CN 061

IMPACTS OF COPPER-NICKEL MINING AND PROCESSING ON THE HYDROLOGY OF THE COPPER-NICKEL STUDY AREA

Minnesota Environmental Quality Board
Regional Copper-Nickel Study
Authors: Beth Honetschlager
Martha J. Hewett

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A. INTRODUCTION

Placing a copper-nickel mine and associated operations in a watershed would cause changes in the quality, quantity, and timing of water flowing out of that watershed. This report describes the possible impacts on the hydrology of the Copper-Nickel Study Area (Study Area) by copper-nickel mining, milling, smelting, and refining.

The analyses carried out here are based on the water budget of a model copper-nickel operation as described in the water budget report (Hewett 1978) and in the Second Level Report, Volume 3-Chapter 4, Section 4.4 (Water Budget Models).

Sources of additional information are:

Hydrology of the Copper-Nickel Study Area;

Mustalish et al., 1978

Siegel and Ericson, 1979, (surface and groundwater hydrology, surface and groundwater use)

Brooks and White, 1978, (regional analysis of stream flow)

Savard et al., 1978, (stream flow modeling)

Second Level Report, Volume 3-Chapter 4, Section 4.2, Hydrology Characterization

Hydrology Impacts;

Second Level Report, Volume 3-Chapter 4, Section 4.5, Hydrology Impacts

Impacts on Aquatic Organisms;

Second Level Report, Volume 4-Chapter 1, Aquatic Biology

Water Needs for Copper-Nickel Development;

Hewett 1978

Second Level Report, Volume 3-Chapter 4, Section 4.4, Water Budget Models

1. Model Assumptions

The mining operation models used for the analyses in this report are from Hewett (1978). The 20 X 10^6 mtpy open pit mine model with a 100,000 mtpy smelter/refinery is presented in most detail, while information on the 12.34 X 10^6 mtpy mine model, which would produce the same amount of ore, is included for comparison. Each model has been divided into three subsystems for determining the water budget. Subsystem A consists of the mine, stockpiles, and undisturbed watershed area. The mill and tailing basin make up subsystem B, and the smelter/refinery with the slag heaps are subsystem C.

Most of the hydrologic impacts examined here are caused by an operation which has maximum water recycling. This includes a completely contained site, so all runoff is collected, and collection of seepage from the toe of the tailing dam. Each subsystem has different water needs and excesses. Subsystem A would have an excess of water from mine pit water and surface runoff that could be used in subsystem B, which receives almost no natural water input. Subsystem C also receives little water, but would need clean makeup water, so water from other parts of the system may not be suitable. For certain types of impacts, the effects of an individual subsystem or component of a subsystem, such as a stockpile, will be considered.

There are a number of characteristics of a mining operation that can determine water deficits and excesses. Some water is assumed to be stored in the tailing basin. The tailing basin will leak, however, both from the toe of the taiing dam and through the floor of the basin. It is assumed in the maximum recycling cases that seepage from the toe of the tailing dam is collected, but seepage through the floor of the basin is not collected. Rate of leakage through the floor is determined by the permeability of the underlying material. Three permeability types, as defined in Hewett (1978) are used here to explain the 20 X 10^6 mtpy operation. Seepage rates are: impermeable, 0 ft/yr; semipermeable, 0.2 ft/yr; and permeable, 2.1 ft/yr. These represent volumes of 0, 830, and 8,300 acre feet per year.

Stockpiles hold less water than tailing basins, but seepage from them is also controlled in part by the permeability of underlying material. The same permeabilities used for tailing basin bases are used for stockpile bases in this report.

Storage of water can reduce the amount that must be appropriated to meet a deficit. A system with storage is one which has enough water stored to supply subsystems A and B during the five-year drought of record, which is 12,070 acre feet for a system with impermeable base tailing basin or 16,220 acre feet for a system with a semipermeable base tailing basin. During this time, there would be some site runoff and mine pit water collected, but not enough to supply the operation.

2. Climatology Assumptions

Water excesses and deficits of a mine model are caused in part by precipitation amounts. An "average year" refers to a year during which 28.6 inches of precipitation falls, the average at Babbitt for 56 years of record. A "wet year" with 39 inches of precipitation, is the 100-year wet year; and a "dry year" with 16 inches, is the 100-year drought (Watson 1978). A 100-year wet or dry year has a one percent chance of occurring in any one year, but a 26% chance of occurring during the 30 year projected lifetime of a mining operation.

The five-year drought of record is another precipitation statistic used in some analyses. During this time (June, 1921 to 1925), 106.65 inches of precipitation fell at Babbitt, or an average of 21.25 inches per year.

3. Hydrology Assumptions

Stream hydrology is the object of the analysis presented in most of this report. Many streams in the Study Area carry small volumes of water, at least during parts of the year, so may be greatly affected by reduced flow caused by some aspect of a mining operation. Lakes, on the other hand, are more stable water bodies with larger volumes and may not be affected as quickly or as severely as streams. Impacts on lakes are slow to appear and difficult to determine, and data to predict impacts in detail are not available for most lakes in the Study Area. Because groundwater supplies are small and stable, it is unlikely that they would be used as make-up water. Groundwater paths are relatively short, and in most cases poor quality discharge would re-emerge and join surface water within a short distance.

A number of different flow parameters are used in this report. Flows have been estimated based on drainage area size by Brooks and White (1978) using 17 streams, and Siegel and Ericson (1979), using 10 streams. Table 2 shows the equations used. The actual flow of a stream may differ from the estimated value because streamflow depends on more than just drainage area size.

The 30-day 20-year low flow is used to determine the suitability of streams as appropriation sources. A constant, year-round appropriation would require a stream with sufficient flow even during extreme low flow periods. During a period of less than 30 days, it is assumed that an operation would shut down. The 20 year interval is the longest which can be estimated with the available data.

Table 2. Equations relating flow to drainage area[a].

Description	Equation	Conditions	Source
Average annual flow	$Q^b = 0.79$ d.a.[c]	d.a. > $50 mi^2$	Siegel and Ericson, 1979
April and May flow	Q = (.415) 0.79 d.a.	d.a. > $50 Mi^2$	Siegel and Ericson, 1979
7 day, 2 year low flow	$\text{Log}Q^d = -1.62 + 1.28 \log$ d.a.		Calculated from Brooks and White, 1978
7 day, 20 year low flow	LogQ = −1.9336 + 1.1951 Log d.a.		Brooks and White, 1978
30 day, 20 year low flow	Log Q = −1.8842 + 1.2091 Log d.a.		Brooks and White, 1978

[a] Values are for the Study Area only.
[b] Q = flow in cfs
[c] d.a. = drainage area in mi^2
[d] all logarithins in base 10

The 7-day 2-year low flow is considered the average low flow of a stream. A flow at least this low can be expected to occur on the average every other year. Impacts on low flow that occur often may cause changes in the aquatic life of a stream. The average low flow is compared with various mining operation sizes, discharges, and appropriations to predict worst cases in an average year.

The 7-day 20-year low flow is used in one case to show effects of a more severe and less common low flow.

The average flow of a stream could be changed due to various mining activities. A discharge or appropriation proportional to flow can be compared to average annual flow to determine impacts during an average year. The average year impacts are of importance to aquatic organisms since these impacts will recur often.

A large amount of water is available during spring flow for appropriation or dilution of discharge. The spring (April and May) flood flow of streams in and adjacent to areas of potential copper-nickel development has been found to be 41.5% of the average annual flow by Siegel and Ericson (1979). Changes in spring flow may, however, cause impacts on spawning fish.

Hydrologic impacts will be greatest in the near vicinity of copper-nickel developments. Farther away, or farther downstream, the impacts will, in effect, be diluted. As an extreme example, an operation located in a small watershed near the headwaters of a stream may appropriate the entire flow of that stream during a dry period, thus drying up the stream. Farther downstream, where several tributaries join the stream, there may be a noticeable reduction in flow, but the stream will still be flowing. At a point many miles and tributary additions farther down the stream, the effect of the mine and smelter may be nearly impossible to detect.

Much of the information presented in this report is quite general, and qualitative rather than quantitative. A number of reasons for this exist. There are many combinations of size of operation, location, appropriation needs, discharge volumes, mitigating measures, and climatic factors that could be examined. In order to make this discussion a reasonable length, only two model operations have been selected for discussion, and only one model is analyzed in detail. Streamflow characteristics are generalized for the region, and precipitation inputs are based on the average, wet and dry years. Impacts of the various mining operation activities are considered individually, not cumulatively. A methodology has been presented here, using one model as an example. The same methodology could be used with other models and other climatic factors, and different results would be obtained. The best analysis would be based on site-specific characteristics and on actual mining operation plans.

B. SUMMARY OF POTENTIAL HYDROLOGY IMPACTS

Impacts on hydrology from copper-nickel development may occur both during and after operation.

During operation, the entire mine site would be contained, according to the model. This would prevent runoff from the area from influencing streamflow. All flows would most likely be reduced. If a lake or bog area would contained, flows could be increased because of loss of water storage area.

Appropriation from a stream or lake would reduce flows or lower lake level. Use of stored water during dry or low flow periods could reduce impacts.

Water may be released to the environment from a copper-nickel operation by direct discharge, site runoff, or seepage from the tailing basin or stockpiles to groundwater. Increase in flow, raising of lake levels, and decrease in water quality are possible impacts of discharge. It would be possible to treat the water or control the release in order to reduce impacts. Impacts of uncontrolled discharge are dependent on timing in comparison to streamflow, and are difficult to predict. Accidental discharge, due to a failure in some part of the system, can also occur, and has the potential for severe, though short-term, water quality and hydrology impacts.

Post-operational impacts on hydrology could continue for many years, because the watershed would be altered from its original state. The quality of runoff would be degraded and timing of runoff and proportions of surface runoff, interflow, and baseflow could change. Impacts of the post-opration phase are difficult to predict.

Changes in hydrology due to copper-nickel development would have impacts on other users of water, principally aquatic organisms and humans.

Streamflow changes that may occur due to copper-nickel development are: reduced low flow, reduced high flow, and increased high flow. Loss of aquatic habitat and food producing areas, channel siltation, stagnation in pools, and disruption of life cycles may be the results of reduced low flows (see Second Level Report, Volume 4-Chapter 1). If the reduction recurs every year or two, the population of aquatic organisms may be affected. Reduced high flows could interfere with spawning, because there would be less flooded area. If a discharge enters a stream with low flow, there is less clean water to dilute the discharge. Increased high flows could cause scouring of stream channels.

Lake levels fluctuate naturally; however, frequent or extreme fluctuations caused by a mining operation may result in the drying up of shallow areas at the edge of a lake. These shallows are important food supply and spawning areas for some aquatic organisms.

Reduced streamflows and lake level fluctuation could also cause impacts on human use of water. The major surface water users in the region, power plants and taconite mining operations, could compete with copper-nickel development for water supplies. Other surface water users, including municipal supplies, campgrounds, and irrigation, could be affected by either water quality or quantity changes.

Recreational use of surface water depends, to a certain extent, on the aesthetic quality of the water body. Exposed lake or stream beds caused by inadequate water supply, or poor water quality caused by discharges, would discourage water-oriented recreational activities. Reduction of the fish population is another factor that could reduce recreational use of lakes and streams.

Groundwater level drawdown is a possible effect of copper-nickel development, although most current groundwater use in the region is for taconite mine-pit dewatering, a nonconsumptive use. Rural water systems dependent on groundwater could experience difficulties if their water supply was in communication with a copper-nickel mine.

Any impacts on human water use could ultimately cause economic impacts. Decreased tourism and the necessity of increasing water treatment and increasing the depth of wells are examples of factors which may cause economic impacts.

C. HYDROLOGY IMPACTS

Six types of activities in a copper-nickel operation that may cause hydrology impacts have been determined:

1) Containment of site runoff from the mine/mill site
2) Appropriation of water
3) Controlled discharges
4) Non-point discharges
5) Accidental discharges
6) Post-operational watershed modifications

The impacts of these activities on fifteen streams, whose watersheds are near the mineralized zone (Figures 1 and 2), are described in this section.

1. Containment of Site Runoff

If part or all of a watershed is contained so that no runoff is allowed, hydrologic impacts will occur. Decreased streamflow is one of the primary impacts that would be expected. The amount of streamflow decrease can be directly related to the area of watershed contained. In this analysis, the reduction of low flow, annual yield and spring flow due to a model mine is discussed.

General Impacts of Containment of Site Runoff--For simplicity, it can be assumed that removal of x percent of a watershed will reduce all flows by x percent. This approach has been used here, as well as in modeling by Savard et al. (1978). Table 2 lists the equations used to relate watershed area to streamflow.

Low flows of streams would likely be decreased if site runoff were controlled. Baseflow could be affected if areas which normally store water and help retain flow during dry periods, such as lakes and wetlands, are removed. Streams which already exhibit extreme low flows could have their flows reduced to zero due to control of runoff in their watersheds.

