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WATER QUALITY OF THE
DUNKA RIVER

"The Characterization of a Watershed
Affected by Mining"

JUNE 1977

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DUNKA RIVER

"The Characterization of a Watershed Affected by Mining"

A Plan B Paper
Presented to
O.R. Ruschmeyer Ph.D.
University of Minnesota

Veith
Lieberman ✓

In Partial Fulfillment
of the Degree of
Master of Science

mass balances?
ion balances?
lag in conductivity change with flow change?
pumping rates & Reserve discharges?

Dan Benzie
June 1977

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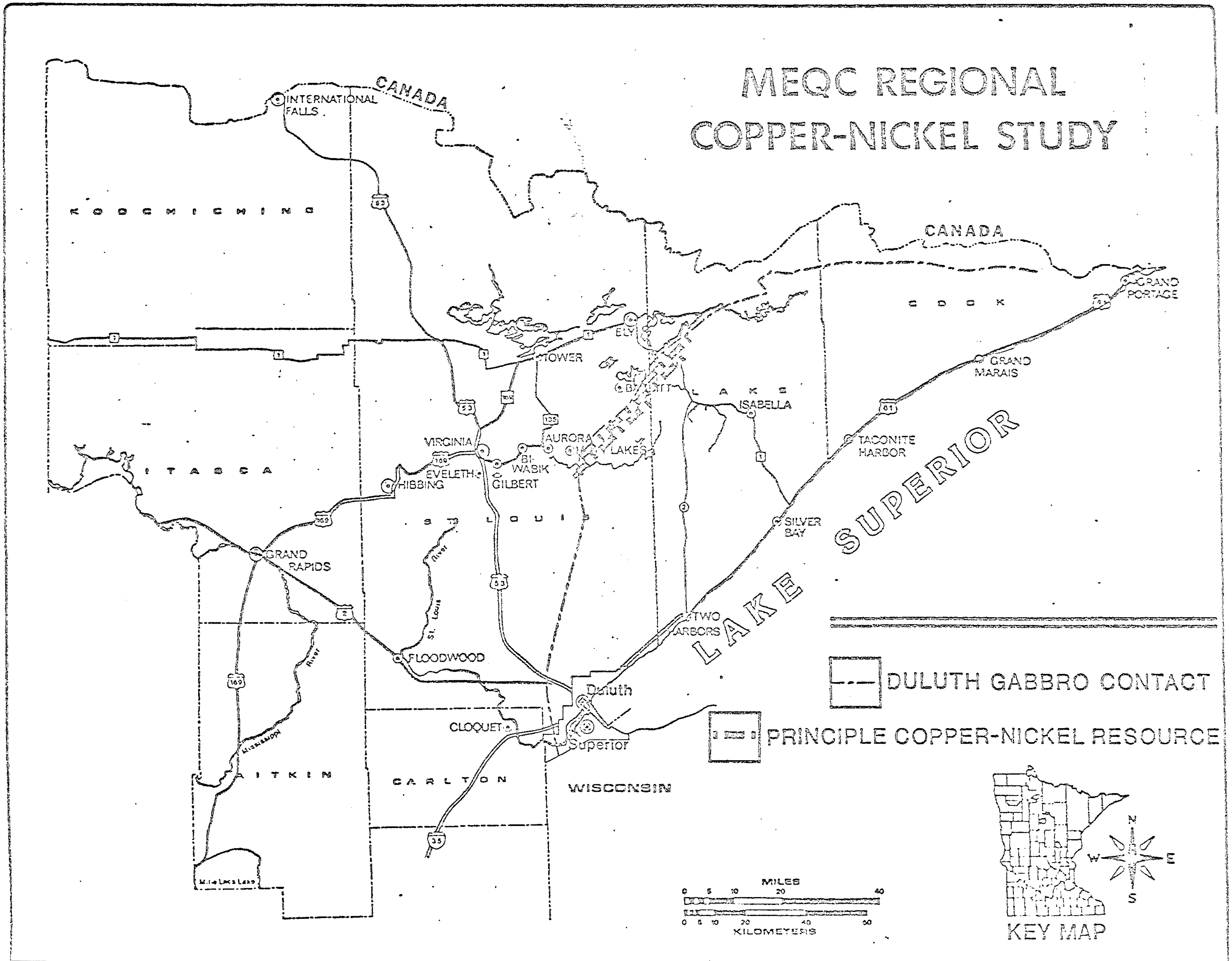
1. INTRODUCTION

A geological formation in Northern Minnesota, known as the Duluth Gabbro complex contains a significant amount of the ? countries domestic copper resources, and possibly the world's largest nickel resource (1). Copper-Nickel mining will ? probably be taking place in this area on a large scale within the next decade. (The location of the ore deposits is shown in Figure 1). This report is of some work I have been doing with the State of Minnesota Environmental Quality Council's Regional Copper-Nickel Study. The purpose of this Regional Study is to obtain baseline data for the region which will potentially be affected by mining, and too determine what affects mining may have on this area. All aspects of potential impact are being investigated. These include physical, chemical and biological monitoring of the water, terrestial and air environments as well as studies on the health, social and economic impact to the population in this area. Also included is the technical assessment of the mining methods which may be employed, and the quantity and quality of ore in the region.

The work I have done involves the characterization of a watershed in this region which has already been influenced by the mining of taconite, and will probably be directly affected by Cu-Ni mining. I have used the water analysis

Figure 1. Copper-Nickel Ore Deposits



done by the U.S. Geological Survey (USGS), the Environmental Quality Council (EQC), American Metals Climax (AMAX) and Reserve Mining Company, and have attempted to determine any impacts this watershed has recieved from the operations of the taconite mining. This type of study is necessary in obtaining baseline data for the Cu-Ni study, and in the assessment of any future impacts by the mining of Copper and Nickel within this watershed.

SUMMARY

The water quality of a watershed which has been influenced by taconite mining for 25 years has been compared with an undisturbed watershed nearby. A continuous monitor downstream from the mining operations has shown peaks in the conductivity of the river during periods of low flow. These peaks occur 2 to 3 times a week and last from 8 hours to several days. The flow pattern of the river shows peaks corresponding to the conductivity peaks, however these are evident during high flow as well as low flow. The downstream concentrations of chloride, sulfate, calcium, sodium and potassium are significantly higher than upstream, while the control watershed shows no differences in these parameters. While the mine is operating, it is necessary to pump the basins where they collect water from rainfall, runoff and groundwater seepage. They generally pump 2 to 3 days a week for

periods of 8 hours or more until the basin is empty. The mining discharges have a significantly higher conductivity than the upstream sampling sites, and also higher concentrations of chloride, sulfate, calcium, sodium and potassium. The concentrations and conductivity however, are not significantly different from the downstream monitor. It is concluded that a specific mining discharge several hundred feet from the monitor is responsible for the observed peaks. Other impacts the mining operation has on the watershed are discussed, as are the potential impacts from a Copper-Nickel mining operation.

2. BACKGROUND ON COPPER-NICKEL

2.1 History

The copper-nickel reserves in this area have been suspected for a long time, but were not accurately identified until 1953, when the U.S. Bureau of Mines completed three diamond drill holes (2). This is the method used to investigate the quality, and make estimates on the quantity of any ore in a given area. They concluded there was a significant volume of Copper-Nickel mineralization of low or marginal grade. Several years earlier, in 1951, International Nickel Company Inc. (Inco) had indicated an interest in sampling the ore for potential mining in this area. By 1967 200,000 acres of federal and state land were held by mining interests. The closeness of these operations to the Boundary Waters Canoe Area (BWCA), and the increased interests of the mining companies created a great deal of public interest, and in 1972 Governor W. Anderson appointed an Inter-Agency Copper-Nickel Task Force to review possible impacts (3). This task force included members from the Pollution Control Agency (PCA), the Minnesota Department of Natural Resources (MDNR), and public interest groups. Later in 1972 the MDNR published a report entitled, "Possible Environmental Impact of Base-Metal Mining in Minnesota". In January of 1973 they published "Inter-Agency Task Force Report on Base Metal Mining Impacts" (2). In this report they included information from USGS investigations which estimated 6.5 $X10^8$ tons of crude ore grade ? were contained within the Duluth Complex. A number of important recommendations came out of this report. They recommended that the task force continue there study, and that exploration and developement of minerals be encouraged. They also stressed the need for a pre-operational monitoring program, and a study of potential impacts of the various mining processes. These include exploration, developement, beneficiation (which includes crushing, concentrating and dewatering), pyrometallurgical extraction (which includes roasting, smelting, and converting), refining, ancillary operations and termination. They also presented a comprehensive list of possible environmental impacts which should be investigated.

The task force also recommended consideration of the economic benefits of a short-term mining operation, and whether this would exceed the long-term impact to the public, and especially those supplying services and facilities to the mines. The social risks involved with the large influx of workers including employement, land use, public services, and recreation were mentioned, and the need for post-operational monitoring was pointed out.

In August of 1974 Ronald Hayes, working with the Bureau of Mines published a report called "Environmental, Economic, and Social Impacts of Mining Copper-Nickel in Northeastern Minnesota" (1). This report estimated that the Duluth Gabbro formation had an average ore grade of 0.85 percent tonnage? Cu-Ni, and could supply the U.S. copper and the world nickel demands for 20 years. He also discussed several of the mining methods being considered, and the impacts they each may have.

In October of 1974 the EQC voted to require a regional environmental impact statement (4), and in 1975 contracts No- were obtained from the DNR to do the biological studies, and from the PCA to do the water and air studies. These agencies misleading are responsible for data collection and baseline monitoring. Two exceptions to this division of duties are; the leachate study which is being done by the DNR, and the bioassay work which is being done by the PCA. The EQC then hired its own staff, and in March of 1976 began administering the monitoring program.

