% decrease in suspended sediments even though we went from normal to dry in 1984 and dry to wet in 1985. Similarly, the reservoir acted as a trap in the two early periods with no apparent affect in the late periods even though the wet/dry cycle reversed itself from 1984 to 1985. The seasonal landscape changes may be affecting the results and overriding the hydrology. After the crop canopy is closed, much of the energy from falling rain is dissipated on the crops and not the soil surface. Less sediment is dislodged and carried with runoff compared to when the canopy is open. No consistent pattern of increase or decrease as one proceeds downstream of the reservoir was observed in either year.

Peaks:

Suspended sediment concentrations for the three 1985 peaking events are shown in Table XIII.

8/9: The August 9 event at Site 3 showed a significant increase from the 8-7 baseline of 0.04 g/L (Table XI). This event was preceded by 9 days of no rain. The same relationship held for site 5. Site 5 showed an increase in the ascending leg and early plateau followed by a drop off.

8/26: The August 26 event was immediately preceded by abnormally high precipitation. The values for the pre-event corresponded closely to the 8-13 baseline data. Sites 3 and 5 showed little change over the course of the event indicating the reservoir had little effect. Site 6 however showed a dramatic increase (almost 400%).

8/30: The August 30 event was proceeded the day before by a 2.62 inch precipitation event. The pre-event data as on 8-26 corresponded closely to 8-13 baseline data. Unlike 8-26 and 8-9, Site 3 showed a significant increase in suspended sediment during the event. Site 5 and 6 showed an initial increase in the ascending leg and then dropped back to pre-event levels or lower (Site 6). Site 8 increased significantly to the end of the plateau.

Table XI: Baseline Suspended Sediment- grams per liter for each sampling date in the 1984 and 1985 sampling seasons at Sites S1-S8.

Precipitation	Rainfall and Deviation (inches)	Mean Monthly Flow (CFS)	Date	S1	S2	S3	S4	S5	S6	S7	S8
Normal	6.9 (2.0)	5184	6/1/84	.39	.14	.26	.16	-	.22	.16	.25
			6/15/84	.51	.60	.17	.11	.06	-	.38	.23
			6/27/84	.12	.11	.19	.14	.29	.08	.22	.37
	2.4 (-1.7)	1870	7/12/84	.22	.23	.19	.22	.08	.24	.18	.16
			7/17/84	.34	.27	.42	.34	.03	.21	.09	.10
			7/30/84	.17	.20	.19	.13	.18	.26	.19	.22
Dry	2.9 (-0.8)	313	8/8/84	.20	.20	.10	.08	.18	.13	-	-
			8/21/84	.11	.12	.14	.10	.13	.11	.28	.13
	1.7 (-1.3)	134	9/5/84	.09	.09	.10	.11	.09	.13	.07	.14
			9/28/84	.12	.10	.11	.13	.12	.10	.11	.10
	5 (3.3)	193	10/27/84	.12	.13	.11	.12	.10	.08	.15	.13
Very Dry	2.4 (-2.5)	933	6/24/85	.29	.26	.25	.31	.29	.19	.24	.27
	2.2 (-2)	262	7/2/85	.25	.29	.22	.26	.19	.19	.18	.20
			7/11/85	.16	.23	.14	.16	.15	.13	.10	.48
			7/22/85	.17	.14	.28	.06	.08	.11	-	.48
Abnormally Wet	9.1 (5.3)	159	8/7/85	.07	.04	.04	.11	.08	.07	.12	.11
			8/13/85	.16	.11	.10	.03	.17	.13	.10	.10
	5.3 (2.2)	684	9/27/85	.03	.22	.22	.11	.10	.13	.02	.17

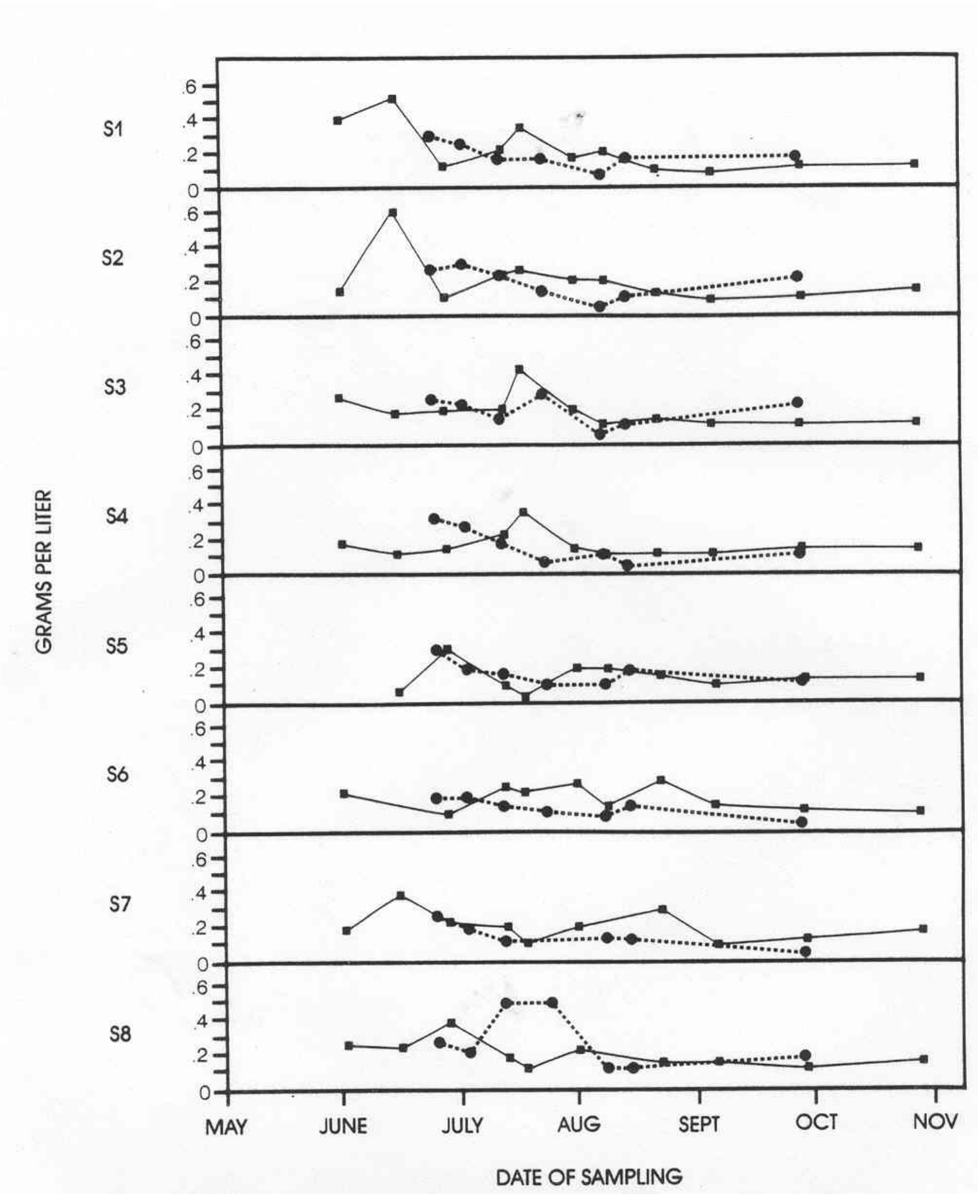


Figure 67. Baseline suspended sediment-grams per liter for 1984 (■) and 1985 (●) sampling seasons at Sites S1-S8.

Table XII: Summary of baseline suspended sediments (grams/liter) and corresponding percent grain size and organic matter by precipitation periods and sampling sites.

Precipitation	Date	S1	S2	S3	S4	S5	S6	S7	S8	$\bar{X}$*
Normal	6/1-7/30 1984	0.29 45 53 18 54 37	0.26 31 54 23 41 46	0.24 34 72 23 67 43	0.18 34 40 13 69 53	0.13 34 48 12 75 52	0.20 45 37 20 85 39	0.20 31 54 24 55 45	0.22 20 20 22 54 58	0.22 34 47 19 63 47
Dry	8/8-9/28 1984	0.13 25 47 18 60 57	0.13 28 41 15 63 58	0.11 13 76 35 87 52	0.11 9 79 21 73 70	0.13 15 47 15 73 70	0.12 31 93 24 57 45	0.15 26 52 12 60 60	0.12 41 59 13 72 49	0.12 24 56 19 58 68
Very Dry	6/24-7/22 1985	0.22 37 34 21 49 42	0.23 44 45 20 35 46	0.22 44 33 14 42 45	0.20 5 23 40 43 55	0.18 6 52 16 59 77	0.16 14 41 17 56 69	0.17 22 57 30 49 48	0.36 50 59 12 60 38	0.22 28 43 21 49 53
Abnormally Wet	8/7-9/27 1985	0.9 3 36 16 58 81	0.12 40 58 10 93 50	0.12 26 49 42 68 31	0.08 24 47 9 60 67	0.12 62 81 0 68 38	0.11 62 34 8 44 51	0.08 40 44 44 46 16	0.13 26 73 0 67 73	0.11 35 53 16 63 51

Key	
Mean Suspended Sediments (Grams/Liter)	
Mean % Coarse and Medium Silt	Mean % Organic Silt and Clay
Mean % Fine and Very Fine Silt	Mean % Organic Clay
Mean % Clay	

* Mean of S1-S

Table XIII: Grams per liter of suspended sediment for 1985 peaks.

9-Aug			26-Aug			30-Aug		
Site	Time	g	Site	Time	g	Site	Time	g
3	*0	.22	3	*0	.14	3	*0	.1
	5	.22		5	.16		60	.09
	10	.2		90	.16		105	.16
	15	.22		150	.11		195	.05
	20	.21		210	.16		285	.23
	25	.25		270	.12		330	.26
	30							
	45	.2	5	*0	.12	5	*0	.16
	60	.24		20	.12		10	.12
	75	.23		45	.15		20	.25
				**90	.11		**30	.12
5	*0	.21		135	.18		150	.18
	5	.09		225	.13		240	.01
	15	.2		***260	.16		***300	.11
	25	.34		300			345	.18
	**35	.24		330	.23			
	45	.28				6	*20	.2
	55	.2	6	*0	.12		164	.12
	85	.22		72	.12		180	.08
	100	.21		162	.17		210	.29
	115	.2		182	.25		**305	.17
	130	.25		**262	.44		380	.08
	145	.05		292			***445	.08
				***332	.29			
				367	.21	8	*240	.11
							270	.14
							300	.17
							**330	.18
							360	.29
							390	.27
							***510	.34
							540	.24

* Pre Event
** Plateau
*** Descending Leg

Suspended Sediment: Coarse and Medium Silt

Baseline:

The percent of suspended sediment that is coarse and medium silt by date and site is shown in Table XIV and Figure 68. The values of percent coarse and medium silt ranged from 95% to 0%, with seasonal means ranging from 62% to 3% (Tables XIV and XII). Early and late seasons for 1984 showed a decrease in means for seven out of eight sites (Site 8 being the exception) with 1985 not showing any evident trend (Table XII). The overall seasonal means for the combined eight sites showed a seasonal decrease in 1984 and increase in 1985. This follows the precipitation cycles. Only in the dry season of 1985 does the reservoir act as a trap for coarse and medium silts. However, the levels still increase progressively downstream of the dam. During the wet period of 1985 the reservoir did not act as a trap for the category course and medium silts. A relationship of higher percentage coarse and medium silt to suspended sediment concentration was not apparent.

Peaks:

The concentrations were generally lower at Site 3 (start of reservoir) than at Site 5 (the first downstream site), although data were mixed for all three peaks. It appears there was some suspended sediment released from the reservoir. Downstream of the reservoir, there was a decrease on August 26 and on August 30 an increase from Sites 5 to 6 and decrease from 6 to 8 (Table XV). However, these data were very mixed and no clear pattern was discernable.

Table XIV: Baseline total percent of suspended sediments that is coarse and medium silt for each sampling date of the 1984 and 1985 sampling seasons of Sites S1-S8.

	Precipitation	Rainfall and Deviation (inches)	Mean Monthly Flow (CFS)	Date	S1	S2	S3	S4	S5	S6	S7	S8
Early	Normal	6.9 (2.0)	5184	6/1/84	57.58	22.81	41.44	28.99	- - -	11.96	0.00	19.33
				6/15/84	48.37	6.34	55.56	68.75	40.74	0.00	39.75	10.42
				6/27/84	48.08	73.33	0.00	39.34	33.33	55.56	35.50	29.78
		2.4 (-1.7)	1870	7/12/84	39.78	23.96	12.62	14.29	68.57	85.86	41.38	63.64
				7/17/84	63.89	49.56	73.60	32.64	15.63	77.52	35.29	0.00
				7/30/84	12.33	10.47	19.15	18.18	12.99	39.45	35.87	0.00
Late	Dry	2.9 (-0.8)	313	8/8/84	12.72	18.82	26.14	11.76	11.14	27.00	26.00	26.12
				8/21/84	60.64	62.89	5.08	9.76	3.74	54.02	63.01	76.83
		1.7 (-1.3)	164	9/5/84	0.00	16.88	0.00	0.00	15.07	21.82	0.00	17.21
				9/28/84	26.26	11.11	20.48	12.96	28.57	18.95	15.88	44.30
		5 (3.3)	193	10/27/84	23.08	1.89	6.52	40.00	30.00	34.78	26.61	33.02
Early	Very Dry	2.4 (-2.5)	933	6/24/85	24.11	18.52	3.10	18.69	0.00	23.46	6.80	20.00
		2.2 (-2)	262	7/2/85	31.78	36.88	51.06	0.00	0.00	0.00	50.64	29.07
				7/11/85	14.81	50.00	55.00	2.22	0.00	20.56	9.20	75.99
				7/22/85	77.30	68.37	65.27	0.00	24.78	12.78	- - -	75.99
Late	Abnormally Wet	9.1 (5.3)	159	8/7/85	0.00	0.00	0.00	54.74	38.80	83.61	25.96	20.22
				8/13/85	9.16	65.63	8.53	0.00	66.19	57.94	0.00	23.53
		5.3 (2.2)	684	9/27/85	0.00	54.83	69.78	15.63	79.54	43.51	95.24	34.06

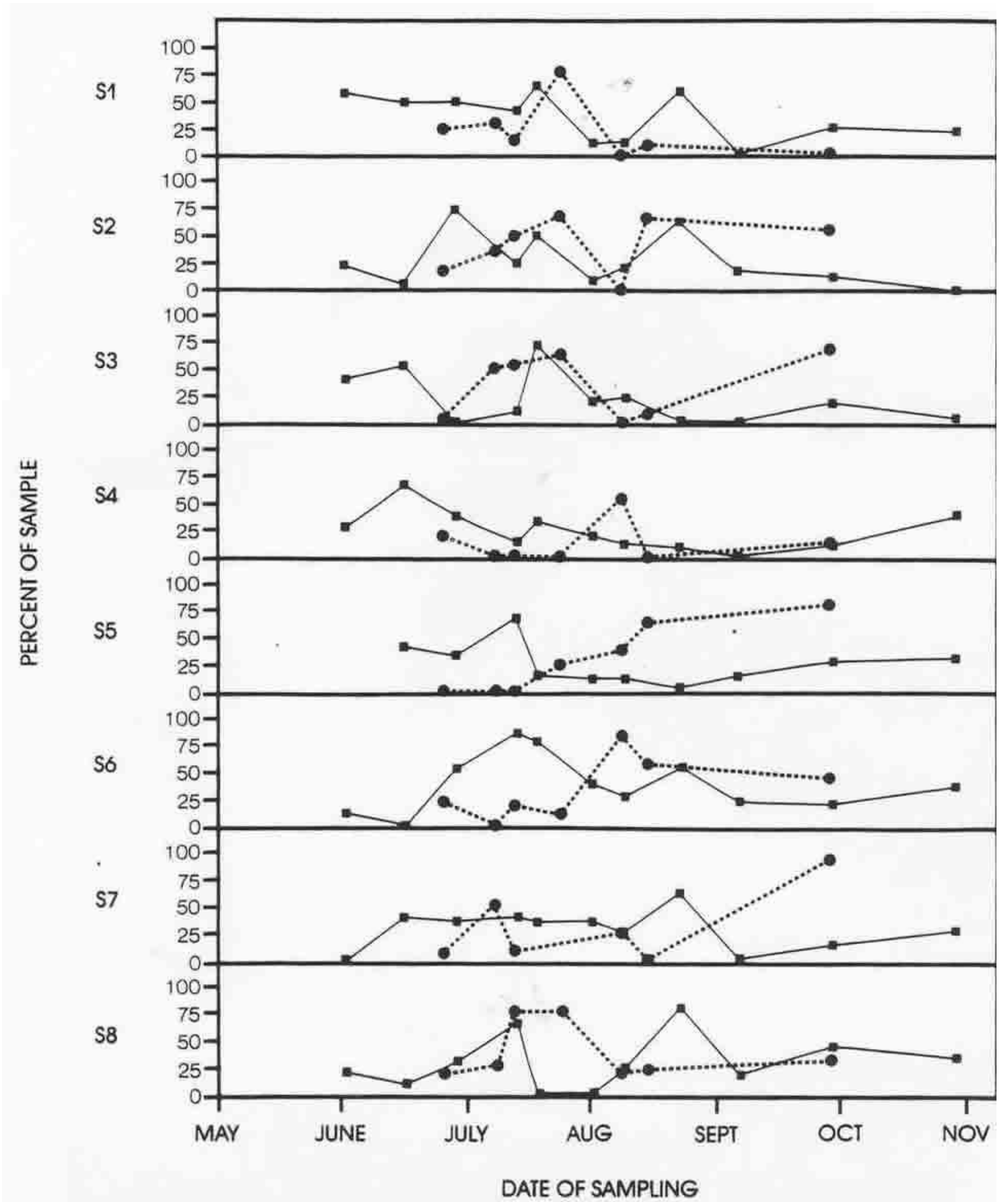


Figure 68. Baseline suspended sediment- percent of sample that is coarse and medium silt for the 1984 (■) and 1985 (●) sampling seasons at Sites S1-S8.

Table XV: Percent of suspended sediment that is coarse and medium silt for 1985 peaks.

