Regional Copper-Nickel Study

State Planning Agency

THE MINNESOTA REGIONAL COPPER-NICKEL STUDY

1976-1979

VOLUME 1

EXECUTIVE SUMMARY

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Minnesota Environmental Quality Board

PREFACE

The State of Minnesota faces a unique challenge. A major domestic resource of copper, nickel, and cobalt exists in northeastern Minnesota within the Superior National Forest and adjacent to the Boundary Waters Canoe Area. The exploitation of this resource could bring large economic and employment benefits to the state, but it could also bring widespread environmental damage to an environmentally sensitive region of the country.

The future of a region's economy and a very unique environment will be determined by numerous federal, state, local, and private actions taken over the next several years. In the past, such actions were based on limited knowledge of their possible consequences. Minnesota is now in the unique position of having a comprehensive compilation of information on this resource issue before any commercial development has occurred.

The Minnesota Environmental Quality Board's Regional Copper-Nickel Study is a comprehensive technical examination of the environmental, social, and economic impacts associated with the potential development of copper-nickel sulfide mineral resources of the Duluth Complex in northeastern Minnesota. This executive summary of the 5 volume, 36 chapter report presents some of the major findings of the Study, but in order to get a complete picture of the complex issues associated with exploiting this valuable mineral resource, the entire document should be examined. In addition to this report over 180 technical reports, extensive environmental monitoring data files, special sample collections, and other information resources were compiled by the Study.

The review and establishment of public policy pertaining to the management and possible exploitation of the state's mineral resources is an evolving process guided by technical information but directed by socio-political needs which change over time. The socio-political environment in the state has changed significantly since 1974 when the Regional Study was first conceived. While this Study makes a significant contribution to the state's mineral policy development process, it is not an end in itself. Consistent with directions from the Minnesota Legislature, the Regional Copper-Nickel Study presents technical findings but does not make policy recommendations based on these findings. The success and usefulness of the $4.3 million state investment in the Study will be determined by future actions of the legislature, local, state, and federal agencies, the mining industry, and private citizens.

A "regional study" was commissioned because it was believed that conventional site-specific environmental impact statements (EIS's) and the corresponding regulatory process were inadequate to deal with the broader issues involving this unexploited resource. In addition, specific policy guidance for the site-specific process and a re-examination of existing laws, rules, and regulations was envisioned before action on specific copper-nickel development proposals is initiated by the state. Comprehensive technical information is now available for this policy activity and regulatory review. The completion of the Regional Study, and MEQB's acceptance thereof, marks the end of the copper-nickel development moratorium in Minnesota. Development applications from mining companies are expected within the next year and it is now time to prepare for this new resource management.

TABLE OF CONTENTS

TABLE OF CONTENTS (contd.)

LIST OF FIGURES

LIST OF TABLES

ABBREVIATIONS

As	-	Arsenic
BTU	-	British Thermal Unit
BWCA	-	Boundary Waters Canoe Area
Cd	-	Cadmium
CEU	-	Copper Equivalent Unit
cfs	-	cubic feet per second
Co	-	Cobalt
CSI	-	Calcite Saturation Index
Cu	-	Copper
dcfror	-	discounted cash flow rate of return
EIS	-	Environmental Impact Statement
EPA	-	Environmental Protection Agency
ft	-	foot
gal	-	gallon
gm/sec	-	grams per second
ha	-	hectare
Hg	-	mercury
kg	-	kilogram
km	-	kilometer
MDNR	-	Minnesota Department of Natural Resources
MEQB	-	Minnesota Environmental Quality Board
MPCA	-	Minnesota Pollution Control Agency
mg	-	milligram
mi	-	mile
min	-	minute
mm	-	millimeter
mt	-	metric ton
mtpy	-	metric tons per year
N	-	Nitrogen
Ni	-	Nickel
P	-	Phosphorus
Pb	-	lead
ppb	-	parts per billion
ppm	-	parts per million
PSD	-	Prevention of Significant Deterioration
SO_2	-	Sulfur dioxide
st	-	short ton
TSP	-	Total Suspended Particulates
ug/m^3	-	micrograms per cubic meter
ug/l	-	micrograms per liter
USBM	-	United States Bureau of Mines
yd^3	-	cubic yard
yr	-	year
Zn	-	Zinc

ACKNOWLEDGEMENTS

The Regional Copper-Nickel Study was organized as an ad hoc research and environmental assessment project under the administration of the Minnesota Environmental Quality Board. The Study was directed by Robert H. Poppe, supervised by Peter Kreisman, Ph.D. (natural sciences), and Royden Tull (social sciences), and major disciplines coordinated by Gerald L. Lieberman, Ph.D. (biological sciences), David Veith (mining and metallurgical engineering), Daryle Thingvold, Ph.D. (physical sciences), and Norm McNeal, Ph.D. (data management and systems analysis).

The over 180 reports, associated data files, and other research documents produced by the Study were the product of an interdisciplinary staff of researchers, planners, technicians, and assistants on temporary assignment with the Study; as well as state and federal agency personnel and consultants. During the peak in the Study activities, over 75 professionals were involved in monitoring and research programs. The success of this project is due to the eff orts of these individuals. The Appendix specifically acknowledges these individuals by major study subject areas.

In addition to project staff, many state and federal agencies and university researchers were of invaluable help to the Study. Active agency participants included the Minnesota Department of Natural Resources, Minnesota Pollution Control Agency, Minnesota Department of Health, Minnesota State Planning Agency, Minnesota Energy Agency, U.S. Bureau of Mines, U.S. Forest Service, U.S. Geological Survey, U.S. Environmental Protection Agency, Mineral Resources Research Center (University of Minnesota), Minnesota Geological Survey, University of Minnesota, and the University of Minnesota-Duluth.

Important data, information, assistance, and advice was given to the Study by the companies exploring along the Duluth Complex, by adjacent taconite mining companies, and by many of the industries operating in the region. Assistance was also received from several environmental organizations, individuals concerned about the environmental quality of the region, and researchers in Canada, Europe, and the United States. Cooperation from the many parties interested in this issue greatly increased the quality of the Study's research.

Special thanks are due for the efforts of the Study's clerical and graphics personnel and specifically to Sharon Todoroff, Susan Masson, and Kevin Kelley, who skillfully converted illegible handwriting and drawings into numerous professional documents.

1. HISTORICAL PERSPECTIVE

Although copper and nickel minerals were found in northern Minnesota in the late 1800's, significant interest in mining has only begun to unfold within the past thirty years. In 1948, during construction of a United States Forest Service logging road southeast of Ely, the presence of copper-nickel mineralization was observed. Geologic mapping, sampling studies, and drilling in the mineralized area began in the early 1950's by the Minnesota Geological Survey and the United States Bureau of Mines. Simultaneously, private concerns initiated exploration activities. During the 1960's exploration activities increased. The identification of large deposits of potentially mineable copper-nickel sulfides, the changing world supply situation, the more favorable attitudes of the federal and state governments, and the economic feasibility of mining large deposits of low grade ores have contributed to the increased commercial viability of these deposits.

In 1972, Governor Wendell Anderson established an Inter-Agency Task Force to determine the capacity of the state to deal with the many ramifications of the entire copper-nickel mining process. Chaired by the Department of Natural Resources, the Task Force consisted of representatives of six state agencies and was advised by a group composed of representatives from citizen groups, mining companies, and local governments. Their report, issued in January, 1973, contained information on state mineral policy, mineral potential, metal markets, exploration techniques, methods and processes used in mining, beneficiation, extraction and refining, environmental considerations during the various mining phases, potential economic impact, and socio-economic attitudes relating to northern Minnesota.

In 1973, the Minnesota Legislature appropriated $100,000 to the Department of Natural Resources, the State Planning Agency, and the University of Minnesota to conduct additional studies relating to copper-nickel development.

In 1974, both INCO and Amax informed the Minnesota Environmental Quality Board (MEQB) that they were preparing environmental assessments for their copper-nickel projects. Realizing that the studies up to that point did not adequately consider the regional impact of copper-nickel development, the MEQB adopted a resolution on October 8, 1974 stating, "That the MEQC require that an adequate regional EIS be completed prior to the acceptance of any site specific EIS on any mining development proposal." This resolution (subsequently amended on June 21, 1976, to require a comprehensive regional study rather than a formal EIS) effectively put a moratorium on copper-nickel mining until the completion of this report by the Regional Copper-Nickel Study.

2. STUDY GOALS AND OBJECTIVES

The concept of a regional environmental impact statement arose in 1974 when the Minnesota Environmental Quality Board (MEQB) became convinced that the state and federal environmental impact statement process for site specific copper-nickel mining proposals would not adequately address regional and cumulative environmental, social and economic impacts associated with the establishment of a new minerals industry in northeastern Minnesota. At that time, the concept of a regional (non-site-specific) environmental impact statement was a new one and apparently without precedent.

Because of the complexity, the importance, and potential controversy of developing the copper-nickel resources in northeastern Minnesota, the MEQB and the Legislative Commission on Minnesota Resources (LCMR) instructed that the Regional Copper-Nickel Study be a neutral, technical information gathering and impact analysis process. The Study was to present information useful for the analysis of various policy and regulatory options; it was not intended to make policy recommendations itself.

The Regional Copper-Nickel Study developed its program under a workplan approved by the MEQB and LCMR which included the following objectives:

- Look at the cumulative development of the region, instead of one piece of the total development at a time and address cumulative impacts of such development.

- Provide information for the Legislature in a format that is useable by the Legislature for the future evaluation and enactment of state policy on copper-nickel development.

- Enable agencies and other investigators, through a coordinated, interdisciplinary process, to study the generic and regional aspects of copper-nickel development in detail prior to future site-specific EIS and regulatory activities, which all too often are conducted without sufficient time.

-Examine common problems at the regional level, leaving examination of specific problems to a site-specific EIS level.

-Collection of baseline data in order to develop a regional perspective as input to predictive impact analysis and for future design of site-specific studies.

-Analyze alternative copper-nickel development policies, but not develop a resource management plan for the region.

3. STUDY AREA AND MINERAL RESOURCES

Study Areas. To allow for a discussion of the potential environmental and socio-economic effects of copper-nickel development, an area of approximately 2100 square miles was designated as the Regional Copper-Nickel Study Area (or simply, the Study Area). This area contains Virginia in the southwest corner and Ely in the northeast corner (Figure 1). The major copper-nickel deposits of interest occur along the Duluth Gabbro Contact, in a band three miles wide and fifty miles long (the Resource Area); however, additional deposits may extend beyond this band. For reference purposes, this band has been divided into a set of seven resource zones. A larger development area containing seven "development zones" is expected to contain the bulk of facilities needed to serve any mines (Figure 1). Current mineral rights holdings, company interests, watershed divides, and vegetation boundaries were not used to designate the zones with the exception of zone 7, which, in the absence of adequate information showing significant copper-nickel mineralization, was created on the basis of mineral lease holdings.

Figure 1

Three other areas of study were defined for specific subject areas in addition to the Study Area described above. The Water Quality Research Area, which includes the complete watersheds of 14 streams of interest, is shown in Figure 2. Waters north of the Laurentian Divide are part of the Rainey River Watershed, which includes a portion of the Boundary Waters Canoe Area, and whose waters eventually drain into Hudson Bay and the North Atlantic. Waters south of the Divide are a part of the St. Louis River Watershed which drains into Lake Superior and eventually into the Atlantic Ocean via the St. Lawrence River.