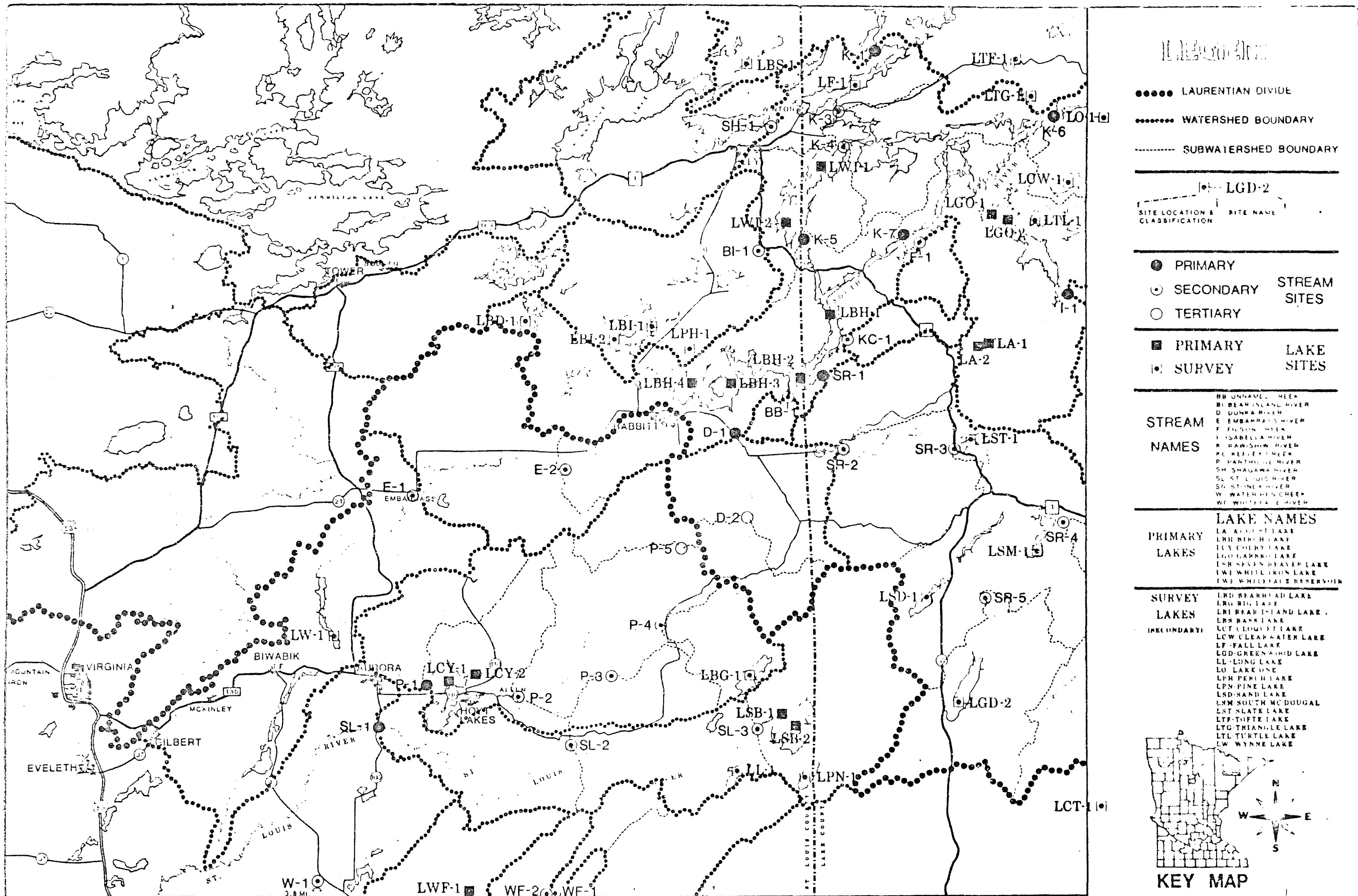

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Figure 1. SURFACE WATER QUALITY MONITORING SITES AND WATERSHED BOUNDARIES

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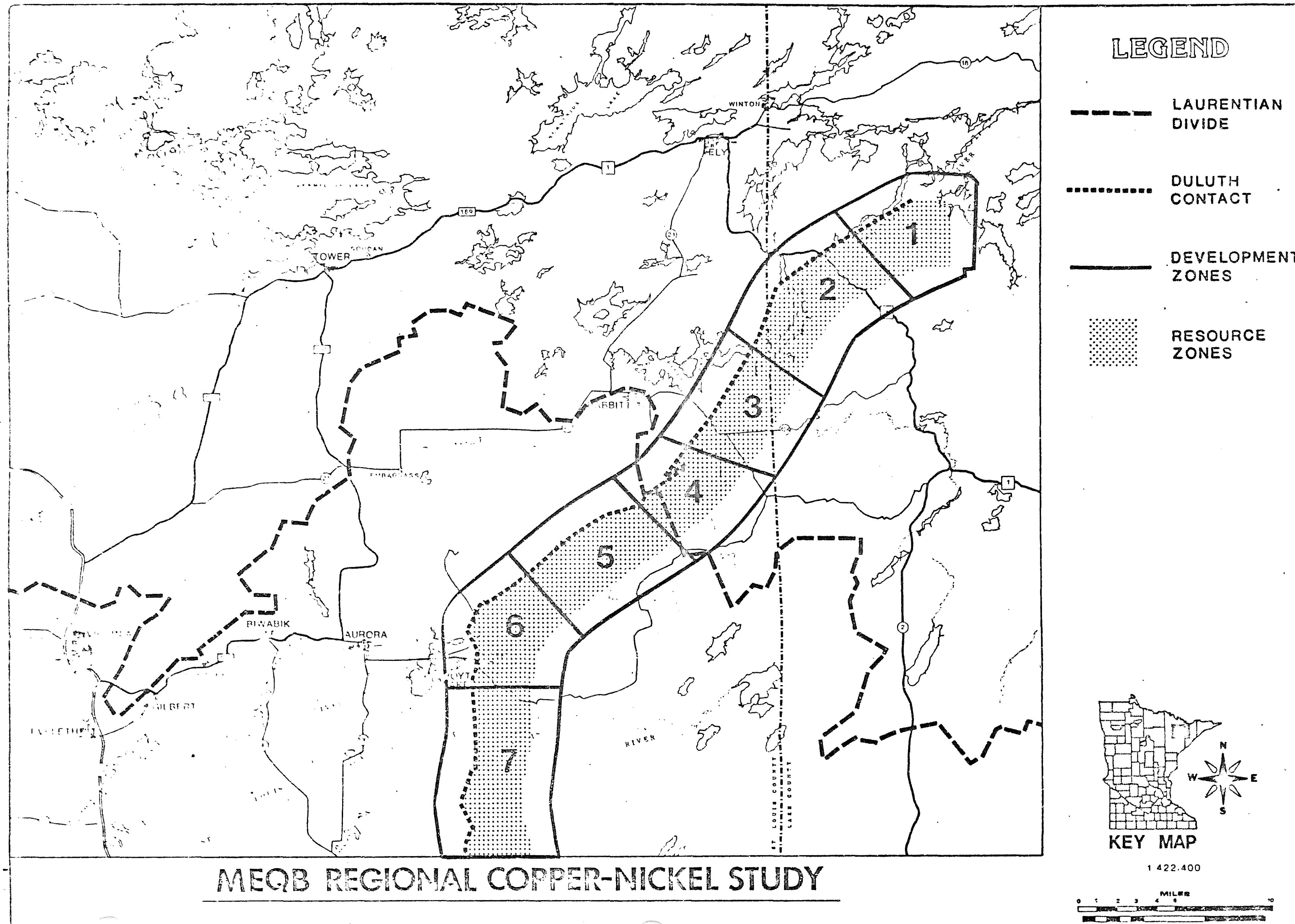


MEQB REGIONAL COPPER-NICKEL STUDY

gure 2, MN CU-NI DEVELOPMENT AND RES RCE ZONES

High flow of a stream may be affected in a number of ways if part of the watershed is removed. Peak flows could be expected to be reduced, and their duration shortened. Peak flow could be increased if an area which normally stores water and damps peak flows, such as a lake or wetland, is removed from the watershed.

If the drainage area of a lake is encroached upon, the water level may be lowered because of decreased inflow.

There would also be the possibility of decreased recharge to groundwater if a recharge area were covered over, and less water could infiltrate to the underground water supply.

Impacts of Containment of Site Runoff on Copper-Nickel Streams--The impacts of containing site runoff on streams in the vicinity of copper-nickel mineralization are assessed here, based on area of the watersheds and area of the entire 12.35 X 10^6 mtpy and 20 X 10^6 mtpy model operations. Table 3 presents the watershed areas and Table 4 the mine model areas.

Figure 3a shows how containing watershed area can affect the low flow of streams. Watershed areas and the areas of the two mine models are along the x axis and flow along the y axis. The 7-day 2-year low flow and the 7-day 20-year low flow are shown.

As can be seen in Figure 3a, three watersheds (Unnamed Creek, Filson Creek, and Keeley Creek) are smaller in areal extent than the model 20 X 10^6 mtpy operation. If an operation of this size were placed in one of these watersheds and the entire area contained, there would be no natural outflow from the watershed.

Table 3. Areas of watersheds in vicinity of copper-nickel developments zones.

WATERSHED	AREA IN MI^2
Unnamed Creek at BB-1	3.63
Filson Creek at F-1	10.4
Keeley Creek at KC-1	11.2
Second Creek at SC-1	22.4
Water Hen Creek at W-1	45.6
Whiteface River at WF-2	47.9
Dunka River at D-1	49.4
Bear Island River at BI-1	68.5
Embarrass River at E-1	88.3
Shagawa River at Sh-1	99.0
Partridge River at P-1	124
Stony River at SR-1	244
St. Louis River at SL-1	277
Isabella River at I-1	341
Kawishiwi River at K-1	1352

Source: USGS 1979.

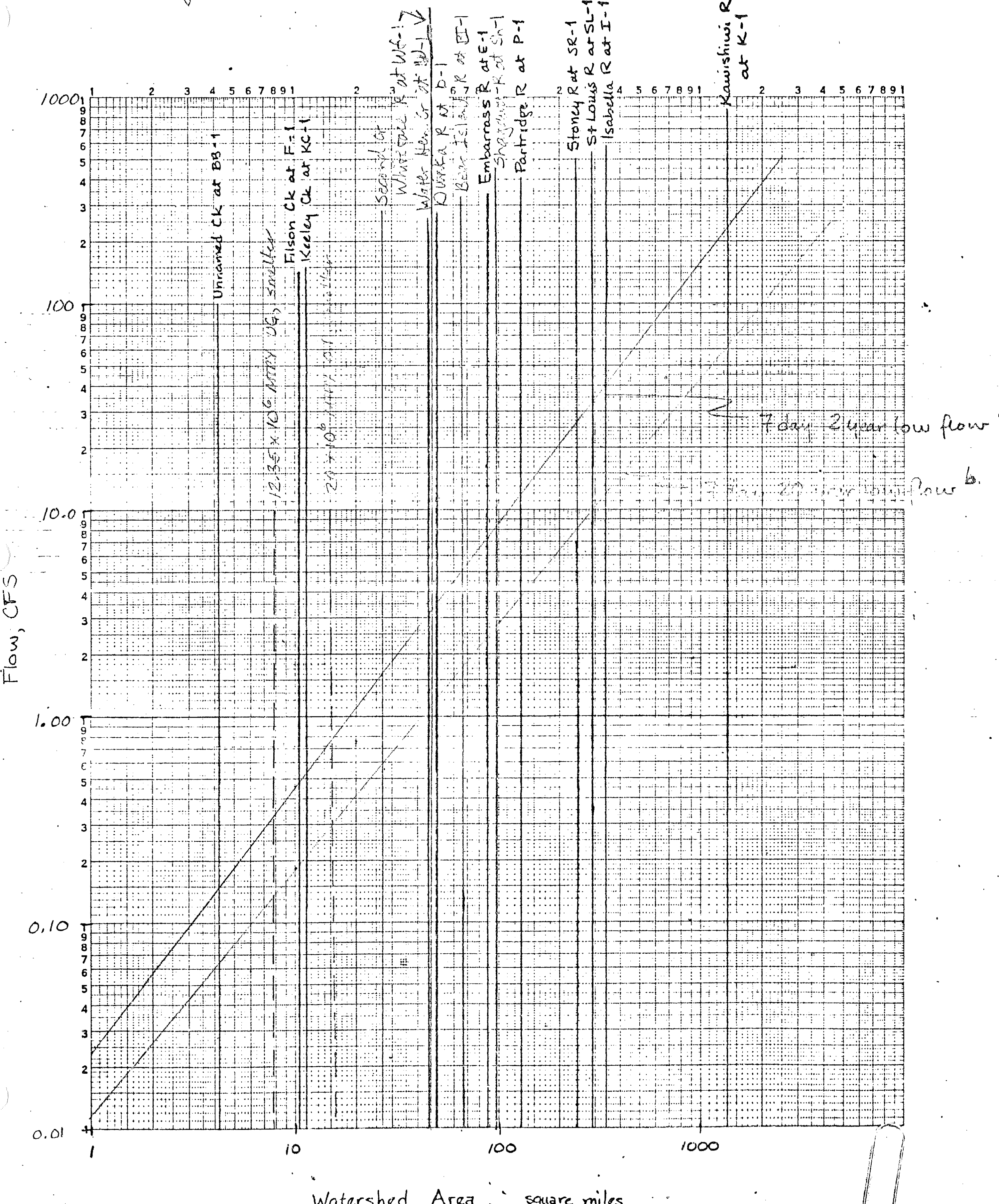
Table 4. Mine model areas

Model Element	20 x 10^6 MTPY Open Pit with 1 mill		12.35 x 10^6 MTPY Underground with 1 mill	
	Acres	Sq. Mi.	Acres	Sq. Mi.
Plant Site	400	.63	260	.41
Open Pit Mine	563	.88	0	0
Overburden Piles	173	.27	0	0
Lean Ore Piles	994	1.55	48	.08
Waste Rock Piles	994	1.55	48	.08
Undisturbed Watershed	2926	4.57	1436	2.24
Tailings Basin	4016	6.28	2309	3.61
Smelter-Refinery	150	.23	150	.23
Slag Piles	25	.04	25	.04
Underground Mine	0	0	750	1.17
Total	10241	16	5026	7.85

Source: Table __. Volume II, Second Level Report.

Containment of Site Runoff

Figure 3a. Effect on Low Flows of Streams



a. Calculated from Brooks and White 1978
b. from Brooks and White 1978 . 10c

The reduction of flow from watersheds is explained in Table 5. The Dunka River is used as an example. The area of the Dunka River Watershed is 49.4 mi^2, and the area of the 20 X 10^6 mtpy model operation is 16 mi^2, or about 32% of the watershed area. If runoff from a model operation in the Dunka Watershed is contained, the 7-day 2-year low flow of the Dunka River would be reduced 26 to 41%. The effect on a 7-day 20-year low flow would be a 26 to 37% decrease.

A larger watershed, such as the Kawishiwi, would not be as greatly affected by this mine model. The size of the model is only about one percent of the size of the watershed, so the flow reduction could be expected to be close to one percent.

The effect of location of a mine in a watershed can be illustrated using these examples. A mining operation placed in the Dunka Watershed would have a large effect on the low flow of the Dunka River. The Dunka Watershed is a part of the much larger Kawishiwi Watershed, so an operation in the Dunka Watershed would also be in the Kawishiwi Watershed. The Kawishiwi River flow would not be greatly affected, however, because the Kawishiwi has a much larger drainage area than the Dunka.

The reduction in average annual yield (total volume of outflow over a year) due to prevention of site runoff can be calculated from Figure 3b. Table 5 shows how to work the calculation. The Dunka River annual yield would be reduced by about 33%, as could be expected from the size of the 20 X 10^6 mtpy model operation.

Figure 3b also includes the spring flood flow compared to watershed area. The decrease in spring flow is close to the decrease in other flows that would be caused by prevention of site runoff from a 20 X 10^6 mtpy model mining operation.

ect on streamflows; example showing use of Figure 3a + b.