9-Aug			26-Aug			30-Aug		
Site	Time	%	Site	Time	%	Site	Time	%
3	*0	46.81.	3	*0	46.72	3	*0	23.53
	5	43.96		5	13.76		60	0.00
	10	11.76		90	14.60		105	0.00
	15	7.53		150	0.00		195	31.58
	20	6.74		210	15.59		285	51.57
	25	3.51		270	0.00		330	19.82
	30							
	45	11.90	5	*0	50.64	5	*0	18.32
	60	45.54		20	44.00		10	0.00
	75	6.32		45	29.69		20	21.13
				**90	0.00		**30	68.27
5	*0	58.43		135	41.67		150	14.77
	5	33.33		225	57.52		240	41.00
	15	35.71		***260	54.14		***300	0.00
	25	58.74		300	87.34		345	52.00
	**35	31.68		330	76.17			
	45	46.09				6	*20	0.00
	55	0.00	6	*0	25.00		164	0.00
	85	51.61		72	32.70		180	0.00
	100	18.89		162	23.81		210	33.47
	115	44.19		182	47.37		**305	71.83
	130	10.48		**262	27.57		380	0.00
	145	0.00		292			***445	83.80
				***332	67.80			
				367	32.78	8	*240	58.89
							270	48.31
							300	0.00
							**330	38.06
							360	61.94
							390	31.16
							***510	32.87
							540	4.50

* Pre Event
** Plateau
*** Descending Leg

Suspended Sediment: Fine and Very Fine Silt

Baseline:

The percent of suspended sediment that is fine and very fine silt by date and site is shown in Table XVI and Figure 69. In most cases the fine and very fine silt makes up the smallest component of the suspended sediment (Table XII). In a fair number of cases there was no suspended sediment in the fine and very fine category, especially in the later period of 1985 where there was none in 16 out of 24 samples (Table XVI). The baselines for 1984 and 1985 tended to follow each other closely by date (Figure 69). The reservoir does not appear to be acting as a settling basin in any consistent fashion. A relationship of fine and very fine silt percentage to concentration of suspended sediment was not apparent.

Peaks:

All three peak-events at Site 3 started at 0.0% suspended fine silt and very fine silt and reached significant amounts although the readings were without pattern and highly mixed (Table XVII). The outlet from the dam, Site 5, showed higher concentrations sporadically than the pre-values indicating some flushing of reservoir sediments. No downstream pattern was discernable during any of the peaks.

Table XVI: Baseline total percent of suspended sediment that's fine and very fine silt

Precipitation	Rainfall and Deviation Index (inches)	Mean Monthly Flow (CFS)	Date	S1	S2	S3	S4	S5	S6	S7	S8
Normal	6.9 (2.0)	5184	6/1/84	13.94	28.07	7.20	24.63	---	33.70	43.48	17.31
			6/15/84	23.72	21.19	38.89	0.00	0.00	75.00	23.60	29.17
			6/27/84	30.76	6.67	29.27	0.00	22.76	7.41	16.25	9.57
	2.4 (-1.7)	1870	7/12/84	29.03	40.63	52.43	56.04	2.86	0.00	20.69	27.27
			7/17/84	0.00	23.89	0.00	0.00	28.13	0.00	28.57	46.43
			7/30/84	9.59	18.60	13.58	0.00	15.58	2.75	10.86	0.00
Dry	2.9 (-0.8)	313	8/8/84	44.24	30.00	11.36	0.00	29.056	53.70	16.67	13.43
			8/21/84	6.38	18.56	10.17	12.20	.54	17.24	0.00	0.00
	1.7 (-1.3)	164	9/5/84	14.10	0.00	65.48	35.56	25.81	17.27	32.76	40.16
			9/28/84	7.07	12.34	55.56	36.11	0.00	9.47	6.54	0.00
	5 (3.3)	193	10/27/84	5.77	44.34	9.78	0.00	3.75	0.00	25.81	0.00
Very Dry	2.4 (-2.5)	933	6/24/85	16.07	35.19	22.42	15.5	16.94	8.64	42.71	21.74
	2.2 (-2)	262	7/2/85	14.95	4.10	5.32	17.43	0.00	18.29	0.00	0.00
			7/11/85	36.27	17.86	0.00	37.04	35.43	40.19	45.95	11.88
			7/22/85	15.60	21.37	28.87	92.16	13.93	0.00	---	11.88
Abnormally Wet	9.1 (5.3)	159	8/7/85	0.00	0.00	87.88	0.00	0.00	0.00	62.50	0.00
			8/13/85	48.09	0.00	39.02	0.00	0.00	23.36	69.14	0.00
	5.3 (2.2)	684	9/27/85	0.00	29.57	0.00	28.13	0.00	0.00	0.00	0.00

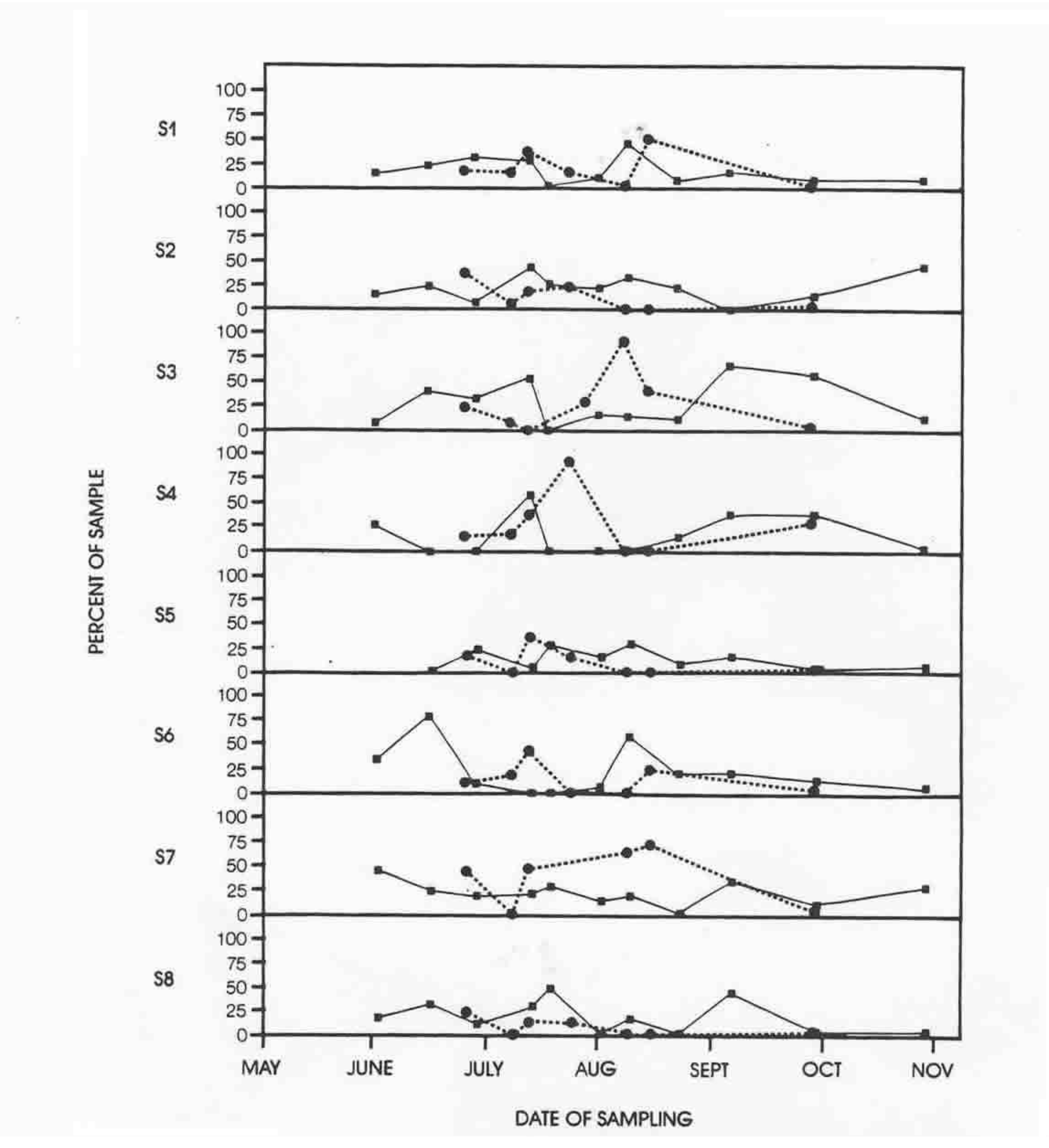


Figure 69. Baseline suspended sediment- percent of sample that is fine and very fine silt for the 1984 (■) and 1985 (●) sampling seasons at Sites S1-S8

Table XVII: Percent of suspended sediment that is fine and very fine silt for 1985 peaks.

9-Aug			26-Aug			30-Aug		
Site	Time	%	Site	Time	%	Site	Time	%
3	*0	0.00	3	*0	0.00	3	*0	0.00
	5	0.00		5	29.36		60	28.00
	10	8.23		90	10.22		105	51.15
	15	0.00		150	0.00		195	0.00
	20	3.37		210	23.70		285	0.00
	25	0.93		270	16.34		330	49.99
	30							
	45	0.00	5	*0	23.08	5	*0	35.88
	60	0.00		20	0.00		10	0.00
	75	29.47		45	0.00		20	20.19
				**90	74.73		**30	0.00
5	*0	7.87		135	12.50		150	40.27
	5	5.56		225	0.00		240	12.50
	15	0.00		***260	27.82		***300	29.03
	25	10.50		300	2.53		345	37.33
	**35	16.83		330	19.68			
	45	31.30				6	*20	79.52
	55	52.33	6	*0	0.00		164	0.00
	85	0.00		72	26.53		180	19.70
	100	0.00		162	21.09		210	0.00
	115	0.00		182	13.88		**305	0.00
	130	0.00		**262	42.97		380	0.00
	145	0.00		292			***445	0.00
				***332	4.49			
				367	39.44	8	*240	0.00
							270	48.31
							300	56.25
							**330	0.00
							360	21.86
							390	0.00
							***510	43.94
							540	54.00

* Pre Event
** Plateau
*** Descending Leg

Suspended Sediment: Clay

Baseline:

The percent of suspended sediment that is clay by date and site is shown in Table XVIII and Figure 70. Clay represents the dominant component of the suspended sediment in most cases both by individual samples and seasonal means (Tables XVIII, XII). The dry seasons averaged slightly higher mean percents than the wet seasons even though these two reversed themselves in 1984 and 1985 (Table XII). The reservoir, Site 4, revealed clay percentages that were generally higher than the water coming in and generally lowered downstream of the dam. Similarity in percent clay between the two years was seen by date except for Site 5 and 7 (Figure 70). There was no discernable relationship between suspended sediment concentrations and percentage clay.

Peaks:

In all three peaks at Site 5 there was an initial significant increase in percent clay during the ascending leg (Table XIX). This indicates contribution from the reservoir. During the 8/9 peak, Site 3 was consistently higher than Site 5, and during the 8/26 peak, Site 3 was consistently higher than Sites 5 and 6. The 8/30 peaks did not show these relationships.

Table XVIII: Baseline total percent of suspended sediment that is clay for each sampling date of the 1984 and 1985 sampling seasons at Sites S1-S8.

Precipitation	Rainfall and Deviation (inches)	Mean Monthly Flow (CFS)	Date	S1	S2	S3	S4	S5	S6	S7	S8
Normal	6.9 (2.0)	5184	6/1/84	28.48	49.12	51.36	46.38	---	54.34	56.52	63.46
			6/15/84	27.91	72.47	5.58	31.25	59.26	25.00	36.65	60.41
			6/27/84	21.16	20.00	70.73	60.65	56.09	62.97	50.75	60.65
	2.4 (-1.7)	1870	7/12/84	31.19	35.41	34.95	29.67	28.57	14.14	37.93	9.09
			7/17/84	36.11	26.55	25.40	67.36	43.76	22.48	36.14	53.57
			7/30/84	78.09	70.93	66.67	81.82	71.43	57.80	53.27	100.00
Dry	2.9 (-0.8)	313	8/8/84	43.04	51.18	62.50	88.24	59.81	19.37	57.33	60.45
			8/21/84	32.98	18.55	84.75	78.04	89.72	28.74	36.99	23.17
	1.7 (-1.3)	164	9/5/84	85.90	83.12	34.52	64.44	59.12	60.91	67.24	57.37
			9/28/84	66.67	76.55	23.96	50.93	71.43	71.58	77.58	55.70
	5 (3.3)	193	10/27/84	71.15	53.77	83.70	60.00	66.25	65.22	47.58	66.98
Very Dry	2.4 (-2.5)	933	6/24/85	59.82	46.29	74.48	65.81	83.06	67.90	50.49	58.26
	2.2 (-2)	262	7/2/85	53.27	59.02	56.35	82.57	100.00	81.71	49.36	70.93
			7/11/85	48.92	67.86	45.00	60.74	64.57	39.25	44.82	12.13
			7/22/85	7.10	10.26	5.86	7.86	61.29	87.22	---	12.13
Abnormally Wet	9.1 (5.3)	159	8/7/85	100.00	100.00	12.12	45.26	61.20	16.39	11.54	78.78
			8/13/85	42.75	34.37	52.45	100.00	33.81	81.30	30.86	76.47
	5.3 (2.2)	684	9/27/85	100.00	15.60	30.22	56.24	20.46	56.49	4.76	65.04

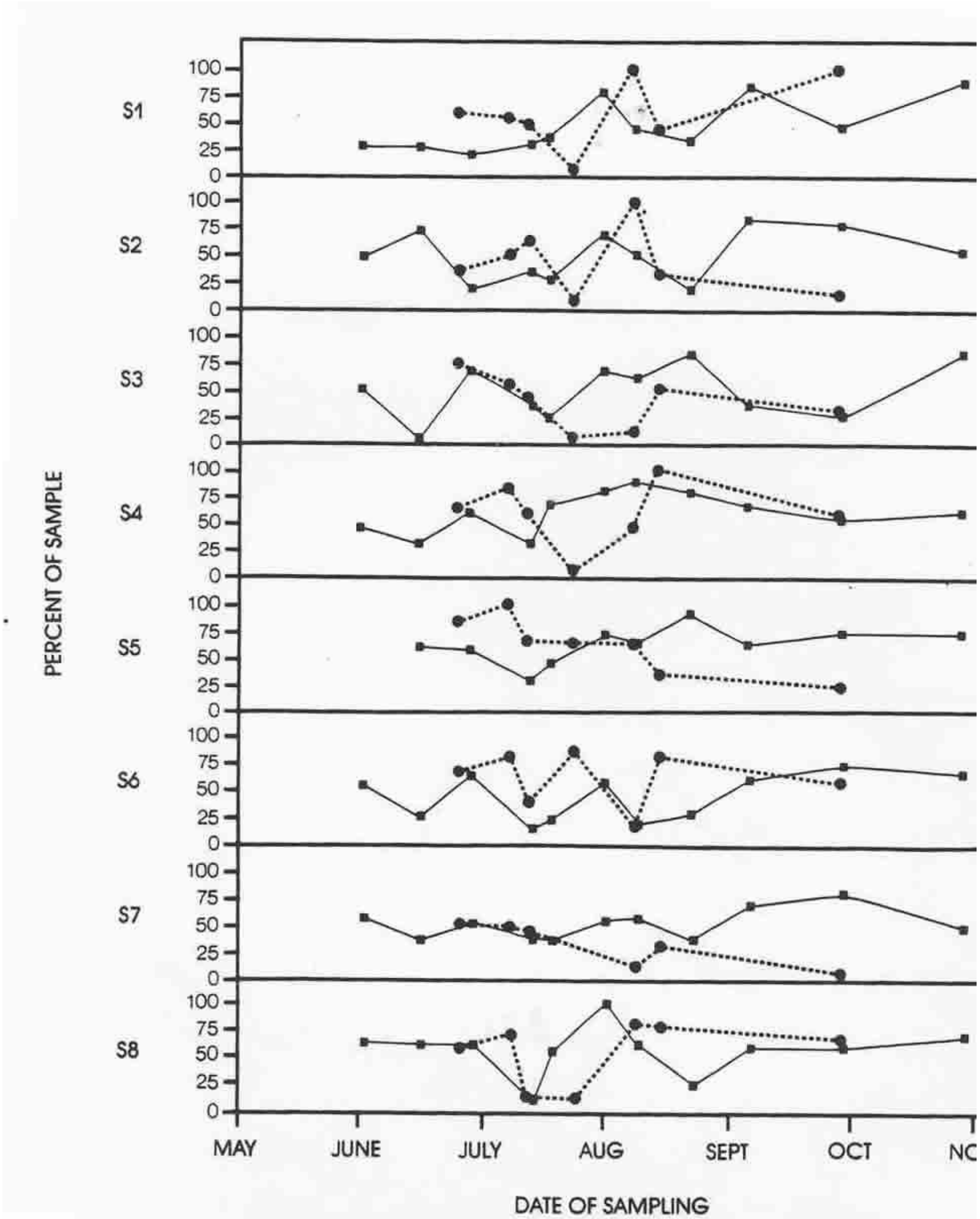


Figure 70. Baseline suspended sediment- percentage of sample that is clay for 1984 (■) and 1985 (●) sampling seasons at Sites S1-S8.

Table XIX: Percent of suspended sediment that is clay for 1985 peaks.

9-Aug			26-Aug			30-Aug		
Site	Time	%	Site	Time	%	Site	Time	%
3	*0	53.19	3	*0	53.28	3	*0	76.47
	5	56.04		5	60.88		60	72.00
	10	80.01		90	75.18		105	48.85
	15	92.47		150	100.00		195	58.42
	20	89.89		210	63.71		285	48.43
	25	63.56		270	83.66		330	39.19
	30							
	45	88.10	5	*0	26.28	5	*0	45.80
	60	54.46		20	56.00		10	100.00
	75	64.21		45	70.31		20	58.68
				**90	25.27		**30	31.73
5	*0	33.70		135	45.82		150	44.96
	5	61.11		225	42.48		240	46.50
	15	64.29		***260	18.04		***300	70.97
	25	30.76		300	10.13		345	10.67
	**35	51.49		330	4.15			
	45	22.61				6	*20	20.48
	55	47.67	6	*0	75.00		164	100.00
	85	48.39		72	40.77		180	80.30
	100	81.11		162	55.10		210	66.53
	115	55.81		182	38.75		**305	28.17
	130	85.52		**262	29.46		380	100.00
	145	100.00		292			***445	17.20
				***332	27.71			
				367	27.78	8	*240	41.11
							270	3.38
							300	43.75
							**330	61.94
							360	16.20
							390	68.84
							***510	23.19
							540	41.50

* Pre Event
** Plateau
*** Descending Leg

Suspended Sediment: Silt and Clay, Percent Organic

Baseline:

The suspended sediment that is organic in the silt and clay fraction (less than 0.063 mm) generally increases from the early season to the late season in both 1984 and 1985. (Tables XII, XX, and Figure 71). The values average around 50 percent. The reservoir in three out of four seasons was a source. No significant progressive downstream effect was seen.

Peaks:

The three peaks all showed an initial decrease from the pre-event with sporadic rises during the event at Site 3 (Table XXI). Site 5, the initial site downstream of the dam and reservoir, showed an increase in percent in all three events indicating a contribution from the reservoir sediment. Sites further downstream did not show an increase indicating some deposition.

Table XX: Baseline total percent of suspended sediment that is organic (both silt and clay) for each sampling date of the 1984 and 1985 sampling seasons at Sites S1-S8.