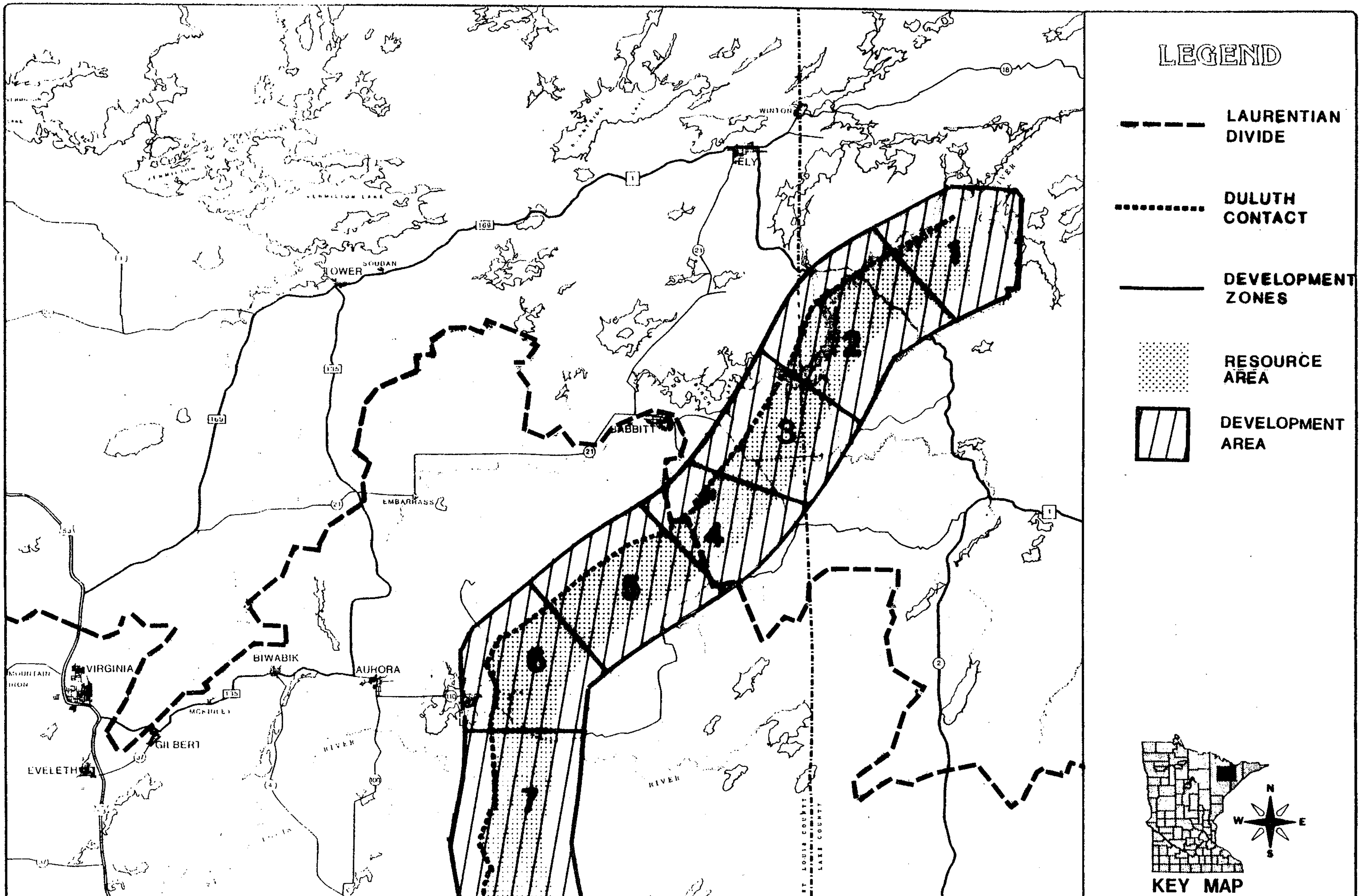


FIGURE 1

MEQB REGIONAL COPPER-NICKEL STUDY

MN CU-NI DEVELOPMENT AND RESOURCE ZONES

Figure 2

The Air Quality Study Region was defined as the area within 93 miles (150 kilometers) of the center of the development zones (Figure 3). This area contains most of Minnesota's Arrowhead Region plus parts of Wisconsin and Canada. Areas of special interest in the Air Quality Study Region include: the wilderness areas of Voyageurs National Park and the Boundary Waters Canoe Area (BWCA); the proposed site of a coal-fired power plant in Atikokan, Ontario; all of the Iron Range communities and the major taconite mines; and Duluth and Superior.

Figure 3

Some of the socio-economic studies focused on the seven county Arrowhead Region (Aitkin, Carlton, Cook, Itasca, Koochiching, Lake, and St. Louis counties). This region had a 1977 population of 377,000 people, of whom 36,000 lived in the communities of the Study Area.

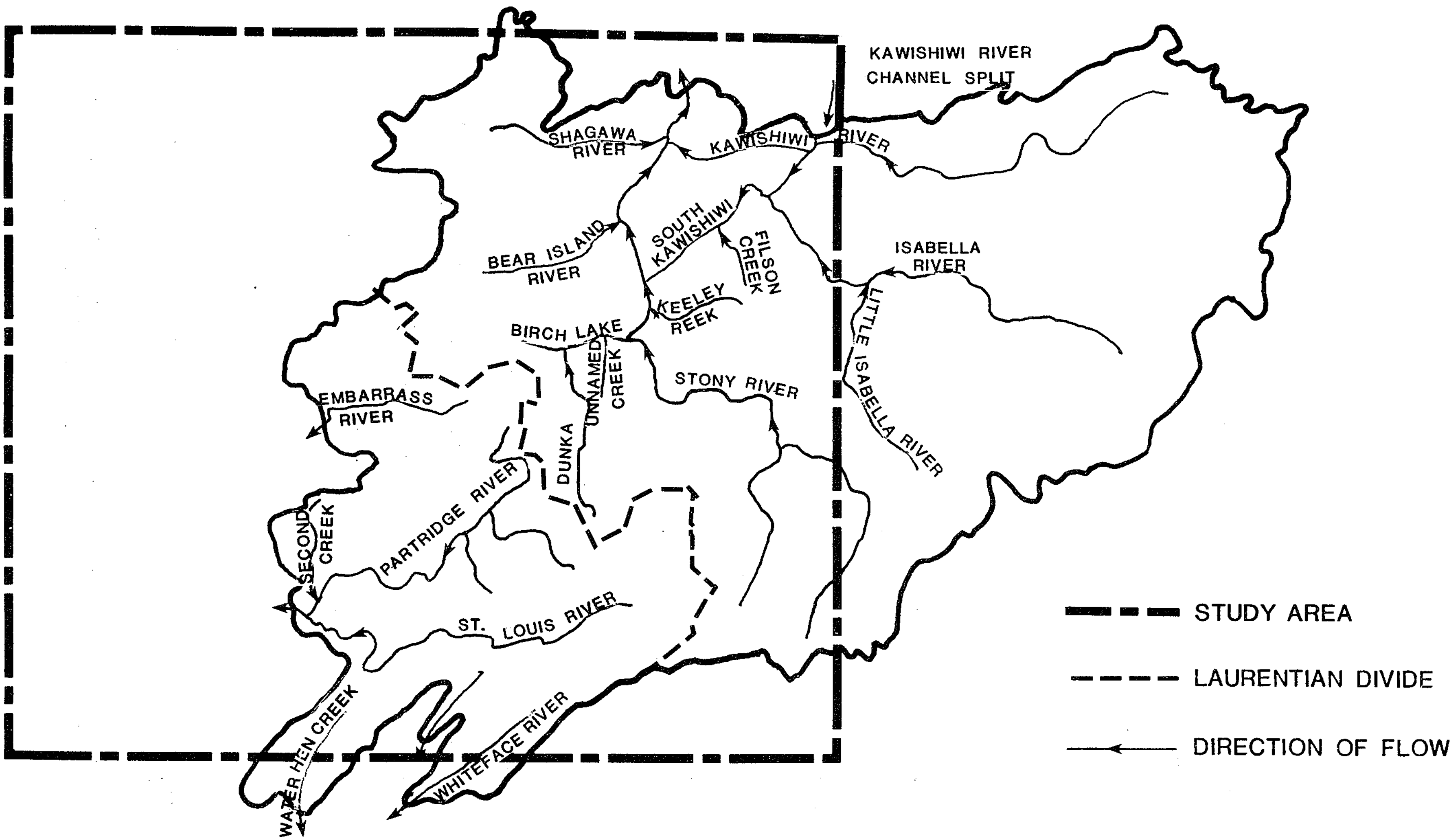
Mineral Resources (Volume 3-Chapter 2). Mineral resource estimates were prepared by the Minnesota Department of Natural Resorces (MDNR) using core assays from 324 drill holes provided by mining companies over an area of 42.2 square miles. This low density of drill holes can only be used as a general indication of the extent of resources present. Tonnage estimates were made for resources meeting one of two criteria:

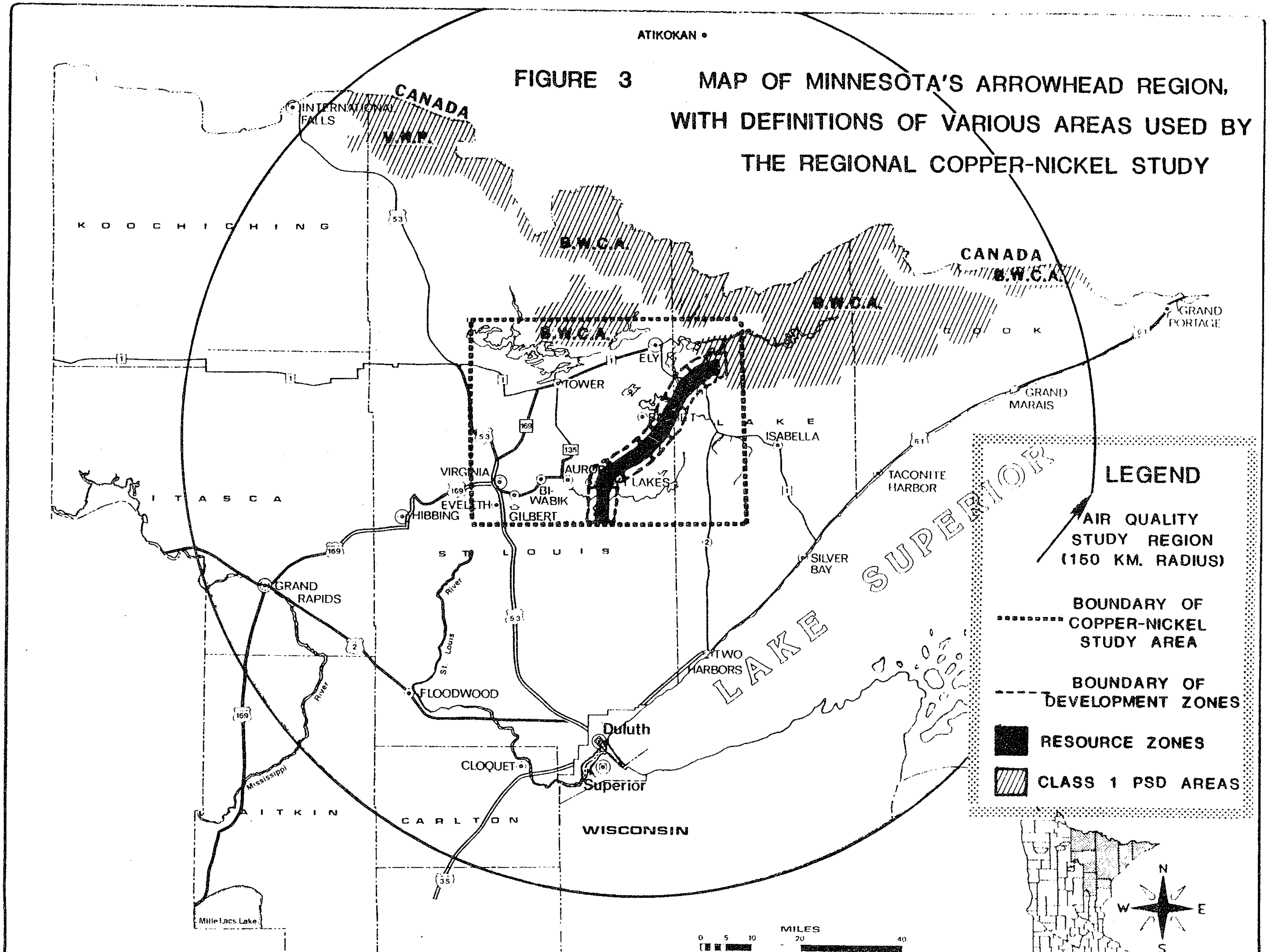
Type 1: resources having a minimum vertical thickness of 50 feet assaying at least 0.5 percent copper.