Dunka R at D1 49.4	$20x10^6$ MTPY OP 16.0	Dunka- $20X10^6$ OP 33.4	PERCENT DECREASE IN FLOW	$12.35x10^6$ MTPY UG 7.85	Dunka - 12.35×10^6 UG 41.6	PERCENT DECREASE IN FLOW
3.53	.83	2.1-2.7[e]	24-41[e]	.34	2.83-3.19[e]	10-20[e]
1.23	.32	.77-.91[e]	26-37[e]	.14	1.00-1.09[e]	11-19[e]
28300	9200	19100	33	4500	23800	16
11700	3800	7900	32	1900	9800	16

involve many simplifications of watersheds properties and behavior. Their purpose is the order of magnitude of effects. Please refer to the text for more detailed

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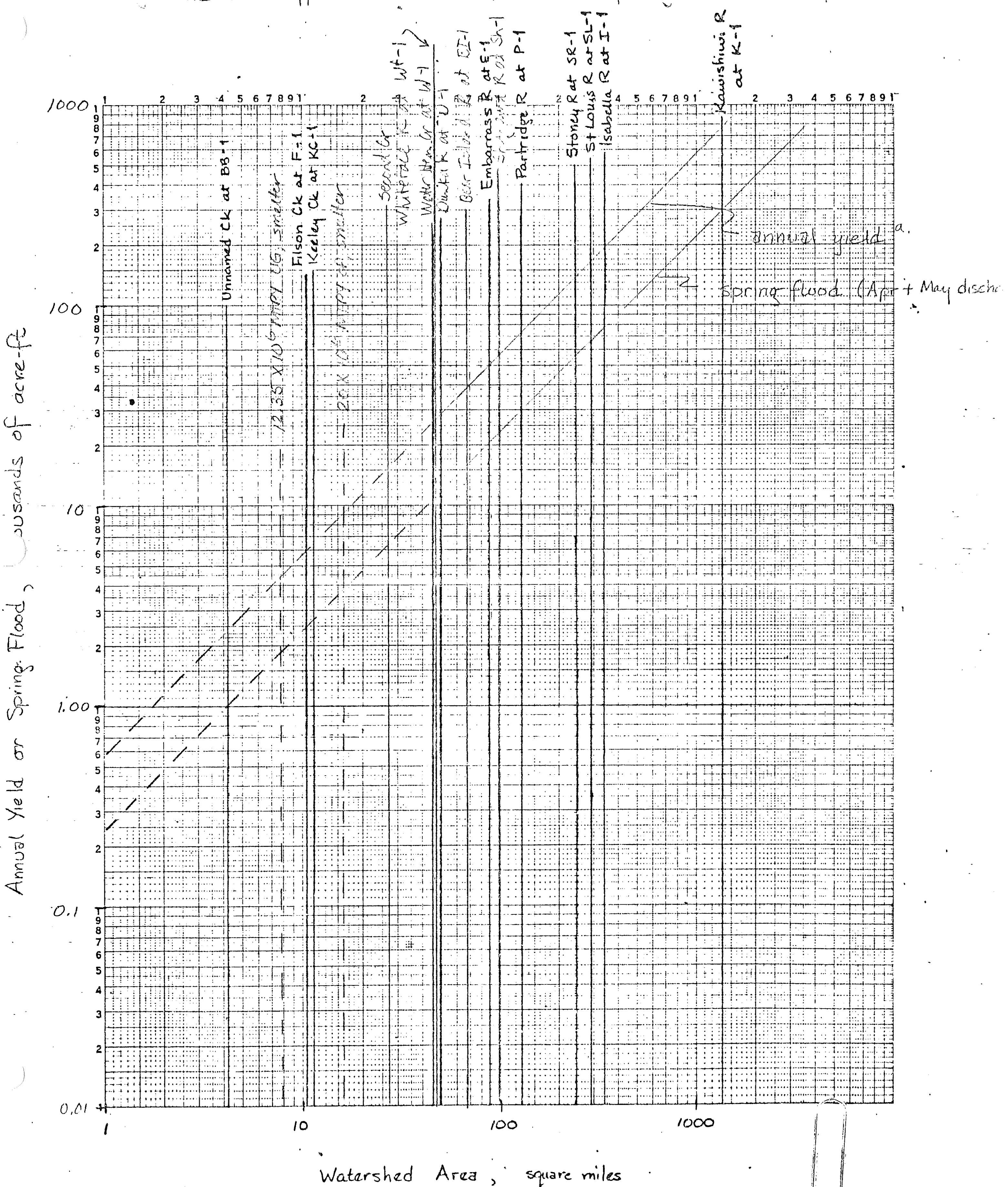
, from Siegel and Ericson 1979
low from river flow
ed area minus mine site area

Containment of Site Runoff

Figure 3 b. Effect on Annual Yield and Spring Flood



a. from Siegel and Ericson 1979

b. Calculated as 41 % of annual yield, from Siegel and Ericson 1979

The model 12.35 X 10^6 mtpy underground operation takes up a smaller area than the model 20 X 10^6 mtpy open pit operation, so the impacts on streamflow from site containment would be less. The size of the model 12.35 X 10^6 mtpy operation is 16% of the Dunka River Watershed. Low flow, annual yield, and spring peak of the Dunka River would all be reduced by about 16%, as shown in Table 5. The 12.35 mtpy operation takes up only about 0.6% of the Kawishiwi River Watershed, and would have a small effect on streamflows.

The examples discussed so far have used the assumption that reduction in flow from a watershed is proportional to the amount of area that is contained by a mining operation. The equations that relate streamflow to watershed area have been worked out based on analysis of a number of streams in the region. For an individual stream in the region, the flow values from such an equation may not be accurate, because flow depends on amount of surface water storage, topography of the watershed, groundwater inputs, and other factors as well as watershed area.

The Dunka River flow provides an example of the discrepancies that can arise due to the regional flow patterns. The 7-day 2-year low flow of the Dunka River as calculated from Brooks and White (1978), based on regional analysis, is 3.53 cfs. The same low flow calculated by Siegel and Ericson (1979), based on the historical flow record of the Dunka River alone, is 2.10 cfs. The difference between these two figures must be due to characteristics of the Dunka River Watershed. The Erie Mining Company's Dunka Pit is located in the watershed. Groundwater is being diverted from entering the river, and instead is flowing into the mine. This diversion caused a loss of about 0.7 cfs of flow from the river during low flow conditions in August, 1976, and may cause an even greater loss during high flow (Siegel and Ericson 1979). The Dunka River Watershed also has a relative lack of surface water storage (Garn 1975). These factors may account for the high estimate of low flow predicted by regional analysis. A site-specific study could take the characteristics of the particular watershed into consideration, and more accurate predictions of streamflow reduction could be made.

Fewer or less severe impacts from site containment would occur if less area were contained. This would be accomplished if the undisturbed watershed area within a mine site was allowed to drain naturally. In the models, undisturbed area is about 40% of the total mine site area. The 20 X 10^6 mtpy mine model area would be reduced to 11.4 square miles if this area were not contained. Operation of an underground rather than an open pit mine would also reduce the amount of contained area (see Table 4).

2. Water Appropriation

This section explains the possible impacts of water appropriation for copper-nickel development on the hydrology of the Research Area. The compound effects of appropriating water from a stream which has had part of its watershed contained by a mining operation are not examined.

A number of cases, all from the 20 X 10^6 mtpy model, will be discussed in this section. The mine and mill (subsystems A and B) will be considered as one case, since there is a good possibility that these components would be operated without a smelter on the same site. During a wet year, these components would have an excess of water from surface runoff and mine pit dewatering. In an average year, there would be a water excess if the tailing basin were on an impermeable or semipermeable base. If the tailing basin were on a permeable base, there would be a water deficit. During a dry year, these components would have a water deficit no matter what type of base was under the tailing basin.

Subsystem B, the mill and tailing basin, will also be considered alone, although it is unlikely that a mill would be located away from a mine. This case receives water in ' only from precipitation on the tailing basin and a minimal amount of water in the ore, so has a continual need for outside water.

The totally integrated mine/mill and smelter/refinery will be considered as the third case. The model smelter/refinery requires a continual supply of fresh make-up water for both cooling and process functions.

A fourth case to be considered is the appropriation need for once-through cooling in the smelter/refinery. This case calls for minimum water recycling and is included as an unmitigated case.

The water deficits discussed above can be made up by use of appropriated water alone, or both appropriated and stored water. Storage can be provided by a man-made reservior which is filled before or during operation, by a dammed stream, or by a lake.

Appropriation can occur from a stream or a lake. Mine pit dewatering, from either a taconite or copper-nickel operation, could also provide part or all of the water supply. Streamflow appropriation may be at a constant rate, only during peak flows, or at a rate proportional to flow (see insets on Figures 5a, b and c). Appropriation from a lake may be at a constant rate, only when inflow is high, or at a rate proportional to inflow.

If no storage reservior is provided and the stream system does not have the flexibility to store large amounts of water during high flow periods, water must be appropriated at a constant rate or as needed. In order to meet this appropriation need during a dry period, a stream would have to be quite large.

If storage is provided, then stored water could be used during dry periods when surface runoff from the site is not sufficient and streamflows are low. There are additional possible appropriation modes with storage: with peak flow and proportional to flow. These two types of appropriation would have a less severe effect on low flow, so a smaller stream could be used with constant appropriation.

Appropriation from a lake, for a system with or without storage, would also be possible. As for streams, constant appropriation would require the largest body of water to supply an operation during a dry year.

<u>General impacts of water appropriation</u>--The impacts on streamflow of appropriating water would depend on the appropriation mode. A constant rate appropriation would reduce all flows, and low flows would be most severely affected. Appropriation from peak flows would reduce spring and flood flows, but would not affect low or average flows. High flows, necessary for spawning in the spring, could be reduced enough to cause impacts on the fish population. Appropriation at a rate proportional to flow would reduce all flows by a certain percent. Appropriation during low flow periods would most likely cause the greatest impacts. Because stored water would be available however, appropriation would not be necessary in dry years, when low flows would be especially low.

Appropriation from a lake may have impacts on lake level. Lake level fluctuates as inflow rate, evaporation, and seepage of groundwater fluctuate. Table 6 shows how evaporative loss from a lake surface varies during a year. If the inflow rate to a lake minus the evaporation and seepage losses, is greater than the appropriation rate, then the level will not be lowered. If the withdrawal rate is greater than the inflow rate, minus the losses, however, the appropriation

Table 6. Calculations of monthly gain or loss from lake surfaces.

MONTH	J	F	M	A	M	J	J	A	S	O	N	D
Aver Precip, Babbitt, mm[a]	23.4	20.0	29.2	48.7	73.0	98.1	103.8	97.9	94.9	61.7	46.8	28.2
Lowest Precip, Babitt, mm[a]	0	1.5	2.3	1.3	7.5	23.9	30.0	15.0	7.4	11.2	5.6	4.1
Ave Pan Evap, Hoyt Lakes,[a] X0.7, mm[b]	0	0	0	52.5	78.4	96.6	112.7	88.9	50.4	28	~10.5	0
Ave Precip-Ave Evap, mm	23.4	20.0	29.2	-3.8	-5.4	1.5	-8.9	9.0	44.5	33.7	36.3	28.2
Ave Precip-Ave Evap, cfsm[c]	0.83	0.71	1.0	-0.13	-0.19	0.05	-0.31	0.32	1.57	1.18	1.28	1.0
Lowest Precip-Ave Evap, mm	0	1.5	2.3	-51.2	-70.9	-72.7	-82.7	-73.9	-43	-16.8	-4.9	4.1
Lowest Precip-Ave Evap, cfsm	0	0.05	0.08	-1.8	-2.5	-2.6	-2.9	-2.6	-1.5	-0.59	-0.17	0.14

[a] From Watson 1978

[b] 0.7 is a standard coefficient to convert pan evaporation observations to estimated evaporation from ponds to shallow lakes

[c] cfsm = ft^3 per second per mi^2 of lake surface area

must dip into storage and lower the lake level. The information available on lake inflow in the region is not sufficient to allow predictions of the impacts of approрriation from lakes. Appendix A shows the mass curve for a lake in a 10 square mile watershed.

Appropriation needs and impacts - systems without storage--Appropriation needs for model 20 X 10^6 mtpy and 12.35 X 10^6 mtpy operations without storage are shown in Table 7. Notice that in an average year there is a net excess of water from case 2, model subsystems A and B with a tailing basin on an impermeable base. Case 1, the totally integrated system, requires an approprition at all times, because the smelter/refinery is in constant need of fresh make-up water. The only internal sources of water to subsystem B, (case 3) are precipitation on the tailing basin and a neglibible amount of water in the crude ore, so this case has a continual need for appropriated water. Case 4, the smelter cooling water with minium recycling, has a large and constant appropriation need.

For model systems without storage, a stream must be able to provide water even during dry periods in order to be a suitable source. The predicted 30-day, 20-year low flow is compared with the 100-year dry year and 5-year drought model appropriation needs in Figure 4. The 100-year dry year would be an extreme case. If, during such a dry year, part of the appropriation need could be made up by water in the tailing basin, a smaller streamflow could be used. The one year appropriation need during a five year drought of record is included to show thg streamflow that could supply an operation in a less severe case. The 100-year low flow should be used to compare with the 100-year dry year needs to be more correct, but this streamflow parameter has not been determined.

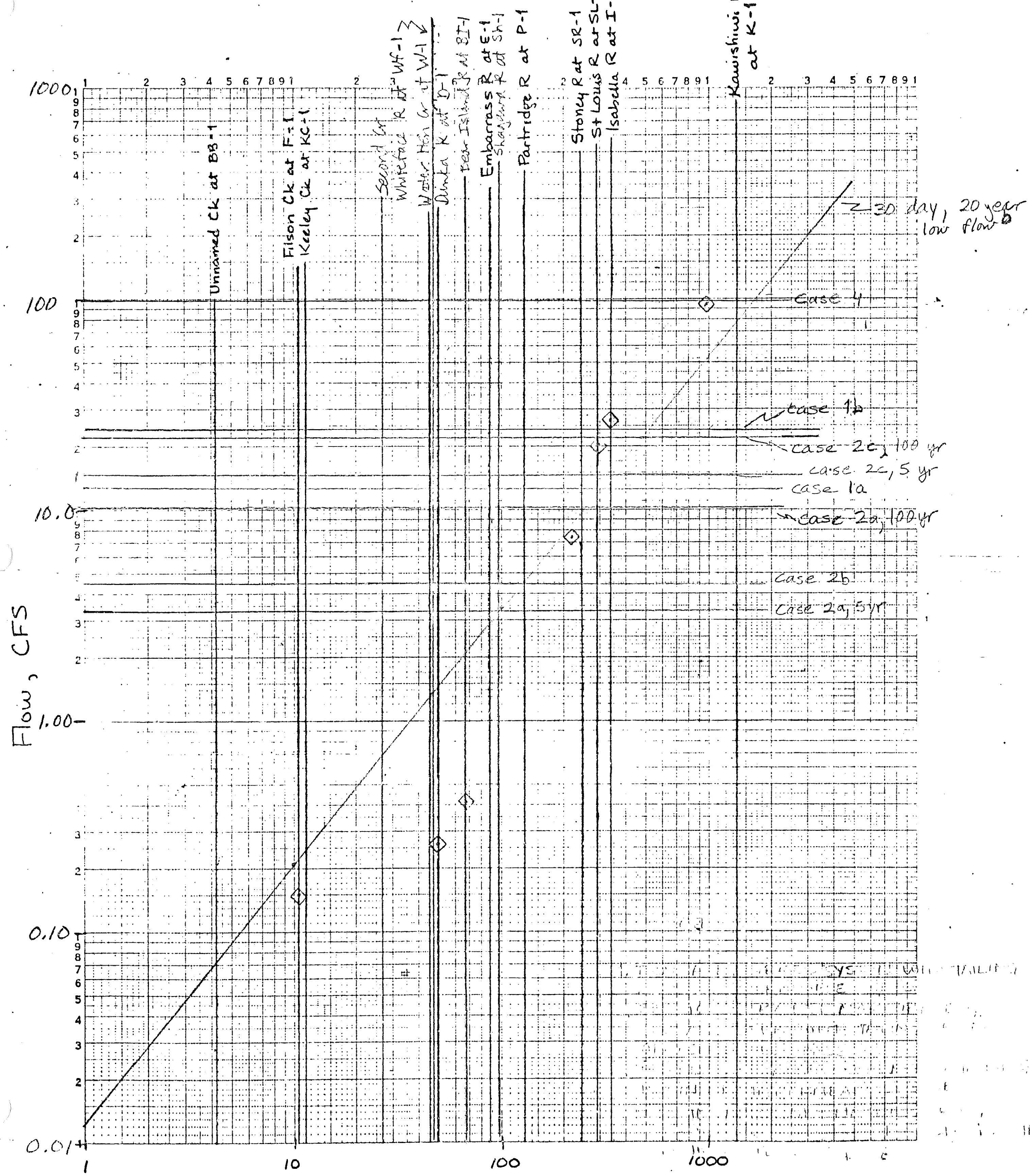
The most severe case shown in Figure 4 is that of the smelter cooling water with minimum recycling. Even the largest stream in the region, the Kawishiwi River,

Table 7. Appropriation needs for systems without storage.