Precipitation	Rainfall and Deviation (inches)	Mean Monthly Flow (CFS)	Date	S1	S2	S3	S4	S5	S6	S7	S8
Normal	6.9 (2.0)	5184	6/1/84	16.36	---	72.97	---	---	13.10	37.68	---
			6/15/84	20.93	12.30	---	---	---	---	50.93	12.50
			6/27/84	94.23	88.81	88.89	31.15	21.14	20.37	77.78	31.91
	2.4 (-1.7)	1870	7/12/84	75.27	55.13	67.96	38.46	---	85.86	82.76	---
			7/17/84	68.06	59.23	65.73	33.33	59.38	4.49	40.34	5.36
			7/30/84	45.21	56.82	61.73	58.18	64.94	59.53	31.52	29.09
Dry	2.9 (-0.8)	313	8/8/84	51.52	29.41	72.62	97.61	27.43	50.00	54.00	43.28
			8/21/84	27.63	49.48	98.31	97.87	59.81	49.43	27.40	100.00
	1.7 (-1.3)	164	9/5/84	33.33	12.98	78.57	42.22	24.66	17.27	66.67	33.61
			9/28/84	72.73	72.10	56.02	75.61	74.73	54.68	58.75	60.34
	5 (3.3)	193	10/27/84	21.15	28.30	77.17	29.52	62.50	36.23	17.74	20.75
Very Dry	2.4 (-2.5)	933	6/24/85	46.43	62.96	48.6	20.16	77.42	56.79	94.17	42.61
	2.2 (-2)	262	7/2/85	10.28	25.23	20.48	1.83	45.00	10.40	12.99	19.77
			7/11/85	34.81	37.76	40.83	42.96	48.82	57.94	64.37	86.63
			7/22/85	45.39	56.41	21.34	27.45	37.19	41.49	---	86.63
Abnormally Wet	9.1 (5.3)	159	8/7/85	23.73	---	81.82	77.89	74.63	49.18	44.44	75.28
			8/13/85	43.70	51.04	14.67	17.86	88.48	29.91	44.44	71.76
	5.3 (2.2)	684	9/27/85	39.13	66.13	49.45	45.83	---	24.07	---	---

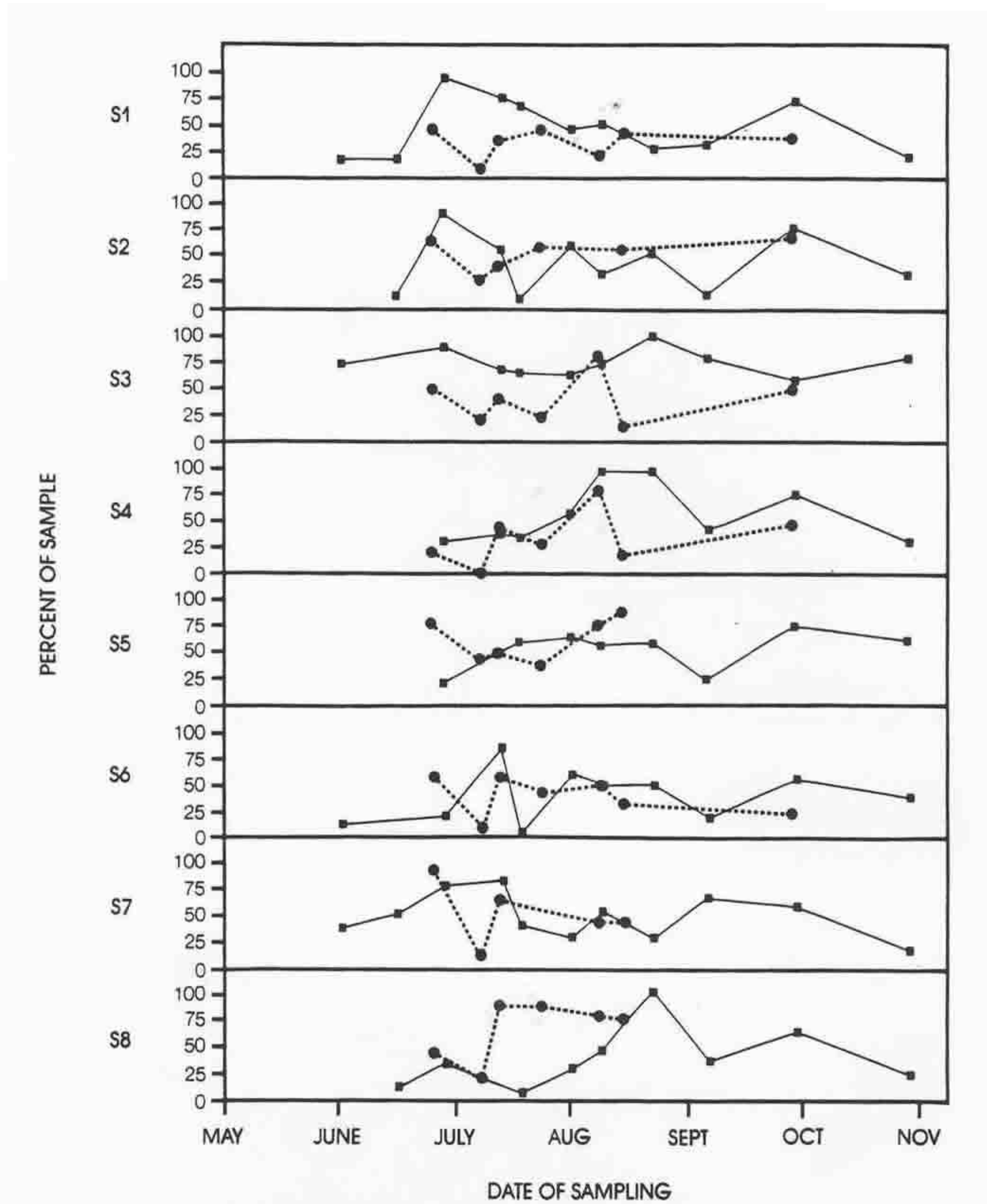


Figure 71. Baseline suspended sediment-percent of sample that is organic (both silt and clay) for the for 1984 (■) and 1985 (●) sampling seasons at Sites S1-S8

Table XXI: Percent of suspended sediment that is organic (silt and clay)

9-Aug			26-Aug			30-Aug		
Site	Time	%	Site	Time	%	Site	Time	%
3	*0	56.65	3	*0	63.96	3	*0	40.00
	5	48.35		5	43.48		60	5.33
	10	67.06		90	49.64		105	9.16
	15	92.47		150	26.04		195	
	20	37.34		210	22.96		285	74.75
	25	75.36		270	82.69		330	41.89
	30							.
	45	49.53	5	*0	45.19	5	*0	41.22
	60	60.40		20	60.71		10	66.67
	75	36.84		45	22.65		20	74.18
				**90	89.01		**30	20.45
5	*0	34.83		135	71.10		150	47.66
	5	47.22		225	35.29		240	33.00
	15	1.19		***260	6.60		***300	27.96
	25	52.44		300	68.42		345	76.67
	**35	89.11		330	16.06			
	45	60.87				6	*20	37.63
	55	37.21	6	*0	52.00		164	5.29
	85	64.91		72	24.49		180	
	100	41.11		162	6.80		210	22.31
	115	44.19		182	8.61		**305	13.38
	130	55.24		**262	44.32		380	54.93
	145	54.55		292	53.63		***445	
				***332	22.04			
				367	24.44	8	*240	30.00
							270	37.29
							300	15.97
							**330	43.23
							360	28.34
							390	12.99
							***510	26.99
							540	65.50

* Pre Event
** Plateau
*** Descending Leg

Suspended Sediment: Clay, Percent Organic

Baseline:

The suspended sediment that is organic in the clay (less than 0.004 mm) fraction is generally higher than the category clay and silt combined in both periods of both 1984 and 1985 (Table XII, XXII). The percents for 1984 and 1985 show a fair degree of similarity especially in sites downstream of the dam (Figure 72). The reservoir appears to act as a source in three of the four seasons (Tables XII, XXII). No correlation was seen between the total suspended solids and percent of organic clay. No downstream consistent pattern was observed.

Peaks:

At Site 3 the three peaks all started high, declined, and then climbed (Table XXIII). Site 5 did not show any consistent impact of the reservoir. Sites 5 and 6 on 8/26 had the highest percent organic on the ascending leg whereas August 30 had the highest percent on the descending leg.

Table XXII: Baseline total percent of suspended sediment that is organic (clay only)

Precipitation	Rainfall and Deviation (inches)	Mean Monthly Flow (CFS)	Date	S1	S2	S3	S4	S5	S6	S7	S8
Normal	6.9 (2.0)	5184	6/1/84	42.86	---	82.89	---	---	90.29	42.00	---
			6/15/84	43.00	21.67	---	---	---	---	28.81	64.41
			6/27/84	53.13	5.54	44.59	30.98	85.11	62.07	53.70	43.86
	2.4 (-1.7)	1870	7/12/84	91.30	80.77	81.25	92.11	---	86.67	82.35	---
			7/17/84	46.60	27.59	58.56	100.00	83.33	90.90	57.58	61.04
			7/30/84	45.76	69.23	64.86	54.76	57.38	96.88	69.39	88.52
Dry	2.9 (-0.8)	313	8/8/84	55.66	82.76	97.01	84.75	73.33	82.00	72.73	88.89
			8/21/84	66.04	42.11	87.72	98.00	67.65	32.84	61.54	88.06
	1.7 (-1.3)	164	9/5/84	50.75	31.25	65.79	39.51	72.13	43.66	35.71	48.78
			9/28/84	65.79	95.74	95.83	68.18	77.88	69.05	66.67	60.53
	5 (3.3)	193	10/27/84	43.24	37.31	40.83	32.74	64.15	70.00	27.78	53.85
Very Dry	2.4 (-2.5)	933	6/24/85	72.83	---	69.84	80.95	50.38	56.80	93.98	92.11
	2.2 (-2)	262	7/2/85	10.53	8.94	11.38	15.13	25.58	21.42	18.42	20.06
			7/11/85	68.18	60.32	33.57	44.44	78.57	83.33	33.96	57.89
			7/22/85	43.18	---	52.58	31.39	79.73	62.96	---	69.39
Abnormally Wet	9.1 (5.3)	159	8/7/85	85.82	100.00	100.00	38.75	58.93	75.67	69.73	68.85
			8/13/85	41.06	100.00	60.00	51.09	77.27	---	56.18	77.952
	5.3 (2.2)	684	9/27/85	46.31	79.71	43.57	89.19	---	11.88	12.42	54.67

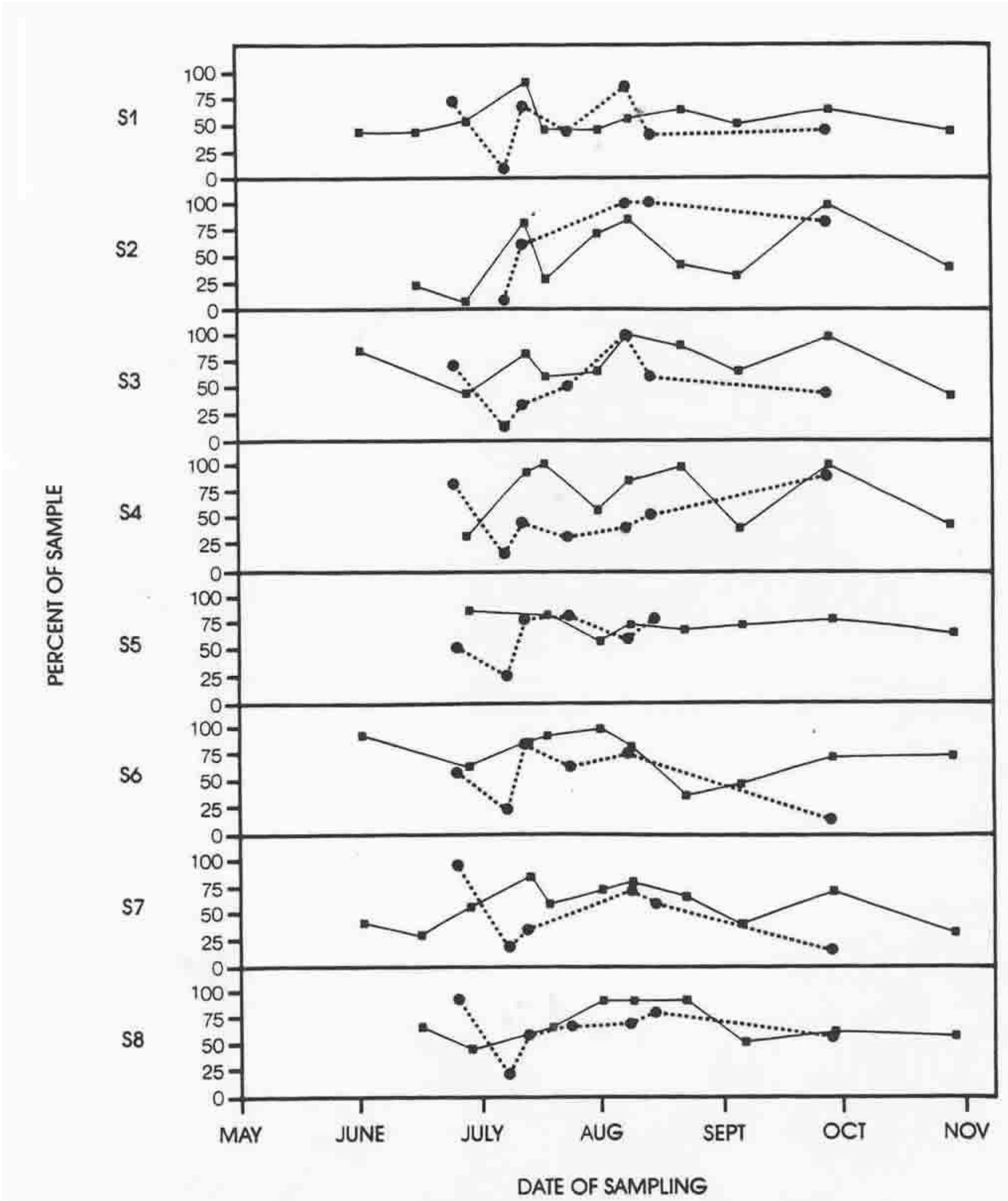


Figure 72. Baseline suspended sediment- percent of sample that is organic (clay only) for 1984 (■) and 1985 (●) sampling seasons at Sites S1-S8.

Table XXIII: Percent of suspended sediment that is organic (clay only)

9-Aug			26-Aug			30-Aug		
Site	Time	%	Site	Time	%	Site	Time	%
3	*0		3	*0	91.07	3	*0	46.43
	5	81.01		5	60.74		60	34.78
	10	86.11		90	12.26		105	4.88
	15	72.22		150	33.33		195	36.11
	20	53.75		210	85.94		285	79.49
	25	12.50		270	36.78		330	50.30
	30							.
	45	42.05	5	*0	23.37	5	*0	33.33
	60	82.98		20	40.19		10	22.41
	75	74.68		45	66.67		20	32.00
				**90	9.32		**30	49.66
5	*0	63.33		135	31.15		150	15.04
	5	53.97		225	8.45		240	38.71
	15	0.15		***260	31.40		***300	86.87
	25	51.39		300	42.03		345	74.14
	**35	60.87		330	8.09			
	45	64.86				6	*20	8.33
	55	37.21	6	*0	66.09		164	33.33
	85	72.41		72	77.50		180	
	100	70.13		162	2.47		210	38.05
	115	18.67		182	74.19		**305	4.00
	130	43.64		**262	59.63		380	54.63
	145	18.52		292	19.35		***445	85.71
				***332	46.15			
				367	52.38	8	*240	55.00
							270	83.54
							300	84.12
							**330	63.46
							360	17.50
							390	47.43
							***510	43.27
							540	

*	Pre Event
**	Plateau
***	Descending Leg

Reservoir Sediments

Grain Size

The reservoir was sampled 7/20/85-7/30/85 along the 21 transects shown in Figure 73. Samples were from the top two centimeters (cms). Figures 74 show the total grain size distribution. Figure 75 shows the breakdown of the sands and Figure 76, the distribution of the fines. During the reservoir storage phase the water is backed up all the way to transect V. Sampling was conducted within the river channel through N as continuous standing water did not occur on the river (reservoir) flood plain until transect M. Gravel and very coarse sand were seen farthest up the Blue Earth River and the mouth of the Watonwan River (Figure 74). Sands were often the dominant sediment from transect U through transect N. At transects S and T the dominant sands were Fine and Very Fine (Figure 75) which is consistent with the higher silt and clay, low energy environment shown in Figure 74. Sampling Site 3 for water chemistry and suspended sediments was located between transect Q and P which were very similar (Figures 74, 75. 76). Transects U through N showed a general increase in silts and clays with a corresponding decrease in sands (Figure 74). All of these samples are within the river channel. This is also seen in the increase of finer sands downstream (Figure 75). As noted above, transects S and T are the exception here and are probably related to backing up of the Blue Earth by both the sand bar and flow from the Watonwan River.

From transect M through C within the old river channel there is almost no gravel and very coarse sand (Figure 74). The non-channel reservoir has coarser sediments from M through transect G (Figure 74, 75). From transect F and increasing through C the sediments become coarser in the channel (Figure 72, 75) probably because of the sucking of the finer sediments by the turbines.

The breakdown of the silts and clays, fines, shows remarkable consistency throughout the channel before the true reservoir starts, transects W through N (Figure 76). Downstream of transect N, the percent of coarse and medium silt increases slightly within the channel and more so outside the channel. However in total there is only very limited change or trends seen in the fines. This is probably due to their ease of dispersal and deposition in this low-energy environment which experiences occasional higher flow. This data was collected before major peaking events.

Percent Organic of Fines

The percent of organic for the reservoir fine sediments are shown in Table XXIV. In both the silt and clay category and in the clay only category the highest values are generally found outside the river channel. The distribution of organic content is however very mixed and scattered both in the channel and in the non-channel reservoir.

The Silt-Clay category has occasional samples above 50% but generally in the single digit to 20's. The Clay category, on the other hand, has organic values 2 to 3 times higher on average than the Silt-Clay (Table XXIV). Overall the smaller the sediment grain size the higher the percent organic.