Type 2: resources having a minimum vertical thickness of 100 feet assaying at least 0.25 percent copper in the top 100 feet of the core (or core less than 100

FIGURE 2

SURFACE DRAINAGE IN THE WATER QUALITY RESEARCH AREA





MEQB REGIONAL COPPER-NICKEL STUDY

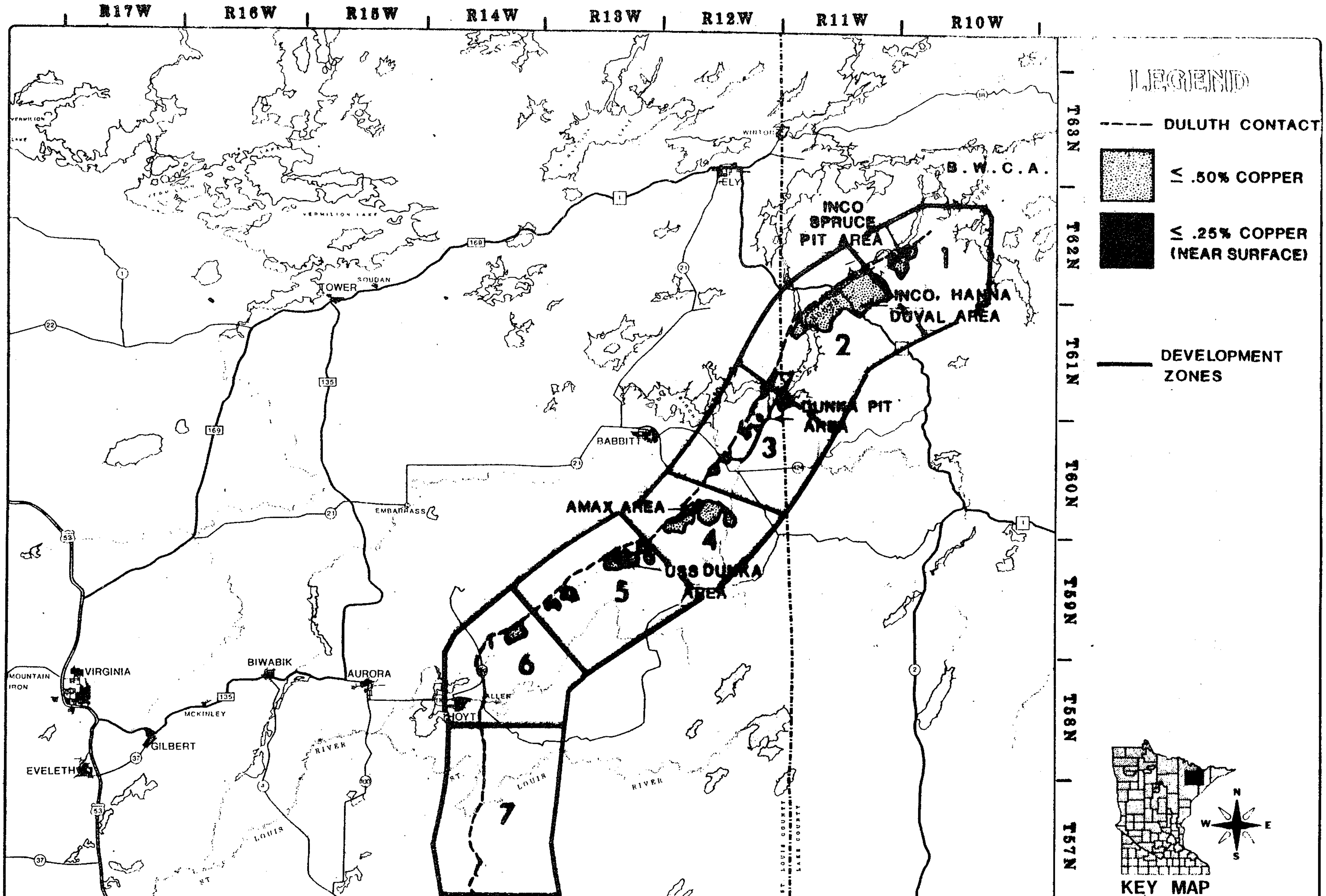
feet in length if the bottom of the Duluth Complex was reached by drilling less than 100 feet and the core contained copper-nickel mineralization throughout).

Figure 4 shows the major concentrations of these two types of mineralization. Resources having at least 0.5 percent copper (type 1) are estimated to total 4.0 billion metric tons (mt), and average 0.66 percent copper. Four major concentrations of the resources containing at least 0.5 percent copper are shown on the map. These are, from north to south, the INCO Spruce Road Pit area in resource zone 1 (635 million mt of resource); the INCO-Hanna-Duval block in resource zone 2 (2.09 billion mt of resource); the AMAX area in zone 4 (726 million mt of resource); and the US Steel Dunka area in zone 5 (272 million mt of resource). Scattered small areas of this type of resource also occur elsewhere along the contact in zones 3, 5 and 7.

Figure 4

Type 2 near-surface mineralization (at least 0.25 percent copper) is estimated to be over one billion metric tons and average 0.34 percent copper. The two major areas of near-surface (type 2) mineralization indicated on Figure 4 are the INCO Spruce Road Pit area (330 million mt) and the Amax area (280 million mt). Significant tonnages (272 million mt) are indicated in the Dunka Pit area at several isolated spots. These three areas account for over 90 percent of the near-surface resources containing at least 0.25 percent copper.

Overall, the MDNR study found the ratio of copper to nickel to be 3.33 to 1. It is known that local variations from these averages occur within specific resource zones, and these variations may be quite important at any particular location. These estimates did not provide a clear picture of the variations in copper and nickel content from zone to zone or as a function of depth within a given zone.



MEQB REGIONAL COPPER-NICKEL STUDY

FIGURE 4

MINERALIZATION LOCATION MAP

The economic viability of a prospective development can only be revealed by detailed drilling. For example, detailed studies in Zone 4 by Amax Exploration Inc. led to 1977 estimates of approximately 370 million metric tons of underground resources containing at least 0.6 percent copper (compared to a MDNR value of 726 million mt with at least 0.5 percent copper). Considering the differing criteria used, the agreement here is quite good. However, the tonnage differences are highly significant in the context of the detailed feasibility studies for a prospect. Though additional data will undoubtedly alter these estimates, the more extensive Amax data make its estimate a much more reliable figure than the MDNR estimate.

The choice of the cutoff grade (the lowest grade which qualifies a unit of rock as a resource) is important in any estimation of resources. By adjusting the cutoff grade downward, the tons of the resource increase, but the cutoff may also be lowered below the level of economic feasibility. MDNR estimated that if the cutoff grade in the type 1 estimate is lowered from 0.5 percent to 0.25 percent copper, the tonnage of resource almost triples. The overall grade of this material would be about 0.45 percent copper.

Although copper and nickel metal contained in sulfide minerals are the major metals of economic interest in the Duluth Complex, there are other metals of interest. Of this secondary group, titanium, contained in the mineral ilmenite, is most likely to be considered for mining. Titanium mining would occur independently rather than as a byproduct of copper-nickel mining. Cobalt, an important metal which occurs in conjunction with copper and nickel, would be recovered as a byproduct in any copper-nickel development. Gold, silver, and other precious metals such as platinum are also present in relatively small amounts and would be recovered, providing important extra income to the mining company.

Copper-nickel resources can be divided into two types: those likely to be recovered by open pit mining and those likely to require underground techniques. For purposes of these estimates, the use of open pit extraction methods is assumed not to exceed a depth of 1,000 feet below surface level. Resources below 1,000 feet are considered underground mining resources. This analysis results in the distribution of resources shown in Table 1. Over two-thirds of the contained copper is present as an underground resource. Over 55 percent of the underground resource is in zone 2 (Inco-Hanna-Duval) with the next largest amount, 19 percent in zone 4 (Amax). The open pit resource is more uniformly distributed, with the largest portion, about 28 percent, in zone 1 (Inco Spruce Road Pit).

Table 1

Estimates for total contained copper by resource zone are given in Table 1. Again, the Inco-Hanna-Duval resource in zone 2 contains almost half (47 percent) of the 28 million metric tons of copper in the resource zones. Zones 1 and 4 each contain 18 percent of the total. Using the average copper-to-nickel ratio of 3.33 to 1 yields an overall estimate of almost 9 million metric tons of nickel contained in the entire resource. As with the copper estimate, two-thirds of this total is present as an underground resource.

The above values of 28 million metric tons of copper and 9 million metric tons of nickel represent estimates of contained metal in the resource zones based on available data. To translate these estimates to quantities of marketable metal, allowances must be made for losses of metal since the recovery processes during mining, milling, smelting, and refining are not 100 percent efficient. Estimates based on detailed mining models indicate overall recoveries of copper and nickel

Table 1. Copper ore tonnage, grade[a], and metal content estimates, by resource zone.

RESOURCE ZONE	OPEN PIT RESOURCE, million mt: 0.25-0.50% Cu Near Surface	≥0.50% Cu Above 1,000 ft	Total Above 1,000 ft	UNDERGROUND RESOURCE (million mt): ≥ 0.50% Cu Below 1,000 ft	TOTAL RESOURCE (million mt)	CONTAINED COPPER METAL (million mt)	PERCENT OF TOTAL COPPER METAL
1	110	370	480	370	850	5	18.0
2	---	340	340	1,600	2,000	13	46.8
2&3[b]	15	110	130	-----	130	0.8	2.9
3	250	19	260	76	340	1	3.6
4	180	49	230	550	780	5	18.0
5	38	73	110	230	340	2	7.2
6	60	52	110	49	160	0.9	3.2
7	---	11	11	-----	11	0.07	0.3
TOTAL	650	1,000	1,700	2,900	4,600	28	100

[a]It is assumed that resources of 0.25-0.50% Cu average 0.34% Cu, and ≥0.50% Cu average 0.66% Cu. The numbers have been rounded.

[b]Zones 2 and 3 underwater resources (Birch Lake and the Kawishiwi River) and between 600 ft and 1,000 ft of the surface, assumed to be accessible only by underground methods.

obtained by open pit mining with subsequent processing, smelting, and refining at 86 percent and 68 percent, respectively. Due to losses inherent in underground mining methods likely to be used in the Duluth Complex, these recoveries decline to 66 percent and 52 percent for copper and nickel, respectively. Applying these recoveries to the overall resource estimate yields values of 20 million metric tons of recoverable copper and 5 million metric tons of recoverable nickel. At average 1977 market prices of $0.68 per pound of copper and $2.30 per pound of nickel, this represents a gross value of over $50 billion.