Description of Case	100 Year Dry Year Appropriation Need, CFS		5 Year Drought, 1 Year Appropriation Need, CFS		Average Year Appropriation Need, CFS		Source[a]
	20x10[6] MTPY	12.35x10[6] MTPY	20x10[6] MTPY	12.35x10[6] MTPY	20x10[6] MTPY	12.35x10[6] MTPY	
1. Totally integrated mine/mill smelter/refinery system with maximum water recycling							
a. Tailing basin on impermeable base	12.5[c]				7.29		
b. Tailing basin on permeable base	24.2[c]				8.44		Table
2. Subsystems A and B, maximum water recycling.							
a. Tailing basin on impermeable base	10.36[c]	5.53	3.33[c]	2.80	-4.97[b]	1.38[b]	
b. Tailing basin on semipermeable base			4.48[c]	3.46			Tables 11,12, 17a,18a,
c. Tailing basin on permeable base	22.10[c]	12.16	14.81[c]	9.41	6.56[d]	5.25	
3. Subsystem B, maximum water recycling							
a. Tailing basin on impermeable base	10.77	6.49			3.18	2.21	
b. Tailing basin on permeable base	22.10	13.12			15.19[d]	8.84	Tables 11,12
4. Smelter cooling water, minimum water recyling					99[c,d]	99	Table

[a] Second level report, Vol. III, Ch. 4, section 4.4
[b] Negative appropriation implies a discharge
[c] Values used in Figure 4
[d] Values used in Figure

Figure 4. Suitability of Streams as Appropriation Sources for systems without storage[a]



a. See Table 7 for description of cases

b. From Brooks and White 1978

could not supply this appropriation need during the 30-day, 20-year low flow. This type of water use is not likely to occur in the Study Area at any rate, because the heated water would not meet the Minnesota standards for thermal discharges. Streams with watersheds smaller than about 100 square miles would not have sufficient flow to supply any of the appropriation cases shown on Figure 4.

Table 8 shows the use of Figure 4, with the Kawishiwi and St. Louis Rivers as examples. The totally integrated system with a tailing basin on a permeable base would need to appropriate 30 percent of the flow of the Kawishiwi River during 30-day, 20-year low flow conditions. In case 2b without the smelter, 28 percent of the river flow would be appropriated.

Cases 1a and 2a are compared to the St. Louis River 30-day, 20-year low flow in Table 8. Eighty-three percent of the streamflow would be appropriated for the case of subsystems A and B with a tailing basin on an impermeable base. The totally integrated system would need more water than the stream could provide.

The Isabella, Stony and Partridge Rivers could also serve as sources for one or more of the appropriation needs shown in Figure 4, so would be suitable as constant appropriation sources. In terms of impacts, the average year appropriation compared to the average low flow streamflow is important, and will be presented later in relation to constant appropriation for systems with storage.

The 12.35 X 10^6 mtpy model operation has a smaller appropriation need, as shown in Table 8. More streams in the Research Area would be suitable as constant appropriation sources for systems of this size without storage.

Table 8. Effect of appropriation on streamflow-systems without storage; example showing use of Figure 3, all volumes in CFS.

Case[a]	30 Day, 20 Year Low Flow	100 Year Dry Year Appropriation[a]	Low Flow-Appropriaton	% Reduction in Flow
Kawishiwi River				
1b. Totally integrated system with tailing basin on permeable base	79.35	24.2	55.15	30
2b. Subsystems A+B with tailing basin on permeable base	79.35	22.10	57.25	28
4. Smelter cooling water	79.35	99[b]	0	over 100
St. Louis River				
1a. Totally integrated system with tailing basin on impermeable base	12.44	12.5	0	over 100
2a. Subsystems A+B with tailing basin on impermeable base	12.44	10.36	2.08	83

[a] See Table 7.
[b] Smelter appropriation need is the same in a wet, average or dry year.

Appropriation needs and impacts-systems with storage--Table 9 shows average year water needs for 12.35 x 10^6 mtpy and 20 x 10^6 mtpy model systems with storage. It is assumed that water would be withdrawn from storage during dry years. In an average year, the combined mine/mill would have a deficit only if the tailing basin were on a permeable base (case 2). Subystem B alone (case 3) would require an appropriation no matter what kind of base the tailing basin had. The totally integrated system would have a water deficit at all times because of the smelter, but the need would be greatest if the tailing basin were on a permeable base (case 1).

The effect on annual yield of appropriation proportional to flow is shown in Figure 5a. The inset illustrates how the appropriation would look compared to an annual hydrograph. It can be seen that most of the streams in the region would be able to supply the necessary amount of water for this type of appropriation. Table 10 show how to use Figure 5a. The Stony River flow, as shown in Table 10, would be reduced only 3 to 8%, if used as a proportional appropriation source. The Dunka River, with a smaller drainage area, would experience a 17 to 38% reduction in flow. The flow reduction would occur all year with proportional appropriation. Both spring flow and low flow would be reduced, which could cause impacts on aquatic organisms.

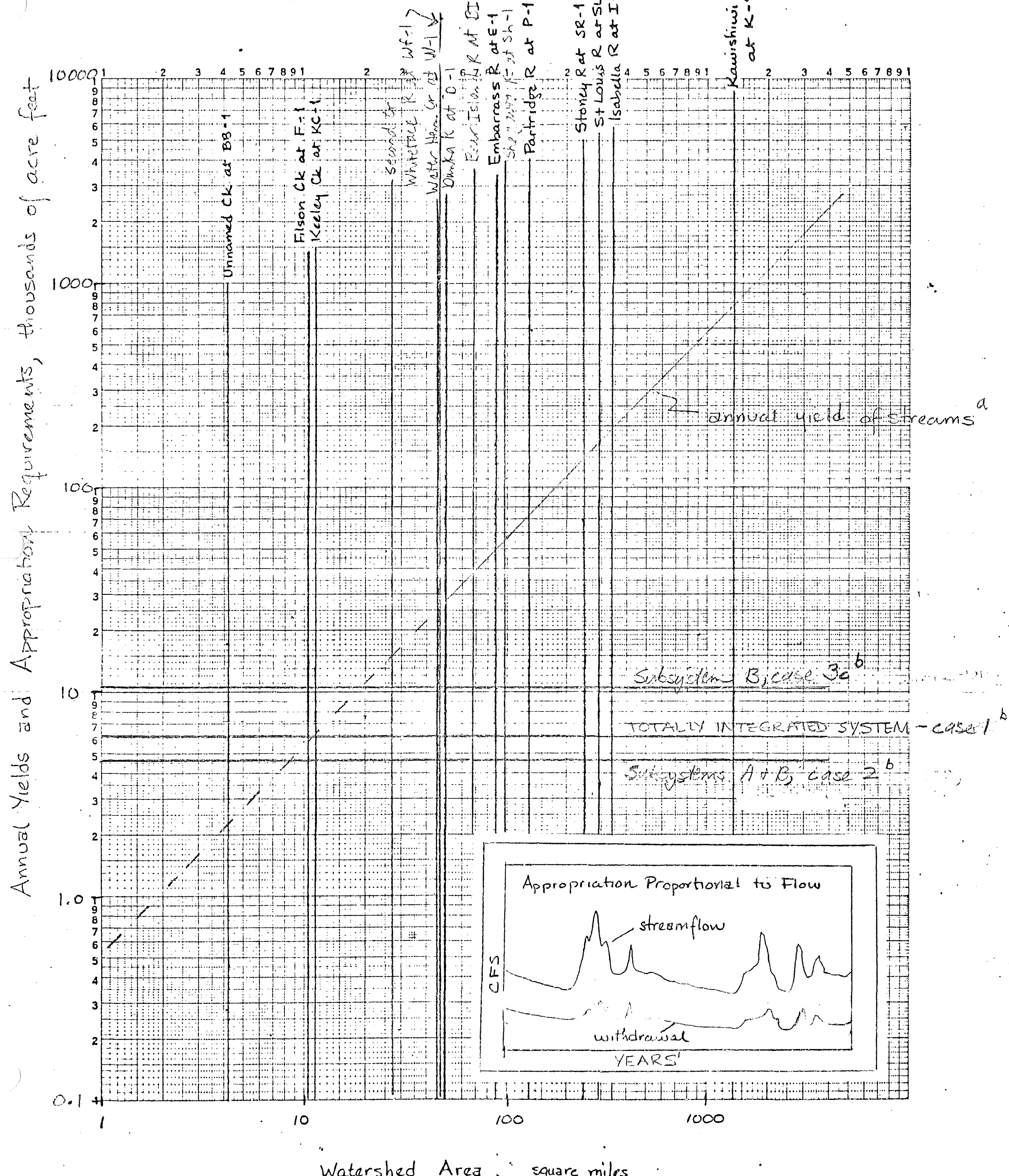
Model appropriation from spring runoff and the effect on streamflow is shown in Figure 5b. The inset shows how this type of appropriation would affect a streamflow hydrograph: the water supply for an entire year would be appropriated in a two month period. It would be possible to also appropriate from peak flows after storms, but spring flow is most important to aquatic organisms, so only impacts on spring flow will be discussed. Fewer streams would be able to supply the appropriation needs of the model cases using this type of appropriation. The

Table 9. Appropriation needs for systems with storage.

DESCRIPTION OF CASE	AVERAGE YEAR APPROPRIATION, ACFT 20x10^6 mtpy	12.35x10^6 mtpy	SOURCE[a]
1) Totally integrated mine/mill smelter/refinery system with tailing basin on permeable base and maximum water recycling	6100[b]	not estimated	Table 16
1a. smelter contact water[e]	1100[d]	1100	Table
1b. smelter non-contact water[e]	4200[d]	4200	Table
2. Subsystems A and B, with tailing basin on permeable base and maximum water recycling	4800[b,c]	3800	Tables 11,12
3. Subsystem B with no water recycling			
3a. tailing basin on impermeable base	2300	1600	Tables 11,12
3b. tailing basin on semipermeable base	3200	2100	Tables 11,12
3c. tailing basin on permeable base	11,000[b]	6400	Tables 11,12

[a] Second level report, Vol. III, Ch. 4, section 4.4
[b] Values used in Figures 5a,b, and c
[c] Value used in Figure 6
[d] Values used in Table 13
[e] Included in 1

Figure 5a. Appropriation Proportional to Flow
for systems with storage



a. From Siegel and Ericson 1979
b. See Table 7

Table 10. Effect of appropriation on streamflow-systems with storage; Example showing use of Figures 5a,b and c.

a. Appropriation proportional to flow (all volumes in acre feet)

Case[a]	Stony River Annual Yield	Average Year Appropriation[a]	Annual Yield Appropriation	% Reduction in Flow
1. Totally integrated system	139,682	6100	133,582	4
2. Subsystems A + B	139,682	4700	134,982	3
3. Subsystem B	139,682	10,600	129,082	8

b. Appropriation from spring runoff (April + May) (all volumes in acre feet)

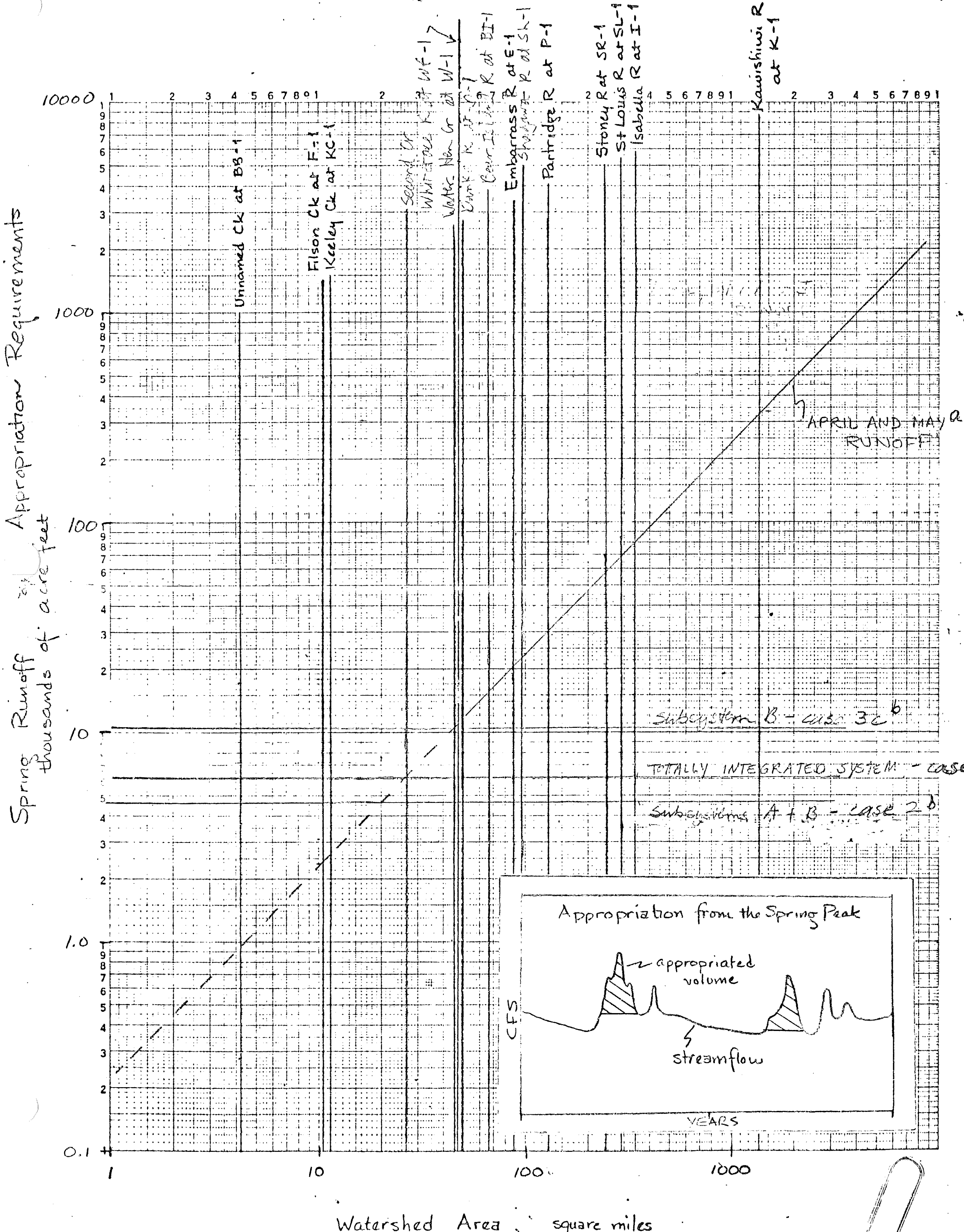
Case[a]	Stony River Spring Runoff	Average Year Appropriation[a]	Spring Runoff -Appropriation	% Reduction in Flow
1. Totally integrated system	57,968	6100	51,868	11
2. Subsystems A + B	57,968	4700	53,268	8
3. Subsystem B	57,968	10,600	47,368	18

c. Constant Appropriation (all volumes in CFS)

Case[a]	Stony River 7-day 2-yr low flow	Average Year Appropriation[a]	Low Flow-Appropriation	% Reduction in Flow
1. Totally integrated	27.3	8.4	18.9	31
2. Subsystems A + B	27.3	6.5	20.8	24
3. Subsystem B	27.3	14.6	12.7	53

[a] see Table 9

Figure 5b. Appropriation from the Spring Runoff for systems with storage



a. [illegible] by Siegel and Ericson 1979

Stony River at SR-1 is again used as an example in Table 10 to show amount of stream flow reduction due to appropriation. The three cases would reduce spring peak flow in the Stony by eight to 18 percent.