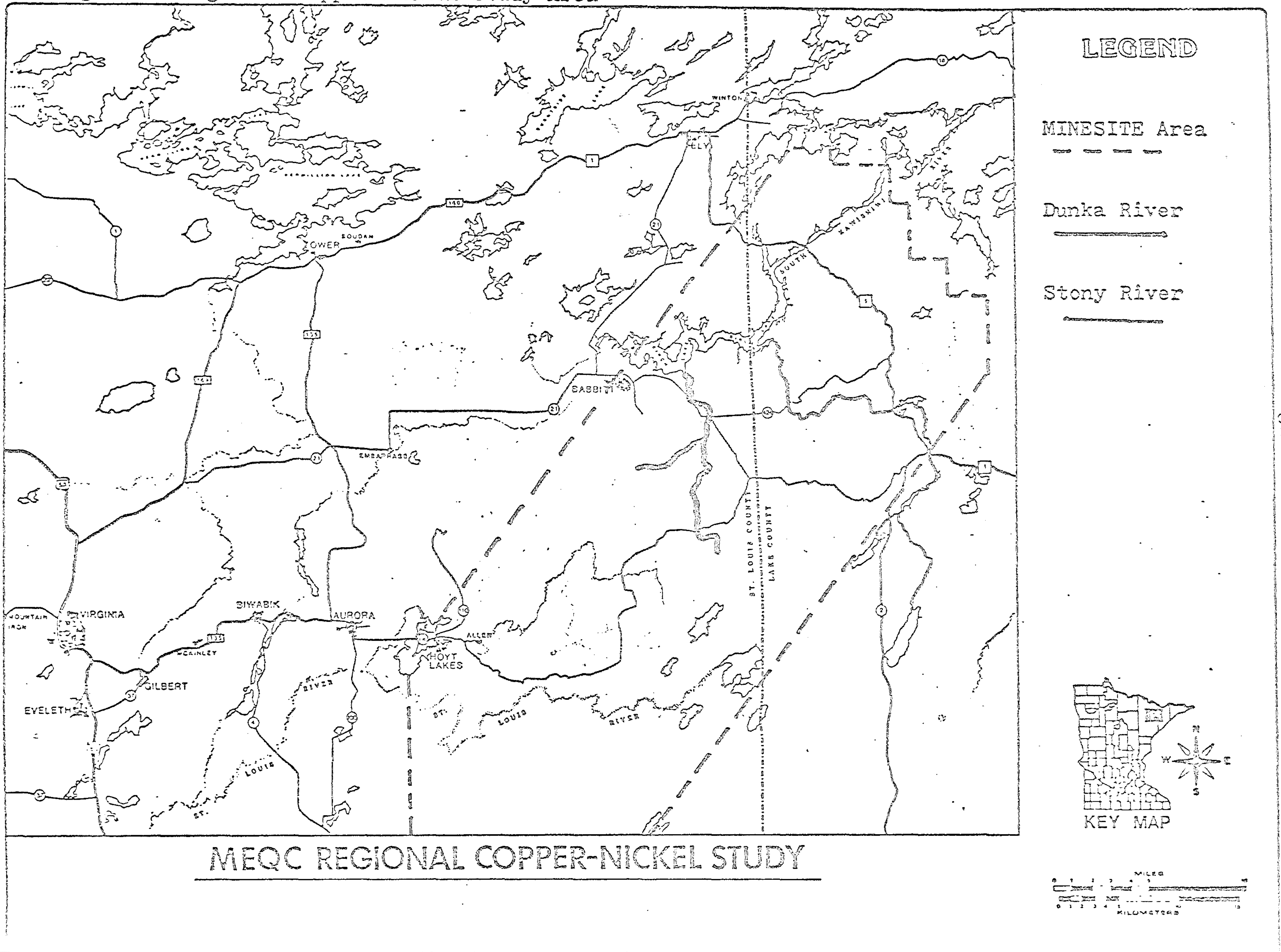
The U.S. Forest Service has also been involved in this study. When Inco applied for permits in the Superior National Forest, the Forest Service was given the responsibility for preparing impact statements (4). By May of 1975 the Forest Service discontinued their monitoring program, because agreement with Inco had not been reached.

The current input from the Forest Service is limited, and that from the PCA and DNR is only in terms of personnel. Although both agencies have a liason person to work with the Cu-Ni study, very little contact is taking place.

2.2 Regional Study

The area included in the Regional Copper-Nickel Study is shown in figure 2. The MINESITE Study area is approximately 560 square miles located in St. Louis and Lake Counties in Northeastern Minnesota. The MINESITE Project was developed by the Minnesota DNR to aid in developing environmental resource management programs (5). It is a computerized mapping project, which has become integrated within the Regional Cu-Ni study (3). The role of this regional study is that of a neutral group of experts, whom will assess any impacts that Copper-Nickel mining may have on this region,

Figure 2. Regional Copper-Nickel Study Area



and communicate these results to all interested parties (6). The geological sampling and the mine modeling is being carried out by the technological assessment group. This group is investigating the possible mining methods being considered for use in Minnesota and how the various stages of each method may alter the environment.

The physical sciences team is studying both the atmosphere and hydrosphere. These areas are further divided into; meteorology and climatology, noise, rivers, lakes, surface water and surficial hydrology and metal pathways study(7). Attempts are being made to describe the physical setting for all organisms within the study area, and to determine which areas may be most affected by copper-nickel mining.

The biological sciences are divided into aquatic and terrestrial systems. Each area is attempting to characterize all the organisms present, their relationships to one another and the environment, and how these relationships may be altered by mining. This area also includes the environmental health studies which is working closely with the State Health Department and the Epidemiology Department at the University of Minnesota. They are attempting to determine the health significance of specific elements found in the ores already sampled in Minnesota, as well as the health problems associated with other copper-nickel mines throughout the country.

The socioeconomic group is relying on information obtained from the present and expanding taconite industry, and will assess what impacts the copper-nickel mining will have on this region. The areas they are investigating include land use, community impacts, energy trends and economic effects on the people of Northeastern Minnesota. A recent publication by King and Kreisman (6) has summarized the areas which will be investigated and the objectives of this study. (See Table 1)

Table 1. Objectives of the Environmental Quality Council
Regional Copper-Nickel Study *

Objective 1. Regional Impact Assessment

STUDY SPHERE	STUDY DISCIPLINE	
Geology	bedrock geology	minerology
(Lithosphere)	surficial geology	hydrous minerals
Atmosphere	air quality	noise
	meteorology	precipitation chemistry
Water Resources	groundwater hydrology, quality	
(Hydrosphere)	surface water hydrology, quality	
Aquatic Life	decomposers	invertebrates
(Aquatic biosphere)	aquatic vegetation	fish
Terrestrial Life	soil	reptiles
(Terrestrial biosphere)	vegetation	birds
	insects	mammals
	amphibians	human health & safety
Socio-economic sphere	energy	demography
	community profiles	economics
	taxes	land use

Objective 2. Communication of Results

Governmental	Minnesota EQC	Legislature
	Legislative Committees	State Agencies
	Federal Agencies	Local/Regional Govern.
Industrial	AMAX, Erie, Inco, Reserve etc.	
Scientific	Academic - University and college researchers	
	Agency Scientists, and Private companies	
Environmental	Cu-Ni coalition, MPIRG etc.	
Public	General Public and News Media	

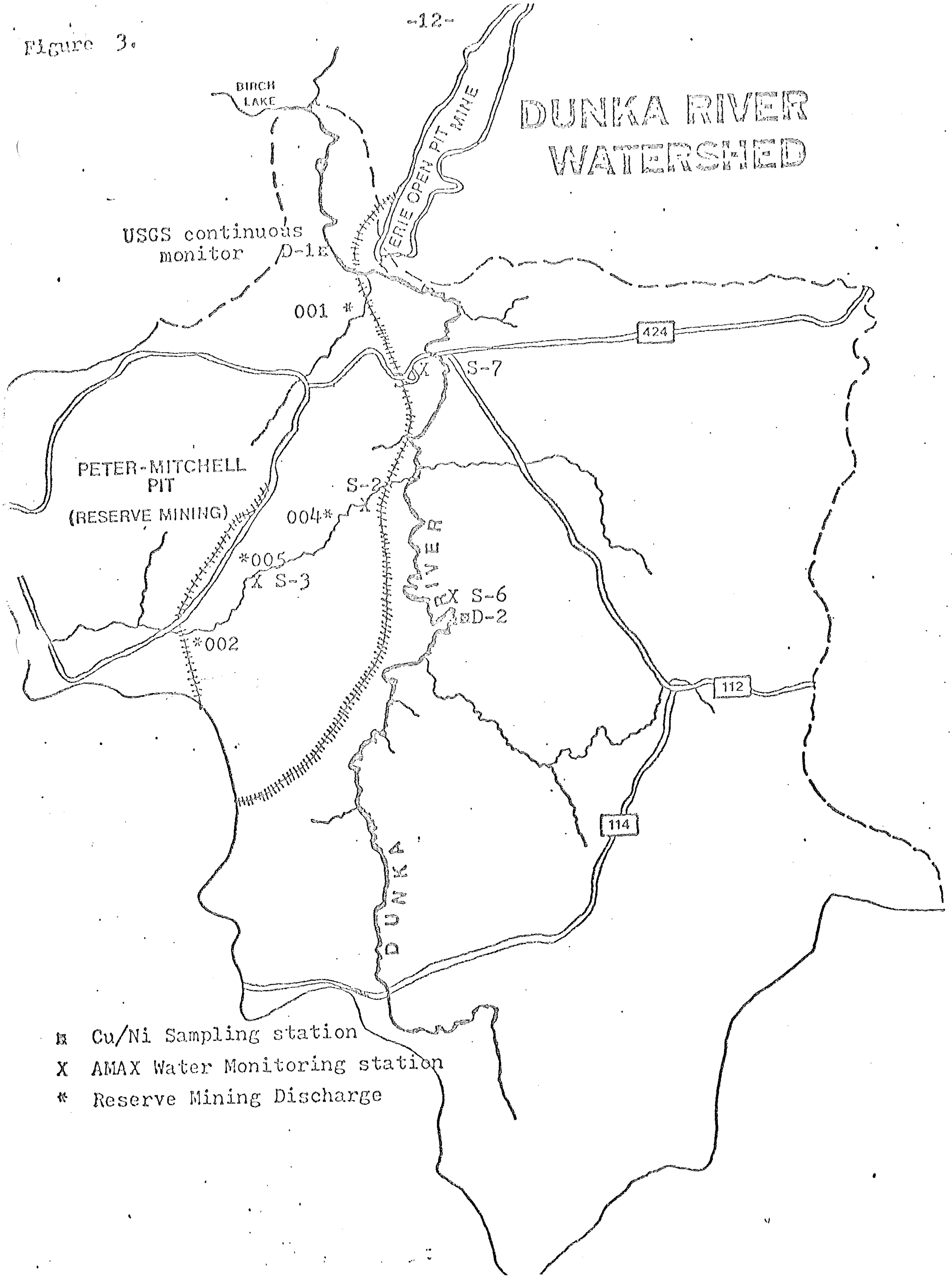
*Taken from King and Kreisman (6).

3. DUNKA RIVER WATERSHED

The work I have been doing is on the Dunka River. This watershed is a distinct hydrologic unit draining 53 square miles (8), and is bounded by the Laurentian Divide on the South and West, with all the water flowing north into Birch Lake. From here the water flows into the Kawishiwi River which is the major river north of the divide. This water then flows through a chain of lakes in the Boundary Waters Canoe Area, and eventually into the Hudson Bay drainage system.

The bedrock geology of this region consists of gabbro in the Southeast to Virginia slate and Biwabik iron formation in the Northwest. Outcroppings of bedrock are light throughout the eastern half, being slightly heavier in the South. More and larger outcroppings occur in the Southwest quarter of the watershed. The surficial geology is primarily bogs and glacial outwash. There is peat deposition to an average where? depth of 13 to 15 feet. The entire watershed is potentially a surface aquifer. The topography ranges from 1500 feet at the mouth of the Dunka to 1720 feet at the Laurentian Divide. As can be seen in figure 3 the southern end of Erie mining companies open pit is in the watershed, and the Northeastern portion of Reserve mining's Peter-Mitchell pit. Reserve appropriates water from the Dunka river, and has four discharges into it or tributaries of it. It also appears

Figure 3.