The mining models further indicate that roughly 400-450 metric tons of cobalt are expected to be recovered for every 100,000 metric tons of copper produced. This estimate indicates that overall there are 80,000-90,000 metric tons of recoverable cobalt.

Assuming a single operation would produce 100,000 metric tons of copper per year, it would take 200 years to recover the estimated 20 million metric tons of recoverable copper. Of course, larger or multiple operations would exhaust the resource more rapidly. For example, four operations each producing 100,000 metric tons per year could operate for 50 years. This life estimate, even though it is quite crude, illustrates that the resource has the potential to support a regional industry with a life expectancy of many decades. Operating periods of 20-50 years are likely for developments at any one location.

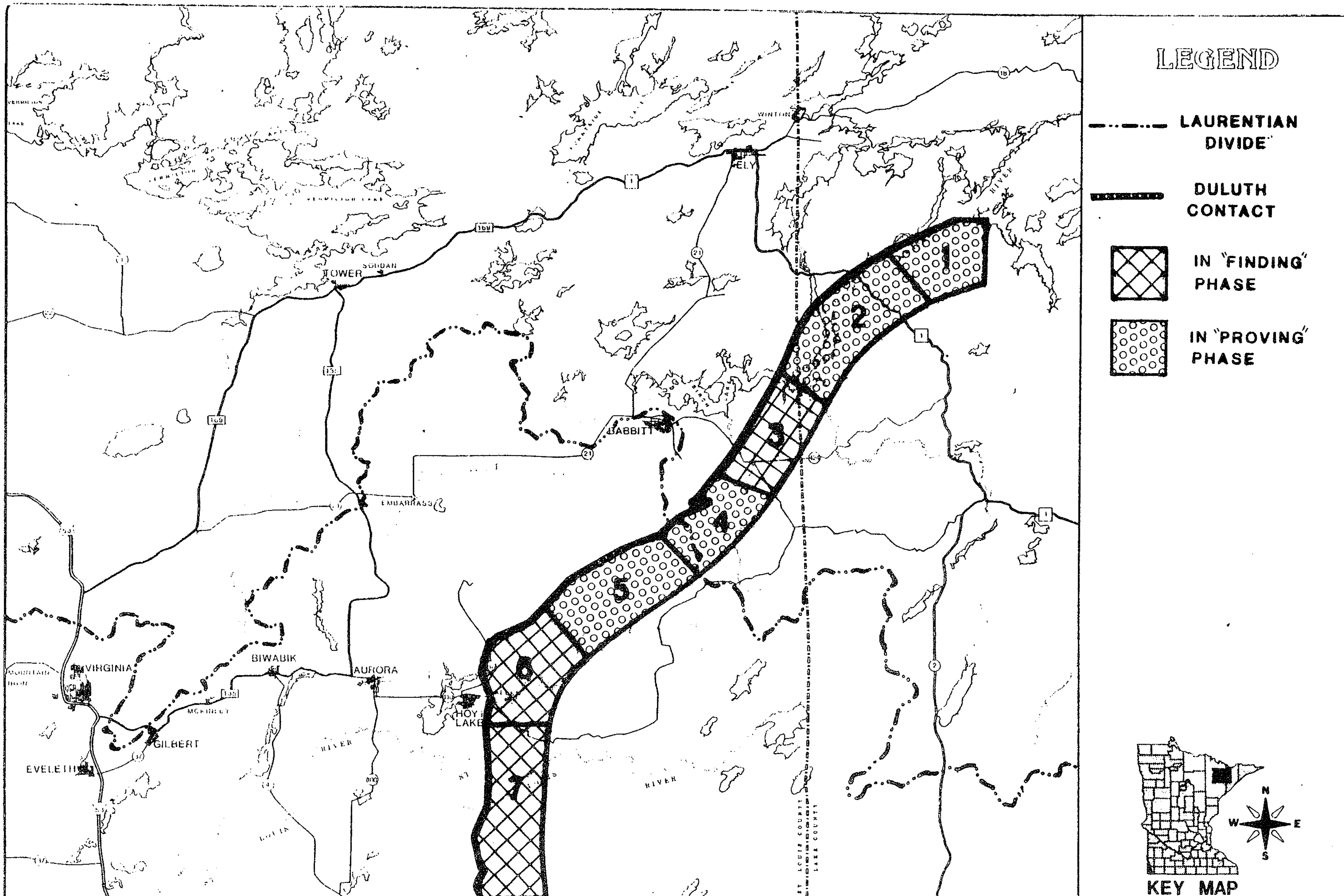
As indicated earlier, certain areas along the Duluth Complex have undergone relatively more thorough exploration than have other areas (Volume 2-Chapter 1). The definition of exploration used here--that of all activities required prior to the decision to actually develop a producing mine--is quite broad. It is useful to subdivide exploration into the two activities of "finding" and "proving." Finding includes all activities required to locate a potentially mineable mineral deposit, including preliminary drilling. This phase typically may cost $2 million, with less than 1 prospect in 10 resulting in the development of an actual mine. The "proving" phase then proceeds on promising finds, with extensive drilling, bulk sampling, pilot plant testing, and feasibility evaluations. This phase, with highly variable costs typically ranging from $3 million to $25 million, is only undertaken on those relatively few finds which show a high degree of promise for development in the near or medium term future, typically 5 to 15 years. The finding phase may require 3 to 5 years (or longer), with another 3 to 5 years (or longer) proving period.

No data have been found on the success rate of projects once they enter the proving phase. Early stages of this phase must determine the amount, grade, and distribution of mineralization. Mining methods for ore extraction and metallurgical methods for metal extraction are evaluated as studies proceed through the proving phase. The question of whether the deposit can be developed requires positive results at each stage. Any negative results lead to a halt in proving activities and rejection of the prospect. The question of when development can occur, however, depends on external factors such as metal market conditions and the availabilty of financing. Thus, it is fair to say that if the finding phase progresses through all the studies noted above, the most appropriate question is not whether the deposit is worth developing, but when. Even though the results may not indicate a profitable operation at current metal prices, a company with a substantial investment in the prospect is not likely to totally abandon control of the site. Unless restricted by lease terms or prohibitive rent payments, the company will retain its interest in the property based on forecasts that market conditions, as well as tax and environmental laws, will justify development in the future. Actual development may be by the company which conducted the exploration or by another company under appropriate development agreements.

In the Study Area, the work done by INCO in Resource zones 1 and 2, by Amax in zone 4, and by U.S. Steel in zone 5 qualifies these areas as being in the "proving" phase (Figure 5). The rest of the Duluth Complex, to the north and east of zone 1, in zones 3, 6, and 7, as well as the area south to Duluth, must be considered to be in the finding phase. Extensive drilling has occurred in zone 3, but a find that warrants increasing activities to the "proving" phase has not as yet been identified. Exploration in areas in the finding phase was restrained during the Regional Copper-Nickel Study because the State did not hold any mineral lease sales of copper-nickel lands. Future lease sales would serve to promote exploration and might lead to other areas entering the proving phase.

Figure 5

World Minerals Perspective (Volume 5-Chapter 14). Forecasts of the world market conditions for copper and nickel through 1985 range from cautiously optimistic to highly encouraging. Because an oversupply of copper and nickel from 1975 to 1978 resulted in record low prices, many planned expansions and new capacity operations for the late 1970's were cancelled or postponed. This occurred as a result of the reluctance of mining companies and their financiers to commit capital to increased capacity until a resonable return on investment was likely. Moreover, some existing capacity was cut back while demand for both metals has continued to increase.



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MILES

KILOMETERS

MEQB REGIONAL COPPER-NICKEL STUDY

FIGURE 5

EXPLORATION PHASE OF RESOURCE ZONES

Market conditions favorable to the development of copper-nickel mining in Minnesota and elsewhere are expected to occur during the mid to late 1980's. Because Minnesota's sulfide ore contains both copper and nickel, it is more attractive than an ore containing only copper of the same concentration as Minnesota's ore. Given the higher value and lower grade relative to copper, nickel can be expected to contribute 20-40 percent of total gross revenue. Thus an ore body containing only copper would need either higher copper prices or a higher copper ore grade than a Minnesota copper-nickel ore to provide equal revenue.

Copper prices in 1985 were forecast by Commodities Research Unit in 1977 to be between $.90 and $1.50 per pound ($1977). Other sources estimate nickel prices to reach $3.00 per pound ($1977) and possibly higher. In 1979, Chase Econometrics forecast the price of copper to be $1.36 per pound ($1977) by 1985. Overall, the gross value of a pound of copper-nickel metal in 1985 would be equivalent to $1.22 to $1.78 per pound ($1977) of copper. Assuming other products processed from the ore will contribute an additional 10 percent to the combined copper-nickel revenues, then the total value of products derived from Minnesota's copper-nickel ore is equivalent to $1.34 to $1.96 per pound ($1977) of copper. Under most operating circumstances, a forecast of this nature makes Minnesota's copper-nickel resource an attractive domestic resource relative to other known U.S. copper deposits.

Through the mid to late 1980's some copper-nickel projects will be more profitable than others depending on the type of operation, the ore grade, and the efficiency of management. Assuming that the above forecast of a copper equivalent value of $1.34 to $1.96 per pound ($1977) will occur, all the mine models analyzed will provide a greater than 15 percent discounted cash flow rate of return which is an industry "rule of thumb" for an acceptable investment (Volume 5-Chapter 17).

Many events could occur which would alter the potential markets for Minnesota's copper-nickel resource. A worldwide recession brought on by energy problems would reduce demand for copper and nickel and thereby the price. The mining of seabed manganese nodules, which contain significant amounts of copper and nickel, could be accelerated, saturating the market and reducing prices. Other events could also alter the forecast.

Given the relatively attractive nature of Minnesota's resources and the expected copper and nickel markets, proposals to develop the ore should be expected. If development permits are not applied for by the early to mid 1980's, it will most likely be because sufficient capital is not available for such large undertakings, other resource development investments are more attractive, or metal demand is lower than anticipated.

Minnesota's resource, estimated to contain 28 million metric tons of copper, is approximately one-quarter the size of total U.S. reserves and one-twentieth the size of world reserves. If, for example, Minnesota's copper-nickel resource is developed with annual production of 254,000 metric tons of copper (the equivalent of three hypothetical mine, mill, and smelter-refinery complexes at full production--see section on Mining Models), the state would produce approximately 10 percent of 1977 U.S. refinery capacity and 19 percent of 1977 U.S. refinery production. This amount of production would make Minnesota the second leading copper-producing state in the U.S. (based on 1977 production levels) with 15.6

percent of total U.S. mine production, and would provide 13 percent of USBM forecasted 1985 primary copper demand.

Only one domestic mine (at Riddle, Oregon) is currently producing nickel ore in the United States. In 1976, this mine produced less than 9 percent of the total U.S. primary demand. Nickel resources, though unmined at present, exist in Alaska, California, Minnesota, Montana, Oregon, and Washington. Minnesota's copper-nickel resource would become the nation's largest nickel reserve when development becomes economically feasible. Minnesota's estimated 9 million metric tons of nickel would dwarf the existing U.S. reserves of 181,000 metric tons and would be approximately one-eighth the size of world reserves estimated in 1978. If three hypothetical copper-nickel operations are developed in Minnesota, annual production of 46,000 metric tons of nickel would more than double the 1976 U.S. nickel refinery production and would represent 6 percent of 1975 world nickel production. This amount of production would represent approximately one-half of the USBM forecasted 1985 primary U.S. nickel production.

At present, no cobalt is produced in the United States. The cobalt contained in Minnesota's copper-nickel deposits represents the largest domestic resource of this metal.

