#2998

Sulfate Sampling in Waters Receiving Seepage from the USX Tailings Basin:

Status Report

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1. Introduction

The Minntac taconite mine and plant in Mountain Iron, in operation since 1967, is presently operated by USX Corporation (formerly U.S. Steel). Due to climatic conditions, periods of reduced taconite production, and attempts to operate the tailings basin in an efficient manner, water levels have risen in the basin so that USX anticipates the need to discharge water from the tailings basin in the future. USX, the Minnesota Pollution Control Agency (MPCA), and Department of Natural Resources (DNR) representatives discussed this proposed discharge and permit applications were submitted. The objective of USX, MPCA, and DNR is to manage tailings basin water levels in a manner which minimizes environmental impact.

Upon initial review in late 1986, concern was voiced regarding the influence of the tailings basin on the water quality of streams downgradient of the basin. Particular issues were those of:

1) elevated sulfate concentrations and their impact on wild rice,
2) water temperature differentials and their potential influence on trout in the Dark River,
3) potential routes for regulated tailings basin water discharge, and
4) the influence of the sulfate release on tailings basin reclamation.

In response to concerns 1 and 4 a program was developed to describe sulfate release from the tailings basin. This report summarizes the data collected by this program through January 1988. Additional background information and data are presented in "Compilation of Data Relevant to Discharge, Seepage and Reclamation of USX Tailings Basin" (MN DNR, 1987).

2. Background

2.1. Introduction

Construction of the USX tailings basin began with the 1966 construction of the starter dike in cell 1. According to the Final NPDES Permit (USX, 1987) the basin has a present perimeter of 21.8 km (kilometers, 13.6 miles) and covers 36 km^2 (14 mi^2 or 8972 acres). The U.S. Army Corps of Engineers (1979) reported a storage volume of 462,370 acre-feet. The tailings basin is located on the divide between two watersheds located north of the Laurentian divide. Seepage from the basin flows west to the Dark River and subsequently into the Sturgeon River after approximately 25 km (17 miles). Seepage also flows east through the Little Sandy and Sandy Lakes (Twin Lakes) and down the Sand River (Figure 1). After about 20 km (12 miles) the Sand River joins the Pike River, which drains into Lake Vermilion. Limited flow and water quality data prior to 1972, when the basin reached its present dimensions, are available for both rivers.

(Increase description of flow from basin to and beyond sampling stations.)

2.2. Pre-operational hydrology and water quality

On the Dark River at Forest Road 271 (FR 271) gage height has been measured regularly since August 1942. Eight times between September 1955 and October 1972, the United States Geological Survey (USGS) measured discharge and analyzed a suite of up to 26 physical and chemical parameters, including sulfate (appendix 1). Sulfate concentrations ranged from 6.5 to 12 mg/L, with an mean of 8.2 mg/L. The tailings basin installation presently covers 25 km^2 (9.5 mi^2) of the Dark River watershed, or approximately 20 percent of the watershed at FR 271 (USX, 1987), and has reduced discharge at the site. Army may have data

On the Sand River, discharge at Trunk Highway 53 (TH 53) was measured approximately 20 times between April 1958 and September 1961 by the USGS. A suite of up to 22 physical and chemical parameters was also analyzed on most of these occasions (appendix 1). Sulfate concentrations ranged from 1.8 to 12 mg/L, except for one reading of 26 mg/L. Ignoring the anomalous value, the

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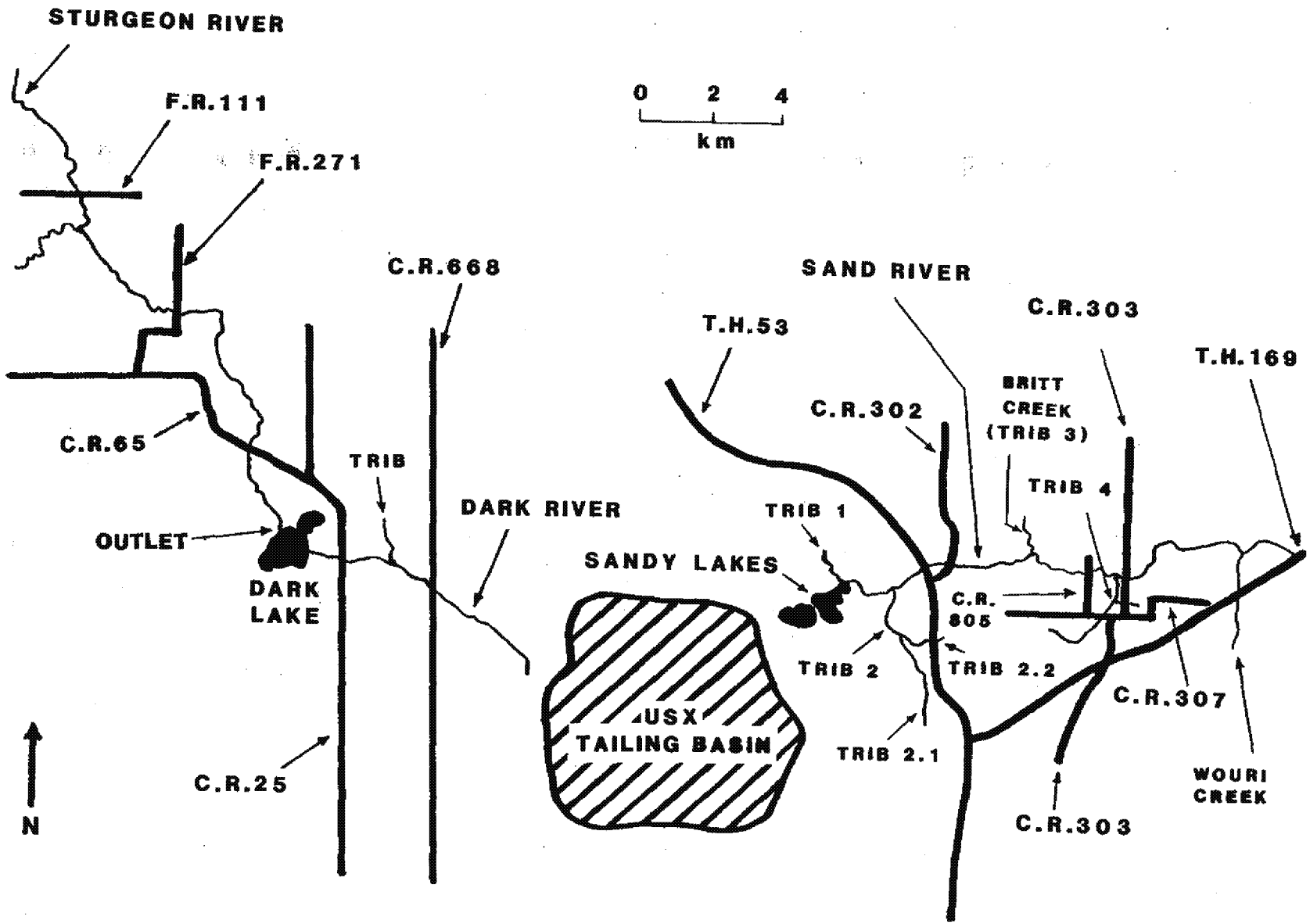
STURGEON RIVER
F.R.111
F.R.271
0 2 4
km
C.R.668
SAND RIVER
C.R.303
T.H.53
T.H.169
BRITT CREEK (TRIB 3)
C.R.302
C.R.65
TRIB
TRIB 4
DARK RIVER
TRIB 1
OUTLET
SANDY LAKES
DARK LAKE
C.R. 805
TRIB 2
TRIB 2.2
C.R.307
USX TAILING BASIN
TRIB 2.1
WOURI CREEK
C.R.25
C.R.303
N

average concentration was 7.6 mg/L, and the median was 7.8 mg/L. The tailings basin covers 10 km^2 (4.0 mi^2) of the Sand River watershed, or approximately 20 percent of the watershed at TH 53 (USX, 1987).