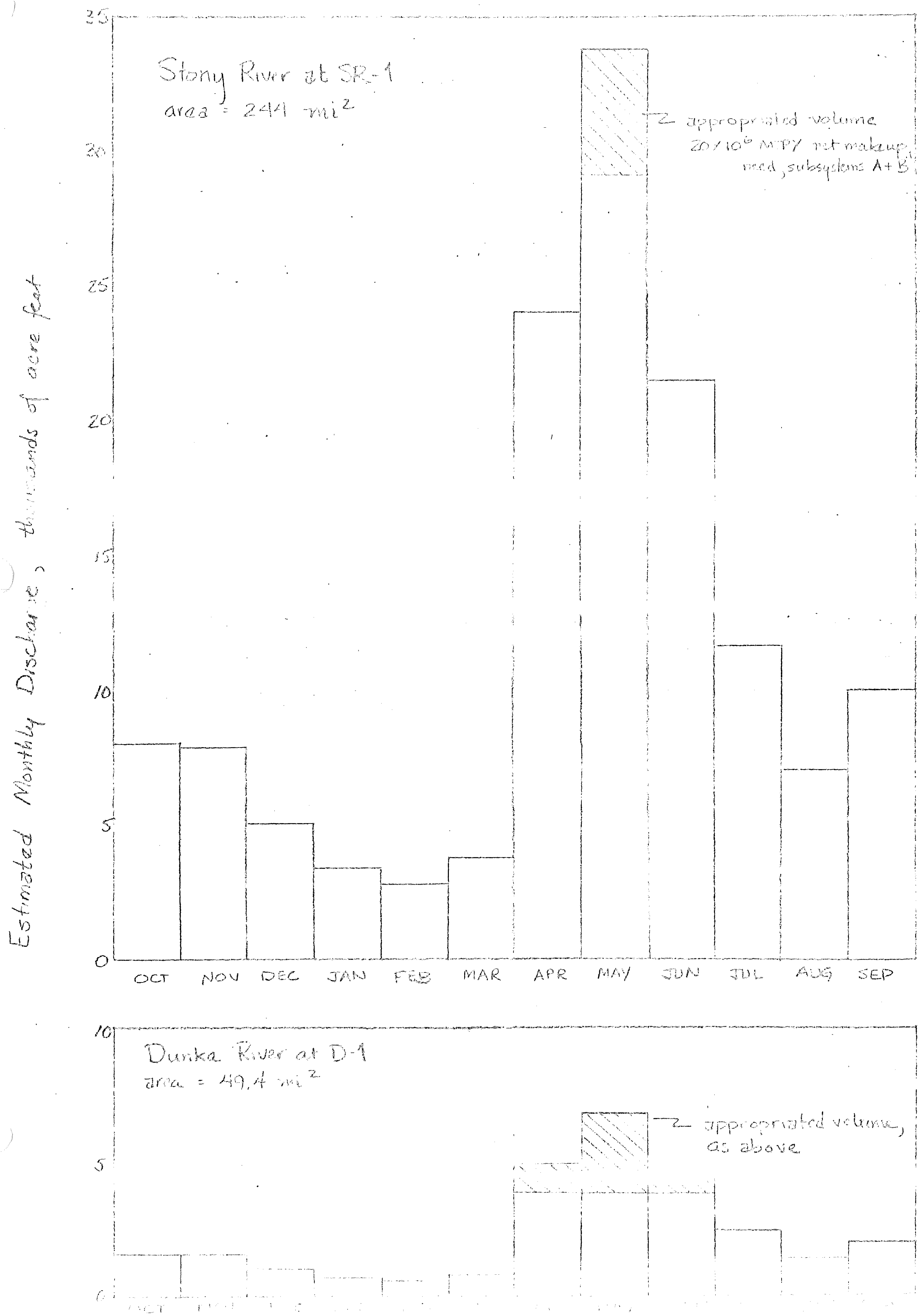
Figure 6 illustrates flow reduction by spring peak appropriation in another way. The bar graph shows the average percentage of annual flow occuring in each month in the Stony and Dunka Rivers, as determined by Siegel and Ericson (1979). The shaded area represents the volume of water needed for the case 2 appropriation (subsystems A and B with a tailing basin on a permeable base). It is obvious that the impact on the Dunka River would be much greater than the impact on the Stony River if this type of appropriation were to occur.

Constant appropriation would also be possible for systems with storage but is probably not very likely. The storage reservoir would eliminate the need for this type of appropriation. The effect on low flow of streams by constant appropriation is shown in Figure 5c. The insert at the bottom of the figure illustrates how a constant appropriation appears on a streamflow hydrograph.

Only four streams on Figure 5c could meet the appropriation needs of all the cases. The Stony River at SR-1 is the smallest stream that could accomodate all three of the cases. Table 10 shows that low flows of the Stony River would be reduced 24 to 53 percent by these models cases.

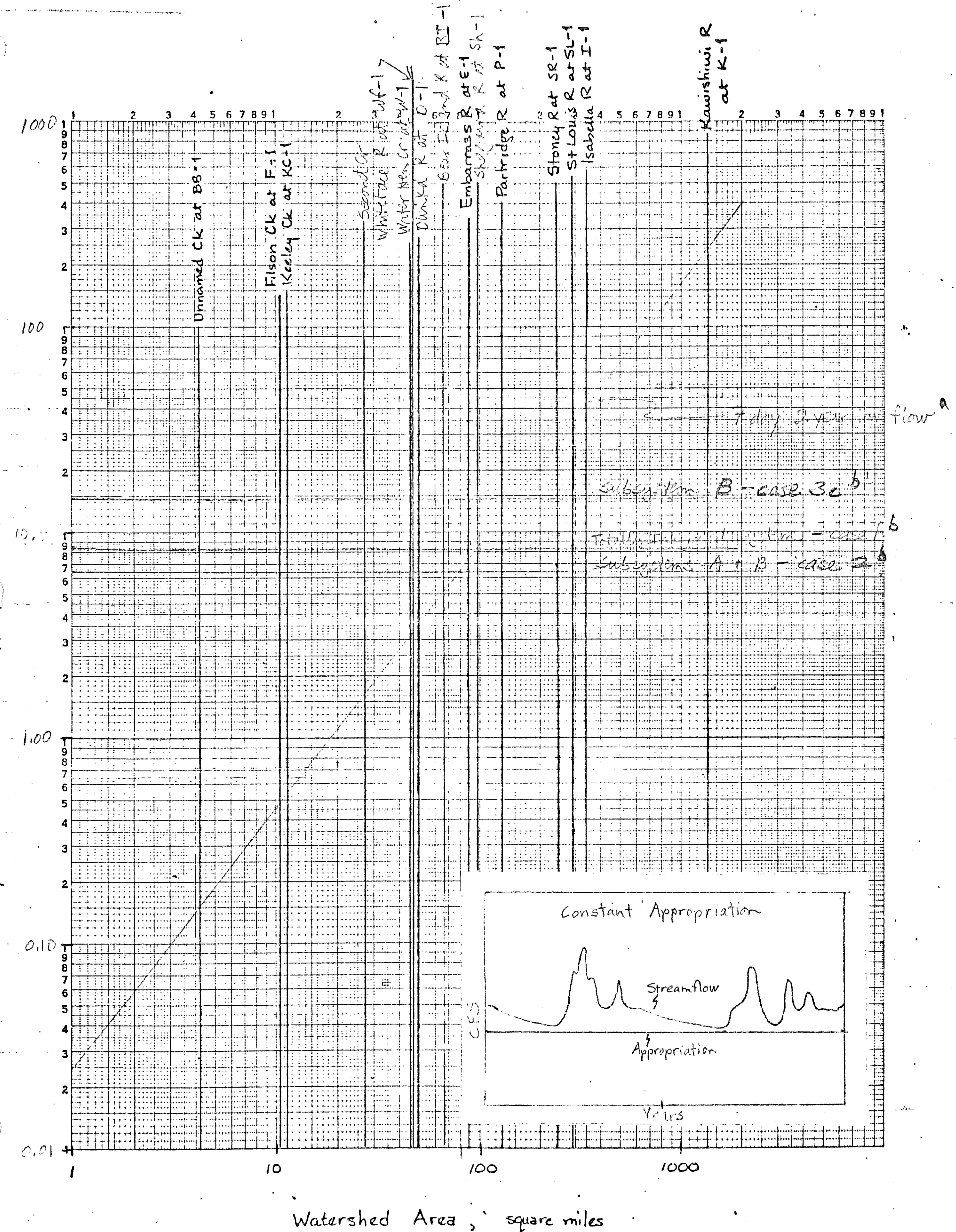
Figure 5c can also be used to predict impacts on streams by appropriation for model systems without storage. In the previous section it was shown that only the Kawishiwi River at K-1, the Isabella River at I-1 and the St. Lous River at Sl-1 would be suitable appropriation sources during a dry year. In an average year, the cases shown in Figure 5c would reduce the low flow of the Kawishiwi by only three to six percent.

Figure 10. Appropriation from Spring Runoff for systems with storage - effect on two streams



values from Siegel and Ericson 1979, Table 10

Figure Ic. Constant Appropriation for Systems with Storage



a. Calculated from Brooks and White 1978
b. See Table 9

A number of methods of mitigating impacts due to appropriation have been suggested in this discussion. The 12.35 x 10^6 mtpy underground operation has smaller water needs than the 20 x 10^6 mtpy open pit operation, and if built, would appropriate less water.

Maximum water recycling could be used as a mitigation measure. The case of the once-through smelter cooling water shows that without recyling, no streams in the region would be suitable appropriation sources. Reducing loss of water from the system would provide more water to recycle. Tailing basin seepage could be collected and returned to the system, or an impermeable base could be used to prevent large water losses.

The use of a storage reservoir is an obvious way to mitigate impacts from appropriation. If storage was available, no appropriation would be necessary in a dry year, when less stream and lake water would be available. A choice of appropriation modes would be possible. Constant appropriation would be unlikely, but if used, would only be possible from a few of the larget streams in the area. Spring flow appropriation would be possible from a greater number of streams, although it may not be desirable to appropriate large amounts of water at spawning time. The least severe impacts would occur if appropriation proportional to flow was used.

The storage reservoir would need to be filled initially, which could cause impacts on a lake or stream. Impacts could be minimized by filling the reservoir slowly over a long period of time. If the reservoir were filled quickly there could be severe impacts for a short period of time. The company could find it advantageous to fill the reservoir quickly so that the water was available when operation began.

3. Controlled discharges

An excess of water would be accumulated by some of the mine models, and would need to be discharged to the environment. These discharges would increase the flow of receiving waters and could degrade water quality. This section will describe the impacts of model discharges on streamflow. The most serious problem will probably be water quality impacts, and dilution ratios will be presented to illustrate this problem.

Controlled discharges from four model cases of the 20 x 10^6 mtpy operation will be discussed: Subsystems A and B combined, the waste rock and lean ore stockpiles, smelter contact water, and smelter non-contact water.

Subsystem A and B; the mine, mill, tailing basin and stockpiles, will be considered as one case. These elements would have a water excess and would be required to discharge during a wet or average year if the tailing basin were on an impermeable base. Water would seep out the edges of waste rock and lean ore stockpiles on impermeable bases during wet or average years. This could be collected and discharged in a controlled manner and will be considered as another discharge case. Seepage from stockpiles is potentially some of the most toxic discharge from a mining operation.

Only the average year discharge, compared to the average year streamflow, will be considered for these two cases. The average year impacts are of most concern, since they would recur often, whereas the impacts of occassional wet year discharges would be unnoticable after a number of average years. The impacts of discharges will be considered alone, not in addition to impacts from preventing site runoff or appropriating water.

A discharge of contact and non-contact water from the smelter/refinery would always be necessary. The amount discharged would be the same in a wet, dry, or average year. Contact water or process water comes in contact with materials being processed by a plant, and must be treated before discharge. Non-contact water flows in closed systems and has the function of removing heat. The water is increased in temperature, but not exposed to contamination (except for bacteriacides, algacides or fungicides to keep the cooling tower clean, and corrosion and scale inhibitors to keep the condensor and piping clean). A certain amount of non-contact water must be continually discharged in order to prevent buildup of natural constituents in the water. The discharge water would have about a 30 percent higher concentration of constituents than the intake water. More information on smelter discharge can be found in Hewett (1978).

Since discharge of water from the smelter/refinery complex is constantly necessary, fresh make-up water is also always necessary. For this reason, the impacts of discharging into the same stream which is appropriated from will be considered. The net effect is to decrease the flow of a stream, since some of the appropriated water evaporates; and degrade the water quality, since the discharge is not as clean as the appropriated water.

Discharge to a stream can be timed in a manner similar to appropriation timing: at a constant rate, with spring flow, or proportional to flow.

<u>General impacts of controlled discharges</u>--The major problems associated with discharges in the Study Area would probably be water quality impacts. Constant discharge would cause the worst impacts: during low streamflow periods, a large discharge could make up nearly the entire flow of a stream, so that little dilution could occur. If the discharge were toxic, aquatic organisms could be

harmed. Repeated or prolonged episodes of high concentrations of toxic materials could destroy the population of organisms in a stream. Discharge proportional to flow would probably cause less severe impacts, because the amount of water available during low flow to dilute the discharge would be greater.

Discharge during spring peak flow could cause high concentrations of toxic materials to enter a stream during the vulnerable spawning period. Constant discharge or discharge proportional to flow would cause fewer impacts during spring flow, since not as much material would be discharged.