4. COPPER-NICKEL DEVELOPMENT ALTERNATIVES

Full understanding of the nature and workings of the mining industry, from initial exploration to the shipment of refined products, is necessary for an accurate prediction of environmental, social, and economic impacts. From a mining point of view, mineral development in the Duluth Complex is thought of primarily as a copper operation, with emphasis placed on the copper recovery process because of the high ratio of copper relative to nickel. Although nickel will be treated as a secondary product, it will also receive careful attention because of its higher market value. Most, if not all, of the technology currently applied to the recovery of copper from sulfide ores in the U.S. and around the world is potentially applicable to the recovery of copper from the deposits in northeastern Minnesota. Thus, the well-developed U.S. copper industry has served as a major source of information. Since there is no domestic sulfide-based nickel industry which can be studied as an indicator of procedures applicable in Minnesota, the Regional Study began with an overview of the technology of copper recovery, and then drew on information from operations elsewhere in the world to understand the special procedures applicable to the separation and recovery of nickel from a copper ore.

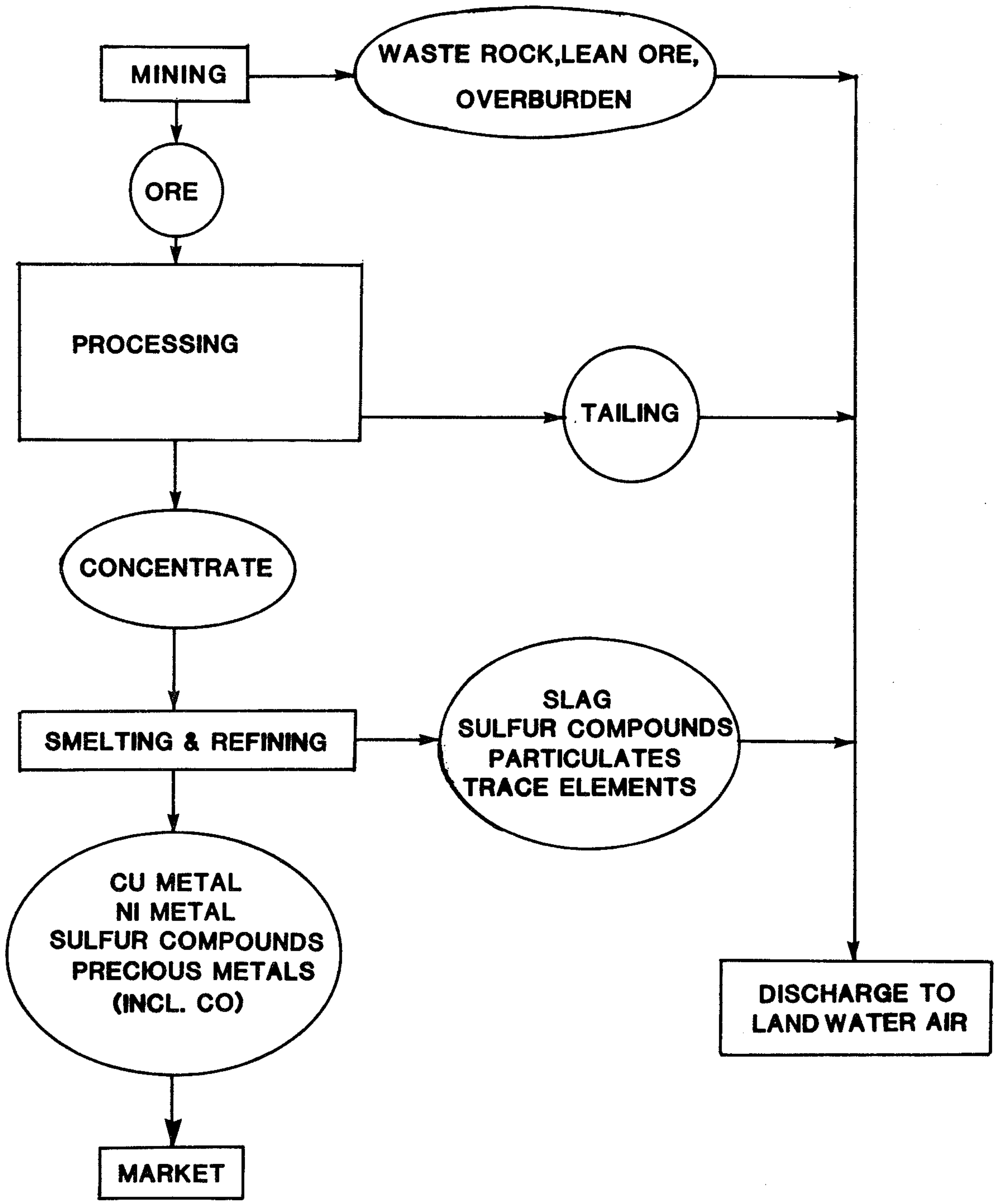
The general procedure for developing copper-nickel sulfide resources follows the flowchart shown in Figure 6. The procedure is conveniently broken into three phases: mining, processing, and smelting and refining.

Figure 6

Mining (Volume 2-Chapter 2). In the first phase, the copper-nickel bearing rock is broken loose and physically removed from the ground. Depending on factors

GENERAL COPPER-NICKEL DEVELOPMENT FLOWSHEET

FIGURE 6



such as the depth of the ore and its grade, open pit or underground mining methods may be used. In certain cases a combination of both methods may provide the best approach. Since copper-nickel mineralization in the resource zones is known to occur both near the surface and at great depths, the creation of both open pit and underground mines appear to be distinct possibilities in northeastern Minnesota.

Open pit mining for copper-nickel would consist of creating a large excavation open to the weather, as is done in taconite mining. Any soil and glacial till over the ore (overburden) is removed and stored in piles. Mining proceeds with the drilling and blasting of up to a million metric tons of rock at a time, which are then typically loaded by electric shovels into large trucks for removal from the mine. Conveyors may also be used to remove the broken ore and waste rock. The copper-nickel bearing ore is then sent on for further processing. Rock containing insufficient quantities of copper and nickel is dumped on lean ore piles for storage or disposed of permanently on waste rock piles. Lean ore piles would be intended for future processing when market conditions warrant the recovery of the reduced amounts of metals in this material

As with taconite mining, a Minnesota open pit copper-nickel mine may be from one to several miles long, and up to a mile wide. Unlike taconite, a copper-nickel mine would likely be quite deep because the deposits dip quite steeply. Based on existing mining technology and knowledge of the geology in the Duluth Complex, final depths of 1,000 to 1,500 feet are likely. Trucks with capacities of up to 200 metric tons would haul ore and wastes out of the mine on roads which spiral up the pit sides.

In contrast to open pit mining, underground methods obtain access to the ore through vertical shafts and horizontal tunnels (drifts) which greatly limit the size of the equipment and correspondingly increase the cost of removing a given amount of rock. As a result, shafts and drifts are located to minimize the amount of waste rock which must be moved while maximizing the removal of ore. Rock is broken by relatively small, carefully controlled blasts. A combination of small mobile loading equipment coupled with an underground railroad is a likely choice to move the broken ore to the mine exit points. Then, still underground, the ore is further broken up by a crusher to facilitate handling and loaded into containers (called skips) for hoisting up a vertical production shaft to the surface.

In certain cases there is the possibility that as underground mining proceeds and large openings are created, the overlying rocks may give way, falling into the opening and causing caving or subsidence at the surface. However, due to the apparent strength of the rocks in the Duluth Complex, this should be easily avoided by careful mine planning while still allowing underground extraction to proceed upward to within 1,000 to 500 feet of the surface. Underground methods may be used to recover resources to depths of several thousand feet. In the Duluth Complex current information indicates the depths of major interest for underground mining purposes are between 1,000 and 3,000 feet.

<u>Processing</u> (Volume 2-Chapter 3). Once on the surface, whether recovered from an open pit or an underground mine, the copper-nickel ore moves to the processing phase. Because of the relatively high cost of transporting low grade ore, processing facilities will likely be located no more than a few miles from the mine.

In order to free the small particles of copper- and nickel-bearing sulfide minerals contained in the ore, it is first crushed in crushers and then ground in large mills to a fine consistency. At the end of this size reduction stage, essentially all the particles of ore are smaller than 0.2 millimeters in diameter. Water has been added during and after grinding and the resultant slurry is ready to proceed to flotation.

During the flotation portion of the processing phase, chemicals are added to the ore slurry to aid in physically separating the sulfide minerals from the waste silicates. Typically, the chemicals will coat the surface of the desired metal sulfide minerals, causing them to stick to the surface of air bubbles which are forced through the ore slurry. The bubbles then carry (or float) the desired minerals to the surface where they are skimmed off to form the concentrates which are sent to a smelter/refinery for metal recovery. The bulk of the waste silicate minerals do not float during this process and are pumped as a tailing slurry to permanent disposal sites. For a copper-nickel operation, an expected 95-97 percent of the ore is rejected as tailing in the processing stage. If underground mining is used, some of the tailing may be returned to mined-out areas for disposal.

Depending on the flotation scheme selected by the mining company, the product from the flotation operation may consist of a single material (bulk copper-nickel concentrate) containing all the recoverable copper and nickel. Preliminary data indicate that the copper-nickel concentrate resulting from bulk flotation techniques would likely range from 10 to 22 percent copper and 2 to 3 percent nickel. Alternatively, two concentrates may be produced (using either differential or selective flotation). In this event, two concentrates are formed: one containing the majority of the recoverable copper and a negligible amount of nickel (a copper concentrate); and one containing essentially all of the nickel as well as a portion of the copper (a nickel-copper concentrate). If differential or selective flotation techniques are used, the nickel-copper concentrate would likely range from 4 to 7 percent copper and 4 to 7 percent nickel, and the copper concentrate would range from 11 to 24 percent copper.

Smelting and Refining (Volume 2-Chapter 4). The valuable sulfide concentrates produced in the processing phase are sent on to the smelting and refining phase. Here copper and nickel are recovered from the sulfide minerals in the concentrate and are converted to forms suitable for marketing. During this phase valuable byproducts, including cobalt, gold, silver, and other precious metals, are also produced. Depending on the type of technology used, some sulfur-containing byproducts such as sulfuric acid will likely be produced as well.

Regardless of whether one or two concentrates are treated, the first step in the smelting phase is to dry the concentrates and then to melt them in a smelting furnace. In the case of two separate concentrates, two smelting furnaces are used. The liquid is moved through a series of steps which remove the bulk of the iron, silica, and sulfur. If a bulk copper-nickel concentrate is being treated, a further step separates the majority of the copper from the nickel to produce a blister or anode copper, and a combined-metal product termed a nickel-copper matte. In the case of a copper concentrate, blister copper is the only product from this portion of the operation. The two products, blister copper and nickel-copper matte, then move from the smelting stage to a refining stage for purification. Following cleaning in order to maximize recovery of copper and nickel, the iron and silica removed during smelting are discarded as slag. The majority of the sulfur is removed for further treatment as gaseous sulfur dioxide.

The smelting processes likely to be used to treat copper-nickel concentrates require high temperatures, in the vicinity of 2,200-2,400 degrees Fahrenheit. One source of this heat is provided by the oxidation of sulfur to sulfur dioxide gas. Additional heat is needed, however, and will likely be provided by the use of a fuel such as coal, and also possibly from electrical energy used to operate resistive heating electrodes in electrical furnaces. The overall system will result in surplus heat which may be used to provide steam for uses including electrical power generation and space heating.

