ORIGINAL
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DEPARTMENT OF
NATURAL RESOURCES

IMPACT OF COPPER-NICKEL MINING ON STREAMFLOW OF THE KAWISHIWI AND UPPER ST. LOUIS RIVERS, NORTHEASTERN MINNESOTA

Environmental Quality Board
Regional Copper-Nickel Study
Water Resources Section
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ABSTRACT

Potential copper-nickel mining and impacts to surface water resources along the Kawishiwi and upper St. Louis Rivers in northeastern Minnesota are discussed. Projected regional development includes three major mining operations with six mines, four processing plants, six tailing basins, and one smelter. Direct surface water withdrawals required to maintain various mining operations during drought periods are calculated with mass curves. Given certain meteorological and plant design assumptions, a typical surface water withdrawal of 9 cfs maintains a 20 million metric ton per year production capacity in a five year drought.

Changes in streamflow due to surface water withdrawals, loss of watershed area by containment, and seepage from tailing basins are compared for sub-watershed areas. Cumulative effects on the Kawishiwi River where it enters Fall Lake and the Boundary Waters Canoe Area represent a 3.5% reduction in drainage area and 8% reduction in average flow. Low flows are controlled by existing dams on Birch and Garden Lakes. Cumulative effects on the upper St. Louis River above Aurora represent a 4% reduction in drainage area and 6% reduction in average flow. Low flow reductions of 1 cfs may be less than uncontrolled seepage rates from a tailing basin.

INTRODUCTION TO THE REGIONAL COPPER-NICKEL STUDY

The Regional Copper-Nickel Environmental Impact Study is a comprehensive examination of the potential cumulative environmental, social, and economic impacts of copper-nickel mineral development in northeastern Minnesota. This study is being conducted for the Minnesota Legislature and state Executive Branch agencies, under the direction of the Minnesota Environmental Quality Board (MEQB) and with the funding, review, and concurrence of the Legislative Commission on Minnesota Resources.

A region along the surface contact of the Duluth Complex in St. Louis and Lake counties in northeastern Minnesota contains a major domestic resource of copper-nickel sulfide mineralization. This region has been explored by several mineral resource development companies for more than twenty years, and recently two firms, AMAX and International Nickel Company, have considered commercial operations. These exploration and mine planning activities indicate the potential establishment of a new mining and processing industry in Minnesota. In addition, these activities indicate the need for a comprehensive environmental, social, and economic analysis by the state in order to consider the cumulative regional implications of this new industry and to provide adequate information for future state policy review and development. In January, 1976, the MEQB organized and initiated the Regional Copper-Nickel Study.

The major objectives of the Regional Copper-Nickel Study are: 1) to characterize the region in its pre-copper-nickel development state; 2) to identify and describe the probable technologies which may be used to exploit the mineral resource and to convert it into salable commodities; 3) to identify and assess the impacts of primary copper-nickel development and secondary regional growth; 4) to conceptualize alternative degrees of regional copper-nickel development; and 5) to assess the cumulative environmental, social, and economic impacts of such hypothetical developments. The Regional Study is a scientific information gathering and analysis effort and will not present subjective social judgements on whether, where, when, or how copper-nickel development should or should not proceed. In addition, the Study will not make or propose state policy pertaining to copper-nickel development.

The Minnesota Environmental Quality Board is a state agency responsible for the implementation of the Minnesota Environmental Policy Act and promotes cooperation between state agencies on environmental matters. The Regional Copper-Nickel Study is an ad hoc effort of the MEQB and future regulatory and site specific environmental impact studies will most likely be the responsibility of the Minnesota Department of Natural Resources and the Minnesota Pollution Control Agency.

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I. INTRODUCTION

The purpose of this report is to present a general discussion of the potential effects or impacts of copper-nickel mining on streamflow of the Kawishiwi River and upper St. Louis River watersheds. The scope of the discussion is limited primarily to impacts of a regional scale and areas defined by the United States Geological Survey (USGS) surface-water gaging stations. The Kawishiwi River watershed is the area upstream of the USGS surface-water gaging station on the Kawishiwi River near Winton, Minnesota. The upper St. Louis River watershed is the area upstream of the USGS surface-water gaging station on the St. Louis River near Aurora, Minnesota. Tributary watersheds are the areas upstream of the following USGS surface-water gaging stations:

Tributaries to the Kawishiwi River:

- Filson Creek near Ely, Minnesota
- South Kawishiwi River near Ely, Minnesota
- Stony River near Babbitt, Minnesota.
- Dunka River near Babbitt, Minnesota
- South Kawishiwi River above White Iron Lake near Ely, Minnesota.

Tributaries to the St. Louis River:

- Partridge River near Aurora, Minnesota

Previous works describing the streamflow characteristics of these watersheds are listed in the bibliography at the end of this report. Brooks (1978) includes frequency analysis of annual peak discharges and selected low-flow events for gaged watersheds in the region. The U.S. Geological Survey is completing a report on the region and its water resources including watershed descriptions, analysis of streamflow characteristics, geology, physiography, and existing groundwater conditions.

The Regional Copper-Nickel Study, mining technology group has developed models of several characteristic copper-nickel mining operations. Each model includes a mine, processing (beneficiation) plant, smelter, and related facilities. Further discussion of production rates, stages of development, and design criteria for these basic models is contained in the Regional Copper-Nickel Study, Second Level Report. Golder and Associates (1978) includes an expanded discussion of the engineering aspects of tailing disposal for these models.

II. COPPER-NICKEL MINING - IMPACTS RELATED TO STREAMFLOW

Differences in water yield among the various watersheds in the Copper-Nickel Region may be due to differences in basin characteristics, areal distribution of precipitation, or both. Ericson et al. (1976) noted that annual water yield in the Rainy Lake watershed is dependent on basin size, annual precipitation and temperature, surficial geology, vegetation, and basin slope. The largest annual water yields (.75 to .85 cubic feet per second per square mile, or cfsm) are from areas with a high density of lakes, thin discontinuous drift, maybe factors which influence water yields are and numerous bedrock outcrops. Smallest yields (.60 to .75 cfsm) are from areas with few lakes even though sand and gravel make up a considerable part of the surficial material. Garn (1975) noted that the greatest water yields in the Superior National Forest occur in areas of steep topography, exposed bedrock, thin glacial deposits, shallow soils, and little surface water storage.

Several basin characteristics appear to be important influences on peak and low flows in the copper-nickel region. Ericson et al. (1976) noted that duration both high and low flows on large watersheds are sustained by discharge from lakes and, to a lesser extent, from ground-water. Bowers (1977) noted that the large area of lakes in the Kawishiwi River watershed tends to smooth out fluctuations in precipitation or moisture supply. Guetzkow (1977) noted the relative importance of channel slope in regional flood-frequency equations for the upper St. Louis River watershed. Bowers (1978) noted a "shift" in basin parameters in fitting model (SSARR) hydrographs to observed events of extreme frequencies. Multiple correlation studies have related flow characteristics to watershed size in the Study Area. Bowers (1977) established a good correlation between average flows of record and watershed area. Based on this work, Ramquist (1977) found the relationship also applicable to several watersheds of less than 10 square miles. Ericson et al. (1978) noted a good correlation between average annual discharge and drainage area for watersheds of more than 50 square miles. Other researchers have established good correlations between high and low flows of various durations and frequencies with watershed area (Brooks, 1978; Bowers, 1977; Guetzkow, 1977; Ericson et al., 1978).

These regression analyses are useful for predicting flow characteristics of ungaged sites based on regional averages. As noted by Guetzkow (1977), the applicability and reliability of these relationships depend on the basin characteristics at the site under consideration being within the range of characteristics used to define the frequency relations. A site located below a lake with large storage capacity in relation to total drainage area, such as the Shagawa River gage, could have unusual outflow flood characteristics. A watershed with limited surface storage or large area of bedrock outcrops, in relation to total drainage area, may have low flow characteristics quite removed from values determined by regional analysis.

As noted in Table 1, the coefficients of variation and approximate confidence limits increase considerably for less frequent streamflow events. The likelihood of an estimated 100-year peak discharge on an ungaged watershed being correct is far less than for an estimated average flow on the same watershed. The likelihood of an estimated 7-day, 10-year low discharge being the same for two watersheds of the same area may also be far less than for average annual flows on the same watersheds.

The application of streamflow-area relationships, based on regional regression analyses, to small drainage areas (<100 sq. miles) must be viewed with caution. The preponderance of large watersheds in available streamflow information may tend to suppress the significance of basin characteristics in either direct estimates or transfer of data to other sites. On the Kawishiwi River watershed (1229 sq. mi.), channel processes including lake storage and backwater effects may play a greater role than basin characteristics in defining low flows and certain peak flows. Although overland flow influences may not be significant in the study region, streams draining areas of less than 100 square miles are probably sensitive to high intensity rainfalls of short durations and to land-use.

The hydrologic influence of land use changes due to mining in small watersheds needs site-specific study before cumulative effects can be addressed on a regional scale. As a result, prediction of impacts based on regional analysis is more reliable for large areas (>100 sq. miles) than small, and average rather than extreme flows. Site-specific or small (<100 sq. miles) watershed influences should be addressed in specific studies that include project design, location, and more detailed accounting of both watershed and channel characteristics. Cumulative effects of specific actions may be more accurately predicted at that time.

Table 1. Variation in Flow Characteristics

Watershed	Drainage Area Sq Mi)	Average Discharge of Record (Cfsm)	10-year Peak Discharge (cfsm)	100-year Peak Discharge (cfsm)	7-day 10-year low flow (cfsm)	August 1976 low flow (cfsm)
Second Creek	29	.78	7.4	9.25	.075	*
Partridge River	161	.78	13.8	32.88	.029	.085
St. Louis River	290	.84	10.8	17.68	.034	.066
Embarrass River	88	.73	15.8	28.20	.020	.020
Upper Kawishiwi River	253	.88	6.9	7.72	.053	.146
Isabella River	341	.80	11.1	18.22	.093	.106
Stony River	180	.71	10.6	17.02	.043	.037
Dunka River	53	.69	11.3	17.49	.017	.001
Bear Island River	69	.60	6.3	11.52	.009	.026
Kawishiwi River	1229	.83	7.5	13.93	*	*
Standard Error		.08	3.1	7.92	.028	.049
Mean		.76	10.2	17.39	.041	.061
Coefficient of Variation		.11	.30	.46	.68	.81
Confidence Limits		±2.6%	±36%	±47%		±72% **

* Regulation or lake influence

** Estimate

III. SURFACE WATER APPROPRIATION REQUIREMENTS AND LOSS OF WATERSHED AREA.

Mining development along the copper-nickel ore body in northeastern Minnesota would require a long-term commitment of public water supplies to maintain the industry during drought conditions. Direct impacts of this commitment include loss of watershed area as well as direct withdrawal (appropriation) of surface water supplies. Loss of watershed area would be due to containment and runoff control at the mine, processing plant, stockpiles, tailings basin, and smelter facilities. Groundwater discharge or precipitation on these areas may be collected, stored in the tailings basin, and eventually recycled for use in the plant. The appropriation requirement would be the amount of water required to operate a plant in excess of what was collected in these contained areas.

may be include some discussion & alternative [illegible]

Enough water to operate a plant could usually be collected and stored in the tailings basin during seasons of above average precipitation or snowmelt. Water would have to be appropriated, however, to operate the same plant during consecutive seasons of low precipitation or high evaporation. The purpose of this analysis is to define these times of deficient precipitation or excess evaporation and to estimate a reasonable rate of appropriation that may be required to keep the plant in operation.

1. PLANT WATER BUDGET

A detailed annual water budget for a 20 million metric ton per year (MTPY) copper-nickel mining operation with an open pit mine has been prepared by the Regional Copper-Nickel Study. This budget includes a subsystem A of passively managed elements (plant site, open pit, and stockpiles) and a subsystem B of operations or water management for the processing plant and tailings basin (figures 1 and 2). The budget includes annual water balance for an average year, a wet year, and dry year given precipitation and evaporation rates with 100-year recurrence intervals or .01 probabilities of occurrence. It should be noted that although these extreme rates have low probabilities of occurring any given year, there is a 26% probability either of them may occur in a 30-year mining operation.

The processing mill water balance was prepared by the Copper-Nickel Study, Mining Technology Group and includes water consumption of 650 gallons per metric ton of ore and process water make-up requirements of 102 gallons per ton of ore, as shown in figure 3.

The smelter/refinery water balance for a 635,000 MTPY concentrate operation includes water consumption of 1108 gallons per minute (gpm) and process water make-up requirements of 494 gpm as shown in figure 4.

The processing plant for a 20 million MTPY open pit mining operation would require 650 gallons of water per metric ton of ore plus potable/sanitary water. Some water may be recovered from the ore and has been estimated at 1% by volume or roughly 3 gallons/metric ton. The potable/sanitary water requirement has been estimated at 400 gpm or 618 acre-ft/yr. Total plant requirement then would be approximately 40,000 acre-ft/yr.