Water quantity impacts could occur due to discharge from a copper-nickel operation. Flooding is not generally a problem in the Study Area, but an increase in current velocity could cause scouring of a stream channel and may be detrimental to aquatic ecosystems. Potential problems could be an increase in spring flows if discharge during spring runoff occurred, and increases in low flow due to constant discharge (however, increase in low flow could quantitatively benefit a stream).

Discharge into a lake is also possible, or discharge materials could enter a lake from a stream. Water quality change would again probably be the most serious impact. The impact on lake water quality may be dependent on how quickly a discharge moves through the lake. The flushing rates of 26 lakes studies by the Copper-Nickel Study ranged from .11 to 82 times per year (second level report Volume III, Chapter 4, section 4.2), with the average rate of 8.25 times per year. One could assume that a molecule of contaminant would remain in a lake for about a month and a half before being discharged. A certain amount of the contaminant would accumulate in the lake if this were the case.

The problem is not this simple, though. If the discharge has a higher temperature than the lake water, it may float along the top to the outflow point very quickly. If, on the other hand, the discharge has a lower temperature than the lake water, it may slide along the bottom of the lake. In a thermally stratified lake, there is no mixing between the cold bottom layer (hypolimnion) and the warmer top layer (epilimnion) during most of the year. A discharge could accumulate in the hypolimnion, and then in the spring or fall when mixing occurred, become mixed throughout the water column, at which time some of the material could be discharged. Both the accumulation of material in the hypoliminion, and the relatively sudden mixing of material into the rest of the lake during spawning periods, could stress aquatic organisms. The same types of problems could occur if materials from a mining operation became trapped in lake sediment, and were released periodically.

<u>Impacts of controlled discharges on Copper-Nickel streams</u>--The quantities of discharge water from the four cases to be discussed are shown in Table 11. Quantities for both the 12.35 x 10^6 mtpy and the 20 x 10^6 mtpy operations are included, although only the latter operation will be discussed in detail.

Discharge at a constant rate compared to low flow of streams in the Research Area is shown in Figure 7a. The most serious impacts from this type of discharge would occur during low flow, and then 7-day, 2-year low flow represents the average low flow condition of a stream. Table 12 shows how the figure can be used to determine the dilution ratio and flow increase caused by two of the model discharges. The discharge from model subsystems A and B would cause a 140 percent increase in the Dunka River low flow. Because the discharge would be greater than the flow of the stream, dilution of the discharge would be poor (0.58) (The smaller the number, the better the dilution.) The inset at the bottom

Table 11. Quantities of discharge water.

DESCRIPTION OF CASE	DISCHARGE IN ACRE FEET/YR 20×10^6 mtpy	12.35×10^6 mtpy	SOURCE[a]
1. Subsystems A and B with tailing basin on impermeable base and maximum water recycling, in an average year	3600[b]	1000	Tables 11,12
2. Waste rock and lean ore piles on impermeable bases, in an average year	1420[b]	70	Table 9
3. Smelter/refinery contact water	310[b]	310	Table 15
4. Smelter/refinery non-contact water	3200[b]	3200	Table 15

[a]Second level report, Vol. III, Ch. 4, section 4.4
[b]Values used in Figures 7a,b and c

Figure 7a. Constant Discharge

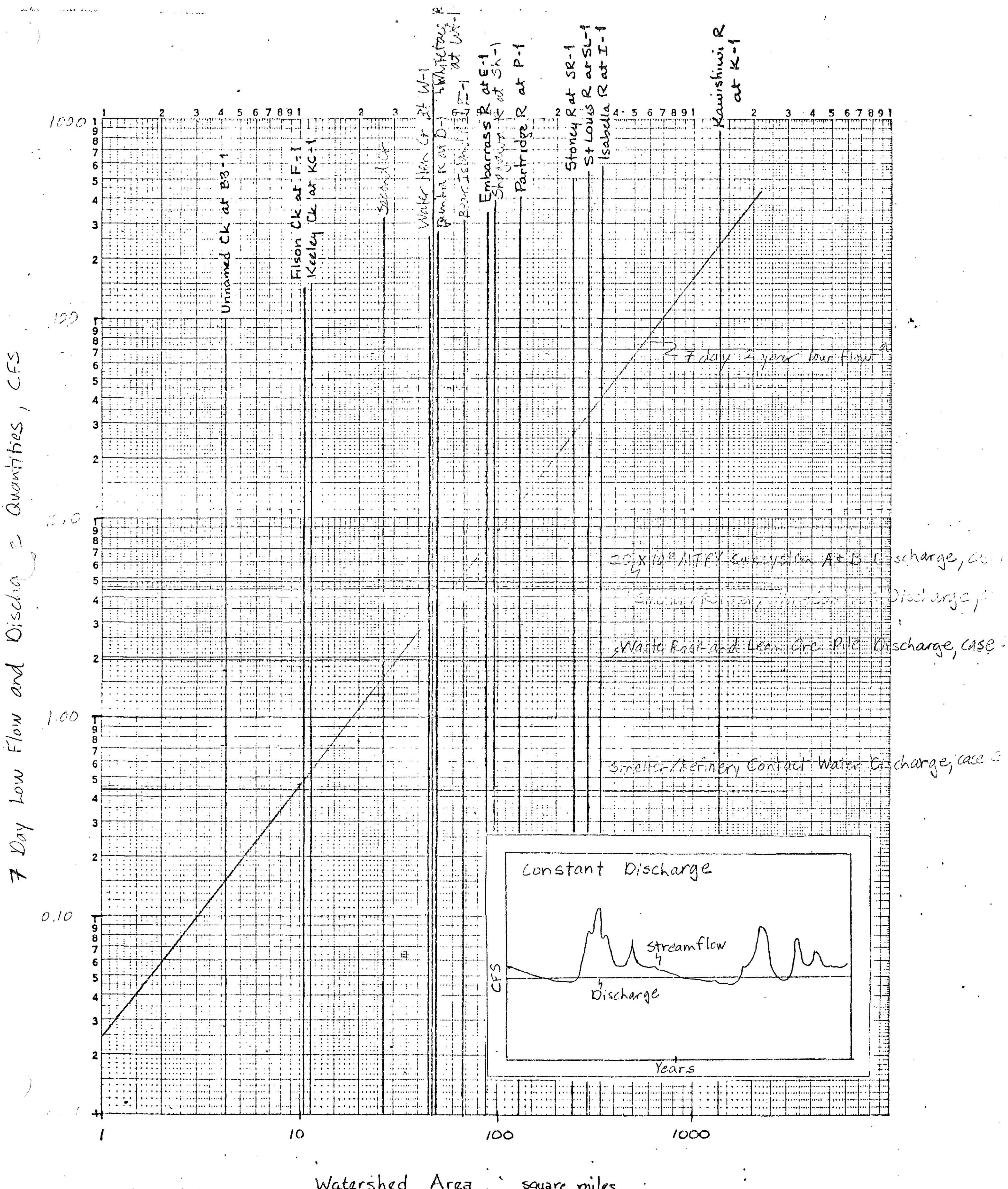


Table 12. Dilution of mine/mill discharges and effect of discharge on streamflow, example showing use of Figures 7 a,b and c.

a. Constant discharge (volumes in CFS)

Case[a]	A. Dunka River 7-day 2-yr low flow	B. Discharge[a]	C. Flow + Discharge	Dilution Ratio[b] (B/C)	Percent Increase in Flow
1. Subsystems A + B	3.53	4.97	8.50	0.58	141
2. waste rock & lean ore piles	3.53	1.96	5.49	0.36	56

b. Discharge with Spring Runoff (volumes in acre feet)

Case[a]	A. Dunka River Spring Runoff	B. Discharge[a]	C. Flow + Discharge	Dilution Ratio (B/C)	Percent Increase in Flow
1. Subsystems A + B	11,700	3,600	15,300	0.24	31
2. waste rock & lean ore piles	11,700	1,420	13,100	0.11	12

c. Discharge proportional to flow (volumes in acre feet)

Case[a]	A. Dunka River Annual Yield	B. Discharge[a]	C. Flow + Discharge	Dilution Ratio (B/C)	Percent Increase in Flow
1. Subsystems A + B	28,300	3,600	31,900	0.11	13
2. waste rock & lean ore piles	28,300	1,420	29,700	0.05	5

[a] see Table 11
[b] the smaller the ratio, the better the dilution

of figure 7a illustrates the condition of discharge flow exceeding streamflow in low flow periods. The increase in low flow in the Dunka from just the stockpile discharge would be 56 percent, which could cause quality impacts.

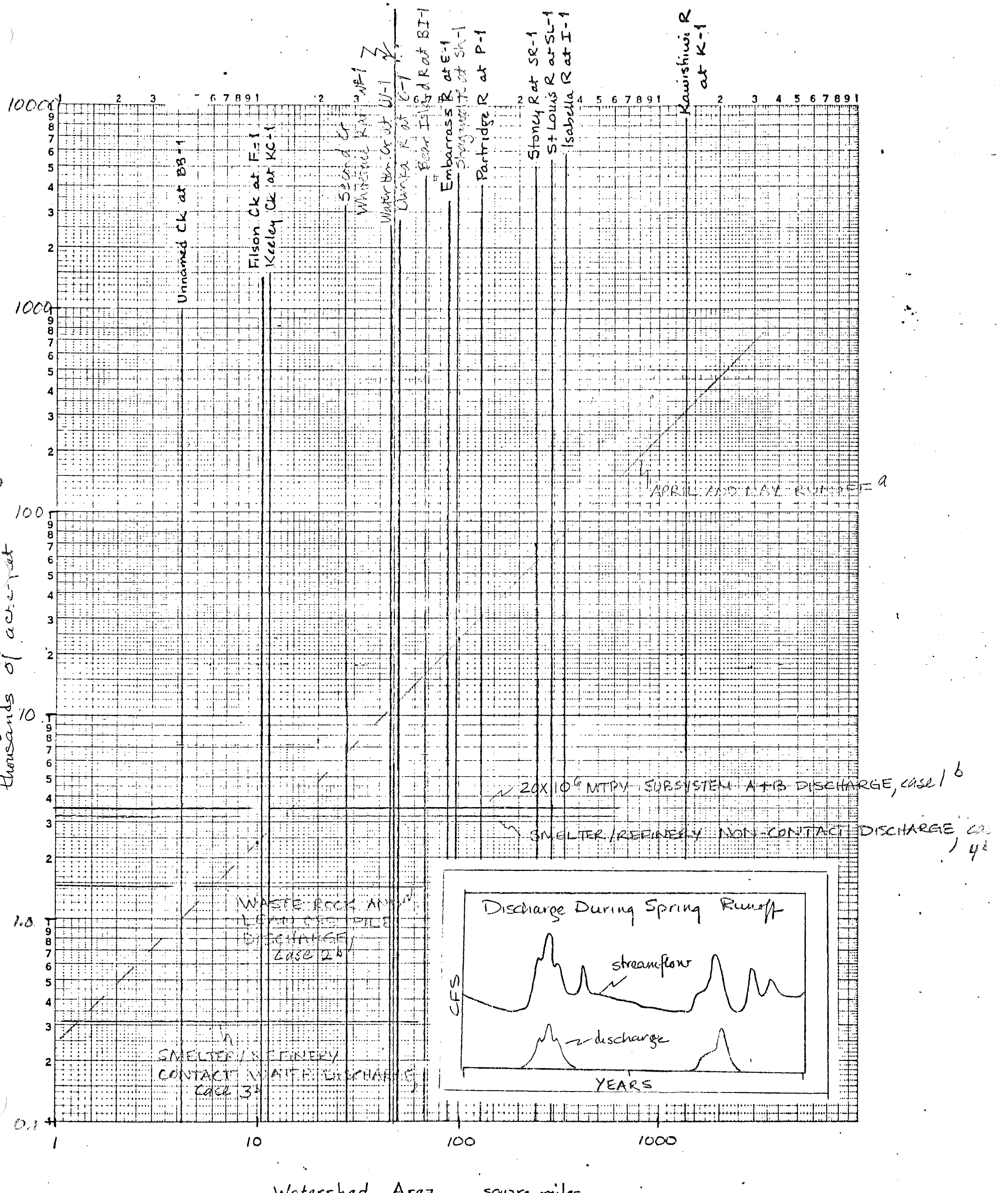
Streams in larger watersheds would not experience such extreme flow increases due to these model discharges. The Kawishiwi River low flow, for example, would increase only about one percent with the addition of Subsystems A and B discharge.

Figure 7 b shows discharge during spring runoff compared to April and May flow of streams in the Research Area. The inset shows how this type of discharge occurs only in the spring, and the rest of the year the stream is unaffected. The increase in spring flow of the Dunka River due to Subsystems A and B discharge would be 31 percent (see Table 12), and the increase from stockpile discharge would be 12 percent. The dilution ratios are better than those in the previous example: 0.24 and 0.11.

The final discharge mode, proportional to flow, is compared in Figure 7c to the annual yield of streams and illustrated by the inset. Table 12 shows the flow increase and dilution ratio in the Dunka river caused by two discharge cases. The annual yield would be increased 13 and five percent by discharge proportional to flow from these cases. Dilution ratios would be 0.11 and 0.05.