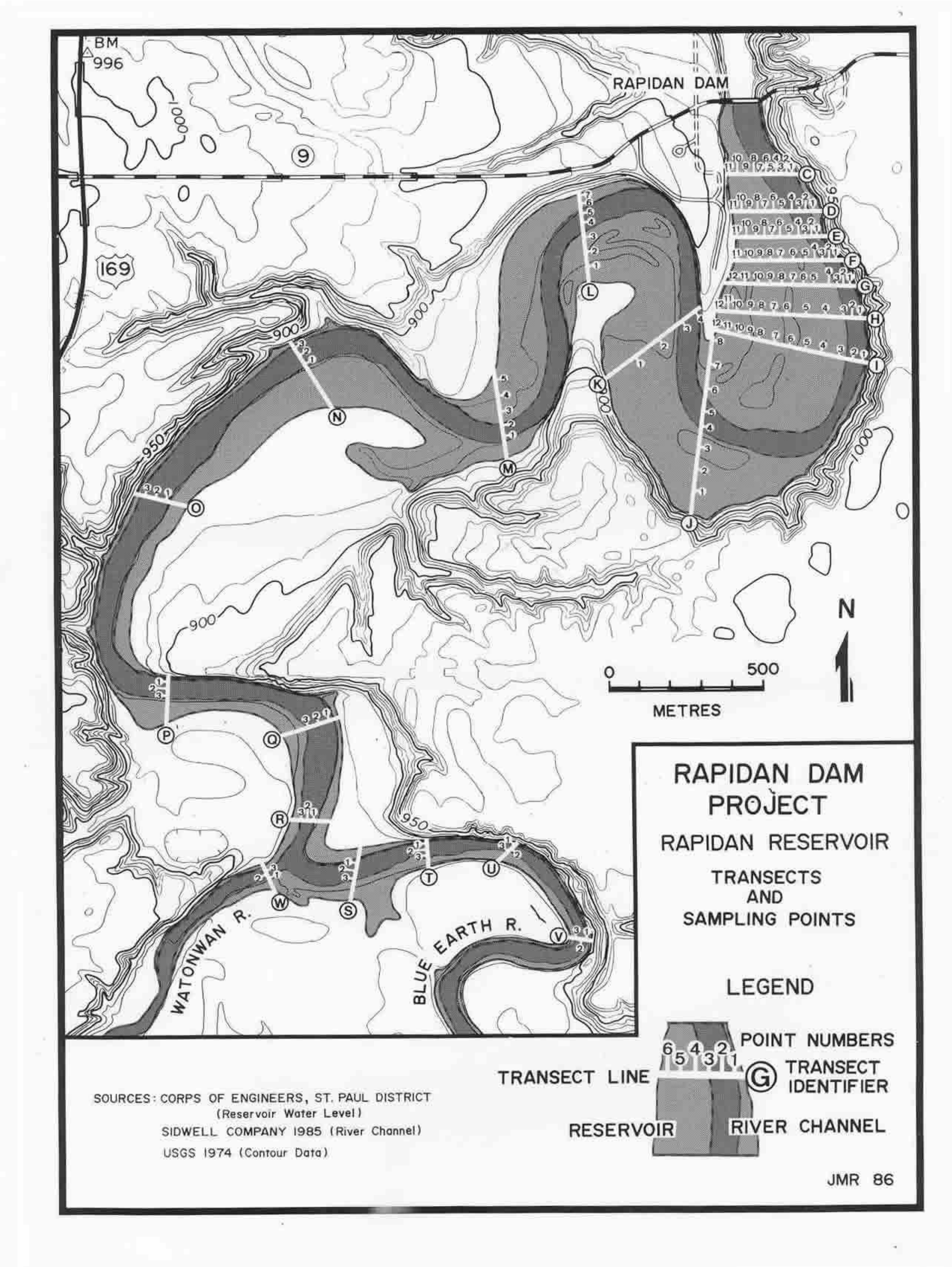


Figure 73. Reservoir transects and sampling sites, July 1985

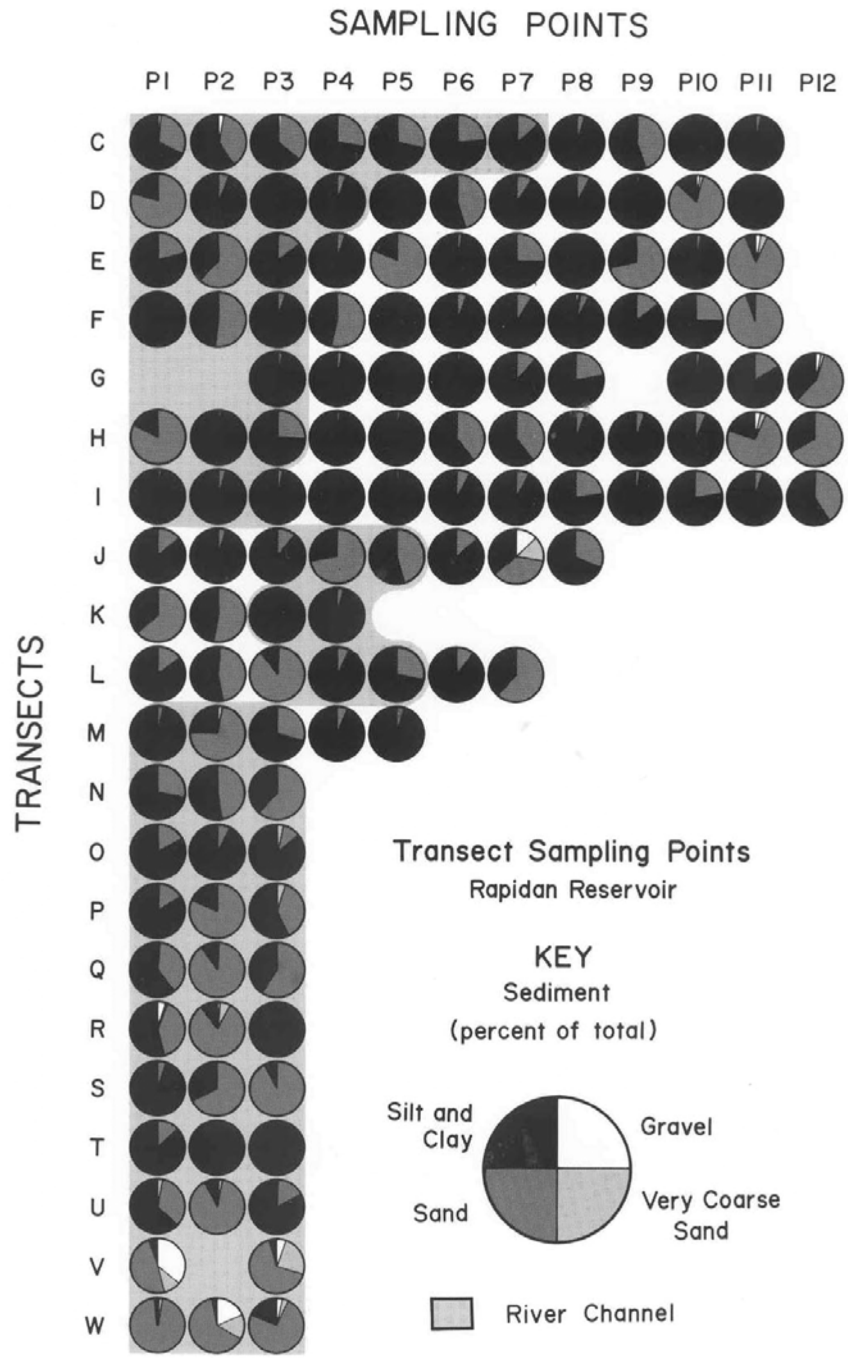


Figure 74. Sediment analysis of grabs taken in the summer of 1985:
Gravel (large than 2mm) ,Very Coarse Sand (2mm-1mm), Sand (1mm to 0.062 mm), and Silt and Clay (less than 0.062 mm).

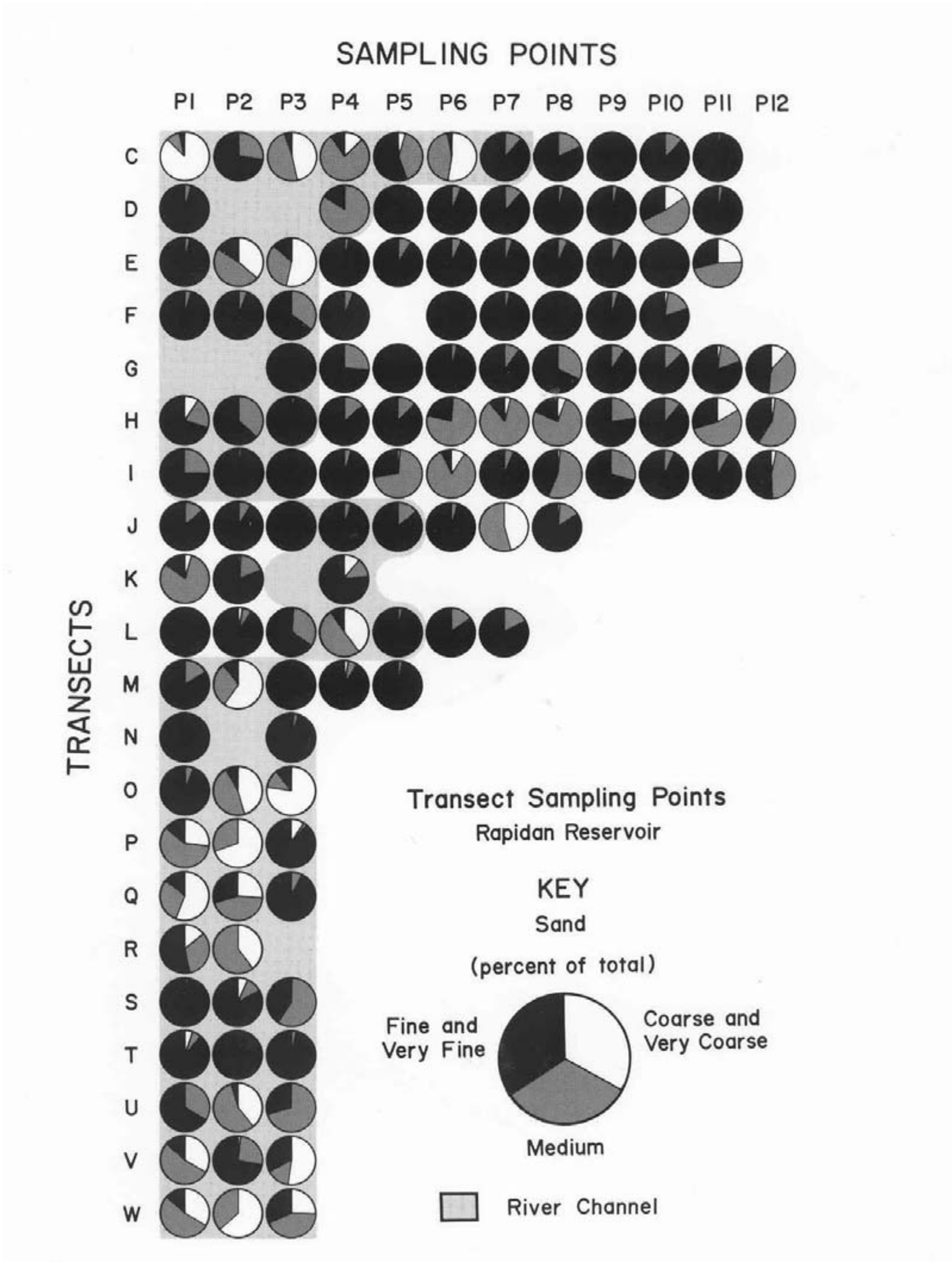


Figure 75. Sand analysis of grabs taken in the summer of 1985: Coarse and Very Coarse (2mm to 0.5 mm), Medium (0.5mm to 0.25 mm), and Fine and Very Fine (0.25 to 0.06 mm).

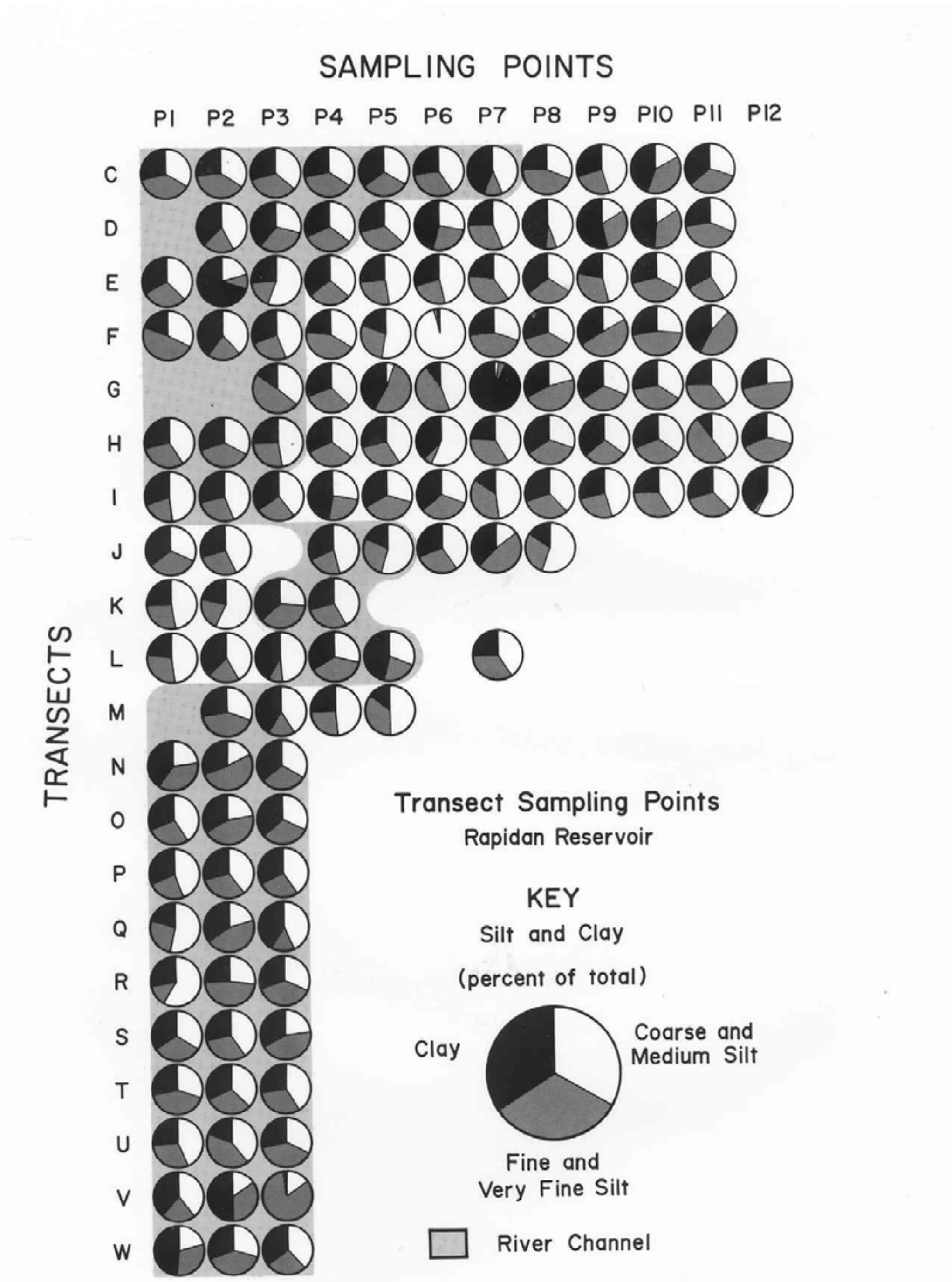


Figure 76. Silt and clay analysis of grabs taken in the summer of 1985: Coarse and Medium Silt (0.62mm to 0.016 mm), Fine and Very Fine Silt (0.016mm to 0.004 mm), and Clay (0.004mm and less).

Table XXIV: Percent organic silt and clay and percent organic clay (7/20-7/30/1985) of surficial reservoir sediment (Numbered sites as Figure 73).

	1	2	3	4	5	6	7	8	9	10	11	12
C	7 24	10 18	7 36	24 26	8 23	11 13	16 54	12 32	4 1	5 21	5 34	
D	65 47	8 34	5 31	11 31	10 13	8 19	12 25	7 51	3 42	5 28	7 13	
E	6 10	61 85	6 36	7 22	2 43	12 47	2 9	9 31	95 100	9 22	2 45	
F	1 21	26 30	9 27	12 28	80 91	1 37	11 19	11 11	27 18	9 65	52 89	
G		25 100	34 100	6 18	5 100	61 90	50 78	6 24	29 84	7 29	3 9	18 39
H	7 5	9 13	14 33	9 19	8 25	22 30	12 14	7 12	18 18	4 8	15 100	15 34
I	1 0	8 25	7 34	0 30	6 17	17 16	3 0	11 7	9 28	2 9	8 32	0 11
J	7 7	2 42	2 13	8 3	10 3	24 43	3 14	16 22				
K	9 23	9 14	8 20	9 31								
L	6 44	- 11	22 36	13 31	12 16	2 0	7 9					
M	11 28	10 9	5 22	14 59	34 48							
N	7 52	20 100	18 19									
O	7 45	11 12	7 18									
P	6 6	17 17	8 8									
Q	3 3	73 73	13 13									
R	1 1	7 7	23 23									
S	26 26	3 3	7 7									
T	7 16	5 24	12 19									
U	8 33	6 20	4 18									
V	21 100	21 37	16 77									
W	10 24	19 66	9 58									

Key	
#x	Percent organic silt and clay
#y	Percent organic clay
(shaded)	= River Channel

Comparison of pre and post peaking reservoir sediment

A second sampling of reservoir surface sediment was conducted in early October of 1985. The same methodology, field and laboratory, was used as the 7/20-7/30 sampling. This sampling was to compare the earlier very dry period, May and June, to the abnormally wet period, August and September, and simultaneously pre-peaking to post-peaking. Any effects found can not be definitely assigned to one or the other, however the peaking events with their major draw downs at Site 3 (Between transect Q and P) appeared to have the most impact.

The data comparing the two dates where we had similar point sampling are shown in Table XXV. It is immediately clear that a significant change occurred between the two sampling dates which resulted in a change to a very high ratio of coarse (sand) to fines (silts and clays) in the river channel from W through M. This reach represents the pre-continuous reservoir. It is thought that this was the result of the significant draw down and therefore pulling of fine sediments into the reservoir caused by the peaking. An alternate hypothesis could be that it was due to high flow, which with increased energy, moved the finer sediments into the reservoir proper. Within the reservoir proper we see the reverse which indicates the deposition of stripped fine sediment from upstream. Note that M is intermediate between upstream N and downstream I.

Table XXV: Comparison of reservoir sediment percent coarse (sand and gravel) and fine (silt and clay) pre and post peaking in 1985 (numbered sites as figure 73).