Approximately ~~13.7~~ 11.0 km (~~8.5~~ 7.4 miles) downstream of the confluence of the Sand and Pike Rivers, near Embarrass, instantaneous flow of the Pike River was measured eight times between April 1958 and September 1963. Twenty two physical and chemical parameters were analyzed on most of these occasions. Sulfate concentrations were analyzed eight times and ranged from 10 to 16 mg/L, with a mean of 11.8 mg/L (appendix 1).

2.3. Wild rice surveys

DNR Fish and Wildlife Division - Wildlife Section conducted a game lake survey on Sandy and Little Sandy Lakes in 1966 and July 21, 1987. Water levels in the lakes were approximately 2 ft. higher in 1987 compared to 1966; water clarity increased from 1.3 ft. in 1966 to 6 ft. in 1987; and aquatic vegetation changed very little except that wild rice was absent from both lakes in 1987. In a good year, these lakes have 200 acres of wild rice (G. McHugh, see MN DNR, 1987, appendix 18). The wild rice crop was good in 1970 and 1972, fair in 1966, 1968, 1973, 1980, 1981 and poor in 1977, 1978, 1982, 1984 through 1987. The extent of the wild rice crop was not documented in 1967, 1969, 1971, 1974 through 1976, 1979 or 1983.

In good years a 40 to 50 acre area of wild rice grows in a wide spot in the Sand River just upstream of TH 169. The crop was good in 1984, 1985, and 1987 and poor 1986 (G. McHugh, see MN DNR, 1987).

3. Operational phase data collection

USX has collected water quality data at and near their plant site since 1981. Water quality has been sampled at the tailings basin, ground water near the basin, and other sites including the Dark and Sand Rivers, where discharge has also been measured. The sampling and the data collected are summarized in an earlier report (MN DNR, 1987).

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4. Present studies

4.1. Survey of Dark and Sand Rivers

On four occasions between March 4 and July 16, 1987, the DNR sampled sulfate and specific conductance at several sites on the Dark and Sand Rivers and their tributaries. This sampling was done to examine the magnitude of other sulfate sources in the Dark and Sand River watersheds, obtain a preliminary picture of sulfate transport in these watersheds, and provide information relevant to selecting sites for a more extensive sampling program.

Sulfate concentrations decreased as the distance downstream from the basin increased (appendix 2). This is consistent with dilution by tributaries downstream of the tailings basin. Sulfate concentrations in one tributary to the Dark River and four tributaries to the Sand River were less than 8 mg/L. Comparison of these values with those observed in the Dark and Sand Rivers indicated that the tailings basin seepage was the major sulfate contributor to these receiving waters.

4.2. Stream monitoring program

Based on the stream survey, previous data, present USX sampling, and the amenability of sites to flow gaging, five stations were selected for more extensive water quality sampling and discharge gaging by the DNR. On the Dark River stations were established at County Road (CR) 668, CR 25 and Forest Road (FR) 271. These sites are 6.6, 9.6, and 21.6 km, respectively, downstream from the western tailings basin seepage.

The Dark River at CR 668 was quite swampy and, due to the slow velocity, discharge could not be gaged. The water was deep, approximately 1.6 m in June 1987. At CR 25 the river passed through two concrete box culverts. Although the current at this station was not strong, discharge was measureable. The channel width at the culvert was 5.7 m (??), and on one occasion in June 1987 the average water depth was about 0.5 m. The stream at FR 271 was shallow and the current relatively fast. This site was conducive to gaging, and had been gaged previously by the USGS. USX presently gages at this site.

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On the Sand River stations were established at TH 53 and CR 303, which are located 8.3 and 14.7 km, respectively, downstream from the tailings basin perimeter. At TH 53 the channel was fairly deep and, due to the large cross-sectional channel area, the velocity of flow was slow, lending to error at low flows. In contrast, the channel at CR 303 was more conducive to gaging since the river bottom was firm and the water was shallow, yielding comparatively high velocities at low flows. The channel width on one occasion in June 1987 was 12 m and the average water depth was 0.21 m.

Since July 16, 1987, at an interval of two to four weeks, these stations have been sampled for sulfate concentration and specific conductance and, where feasible, gaged for flow (appendix 3). Since USX also samples and gages on the Dark and Sand Rivers a schedule was established for the DNR and USX to sample on alternate weeks, thereby optimizing data collection.

4.3. Methods

Flow was measured using a Pygmy meter and methods described by Buchanan and Somers (1969). Specific conductance was measured using a Myron L conductivity meter and sulfate was analyzed using the barium sulfate turbidimetric technique (APHA et al., 1975).

4.4. Results and Discussion

Since June 1987, sulfate concentrations on the Dark River at CR 25 averaged 220 mg/L, ranging from 93 to 280 mg/L. The concentrations were low in June and typically remained between 250 and 280 mg/L subsequently (figure 2). The maximum values were observed in January 1988. The average flow was 140 L/s, with a range of 33 to 250 L/s. Flow was lowest in July and highest in September. Over the period of record the average sulfate flux was 33 g/s (8.2 to 70 g/s, n=11). The maximum value was observed in September.