BIRCH LAKE
ERIE OPEN PIT MINE
DUNKA RIVER WATERSHED
USGS continuous monitor D-1
001 *
424
X S-7
PETER-MITCHELL PIT (RESERVE MINING)
S-2 X
004*
*005
X S-3
RIVER
X S-6
D-2
*002
112
114
DUNKA
Cu/Ni Sampling station
X AMAX Water Monitoring station
* Reserve Mining Discharge

that water is being lost from the Dunka by seepage into Erie's pit.

3.1 Dunka River Water Quality

This investigation began as a result of peculiar peaks occuring on the USGS conductivity recorder at the Cu-Ni sampling station D-1. (see figure 3). The goals were to characterize these peaks, attempt to identify what is causing them, and determine the overall effects of mining on this watershed, as compared to an undisturbed watershed.

3.1.1 Conductivity and Flow Patterns

I began by plotting hourly conductivity data at the D-1 site from March through August 1976. During the first three weeks of March the conductivity peaked nine times. The baseline appeared to be about 250 - 275 µmhos/cm, and the peaks ranged from 390 to 465 µmhos/cm. The first peak lasted about 68 hours, while all the others lasted from 8 to 10 hours. One more moderate peak (350 µmhos/cm) occured on March 23, and the conductivity then gradually dropped until it reached 60 µmhos/cm on April 9th. It was very constant throughout April, and then began gradually rising again in May. By May 24th it had reached 225 µmhos/cm, and peaks then occured on the 26th, 27th, and 29th. Three more peaks occured in the first week of June ranging from 350 to 405 µmhos/cm, and a single peak of 360 µmhos/cm lasting for 3 days occured during the second week. The conductivity was very irregular throughout the remainder of June and the first week of July. The values ranged from 75 to 200 µmhos/cm. This may be a series of smaller peaks, but they would be difficult to identify. Throughout the rest of July and the first part of August peaks occured regularly. The baseline appeared to be about 150 to 200 µmhos/cm, while the peaks ranged from 400 to greater than 520 µmhos/cm, which was the limit of the scale. There were 8 peaks occuring in the last three weeks of July, some lasting several days. These were much more irregularly shaped, and of a much greater magnitude than those occuring earlier in the year. Data was available through the first five days of August, at which time the conductivity was still dropping from the last peak which occured on the 31st of July.

The peaks throughout the entire period studied, began shortly after noon, and appeared on all days of the week (no particular days seemed to have more peaks than others).

I then compared the conductivity data available from monthly samples at the four AMAX sites, and the two Cu-Ni sites. (See figure 3). These are shown in figure 4, and table 2. The lowest values found are those upstream where the watershed is not affected by any mining activity. The highest values are found at the AMAX S-2 and S-3 sites on Langley Creek which receives 3 of Reserve minings discharges. The sample

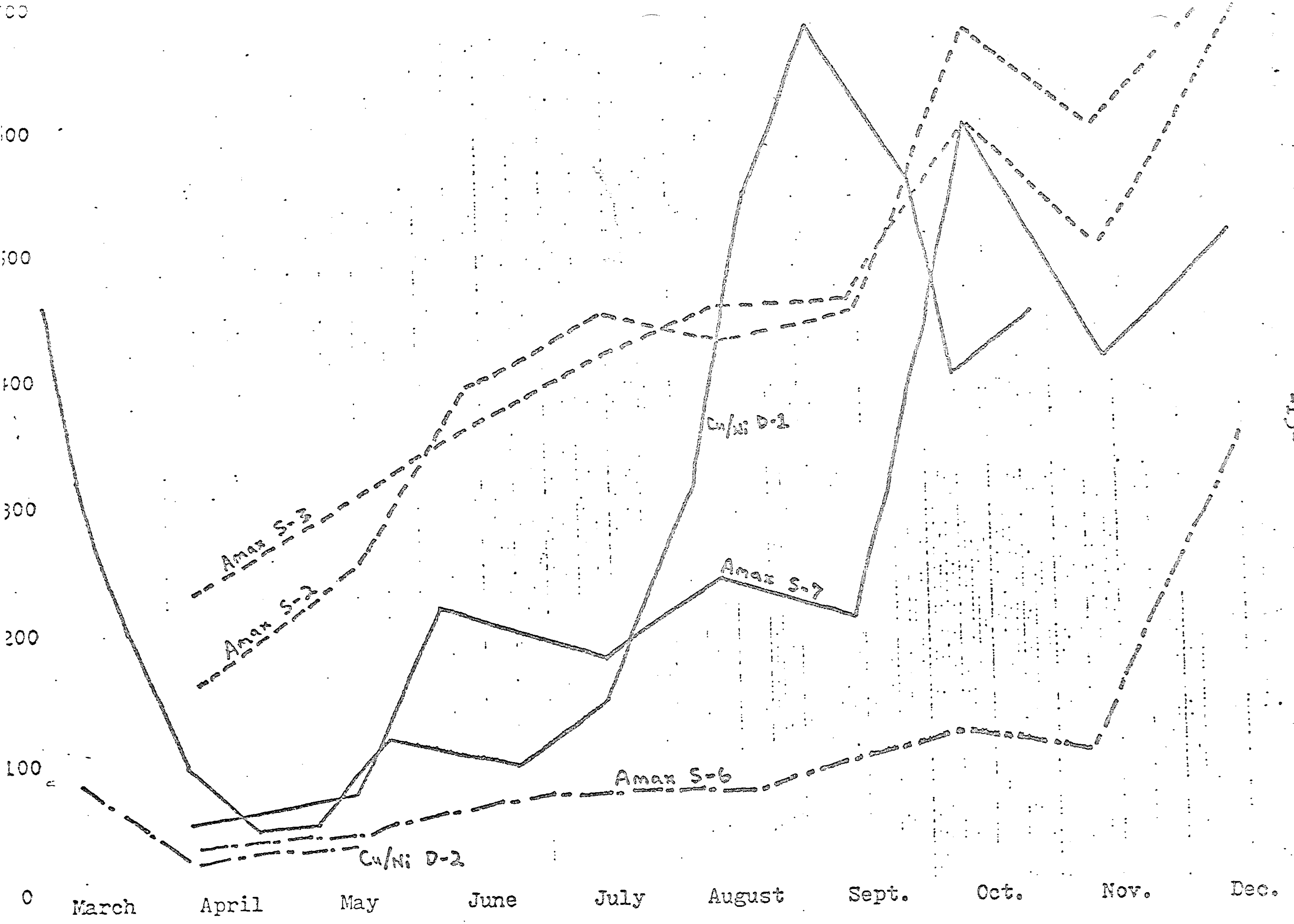

00
00
00
400
300
200
100
0
March
April
May
June
July
August
Sept.
Oct.
Nov.
Dec.
Amax S-3
Amax S-2
Amax S-7
Amax S-6
Cu/Ni D-1
Cu/Ni D-2

Table 2. Conductivity in µmhos/cm of the Dunka River

sample site	mean	range	std. dev.	#samples	SEM	2 SEM 95% CI
D-1	301.5	58-680	203.7	11	61.7	165.6-437.4
AMAX S-7	274	60-600	179.5	9	59.8	138.6-409.4
AMAX S-2, S-3	464	170-880	187.4	18	44.2	371.1-556.9
D-2, AMAX S-6	106	33-350	85.5	13	23.8	54.7-157.3

stations downstream from Langley Creek showed intermediate values, possibly indicating a dilution of the Langley water. However the D-1 samples did at times record values higher than Langley sites, indicating there may be some influence on the mean conductivity from Reserve discharge number 001.

do mass balance

To determine whether the differences between the sampling sites is significant, I have determined the standard error of the mean (SEM) using the standard deviation divided by the square root of the number of samples. Using a 95% confidence interval obtained from a t-table, I then determined if the values from different stations overlapped. If no overlap occurs, the differences are significant at the 95% confidence level.

is average one of appropriate pairs
If not, this could would not all information

For the Dunka river conductivity, the samples taken at D-1, S-7, and Langley Creek are not significantly different. The D-2 samples, however are significantly different from D-1, and from Langley Creek.

To determine whether these fluxuations are naturally occuring in a stream, I have looked at the conductivity of an undisturbed watershed. The Stony River watershed (see fig. 2), is nearby, has a continuous monitor, has been sampled at approximately the same times, and is undisturbed by mining or other industries.

The hourly conductivity of the Stony River does not show the peaks observed in the Dunka, and the variability is much less. However there is a significant increase in the mean downstream conductivity from that upstream. Table 3 shows the conductivity in umhos/cm of the Stony river both upstream and downstream as obtained from the bimonthly samples of the Cu-Ni study.

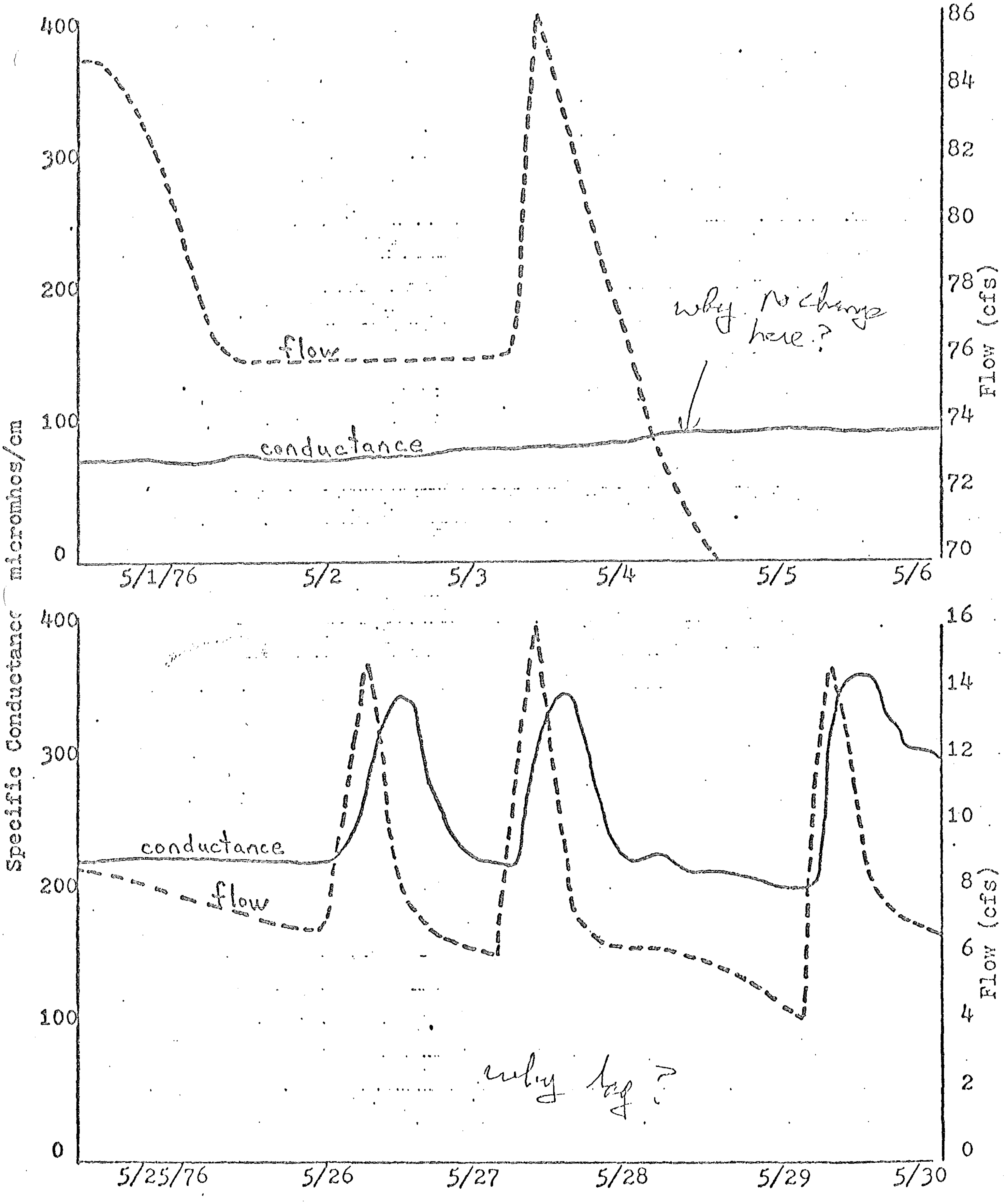
Table 3. Conductivity in umhos/cm of the Stony River