In the refining stage, the smelting products may be dissolved in an aqueous solution and the metals recovered by chemical precipitation or electrical plating (electrowinning). Alternatively, purification may be accomplished by electrorefining where direct transfer of the metal takes place from the impure anode through an electrolytic solution to the purified cathode. This is typically done to purify blister copper. In these processes, trace metallic impurities and remaining sulfur are recovered. It is here that cobalt and the precious metals are also separated from the copper and nickel. The final outputs of copper, nickel, cobalt, and precious metals are suitable for sale directly to manufacturers.

Due to the small quantity and high value of the concentrates produced from the ore, the smelter does not necessarily have to be located at the mine and processing site. It may be feasible to locate a smelter elsewhere in Minnesota, in the nation, or in a foreign country. Similarly, refining operations for copper and/or nickel produced in the smelter may take place at locations remote from the smelter site. There are many factors which influence where a mining company will propose the siting of smelting and refining facilities. The major factors include: distance to metal and byproduct markets; local labor supply; energy costs and availability; taxes; expansion capabilities at existing facilities; and site-specific development costs, including pollution control requirements.

<u>Mining Models</u> (Volume 2-Chapter 5). The preceding discussion of copper-nickel technology provides the basis for understanding the types of operations which may be proposed for use in Minnesota. In the absence of site-specific development proposals, the Regional Copper-Nickel Study developed a number of realistic hypothetical models so that impacts could be consistently assessed. In general, impact mitigation is a matter of tradeoffs, with reductions in one type of impact leading to increased impacts in another area. These development models aid in identification of these tradeoffs.

The mining models developed here are representative, not predictive. In many cases, a variety of differing technologies are available. Specific selections for modelling purposes were made with the goal of generating representative models, rather than for predicting or recommending the choices that might actually be made by a company developing a specific ore deposit. Therefore the following criteria were used in developing the mining models:

- Cover the possible range of sizes for Minnesota copper-nickel development to provide a feeling of scale.
- Include all basic types of mining applicable (i.e. open pit, underground, and combinations of both).
- Include typical values of resource inputs and material outputs for the various sizes of operations modeled.

-Serve as an educational tool to show the workings of actual operations.

In contrast to the mining models, models used to assess environmental, social, and economic impacts were predictive and depend upon the output of the mining development models discussed here.

Four basic mining models were created. There are two underground mining models with annual capacities of 5.35 million and 12.35 million metric tons of ore, which are large when compared to existing underground mines around the world. Also, there are two open pit mining models, 11.33 million and 20 million metric tons of ore per year, which again depict larger than existing operations. A combination of 5.35 million underground and 11.33 million open pit, totalling 16.68 million metric tons of ore per year was also developed to evaluate the possibility of both mining methods being employed simultaneously.

In addition to providing a realistic approach to mining operations as dictated by the ore quality and the difficulty of valuable mineral separation, the integrated operations were designed to produce adequate feed to allow for the annual production of 100,000 metric tons of copper plus nickel metal from the model smelter/refinery operations. Technology and economic conditions require large-scale operations for Minnesota's low-grade resource to compete in today's market. The 12.35 million metric tons per year (mtpy) underground, the 16.68 million mtpy open pit-underground combination and the 20.00 million mtpy open pit operations each result in sufficient ore to meet the above metal production requirement. Models were designed for processing facilities suitably sized to handle the amount of ore generated by these three mine models, producing sufficient concentrate to supply the smelter/refinery model. In this way, three fully integrated copper-nickel operations were modeled.

The models reflect an assumption of an overall life of thirty years for each fully integrated facility. For simplicity, only operations generating a single bulk copper-nickel concentrate are modeled, but this should not have an important effect on the resulting resource and production estimates. The smelter is assumed to use flash smelting technology with a sulfuric acid plant to clean sulfur dioxide from smelter gases. Table 2 summarizes the estimates used for various parameters over the 30-year life of the three integrated models. Note that each model has a different actual operating life as a result of the longer development period required for an underground mine relative to an open pit mine.

Table 2

Estimates of the total land requirements over the life of the three integrated models are illustrated in Figure 7. Substantial land area is needed even for the underground operation with the smallest land use of 5,000 acres (8 square miles). The open pit operation with its lower grade ore (0.49 percent copper and 0.11 percent nickel compared to 0.80 percent copper and 0.18 percent nickel for the underground model) and large volume of waste rock requiring disposal, would need twice the area of the underground operation. In each case, most of the land is used for waste disposal, with approximately half of all the area devoted to tailing disposal. The estimates also include land which is relatively undisturbed but is between and adjacent to mine facilities with restricted access imposed by the company for reasons of security and public safety.

Figure 7

The smelter and refinery phase dominates the capital costs (42-50 percent of the total) due to the amount of equipment needed in this phase. Overall, the

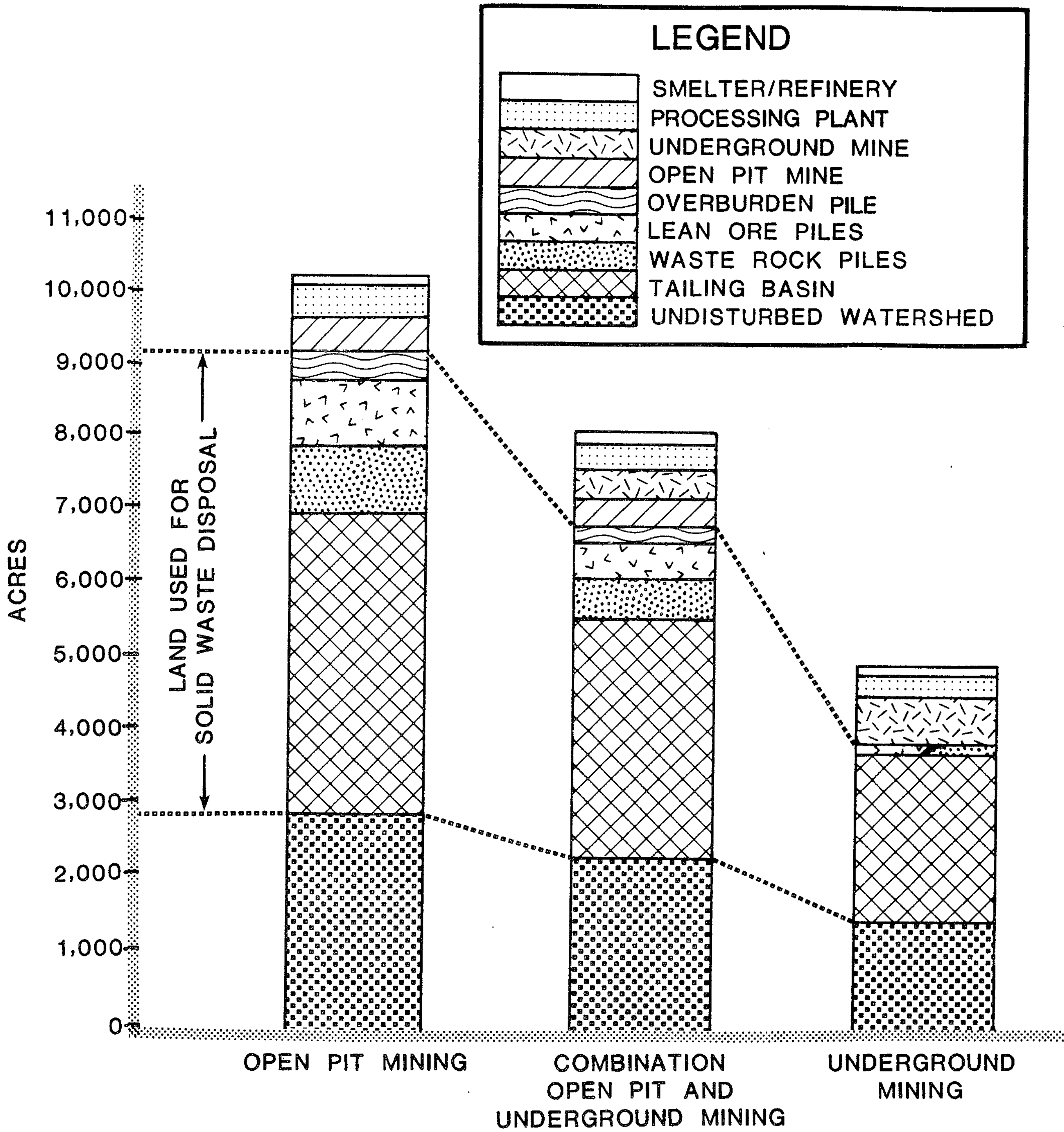
Table 2. Summary of Minnesota copper-nickel development model requirements over the total life for each model.

TOTALLY INTEGRATED OPERATION COMPARISON PARAMETER[a]	MINING OPERATION TYPE AND SIZE, million mtpy ore 12.35 Underground	16.68 Combination	20.00 Open Pit
Total land use, acres	5,000	8,200	10,000
Total materials produced			
Overburden, million yd^3	0	19	25
Waste rock-lean ore, million mt	28	380	650
Ore, million mt	280	410	500
Concentrate, million mt	15	15	16
Tailing, million mt	270	390	480
Metal (85%Cu + 15%Ni) million mt	2.3	2.4	2.5
Slag, million mt	14	15	15
Sulfuric acid, million mt	10	11	11
Total capital cost, $million[b]	660	760	760
Total cumulative operating cost, $million[b]	3,200	3,100	3,000
Total cumulative energy requirement, trillion BTU	330	370	400
Full production operating workforce	2,480	2,220	1,990
Mine	1,560	1,220	960
Mill	300	380	410
Smelter/refinery	620	620	620
Peak construction workforce	2,520	2,760	2,820
Mine	280	360	320
Mill	990	1,150	1,250
Smelter/refinery	1,250	1,250	1,250

[a]Based on an effective operating life of 23.0, 24.4, and 25.0 yr for the 12.35, 16.68, and 20.00 million mtpy operations, respectively. All values have been rounded (see Volume 2-Chapter 5).

[b]Includes a smelter/refinery with acid plant and secondary hooding control of SO_2 ($1977).

FIGURE 7 MINNESOTA CU / NI DEVELOPMENT MODELS LAND REQUIREMENTS



underground model requires approximately ten percent less capital investment (a total of $670 million) than the other developments due to the higher ore grade and smaller processing plant facilities. These trends are reversed for operating costs. The relatively labor-intensive mining phase takes a more prominent share of the operating costs, ranging from 33 percent of the total in the open pit model (less labor intensive) to 53 percent of the total in the underground model (more labor intensive). Therefore, annual operating costs for the underground model ($140 million per year) are 3-7 percent more than the other models.

The total energy requirement estimated for each of the three models is dominated by the smelting and refining phase and varies from 57 to 64 percent of the total. The requirements for the mining phase are the same in each case, because high requirements in the form of diesel fuel in the open pit mine are balanced by increased use of electricity in the underground mine. As a result, the overall requirements for the underground model are the smallest due to the reduced size of the processing facility needed to handle the higher grade ore.

Estimates for the various forms of the energy needed for the development models are shown in Figure 8. Electricity dominates in all cases and supplies about three-fourths of the energy needs, corresponding to approximately 150 megawatts of generating capacity. Roughly one-half of this electrical demand is created by the smelting and refining phase with the balance coming from the mining and milling phases. The remaining fuel types consist principally of coal used only in the smelter and diesel oil used in mining equipment. Small amounts of gasoline and propane and/or natural gas are used for purposes such as incidental transportation of personnel and supplies, and for special heating needs. Some 11-12 percent of the total energy is for heating buildings and can be supplied in open pit mining, and has a lower overall resource recovery.

Figure 9

Sequencing of Development. Any mineral venture is developed in stages which generally flow in the following sequence: exploration, pre-production, production, and post-production.