Downstream at FR 271, where data collection began in August 1987, sulfate concentrations were lower. The average concentration was 100 mg/L, with a range of 57 to 150 mg/L. Concentrations were lowest in August and September and gradually increased to their maximum values in January. The decrease in

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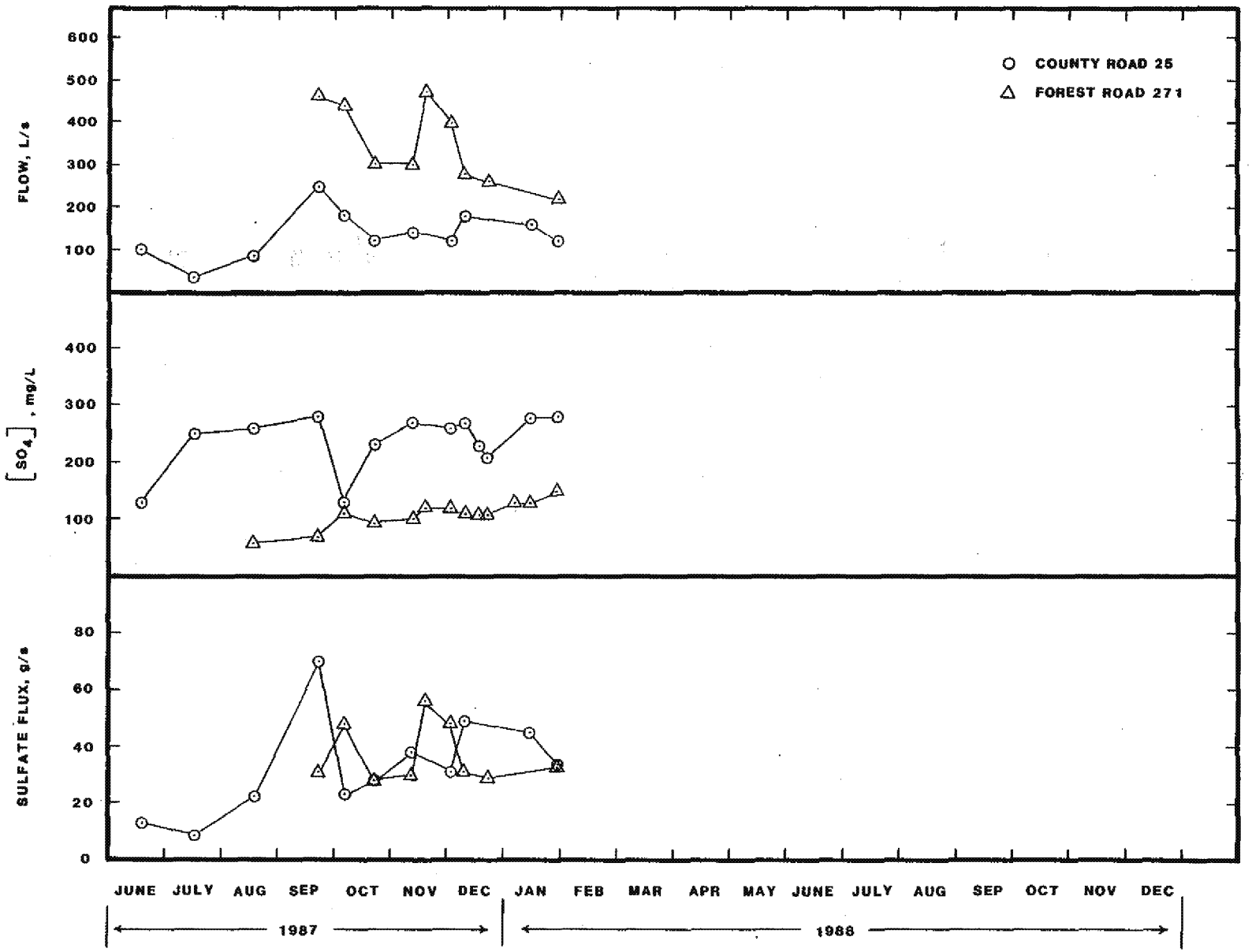

Figure 2. Flow, sulfate concentration and flux on the Dark River.

concentration, relative to the CR 25 site, was due to dilution over the 12 km stretch of stream, as indicated by an average flow of 330 L/s. The sulfate flux averaged 37 g/s (29 to 56 g/s, n=9) for the period of 22 September 1987 to 29 January 1988. The flux was highest from the middle of November through the beginning of December.

From 1981 through 1985, discharge was measured at FR 271 while sulfate was sampled at CR 668. In order to estimate the sulfate flux for this period, both discharge and sulfate concentration are required at one site. In December 1987 sampling of sulfate at CR 668 was begun to determine a ratio of discharge at CR 668 to that at FR 271. The ratio will be determined based on the assumption that the sulfate flux at the two sites is equal. Using this ratio, the flow at CR 668 can be estimated based on data from FR 271, then multiplied by the existing sulfate concentrations to determine the sulfate flux.

Area ratio not used.

On the Sand River at TH 53, sulfate concentrations from June 1987 to January 1988 averaged 170 mg/L (63 to 370 mg/L, n=13). Concentrations were low in the summer and increased to maximum values in January (figure 3). The average discharge was 140 L/s, ranging from 110 to 230 L/s. The water was deep and the current slow at this site and, consequently, discharge measurements were prone to error. The situation improved somewhat when a beaver dam, approximately 30 m downstream of the site, was removed on 18 December 1987. The sulfate flux averaged 29 g/s, with a range of 13 to 63 g/s (n=7). The maximum flux occurred in January 1988, but no consistent temporal trends were observed.

An additional 6.4 km downstream at CR 303 the average sulfate concentration was 130 mg/L (43 to 350 mg/L, n=11). Concentrations were low in the summer and increased to maximum values in January. Concentrations were lower than those observed at TH 53 due to additional dilution, as indicated by an average flow of 270 L/s (130 to 630 L/s, n=10). The sulfate flux averaged 32 g/s (8.6 to 63 g/s, n=10). The flux values tended to be low in June and July, and the maximum occurred in January.