sample site	mean	range	std. dev.	#samples	SEM	2 SEM 95% CI
downstream (SR-1)	77.0	39-150	32.2	16	8.1	60.0-94.1
upstream (SR-5)	43.9	30-70	14.1	7	5.3	31.3-56.5

The 95 percent confidence intervals do not overlap. This would indicate that the runoff from the watershed or some other natural occurence has some influence on the increased conductivity downstream.

I then obtained the hourly flow data from the USGS monitor at D-1 and plotted this against the conductivity at different times of the year. Several sections of this are shown in figure 5. During periods of low flow, the flow pattern

Figure 5. Hourly Flow and Specific Conductance of the Dunka River *



why no change here?

why lag?

* Data from US Geological Survey continuous monitor on Dunka River near Babbitt (D-1).

shows the same peaks as the conductivity, preceding them by one or two hours. In the first three weeks of March the daily flow reported by the USGS is generally from 2 to 5 cubic feet per second (cfs), however when measured during a peak it reached values as high as 16 cfs. The flow increased rapidly during spring runoff, reaching 140 cfs by the end of March. It continued to increase until the second week of April when it reached 380 cfs and then began dropping off by the last week of April. This gradual drop continued until the 25th of May when 8 cfs was flowing, and at this time the conductivity peaks appeared again. The flow remained low (2 to 4 cfs) through the first several weeks of June when conductivity peaks were occuring. Rainfall in June increased the flow to about 130 cfs and then it gradually dropped to less than 10 cfs in early July. Because of the exceptionally dry year, less than 1 cfs was flowing by the end of July and early August when the large conductivity peaks were occuring.

explain this lag?

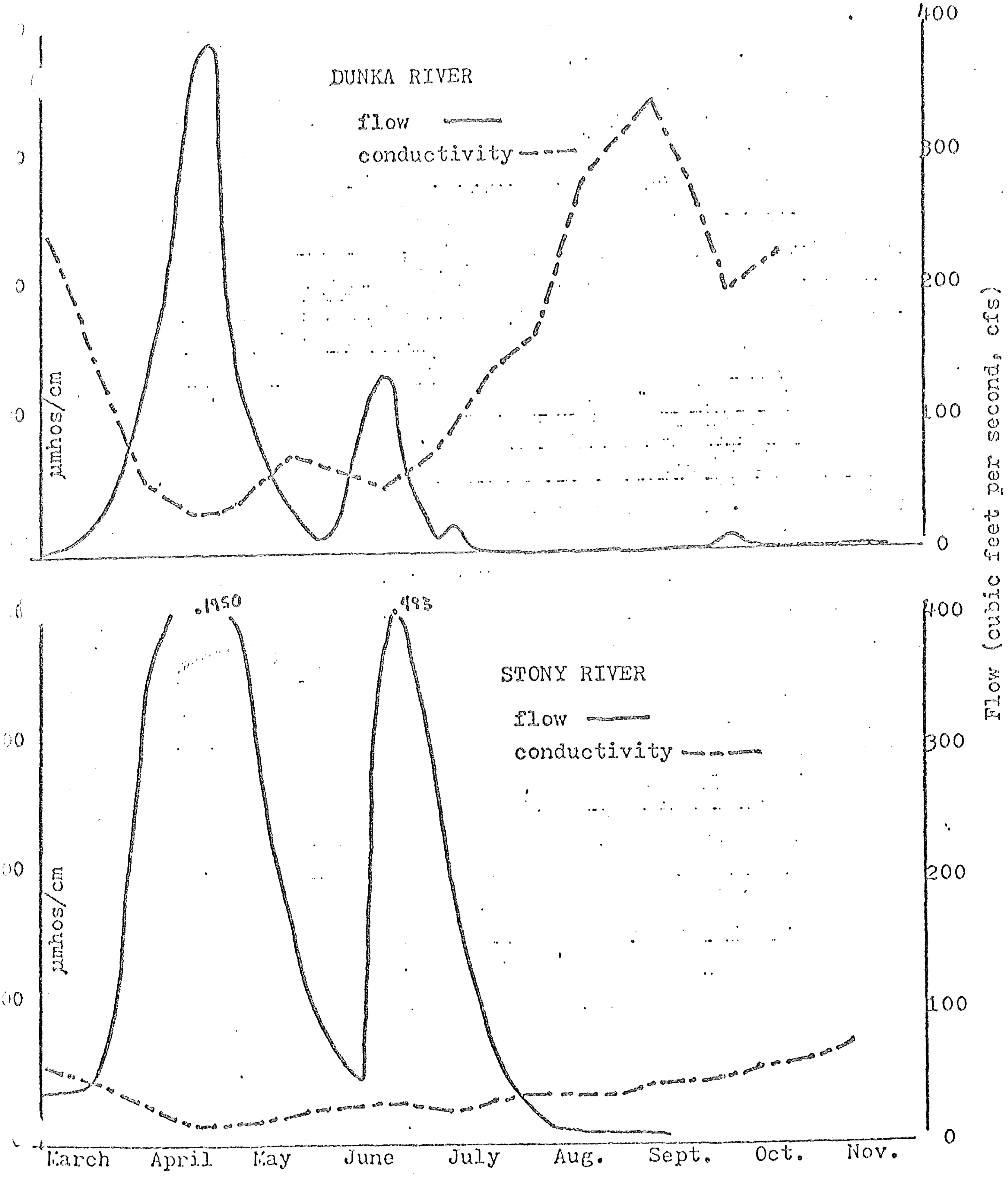
Would you believe? This increase in flow is initially due to the rain that hits the stream directly. The peak in conductance comes along with the water that is reaching the stream after traveling overland or percolating [illegible] the soil.

Ammonia problems then?

Figure 5 shows that during times of high flow the conductivity shows a straight line while peaks in the flow still appear to be occuring several times a week. An estimate of the volume of one of the small peaks in figure 5, shows it contains approximately 117,000 gallons of water. Many of the larger peaks contain considerably more.

A comparison of the flow and conductivity patterns between

Figure 6. Flow and Conductivity Patterns of The Dunka and Stony Rivers, 1976



the Dunka and Stony rivers (see figure 6), shows that the Dunka exibits a great deal more variation in the conductivity. This is at least partially due to the low flow of the Dunka (at times there was zero flow), but may also be influenced by the increased conductivity in the peaks occuring at times of low flow. The low flow alone does not appear to be able to account for the large variation observed, because the Stony shows little variation in conductivity even during its low flow.

3.1.2 Composition of the Conductivity Peaks

To determine the composition of the conductivity peaks, I first compared the samples obtained from each of the stations on the Dunka river, and chose those parameters showing the most marked differences between D-1 and D-2. These included chloride, sulfate, calcium, sodium, potassium, and possibly magnesium and nitrates. Tables 4 through 10 show the values obtained for these at each of the four locations in the Dunka river watershed. The differences between D-1 and D-2 were not significant for Mg and NO_3, while Cl, SO_4, Ca, Na, and K all showed significant differences in the 95 percent confidence intervals. The intermediate stations generally show values higher than D-1 or intermediate between D-1 and D-2.

Table 4. Concentration of Chloride in the Dunka River (mg/l)

sample site	mean	range	std.dev.	#samples	SEM	2 SEM 95% CI
D-1	39.5	5.1-88	30.7	15	7.9	22.5-56.5
AMAX S-7	33.3	6-69	32.3	3	18.7	<0-113.6
AMAX S-2, S-3	49.3	29-81	20.2	6	8.4	27.7-70.9
D-2, AMAX S-6	2.0	<1.0-4.0	0.99	8	0.35	1.2-2.8

Table 5. Concentration of Sulphate in the Dunka River (mg/l)

sample site	mean	range	std.dev.	#samples	SEM	2 SEM 95% CI
D-1	28.1	5.3-70.0	23.3	15	6.0	15.2-41.0
AMAX S-7	16.5	5-58	19.2	8	6.8	0.5-32.5
AMAX S-2, S-3	23	8-68	16.4	16	4.1	14.3-31.8
D-2, AMAX S-6	5.1	<1.0-11	3.1	12	0.9	3.1-7.1

Table 6. Concentration of Calcium in the Dunka River (mg/l)

sample site	mean	range	std.dev.	#samples	SEM	2 SEM 95% CI
D-1	32.0	3.8-84	26.0	10	8.2	13.4-50.6
AMAX S-7	22	6-36	15.1	3	8.7	<0-59.5
AMAX S-2, S-3	34.8	22-42	8.4	6	3.4	26.0-43.6
D-2, AMAX S-6	6.9	3.1-10.0	2.8	5	1.3	3.4-10.4

Table 7. Concentration of Sodium in the Dunka River (mg/l)

sample site	mean	range	std.dev.	#samples	SEM	2 SEM 95% CI
D-1	13.4	0.5-35	13.6	10	4.3	3.7-23.1
AMAX S-7	15.2	2.4-35	17.4	3	10.1	<0-58.6
AMAX S-2, S-3	20.3	8-38	13.2	6	5.4	6.5-34.2
D-2, AMAX S-6	1.8	0.9-2.7	0.8	5	0.36	0.8-2.8

Table 8. Concentration of Potassium in the Dunka River (mg/l)

sample site	mean	range	std.dev.	#samples	SEM	2 SEM 95% CI
D-1	2.6	0.7-5.2	1.6	10	0.5	1.5-3.8
AMAX S-7	2.6	0.4-5.5	2.6	3	1.5	<0-7.4
AMAX S-2, S-3	4.2	2.3-6.3	1.8	6	.75	2.3-6.1
D-2, AMAX S-6	0.5	0.4-0.8	.16	5	.07	0.3-0.7

Table 9. Concentration of Magnesium in the Dunka River (mg/l)

sample site	mean	range	std.dev.	#samples	SEM	2 SEM 95% CI
D-1	18.2	3.9-68	19.4	10	6.1	4.3-32.1
AMAX S-7	12.2	4.6-18	6.9	3	4.0	<0-24.9
AMAX S-2, S-3	15.3	11-19	3.9	4	2.0	9.9-20.7
D-2, AMAX S-6	5.4	3.2-7.6	2.4	4	1.2	2.1-8.7

Table 10. Concentration of Nitrates in the Dunka River (mg/l)

sample site	mean	range	std.dev.	#samples	SEM	2 SEM 95% CI
D-1	3.7	0.16-13	5.2	8	1.8	<0-7.9
AMAX S-7	1.0	<0.1-2.8	1.6	3	0.9	<0-3.9
AMAX S-2, S-3	1.6	<0.1-5.0	2.1	6	0.9	<0-3.7
D-2, AMAX S-6	0.27	<0.1-0.6	0.29	3	0.17	<0-0.8

To determine if the changes occuring from the upstream site (D-2), to the downstream site (D-1) were due to natural occurences within the watershed, I again looked at the Stony river. The data from two sites on the Stony river are shown in tables 11 and 12.