Figures 7a, b and c also include values for model smelter/refinery discharges. Table 13 shows how the effect on streamflow from these discharges can be analyzed using the Stony River as an example. Since the smelter constantly requires fresh make-up water, the combined effects of appropriation from and discharge to an individual stream are considered. The appropriation mode is the same as the discharge mode in each case. (Appendix B shows how the dilution ratio would vary

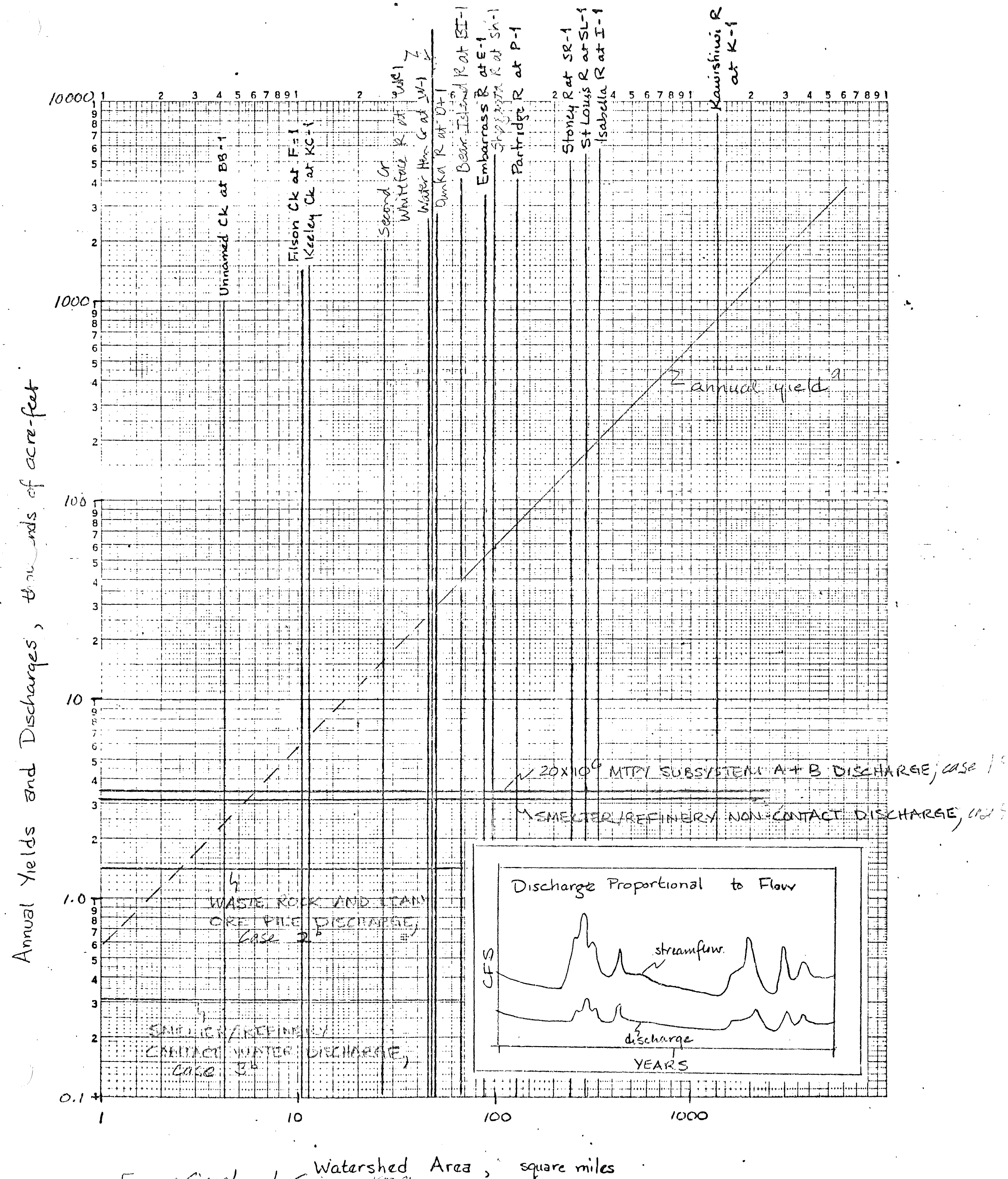
Figure 7b Discharge During Spring Runoff



a. Calculated ... by Siegel and Ericson 1979

b. "

Figure 7c Discharge Proportional to Flow



a From Siegel and Ericson 1979

b. See Table 11

Table 13. Dilution of smelter/refinery discharges and effects of discharge on streamflow, example showing use of Figures 7 a,b and c.

Case[a]	A. Stony River 7-day, 2-year Low Flow	B. Appropriation[a]	C. Discharge[b]	D. Impacted Streamflow (A-B+C)	Dilution Ratio[c] C/D	% Decrease in Flow (A-D)/A x 100
a. constant discharge	cfs	cfs	cfs	cfs		
3. contact water	27.3	1.52	0.43	26.2	0.02	4
4. non-contact water	27.3	5.80	4.42	25.9	0.17	5
	A. Stony River Spring Runoff					
b. discharge with spring runoff	acft/yr	acft/yr	acft/yr	acft/yr		
3. contact water	58,000	1100	310	57,210	0.005	1.4
4. non-contact water	58,000	4200	3,200	57,000	0.06	1.7
	A. Stony River Annual Yield					
c. discharge proportional to flow	acft/yr	acft/yr	acft/yr	acft/yr		
3. contact water	140,000	1100	310	139,210	0.002	0.6
4. non-contact water	140,000	4200	3,200	139,000	0.02	0.7

a See Table 9
b See Table 11
c The smaller the ratio, the better the dilution.

during a year if appropriation proportional to flow and constant discharge were used.).

Both contact and non-contact water discharges are included in Table 13. The volume of non-contact water is greater than that of contact water, so in all cases greater dilution of contact water occurs. Contact water is, however, much more contaminated than non-contact water.

The net result of appropriating and discharging from the same stream is a reduction in flow, as shown in the last column of Table 13. This is because some of the appropriated water is lost in the system before it is discharged.

Constant appropriation and discharge would have the worst effects on a stream during low flow, and are compared to the 7-day, 2-year low flow of the Stony River in Table 11. Non-contact water would have a 0.17 dilution ratio, contact water a 0.02 dilution ratio. The decrease in flow from these two discharge cases would be 5 and 4 percent.

Spring flow appropriation and discharge for the smelter contact and non-contact water in the Stony River is also shown in Table 13. In these cases the flow decreases would be only 1.7 and 1.4 percent. The dilution ration of non-contact water would be 0.06, and of contact water, 0.005.

Appropriation and discharge proportional to flow would spread the impact out over an entire year of flow, and the annual yield of the Stony River is used for the calculation in Table 13. Non-contact water would be diluted by 43 times its flow in streamflow and contact water by 450 times its flow in streamflow. Flow decrease would be 0.7 or 0.6 percent.

Impacts on a stream due to a discharge will depend on the quality of the discharge and the quantity and timing compared to streamflow. Mitigation of impacts c 'e accomplished in a number of ways. Maximum recycling, which has been assumed in the caes presented here, can reduce the quantity of water discharged. Operation of an underground mine would require discharge of less water than operation of an open pit mine. Another way to reduce the amount discharged is to contain less area. For example, runoff from the undisturbed area within the mine site could be allowed to drain naturally, instead of being collected and discharged. The amount of water seeping out of a stockpile could be reduced if the pile were made taller. With a smaller area, the stockpile would collect less precipitation, so would discharge less water.

The discharge mode could be chosen to reduce impacts on a stream. Constant discharge would probably cause the most severe quality impacts since discharge during low flows could be poorly diluted. Discharge during spring flow could also cause problems because spring is a spawning time. Discharge proportional to flow would probably cause the least water quality impacts.

4. Non-point discharges

A certain amount of water which falls on or is cycled through a mining operation may be discharged in an uncontrolled manner as surface runoff from all or part of the site, seepage from the tailing basin, or seepage from waste rock and lean ore stockpiles. This water could run off the surface into a stream, or could seep into the ground and then reemerge and join a stream.

One source of uncontrolled discharge from the mine models considered in this section could be surface runoff from the entire mine site. The assumption that has been made up to this point is that all runoff would be collected and used or discharged in a controlled manner. It is possible, though, that all or part of the site would not be contained, and runoff could flow into a lake or stream. If this were the situation, the best case would be if runoff occurred proportional to streamflow, so that maximum dilution would occur. A more likely case would be that peak flow from the mine site and peak flow in the stream would not coincide, and mine site discharge would be poorly diluted. Because the timing of flow from a mine site compared to the timing of streamflow is unknown, impacts cannot be discussed quantitatively.

Seepage from a model tailing basin is more easily predicted. Two seepage losses are possible: through the toe of the tailing dam, or through the basin floor into the underlying surficial strata. The model assumes a seepage collection system around the dam which would return water seeped through the toe of the basin. Seepage through the floor of the tailing basin is fairly constant and the rate depends on permeability of the underlying material. Two cases of tailing basin seepage will be considered in this section: seepage from a tailing basin on a permeable base and from a tailing basin on a semipermeable base, both from the 20 x 10^6 mtpy model. It is assumed for this discussion that the leachate reemerges in the same watershed in which the tailings basin is located.

Seepage from waste rock and lean ore stockpiles is another possible source of uncontrolled discharge. The hydrology of stockpiles has been discussed in the "Copper-Nickel Development Water Budget" (Hewett 1978). Water from precipiation infiltrates through the stockpile to the bed of fine material at the bottom of the stockpile. From here, some of the water will flow over the bed of fine material and seep out of the edge of the stockpile. This is called interflow.

The rest of the water flows through the fine material and seeps out at the edge of the stockpile if the pile is on an impermeable base, or seeps into the local groundwater system if the stockpile is on a permeable base. This is called baseflow. Inteflow and baseflow from a stockpile on an impermeable base are assumed in the model to be collected, and have been discussed as case 2 in the controlled discharge section.

Water which seeps into the groundwater system from a stockpile is much more difficult to collect for treatment than water which seeps out at the edge of a pile. Seepage from stockpiles on permeable bases for a 20 x 10^6 mtpy model operation will be considered. Where the permeable surficial material is a thin layer over bedrock, the leachate would probably travel a short distance before reemerging to join a stream. This condition will be assumed for our discussion.

General impacts of non-point discharges--Effects of uncontrolled discharges on streams could be both water quality and quantity impacts, however quality impacts are expected to be most severe. If a constant uncontrolled discharge is substantial compared to streamflow, there may be a change in the type of organisms that could survive in the stream. Increase in high flow could cause scouring of a stream channel. Baseflow increases due to uncontrolled discharge may be beneficial from a water quantity standpoint.

Water quality impacts caused by uncontrolled discharges would depend on the quality of the discharge and the volume and timing of discharge compared to streamflow. The worst quality water is expected to be the stockpile baseflow, which could be in contact with toxic material in the stockpile for tens of days. Because this flow is slow and sustained, there is a good chance that it would enter a stream during low flow conditions. Degraded water quality could have impacts on aquatic organisms.

Lake water quality could be degraded due to non-point discharges. The same factors influencing mixing of a controlled discharge in a lake, discussed earlier, would operate with a non-point discharge.

A non-point discharge which entered the groundwater reservior could be filtered by the soil and some of the contaminents could be removed. Large areas would probably not be affected by contaiminated groundwater because flow paths in the region are relatively short and the water reemerges within a few miles. Because groundwater is not heavily used in the region, most groundwater contamination would probably not be noticed.

Impacts of non-point discharges on Copper-Nickel streams--Table 14 shows the quantities of several uncontrolled seeps from model 12.35 x 10^6 mtpy and 20 x 10^6 mtpy operations. The stockpile seepage amount is for an average year; tailing basin seepage is the same no matter how much precipitation falls. Discharge of the seepage is assumed to be constant for this discussion.

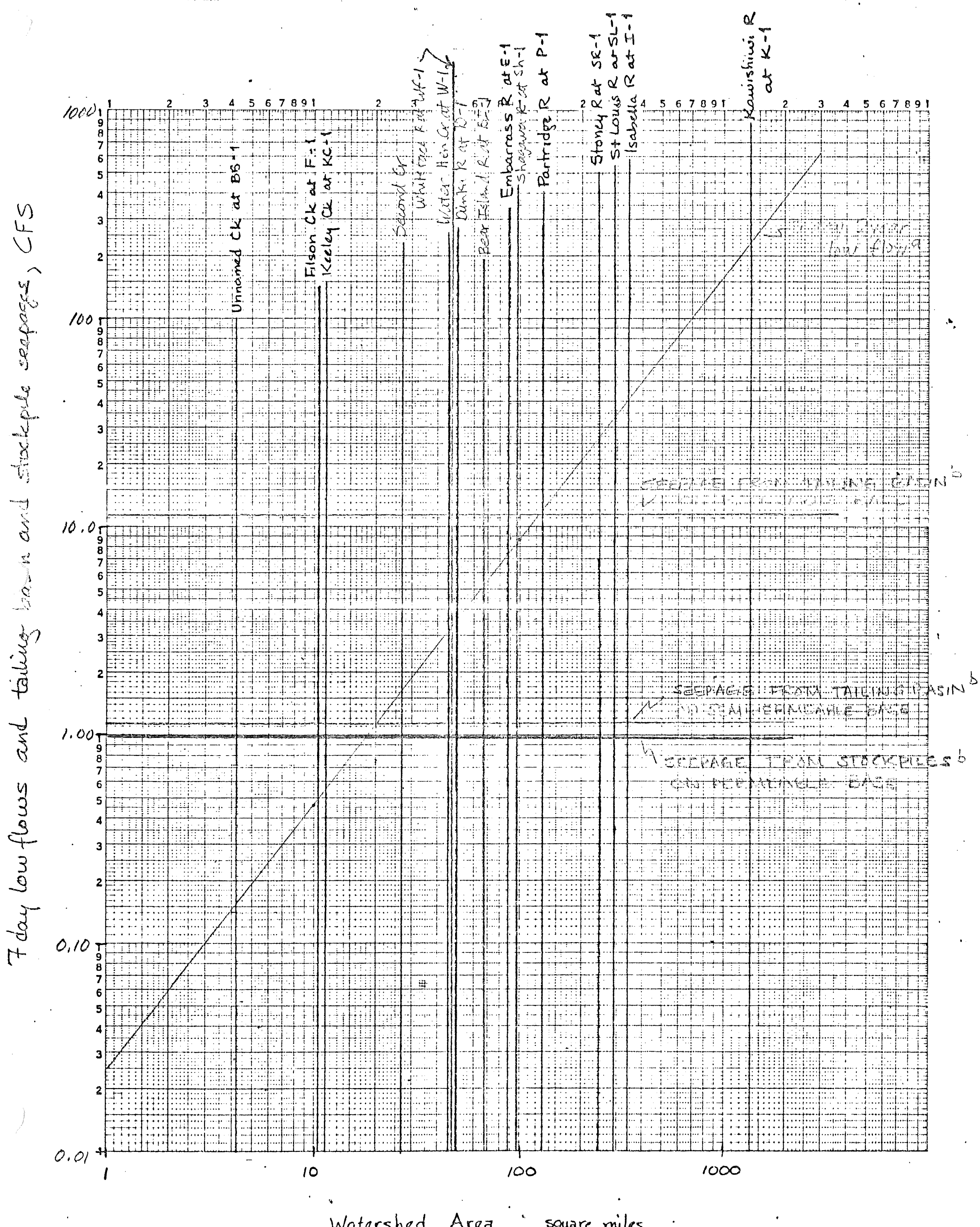
The effect of seepage on the low flow of streams is shown in Figure 8. The three seepage cases from Table 14 are shown compared to the 7-day, 2-year low flow of streams. This low flow period would be the time during an average year when the least dilution of a seep would occur. Table 15 shows the effects of uncontrolled seepages on the low flow of the Embarrass River, as an example. The discharge from a tailing basin on a permeable base would be the largest volume, and would increase the low flow of the Embarrass by 155 percent. Dilution of this discharges would be less. The Kawishiwi River has the largest watershed of the streams studied, so would be least affected by seeps. The seepage from a tailing basin on a permeable base would increase the low flow of the Kawishiwi by less than five percent, and would be diluted by 21 to one.

Table 14. Possible uncontrolled seepages during operation.

CASE	QUANTITY, ACRE FEET/YR 20x10^6 mtpy	12.35x10^6 mtpy	SOURCE[a]
1. Tailing basin on permeable base	8300[b]	4800	Table 10
2. Tailing basin on semipermeable base	830[b]	480	Table 10
3. Waste rock and lean ore stockpiles on permeable bases, average year	710[b]	45	Page_____

[a] Second level report, Vol. III, Ch. 4, section 4.4
[b] Values used in Figure 8

Figure 8. Seepage during operation



a. Calculated from …
b. See Table 14

Table 15. Effect of uncontrolled seepages on streamflow, example of how to use Figure 8, volumes in CFS.