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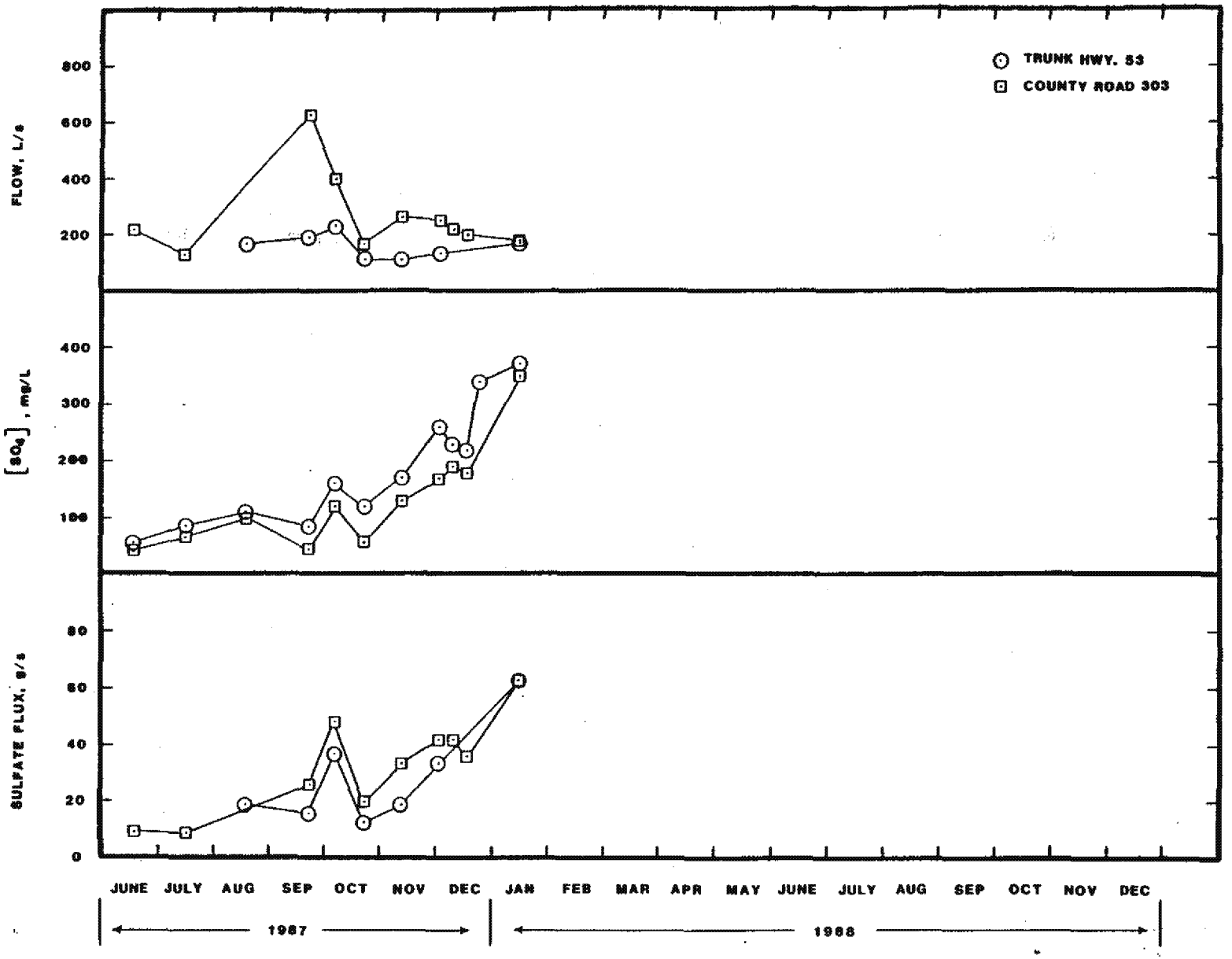

Figure 3. Flow, sulfate concentration and flux on the Sand River.

A t-test was conducted on the paired sites on both rivers. It was not possible to reject the null hypothesis in either case (H_0: The mean sulfate concentration at the upstream station equals the mean sulfate concentration at the downstream station, $p = 0.05$, 95% confidence interval.) The agreement in flux values between the paired sites of individual streams suggests that sulfate was conserved and that the tailings basin was the major sulfate source. The agreement also indicates that the technique used provides fairly accurate quantification of sulfate flux.

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APPENDIX 1

PREOPERATIONAL DATA ON THE DARK AND SAND RIVERS

Table A1.1. Pre-operational sulfate concentration and specific conductance in Dark River at Forest Road 271 (by USGS).

Date	SO_4 mg/L	S.C. uS	Q L/s
09/28/55	7.5	74	790
09/26/57	12	77	710
04/18/58	9.3	78	680
10/02/58	7.3	70	790
06/04/59	7.8	57	1500
09/05/59	8.5	55	2700
08/10/60	6.5	61	1100
05/11/61	6.5	68	2200
10/18/72	14	130	620
Ave.	8.8	74	1200

Table A1.2. Pre-operational sulfate concentration and specific conductance in Sand River at Trunk Highway 53 (by USGS).

Date	SO_4	S.C.	Q
04/26/58	7.5	43	340
05/21/58	7.8	47	310
06/25/58	9.5	38	620
06/04/59	8.3	37	---
08/04/59	9.5	--	88
08/26/59	10	57	510
09/04/59	12	41	8900
07/06/60	11	43	240
07/28/60	---	41	760
08/10/60	9.3	44	---
09/30/60	7.8	--	---
10/29/60	9.3	--	120
11/16/60	7.3	39	250
12/22/60	10	120	24
01/23/61	5.5	120	10
02/21/61	2.0	110	15
05/11/61	6.0	37	1200
05/23/61	---	39	1700
06/21/61	7.3	--	140
07/17/61	1.8	--	37
08/14/61	2.8	--	11
09/13/61	26	76	650
Ave.	7.6[1]	57	840

SO_4: sulfate concentration (mg/L)

S.C.: specific conductance (microsiemens)
Q: instantaneous discharge (L/s)

Note: --- indicates that no figure was available for this date.

[1]9/13/61 data omitted from average.

17.4 mi downstream of

Table A1.3. Preoperational water quality ~~at~~ the confluence of the Sand and Pike Rivers near Embarrass.

Date	Flow CFS	Sulfate mg/L	Sp. Conductance uS/cm
04/18/58	87	11	56
10/01/58	60	11	65
06/03/59	258	10	47
09/03/59	258	16	57
08/09/60	46	11	60
05/11/61	229	13	53
05/23/62	430	11	51
09/26/62	26	11	84

APPENDIX 2

STREAM SURVEY OF THE

SAND AND DARK RIVERS AND THEIR TRIBUTARIES

RECONNAISSANCE OF POTENTIAL GAGING SITES ALONG STREAMS
RECEIVING SEEPAGE FROM THE USX TAILING BASIN, 6/18/87

usx6/18,KIM

Sand River sites in the Little Sandy/Sandy Lake area were accessed along a U.S. Forest Service road. The inflow to Little Sandy Lake was monitored at the second bridge upstream from the lake. The specific conductance and sulfate concentration were 800 uS and 250 mg/L, respectively, and the flow was 0.059 m^3/s. The flow occurred largely along the right side of the channel, which was 4.5 m wide and averaged 0.45 m deep.

At the bridge between the two lakes specific conductance and sulfate concentrations were 485 uS and 170 mg/L, respectively. The flow velocity between the two lakes was below the detection limit of the flow meter, due to the combination of low flow and large cross sectional area of the channel. This area was calculated as about 17 m^2, based on a width of 18.5 m and an average depth of 0.9 m.

A tributary (Tributary 1) entered the northeast end of Sandy Lake but it was not sampled until 25 June. Near the headwaters of the tributary, the water was impounded by a beaver dam. Below this dam are the remains of a man-made dam and, further downstream, are several debris dams. The specific conductance of water ponded by one of these debris dams was 115 uS, while that of water flowing into this ponded area was 135 uS. The sulfate concentration of both samples was 2 mg/L. The water was roughly five to ten centimeters deep and about 30 centimeters wide. The channel was 2 to 4 meters wide, and the channel banks were about 0.15 to 0.6 m high.

About three kilometers downstream from Tributary 1 and one kilometer upstream of Trunk Highway 53, a tributary (Tributary 2) entered the Sandy River from the south. This stream was the confluence of two smaller streams which were sampled from Trunk Highway 53. The specific conductance and sulfate values in the northern drainage (Tributary 2.2) were 112 uS and 2 mg/L, while the southern drainage (Tributary 2.1) values were 130 uS and 6 mg/L.