FIGURE 1

20×10^6 MTPY OPEN PIT MINE
SUBSYSTEM A

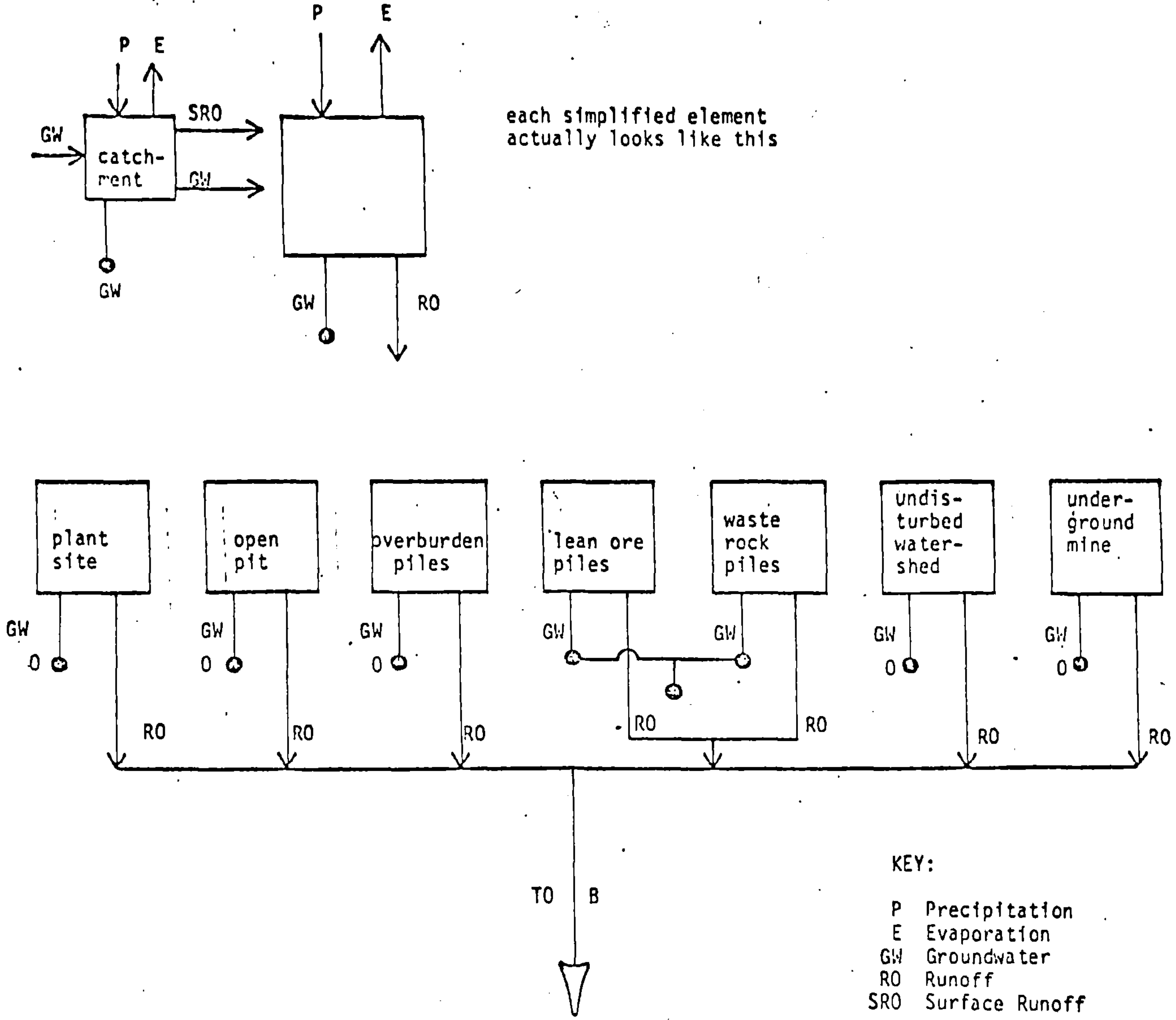


FIGURE 2

20×10^6 MTPY
SUBSYSTEM B

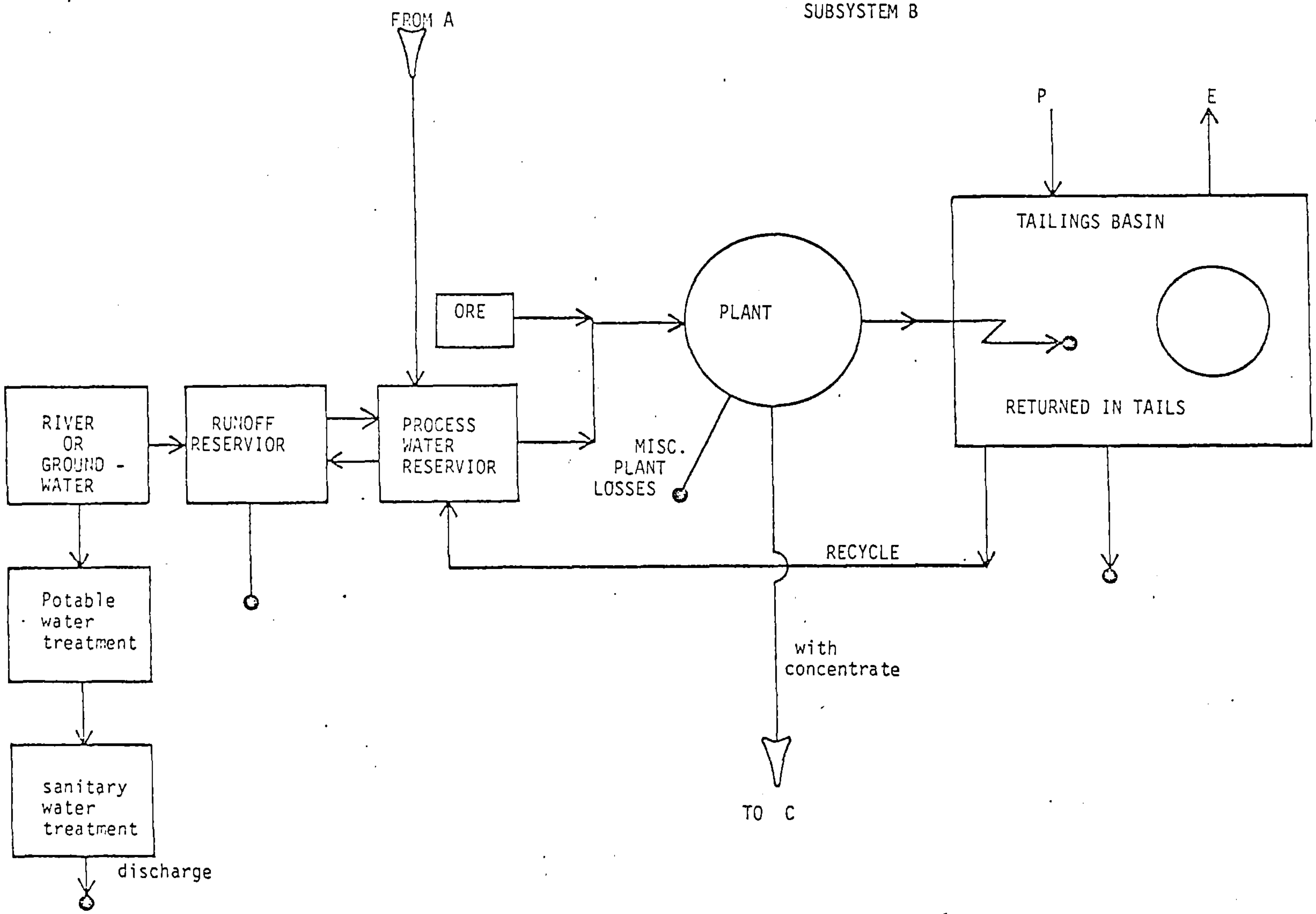
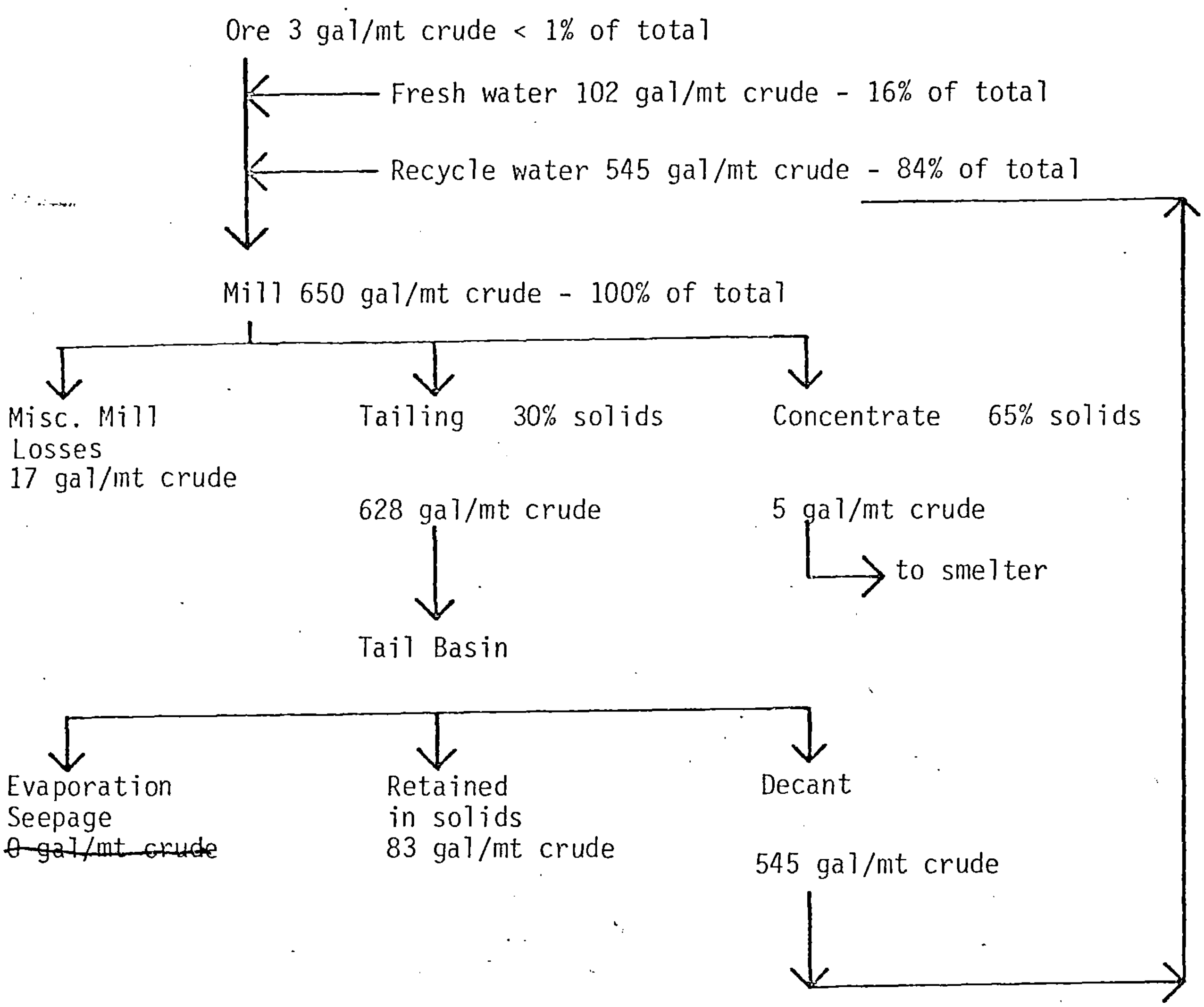