Table 11. Downstream Stony River (SR-1)

mg/l	mean	range	std.dev.	#samples	SEM	2 SEM 95% CI
Cl	1.9	1.1-3.7	0.74	15	0.2	1.5-2.3
SO_4	6.2	2.7-8.6	1.4	16	0.3	5.5-6.9
Ca	10.3	3.0-22	6.9	11	2.1	5.7-14.9
Na	1.7	0.3-3.1	0.6	11	0.2	1.3-2.1
K	0.6	0.4-0.7	0.1	11	.03	.53-.67
Mg	11.8	2.4-37	12.5	11	3.8	3.5-20.1
NO_3	.08	0-.28	.09	9	.03	.01-.15

Table 12. Upstream Stony River (SR-5)

mg/l	mean	range	std.dev.	#samples	SEM	2SEM 95% CI
Cl	1.8	1.0-3.3	0.8	7	0.3	1.1-2.5
SO_4	7.2	6.6-9.0	1.4	7	0.5	6.0-8.4
Ca	7.0	2.5-15	5.6	4	2.8	<0-14.8
Na	1.15	0.4-1.7	0.6	4	0.3	.35-2.0
K	0.8	0.6-0.9	0.15	4	.08	.6-1.0
Mg	2.4	1.8-2.9	0.6	3	.35	1.3-3.5
NO_3	.13	.02-0.3	0.15	3	.09	<0-0.4

The 95 percent intervals, determined from the SEM show no significant difference between SR-1 and SR-5 for any of the seven parameters tested.

The variation observed in the Dunka river is primarily due to large values obtained during periods of low flow. This does not occur in the Stony river system. Appendix I shows the yearly flow pattern for the two river systems, and the variation occuring in chloride, sulfate, calcium, sodium, and potassium.

3.1.3 Source of the Conductivity Peaks

Observations of the Dunka watershed, have shown that the only discharges into this system are from Reserve mining company's Peter-Mitchell pit. Erie mining company's Dunka pit is partially in the watershed, and dust emmissions may influence the water quality, but they have no direct discharges. There is also the Lindy oxygen plant located upstream from the AMAX S-7 site, however they have no apparent discharges.

Data from Reserve's discharges was obtained from permit applications to the National Pollutant Discharge Elimination System (NPDES) and State Disposal System Permit Program. The discharge data for the conductivity and the 7 parameters which appeared to be elevated at the D-1 site are shown in tables 13 through 16.

Table 13. Water Quality of Reserve Discharge 001

	mean	range	std.dev.	#samples	SEM	2 SEM 95% CI
conductivity µmhos/cm	413.3	280-800	135.7	12	39.2	327.9-498.8
Cl mg/l	40.4	22.5-63.0	12.6	12	3.6	32.5-48.3
SO$_4$ mg/l	40.9	23.0-60.4	11.1	12	3.2	33.9-47.9
Ca mg/l	33.4	22.8-63.6	10.5	12	3.0	26.8-40.0
Na mg/l	15.7	9.4-36.6	7.3	12	2.1	11.1-20.3
K mg/l	3.2	2.1-6.8	1.2	12	0.4	2.4-4.0
Mg mg/l	17.3	11.6-30.9	5.1	12	1.5	14.1-20.5
NO$_3$ mg/l	4.5	1.5-8.8	2.4	12	0.7	3.0-6.0

Table 14. Water Quality of Reserve Discharge 002

	mean	range	std.dev.	#samples	SEM	2 SEM 95% CI
conductivity µmhos/cm	394.6	210-500	77.6	12	22.4	345.7-443.5
Cl mg/l	39.6	21.5-56.7	10.5	12	3.0	33.0-46.2
SO$_4$ mg/l	29.9	20.8-44.0	9.1	12	2.6	24.2-35.6
Ca mg/l	34.0	16.2-41.4	7.0	12	2.0	29.6-38.4
Na mg/l	17.4	6.8-29.2	7.1	12	2.1	12.9-21.9
K mg/l	4.3	2.48-5.23	.72	12	0.2	3.8-4.8
Mg mg/l	16.1	8.5-19.7	3.1	12	0.9	14.1-18.1
NO$_3$ mg/l	1.2	<0.1-2.1	.64	12	0.2	0.8-1.6

Table 15. Water Quality of Reserve Discharge 004

	mean	range	std.dev.	#samples	SEM	2 SEM 95% CI
conductivity µmhos/cm	1146.3	1090-1225	57.9	4	29.0	1065.9-1226.7
Cl. mg/l	270.5	238.9-310	29.5	4	14.8	229.5-311.5
SO_4 mg/l	18.6	7.5-34.4	13.2	4	6.6	0.3-36.9
Ca mg/l	113.6	105.4-120.5	6.6	4	3.3	104.4-122.8
Na mg/l	39.9	30.6-48.4	7.5	4	3.8	29.3-50.5
K mg/l	8.4	7.1-9.5	1.1	4	0.6	6.7-10.1
Mg mg/l	30.1	29.3-31.8	1.2	4	0.6	28.4-31.8
NO_3 mg/l	0.1	<0.1-0.13	.02	4	.01	<0-2.9

where do all these CI's come from

Table 16. Water Quality of Reserve Discharge 005

	mean	range	std.dev.	#samples	SEM	2 SEM 95% CI
conductivity µmhos/cm	613.8	575-680	45.7	4	22.9	550.2-677.4
Cl mg/l	135.4	122-148	13.9	4	7.0	116.0-154.8
SO_4 mg/l	8.9	5.6-14.8	4.3	4	2.2	2.8-15.0
Ca mg/l	64.8	59-75	7.5	4	3.8	54.2-75.4
Na mg/l	12.4	11.3-13.5	.89	4	0.5	11.0-13.8
K mg/l	3.9	2.98-4.72	.9	4	0.5	2.5-5.3
Mg mg/l	19.1	18.2-20.3	.9	4	0.5	17.7-20.5
NO_3 mg/l	<0.1	<0.1	0	4	-	-

Discharge 001 has significantly higher concentrations (95 percent confidence intervals do not overlap) than D-2 for all parameters tested, and is not significantly different from D-1 for any of the parameters. The other two stations, S-7 and Langley Creek show no significant difference from discharge 001 except for SO_4 which are higher in the discharge.

The concentrations in discharge 002 are significantly higher than D-2 for all parameters except nitrates, while D-1, S-7 and Langley Creek show no significant differences.

The conductivity of discharge 004 is significantly higher than any of the sampling stations, as is the concentration of calcium and chloride. The concentrations of sulphates and nitrates are not significantly different from any of the stations. The magnesium in 004 is significantly higher than D-2, S-7 and Langley. The potassium is significantly higher than D-1, D-2 and Langley, and the sodium is significantly higher than D-1 and D-2.

Discharge 005 has a significantly higher conductivity than D-1, S-7 and D-2. The sulphate concentration is significantly lower than D-1, while the calcium is significantly higher than D-1, Langley and D-2. The Mg, Na and K are significantly higher than D-2.

In order to assess the impact of these discharges on the watershed, it is also necessary to look at the volume of these discharges. For the year 1975, when these samples were obtained, the average discharges were; 2.89 million gallons per day (mgd) for discharge 001 (maximum 12.67 mgd); 2.10 mgd for discharge 002 (maximum 19.01 mgd); 0.22 mgd for discharge 004; and 0.28 mgd for discharge 005. (Taken from NPDES

validity?

permit application.) Although discharges 001 and 002 have lower concentrations for most of the parameters, the amounts of the particular elements that they are contributing are higher. The other components which Reserve analyzed for in these discharges have been summarized in Appendix II. None of these appear to have concentrations high enough to be influencing the conductivity to a very great extent.

The constituents which appear to be responsible for the conductivity peaks occurring at the D-1 monitor are primarily chloride, sulfate, calcium, sodium, and potassium, and the source appears to be discharges from Reserve Mining.

Although discharge 004 is significantly higher than any of the sampling stations for most parameters, the large distance from the monitor, and the small volume of the discharge make it unlikely that this would be causing the peaks. Discharge 005 also has a very small volume, and the differences in conductivity are not that pronounced for the distance it is from the monitor.

Discharge 002 has a large volume, is significantly different from upstream conductivity, and is the same as the monitor conductivity. The distance this discharge must travel down Langley Creek, and then the mixing with upstrean Dunka water before reaching the monitor would reduce the conductivity considerably below that appearing in the peaks.

Discharge 001 appears to be the likely source of the conductivity peaks. The even-ness, and duration of the peaks, the magnitude of the conductivity, and the similarity to the D-1 values would support this.

Further evidence indicating the relationship between an increase in concentrations of certain parameters and the conductivity peaks, are the linear regression analysis done by the USGS in 1975. The data consisted of only 11 samples over a nine year period, and cannot be considered to be an accurate representation of what the relationships are throughout the year. The correlation coefficient for chloride concentration and conductivity was 0.80502, while that for sulphate and conductivity was 0.38729. The other parameters were not analyzed, however dissolved solids and conductivity has a correlation coefficient of 0.86216.

is this relevant? If so develop further to be useful.

To determine why the concentrations of these five elements are elevated, and where the discharges originate from, it is necessary to investigate the operations at Reserve's Peter-Mitchell Pit.

4. RESERVE MINING (9)

Reserve mining which is owned jointly by Republic Steel

Corporation of Cleveland, Ohio, and Armco Steel Corporation of Middletown, Ohio, started construction on their taconite mining facilities in 1951. They began operation in 1955 with a capacity of 3,750,000 tons of iron ore pellets annually. At present their open pit is 9 miles long by one mile wide and they have mined 477,500,000 tons of ore. They are presently mining about 90,000 tons of ore per day from the Biwabik Iron Formation. This formation consists of chemical precipitates of iron silicates, carbonates, silica and iron oxides, both magnetic and non-magnetic.