In the Sand River at Trunk Highway 53, the specific conductance was 270 uS, as it was slightly further downstream at County Road 302. The sulfate concentrations at these two sites were 56 and 55 mg/L, respectively. Flow was gaged at 0.031 m^3/s at County Road 302 but this value was subject to considerable error. The flow velocity was measurable only near the water surface where the wind may have affected the readings. Measuring low flows at either Trunk Highway 53 or County Road 302 would be difficult due to the large cross sectional areas of the channels at these points. At County Road 302 the cross sectional area of flow was 3.4 m^2, based on a 9.4 m width and an average water depth of 0.36 m.

Roughly three km downstream from this area, the Britt Creek tributary (Tributary 3) enters the Sand River. The specific conductance and sulfate in this creek were 57 uS and 1 mg/L, respectively.

About 1.6 km downstream of the tributary, the Sand River passed through two concrete culverts under County Road 805, where the specific conductance and sulfate were 235 uS and 50 mg/L, respectively. The water depth was 0.58 m in the north culvert and 0.51 m in the south culvert. The culverts were 1.5 to 1.6 m high with an inside throat width of 3.65 m. They would be difficult to gage since the culvert walls would obstruct a wading rod near the edges.

Slightly more than one kilometer downstream from County Road 805, Sandy River received flow from an unnamed tributary (Tributary 4). At the intersection of County Road 303 and 307 the specific conductance and sulfate concentration of this flow were 52 uS and 1 mg/L.

Less than a kilometer further downstream the flow passed under a bridge on County Road 303. The specific conductance and sulfate concentration were 210 uS and 43 mg/L, respectively, and the flow was gaged as 0.219 m^3/s. This site was conducive to flow gaging since the river bottom was firm and the water was shallow, yielding a relatively high velocity at low flows. The channel width was 12 m and the average water depth was 0.21 m, yielding a cross-sectional area of 2.53 m^2.

The Dark River was sampled about 4 km west of the northwest corner of the tailings basin at County Road 668. The specific conductance and sulfate concentration at this site were 950 uS and 306 mg/L. Flow was not gaged since the water was quite deep and the area was generally swampy. During a visit to this site on 5 June 1987, the depth of water was measured as roughly 1.6 m. The site is not conducive to flow gaging.

A tributary entered the river about one to two kilometers downstream. The specific conductance and sulfate concentration at this site were 70 uS and 2 mg/L. These values were measured downstream of a culvert under an east-west county road between County Roads 668 and 25.

About one mile downstream of this tributary the river passed under County Road 25 through two large (about 2.3 m high) concrete box culverts. The specific conductance at this site was 450 uS and the sulfate concentration was 130 mg/L. discharge was gaged as 0.10 m^3/s. The site seemed to be adequate for flow gaging, with the exception of possible backwater at high flow due to a bend about 20 m downstream of the bridge. The total channel width was 5.7 m with an average water depth of 0.50 m, yielding a cross sectional flow area of 2.83 m^2.

USX Stream Sampling: 16 July 1987

Buddy Campbell, Bob Leibfried, Amy Loiselle, and Kim Lapakko sampled the Sand River and Dark River, as well as relevant tributaries on 16 July 1987. The sites sampled and the parameters analyzed were similar to those on 18 June 1987. Discharge of the Sand River was gaged at County Road 303 and that of the Dark River at County Road 25. In addition to sampling, the section of the Sand River between Sandy Lake and T.H. 53 was traversed by canoe.

The flow in the Sand River at County Road 303 was 0.127 m^3/s as compared to 0.219 m^3/s in June. Two lines of rocks, apparently hand placed, crossed the channel on either side of the bridge. In June the flow was gaged a few feet downstream of the downstream line of rocks. This line of rocks caused alternating areas of low and high velocity by restricting flow to the spaces between the rocks. To eliminate this undesirable feature, the downstream line of rocks was removed, and a more consistent flow was attained. Although the water was shallow (average depth over the 9.3 m width was 0.16 m this gaging) and there was some unquantifiably low flow along the right edge of water, adequate gaging will be possible during both low and high flows. Precipitation at --- during the previous two weeks was --- cm.

The site at County Road 303 is the best Sand River gaging site downstream of Sandy Lake and upstream of the confluence with the Pike River (check RR bridge and T.H. 169). Reconnaissance of the stretch between Sandy Lake and T.H. 53 revealed no desirable flow gaging sites. In addition to the difficult access to this area, the channel bed was often soft and mushy, and the low swampy area through which the river flows does not confine the stream at high flows. The double culvert under County Road 805 was examined again and the inadequacy of the site for gaging was confirmed. Due to the relatively large cross-sectional channel area, the flow velocity was below the sensitivity level of the Pygmy meter.

As was the case in June, specific conductance and sulfate concentrations in the Sand River decreased with distance downstream, but the levels were 25 to 60 percent higher than during the previous visit. For the Sand River system, the sulfate increased from 250 to 310 mg/L at the inlet to Little Sandy Lake and from 43 to 68 mg/L at County Road 303.

The sulfate concentrations in the tributaries ranged from 2 to 6 mg/L with the exception of apparent backwater areas of Tributaries 1 and 2. A sulfate concentration of 18 mg/L was observed at Tributary 1 but a value of 2 mg/L for a previous sampling seemed more realistic. A value of 70 mg/L was determined for a sample taken about 100 m upstream on Tributary 2. This was most likely due to backwater from the Sand River since upstream values for this tributary were measured in the range of 4 to 6 mg/L later this day and on the 18 June sampling.

Upon examination of the area around Tributary 4, two more tributaries were discovered. The combined flow from the new tributaries and Tributary 4 was sampled downstream from their confluence. The specific conductance was 88 uS and the sulfate concentration 4 mg/L.

The specific conductance in the Dark River at County Road 25 was 750 uS, as compared with 450 uS in June. The discharge at this site was 0.033 m^3/s as compared with 0.1 m^3/s on the previous visit. There was probably considerable error in the flow measurement since the velocity was low and often below the detection limit of the Pygmy current meter. The cross-sectional area of flow at this site was 3.1 m^2 based on a width of 6.9 m and an average depth of 0.45 m. The site should be adequate for gaging at moderate and high flows.

Table A2.1. Sulfate and specific conductance survey on the Dark River

Sulfate concentration (mg/L)

Date	Trib.	CR25	Outlet	FR65	FR271	FR111	Sturgeon
03/04/87	---	---	---	150	---	73	---
06/18/87	2.0	130	---	---	---	---	---
07/16/87	1.5	250	---	---	---	---	---
08/18/87	1.5	260	120	98	57	---	1.5

Specific conductance (uS)

Date	Trib.	CR25	Outlet	FR65	FR271	FR111	Sturgeon
03/04/87	---	---	---	460	---	315	---
06/18/87	70	450	---	---	---	---	---
07/16/87	75	750	---	---	---	---	---
08/18/87	73	750	400	370	250	---	108

Trib.: Tributary to Dark River
CR25: Dark River at County Road 25
Outlet: Outlet from Dark Lake
FR65: Dark River at Forest Road 65
FR271: Dark River at Forest Road 271
FR111: Dark River at Forest Road 111
Sturgeon: Sturgeon River