Figure 3

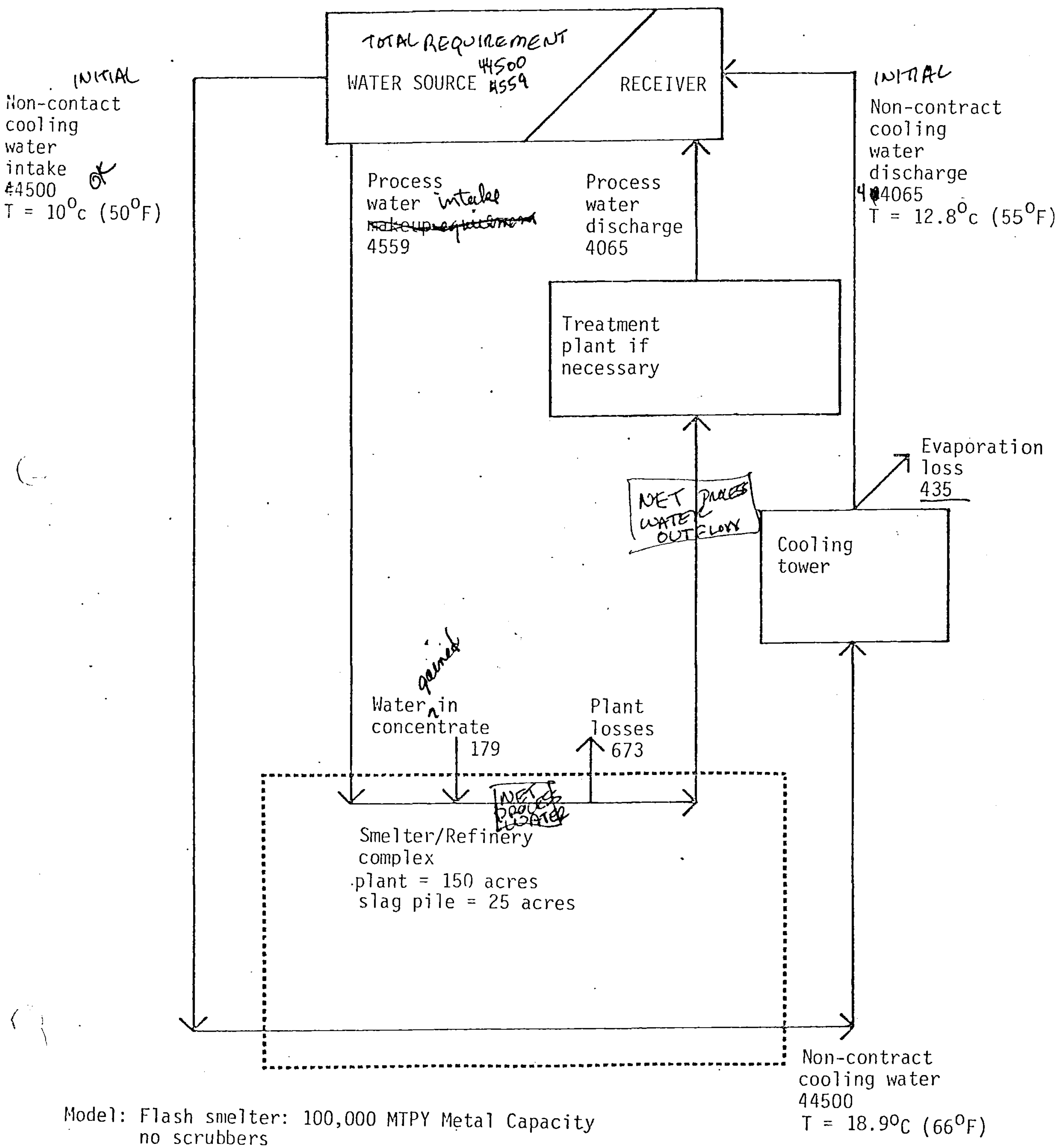
PROCESSING MILL WATER BALANCE



Based on concentrate thickening to 65% solids for feed to a spray drying unit.

Figure 4

SMELTER/REFINERY
WATER BALANCE



Model: Flash smelter: 100,000 MTPY Metal Capacity
no scrubbers
Units: Gallons Per Minute

2. MINING DEVELOPMENT SCENARIO

The mining development scenario is a projected picture of mine, processing plant, and smelter development along the copper-nickel ore body. This level of development is used only for analysis of impacts due to cumulative surface water appropriation or loss of watershed area. The scenario includes three major mining operations with six mines, four processing plants, six tailings basins, and one smelter. Land area associated with major components of the scenario are summarized by location above stream gaging stations as shown in the following table. An additional smelter would normally be required for this scenario, but was assumed to be located outside of the Study Area.

Table 2. Mining development land areas (acres)

WATERSHED	OPEN PIT MINE	PLANT	STOCKPILES	TAILINGS BASIN	OVERBURDEN PILES	SMELTER	SLAG PILES
1) So. Kawishiwi River near Ely	563	400	1988		173		
2) Local inflow to Birch Lake	*	520	248				
Keeley Creek at mouth near Ely				2309			
3) Stony River near Babbitt				6324			
4) Dunka River near Babbitt	1126	800	3976	4015 4015	346	150	25
5) Partridge River near Aurora	563	400	988	4015	346		

*24.7 x 10^6 mtpy Underground Mining Operation (2 mines)

Note: Waste rock-lean ore stockpiles are square, 61 m high
13 unit piles per 20 mtpy open pit mine
Tailings basins are 21 m high
Smelter/refinery slag piles are 33 m high

3. SURFACE WATER APPROPRIATION REQUIREMENTS

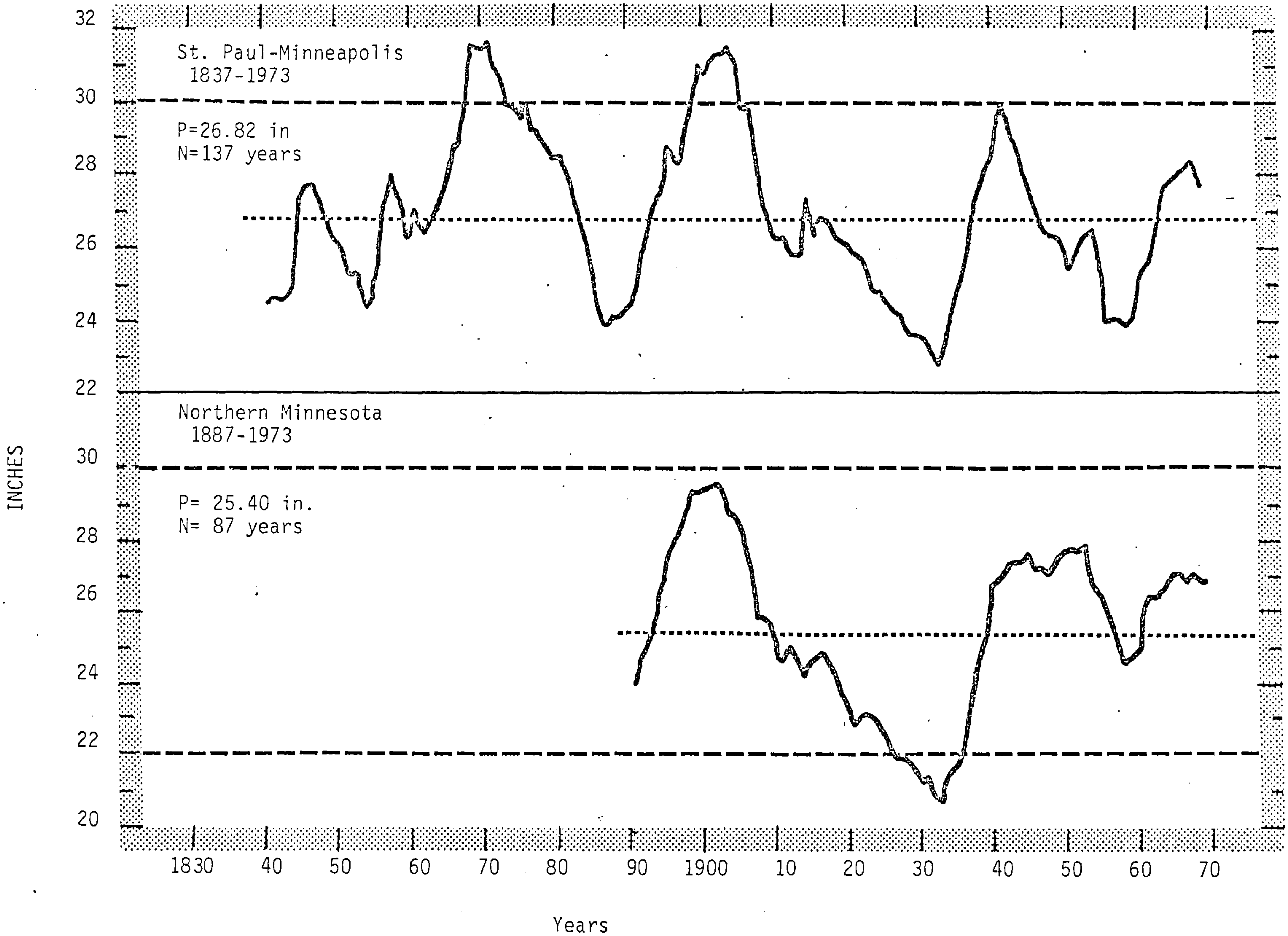
The calculation of surface water appropriation requirements begins with the definition of a design drought and selection of appropriate precipitation, evapotranspiration, and runoff conditions. Precipitation records for 1921-25 were used for the design drought in this analysis. Monthly precipitation totals are available for this period at the Virginia climatological station and can be adjusted for precipitation expected at Babbitt (Hickok and Assoc., 1977). The 5-year duration of this dry period is significant to plant operation but is not the most severe of record as shown in the Figure 5 diagram of a 9-year running mean precipitation for northern Minnesota (Baker and Kuehnast, 1977). Stochastic properties of wet and dry period succession have not been studied although the design drought could be expected to have a higher probability of occurrence during a 30-year plant life than a longer drought duration including the 1930's. Average monthly precipitation for this period is also greater than lowest monthly precipitation of record (1921-1976). Precipitation during November to April was accumulated and considered as snowmelt in May. Precipitation values used in this analysis were as follows:

PRECIPITATION AT BABBITT (INCHES)

	1920	1921	1922	1923	1924	1925
January		.75	.38	1.08	.62	.30
February		1.00	1.44	.37	.64	.92
March		1.28	1.31	.95	.54	.56
April		1.50	1.78	1.43	2.42	.99
May		3.19	3.63	1.09	1.16	.31
June		2.60	3.15	4.79	4.25	4.22
July		4.85	2.77	2.04	4.10	2.54
August		1.17	2.95	2.95	4.77	4.81
September		3.72	2.33	1.46	3.56	5.62
October	2.32	.21	.74	.82	2.10	
November	1.06	.32	2.40	.65	.65	
December	1.25	1.23	1.15	.69	.59	

Figure 5 Drought in Minnesota.

The upper curve is smooth with the normal curve smoothing function of length 2a = 9 years. This procedure serves to reduce the "noise" of the year to year variation and permit trends to be observed. the lower curve is the smoothed average of five northern Minnesota stations. (Baker and Kuehnast, 1977).



Maximum monthly pan evaporation for May to October, 1958-77 at the Hoyt Lakes climatological station were adjusted to approximate contained area evapotranspiration (ET) conditions for the design drought. Contained area included stockpiles and plant sites as well as tailings basins. Extreme pan evaporation observations were used as a conservative estimate in the design drought although other investigations (Hickok and Assoc. 1977) have not been able to establish that high evaporation rates occur at the same time as extreme low ~~a negative correlation between~~ annual precipitation. ~~and May-October evaporation over the period of record~~. Evaporation from a shallow lake was considered a reasonable approximation of monthly actual ET on the drainage area and a local pan coefficient of 0.78 (Kohler et al, 1959) was used for May-July. A pan co-efficient of 0.68 was used for August-October to account for lesser evaporation in the Fall. Pan evaporation for May-October was equivalent to the 100-yr annual pan evaporation determined by frequency analysis of the Hoyt Lakes record. ET values in (in.) were as follows:

May	June	July	August	September	October
4.8	5.2	6.0	4.5	2.8	1.5

Storage of 13,300 acre-ft. of water in the tailings basin was assumed to be available for plant use at the beginning of the drought. This quantity should be sufficient to operate a 20 million MTPY plant on closed cycle for one year with no runoff from the contained area and no outside make-up water. Water quality conditions within the tailings basin were assumed adequate to allow recycling of stored water for plant use. Evaporation or seepage loses from water treatment or alternative storage facilities were not evaluated. Seepage from the tailings basin in excess of 574 gallons per minute (gpm) was assumed returned to the basin. Expand to include fact that excess seepage in existing basins

A mass curve of accumulated water in the tailings basin for the duration of the design drought was constructed for monthly volumes. This figure included tailings discharge, monthly runoff from contained area, seepage losses from the tailings basin, and estimated water retention in the tails. A constant plant demand for water (draft rate) was plotted on the same graph with the point of initial appropriation requirement at the first intercept. The rate of appropriation required to carry the plant through the drought was considered at maximum divergence of the two curves (volume unit) for the period of insufficient supply (time unit). It should be noted that this figure represents the rate required to supply the draft rate for that period although alternative practices could be used. For example, a lesser rate of appropriation could supply the same volume if started earlier in the drought and so continued for a greater duration. A variable rate of appropriation could also be used to divert high flows during snowmelt periods or rainstorms, with little or no appropriation during low flow periods, and still provide the required volume of water.

a. South Kawishiwi River Near Ely (Filson Creek)

The mining development scenario includes the following developments in the watershed above the South Kawishiwi River near Ely stream gaging station:

1 open pit mine 20 million MTPY

1 plant site

waste rock-lean ore stockpiles

overburden piles, and

a tailings basin to service the plant but located outside of this watershed.

The water accumulated for the 1921-1925 period ranged from 16,670 acre-ft. to 183,400 acre-ft at the end of the drought as shown in the following table:

TABLE 3

ACCUMULATED WATER

(ACRE-FEET)

Tailings discharge 24938 gpm
Seepage 575 gpm
Retention in tails 3285 gpm
Contained area 7139 acres
Draft Rate 40000 acre ft/yr
Water in storage 13,300 acre-ft

	1921	1922	1923	1924	1925
Oct	16670	51061	83586	116957	152060
Nov	19460	53851	86376	119747	154850
Dec	22343	56734	89259	112630	157733
Jan	25226	59617	92142	125513	160616
Feb	27830	62221	94746	128117	163220
Mar	30713	65104	97629	131000	166103
Apr	33503	67894	100419	133790	168893
May	39086	72154	105485	137815	171615
June	41006	74258	108138	140287	174077
Jul	43504	76060	109696	142534	175802
Aug	45273	78324	111960	145578	178869
Sep	48610	80957	114302	148820	183387

It should be noted that this maximum water accumulation figure does not represent an actual quantity of water in storage. The actual quantity of water in storage at any one time would be the accumulated volume less the volume recycled for plant use. The water appropriation for this mining operation would be 9 cfs as shown in figure 6.