The mining operation is preceded by diamond drilling which produces core samples that are analyzed to determine the quality and extent of the ore body. Once the area to be mined has been established, all the vegetation is removed with tractors. The surface overburden, which is from 2 to 25 feet thick is removed with electric power shovels at a rate of 1,000,000 cubic yards each year. Rock stripping then removes material up to 100 feet thick, and exposes the ore. After cleaning up the remaining waste material, blast holes are drilled with jet piercing machines. These use a high temperature (4400° F) fuel oil-oxygen flame which causes the rock to chip. Water is used to cool the burner and carry the chips out of the hole. Reserve presently operates 11 jet piercing machines throughout the mine, and blasts about

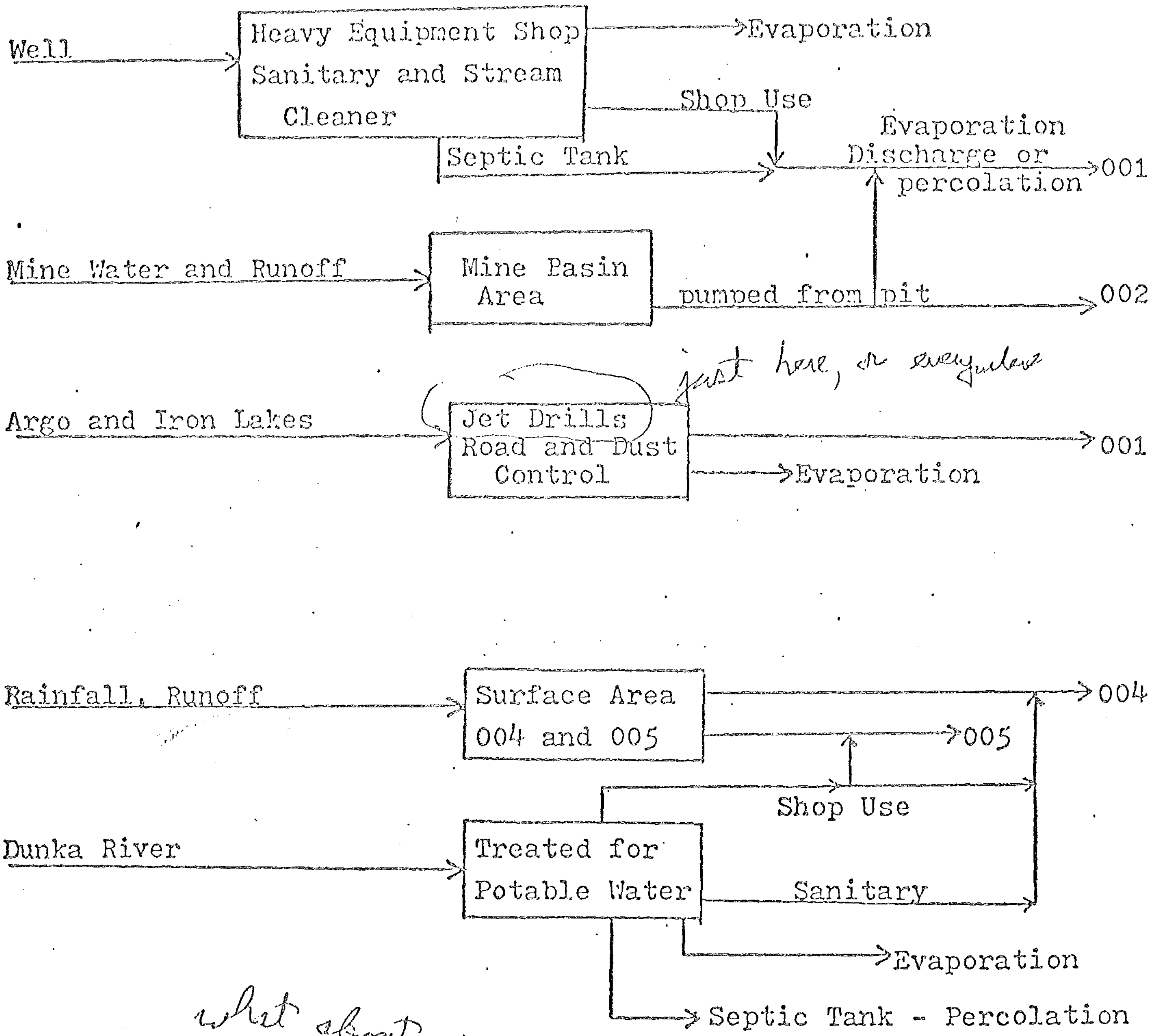
90 times a year. An average blast consists of 250 holes, 38 feet in depth, and breaks approximately 350,000 tons of taconite. The explosive used is an ammonium nitrate-based slurry, and the holes are connected by diagonal rows of detonating fuse with extremely short (5 to 17 milliseconds) delays. Haul roads are then cleared through the blasted ore and 11 and 12 yard capacity electric shovels load the taconite into 90-ton and 135-ton capacity trucks. These trucks haul the 90,000 tons of taconite per day an average of 1.9 miles to the primary crushers. Six shovels are generally in operation to maintain the annual production of 30,000,000 tons of ?taconite?. ore Once the ore has gone through several crushers, it is loaded by conveyor belt into 85-ton capacity railroad cars. About 160 cars make up a train, and they travel the 47 miles to Silver Bay about 52 times a week. There the ore is processed into concentrated pellets. Appendix III shows the present extent of the Peter-Mitchell Pit mining operation.

4.1 Water Flow in Peter-Mitchell Pit

The Laurentian divide crosses the middle of the pit with the water in the eastern end flowing into the Dunka River watershed, and that in the western end, where most of the present mining activity is, flowing into the Partridge River watershed. The water collects in the mine basins from rainfall, runoff, ground water seepage, and drainage from lakes. During mining operations, this water must be pumped from the basins and it is usually pumped 2 to 3 times a week for periods of 8 hours or more at a time (9). The east end of the pit has four primary discharge points into the Dunka River watershed (see figure 3).

Discharge 001 contains runoff from a heavy equipment repair shop which contains a steam cleaner, the mine personnel entrance road, and a sanitary septic system for about 42 men. This along with rainfall, ground water, and drainage from Iron and Argo Lakes is pumped through a culvert into a swampy area, and natural drainage carries it into the Dunka River several hundred yards upstream from the D-1 monitor. Discharge 002 is largely surface runoff and ground water in the mine pit which is pumped into a swamp, forming the headwaters of Langley Creek. There are, however, trucks and shovels operating in this area creating dust. Discharge 005 is surface runoff from 210.3 acres, which contains a wash and paint shop, septic system for 6 men, locomotive fueling station, tire shop and a taconite stock pile. Discharge 004 is also primarily surface runoff, however the 146 acres which drain here include the Number 1 crusher, vehicle repair shops, railroad repair shop, water treatment plant, railroad ballast plant, and Imhoff sewage treatment

Figure 7 Schematic of Water Flow in the East End of Reserve's Peter-Mitchell Pit *



just here, or everywhere

what about salt on roads

Show volumes of flow, water balance

* Adapted from Reserve permit applications to National Pollutant Discharge Elimination System, and State Disposal System Permit Program.

plant serving approximately 955 employees. Figure 7 shows the general water flow in the east end of the Peter-Mitchell Pit.

4.2 Factors Influencing The Conductivity Peaks

The shape and size of the conductivity peaks seems to indicate that little dispersion or dilution has taken place before passing the monitor. This would imply that discharge 001 is primarily responsible for the peaks. Langley Creek enters more than 2.5 miles upstream from the monitor and this is where the other discharges are located. Although discharges 004 and 005 have very high conductivity, the peaks probably would not appear as sharp if the water had traveled that far. Discharge 002 is even farther away.

what?
estimate!
what is dilution?

The discharges are a result of dewatering the mine pits, and this water has come from ground water seepage and surface runoff. To determine the characteristics of the ground water in the region, I have looked at well samples taken by AMAX. These wells were poorly constructed and the values may not be very accurate, however, they will serve to indicate the general quality of ground water in the area. Table 17 shows a summary of the parameters which have appeared elevated in the discharges. These values have been obtained using 15 samples taken from 5 wells in 1975. (AMAX wells WT-3,4,6,7 and 8).

Table 17. Groundwater Quality of Dunka Watershed *

	mean	std.dev.	#samples	SEM	2 SEM 95% CI
conductivity µmhos/cm	333.7	200.8	15	51.9	223.1-444.3
Cl mg/l	2.9	1.3	15	.34	2.2-3.6
SO_4 mg/l	5.9	7.0	15	1.8	2.0-9.8
Ca mg/l	28.1	15.9	15	4.1	19.3-36.9
Na mg/l	3.6	1.3	15	.34	2.9-4.3
K mg/l	.68	0.3	15	.08	.20-.85
Mg mg/l	19.9	12.9	15	3.3	12.8-27.0
NO_3 mg/l	0.5	0.3	15	.08	.33-.67

* Taken from AMAX 1975 Summary

The conductivity, calcium and magnesium are not significantly different from discharge 001, or sampling site D-1, however, they are significantly higher than D-2. The concentrations of chloride, sulphate and potassium in the well water are significantly lower than discharge 001 and D-1. These parameters are not significantly different from sample site D-2.

Other factors within the mining operation which may increase the conductivity of the discharges include runoff from water and sewage treatment facilities, drilling operations, hauling roads and machine and repair shops.

Samples taken by Reserve during 1975 showed that the septic system draining to discharge 001 had a conductivity ranging from 950 to 1030 µmhos/cm, while that draining to discharge 004 ranged from 610 to 3000 µmhos/cm. The water treatment

volume? mass balance?
could this account for 001 [illegible]

facilities in the 004 drainage area use 2,600 lbs. of $AlSO_4$ and 2184 lbs. of sodium aluminate per month to flocculate the suspended solids. The water is then run through a sand filter which is back-washed into the 004 discharge. They also add 100 lbs. of sodium carbonate and 10 lbs. of chlorine daily.

Flow? mass balance? account for 004 values?

The primary factors responsible for the increased conductivity appear to be ground water seepage, and runoff from sewage and water treatment facilities.

Salting roads?

4.3 Other Impacts of Taconite Mining

Although the primary purpose of this investigation was to characterize the conductivity peaks, it is also important to consider other changes which may be occurring in the water quality as a result of taconite mining. Some of the other impacts include; changes in stream flow, discharge of heavy metals, and discharge of sewage wastes.

According to data from the U.S. Forest Service, Reserve Mining appropriated 23,537,000 gallons of water from the Dunka River in 1975 for potable sources. Observations of the stream flow above and below Erie's Dunka Pit show that water is also being lost here through seepage. Inside the pit water can be seen seeping through the bank, and this at times can

relevant
[illegible]
compared
to dis.
is this
significant

amount to very significant amounts. ? define how much? where?