Exploration begins with the belief that mineralization may be located in a general area and that the company has need of such mineralization. An exploration program proceeds according to definite stages of testing and evaluation until (in the case of a successful venture) a specific area is identified which contains sufficient mineral resource amenable to metal recovery to supply the company's needs. A successful exploration program may require up to 10 years or more before enough information is acquired to allow a decision to be made to proceed with development. Such a program may cost up to $25 million ($1977) and employ up to 50 people in the final stages (see Volume 2-Chapter 1).

As the successful exploration program proceeds, plans are made for processing the mineral resource. Based on the characteristics of the resource, annual capacities are selected, technologies to concentrate the valuable minerals are tested, and metal smelting and refining techniques to produce the final metal products are developed. If all exploration results are positive, detailed engineering studies are begun, construction schedules are planned, and cost estimates are made. Many other areas must be investigated along with those described here, such as socio-economic considerations, legal requirements, and environmental concerns. When the exploration results and engineering studies are complete, a

FIGURE 9

QUALITATIVE COMPARISON OF
OPEN PIT AND UNDERGROUND MINING IMPACTS
FOR COPPER-NICKEL DEVELOPMENT IN MINNESOTA

	MINING METHOD	
I M P A C T	OPEN PIT	UNDER-GROUND
MORE LAND DISTURBED		
HIGHER WATER DISCHARGE POTENTIAL		
MORE SOLID WASTE PRODUCTION		
MORE FUGITIVE DUST EMISSION		
LESS EMPLOYMENT OPPORTUNITIES		
GREATER ENERGY DEMAND		
LESS RECLAMATION POTENTIAL		
GREATER CAPITAL COST		
GREATER OPERATING COST		
GREATER TOTAL PRODUCTION COST		
GREATER OCCUPATIONAL HAZARD		
LOWER RESOURCE RECOVERY		

"go"/"no-go" decision must be made. A positive response is followed by the pre-production stage with the immediate scheduling of all subsequent stages to insure a smooth transition from pre-production to production to post-production.

Pre-production is generally a 3-5 year period beginning when a mining company decides to develop a project and applies for the necessary permits, and ending when the operation begins production. During this period, the facility is constructed and operating staff are hired and trained. Pre-production is the "boom" period, a period of significant and rapid change. Most of the major decisions affecting the future operation of the project and its impact on the state, the region, local communities, and the environment are made during this phase. Schedules are fixed subject to change resulting from new information on site conditions, equipment delivery schedule adjustments, changes in the international market conditions affecting metal prices, the ability of the company to market its new product, and so forth.

Some of the important pre-production activities include:

- Necessary land would be purchased or leased. The land would be cleared and/or otherwise prepared for development. Needed access roads and rail spurs would be built.

- Removal of overlying soil and glacial till (overburden) would begin in the case of an open pit mine, or shaft sinking started for an underground operation.

- Sudden and possibly large changes in area population and employment would occur as construction commences and as the operating workforce is gradually assembled and trained.

- Facility construction would take place.

- Mining and reclamation plans would be developed.

The majority of direct land impact and major capital investment would occur during the pre-production phase. It is a most important phase as the project's future is established for years to come--sometimes irreversibly so.

The pre-production stage ends and the production stage starts when the facility begins production of ore from the mine, concentrate from the mill, and finally metal from the smelter/refinery complex. This production stage generally has 3 sub-stages: start-up, full production, and shut-down.

During start-up, the facility is developing toward full production rates. This may take several years. Full production exists when the operation is working at design capacity, which generally occurs over 75 to 85 percent of the total life of the operation. Shut-down occurs toward the end of the total life of the operation when the known economic mineral supply has almost been exhausted.

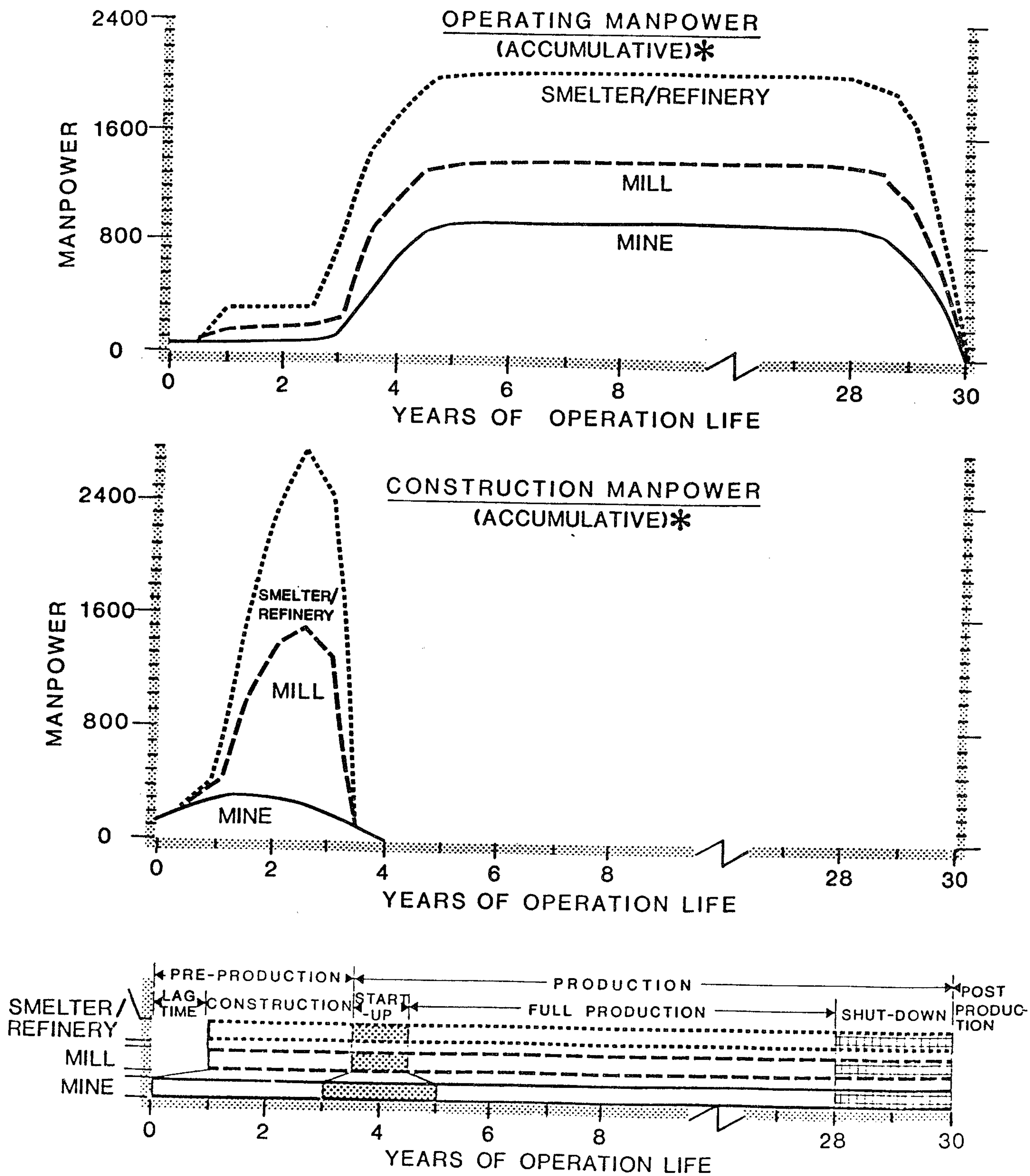
In some cases, mining operations are shut down with the expectation that future market conditions or technological advances will allow reopening of the operation. In contrast, an operation may be terminated, facilities removed, mines sealed, and the site returned to a previous or new use. Depending on the nature of abandonment and the company's ability to eliminate long-term pollution sources, post-production responsibilities may continue for five to ten years after production ceases. Some level of responsibility may continue indefinitely on either a continuous or intermittent basis, depending on reclamation requirements.

As an example of the sequencing of activities over the life of an operation, Figure 10 models the progression of the fully integrated 20 million metric tons of ore per year open pit development in terms of construction and operating manpower. The sharp peak in construction manpower illustrates the reason for the short-term population boom typically experienced in towns adjacent to major developments of this type. This boom is followed by a more stable increase in population due to the more gradual in-migration of the workforce. The operating workforce increases steadily during the roughly two-year start-up period due to the hiring and training of first the supervisory staff and then the remainder of the necessary workforce. The staffing increase during startup is generally reversed during the shut-down period when the operation has exhausted the mineral resources. Again, a roughly two-year period of planned shut-down would reduce the workforce to zero.

Figure 10

FIGURE 10

TYPICAL 20X10^6 MTPY ORE INTEGRATED OPERATION TIME LINE



* EACH GRAPH INCLUDES THE MANPOWER REQUIREMENTS OF ALL THE OPERATIONS LISTED BELOW IT

5. ENVIRONMENTAL, ECONOMIC, AND SOCIAL IMPACT ISSUES

Historically, the exploitation of base metal sulfide resources (such as copper-nickel resources) throughout the world has been accompanied by the significant degradation of the quality of water resources and the destruction of aquatic and terrestrial biota in the vicinity of such developments. Acid mine drainage, toxic heavy metals contamination, erosion, sedimentation, increased salinity, and other water pollution problems associated with mining were common. The non-ferrous minerals smelting industry (principally copper, lead, and zinc) has also been a major source of manmade air pollutants. While new technology has been developed to minimize many of these impacts, adverse impacts of past practices continue to cause close scrutiny of new mining proposals.

Mineral development is not new to Minnesota. Iron ores have been mined and processed in the state for almost 100 years. However, copper-nickel mining, if it occurs, would be new to the state and bring with it the potential for environmental impacts not experienced with iron ores--impacts which must be considered in developing mineral policies. To assess these impacts, an understanding of existing regional characteristics is necessary.

5.1 Characterization of the Region

Land Use (Volume 5-Chapter 3). Land is a finite resource that can accomodate only a limited number of uses. This means that there is often competition for a parcel of land among interests that would occupy or use the land for different activities. Multiple use policies are designed to minimize conflicts among users while at the same time maximizing the benefits received from the land. This approach is limited by the fact that certain land uses (mining for instance) effectively exclude other uses, while others (commercial forestry for instance) may be more productive if the accompanying uses are carefully selected and managed.

Land use patterns not only reflect the Study Area's local economic structures, history, and geography, but also government management decisions calculated to help meet future state and national needs for resources such as timber, recreation, and minerals. Approximately 52 percent of all surface lands in the 2,100 square mile (1.36 million acres) Study Area (Figure 1) are under federal, state, or county ownership. Federal land ownership (30 percent of all Study Area lands) is concentrated in the Superior National Forest. Management plans implemented by the U.S. Forest Service reflect a philosophy of multiple land uses (timber management, mining, recreation, wildlife management) coupled with the traditional forestry practice of managing extensive acreages at low productivity levels. State owned and administered lands (12 percent of Study Area land) are uniformly scattered throughout the Study Area and include state parks, state forest lands, swamplands, university trust lands, and miscellaneous dispersed parcels. County managed land (10 percent of all Study Area lands) are primarily tax-forfeited lands, where the State has delegated administrative control to the counties.

The land and its resources directly generate income in the taconite, timber, and tourist industries. While land use decisions made by private builders are generally guided by economic considerations, both industrial and individual owners are subject to government regulation of land use through devices such as environmental protection laws and zoning ordinances.