Transect	Site Number 1		2		3		4		5		6	
D	80	9	6	4	0	1	5	13	1	1	45	1
	20	91	94	96	100	99	95	87	99	99	55	99
E	20	5	62	8	15	12	4	1	82	1	2	13
	80	95	38	92	85	88	96	99	18	99	98	87
F	1	22	52	2	5	1	54	1	1	31	6	2
	99	73	48	98	95	99	46	99	99	69	94	98
G				1		4		1		22		15
				99		96		99		78		85
H			1	1	25	1	1	27				
			99	99	74	99	99	73				
I	2	2										
	98	98										
J	31	6										
	69	94										
K	4	59										
	96	41										
L	62	20										
	38	80										
M	4	67										
	96	33										
N	61	99										
	39	1										
O	14	99										
	86	1										
P	43	99										
	57	1										
Q	59	100										
	41	0										
R	0	99										
	100	1										
S	91	99										
	9	1										
T	1	99										
	99	1										
W	81	100										
	19	0										

Key

% Coarse July 85	% Coarse October 85
% Fine July 85	% Fine October 85

[shaded] = in river channel

Bedload Sources

This component of the sediment study involves a comparison of sediment grain size distribution in the bottom sediments of the Blue Earth and Watonwan Rivers in the fall of 1984. A 1983 reconnaissance of the river channel, now within the reservoir, and downstream of the dam revealed a large number of sand dunes often as height as a foot or more. The two questions to be answered were 1. Did the sand come from the Blue Earth, Watonwan, or both rivers? And 2. Did the sediment come from the immediate sandstone cliffs on these two rivers?

The grain size distribution of sands as well as other sediment categories appear to be quite similar between the two rivers (Tables XXVI, XXVII). Further, the upstream-downstream of each location (major cliff) shows no significant differences. This indicates that the rivers are similar, in equilibrium and that upstream sources of sand exist.

In 1985, with the restoration of the dam completed and filling of the reservoir, the surface bed load deposits were not observed or documented from Transects V and W downstream (Figure 73). This is consistent with the increased impounding that both slows the flow back upstream and allows for the deposition of fines on top. The ratios of Silts to Clays (Table XXVI) is consistent with the ratios of Silts to Clays in the surface sediments of the reservoir (Figure 76) as well as the percent organics of the fines (Table XXIV).

	Blue Earth										Watonwan									
	downstream <---- Cliff ----> upstream										downstream <---- Cliff ----> upstream									
	Site 1					Site 2					Site 3									
Sediment Size Breakdown	a	b	c	d	*e	a	b	c	d	*e	a	b	c	d	*e	a	*b	c	d	e
Site Water Depth	dry	dry	6"	12"	2' 6"	dry	dry	12"	12"	2'	dry	1' 3"	2' 2"	2'	2' 8"	8"	2' 3"	12"	1' 5"	12"
Coarse % (+ #230 sieve)	86.7	98.2	97.3	99.5	95.2	96.3	98.6	97.4	98	92.6	87	97.7	93.1	95.6	97.4	98.2	95.7	98.3	98.4	95.6
Fine % (-#230 sieve)	13.3	1.8	2.7	0.5	4.8	3.7	1.4	2.6	1.9	7.4	13	2.3	7	4.4	2.6	1.7	4.2	1.7	1.6	4.4
Gravel % (+ #5 and 10 sieve)	0	0.2	0.4	11.5	8	0.1	50.6	34.5	21.4	5.1	0	5	4	30.7	61.2	0.04	33.6	11.6	80	1
Sand % (+ #230 sieve)	86.7	98	96.9	88	87.2	96.2	48	62.9	76.6	87.5	87	92.7	89.1	64.9	36.2	98.2	62.1	86.7	18.4	94
Silt % (+ .004 mm)	12.6	1.8	2.6	0.37	4.1	3.6	1	2.3	1.8	6	12	2	6.5	3.8	2.5	1.4	3.7	1.5	1.6	4.4
Clay % (- .004 mm)	0.6	0.04	0.05	0.13	0.7	0.1	0.3	0.3	0.1	1.5	1.1	0.4	0.5	0.6	0	0.4	0.4	0.2	0	0
% Totals	99.9	100.04	99.95	100	100	100	99.9	100	99.9	100.1	100	100.1	100.1	100	99.9	100.04	99.8	100	100	100
% Organics of Fines	24.4	8.1	4.5	13.8	8.3	6.9	2.9	4.5	6.9	9.8	8.4	9.8	5.2	4.2	6.3	6.2	5.6	6.7	7	10

* Main Channel

		Blue Earth											**Watonwan**								
		downstream			<----	Cliff		---->		upstream			downstream			<----	Cliff		---->	upstream	
		Site 1					Site 2					Site 3									
Sediment Class Name	Detailed Size Range (micrometers)	a	b	c	d	*e	a	b	c	d	*e	a	b	c	d	*e	a	*b	c	d	e
Coarse-Very fine gravel	----	0.0	0.0	0.0	1.8	1.1	0.0	27.9	14.5	3.0	1.0	0.0	4.0	0.8	22.4	39.6	0.0	16.2	5.0	76.2	0.0
Very Coarse Sand	2000-1000	0.0	0.2	0.4	9.7	6.9	0.1	22.7	20.0	18.4	4.1	0.0	1.0	3.2	8.3	21.6	0.0	17.4	6.6	3.8	1.0
Coarse-Very fine sand	1000-700	0.0	0.0	3.4	1.8	1.7	0.0	3.8	0.6	0.0	3.4	0.0	0.0	2.1	1.5	1.7	0.0	1.4	1.8	1.0	1.0
	700-500	0.0	6.5	11.1	30.2	27.6	6.4	19.3	18.0	11.0	18.9	0.0	0.0	6.3	14.7	10.1	7.0	18.3	10.1	7.0	2.7
	500-350	0.0	24.0	26.6	26.8	19.3	21.1	8.6	9.3	40.2	18.0	0.0	2.2	31.4	21.4	2.4	13.1	5.6	13.7	5.3	16.6
	350-250	1.3	39.8	25.8	11.2	9.2	20.2	9.4	7.5	15.6	19.8	0.0	15.5	17.8	8.8	5.4	22.0	9.9	23.8	1.2	30.6
	250-175	5.2	22.2	20.5	10.4	5.8	11.0	3.8	10.6	5.8	12.0	0.0	18.7	13.6	6.6	4.0	27.1	11.3	25.6	1.2	21.4
	175-125	8.7	4.6	7.8	6.1	5.1	8.3	2.6	9.3	3.2	5.2	9.2	34.2	10.5	5.9	4.3	20.0	10.6	9.1	1.2	13.9
	125-88	16.8	0.9	0.9	0.9	5.8	12.8	0.4	2.5	0.6	3.4	23.8	17.6	5.6	3.7	3.4	7.0	3.5	1.8	1.0	4.6
	88-62.5	31.0	0.0	0.0	0.9	8.4	11.0	0.0	3.1	0.0	3.4	33.0	3.3	1.1	1.5	3.4	1.0	0.7	0.9	0.4	2.7
	62.5-62	23.3	0.0	0.9	0.0	4.2	5.5	0.0	1.9	0.0	3.4	21.1	1.1	1.1	0.7	1.7	1.0	0.7	0.0	0.0	1.0
Coarse Silt	62-31	2.8	0.2	0.3	0.2	0.2	0.9	0.0	0.9	0.3	2.6	4.7	0.6	1.3	0.7	0.9	0.4	0.6	0.0	0.2	0.8
Medium-very fine	31-16	5.2	0.8	0.3	0.1	0.9	1.0	0.7	0.3	0.4	1.6	4.3	0.4	1.0	1.0	0.8	0.9	0.8	0.2	0.6	1.9
	16-8	1.5	0.4	0.9	0.1	1.5	1.3	0.2	1.0	0.8	0.8	1.3	0.9	2.3	0.9	0.6	0.0	1.2	0.9	0.4	1.7
	8-4	3.1	0.4	1.1	0.0	1.5	0.4	0.1	0.1	0.3	1.0	1.4	0.1	1.9	1.2	0.2	0.1	1.1	0.4	0.4	0.0
Coarse Clay	4-2	0.6	0.0	0.1	0.1	0.7	0.1	0.3	0.3	0.1	1.5	1.1	0.4	0.5	0.6	0.0	0.4	0.4	0.2	0.0	0.0
Total Sample %	Total Sample %	99.6	100.0	100.1	100.3	99.9	100.1	99.8	99.8	99.7	100.1	99.9	100.0	100.2	99.9	100.1	100.0	99.7	100.1	99.9	99.9

* Main Channel

Synthetics

Introduction

No chlorinated pesticides were found, phthalates were present. This is not unusual. Phthalates are found almost everywhere in water. Phthalates have been used for decades in plastics, adhesives, etc. The amount of research into endocrine disruption has exploded over the past decade. A major emphasis is on anti-androgens and male reproductive health with a focus on the phthalates and testicular dysgenesis syndrome (Fisher, J.S., 2004). The phthalate results are presented, even though definitive human endocrine disruptor correlation data are still not available to show the impact of peaking on this chemical group.

Water samples that were first run on the Varian G.C. revealed two distinct peaks, neither of which provided any correlation to any of the chlorinated pesticide standards that were run. Minnesota Valley Testing confirmed that no chlorinated pesticides were in the samples that were run, but they were able to identify the presence of two pthalate plasticizers; Butyl octyl pthalate = 1,2-Benzenedicarboxylic acid, Butyl octyl ester, with a 94.6 percent of certainty, and 2-butoxyethyl butyl phthalate = 1, 2-Benzenedicarboxylic acid, 2-butoxyethyl butyl ester, with a 79.7 percent certainty. We then switched to the Hewlett Packard HP-5890 as described in the methods for a more sensitive detector.

Peaks

Peaks # 4.43 and 4.81 were almost identical in behavior and concentrations at all sites for all peaks and therefore only # 4.43 will be used for illustrative purposes.

Peak 1

Peak one, August 9, showed significant fluctuations in pthalate as the river was drawn down, 7507 to 0 ppb (Figure 77). This was a continuous draw down, although from one turbine only, dropping a total of 12 cms. Relationships to turbidity were seen but not consistantly.

Site 5 as seen in Figure 78, shows turbidity building up to the middle of the ascending leg, 15 minutes and then falling back to fairly level for the last half of the ascending leg and the event plateau. The turbidity is consistently higher at 5, below the dam, during the event than at Site 3. The pthalates however showed no clear-cut relationship to turbidity and no evidence of reservoir impact.

Peak 2

Peak 2 at Site 3 resulted in a straight draw down of 95 cms. Again this involved 2 turbines rather than the single turbine in Peak 1. The pthalates followed the turbidity curve and climbed after the decline of 75 cm's, in depth of the river. Starting values were very similar to Peak 1 but climbed to twice the concentration (Figure 79).

Site 5 started at 2x the concentration of Site 3, and of Site 5 in peak 1, and showed decline throughout the ascending leg to low values (decrease of 10x) which held throughout the plateau and descending leg (Figure 80). Unlike Site 3 the pthalate curve was the mirror opposite of the turbidity curve. The ending high concentration of pthalate at Site 3, in this event, was either greatly diluted or settled out in the reservoir.

Site 6 of peak 2 showed a corresponding relationship between pthalate and turbidity with pthalates preceding the turbidity (Figure 81). The ascending leg (70 –165 minutes) showed pthalates decreasing by 5x and turbidity increasing by 3x. The plateau showed a drop and leveling out for both parameters.

Peak 3

The pthalate curve was similar to the turbidity curve with some offset at Site 3 (Figure 82). The turbidity increased above its baseline from 23 to 27 whereas the pthalates started at 12,000 ppb and dropped to a low of 8,161 ppb. The increase in pthalates and turbidity corresponds to a slight increase in depth, (flow), at 280 minutes. It also should be noted that the base level at Site 3 for peak 3 was 2 to 3x higher than for peak 1 and peak 2.

The pthalate and turbidity curve for Site 5 were quite opposite of each other (Figure 83). During the ascending leg pthalates halved while turbidity increased (0-30 minutes). It appears that the reservoir sediment was not a source of pthalates.

Sites 6 and 8 further downstream show similarity in behavior. Site 6 showed an increase in turbidity and pthalates during the ascending leg (160-240 minutes) an increase in turbidity for the plateau (240-380 minutes) with an increase and then decrease for pthalates. During the descending leg turbidity declined and pthalates declined and then rose (Figure 84).

At Site 8 turbidity rose and pthalates were flat during the ascending leg (260-320 minutes) both were flat during the plateau (320-500 minutes) and both rose during the descending leg with pthalates rising significantly at the end (Figure 85).

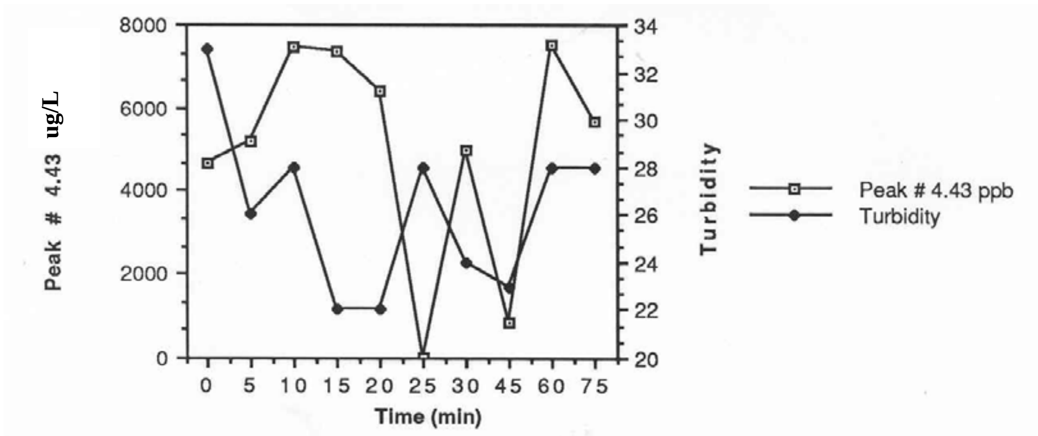
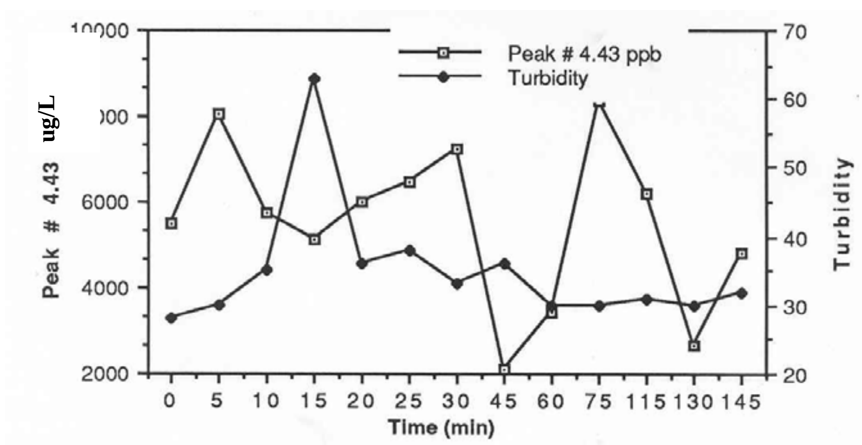