Flow measurements taken by the USGS near the AMAX S-7 site and D-1 show a decrease downstream during low flow. A measurement in April 1976 reported 0.76 cfs flowing at S-7 and only 0.06 cfs at D-1, while a November measurement reported 1.68 cfs at S-7 and 0.30 cfs at D-1. Measurements in October during higher flow showed 9.15 cfs at S-7, and 9.46 cfs at D-1 (10). The decrease in flow observed in April and November is probably due to seepage. Reserve only appropriates during times of high flow and the difference in volume would be much larger.

why is this relevant?

absolute? 95% interval? are these significantly different?

Although the concentrations of heavy metals in the discharge is very low, the actual amounts may be significant. To determine the amounts of some of the heavy metals in discharge 001, I have used the average concentration (Appendix II), and the average daily discharge of 2.89 mgd reported in the NPDES permit application. Some of the amounts in an average discharge per what time interval? are; 14.22 grams of copper, 48.13 grams of zinc, 32.82 grams of nickel, 3.28 grams of cadmium and 14.22 grams of lead. Even small concentrations of these metals can effect aquatic organisms, and interactions between them can multiply these effects. Estimated toxic levels of lead are from 0.01 to 0.1 mg/l, while cadmium can kill newly-hatched trout

define?

and Daphnia at concentrations as low as .0005 mg/1. (11) Other constituents of the discharge may at times reach concentrations which are lethal to aquatic organisms. Using toxicity data compiled by Clarke (12), parameters in Reserve's discharge with a mean concentration above the minimum known toxicity to fish or aquatic invertebreates include: Na, Ca, NH_3, Mn, and Fe.

verify here -
aquatic bio staff

The large number of employees in a mining operation necessitates sewage treatment facilities on the premises. Reserve has sewage effluents draining to discharge 001 and 004. Samples of the effluent draining to 004 showed the following counts: fecal coliform bacteria, 200-126,000 cts/100ml; total coliform bacteria, 20,000-740,000 cts/100 ml; and fecal streptococci bacteria 5,800-260,000 cts/100 ml. These counts are very high and would be of concern to public health officials. A chlorinator has been installed, and is awaiting permit approval from the PCA. The overall impacts on the water quality of the Dunka River do not appear to be very severe. The taconite mining has caused fluctuations in the flow and peaks in the conductivity readings, however, these factors apparently have not adversely affected the water quality. The baseline values for the parameters of concern in the discharge effluent are diluted in the river water and should not be a concern for most aquatic organisms.

Source of data?

Says who?

There seems to be a slight conflict here.

These are not necessarily the same effects a copper-nickel mine would have on the area. The usefulness of the baseline data being collected, and the necessity of a continual monitoring program for any mining operation can be seen by looking at the potential impacts a copper-nickel mine would have on this watershed.

5. Potential Impacts of Copper-Nickel Mining

The three major effects which a mining operation has on a watershed are appropriations, discharges and sewage wastes. & [illegible] water quality The stages of a copper-nickel mining operation where appropriations would be necessary are development, beneficiating and smelting. (1) Discharges will also occur during these stages as well as during the mining and termination. The quantity and composition of the discharges will depend on the characteristics of the ore body, mining methods used, and hydrogeology of the watershed. (12)

While Reserve has only been mining in this watershed and shipping the ore to Silver Bay for processing, a copper-nickel mine will probably do the processing here as well. This will ? [illegible], will result in effluents containing heavy metals, sulphur compounds and organic reagents.

The technology has been greatly improved since the Canada

The EQC should have just hired [illegible] to [illegible]

mines began operation, and the extensive environmental destruction which occurred there would not occur in Minnesota. These do, however, serve as examples of the destruction that can occur from lack of environmental concern. Heavy metal emissions, SO_2 and acidic rains in the Sudbury area have damaged the forests, acidified the soils and led to extensive soil erosion. (13) Aquatic species diversity has been greatly reduced in the nearby lakes, and many have lost their entire fish populations. The major chemical changes in the water quality were seen in suspended solids, heavy metals, total dissolved solids, pH, hardness, sulphates and arsenic. Also the aquatic biota were adversely affected in 19 of 22 localities investigated. (12)

These examples show a definite need to characterize any region as completely as possible before a mining operation begins and to continuously monitor the operations to avoid degradation of the water quality.

6. Conclusions

There appears to be good evidence indicating that the conductivity peaks occurring in the Dunka River are caused by discharges from Reserve Mining. The parameters most likely responsible for this are chloride, sulphate, calcium,

Cation-anion Balance ?

sodium and potassium. It is not as clear which specific discharge is responsible or what aspect of the mining operation may have increased these concentrations. However, it appears that discharge 001 is probably responsible, and the source is the dewatering of the pit which includes groundwater seepage and runoff from sewage treatment facilities.

wouldn't it
look the same
just below [illegible]
etc ?

Some of the complications in determining the source of the discharge include: 1) most of the data available on the mining discharges was collected in 1975, while the river samples were collected in 1976; 2) the samples have been collected and analyzed by different people (AMAX, Reserve, USGS, and the Copper-Nickel Study) and no attempt has been made to investigate the analytical procedures used by the various laboratories; except AMAX, USGS, CuNi ? and 3) the well-water samples used were collected poorly and may not be an accurate representation of the groundwater in the area. Eger's data ?

[illegible]

Comparisons with the Stony River, an undisturbed watershed, have shown that the baseline conductivity appears to increase downstream due to natural conditions. However, the specific parameters responsible for the conductivity peaks show no such increase in the Stony River, and are significantly increased downstream in the Dunka River. The differences in volume of flow between these two rivers and the extremely

what? the
season
contributing

Compare
[illegible], up-r
down-stream
for Dunk,
Stony ?

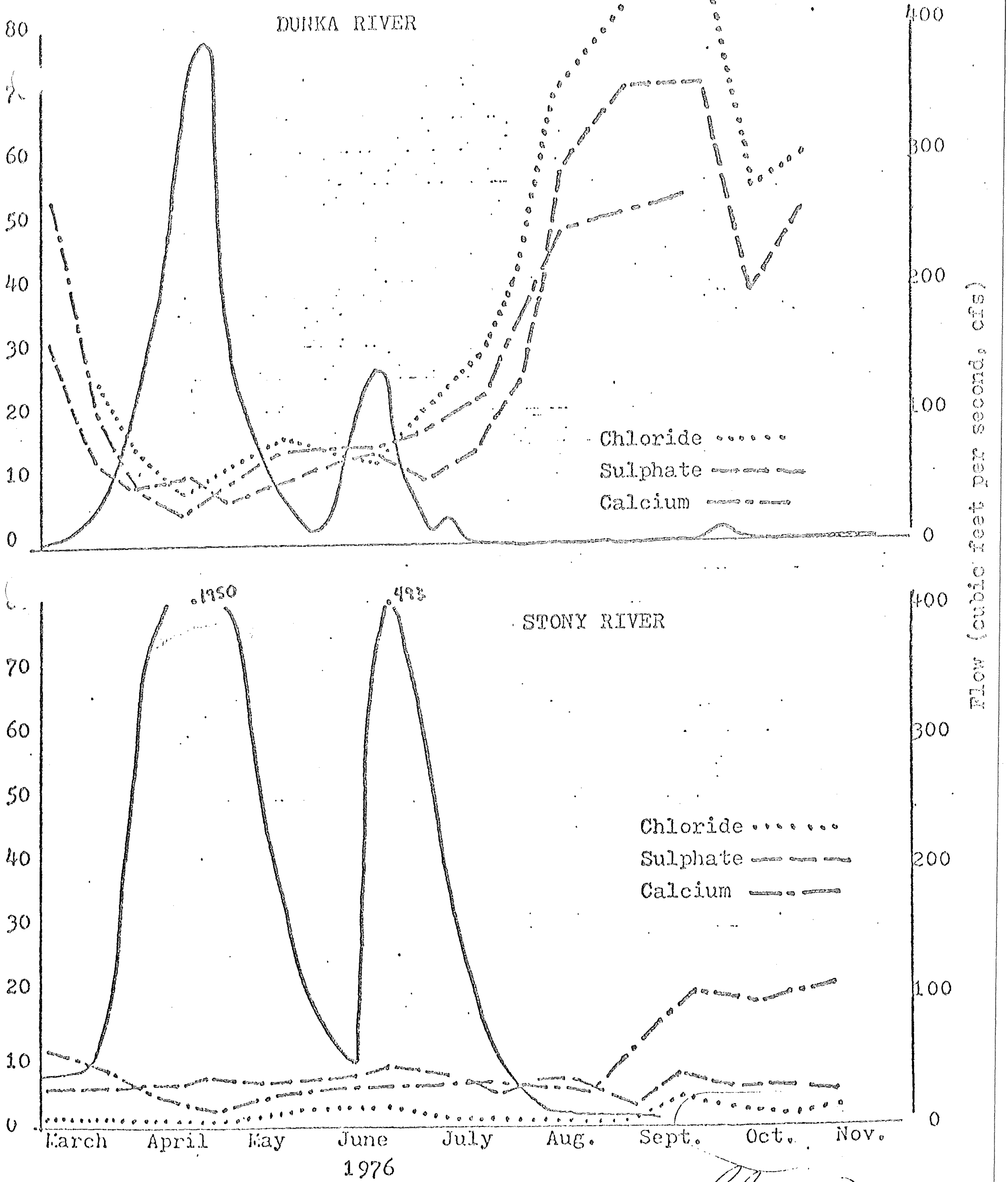
for the Stony the only parameters →
that change significantly are Ca & Mg, they increase down[illegible]
almost all parameters in the Dunka drainage
increase downstream

dry year in 1976 are factors which may be of importance in assessing the differences which occur.