Note: --- indicates that no sample was taken on this date

Table A2.2. Sulfate and specific conductance survey data on the Sand River. usxstatapp2,USX

Sulfate concentration (mg/L)

Date	I.B.	B.B.L.	TH53	CR302	CR805	CR303	TH169
03/04/87	350	---	250	---	---	230	150
06/05/87	---	140	63	---	---	---	---
06/18/87	250	170	57	55	50	43	---
07/16/87	310	250	84	---	74	68	---

Specific conductance (uS)

Date	I.B.	B.B.L.	TH53	CR302	CR805	CR303	TH169
03/04/87	---	---	850	---	---	750	750
06/05/87	---	410	250	---	---	---	---
06/18/87	800	490	270	270	240	210	---
07/16/87	990	750	350	---	330	320	---

I.B.: Inlet bridge to Little Sandy Lake
B.B.L.: Bridge between Little Sandy Lake & Sandy Lake
TH53: Sand River at Trunk Highway 53
CR302: Sand River at County Road 302
CR805: " " " " " 805
CR303: " " " " " 303
TH169: " " " Trunk Highway 169

note: --- indicates that no sample was taken on this date

Table A2.2. Sulfate concentration and specific conductance in Sand River tributaries.

	06/18/87		06/25/87		07/16/87	
	SO_4 (mg/L)	S.C. (uS)	SO_4 (mg/L)	S.C. (uS)	SO_4 (mg/L)	S.C. (uS)
Tributary 1						
Mouth	---	---	2.0	135	130	400
Upstream	---	---	2.0	115	18	160
Tributary 2						
Mouth	---	---	---	---	80	345
Upstream 100m	---	---	---	---	70	320
From impoundment	---	---	---	---	4.5	110
Trib 2.2	2.3	112	---	---	5.3	350
Trib 2.1	6.5	130	---	---	5.5	122
Trib 3 (Britt Creek)	1.0	57	---	---	1.5	---
Trib 4						
Confluence	---	---	3.5	88	---	---
C.R.303	---	---	6.5	92	---	---
C.R.303 + 307	1.0	52	---	---	2.3	80

APPENDIX 3

OPERATIONAL PHASE FLOW AND WATER QUALITY IN THE DARK AND SAND RIVERS

usxtab2, USX

Table A3.1. Operational phase sulfate concentration, specific conductance and flow in Dark River.

Date	By	COUNTY ROAD 668			COUNTY ROAD 25			FOREST ROAD 271	
		SO_4 (mg/L)	S.C. (uS)	Q (L/s)	SO_4 (mg/L)	S.C. (uS)	Q (L/s)	SO_4 (mg/L)	S.C. (uS)
09/25/81	U	135	700		---	---	230	---	---
12/21/81	U	340	760		---	---	450	---	---
04/30/82	U	86	235		---	---	1700	---	---
07/29/82	U	73	320		---	---	480	---	---
10/21/82	U	93	250		---	---	1200	---	---
05/12/83	U	120	290		---	---	760	---	---
07/26/83	U	30	290		---	---	400	---	---
11/01/83	U	80	210		---	--	590	---	---
06/22/84	U	47	220		---	---	1100	---	---
10/22/84	U	120	270		---	---	1600	---	---
05/21/85	U	96	190		---	---	1500	---	---
08/27/85	U	220	730		---	---	420	---	---
11/08/85	U	210	880		---	---	---	---	---
03/04/87	D	440	1200		---	---	---	---	---
06/05/87	D	---	---		93	330	---	---	---
06/18/87	D	310	950	100	130	450	---	---	---
07/16/87	D	---	---	33	250	750	---	---	---
08/18/87	D	---	---	85	260	750	---	57	250
09/22/87	D	---	---	250	280	790	460	68	265
10/06/87	D	---	---	180	130	400	440	110	365
10/22/87	D	---	---	120	230	880	300	93	330
11/12/87	D	---	---	140	270	790	300	100	345
11/19/87	U	---	---	---	---	---	470	120	340
12/02/87	D	---	---	120	260	640	400	120	360

12/09/87	D	430	1220	---	---	---	---	---	---
12/10/87	D	---	---	180	270	690	280	110	340
12/17/87	D	400	1200	(0.605)[1]	230	710	(0.53)	110	410
12/22/87	D, U	420	1280	(0.61)	210	790	260	110	380
01/07/88	D	---	---	---	---	---	200	140	420
01/15/88	D	490	1400	160	280	900	---	130	420
01/21/88	U	---	---	---	---	---	380	120	430
01/29/88	D	460	1300	120	280	920	220	150	450
02/03/88	D	---	---	---	---	---	260	130	460
02/17/88	U	---	---	---	---	---	200[2]	51	260
02/26/88	D	510	1320	---	340	1020	240	120	450
03/02/88	U	---	---	---	---	---	220	92	460
03/16/88	U	---	---	---	---	---	300	120	440
03/24/88	D	350	1100	150	250	900	270	94	460
03/30/88	U	---	---	---	---	---	280	120	470
04/07/88	D	120	440	---	120	400	1740	86	320
04/13/88	U	---	---	---	---	---	2140	82	320
04/15/88	D	160	480	790	82	300	1390	90	290
04/22/88	D	260	820	290	110	440	620	110	420

DATA CHECKED THROUGH 4/22. K.L.(5/20)

Note: --- indicates that no sample was obtained on this date
[1]Values in parentheses are gage heights in meters.
[2]Problems with counter on flow meter.

Table A3.2. Operational phase sulfate concentration (mg/L), flow (L/s) and specific conductance (uS) in Sand River.

		Trunk Hwy. 53			County Road 303		
Date	BY	Q	SO_4	S.C.	Q	SO_4	S.C.
09/25/81	U	---	64	350	---	---	---
12/21/81	U	---	190	455	---	---	---
04/30/82	U	---	43	130	---	---	---
07/29/82	U	---	72	245	---	---	---
10/21/82	U	---	57	200	---	---	---
05/12/83	U	---	71	170	---	---	---
07/26/83	U	---	77	310	---	---	---
11/01/83	U	---	83	230	---	---	---
06/22/84	U	---	74	130	---	---	---
10/22/84	U	---	110	210	---	---	---
05/21/85	U	---	40	130	---	---	---
08/27/85	U	---	44	270	---	---	---
11/08/85	U	---	41	520	---	---	---
03/04/87	D	---	250	850	---	230	750
06/05/87	D	---	63	250	---	---	---
06/18/87	D	---	57	270	220	43	210
07/16/87	D	---	84	350	130	68	320
08/18/87	D	170	110	410	---	100	360
09/22/87	D	190	83	370	630	43	230
10/06/87	D	230	160	550	400	120	430
10/22/87	D	110	120	440	170	58	250
11/12/87	D	110	170	650	260	130	550
12/02/87	D	130	260	690	250	170	590
12/10/87	D	---[1]	230	770	220	190	630
12/17/87	D	---	220	810	200	180	750
12/22/87[2]	U	170	340	1000	200	---	---
01/15/88	D	170	370	1100	180	350	1000
01/21/88	U	96	370	1100	---	---	---
02/17/88	D	170	370	1200	150	340	1200
02/17/88	U	150[3]	220	720	---	---	---
03/02/88	U	120	350	1100	---	---	---
03/10/88	D	140	340	1100	140	320	1000
03/16/88	U	---	340	1000	---	---	---
03/30/88	U	---	340	1000	---	---	---
04/07/88	D	---	110	400	950	70	250

04/14/88	U	1100	75	280	---	---	---
04/15/88	D	1200	80	250	2300	48	140
04/22/88	D	600	84	290	990	65	220

**DATA CHECKED THROUGH 4/22. K.L. (5/20)

U,D: sampled by USS or DNR, respectively

Note: --- indicates that no sample was taken on this date

[1]Velocity too slow to gage.
[2]Beaver dam removed 12/18/87, approximately 30m downstream from TH 53 site.
[3]Trouble with counter on flow meter.