Figure 77. Pthalate peak #1 4.43 and turbidity for August 9 peak at Site 3



Ascending Leg: 0-28 minutes
Plateau: 29-150 minutes

Figure 78. Pthalate peaks #1 4.43 and turbidity for 8/9 peak at Site 5

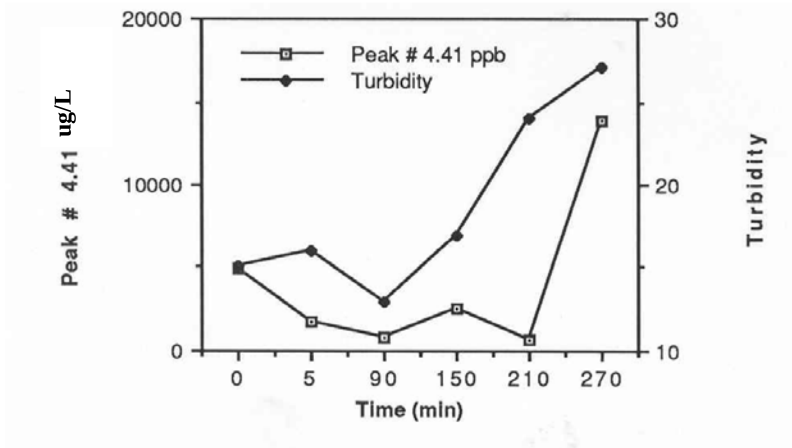


Figure 79. Pthalate peaks 4:43 and turbidity for 8/26 peak at Site 3

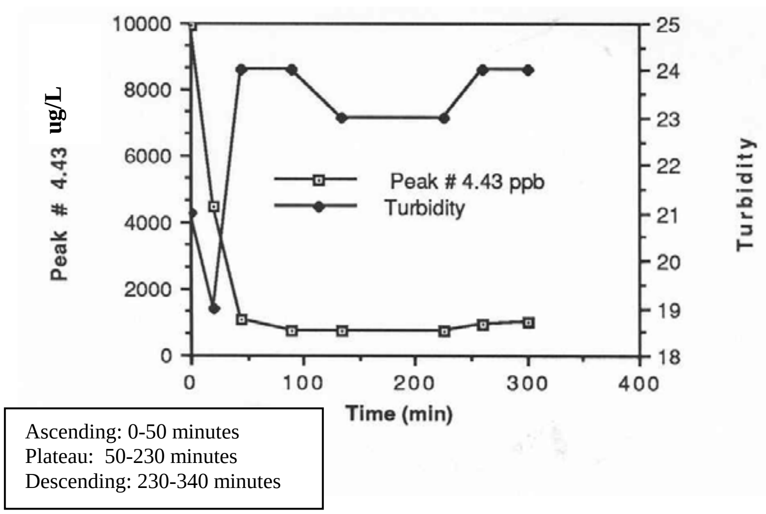


Figure 80. Pthalate peaks 4.43 and turbidity for 8/26 peak at Site 5

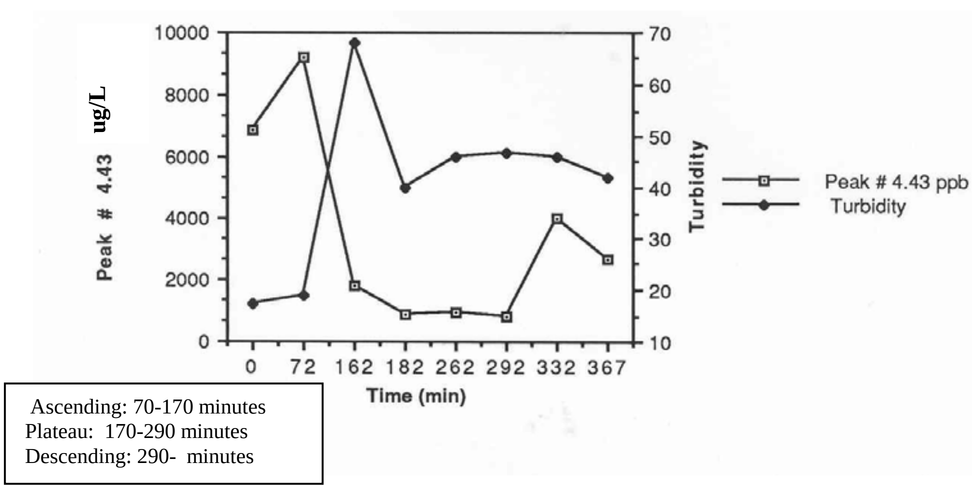


Figure 81. Pthalate peaks 4.43 and turbidity for 8/26 peak at Site 6

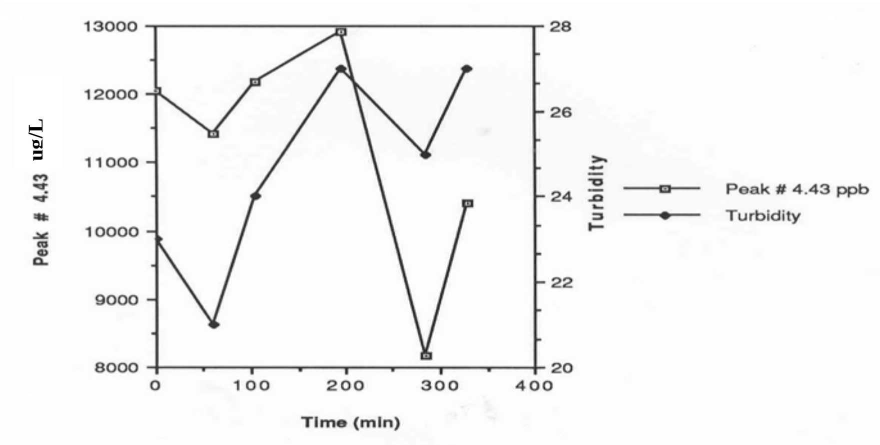


Figure 82. Pthalate peaks 4.43 and turbidity for 8/30 peaks at Site 3

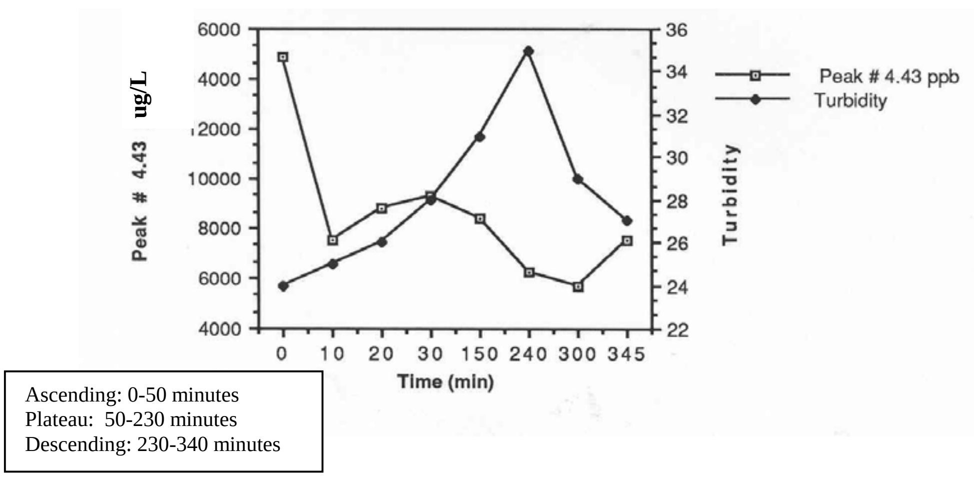


Figure 83. Pthalate peaks 4.43 and turbidity for 8/30 peaks at Site 5

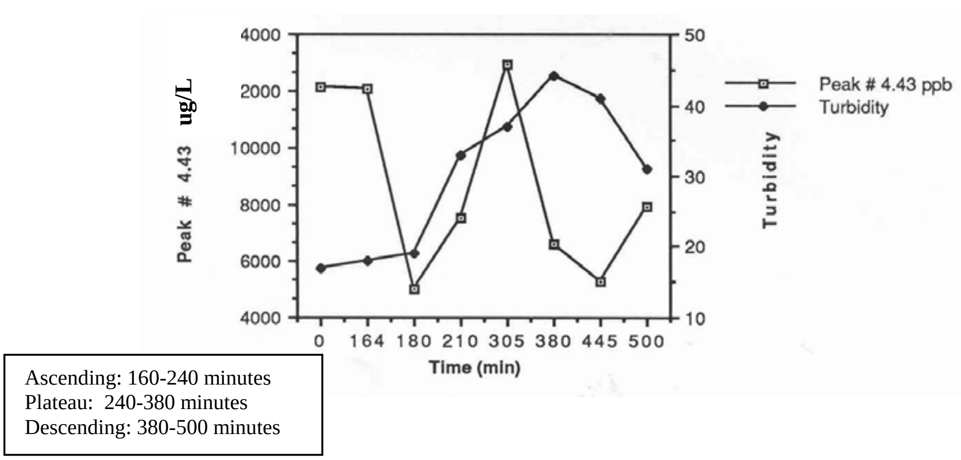
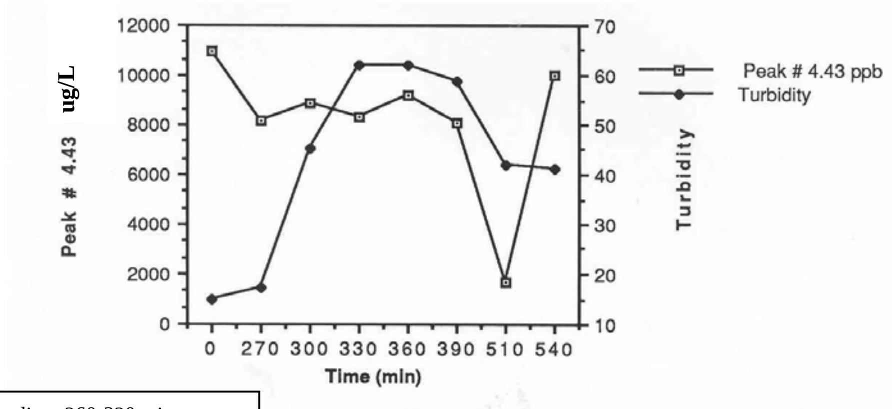


Figure 84. Pthalate peaks 4.43 and turbidity for 8/30 peaks at Site 6



Ascending: 260-320 minutes
Plateau: 300-500 minutes
Descending: 500-540 minutes

Figure 85. Phthalate peaks 4.43 and turbidity for 8/30 peaks at Site 8

Macroinvertebrates

Introduction

The reconstruction of the Rapidan Dam on the Blue Earth River for hydroelectric-generated power provided a unique opportunity to study the effects of rapidly fluctuating flows on the macroinvertebrate community of the river. River discharge had not been manipulated for 18 years since abnormally high spring rains and ice break-up rendered the dam inoperable. Relicensing of this dam required managing its operation for peaking- the storing of water in the reservoir during low energy use periods and releasing water during high energy use periods.

Sampling of the macroinvertebrates began in August, 1983 when flows were still run-of-the-river. Subsequent renovation and operation of the dam changed this flow regime to a store-and-release, or peaking, regime. The size of the reservoir increased to include Site 3 during periods of water storage. The reservoir remained unstratified throughout the study, according to Ruff (1987). Downstream of the dam, flows changed rapidly as the reservoir levels were manipulated. The anticipated changes in the flow regime due to the peaking operation of the dam suggested subsequent changes to the macroinvertebrate community might occur.

A total of 856 Surber and three-kick samples were identified and enumerated. The various phyla collected were Coelenterata (hydra, jellyfish), Nematophora (unsegmented worms) , Platyhelminthes (flat worms, tape worms, flukes), Annelida (segmented worms and leeches), Mollusca (clams, snails,mussels) and Arthropoda (insects, crustaceans, spiders). All of these phyla were represented in the Blue Earth River, whereas only the Annelida, Mollusca and Arthropoda were found in the Le Sueur River.

The insects represented the majority of the organisms sampled. The Ephemeroptera (mayflies)and Diptera (flies and midges) comprised 19 families each whereas the Odonata (dragonflies and damselflies) and Megaloptera (dobsonflies,alderflies,fishflies) both had one family present. Three families of Plecoptera (stoneflies), Hemiptera (true bugs), and Trichoptera (caddisflies) , respectively, and four families of Coleoptera (beetles) were identified. Of the 55 genera collected in the study, 19 were ephemeropterans, four were odonates, four were plecopterans, six were hemipterans, one was a megalopteran, 11 were trichopterans, five were colepterans and five were dipterans. The dipterans were identified to the Family level. The rest of the insect groups were identified to the genus level when possible, usin several keys (Merritt and Cummins, 1984; Hilsenhoff, 1971; Pennak, 1978).

The Mollusca were not analyzed even though counts were made because most of the mollusks collected were empty shells. They are viewed here only as a historical presence.

Macroinvertebrate Abundance

Mean total abundance from Surber samples did not appear to be different between sites at Stations 1 or 2 below the dam in 1983. At Station 2 of Sites 5e and 6 there appeared to be a large increase in mean abundance between August and September. This may be due to the growth patterns of many aquatic insects; more organisms had grown to a size that was vulnerable to sampling. In general, the mean total abundance of organisms was lower at Stations 1's (shallow water) than at Station 2's (deeper water) downstream of the dam during 1983.

The mean total abundance of organisms below the dam at Sites 5e through 6 appeared to decline from 1983 to 1984. These lower mean abundance levels persisted into 1985. There were no apparent changes at Site 2 upstream of the reservoir or at the control location, Site 7. Similar trends in mean total abundance decline were observed at both Stations 1 and 2 within Sites 5d, 5c, 5b, and 5a. Station 1 at Sites 5e and 6 did not follow this general pattern. The apparent decline in mean total abundance of organisms below the dam seemed to be the result of fluctuating flows caused by dam operations. These same reductions in abundance were not observed in the Le Sueur River, the control.

Benthic invertebrates can respond to sudden fluctuations in flow by drifting downstream (Cushman 1985; Hynes 1970; Irvine 1985). Initial flow fluctuations can have a much greater effect on invertebrate drift than subsequent fluctuating flow regimes (Irvine 1985) because invertebrates become depleted from the area with repeated fluctuations. This was observed in this study from 1983 to 1984. Invertebrates may drift downstream for a variety of reasons. These may include searching for food or habitat, to avoid predation, changes in temperature, and response to environmental stresses (Hynes 1970).

Invertebrates may drift in response to less food in the form of coarse particulate organic matter (CPOM) available from upstream transport during periods of reservoir recharge (storing). The reservoir contributed an unstratified lake effect to the riverine system. Current slowed allowing larger particles of CPOM to settle out. Hence, the reservoir acted as a nutrient sink or trap (Ruff 1987). Alternately, high discharge from the dam may have a scouring effect on the downstream substrate, removing organisms and particulate matter used as food sources by gathering-collectors.

The abundance of organisms collected in deeper water of the Blue Earth River was higher than near the stream bank. Fluctuating flows can cause exposure of near-shore substrates resulting in reduced abundance. Gersich and Brusven (1981) reported recolonization rates to carrying capacity levels to be at least 66 days in a regulated stream. Recolonization of these substrates may not result when fluctuating flows due to dam operation occur more often than this suggested time period. Frequent dewatering of the near-shore substrates may produce an intertidle zone (Fischer and LaVoy 1972). Freshwater intertidal zones are not usually productive since they are recent developments. Such communities take a long period of time to become established.

Apparent declines in abundance seemed less pronounced at Site 6 than at those sites immediately below the dam, suggesting a reduction in flow gradient. Reductions in abundance caused by fluctuating flows have been observed in other studies (Fisher and LaVoy1972; Trotzky and Gregory, 1974; Williams and Winget 1979; Gislason 1985; Garcia de Jalon, et. al. 1988; Troelstrup and Hergenrader 1990).

Taxonomic Richness

Decreases in genus richness were observed as well as decreases in abundance. A total of 16 fewer genera were collected in Surber samples from the Blue Earth River in 1985 than in 1983 (45 in 1983, 28 in 1984, 29 in 1985), whereas, 14 fewer genera were collected with the three-kick method during the same time period (46 in 1983, 37 in 1984, 32 in 1985). Since this declining trend was not observed in results from sampling the Le Sueur River, the likely variable contributing to the reduction of genera in the Blue Earth River was flow fluctuations caused by operation of Rapidan Dam. Richness also seemed stable at Sites 2 and 6. Fluctuating flows caused by peaking operation may have a deleterious effect on the habitat and food availability of various organisms and also affect invertebrate drift. Various insects have developed behavioral and physical adaptations in response to their environment over an evolutionary time frame. Examples of such adaptations are the flattened body shape of sprawlers and clingers, such as <u>Leptophlebia</u> sp. or <u>Acroneuria</u> sp. which allow them to cling to rocks in fast current, or clinging shredders that are dependent on periphyton for food and habitat, like <u>Stactobiella</u> sp. which require a specific range of current velocities (Fisher and LaVoy 1972; Cushman 1985). Drastic changes in these requirements can lead to losses of invertebrate populations. Flow fluctuations have been observed in other studies to reduce richness as well as abundance (Radford and Hartland-Rowe 1971; Spence and Hynes 1971; Fisher and LaVoy 1972; Garcia de Jalon, et. al. 1988).

Community Diversity

Community diversity was compared at the family level using the Shannon-Wiener Index (Platts, Megahan and Minshall 1983). Only data collected from Surber samplers were used. Diversity was calculated at four sites which included Sites 2, 5e, 6, and 7. The formula for the Shannon-Wiener Index is calculated as:

H' = - (ni/n) log 2 (ni/n)

Where, s= total number of taxa in the community,
ni= the number of individuals in the –ith taxon,
n= total number of individuals of all taxa.

In this study, the s taxon level was family since this level was the most common to all of the arthropods identified. Values for H' (log 2) can range between >3 and 0. Values equal to or greater than 3 indicate pristine environments able to sustain high levels of diversity. Values less than 1 indicate heavily polluted or stressed systems as defined by Platts, Megahan, and Minshall (1983). Values equal to zero indicate all individuals in the sample belong to the same taxon.

The diversity values obtained for the selected four sites are shown in Table XXVIII. Station 1 of Site 5e showed the greatest change in diversity from 1983 values to 1984. Values for 1985 remained low. Stations 1 and 2 within Site 6 exhibited lower diversity values in September 1984. The Le Sueur River (Site 7) appeared to have stable community diversity throughout the study.

According to values obtained by applying the Shannon-Wiener diversity index to selected study sites, it was apparent that the Blue Earth River and Le Sueur River systems were environmentally stressed in 1983 (XXVIII). The values for the family level of taxonomic identification were used to develop this table so as to include the dipterans in the analysis. As stated, the loss of diversity appeared to be greater below the dam at Station 1 of Site 5e. This reduction in diversity immediately below the dam could occur for several reasons. Cushman (1985) cited in his literature review the following factors stated by several authors. Fluctuating water levels can repeatedly expose substrate resulting in an intertidal zone. Receding water levels can strand invertebrates along rocky areas and small pools leading to desiccation, predation by birds, exposure to low oxygen levels, and higher temperatures, and contribute to migration from the shallow water sites to deeper water in narrower channels. Migration of invertebrates from Station 1 to Station 2 may account for the decrease in Shannon-Wiener indices at Station 1 of Site 5e and the relatively constant values obtained for Station 2 at Site 5e. Shannon-Wiener scores for Site 6 showed less variation implying a gradient of impact proceeding downstream from the dam.

Functional Feeding Groups

Benthic insects were assigned to feeding functional groups according to Merritt and Cummins (1984). These groups were generalized as Collectors, Scrapers, Shredders, and Predators. A list of the sampled aquatic insects and their assigned functional groups are presented in Table XXIX.

Table XXVIII: Shannon-Wiener diversity indices for Stations 1 and 2 of Sites 2, 5e, 6, and 7 on the Blue Earth and Le Sueur Rivers during 1983, 1984, 1985. A dashed line indicates no Surber sample was taken.

	Site							
	2		5e		6		7	
	Station		Station		Station		Station	
Year/Month	1	2	1	2	1	2	1	2
1983								
Aug	0.187	0.000	0.270	0.259	0.000	0.000	---	---
Sep	0.067	0.042	0.167	0.135	0.201	0.161	0.066	0.227
Oct	0.169	0.000	0.136	0.136	0.089	0.115	0.000	0.239
1984								
Jul	0.083	0.000	0.000	0.181	0.105	0.098	0.000	0.282
Aug	0.218	0.000	0.117	0.056	0.080	0.168	0.124	0.207
Sep	0.091	---	0.013	0.244	0.078	0.000	0.065	0.261
Oct	0.144	---	0.026	0.209	0.117	0.147	0.096	0.257
1985								
Jul	0.000	---	0.092	0.170	0.168	0.185	0.000	0.199
Aug	0.049	---	0.046	0.212	0.204	0.209	0.144	0.238
Sep	0.000	---	---	---	---	---	0.000	0.288

Table XXIX: Feeding functional groups of insects sampled in the Blue Earth and LeSueur Rivers during 1983, 1984, 1985
(P= predator; S= shredder; C= collector; Sc= scraper; H= piercer-herbivore)

Insect Order/Family/Genus	Feeding Functional Group	Insect Order/Family/Genus	Feeding Functional Group	Insect Order/Family/Genus	Feeding Functional Group
Insecta		Perlidae		Elmidae	
Emphemeroptera		Phasganophora	P	Dubiraphia	C
Baetidae		Perlinella	P	Stenelmis	Sc
Baetis	C	Acroneuriidae		Diptera	
Centroptilum	C	Acroneuria	P	Chaoboridae	P
Cloeon	C	Hemiptera		Chaoborus	P
Paracloeodes	S	Veliidae		Ceratopogonidae	P
Psuedocloeon	Sc	Rhagovelia	P	Simuliidae	C
Oligoneuriidae		Gerridae		Simulium	C
Isonychia	C	Trepobates	P	Chironomidae	C, P
Heptageniidae		Corixidae		Chironominae	C
Heptagenia	Sc	Corisella	P	Orthocladiinae	C
Rithrogena	C	Callicorixa	P	Tanypodinae	P
Stenacron	Sc	Sigara	H	Tabanidae	P
Stenonema	Sc	Trichocorixa	P	Empididae	P
Tricorythidae		Megaloptera		Ephydridae	C
Tricorythodes	C	Corydalidae		Athericidae	P
Caenidae		Corydalus	P	Atherix	P
Brachycercus	C	Trichoptera		Stratiomyidae	C
Caenis	C	Hydropsychidae		Tipulidae	S
Baetiscidae		Symphitopsyche	C	Hexatoma	P
Baetisca	C	Cheumatopsche	C	Limnophila	S
Leptophlebiidae		Hydropsyche	C		
Leptophlebia	C	Potamyia	C		
Paraleptophlebia	C	Hydroptilidae			
Potamanthidae		Hydroptila	Sc		
Potamanthus	C	Stactobiella	S		
Ephemeridae		Mayatrichia	Sc		
Hexagenia	C	Orthotrichia	H		
Polymitarcyidae		Leptoceridae			
Ephoron	C	Cerclea	C		
Odonata		Nectopsyche	S		
Gomphidae		Oecetis	P		
Gomphurus	P	Coleoptera			
Gomphus	P	Gyrinidae			
Ophiogomphus	P	Dineutus	P		
Stylurus	P	Dytiscidae			
Plecoptera		Agabus	P		
Pteronarcyidae		Hydrophilidae			
Pteronarcys	S	Tropisternus	P		

Collectors

The collectors (gatherers and filter-feeders) were the most abundant feeding functional group throughout the study. This is in corroboration with the River Continuum Concept for a sixth order stream (Vannote, et. al. 1980). Collector abundance, as well as abundance of shredders, scrapers and predators displayed an apparent reduction due to fluctuating flow levels. The most impacted site was Site 5e at both stations, although the shallow water areas (Station 1) were more important to shredders than the deeper water at Station 2. Station 2 was habitat to a larger number of collectors. The impact of flows on the collectors seemed to diminish downstream at Station 2 of Site 6 as did the effect on scrapers and predators. This would seem to imply that food and suitable habitats were available at this site. Drifting invertebrates from upstream may be colonizing this area. Also, fine particulate organic matter (FPOM), a food source for collectors may also be carried downstream either scoured from the upstream river bed or as eroded material from the stream banks and riparian zone (Ruff 1987). If suitable food and substrate are available for these organisms, then one may speculate that current velocities are within tolerable limits. If this is so, then it may be possible that a flow gradient is present. Current velocities are greater immediately below the dam and decrease as the gradient decreases.