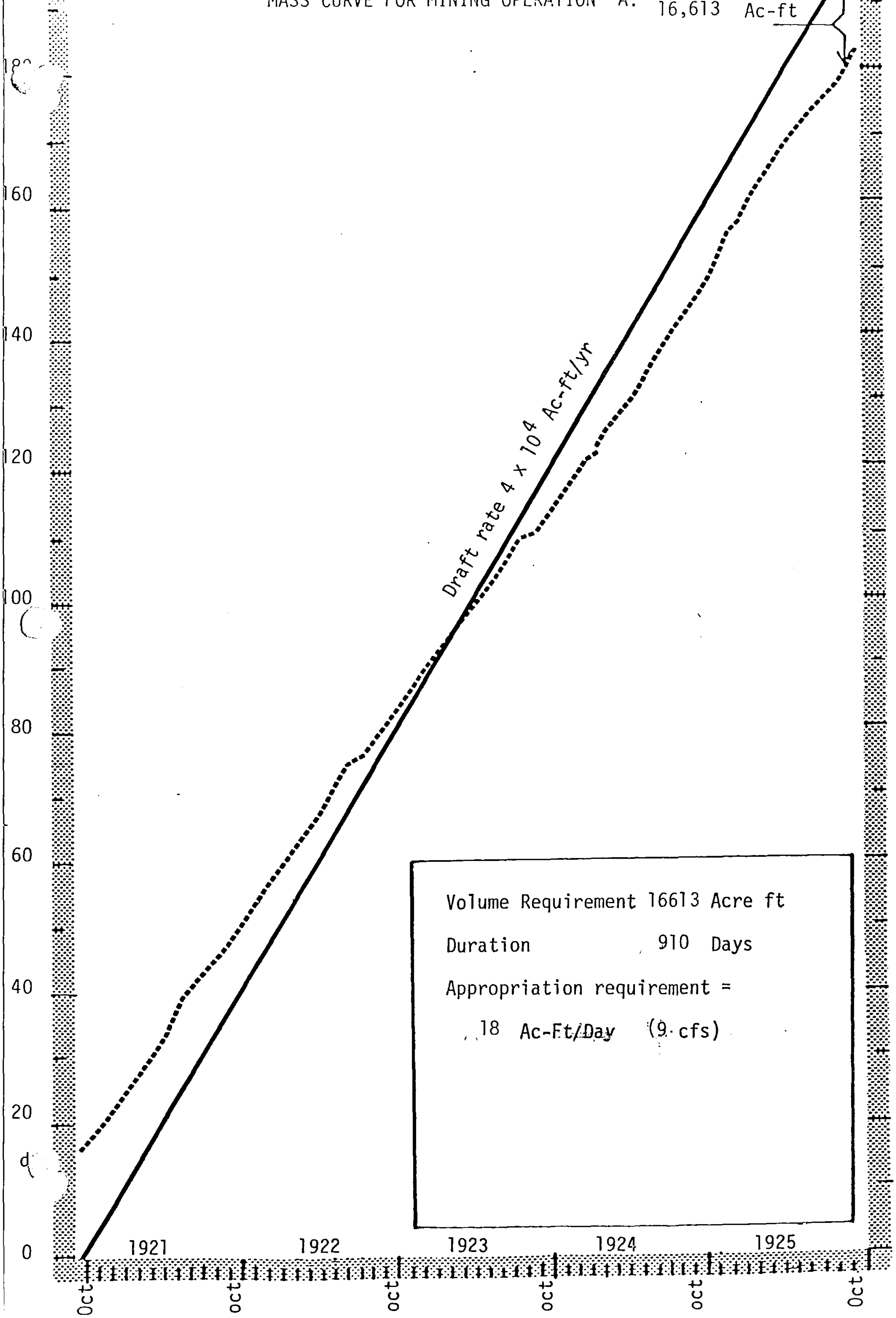
b. Birch Lake Local (South Kawishiwi River)

The mining development scenario includes the following developments in the watershed adjacent to Birch Lake (local inflow):

2 underground mines 12.35 million MTPY each
1 plant site
waste-lean ore stockpiles, and

Figure 6

MASS CURVE FOR MINING OPERATION A.



2 tailings basins to serve the plant but

located outside of the watershed.

The water accumulated for the 1921-1925 period ranged from 11431 acre-ft to 202714 acre-ft at the end of the drought as shown in table 4. The water appropriation requirement for this mining operation would be 14 cfs as shown in figure 7.

TABLE 4

ACCUMULATED WATER (ACRE-FT)

Tailings discharge 28843 gpm
Seepage 1150 gpm
Retention in tails 4057 gpm
Contained area 5386 acre
Draft Rate 49000 acre ft/year
Water in storage 11431 acre ft

	1921	1922	1923	1924	1925
Oct	15037	53173	91062	128278	167724
Nov	18207	56443	94332	131548	170994
Dec	21563	59699	97588	134804	174250
Jan	24819	62955	100844	138060	177506
Feb	28151	66287	104176	141392	189838
Mar	31407	69543	107432	144648	184094
Apr	34677	72813	110702	147918	187364
May	40263	78426	115588	152018	190287
Jun	42366	80776	118674	154862	193117
Jul	45088	82564	120135	157246	194802
Aug	46831	85106	122677	160605	198179
Sep	50514	88165	125345	164216	202714

c. Dunka River Near Babbitt

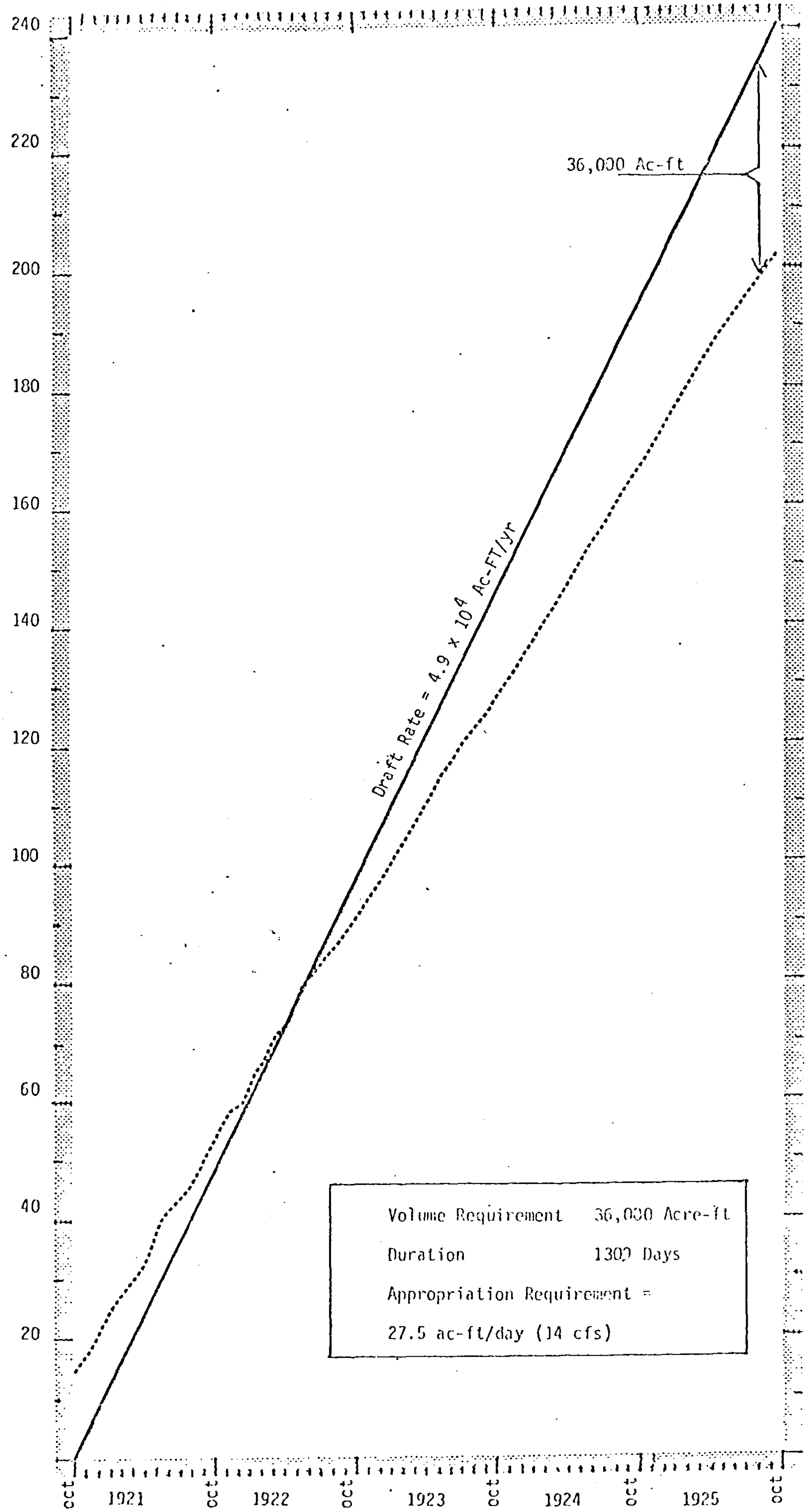
The mining development scenario includes the following development in the watershed above Dunka River near Babbitt stream gaging station.

2 open pit mines 20 million MTPY each

2 plant sites

FIGURE 7

MASS CURVE FOR MINING OPERATION b.



water rock-lean ore stockpiles

overburden piles

2 tailing basins, and

1 smelter/refinery

The water accumulated for the 1921-1925 period ranged from 21,000 acre-ft to 380,767 acre-ft at the end of the drought as shown in table 5. The water appropriation requirement for this mining operation would be 24 cfs as shown in figure 8.

TABLE 5

ACCUMULATED WATFR
(Acre-ft)

Tailings discharge and process water discharge 53743 gpm
Seepage 1150 gpm
Retention in tails 6570 gpm
Contained area 14453 acres
Draft Rate 88057 acre-ft/year
Water in storage 21,000 acre-ft

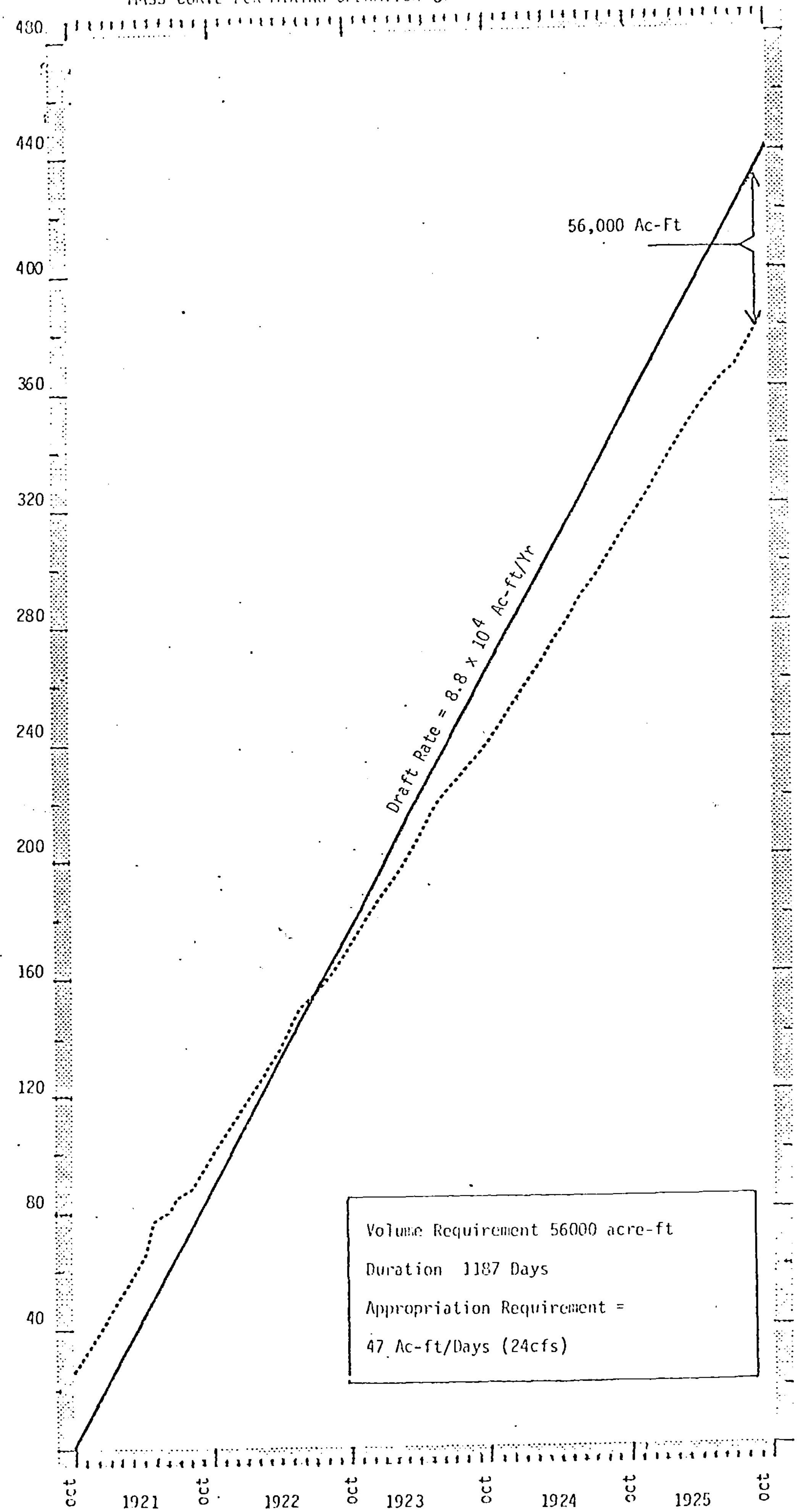
	1921	1922	1923	1924	1925
Oct	28293	99867	170780	239886	314979
Nov	34396	105970	176883	245989	321082
Dec	40707	112276	183189	252295	327388
Jan	47008	118582	189495	258601	333694
Feb	52704	124278	195191	264297	339390
Mar	59010	130584	201497	270603	345696
Apr	65113	136687	207600	276706	351779
May	77718	149365	218326	285325	357527
Jun	80689	152999	223935	290284	362450
Jul	85609	155414	225471	294301	364588
Aug	87904	159853	229910	300932	371267
Sep	95115	165390	234399	307951	380767

d. Partridge River Near Aurora

The mining development scenario includes the following developments in the

FIGURE 8

MASS CURVE FOR MINING OPERATION C



watershed above the Partridge River near Aurora gaging station.