APPENDIX 4

OPERATIONAL PHASE SULFATE FLUX IN THE DARK AND SAND RIVERS

Table A4.1. Sulfate flux in Dark River. usxfluxdark,USX

Date	By	COUNTY ROAD 668			COUNTY ROAD 25			FOREST ROAD 271		
		Q L/s[1]	SO_4 (mg/L)	F g/s[2]	Q L/s	SO_4 mg/L	F g/s[2]	Q L/s	SO_4 mg/L	F g/s[2]
09/25/81	U	120	135	16		---	---	230	---	---
12/21/81	U	230	340	78		---	---	450	---	---
04/30/82	U	880	86	76		---	---	1700	---	---
07/29/82	U	250	73	18		---	---	480	---	---
10/21/82	U	590	93	55		---	---	1200	---	---
05/12/83	U	390	120	47		---	---	760	---	---
07/26/83	U	200	30	6		---	---	400	---	---
11/01/83	U	300	80	24		---	---	590	---	---
06/22/84	U	570	47	27		---	---	1100	---	---
10/22/84	U	830	120	100		---	---	1600	---	---
05/21/85	U	750	96	72		---	---	1500	---	---
08/27/85	U	220	220	48		---	---	420	---	---
11/08/85	U	---	210	---		---	---	---	---	---
03/04/87	D	---	440	---		---	---	---	---	---
06/05/87	D	---	---	---		93	---	---	---	---
06/18/87	D	---	310	---	100	130	13	---	---	---
07/16/87	D	---	---	---	33	250	8.2	---	---	---
08/18/87	D	---	---	---	85	260	22	---	57	---
09/22/87	D	---	---	---	250	280	70	460	68	31
10/06/87	D	---	---	---	180	130	23	440	110	48
10/22/87	D	---	---	---	120	230	28	300	93	28
11/12/87	D	---	---	---	140	270	38	300	100	30
11/19/87	U	---	---	---	---	---	---	470[3]	120	56
12/02/87	D	---	---	---	120	260	31	400	120	48
12/09/87	D	---	430	---	---	---	---	---	---	---

12/10/87	D	---	---	---	180	270	49	280	110	31
12/17/87	D	---	400	---	---	230	---	---	110	---
12/22/87	D, U	---	420	---	---	210	---	260	110	29
01/07/88	D	---	---	---	---	---	---	200	140	28
01/15/88	D	---	490	---	160	280	45	---	130	---
01/21/88	U	---	---	---	---	---	---	380	120	46
01/29/88	D	---	460	---	120	280	34	220	150	33
02/03/88	D	---	---	---	---	---	---	260	130	34
02/17/88	U	---	---	---	---	---	---	200[4]	51	10
02/26/88	D	---	510	---	130	340	44	240	120	29
03/02/88	U	---	---	---	---	---	---	220	92	20
03/16/88	U	---	---	---	---	---	---	300	120	36
03/24/88	D	---	350	---	150	250	38	270	94	25
03/30/88	U	---	---	---	---	---	---	280	120	34
04/07/88	D	---	120	---	---	120	---	1740	86	150
04/13/88	U	---	---	---	---	---	---	2140	82	180
04/15/88	D	---	160	---	790	82	65	1390	90	130
04/22/88	D	---	260	---	290	110	32	620	110	68

**DATA CHECKED THROUGH 4/22. K.L. (5/20)

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[1]Estimated as the ratio of watershed area CR 668 to that at FR 271 (21/41) times flow at FR 271.
[2]Sulfate flux calculated as the product of flow and sulfate concentration.
[3]USX flow was higher than that measured by the DNR at this time.
[4]Problem with counter on flow meter.
Note: --- indicates that the parameter was not analyzed on this date.

usxfluxsand,USX

Table A4.2. Operational phase sulfate flux in Sand River.

Date	BY	Trunk Hwy. 53 Q L/s	Trunk Hwy. 53 SO_4 mg/L	Trunk Hwy. 53 F g/s[1]	County Road 303 Q L/s	County Road 303 SO_4 mg/L	County Road 303 F g/s[1]
09/25/81	U	---	64	---	---	---	---
12/21/81	U	---	190	---	---	---	---
04/30/82	U	---	43	---	---	---	---
07/29/82	U	---	72	---	---	---	---
10/21/82	U	---	57	---	---	---	---
05/12/83	U	---	71	---	---	---	---
07/26/83	U	---	77	---	---	---	---
11/01/83	U	---	83	---	---	---	---
06/22/84	U	---	74	---	---	---	---
10/22/84	U	---	110	---	---	---	---
05/21/85	U	---	40	---	---	---	---
08/27/85	U	---	44	---	---	---	---
11/08/85	U	---	41	---	---	---	---
03/04/87	D	---	250	---	---	230	---
06/05/87	D	---	63	---	---	---	---
06/18/87	D	---	57	---	220	43	9.5
07/16/87	D	---	84	---	130	68	8.6
08/18/87	D	170	110	19	---	100	---
09/22/87	D	190	83	16	630	43	26
10/06/87	D	230	160	37	400	120	48
10/22/87	D	110	120	13	170	58	10
11/12/87	D	110	170	19	260	130	34
12/02/87	D	130	260	34	250	170	42
12/10/87	D	---[2]	230	---	220	190	42
12/17/87	D	---	220	---	200	180	36
12/22/87[3]	U	170	340	58	200	---	---
01/15/88	D	170	370	63	180	350	63
01/21/88	U	96	370	36	---	---	---
02/17/88	D	170	370	63	150	340	51
02/17/88	U	150[4]	220	33	---	---	---
03/02/88	U	120	350	42	---	---	---
03/10/88	D	140	340	48	140	320	45
04/07/88	D	---	110	---	950	70	66
04/14/88	U	1100	75	82	---	---	---
04/15/88	D	1200	80	96	2300	48	110
04/22/88	D	600	84	50	990	65	64

DATA CORRECTED 5/20/88. K.L.

[1]Sulfate flux calculated as the product of flow and sulfate concentration.
[2]U,D: sampled by USS or DNR, respectively.
[3]Velocity too slow to gage.
[4]Beaver dam removed on 12/18/87, approximately 30 m downstream from TH 53.