Scrapers

Scrapers were not very abundant compared to collectors but scrapers did show a slight decrease in abundance from 1983 to 1984 below the dam at Site 5e. The abundance of scrapers at Sites 5a, 6, 7 and 2 seemed relatively stable.

Shredders

The shredders were more abundant in the shallow water stations (Station 1's) than in deeper water (Station 2's). They were also more abundant at Site 5e in 1983. Abundance of shredders declined from 1983 to 1984.

Shredders were not present at Site 6, probably due to the low amounts of leaf litter being deposited in the river from the surrounding riparian zone. Shredder abundance apparently was reduced below the dam high flows which reduced the leaf litter present by washing it downstream (Radford and Heartland-Rowe 1971). Scrapers were also reduced in abundance. Low water levels may have left periphyton exposed to dry out (Gislason 1985), hence valuable food supplies may have been lost.

Predators

The predators exhibited a decline at Site 5e at Station 2 from 1983-1984, but the predator abundance response appeared less pronounced downstream. The mean predator abundance at Site 2, 5b, 5a, 6 and 7 seemed stable.

Discussion

The reservoir, because of its lake effect on the riverine system, may also impact functional group abundance. It can act as a nutrient sink, trapping CPOM and drifting invertebrates from upstream reaches (Spence and Hynes 1971). The frequent flow fluctuations may limit recruitment from downstream and the hyporheic zone

Even though the abundance of the various functional groups were reduced below the dam, the percent composition of the functional group community remained fairly constant. Collectors still comprised a majority (53%-70%) of organisms present in 1985 at Station 1 of Site 5e. This implied food supplies were still available to this active site and that fluctuating discharges were the limiting factor.

The predominance of collectors and, secondarily, scrapers in the Blue Earth River in 1983, fit the River Continuum Concept (Vannote et. al. 1980) for a sixth order stream. The downstream community below the dam took advantage of the nutrient processing inefficiencies of the upstream functional groups (Merritt, Cummins, and Burton 1984). The manipulation of flows in 1984 and 1985 added environmental stresses that resulted in greater than normal seasonal fluctuations, such as spates to which the macroinvertebrate community was forced to respond to.

CONCLUSIONS

The permit for the relicensing of the Rapidan Dam of Blue Earth County, Minnesota, required a study of the impacts of the conversion of run of the river to fluctuating flow (peaks) on water quality, sediments, synthetic chemicals and aquatic macroinvertebrates. The study was for the Blue Earth County Board of Commissioners and was conducted in 1983 (pre-operation) run of the river through 1985 (peaking).

Water Quality

Introduction

The water quality component has addressed three questions pertaining to the Rapidan Reservoir and the peaking operation of the Rapidan Hydroelectric Dam.

1. Did the Rapidan Reservoir impact the concentrations of the water quality and Particulate Organic Matter transport parameters, during the run-of-the-river baseline sampling periods in 1984 and 1985?
2. Did the peak power generations (peak-events) of the hydroelectric facility impact the concentrations of the same water quality and OM transport parameters independent of the reservoir's impacts?
3. Were the water quality and OM transport parameters impacted differently by different types of peak-events, i.e. a peak-event preceded by many consecutive non-generation days as compared to a peak-event preceded by a run-of-the-river operating mode and antecedent storm events?

To try to determine the answers to these questions, the concentrations of eleven water quality parameters and four size classifications of OM were determined during samplings in 1984 and 1985 at eight sites along a 51.8 river km (32.2 river mi) stretch of the Blue Earth River, and three peak power generations (peak-events) in 1985. The samplings in 1984 and the non peak-event samplings in 1985 were used, along with historic data from MPCA records, to establish a baseline for each parameter, which the peak-event data were compared to. The impact on the water quality parameters and OM transport by a peak-event, preceded by many consecutive non-generation days, was compared to impacts caused by two peak-events preceded by run-of-the-river operating conditions; differences in the number of turbines operating and antecedent storm events (Tables VI, IX).

1. Impact of the Rapidan Reservoir

Water Quality Parameters

The Rapidan Reservoir showed evidence of directly impacting the mainstem concentrations of five of the eleven water quality parameters in question, during the baseline sampling periods in 1984 and 1985. The reservoir appeared to act as a trap sometimes, and thereby decreased the downstream concentrations of the parameters Total Phosphorus, Filterable Phosphorus, TNFR, and TVNFR. The reservoir appeared to increase the downstream concentration of the fifth parameter, Nitrite-Nitrogen, within the reservoir and a portion of its tailwaters, which may be due to the oxidation of ammonia to Nitrite-Nitrogen.

OM Transport Parameters

The reservoir appeared to act as a trap for CPOM, thereby decreasing its downstream concentrations during the baseline sampling periods in 1984 and 1985, but did not act as a trap for the FPOM, VPOM and DOC.

2. Impact of Peak Events

Water Quality Parameters

The questions addressed here are whether significantly higher levels for the water quality parameters, above baseline, were reached as a consequence of the peaking and whether the peaking event results in an acute increase in the water quality parameters. Keep in mind that Site 3 is above the reservoir and represents draw down whereas Sites 5, 6 and 8 are below the dam and represent progressive downstream flow from the reservoir. During the 8/9 event we established multiple sampling sites at Site 5 across the river and the data revealed total mixing with similar water quality at all sites. As a result, of this mixing, we were able to move downstream and added Site 6 on 8/20 and Site 8 on 8/26. As a consequence of increasing sites, the peak-event data described represents three events at Site 5, two events at Site 6 and one event at Site 8. Since these peak events are acute events in nature this discussion will focus on highest levels reached at each site. Also, the baseline highs for 1985 cover the period from 6/10 to 9/15 whereas the three peaks all occurred in August.

The Water Quality Parameters maximums are shown in Table XXX and revealed the following:

- The peaking highs for August surpassed the baseline (June-September) in 24 out of 74 cases. Nineteen were downstream of the dam (eight at Site 5, seven at Site 6 and four at Site 8). Also, all three sites below the dam reached higher levels than baseline for Organic Nitrogen, Total Phosphorous, Total Non-Filterable Residue and Total Volatile Non-Filterable residue.
- The pre-event, startup, to maximum event levels during the three events revealed that in 84 of 91 cases the events raised the maximum concentration of the parameters. Great increases were seen at all sites with maximums of 10x at Site 3 (Ammonia), 7x at Site 8 (Total Non-Filterable Residue) and 4x at Sites 5 (Ammonia) and 6 (Ammonia and Total Non-Filterable Residue).

The maximum for peak events increased progressively downstream of the dam for Organic Nitrogen, Nitrate Nitrogen, Total Phosphorous, Total Non-Filterable Residue, Total Volatile Non-Filterable Residue, and pH. This indicates that input from the sediment, including rewetting, was playing a role, however further research is needed in this area.

The above observations from the Water Quality Parameters data revealed important impacts of the peaking operation. Since the peaking is an acute event, the emphasis is placed on the maximum concentrations and changes during peaking. We observed acute, often excessive, fluctuations which occurred in a short period of time. These changes were often amplified downstream. These rapid changes in water quality occurred in a closed system in that there were no tributaries from the dam to the Minnesota River except the LeSueur (Site S7), no immediate run off due to rainfall or inflow, and can be attributed directly to the peaking. That some of the highest levels were found on 8/30, following two previous flushings, is most interesting and raises questions on the contribution dynamics of the river sediment, both wet and rewetted.

Table XXX: Water Quality Parameters 1985 baseline and peaking maximums in mg/L and ug/L.

	Site	Date	Ammonia Nitrogen (mg/L)	Organic Nitrogen (mg/L)	Nitrate Nitrogen (mg/L)	Nitrite Nitrogen (ug/L)	Total Phosphorous (mg/L)	Filterable Phosphorous (mg/L)	Total Non-Filterable Residue (mg/L)	Total Volatile Non-Filterable Residue (mg/L)	Conductivity (uohms/cm^2)	pH	Water Temperature (◦C)
↑ Upstream	1			(1.99)	(13.43)	(8)	(.36)		(359)	(46)	(700)	(7.99)	(27)
	2			(2.03)	(12.49)	(7)	(.47)		(295)	(44)	(720)	(8.10)	(27)
	3	8/9 8/26 8/30	.07/.10 0/.03 .04/.41	(1.93) 1.11/1.28 1.50/1.63 1.46/1.60	(10.99) .12/.14 .11/.32 1.22/1.44	(10) .32/.69 .09/4.64 7.06/7.06	(.26) .18/.19 .12/.17 .21/.24	0.048/0.049 0.042/0.039 0.049/0.042	(108) 75/69 38/62 59/64	(20) 16/23 24/31 27/31	(730) ___/___ 625/675 650/650	(8.17) ___/___ 8.27/8.41 8.00/8.35	(25) ___/___ 21.5/23.0 20.5/22.0
	4			(2.09)	(12.49)	(17)	(.26)		(131)	(35)	(740)	(8.23)	(30)
	Dam												
Downstream ↓	5	8/9 8/26 8/30	.08/.18 .05/.21 .07/.07	(1.78) .98/1.41 1.22/1.51 1.31/1.82	(13.09) .20/.21 .14/.17 .17/.23	(17) 1.16/1.91 .09/.55 .46/1.48	(.23) .15/.27 .13/.16 .17/.21	0.058/0.074 0.034/0.044 0.036/0.042	(84) 49/142 38/46 57/73	(17) ___/23 15/31 24/31	(740) 751/759 675/685 600/625	(8.31) 7.61/8.00 8.15/8.20 7.91/8.08	(25) 26/26 22/22.5 21/22
	6	8/26 8/30	0/.60 .05/.26	(1.65) .99/1.42 1.22/1.72	(12.99) .27/.33 .22/.31	(11) 1.39/1.57 .64/.74	(.23) .13/.31 .15/.39	0.044/0.049 0.049/0.075	(91) 31/157 29/150	(21) 18/35 16/37	(740)	8.50 8.12/8.21 7.79/8.02	(28) ___/___ ___/___
	7			(1.64)	(15.43)	(20)	(.39)		(263)	(40)	(740)	(8.39)	(26)
	8	8/30	.05/.08	(1.51) 1.70/1.89	(13.99) .17/.38	(11) .15/.92	(.30) .16/.36	0.042/0.044	(122) 42/310	(20) 20/54	(700) 630/650	(8.59) 8.34/8.43	(27) 23.5/25.0

Key (a) : (Highest value – baseline 85)

x/v : Pre event level/max event level

OM Transport Parameters

The Organic Matter maximum transport breakdown revealed the following (Table XXXI) :

- The peaking highs at particular sites exceeded the baseline maximums for those sites in 17 of 36 instances with 13 below the dam. Six were in the very fine particulate organic matter category, five in fine particulate organic matter, three in dissolved organic carbon and three in coarse particulate organic matter. Four of the 36 were above the dam and involved the smaller sized fractions. Only fine particulate matter at Site 8 exceeded the total baseline seasonal maximum.
- The pre-event, startup, to maximum event levels revealed that in 33 of 36 cases the events raised the concentration of the parameters. Greatest increases were seen at Site 8 ranging from 60% to almost 500%. The increases were greater as one progressed downstream of the dam. Also, in general, these greater increases as one progressed downstream of the dam indicated recruitment from the deposited sediment. Further, the increases were often greater as one progressed from peak one to peak three. This is interesting because the three peaks were all within 18 days and as stated above cannot be attributed to reservoir release.

These observations revealed important impacts of the peaking operations. We observed short-term, often excessive, acute fluctuations which are often amplified as we move progressively down river. From an organismal standpoint, this creates an altered environment, which is unpredictable and demands a different survival strategy for macroinvertebrates and fish.

3. Impact of Variations in Peak Events.

Water Quality Parameters

The 8-9 peak-event was characterized by 21 consecutive non-generation days. The 8-26 and 8-30 events were preceded by run-of-the-river operating conditions (one turbine was running constantly). At site S5, the 8-9 event produced greater increases in concentration from the pre-event concentration for certain parameters, as compared to the August 26th and August 30th events. The parameters most impacted by the August 9th event included Organic-Nitrogen, Total Phosphorus, TNFR, and TVNFR. The remaining water quality parameters possessed relatively similar increases in concentration at S5 during all three peak-events.

OM Transport Parameters

The August 9th event produced a greater increase from the pre-event concentration for the OM size classification FPOM at S5, than did the latter two events. The remaining three size classes possessed relatively similar increases in concentration at S5 during all three peak-events.

Table XXXI: Organic matter transport; 1985 baseline and peaking maximums in mg/l.

	Site	Date	Course Particulate Organic Matter	Fine Particulate Organic Matter	Very Fine Particulate Organic Matter	Dissolved Organic Carbon
↑ Upstream	1		(1.7)	(6.5)	(29.2)	(6.7)
	2		(0.4)	(3.2)	(29.7)	(5.9)
	3	 8/9 8/26 8/30	(1.2) 0/0.5 0.6/0.5 0.3/1.0	(4.8) 1.2/1.3 1.4/3.4 2.1/2.3	(17.1) 13.7/16.5 16.6/21.8 19.1/21.1	(5.8) 3.9/4.6 6.5/7.6 6.8/7.2
	4		(0.5)	(3.6)	(26.7)	(6.1)
	Dam					
Downstream ↓	5	 8/9 8/26 8/30	(1.2) 0.4/1.6 0.5/0.6 0.1/0.5	(2.3) 1.4/4.1 3.7/3.7 1.7/2.8	(15.4) 14.3/15.4 12.8/15.2 16.5/21.0	(9.1) 5.8/7.3 4.6/5.1 6.9/8.0
	6	 8/26 8/30	(0.4) 0.6/0.7 0.8/0.7	(5.4) 1.5/5.7 1.5/3.1	(18.5) 11.7/22.5 16.1/26.2	(6.3) 3.1/4.4 4.3/5.8
	7		(0.6)	(1.4)	(18.8)	(7.4)
	8	 8/30	(1.6) 0.3/1.0	(2.3) 2.1/10.4	(13.2) 15.0/26.1	(6.3) 5.3/8.6

Key (a) : (Highest value – baseline 85)

x/y : Pre event level/max event level

Sediments

Introduction

The sediment component addressed five questions pertaining to the Rapidan Dam Reservoir, run-of-the-river and the peaking of the Rapidan Hydroelectric Dam.

1. Did the Rapidan Dam Reservoir impact the concentrations of suspended sediments in transport during the baseline sampling periods of 1984 and 1985?
2. Did the peak power generations (peak-events) in 1985 of the hydroelectric facility impact the concentrations of the sediment fractions?
3. What is the nature of the surficial sediment in the reservoir (grain-size and percent organic) and do the old channel surficial deposits differ from the submerged flood plain?
4. Did the peaking-events affect the surficial reservoir sediments?
5. What are the upstream sediment sources in regards to the bed load?

1. Impact of Rapidan Dam Reservoir on Sediment Transport During Baseline Flow (Run-of-the-River)

- Total Suspended Solids

  The reservoir acted as a sediment trap in the two early periods (June-July) with no apparent affect in the late periods (August-September) even though the wet/dry cycle reversed itself from 1984 to 1985.
- Coarse and Medium Silt

  No relationship was observed between a higher percentage coarse and medium silt to suspended sediment during baseline.
- Fine and Very Fine Silt

  In most of the baseline data the fines and very fine silts made up the smallest component of suspended sediments. There were no fine and very fine suspended sediments in the later period of 1985 in 16 of 24 samples. The reservoir did not appear to be acting as a settling basin and no apparent relationship to suspended sediment was observed.
- Clay

  Clay, during the baseline samplings, represented the dominant component of suspended sediment. The dry seasons averaged slightly higher mean percents than the wet seasons even though these two reversed themselves in 1984 and 1985. This is undoubtedly a transport energy relationship. There was no discernable relationship between suspended concentrations and percentage clay.
- Silt and Clay that is Organic

  The baseline suspended sediment in the silt-clay category that was organic generally increased from early season to late and averaged around 50 percent. This indicates algal development and/or organic aggregation. The reservoir was a source in three out of the four seasons (early and late 1984 and 1985) and no significant progressive downstream effect was observed.
- Clay that is Organic

  The baseline suspended sediment that is organic in the clay fraction is generally higher than the clay silt category in both periods of both 1984 and 1985. This indicates organic aggregates of clay sized particles. No observed correlation was seen between total suspended solids and percent organic clay. No consistent, progressive downstream pattern was observed.

2. Impact of Peak Power Generations (peak-events) in August, 1985 on Suspended Sediments

A comparison of maximums, both 1985 baseline and peaks, by site is shown in Table XXXII.

Suspended Sediments (g/l):

- In three of four sites (except Site 6) the maximum in peaking is not as high as baseline high.
- At all sites, the pre-event is surpassed during each peaking event.

Percent Coarse and Medium Silt:

- In one of four sites a peaking maximum exceeded the baseline maximum.
- In seven out of nine peaking site dates the peaking exceeded the pre-event level. The two exceptions were at Site 3 above the reservoir.