1 open pit mine 20 million MTPY

1 plant site

water-rock-lean ore stockpiles

overburden piles, and

tailings basin

The water accumulated for the 1921-1925 period would be similar to that observed for the South Kawishiwi River near Ely operation and range from 16,670 acre-ft. to 183,000 acre-ft. at the end of the drought. The water requirement for this mining operation would be 9 cfs.

4. LOSS OF WATERSHED AREA

Loss of watershed area would be due to containment and runoff control at the processing plant, mine, stockpiles, tailings basin, and facilities. Ground-water discharge and precipitation on these areas would not be available for stream flow and the following would be removed from the watershed area for the gaging station (see also table 1).

South Kawishiwi River near Ely	3124 acres
Birch Lake local inflow	3077
Stony River near Babbitt	6324
Dunka River near Babbitt	14453
Partridge River near Aurora	7139

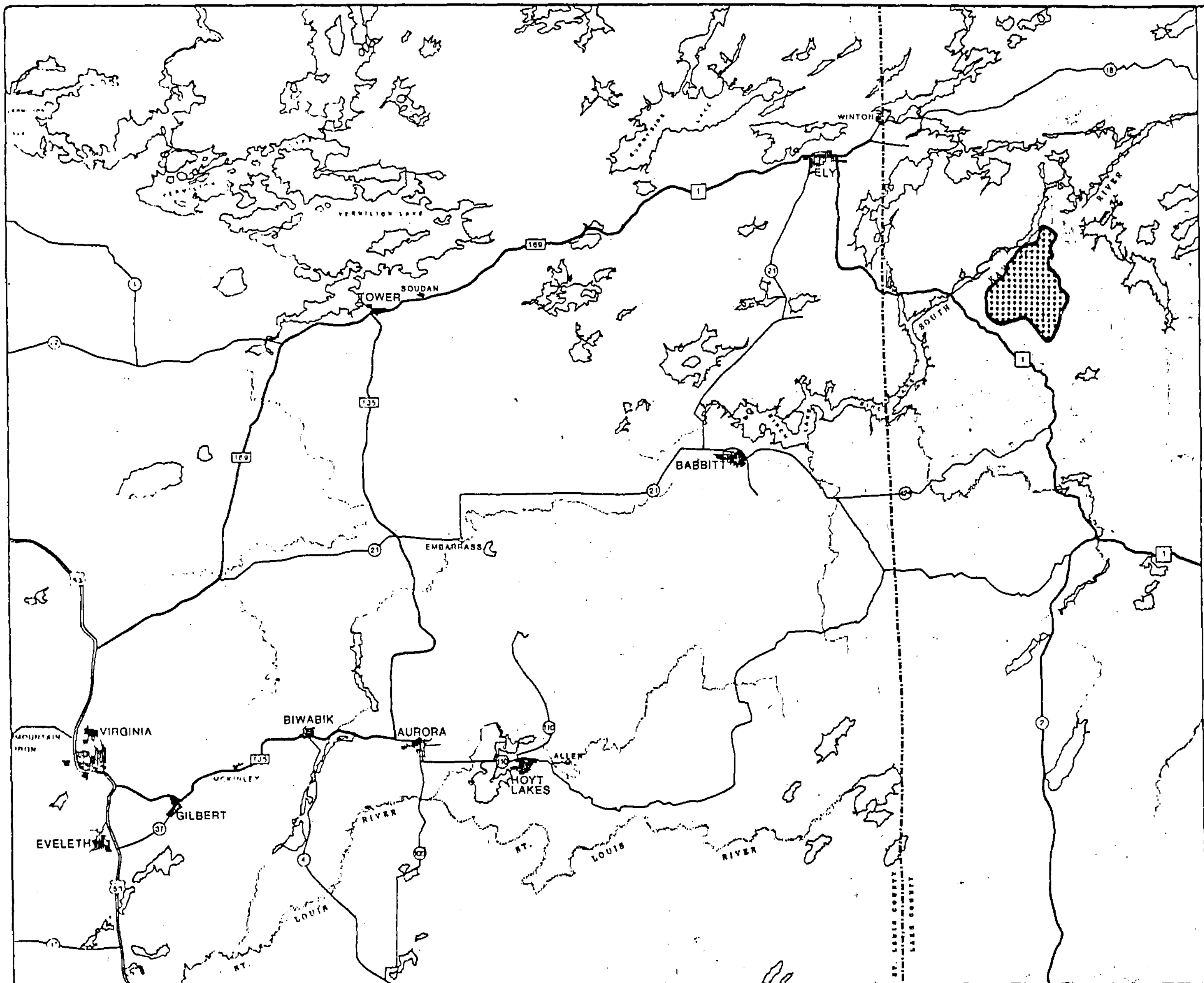
IV. IMPACT OF COPPER-NICKEL MINING AND BENEFICIATION ON STREAMFLOW OF THE KAWISHIWI RIVER

Filson Creek near Ely, Minnesota.

The Filson Creek watershed covers an area of approximately 10 square miles tributary to the South Kawishiwi River upstream of Birch Lake Map A. Lower portions of the watershed overlie ore deposits suitable for copper-nickel mining and are included in a commercial mining proposal.

The watershed includes natural surface storage in Bogberry Lake (82 ac), Omaday Lake (40 ac), Nickel Lake (22 ac), and various marshes and bogs (1740 ac). These areas cover a combined 30% of the watershed area. Filson Creek is primarily a first order stream, nine miles long, with an average gradient of 16 feet per mile.

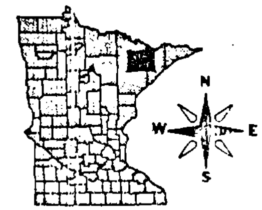
Streamflow has been measured on Filson Creek since October, 1974 and water discharge ranged from zero flow to a maximum of 129 cubic feet per second (cfs). Mean discharge for water year (WY) 1976 was approximately 7 cfs for an annual water yield of 9.5 inches (5000 ac-ft). Regional analysis of streamflow (Brooks, 1978) indicates an annual peak flow, with .50 probability of occurrence in any one year, of 76 cfs. Seasonal or annual 7-day low flows expected each year are less than 1 cfs. Although surface storage may be provided in the numerous bogs and lakes, summer flows may rapidly fall to less than .1 cfs after several weeks of no rainfall.



LEGEND

WATERSHED:

FILSON CREEK NEAR ELY



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MILES

KILOMETERS

MEQB REGIONAL COPPER-NICKEL STUDY

The mining scenario or projected development along the copper-nickel ore body considers a 20 million metric ton per year (MTPY) crude-ore, open pit mine and processing plant in this watershed. A tailing basin to service the plant is located outside the watershed. The development area is approximately 7139 acres as follows:

Open pit mine	563 acres
Processing plant	400
Waste rock and lean ore stockpiles	1988
Overburden piles	173
Tailing basin	4015 (not in watershed)
	7139 Total

For purposes of this study, operation of the development would include control and collection of runoff from the mine, plant site, stockpiles, and overburden piles. The processing plant-tailing basin water management would be essentially "closed-cycle" with use of recycled water for 80% of plant demands.

It appears unlikely that Filson Creek could provide an adequate supply of water to maintain this size of mining operation during extended drought. About 20,000 acre-ft would be available in four average years, unadjusted for evaporation or other losses, if storage of runoff were provided. The 5-year duration drought would require a water supply of about 35,000 acre-ft over four years. a supplemental water supply ~~Some other source of water outside the watershed~~ would probably have to be drawn upon during drought years.

With this development, the natural watershed area of Filson Creek would be reduced by more than 3,000 acres or roughly 50%. Average discharge could be expected to decrease by roughly 3.5 cfs and average annual water yield from undisturbed areas could be 2500 acre-ft. If areas contributing to base flows were adversely affected, this loss of watershed area could cause Filson Creek to go dry rather than simply reduce its low flow by a proportional amount. In that case, the stream would shift from perennial to an intermittent flow regime. The loss of watershed area containing bedrock outcrops or some bog areas that may not contribute to base flows could have little effect on low flow in the stream.

A 50% reduction in watershed area could result from controlling runoff on the lower half of the watershed and diverting flows from the upper reaches into a channel around the mining areas. High flows in the altered channel may be attenuated by the twofold increase in relative channel length and loss of contributing area. Without accounting for the influence of other basin and channel factors, and without direct discharge or seepage, the mining activity would likely decrease peak flow for a watershed of this size.

South Kawishiwi River near Ely, Minnesota.

Flow in the Kawishiwi River below the surface-water gaging station near Ely, Minnesota is split between a North Channel and the South Kawishiwi River. The North Channel runs directly into Farm Lake and the South Kawishiwi River runs into Birch Lake. The proportioning of flows may vary with discharge and medium to low flows are split approximately 2/3 North Channel and 1/3 South Kawishiwi River (Ericson, personal communication). Low flow measurements in August, 1976 noted 37 cfs at the Kawishiwi River station above the split and 24 cfs in the North Channel. Bowers and Gutschick (1976) estimated a medium to high flow (200 to 1200 cfs) split of approximately 40% North Channel and 60% South Kawishiwi River. Because of this variability, drainage area for the South Kawishiwi River near Ely has not been reported. The Isabella River below Gabbro and Bald Eagle Lake (2680 acres combined) has a drainage area of about 416 sq mi and discharges to the South Kawishiwi River between the gaging station and channel split upstream.

Streamflow was measured on the South Kawishiwi River from 1951-61 and again from April, 1976 to present. Water discharge ranged from 25 cfs to a maximum of 5130 cfs. Average discharge for 10 years is approximately 437 cfs or an average annual yield of more than 300,000 acre-ft. Frequency analysis of streamflow characteristics (Brooks, 1978) calculated an annual peak flow with .50 probability of occurrence in any one year as 2500 cfs. Low flow of 7-day duration with a non exceedence frequency of .50 is approximately 100 cfs.

The mining scenario or projected development along the copper-nickel ore body considers two 12.35 million MTPY crude-ore, underground mines adjacent to the South Kawishiwi River upstream from Birch Lake. A processing plant and tailing basin to service the plant are considered within the Birch Lake local watershed. An additional tailing basin is considered outside the watershed. The development area is approximately 3077 acres as follows:

Processing plant	520 acres	
Waste rock and lean ore stockpiles	248	
Tailing basin	2309	
	3077	total

For the purposes of this study, operation of the development would include control and collection of runoff from the plant site and stockpiles. The processing plant-tailing basin water management plan would be closed cycle with use of recycled water for 80% of plant demands.

The South Kawishiwi River at this station could provide enough water to maintain several mining operations, similar to that considered for Filson Creek, during drought periods. The average annual flow of the South Kawishiwi River is roughly 36 times the flow required to meet the 20 million MTPY plant demands (12 cfs) for continuous appropriation during the 5-year drought. Minimum flows of record are twice the flow rate required to meet plant demands. Withdrawal of 24 cfs from the South Kawishiwi River would be approximately 4% of the average inflow or 7% of the driest-of-record 12 month inflow to Birch Lake (after Bowers, 1976).

The processing plant in this scenario would be located near Birch Lake with a tailing basin in the Keeley Creek watershed. The loss of approximately one square mile for the plant site, in the local watershed area of the lake, could be considered insignificant in relation to the 600 square mile watershed of the three major tributaries. The natural watershed area of Keeley Creek, however, would be reduced about one-third by a tailing basin of 2309 acres.. Keeley Creek watershed is only slightly greater in area than Filson Creek although baseflow (August, 1976) was considerably less, or .002 cfsm compared to .007 cfsm. If areas contributing to base flow were removed from the drainage area, the stream could be expected to go dry more often and for longer periods during the low flow seasons.