Note: --- indicates that no sample was taken on this date.

usxfluxsand,USX

Table A4.3. Operational phase sulfate flux in Dark and Sand Rivers.

Sulfate Flux in g/s

		Dark River				Sand River		
Date	By	W Seep	CR668[1]	CR25	FR271	E Seep	TH53	CR303
09/25/81	U	---	16	---	---	---	---	---
12/21/81	U	---	78	---	---	---	---	---
04/30/82	U	---	76	---	---	---	---	---
07/29/82	U	---	18	---	---	---	---	---
10/21/82	U	---	55	---	---	---	---	---
05/12/83	U	---	47	---	---	---	---	---
07/26/83	U	---	6	---	---	---	---	---
11/01/83	U	---	24	---	---	---	---	---
06/22/84	U	---	27	---	---	---	---	---
10/22/84	U	---	100	---	---	---	---	---
11/13/84	U	3.0	---	---	---	2.2	---	---
05/21/85	U	---	72	---	---	---	---	---
08/27/85	U	---	48	---	---	---	---	---
11/08/85	U	---	---	---	---	---	---	---
05/01/86		2.4	---	---	---	4.5	---	---
10/20/86		10	---	---	---	16	---	---
03/04/87	D	---	---	---	---	---	---	---
06/03/87		15	---	---	---	17	---	---
06/05/87	D	---	---	---	---	---	---	---
06/18/87	D	---	---	13	---	---	---	9.5
07/16/87	D	---	---	8.2	---	---	---	8.8
08/18/87	D	---	---	22	---	---	19	---
09/22/87	D	---	---	70	31	---	16	27
10/06/87	D	---	---	23	48	---	37	48
10/22/87	D	---	---	28	28	---	13	10
11/12/87	D	---	---	38	30	---	19	34
11/19/87	U	---	---	---	56	---	---	---
12/02/87	D	---	---	31	48	---	34	42
12/10/87	D	---	---	49	31	---	---	42
12/17/87	D	---	---	---	---	---	---	36
12/22/87	D	---	---	---	29	---	58	---
01/07/88	D,U	---	---	---	28	---	---	---
01/15/88	D	---	---	45	---	---	63	63
01/21/88	U	---	---	---	46	---	36	---
01/29/88	D	---	---	34	33	---	---	---

02/03/88	D	---	---	---	34	---	---	---
02/17/88	D	---	---	---	10	---	63	51
02/17/88	U	---	---	---	---	---	33[5]	---
02/26/88	D	---	---	44	29	---	---	---
03/02/88	U	---	---	---	20	---	42	---
03/10/88	D	---	---	---	---	---	48	45
03/16/88	U	---	---	---	36	---	---	---
03/24/88	D	---	---	38	25	---	---	---
03/30/88	U	---	---	---	34	---	---	---
04/07/88	D	---	---	---	150	---	---	67
04/13/88	U	---	---	---	180	---	---	---
04/14/88	U	---	---	---	---	---	82	---
04/15/88	D	---	---	65	130	---	99	110
04/22/88	D	---	---	32	68	---	50	64

**DATA CHECKED THROUGH 4/22. K.L. (5/23/88)

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[1]Flow estimated based on flow at FR271 and the ratio of watershed areas.
Sulfate flux calculated as the product of flow and sulfate concentration.
Note: --- indicates that no sample was taken on this date

Table A4.4. Operational phase sulfate flux for tailings basin seepage.

Date	West Seep Q L/s	West Seep SO_4 mg/L	West Seep F g/s[1]	East Seep Q L/s	East Seep SO_4 mg/L	East Seep F g/s[1]
			Sulfate Concentrations			
10/22/84	---	400	---	---	290	---
05/21/85	---	480	---	---	410	---
08/27/85	---	490	---	---	420	---
11/8/85	---	370	---	---	280	---
05/16/87	---	670	---	---	420	---
06/10/87	---	740	---	---	400	---
07/16/87	---	430	---	---	600	---
10/14/87	---	470	---	---	430	---
			Flow and Sulfate Flux			
10/15/80[5]	22	---[2]	---	27	---[2]	---
11/13/84	7.6	400[3]	3.0	7.6	290[3]	2.2
05/01/86	4.7	510[3]	2.4	11	410[3]	4.5
10/20/86	20	510[4]	10	39	410[3]	16
06/03/87	20	740[4]	15	43	400[4]	17

[1]Sulfate flux calculated as the product of flow and sulfate concentration.
[2]Sulfate concentration from 10/22/84.
[3]Average of eight dates from 10/22/84 to 10/14/87.
[4]Sulfate concentration from 6/10/87.
[5]Dike was widened after this measurement.

Note: --- indicates that no sample was taken on this date

Changes in flux may be due to changes in sampling locations.

APPENDIX 5

T-TESTS ON PAIRED SAMPLING SITES ON THE DARK AND SAND RIVERS

Sulfate Flux Comparisons for the
Dark and Sand Rivers

Sulfate flux was compared for two locations each on the Dark and Sand Rivers. On the Dark River, county road 25 (upstream) was compared to forest road 271 (downstream) while on the Sand River trunk highway 53 (upstream) was compared to county road 303 (downstream). A complete description of these sites and the project as a whole can be found in Lapakko, et al., ~~1980~~. 1988

The statistical tool used to analyze this data was the T-Test procedure from SPSSPC+ (1986) software. The output results from this test are reproduced below. The numbers to note are the "2-Tail Prob." numbers. In each case, these numbers are greater than 0.05 which means, assuming a 95% confidence level, we can not reject the null hypothesis (H_o:The mean sulfate flux (F) at the upstream site = the mean sulfate flux at the downstream site).

It must be stressed that these numbers are preliminary and the data set is small, eg., n=8 and n=6. A more meaningful analysis of the data will be possible when a full year of information is collected that covers varying hydrological, meteorological and biological conditions.

DARK RIVER

Group 1: LOC EQ 25 Group 2: LOC EQ 271

did not remove value of 70g/s at CR 25

t-test for: F

	Number of Cases	Mean	Standard Deviation	Standard Error
Group 1	8	39.6250	14.880	5.261
Group 2	8	34.7500	8.311	2.938

over

		Pooled Variance Estimate			Separate Variance Estimate		
F Value	2-Tail Prob.	t Value	Degrees of Freedom	2-Tail Prob.	t Value	Degrees of Freedom	2-Tail Prob.
3.21	.147	.81	14	.432	.81	10.98	.436

SAND RIVER

Group 1: LOC EQ 53 Group 2: LOC EQ 303

t-test for: F

	Number of Cases	Mean	Standard Deviation	Standard Error
Group 1	6	30.3333	18.758	7.658
Group 2	6	37.1667	18.335	7.485

		Pooled Variance Estimate			Separate Variance Estimate		
F Value	2-Tail Prob.	t Value	Degrees of Freedom	2-Tail Prob.	t Value	Degrees of Freedom	2-Tail Prob.
1.05	.961	-.64	10	.538	-.64	9.99	.538