Case[a]	A. Embarrass River 7day, 2 year Low Flow	B. Seepage	C. Flow + Seepage	Dilution Ratio(B/C)	% Increase in Flow
1. Tailing basin on permeable base	7.44	11.5	18.9	0.61	155
2. Tailing basin on semipermeable base	7.44	1.15	8.59	0.13	15
3. Stockpiles on permeable base	7.44	.98	8.42	0.12	13

[a] See Table 14.

Non-point discharges could be reduced to mitigate impacts. Stockpiles and tailing basins on impermeable material experience no seepage through their bases. An attempt could be made to collect water that seeps into the ground from these elements on semi- or impermeable bases before it reaches a stream by using collection wells. Tall stockpiles would release less water than shorter piles of larger area, since the smaller area would collect less precipitation. Containing all runoff from the minesite would reduce non-point discharges, but increase controlled discharges.

Uncontrolled discharges have the potential for causing impacts on water quality, and to lesser extent on water quantity. The quality and quantity of the discharge is dependent on a number of factors which can not be predicted exactly. More information about water quality impacts can be found in section 4.7, Chapter 4, Volume III of the Second Level Report.

5. Accidental discharges

The models which are discussed in this report have been assumed to have all components operating correctly. it is possible for something to go wrong, however, and an accidentIal discharge to occur. The impacts of a large accidental discharge could be immediate surface water quality degradation and a large increase in streamflow. Groundwater could be affected if the spill occurred on land. Examples of accidental discharges include:

1. A break in the tailing line between the mill and tailing basin. The tails will probably be transported as a slurry of 29 percent solids. The model tailing disposal system calls for pumping this slurry a distance of one mile from the mill to the basin. A break in the line, especially over a stream, could cause severe impacts.

2. Failure of the collection system around waste rock piles and other contained elements. Runoff from most elements in the model is prevented from flowing to surface water bodies by collection systems. This water would be stored in the tailing basin or treated before discharge. Leakage from a collection system could release poor quality water, especially from stockpiles to the environment.

3. Failure of the tailing dam. A break in the tailing dam could be a safety problem as well as an environmental problem, because such a large amount of water would be released. A more likely occurrance would be slippage of part of the dam, which would release a smaller amount of water.

4. Spillage of concentrate between the mill and the smelter. This concentrate could be very toxic, and spillage could occur if it were transported. Water running off the concentrate could potentially release heavy metals.

There are also other places in the model operation where accidential discharges could occur. Impacts caused by an accident would depend on the quality and quantity of water released, as well as characteristics of the watershed and water bodies the discharge entered.

6. Post-operational changes in hydrology

The hydrologic behavior of a watershed in the post-operational phase of copper-nickel development would be quite different from pre-mining or natural area hydrologic behavior. The outflow from a disturbed watershed could be significantly degraded in quality compared to outflow from an undisturbed watershed. Changes in hydrology would include altered volume of annual outflow, timing of flow, and proportions of surface runoff, interflow and baseflow. The timing and volume of outflow from a mine site would need to be compared with the flow properties of the receiving waters in order to assess impacts. This information is not known, however, so only a qualitative discussion will be presented here. Table 16 summarizes the hydrologic changes expected in a watershed due to a mining operation.

The open pit mine would not contribute to runoff until it filled. This would cut down the amount of water to reach a stream. A certain amount of baseflow in a stream could come from seepage of water in the mine through bedrock fractures.

Overburden piles are composed of local soil materials. Average annual runoff from the piles would probably be similar in amount to runoff from an undisturbed watershed. Expected proportions of surface runoff, interflow and baseflow are not known.

Waste rock and lean ore stockpiles would yield no surface runoff, but interflow, baseflow and annual average flow would probably be increased compared to an undisturbed area. Time to peak flow from a stockpile would probably be longer than from a natural watershed. The potential for water quality impacts is great from seepage from stockpiles.

The undisturbed watershed are would respond the same as before operation.

The plant site and the smelter/refinery site would both have more impermeable surface area than a natural watershed, so surface runoff would be greater and interflow and baseflow would be reduced to zero. Time to peak flow would be decreased from the plant site because there would be no water moving as interflow or baseflow.

The hydrologic behavior of a tailing basin would depend greatly on the permeability of the underlying material. Most of the water which falls on the basin

Table 16. Estimated hydrologic behavior of unreclaimed mined land compared with behavior of undisturbed areas in northern Minnesota.

Element	Average Annual Runoff	Surface Runoff	Interflow	Baseflow	Time of Concentration
Open Pit	Output is approximately zero until filled. The pit is likely to capture groundwater flow from nearby areas	reduced to zero	reduced to zero	Possibly minor seepage to ground-water through bed-rock	not applicable
Overburden piles	probably similar	?	?	?	?
Waste rock & lean ore piles	increased	reduced to zero	increased	Groundwater storage within piles may be substantial, especially if they block natural drainage ways. Baseflows may be higher than from natural areas.	increased
Undisturbed watershed area	same	same	same	same	same
Plant site	increased	increased	reduced to zero	reduced to zero	decreased
Tailing Basin	Depends on tailing infiltration rates and extent of ponding	Depends on final contouring and on tailing infiltra-tion rates.	Water which infiltrates emerges through tailing dams (interflow or baseflow) or through the basin floor (baseflow). Division between the two depends on the permeability of the material underlying the basin and of the tailing dams, and on layering within the tailings.		Depends on division between surface runoff, dam seepage and flow seepage.
Smelter/ Refinery Site	increased	increased	reduced to zero	reduced to zero	decreased
Slag Piles	?	?	?	?	?

would seep through the floor as baseflow, or seep out the edge of the tailing dam as interflow or baseflow. Surface runoff from the basin could also occur, the amount depending on the contouring and the tailing infiltration rate. The time to peak flow would depend on the division between surface runoff, interflow and baseflow.

The hydrologic behavior of the slag piles may be similar to that of the stockpiles, but this is not known. Because slag is quite inert, it is not expected to produce runoff with elevated chemical concentrations.

In general, the quality of outflow from a post operation watershed would be significantly degraded from that of a natural watershed. Runoff patterns of the watershed would also be significantly altered, but the cummulative effects of hydrology changes are unknown. A site specific study would be better able to assess the exact impacts.

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Appendix A. Mass curve for 10 mi^2 watershed.

Mass curve per 10 mi^2 wtsd shows that 1900 ac ft of storage must be provided in order to develop the annual flow of 7.9 cfs.

For most lakes of this size surface area 0.03 to 0.3 * wtsd area, or here, 0.3 to 3.0 miles

Change in lake level

$$\frac{1900 \text{ ac ft}}{(0.3 \text{ mi}^2)(640 \text{ ac/mi}^2)} = 10 \text{ ft}$$

$$\frac{1900 \text{ ac ft}}{(3.0 \text{ mi}^2)(640 \text{ ac/mi}^2)} = 1 \text{ ft}$$

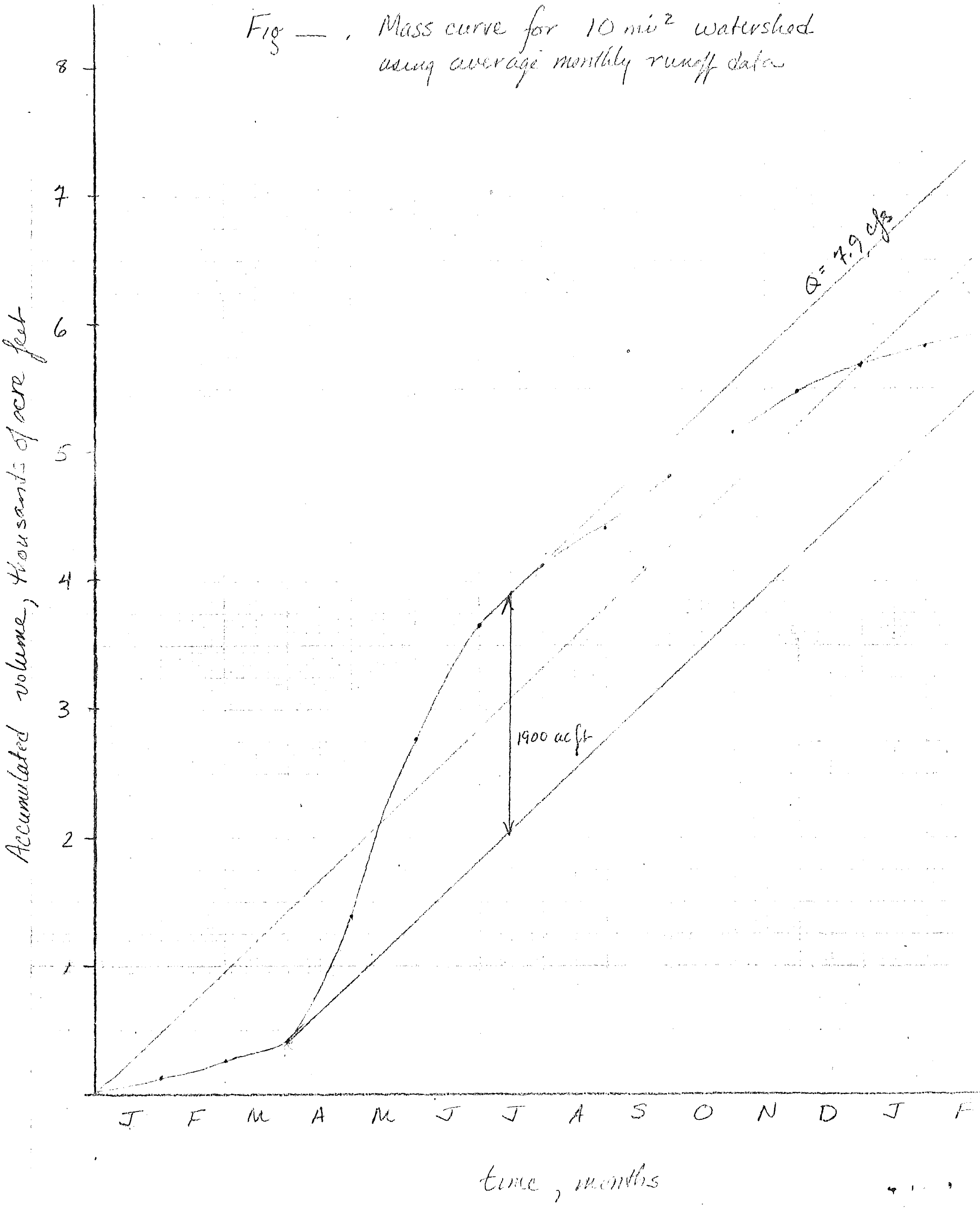
wtsd area = 10 mi^2

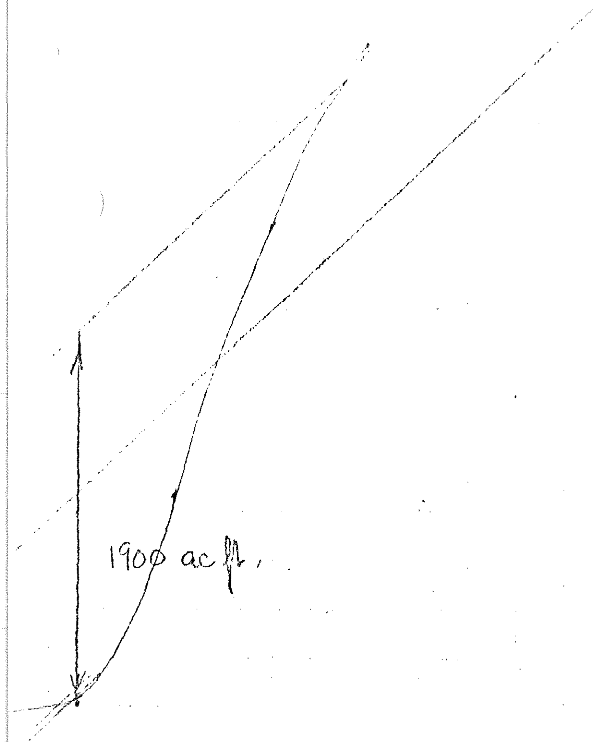
Q annual = 0.79 cfsm* = 5700 acft/yr

	%*	acft	cum
J	2.47	141	141
F	2.01	115	256
M	2.73	156	412
A	17.3	986	1398
M	24.2	1379	2777
J	15.4	878	3655
J	8.38	478	4133
A	5.06	288	4421
S	7.16	408	4829
O	5.81	331	5160
N	5.66	323	5483
D	3.66	209	5692
J			5833
F			5948
M			6104
A			7090
M			8469
J			9347

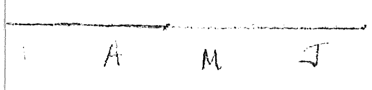
*Siegel and Ericson 1979.

Fig —, Mass curve for 10 mi^2 watershed using average monthly runoff data





maximum positive
or negative departure
≈ 1900 acft



Appendix B. Effect of appropriation proportional to flow and discharge at a constant rate on streamflow patterns and dilution ratios, for a smelter/refinery with maximum recycling.

Case 1, wtsd area = 15 mi^2

month	Qm unimpacted streamflow[1]	Am S/R approp proportional to flow[2]	Dm S/R discharge discharge at a constant rate[3]	Q*m impacted streamflow[4]	P percent change in flow[5]	R_d dilution ratio[6]
O	500	310	300	490	-2	0.61
N	490	300	300	490	0	0.61
D	310	190	300	420	35	0.71
J	210	130	300	380	81	0.79
F	170	110	300	360	112	0.83
M	230	140	300	390	70	0.77
A	1480	910	300	870	-41	0.34
M	2080	1280	300	1100	-47	0.27
J	1320	810	300	810	-39	0.37
J	720	440	300	580	-19	0.51
A	430	270	300	460	7	0.65
S	610	380	300	530	-13	0.57
ANNUAL	8580	5270	3540	6850	-20	

Case 2, wtsd area = 45 mi^2

month	Qm	Am	Dm	Q*m	P	R_d
O	1500	310	300	1490	-1	0.20
N	1470	300	300	1470	0	0.20
D	930	190	300	1040	12	0.29
J	630	130	300	800	27	0.38
F	510	110	300	700	37	0.43
M	690	140	300	850	23	0.35
A	4440	910	300	3830	-14	0.07
M	6240	1280	300	5260	-16	0.06
J	3960	810	300	3450	-13	0.09
J	2160	440	300	2020	-6	0.15
A	1290	270	300	1320	2	0.23
S	1830	380	300	1750	-4	0.17
ANNUAL	25740	5270	3540	24010	-7	

1 calculated from statistics of monthly and annual discharge, Siegel and Ericson, 1979.

2 $A_m = Q_m \times \frac{A_a}{Q_a}$, where A_a is the annual S/R appropriation (= 5500 ac ft) and Q_a is the is the annual streamflow.

3 $D_m = D_a/12$, where D_a is the annual S/R discharge (=3690 ac ft)

4 $Q_m^* = Q_m - A_m + D_m$

5 $P = \frac{Q_m^* - Q_m}{Q_m} \times 100$

6 $R_d = \frac{D_m}{Q_m^*}$