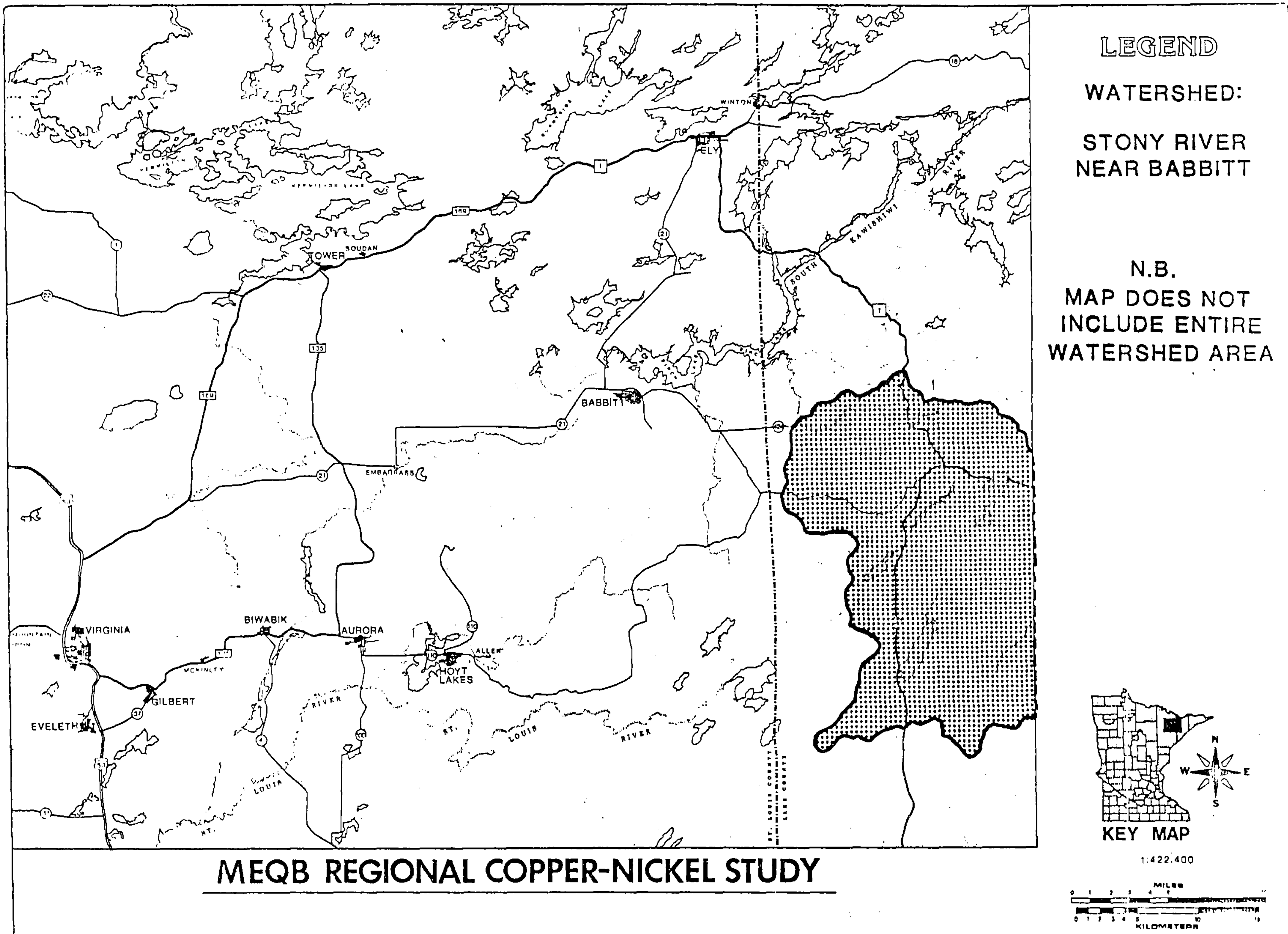
The mining development used in this study assumes seepage from the tailing basin is controlled and minimized with seepage collection ditches, drainfields, or interceptor wells. An average rate of seepage, 875 gpm for a 4015 acre tailing basin, was assumed to pass uncollected where semi-permeable subsoils underlie the basin. A seepage rate of 300 gpm for a 2063 acre tailing basin would be 33 times the baseflow of Keeley Creek as measured during August, 1976. This rate of seepage would not be expected to contribute substantially to an estimated annual peak flow, with .50 probability of occurrence, of 86 cfs (after Brooks, 1978).

Stony River near Babbitt, Minnesota

The Stony River near Babbitt watershed drains an area of approximately 219 square miles tributary to Birch Lake and the Kawishiwi River. The upper half of the watershed includes natural surface storage in numerous lakes and swamps. Lakes, ponds, and swamps make up nearly 20% of the 180 acre watershed area above the Stony River near Isabella surface-water gaging station (Mann and Collier, 1970). The Stony River includes nearly 100 miles of first and second order streams, 29 miles of third order streams, and 25 miles of main stem or fourth order stream. Average length of first order streams is less than one mile. Average channel gradient for the river system is 15 ft/mile.

Streamflow has been measured at the Stony River near Babbitt gage since August, 1975 and water discharge ranged from 6.6 cfs to a maximum of 2,490 cfs. Mean discharge for WY 1976 was 178 cfs for an annual water yield of about 10 inches or 117,000 acre-ft. Regional analysis of streamflow characteristics (Brooks, 1978) computes an annual peak flow with .50 probability of occurrence in any one year as 1050 cfs (.02 probability of occurrence in any one year is 2721 cfs). Low flow of 7 day duration with a non-excedence frequency of .50 is approximately 11 cfs. Low flow measured in August 1976 was 12.4 cfs.

Streamflow was measured at the Stony River near Isabella gage from 1952-64 and 1967-68. Water discharge ranged from 6 cfs to a maximum of 2040 cfs.



MEQB REGIONAL COPPER-NICKEL STUDY

Map B

Page 32

Average discharge was 127 cfs for an average annual yield of 9.6 inches or 92,000 acre-ft. Frequency analysis of streamflow characteristics (Brooks, 1978) computed an annual peak flow with .50 probability of occurrence in any one year as 800 cfs ± 25%. Low flow of 7-day duration with a non-exceedence frequency of .50 was approximately 15 cfs. Low flow measured in August 1976 was 6.6 cfs.

The mining scenario or projected development along the copper-nickel ore-body considers two tailing basins upstream of the Stony River near Babbitt gage. The development area is approximately 6324 acres in two basins of 4015 ac and 2309 ac, respectively.

For the purposes of this study, operation of the tailing basin includes control and collection of both precipitation on the basins and seepage under or through the dike. Water in the tailing discharge from the processing plants would be recycled to the respective plants. An uncontrolled, minimum seepage rate of 1175 gpm or 2.6 cfs (combined) for the tailing basins on semipermeable subsoils would represent 21% of the baseflow of the Stony River measured during August, 1976. This rate of seepage would not be expected to contribute substantially to an estimated annual peak flow, with .50 probability of occurrence, of 1050 cfs.

The combined area of the tailing basins is about 5% of the watershed area at the Stony River near Babbitt gage. The difference in water discharge measured at the two Stony River gages in August 1976 suggests a greater groundwater yield from lower portions of the watershed (.037 upper, .057 lower). In the event tailing basins were located in groundwater discharge areas and seepage from the basins did not occur, base flows in the Stony River could be reduced.

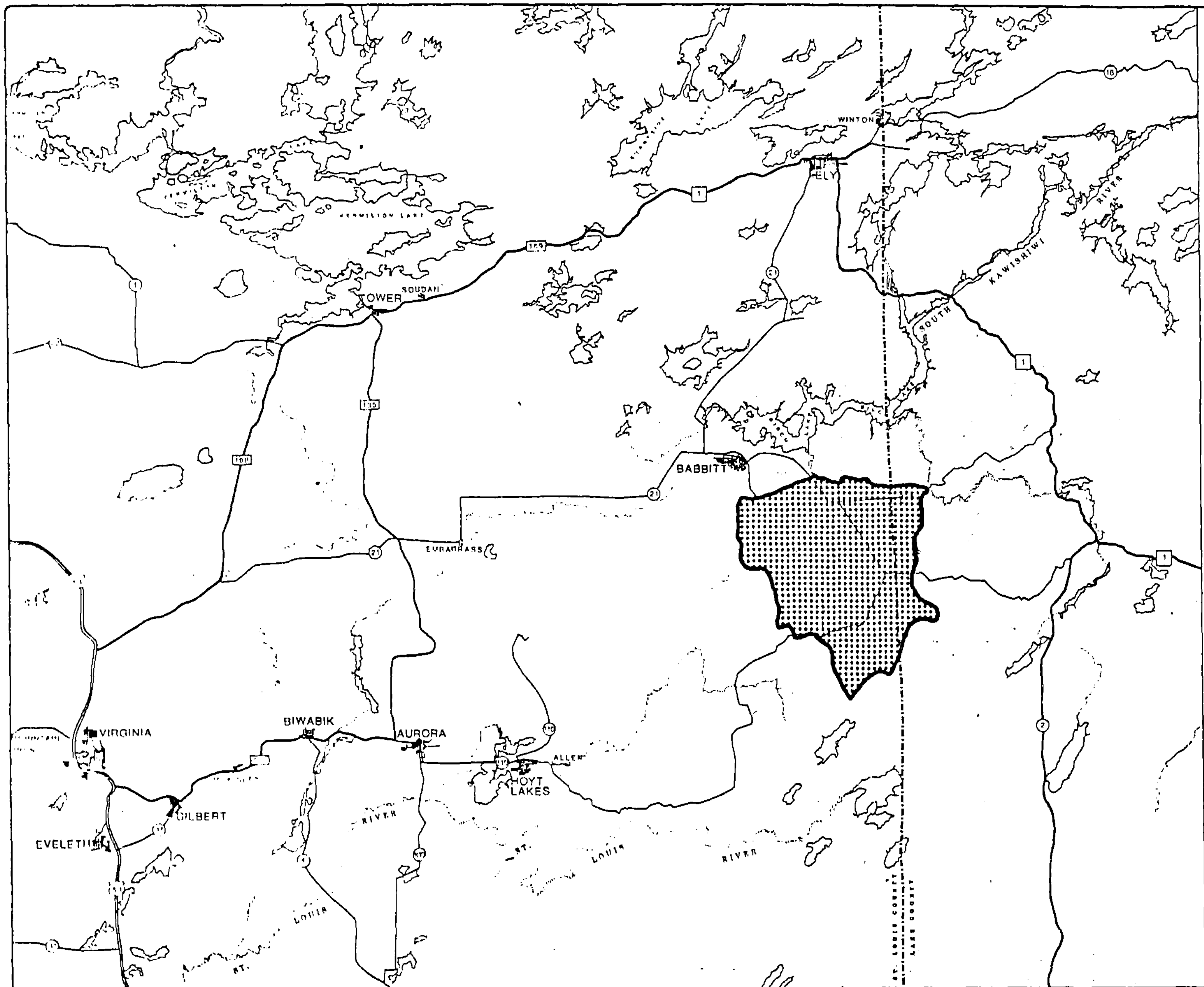
Dunka River near Babbitt, Mn.

The Dunka River near Babbitt, Minnesota watershed drains an area of approximately 53 square miles tributary to Birch Lake and the Kawishiwi River. Almost one-third of the watershed area is in lakes, ponds, and swamps (Mann and Collier, 1970). First order streams make up half the 40 miles of stream in the watershed. Channel gradients for these first order streams average 25.5 ft/mile. Channel gradient for the watershed including first order streams, 10 miles of second order streams, and eight miles of main stem averages 17.5 ft/mile.

Streamflow was measured at the Dunka River near Babbitt gage from 1951-62 and February 1975 to present. Water discharge ranged from no flows in 1976 to a maximum 691 cfs. Average discharge for 12 years of record is 37.5 cfs. Mean discharge for WY1976 was 39 cfs for an annual water yield of about 10 inches or 28,500 acre-ft. Frequency analysis of streamflow characteristics (Brooks, 1978) indicates an annual peak flow with .50 probability of occurrence in any one year would be 350 cfs. Low flow of 7-day duration with a non-exceedence frequency of .50 is approximately 2.5 cfs. Low flow measured in August 1976 was less than .1 cfs.