Table XXXII: Suspended Sediment in transport, 1985, baseline and peaking maximums

	Site	Date	Suspended Sediments (g/l)	Percent Coarse and Medium Silt	Percent Fine and Very Fine Silt	Percent Clay	Percent of Suspended Sediment Silt and Clay that is Organic	Percent of Suspended Sediment Clay that is Organic
↑ Upstream	1		(.29)	(77)	(48)	(100)	(47)	(86)
	2		(.29)	(68)	(35)	(100)	(66)	(100)
	3		(.28)	(70)	(88)	(74)	(82)	(100)
		8/9	.22/.25	47/46	0/29	53/92	57/92	___/86
		8/26	.14/.16	47/16	0/29	53/100	64/83	91/96
		8/30	.10/.26	24/52	0/50	76/76	40/75	46/79
	4		(.26)	(55)	(92)	(100)	(78)	(89)
	Dam							
Downstream ↓	5		(.29)	(80)	(35)	(100)	(88)	(80)
		8/9	.21/.28	58/59	8/52	34/100	35/89	63/72
		8/26	.12/.18	51/87	23/75	26/70	45/89	23/67
		8/30	.16/.25	18/68	36/40	46/100	41/77	33/87
	6		(.19)	(84)	(40)	(82)	(58)	(83)
		8/26	.12/.44	25/68	0/43	75/55	52/54	66/78
		8/30	.20/.29	0/84	80/20	20/100	38/55	8/86
	7		(.24)	(95)	(69)	(50)	(94)	(94)
	8		(.48)	(76)	(22)	(79)	(86)	(92)
		8/30	.11/.34	59/62	0/56	41/69	30/66	55/84

Key (a) : (Highest value – baseline 85)

x/y : Pre event level/max event level

Percent Fine and Very Fine Silt:

- Only at Site 3, above the reservoir, did the baseline maximum exceed the peaking maximum for all three events.
- In eight out of nine peaking sites dates the peaking exceeded the pre-event.

Clay:

- In two out of four sites the peaking maximum exceeded the baseline maximum.
- In seven out of nine peaking site dates the peaking exceeded the pre-event.

Percentage Organic:

1. In all cases of the percentage of suspended sediment, silt and clay, that is organic and the percentage clay, that is organic, exceeded the pre-event levels.
2. The vast majority of the suspended sediment in the dominant clay category is organic
3. Peaking in most cases increases the percent organic, often between two to three times, but seldom exceeds the baseline maximums for the sampling season.

3. Nature of the Surficial Reservoir Sediment (Grain-size, and Percent organic) and relation to the old channel.

Twenty one transects were sampled from V (upstream) to C (at the dam). Transects V though N were flooded only during the reservoir storage phase. Gravels and very coarse sand were seen furthest up the Blue Earth and the mouth of the Watonwan Rivers. Sands were dominant in the old river channel from the start of the reservoir through N, the last transect before the permanent reservoir. The transects V through N showed a general increase in silts and clays with a corresponding decrease in sands which became finer, all indicating a transition to a lower energy environment. From transects M through C, within the old river channel there is almost no gravel or very coarse sand. From transect F and increasing through C, the sediments become coarser in the channel probably because of the sucking of the finer sediments by the turbines. Downstream of transect N, the percent of coarse and medium silt increased slightly within the channel and more so outside the channel. These findings are all before the peaking events began and represent run-of-the-river.

4. Comparison of the Pre and Post Peaking Reservoir Surficial Sediment, July to October, 1985.

The sampling was to compare the earlier very dry period, run-of-the-river, to the abnormally wet period, post peaking. Any effects found can not be definitely assigned to rainfall or peaking, however the peaking events with their major draw downs at Site 3 (between transect Q and P) appear to have had the dominant hydrologic impact. There was a change to a very high ratio of coarse (sand) to fines (silts and clays) in the river channel from W through M. This reach represents the pre-continuous reservoir. This was probably the result of the significant draw down and therefore pulling of fine sediment into the reservoir caused by peaking. Within the reservoir proper we see the reverse which indicates the deposition of stripped fine sediment from upstream.

5. Pre Reservoir Expansion Bed Load Sources.

A 1983 reconnaissance of the river channel, now within the reservoir, and downstream of the dam revealed a large number of sand dunes often as high as one foot. The grain size distribution of sands as well as other sediment categories appear to be quite similar between the Blue Earth and Watonwan Rivers. Further, the upstream-downstream sampling at major cliff locations show no significant differences indicating that the rivers are similar, in equilibrium, and that upstream sources of sand exist. In 1985, with the restoration of the dam completed and filling of the expanded reservoir, the surface bed load deposits were not observed or documented. This is consistent with the increased impounding that both slows the flow back upstream and allows for the deposition of fines on top.

Summary

The August 9th event, which was preceded by 9 days of no rain, showed a significant increase in suspended sediment at both Sites 3 and 5. The August 26th event, which was immediately preceded by abnormally high precipitation, remained close to baseline at Sites 3 and 5, but showed a dramatic 400% increase at Site 6 indicating river bed scouring. The August 30th event, preceded by a 2.62 inch rainfall the day before, showed a significant increase in suspended sediment at Site 3. This was probably due to upstream loading due to the rain. Site 8 also increased significantly. It appears that the suspended sediments increased significantly the further downstream you go.

It is clear that rapid, acute rises do occur during peak events especially in the fines and clays and that these fines and clays have a high organic content.

Synthetic Organics

Introduction

The synthetic organics component addressed two questions pertaining to the Rapidan Dam Reservoir and the peaking of the Rapidan Hydroelectric Dam.

1. What synthetic organics are present?
2. Does the peak power generation (peak-events) in 1985 of the hydroelectric facility impact the concentration of any synthetic organics detected?

1. Synthetic Organics Found.

Only two distinct peaks were found, with neither being a chlorinated pesticide. The two peaks were identified as pthalate plasticizers: Butyl octyl pthalate= 1, 2-Benzenedicarboxylic acid, Butyl octylester and 2-butoxyethyl butyl phthalate=1, 2- Benzenedicarboxylic acid, 2-butoyxethyl butyl ester. This is consistent with recent agency findings for the late summer time of sampling 8/9, 8/26 and 8/30 (Metropolitan Council Environmental Services, et al., 2001).

2. Impact of the Peak Power Generation (Peaking Events).

The behavior of the pthalates during the peaking events, although not of great significance by and of itself is important as an indicator of what some other synthetic organics and other endocrine disrupters could exhibit if present.

Significant fluctuations in pthalates were found at Site 3 which is above the reservoir and experienced draw down during all three peaks. It appears the reservoir was not a source of pthatlates during the peaks (Site 5) but rather they were either diluted or settled out from Site 3. No clear relationship to turbidity was uniformly observed.

Sites 6 and 8 (further downstream) showed a closer relationship of pthalates to turbidity.

Aquatic Macroinvertebrates

Introduction

The aquatic macroinvertebrate component has addressed the question: Did the peak power generation (peak-events) of the hydroelectric facility impact the macroinvertebrate community?

Samples were collected over a three year period beginning in 1983, the year before dam operation, and during dam operation from late 1984 through 1985. Data were analyzed with respect to total abundance, taxa richness, community diversity and feeding functional groups.

Macroinvertebrate total abundance, richness and community diversity declined at sites immediately downstream of the dam in 1984 and 1985. The abundance of functional groups also declined at sites immediately below the dam although percent composition of functional groups remained relatively constant throughout the study. The site most distant from the dam showed minimal changes in the macroinvertebrate community suggesting a gradient of impact. Since feeding functional groups exhibited declines in abundance but did not change in percent composition, it is likely that fluctuating flows, and not food availability, were the reason for changes in the macroinvertebrate community.

Abundance

The mean total abundance of organisms below the dam at sites 5e through 6 declined from 1983 to 1984 and persisted into 1985. In general, the mean total abundance of organisms was lower at station 1's (shallow water) than at Station 2's (Deeper water) for each site downstream of the dam. This decline in mean total abundance of organisms below the dam seemed to be the result of fluctuating flows caused by the dam operation as these same reductions in abundance were not observed in the Le Sueur River (the control) or Site 2 upstream of the reservoir.

Richness

A total of 16 fewer genera were collected in Surber samples from the Blue Earth River in 1985 than in 1983 (45 in 1983, 28 in 1984, 29 in 1985), and 14 fewer genera were collected with the three-kick method during the same time period (46 in 1983, 37 in 1984, 32 in 1985). This declining trend was not observed in results from sampling the Le Sueur River (control). Richness also seemed stable at Site 2 (above the dam). The reduction appears related to the flow fluctuations caused by the peaking.

Community Diversity

Only Surber sample data was used for this parameter. Community diversity values were determined for four selected sites: 2(above reservoir), 5 (just below dam), 6 (downstream before Le Sueur River enters), and 7 (Le Sueur River, the control). Station 1 (Shallow) of site 5 showed the greatest change in diversity from 1983 to 1984 with 1985 remaining low. Migration of invertebrates from Station 1 (low) to Station 2 (deep) may account for the decrease in Shannon-Wiener indices at Station 1 of Site 5e and the relatively constant values obtained for station 2 of 5e. Shannon-Wiener scores for Site 6 showed less variation than Site 5 implying a gradient of impact proceeding downstream from the dam. The LeSueur River (Site 7) appeared to have stable community diversity throughout the study and was significantly higher in station 2 (deep) throughout the study period.

It should be noted that the values obtained in 1983 for both the Blue Earth River and LeSueur River systems were both environmentally stressed before the peaking began.

Functional Feeding Groups

Functional feeding groups reflect availability of different types of food and are related to stream order (stream-river size).

The collectors (gatherers and filter feeders) were the dominant functional feeding group which is consistent with the River Continuum Concept for a sixth order river. The most impacted site was Site 5e at both stations, although the shallow water areas (Station 1) were more important to shredders than the deeper water at Station 2 which was habitat to a large number of collectors. The impact of flow on collectors, scrapers and predators diminished downstream. This implied that food and suitable habitats were available. Drifting invertebrates and fine particulate organic matter (FPOM) a primary food source from scouring of the riverbed (Ruff, 1987) probably provided the needed food source.

Even though abundance of the various functional groups were reduced below the dam, the percent composition remained fairly constant.

Conclusions

This study documented significant reductions in total abundance of invertebrates, loss of genera richness and decreased community diversity downstream of the dam. These negative impacts were most severe at Site 5e and seemed to lessen at Site 6. Although the Intermediate Disturbance Hypothesis (Ward and Stanford 1983; Stanford and Ward 1983) suggests that some level of disturbance favors community diversity and richness within a dynamic equilibrium of the stream environment, the manipulated flows at Rapidan Dam exceeded the optimal level of disturbance that promotes maximum community diversity.

Overall Conclusions

The reservoir itself, during run of the river electric generation, appeared to have some positive and few negatives associated with it for the parameters studied. The positives included the reservoir decreasing the downstream concentration of Total Phosphorous, Filterable Phosphorous, Total Non-Filterable Residue and Total Volatile Non-Filterable Residue as well as Coarse Particulate Organic Matter. Further, the reservoir acted as a sediment trap in the 1984 and 1985 early periods (June-July) with no apparent effects in the late periods (August-September) even though the wet/dry cycle reversed itself. The reservoir acted as a trap for the pthalates (synthetic organics) even during peaking. As a negative the reservoir appeared to increase Nitrate-Nitrogen, which may have been due to the oxidation of Ammonia.

Negative impacts from peaking were observed in all four study categories of Water Quality, Sediments, Synthetic Organics and Aquatic Macroinvertebrates. However, most of the impacts were short term, acute and related directly to the peaking cycles. Sedimentation in the reservoir and the below dam aquatic macroinvertebrate changes (as a consequence of acute fluctuations in water quality and quantity) were long term changes. From a water quality perspective, all three sites below the dam revealed higher levels than baseline (June-September) for Organic Nitrogen, Total Phosphorous, Total Non-Filterable Residue and Total Volatile Non-Filterable Residue. The pre-event, startup, to maximum during the three events revealed that in 84 of 91 cases, the events raised the maximum concentration of the parameters; in some cases (i.e. Ammonia) up to 10 times. The Organic Matter in transport increased with events from pre-event in 33 of 36 cases, ranging up to 500 percent. That the increases were often greater progressively downstream implicates rewetting of the river bed, an area requiring further study. The sediment data revealed that the pre-event was surpassed during each event at all sites for suspended sediments. The synthetic organics data (pthalates) showed significant fluctuations at Site 3. The macroinvertebrate component documented significant reductions in total abundance, richness and species diversity downstream of the dam due to peaking.

The findings of this study document one of several consequences of conversion to peaking (i.e. economics of electrical generation, fisheries, etc.) that need to be weighted in the final decision of switching from run of the river to a peaking generation option. The findings also apply to the option of maintaining the dam and reservoir as a run-of-the-river operation.

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Appendix A:
Photographs of the sampling sites

Site S1 on June 23, 1984 (upstream, high flow)

Site S1 on October 13, 1984 (upstream, low flow)

Site S2 on June 23, 1984 (upstream, high flow)

Site S2 on October 13, 1984 (upstream, low flow)

Site 3 on July 13, 1984
(upstream, high flow, prior to closing the dam's tainter gates)

Site 3 on August 20, 1983
(upstream, low flow, prior to closing the dam's tainter gates)

Site S4 on July 13, 1983
(upstream, high flow, east bank, prior to closing tainter gates)

Site S4 on August 20, 1985
(upstream, low flow, east bank, prior to closing tainter gates)

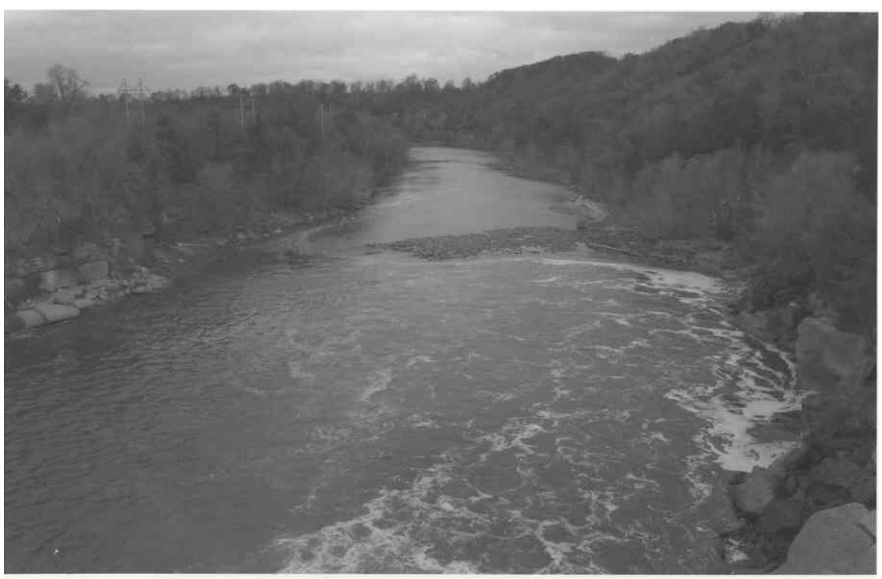
Site S4 on June 23, 1984
(upstream, high flow, after closing of tainter gates)

Site S4 on October 21, 1984
(upstream, low flow, after closing of tainter gates)

The Rapidan Dam on October 8, 1983
(upstream, during rehabilitation)

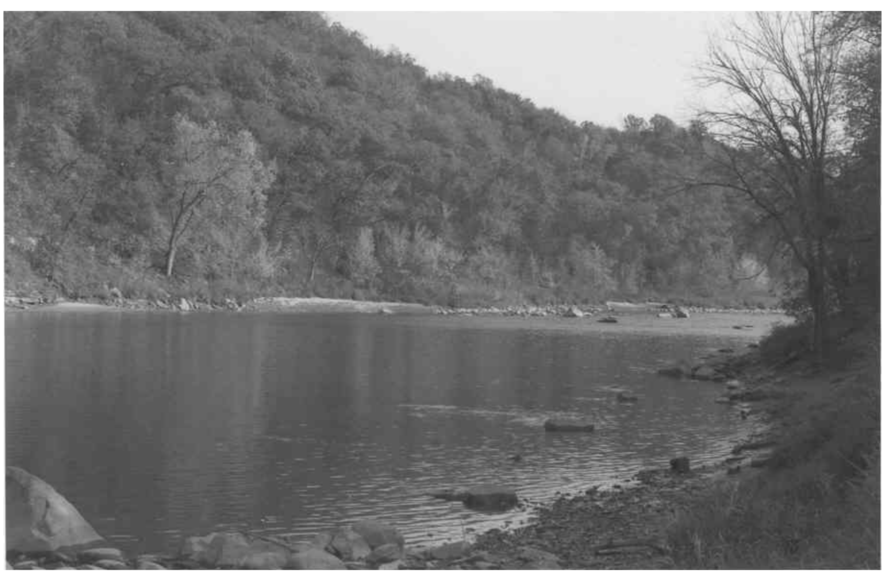
The Rapidan Dam on August 20, 1985
(upstream, post rehabilitation)

Looking downstream towards S5 from the top of the Rapidan Dam, high flow, June 23, 1984



Looking downstream towards S5 from the top of the Rapidan Dam, low flow, October 21, 1984

Site S5 on May 10, 1984
(upstream, high flow)



Site S5 on October 13, 1983
(upstream, low flow)

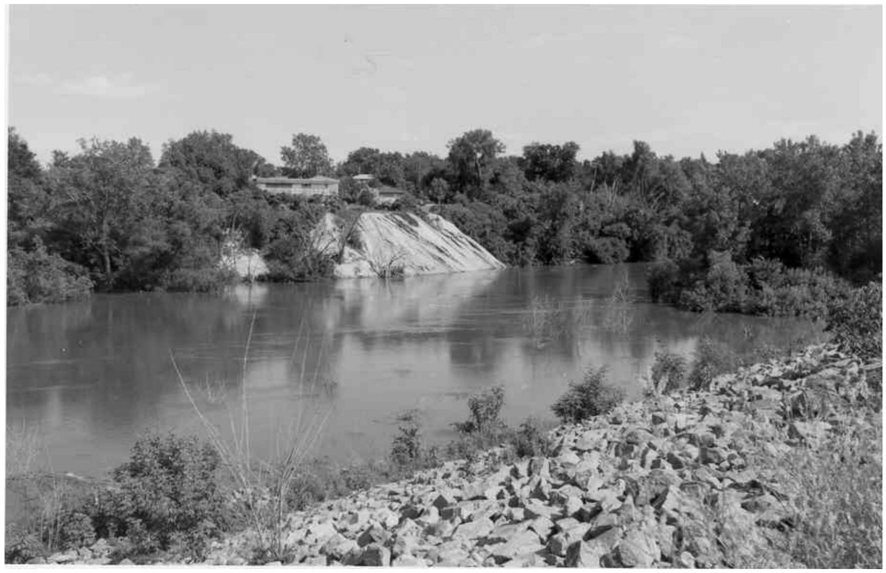
Site S5 on August 20, 1985
(upstream, hypo-minimum flow due to flow manipulation at the Rapidan Dam)

Site S6 on May 10, 1984
(upstream, high flow)

Site S6 on October 13, 1984
(upstream, low flow)

Site S7 on June 23, 1984
(upstream, high flow)

Site S7 on October 21, 1984
(upstream, low flow)



Site S8 on June 25, 1984
(upstream, high flow)

Site S8 on October 21, 1984
(upstream, low flow)