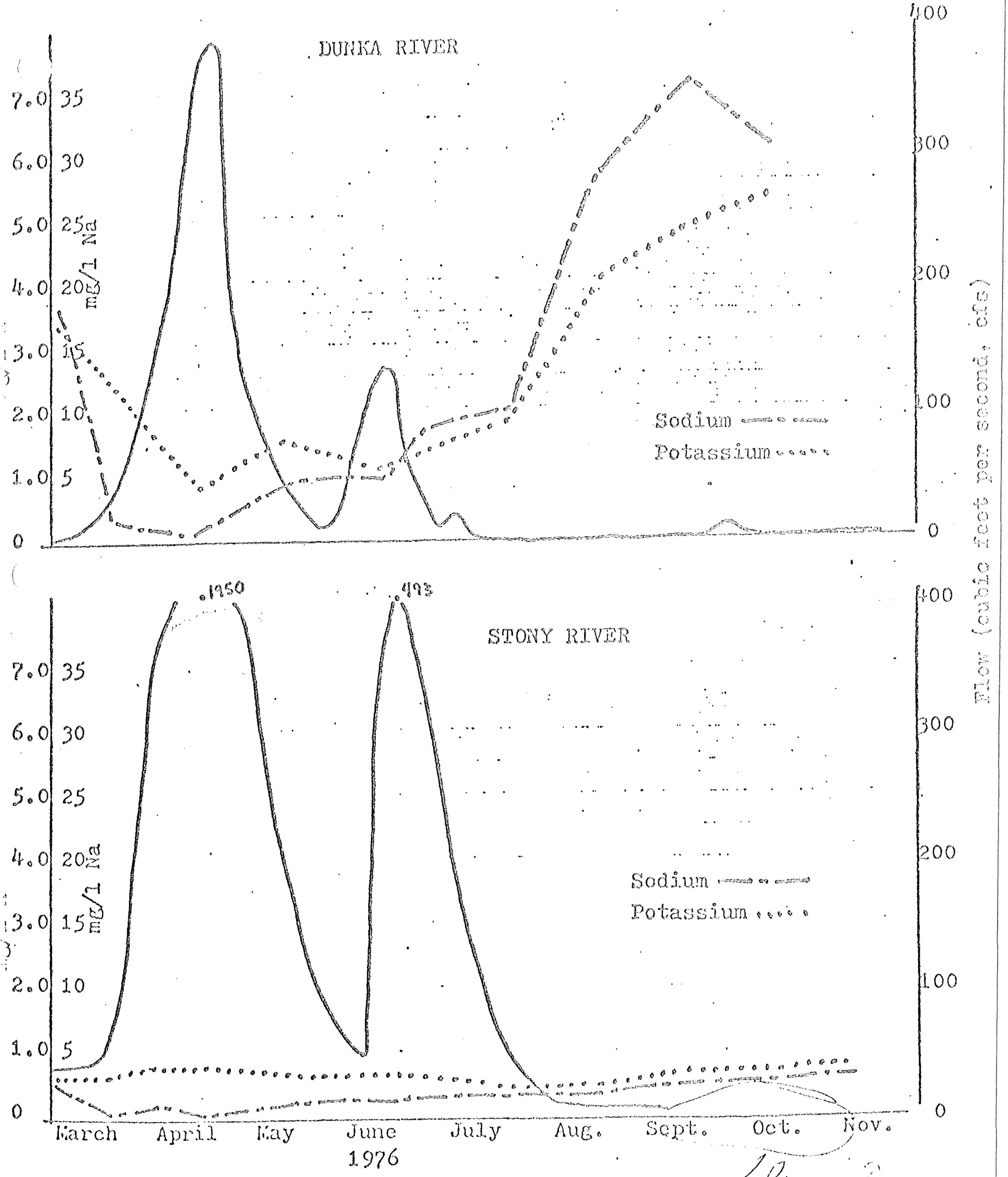
The major impacts this mining operation~~s~~ appears to have on the watershed are fluctuations in the flow and conductivity, discharge of high levels of bacteria in the sewage, and levels of specific constituents reaching high concentrations in the discharges. The dilution by the river water ~~masks~~ reduces these changes except during low flow, hence the changes do not appear to adversely affect the water quality.

Although the taconite mining has not severely degraded the water quality, a copper-nickel mine will have many different problems. This makes it necessary for baseline data collection, and assessment of potential impacts such as the Environmental Quality Council is currently doing.

Appendix I. Water Quality and Flow Patterns of The Dunka and Stony Rivers



Appendix I.(continued) Water Quality and Flow Patterns
of The Dunka and Stony Rivers



Appendix II. Water Quality of Reserve Discharges (mg/l)

mean (standard deviation)

Date & time period?

Discharge	001	002	004	005
Alkalinity (as $CaCO_3$)	73.78(10.35)	110.04(27.09)	134.76(19.91)	80.24(12.38)
Silica	14.3(2.1)	15.69(3.76)	16.45(.759)	14.83(2.253)
Total Phosphorus	.004(.004)	.0166(.0097)	.767(.4632)	.0053(.0042)
Iron	.320(.227)	3.798(8.264)	4.83(2.352)	1.184(.6521)
Manganese	.060(.045)	1.062(1.374)	10.34(.7375)	2.17(1.155)
Copper	.0013(.0008)	.0014(.00096)	.00098(.0004)	.0041(.00058)
Zinc	.0044(.0017)	.0055(.0055)	.00695(.0039)	.0165(.006)
Nickel	.003(.004)	.0024(.0012)	.0083(.002)	.024(.005)
Cadmium	.0003(.00015)	.0003(.00022)	.0005(.00038)	.00033(.00025)
Lead	.0013(.00065)	.0017(.00098)	.0018(.00096)	.0013(.0005)
Cobalt	.001(.0006)	.0014(.00099)	.0014(.001)	.0042(.003)
Chromium	< .001(0)	< .001(0)	< .001(0)	< .001(0)
Mercury	<.0002(0)	<.0002(0)	<.0002(0)	<.0002(0)
Arsenic	< .005(0)	< .005(0)	.0083(.0058)	< .005(0)
Selenium	.005(0)	.0052(.0007)	.005(0)	<.005(0)
Silver	<.001(0)	<.001(0)	<.001(0)	<.001(0)
Barium	.022(.01)	.0255(.0087)	.060(.030)	.034(.014)
Ammonia-N	.24(.42)	.408(.3927)	.95(.556)	.607(1.26)
Nitrite-N	.0076(.0063)*	.0327(.0343)	.0053(.0047)	.0058(.0075)
Nitrate-N	4.7(2.5)	1.236(.639)	.108(.015)	< .10(0)
Organic-N	.235(.192)	1.037(.803)	1.091(1.2)	.516(.232)
Total Kjeldahl-N	.496(.417)	1.446(1.038)	2.09(.645)	1.124(.932)
Cyanide	<.01(0)	.0096(.0015)	< .01(0)	<.01(0)
Fluoride	<0.5(0)	< 0.5(0)	<0.5(0)	<0.5(0)
Phenol	<.005(0)	<.005(0)	.0145(.008)	<.005(0)
Oil and Grease	< 1.0(0)	1.256(.767)	2.73(2.193)	< 1.0(0)
pH	7.79(.12)	7.44(.21)	7.19(.103)	7.31(.215)
Temperature °C	6.4(7.7)	4.84(6.31)	5.0(4.9)	4.83(5.12)
Dissolved Oxygen	10.8(1.97)	7.88(1.2)	3.33(1.92)	7.13(1.52)
Suspended Solids	13.0(4.2)	13.45(34.9)	23.93(24.8)	6.8(4.83)
Turbidity JTU	2.3(1.8)	6.64(7.61)	33.05(14.19)	4.7(1.88)
BOD	1.17(.88)	1.79(1.85)	6.95(1.34)	.875(.556)
COD	12.15(10.8)	45.56(45.52)	93.6(77.35)	38.1(9.04)
Fecal Coliform Bact. Cts/100 ml	4.25(6.4)	4.33(8.003)	1.75(.957)	1.25(.5)
Total Coliform Bact. Cts/100 ml	181(268)	66.5(72.43)	3042.5(4911.9)	188(341.5)
Fecal Streptococci Bact. Cts/100 ml	287(529)	285.83(512.44)	712.25(1128.24)	346.5(636.13)

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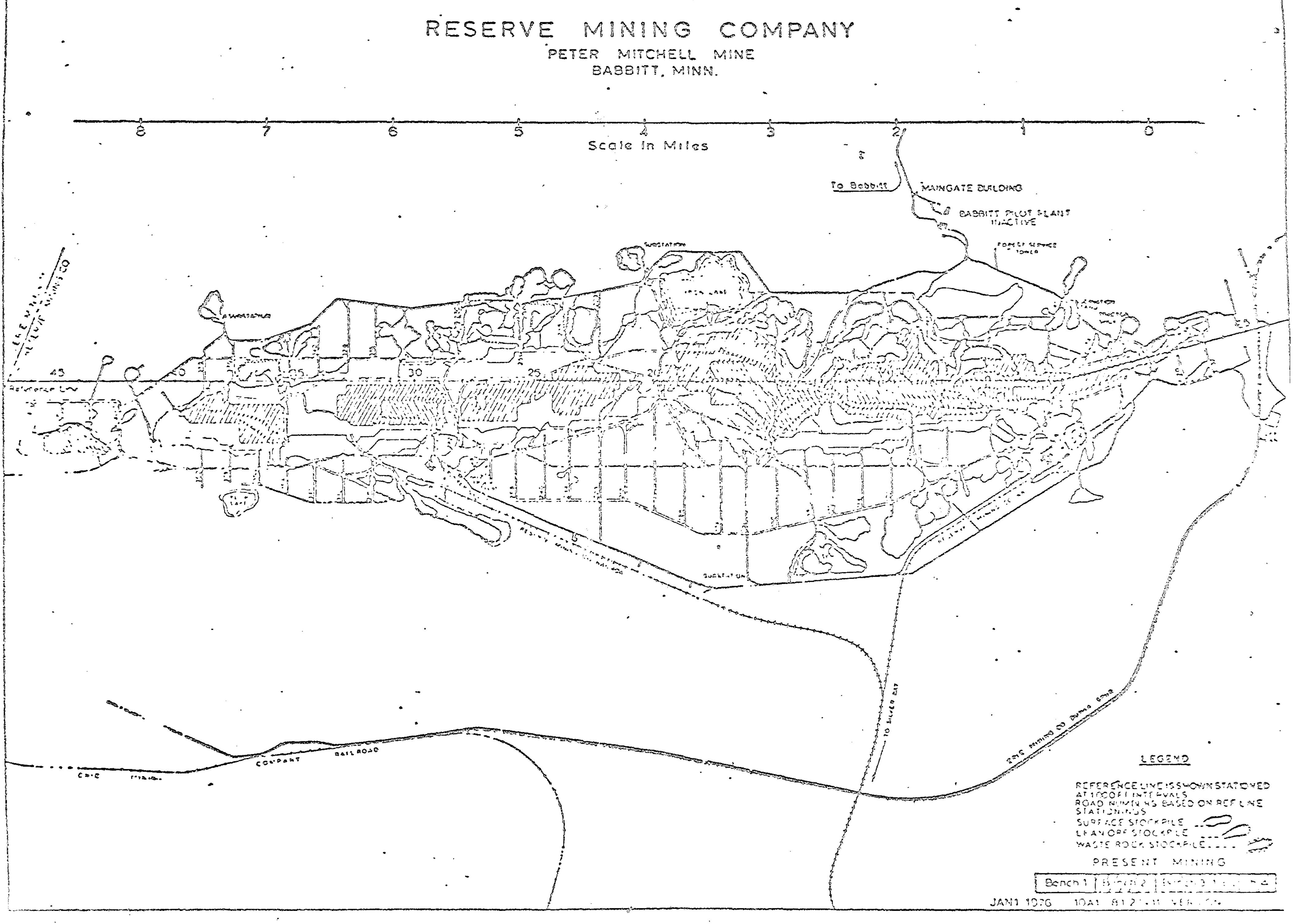
* One extreme value left out of computation (0.65 mg/l)

Appendix III. Map of Peter-Mitchell Pit



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