The mining scenario or projected development along the copper-nickel ore body considers two 20 million MTPY (crude-ore) open-pit mines, processing plants, and one 100,000 MTPY (metal) flash located within the watershed. The development area is about 14,450 acres as follows:

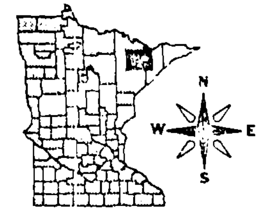
Open pit mines	1126 acres
Processing plants	800
Stockpiles	3976
Tailing basins	8030
Overburden piles	346



LEGEND

WATERSHED:

DUNKA RIVER
NEAR BABBITT



KEY MAP

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MILES

KILOMETERS

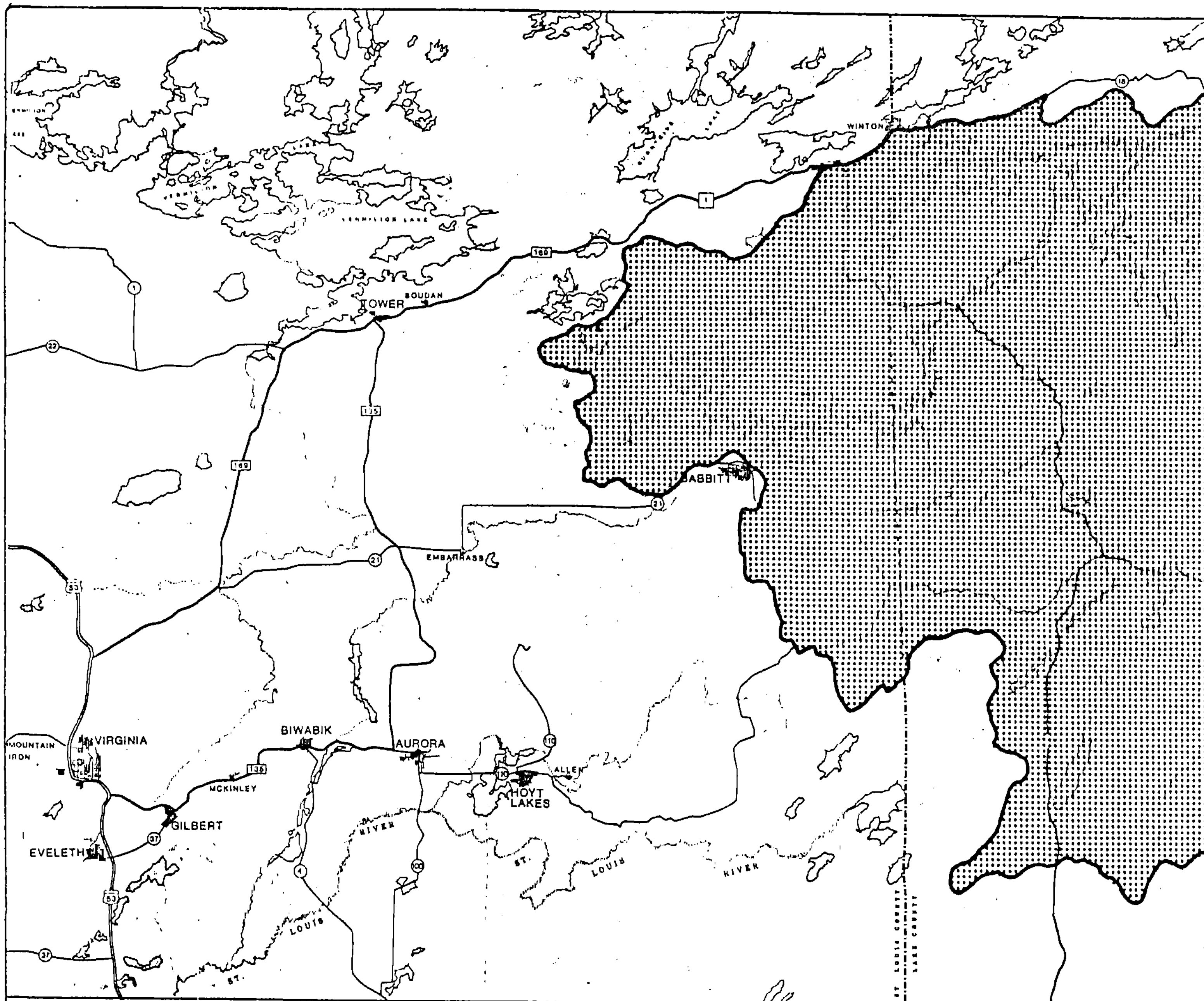
MEQB REGIONAL COPPER-NICKEL STUDY

Open pit mines	1126	acres
Processing plants	800	
Stockpiles	3976	
Tailing basins	8030	
Overburden piles	346	
Smelter site	150	
Slag pile	25	
	14453	Total

For purposes of this study, operation of the developments would include control and collection of runoff from the mines, plant sites, stockpiles, and overburden piles. The management of processing plant-tailing basin water would be essentially "closed-cycle" with use of recycled water for 80% of plant demands. Non-contact cooling water intake and discharge for the smelter were assumed to interact with one of the tailing basins. Water appropriation requirements for the smelter include process water makeup for plant losses and cooling-water makeup for evaporation losses.

It appears that Dunka River might provide an adequate supply of water to maintain this level of mining development during extended drought. About 114,000 acre-ft of water would be available in four average years, unadjusted for evaporation or other losses, if storage of runoff were provided. Flow for the driest 36 months of record averaged 30 cfs (Bowers, 1978) or about 65,000 acre-ft. The 5-year duration drought would require a water supply of about 24 cfs or 56,000 acre-ft.

This appropriation requirement might be met through development of storage in the Dunka River watershed with capture of virtually all runoff during drought periods. One alternative to such an effort may be to use Birch Lake water during droughts. Withdrawal of 24 cfs would be approximately 4% of the average inflow or 7% of the driest-of-record 12 month inflow to the lake. With this level of mining development, the natural watershed area of Dunka River would be reduced by more than 14,400 acres or 43%. Average discharge could be expected to decrease by roughly 16 cfs and average annual water yield from the remaining undisturbed area could be 15,500 acre-ft. The August 1976 discharge observation of .001 cfsm indicates a lack of base flow in the river. The 43% loss of watershed would probably cause the Dunka River to go dry more often, and for longer periods of time, rather than simply reduce low flow by a proportional amount. An average rate of seepage of 1750 gpm from the tailing basins would be almost 4 cfs or 65 times the baseflow measured in August 1976. For comparable seepage rates, mining-related changes in low flows on this river could depend more on seepage control practices at the tailing basins than loss of watershed area by containment.

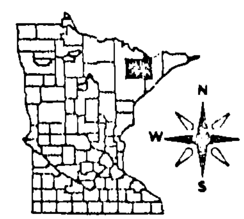


LEGEND

WATERSHED:

KAWISHIWI RIVER
NEAR WINTON

N.B.
MAP DOES NOT
INCLUDE ENTIRE
WATERSHED AREA



KEY MAP

1 422 400

MILES

KILOMETERS

MEQB REGIONAL COPPER-NICKEL STUDY

Map D

Kawishiwi River near Winton, Minnesota

The Kawishiwi River near Winton, Minnesota watershed drains an area of approximately 1200 square miles including the watersheds previously discussed in this section. Below the streamflow gage, the Kawishiwi River drains into Fall Lake and from there into the Boundary Waters Canoe Area (BWCA). First order streams make up 36% of the 200 miles of streams in the watershed. Main stem (fifth order stream) makes up an additional 22%. Average channel gradients on the river range from 22 ft/mile for first order streams to 3 ft/mile for main stem.

The streamflow gage is located at a Minnesota Power and Light hydroelectric dam and daily discharge is computed from powerplant records. Streamflow has been reported for 1905-07, 1912-19 (fragmentary) and September 1923 to present. Water discharged has ranged from no flow at times to a maximum of 16,000 cfs. Average discharge (unadjusted) for 57 years of record was 1,027 cfs or 11.6 inches/year. Mean discharge (adjusted) for WY76 was 950 cfs for an annual water yield of about 11 inches or 690,000 acre-ft. Frequency analysis of streamflow characteristics (Brooks, 1978) indicates an annual peak flow with .50 probability of occurrence in any given year would be about 5200 $\pm$ 500 cfs. By regional analysis, low flow of 7-day duration with a non-exceedence frequency of .10 is approximately 100 $\pm$ 20 cfs. This low flow is influenced by operation of the dam and actual low flows in the river may often be much less. There were 7 consecutive days of no flow in August 1976.

The mining scenario or projected development along the copper-nickel ore body considers a total of six mines, four processing plants, five tailing basins, one smelter, and associated facilities in this watershed. These are the same developments discussed in previous watershed sections. Total development area is about 27000 acres as follows:

Filson Creek near Ely	3124 acres
South Kawishiwi River near Ely	3077
Stony River near Babbitt	6324
Dunka River near Babbitt	14453
	26978 Total

With this level of development, the natural watershed area of the Kawishiwi River at Winton would be reduced by 27000 acres or roughly 3.5%. Average discharge could be expected to decrease by roughly 36 cfs. The combined appropriation requirement for drought periods and this level of mining development is 47 cfs from the South Kawishiwi River - Birch Lake systems. This 47 cfs or 34,000 acre-ft per year appropriation plus the 36 cfs or 26,000 acre-ft per year flow reduction due to loss of watershed area would be about 8% of the average flow past the stream gage. Average annual water yield (inflow to Fall Lake) would still be greater than 680,000 acre-feet.

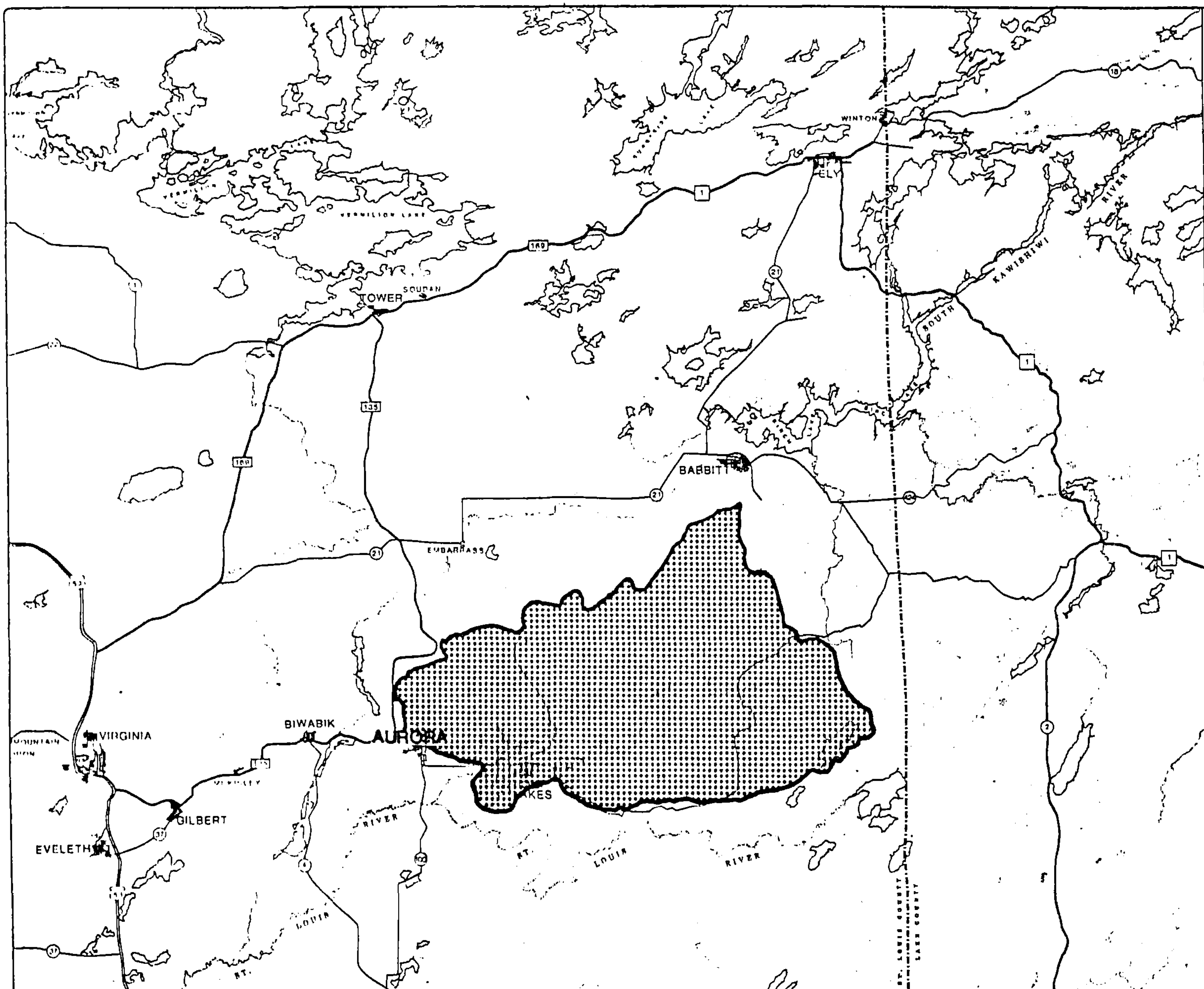
Specific low flow effects would depend somewhat on the operation of the dams on Birch Lake and Garden Lakes. Mining-related flow influences would not appear to affect present operating plans, for both of these structures, that include controlled release for flow maintenance during drought periods. The combined flow loss of 83 cfs represents 10% of the mean outflow from Birch Lake (WY 1976) although more than 520,000 acre-ft of water would still pass the gage each year. Fall Lake has an average depth of 14 feet and area of 2200 acres. The 520,000 acre-ft volume is, by rough estimate, more than 10 times the storage capacity of Fall Lake.

V. IMPACT OF COPPER NICKEL MINING AND BENEFICIATION ON STREAMFLOW OF THE UPPER ST. LOUIS RIVER.

1. Partridge River near Aurora, Minnesota.

The Partridge River near Aurora, Minnesota watershed drains an area of approximately 156 square miles tributary to the upper St. Louis River. First order streams make up 44% of the 113 miles of stream in the watershed. Main stem (fourth order stream) makes up an additional 16%. Average channel gradients range from 23 ft/mile for first order streams to 4.3 ft/mile for third order streams.

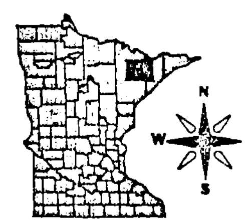
Streamflow has been measured at the Partridge River near Aurora gage since August, 1942. Since 1955, flow has been regulated at times by storage in Partridge (Whitewater) Reservoir. Water discharge ranged from 2.2 cfs to a maximum 3,230 cfs. Average discharge (unadjusted) for 34 years of record is 128 cfs or 11 inches/year. Mean discharge (adjusted) for WY 1976 was 89.5 cfs for an annual water yield of 8 inches or 65,000 acre-ft. Frequency analysis of streamflow characteristics (Brooks, 1978) indicates an annual peak flow with .50 probability of occurrence in any one year would be 1000 $\pm$ 150 cfs. Low flow of 7-day duration with a non-exceedence frequency of .50 is approximately 11 cfs. Low flow measured in August 1976 was 10 cfs although some flow may be due to seepage from Partridge Reservoir and mine dewatering in Second Creek tributary watershed. Low flow at the Highway 110 crossing, 1 mile northeast of Hoyt Lakes, was 50 cfs.



LEGEND

WATERSHED:

PARTRIDGE RIVER NEAR AURORA



KEY MAP

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MILES

KILOMETERS

MEQB REGIONAL COPPER-NICKEL STUDY

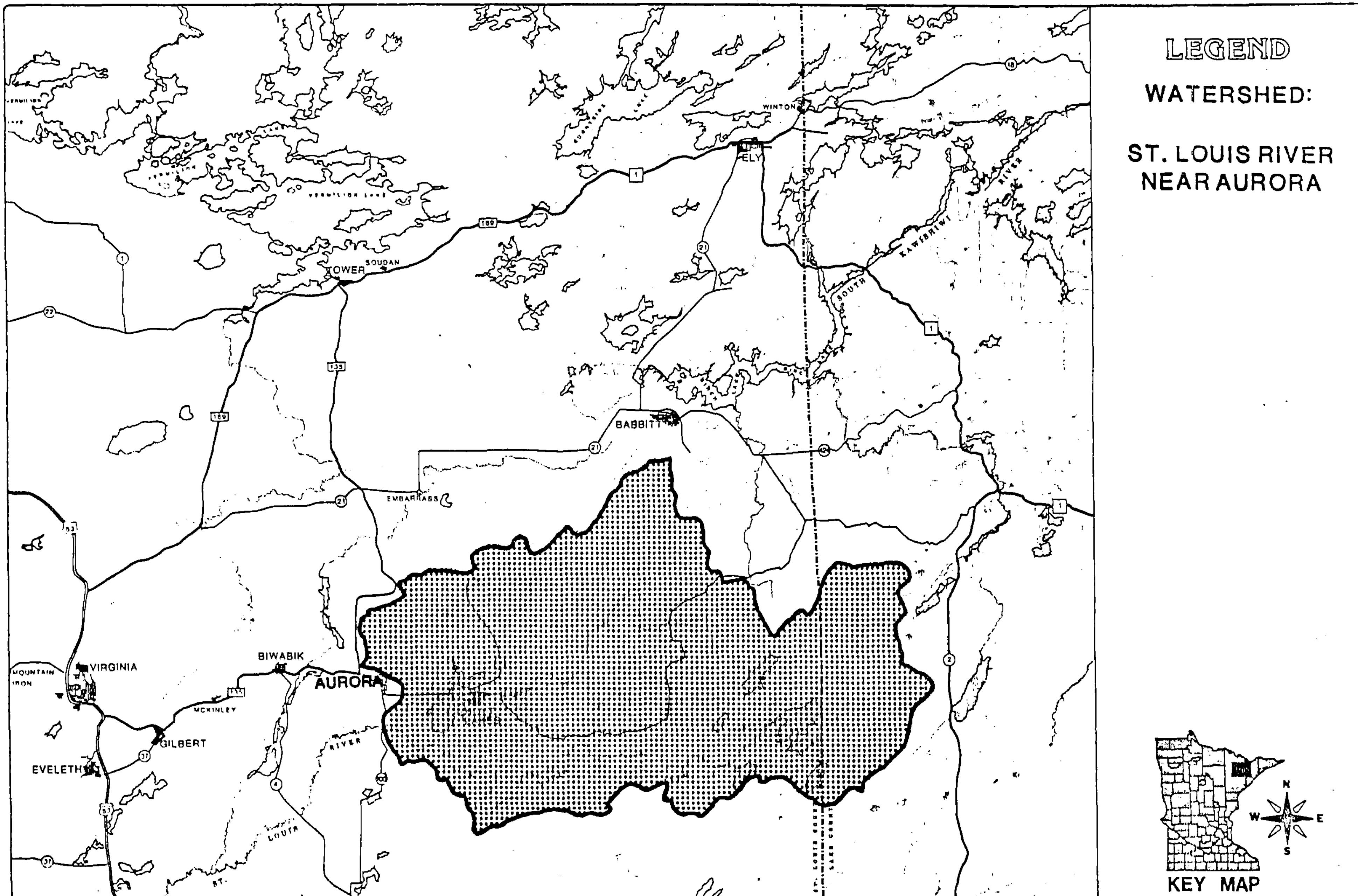
The mining scenario or projected development along the copper-nickel ore body considers a 20 million MTPY crude-ore open pit mine, processing plant, and tailing basin in this watershed. The development area is approximately 7140 acres as follows:

Open pit mine	563 acres	
Processing plant	400	
Waste rock and lean ore stockpiles	1988	
Overburden piles	173	
Tailing basin	4015	
	7139	Total

For purposes of this study, operation of the development would include control and collection of runoff from the mine, plant site, stockpiles, and overburden piles. The management of processing plant-tailing basin water would be essentially "closed-cycle" with use of recycled water for 80% of plant demands.

The Partridge River could probably provide an adequate supply of water to maintain this level of development if additional reservoir storage were developed. About 260,000 acre-ft would be available in four average years, unadjusted for evaporation or other losses, if storage and runoff were provided. The 5-year duration drought would require a water supply of about 35,000 acre-ft over four years.

With this development, the natural watershed area above the Partridge River near Aurora gage would be reduced by about 7140 acres or 7%. Average discharge could be expected to decrease by about 9 cfs and average annual water yield from undisturbed areas could still be 86,000 acre-ft/yr. The August 1976 discharge observation at County Highway 110, 1 mile northeast of Hoyt Lakes, was .50 cfs (.005 crsm) which suggests a relative lack of baseflow from areas of the watershed above Colby Lake and Wyman Creek. An average rate of seepage of 875 gpm from the tailing basin would be almost 2 cfs, or 4 times the baseflow measured in August 1976. Although actual baseflow influence would depend on basic design and site-specific characteristics, mining-related changes in low flows above Colby Lake would probably depend more on seepage control practices at the tailing basin than loss of watershed area by containment.



MEQB REGIONAL COPPER-NICKEL STUDY

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MILES

KILOMETERS

Page 46

Map F

2. St. Louis River near Aurora

The St. Louis River near Aurora, Minnesota watershed drains an area of approximately 291 square miles. First order streams make up 31% of the 77 miles of stream in the watershed. Main stem (third order stream) makes up an additional 52%. Average channel gradients range from 12 ft/mile for first order streams to 6.5 ft/mile for main stem.

Streamflow has been measured at the St. Louis River near Aurora gage since 1950. The gage is located less than a mile downstream of the mouth of the Partridge River and mining-related flow influences on that stream also influence flow on the St. Louis River. Water discharged has ranged from 4 cfs to a maximum of 5380 cfs. Average discharge (adjusted) for 34 years was 247 cfs or 11.5 in/yr. Mean discharge (adjusted) for WY 1976 was 188 cfs for an annual water yield of about 9 inches or 136,000 acre-ft. Frequency analysis of streamflow characteristics (Brooks 1978) indicates an annual peak flow with .50 probability of occurrence in any one year would be 1600 ± 200 cfs. Low flow of 7 day duration with a non-exceedence frequency of .50 is approximately 25 cfs. Low flow measured in August 1976 was 20 cfs although some flow may be due to seepage loss from Partridge Reservoir and mine dewatering in Second Creek tributary watershed. August 1976 low flow 150 feet upstream of Partridge River and 1.5 miles south of Aurora was 5 cfs.

The mining scenario or projected development along the copper-nickel ore body considers a 20 million MTPY crude-ore, open pit mine, processing plant, and tailing basin in the Partridge River watershed. The total development area is approximately 7140 acres as described in the Partridge River watershed section.

With this development, the natural watershed area above the St. Louis River near Aurora gage would be reduced by 7140 acres or 4%. Average discharge could be expected to decrease by about 9 cfs and average annual water yield from undisturbed areas could still be greater than 172,000 acre-ft/yr. Based on regional analysis of streamflow characteristics (Brooks, 1978), the one-day low flow discharge with 0.05 non-exceedence frequency for a watershed area of 291 square miles would be 10 $\pm$ 5 cfs. August 1976 low flow 150 ft. upstream of Partridge River and 1.5 miles south of Aurora was 5 cfs. An average rate of seepage of 875 gpm from a tailing basin upstream would be almost 2 cfs or 40% of this observed flow.

VI. SUMMARY AND CONCLUSIONS

Streamflow changes resulting from copper-nickel mining or beneficiation may be addressed as regional or site-specific impacts. Regional impacts include cumulative surface water withdrawals, loss of watershed area by containment, and seepage from tailing basins. A brief analysis of variability in water discharge in the region suggests these impacts may be predicted with more confidence on large watersheds (>100 square miles) and for average rather than extreme flows. Impacts due to cumulative changes in watershed characteristics or alteration of channel conditions require project designs, specific locations, and detailed surveys.

The base case or typical copper-nickel operation used in the study has an open-pit mine, 20 million metric ton per year crude ore beneficiation plant, and tailing basin. Control and collection of water runoff from the mine, plant site, stockpiles, and overburden piles is assumed. Processing plant-tailing basin water management is "closed-cycle" with use of recycled water for 80% of plant demands.

Enough water to operate the plant could usually be collected from contained areas and stored in the tailing basin during periods of above average precipitation or snow melt. Water would have to be supplied from some other source during consecutive seasons of low precipitation or high evaporation. Given certain design and layout assumptions, the typical operation would require about 16,600 acre-ft of water to endure a five-year drought comparable to the period 1921-25 with extreme evaporation rates. The largest operation with two plants and a smelter would require about 56,000 acre-ft of water under comparable conditions. These water requirements could be met a number of different ways although a constant withdrawal rate (appropriation) is considered for purposes of discussion.

Enough water to meet these appropriation requirements during drought periods is present in the Kawishiwi and upper St. Louis Rivers. The combined appropriation requirements of 47 cfs during drought periods from the Kawishiwi River system could be met from existing natural storage. The combined appropriation requirements of 9 cfs during drought periods from the upper St. Louis River would probably require the development of artificial storage in tributary areas. The appropriation requirements cannot be met in all cases with flows from subwatershed areas in which a specific copper-nickel operation is located. ~~An~~ The operation in the Filson Creek or Dunka River watersheds, for example, would likely have to draw water from the larger South Kawishiwi River or Birch Lake.

As recognized by Bowers (1974), Birch Lake could provide the necessary amount of water to meet the appropriation requirements of the cumulative development discussed in this study. A central water source for mining-related drought protection in the Kawishiwi River basin and transfer of this water for similar uses in the upper St. Louis River basin are ~~state~~ policy issues that may merit further review.

The loss of watershed area by containment for "closed-cycle" water management programs may deplete as much as 50% the low flows from subwatershed areas of less than 100 square miles. The cumulative loss of watershed area does not appear to be significant to low flows on the Kawishiwi River where it enters Fall Lake and the Boundary Waters Canoe Area. At that point, the affected area represents 3.5% of the watershed area and low flows are controlled by existing dams on Birch and Garden Lakes. The cumulative loss of watershed area due to copper-nickel operations along the upper St. Louis River likewise represent about 4% of the natural watershed area.

The impacts on low flows from tributary streams may also be compounded by changes in watershed characteristics or channel conditions. The net effects on low flows of Filson Creek, Dunka River, or the Partridge River for examples should be addressed when actual proposals with specific designs, locations, and additional background data are available.

Flow of streams receiving seepage from tailing basins would be increased during mining. Seepage is quantified for the purposes of this study with assumed permeability of subsoils, dike materials, tailing discharges, and water level management. An uncontrolled seepage rate of 875 gallons per minute is used as an estimate of seepage from a hypothetical structure on a semipermeable subsoil. Seepage in excess of this rate is assumed returned to the basin.

This rate of seepage would tend to increase and sustain base flows in streams that normally have extremely low flows (less than 1cfs) during periods of little or no rainfall. For example, it represents 33 times the baseflow of Keeley Creek (11 square miles) or 65 times the baseflow of the Dunka River (53 square miles) as measured during August, 1976. This seepage may balance some low flow reduction due to loss of watershed area by containment.

Protection of public waters may require low flow maintenance on some streams draining watershed areas of less than 100 square miles. In those cases, water balance in the tailing basin and contained areas, such as stockpiles and plant sites, should be an important factor in design and layout of the mining or beneficiation operations.

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