Figure 11 shows the major land uses in the Study Area. Forested areas cover 77 percent of this region. Almost all of these lands are made up of aspen-birch stands (57 percent of all forested lands), spruce-fir (30 percent), or white, red, and jackpine stands (10 percent). These three cover types account for almost half of all the timber harvested in the region. The quantity of each of three types of forest cover harvested is roughly proportional to the area covered by each. Other major land uses are water (8 percent), mining (3 percent), bogs/swamps (4 percent), pasture/open (4 percent), cultivated/agricultural (2 percent), and residential/commercial (2 percent). By the year 2000, taconite and related expansions (mines, tailing basins, residential/commercial development) are expected to use an additional 20,000 acres. Of the 20,000 acres, over 90 percent will likely be taken from land presently classified as forest.

Figure 11

Population and Residential Settlement (Volume 5-Chapters 1 and 7). In 1977, the Study Area had a population of 51,200. Approximately 7,300 workers (30 percent of the Study Area workforce) were employed directly by the iron industry. Employment in the iron industry is expected to increase to a peak of 8,600 in 1985, before dropping because of increased worker productivity. Assuming copper-nickel development does not occur, total population in the Study Area is expected to peak in the late 1980's at 55,000 before falling to the 1970 level (49,000) in 1995. In 1995, slightly less than 20 percent of the work force is projected to be employed directly by the iron industry.

Virginia, with a population of nearly 12,000, currently provides support services to the taconite industry, and would be the major service center within the Study

Area for the copper-nickel industry. Ely, with a population of 5,200, is a local trade center for households and a center for tourism associated with the Boundary Waters Canoe Area (BWCA).

The taconite formation runs on a southwest to northeast line, almost bisecting the Study Area on a diagonal. The large majority of the urban areas are adjacent to the taconite formation and are economically tied to the taconite industry. The northwestern portion of the Study Area is forested and largely unsettled except around lakes. It contains some wilderness area and significant water and wilderness-oriented recreation. The middle section of the Study Area running west from Babbitt is mostly a rural residential area with a number of old farms which are no longer cultivated. The southwest corner is a more concentrated rural residential settlement area with a heavy incidence of old farmsteads. The northeast corner above the end of the taconite formation is a wilderness and wilderness recreation area containing a portion of the BWCA and fairly widespread rural residential settlement, especially around the lakes. The southeast corner is mostly forests and swamps, and is entirely contained within the boundaries of the Superior National Forest. There is very little rural residential settlement relative to the rest of the Study Area.

<u>Air Quality</u> (Volume 3-Chapter 3). A two-year monitoring program conducted by the Regional Copper-Nickel Study revealed that the present air quality in the region (Figure 3) is generally quite good. In undisturbed areas, sulfur dioxide levels were below detection limits (10 ug/m^3) and particulate concentrations (TSP) were low (annual geometric average of 10 ug/m^3). Concentrations of metals were also quite low with the exception of iron. Increased concentrations of lead were observed near population centers. Annual average particulate levels close to

dust sources such as dirt roads, mining operations, and towns were 2 to 5 times above background levels.

Primary ambient air quality standards governing acceptable concentrations of SO_2 and particulates (Table 3) are designed to protect public health, while secondary standards protect the public welfare. In addition to these ambient standards, the region is also subject to the Prevention of Significant Deterioration (PSD) provision of the amendments to the Federal Clean Air Act of 1970 which were passed by Congress in 1977. These regulations specify maximum allowable increases for SO_2 and TSP concentration above 1977 levels. The entire U.S. portion of the air quality study region is designated as a Class II PSD area, with the significant exception of the Boundary Waters Canoe Area and Voyageurs National Park which are designated Class I and subject to more stringent regulations.

Table 3

It does not appear that ambient standards for sulfur dioxide will be exceeded in the next ten years if copper-nickel development does not occur. However, present development plans in the area are expected to result in increased SO_2 emissions, principally due to coal-fired power plants and conversion of the taconite industry to coal from natural gas and oil. These increased SO_2 emissions are estimated to consume and possibly exceed the 24 hour Class I PSD increment in portions of the BWCA. This situation may prevent locating any new SO_2 emissions sources, such as a copper-nickel smelter or certain taconite expansion projects, in parts of northeastern Minnesota unless the PSD restrictions are waived by variance.

Table 3. State and federal air quality regulations.

A. Ambient air quality standards: applicable throughout Minnesota (values shown in ppm are by volume).

POLLUTANT	WORDING OF STANDARD	PRIMARY STANDARD Federal	PRIMARY STANDARD State	SECONDARY STANDARD Federal	SECONDARY STANDARD State
Suspended Particulate Matter	Maximum annual geometric mean	75 ug/m^3	75 ug/m^3	60 ug/m^3	60 ug/m^3
	Maximum 24-hour concentration not to be exceeded more than once/year	260 ug/m^3	260 ug/m^3	150 ug/m^3	150 ug/m^3
Sulfur Oxides	Maximum annual geometric mean	80 ug/m^3 (.03ppm)	60 ug/m^3 (.02ppm)		60 ug/m^3 (.02ppm)
	Maximum 24-hour concentration not to be exceeded more than once/year	365 ug/m^3 (.14ppm)	260 ug/m^3 (.1 ppm)		260 ug/m^3 (.1 ppm)
	Maximum 3-hour concentration not to be exceeded more than once/year		655 ug/m^3 (.25ppm)	1300 ug/m^3 (.50ppm)	655 ug/m^3 (.25ppm)

B. Maximum allowable PSD increments in Class I and Class II areas.

POLLUTANT	ALLOWABLE INCREMENT[a] (ug/m^3) Class I Areas	Class II Areas
Particulate Matter:		
Annual geometric mean	5	19
24-hour maximum	10	37
Sulfur Dioxide:		
Annual arithmetic mean	2	20
24-hour maximum	5	91
3-hour maximum	25	512

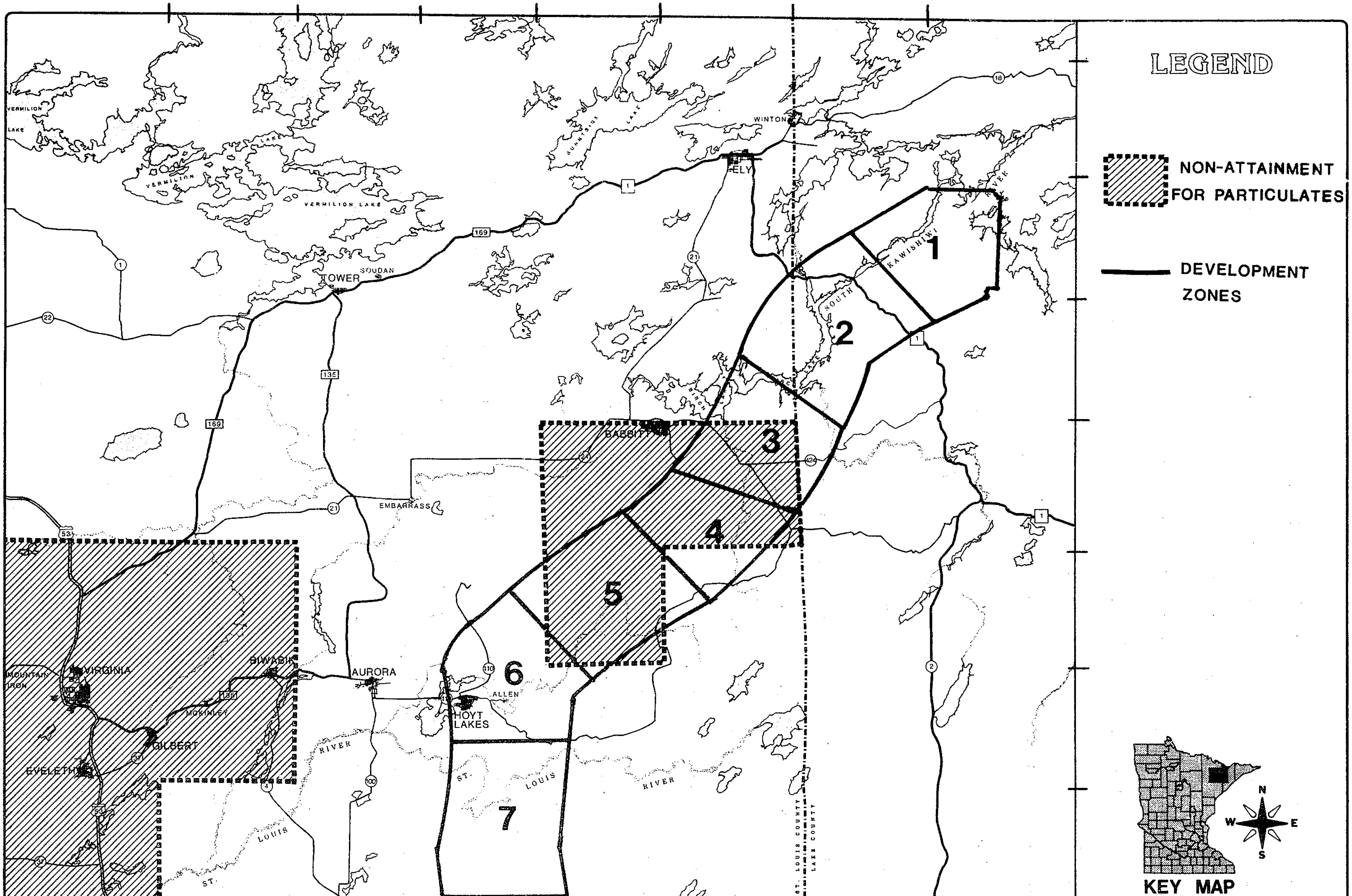
[a]For any period other than an annual period, the applicable maximum allowable increase may be exceeded during one such period per year at any one location.

Elevated 24-hour total suspended particulate (TSP) concentrations were observed during the course of the Regional Study monitoring (20 readings above 150 ug/m^3) and were generally associated with population centers and mining operations on the Mesabi Iron Range. Because primary 24-hour standards have been exceeded, the Minnesota Pollution Control Agency has designated portions of the Study Area as non-attainment areas for particulates (Figure 12). New industrial development in or near these areas could be restricted unless reduction in existing sources of particulates were made to prevent an increase in overall emissions.

Figure 12

Northeastern Minnesota is probably the most susceptible region of the state to the potential environmental impacts of sulfur oxide and heavy metal air pollutants. The pine and aspen vegetation which covers most of this area is sensitive to sulfur dioxide exposure of either a short or long duration. Soils in the region are relatively thin and poorly buffered against acid input, and therefore may be easily damaged by deposition of heavy metals or the influences of acid precipitation.

The susceptibility of terrestrial ecosystems to the impacts of air pollution varies throughout the seven development zones (Volume 4-Chapter 2). Both the vegetation and soils of development zones 1 and 2 (Figure 1) are highly susceptible to both heavy metals and SO_2. Soils in zones 2 and 4 appear to be especially susceptible to acidification because of their limited ability to neutralize acid precipitation. Soils in zones 5, 6, and 7 have a relatively high acid buffering capacity, but are thin and may therefore be highly susceptible to heavy metal deposition.



MEQB REGIONAL COPPER-NICKEL STUDY

FIGURE 12

NON-ATTAINMENT AREAS FOR PARTICULATES IN THE STUDY AREA

Water Quantity (Volume 3-Chapter 4). Surface water is abundant in the Water Research Study Area (Figure 2), due to high surface runoff. Average annual runoff in the region is about 10 inches. The Water Research Study Area includes 360 lakes larger than 10 acres, in addition to 14 small rivers and streams.

Nearly 75 percent of the Water Research Study Area, and an even larger proportion of the surface water is north of the Laurentian Divide. North of the Divide, lakes are more numerous and larger, and the volume of stream flow is greater because a larger area is being drained. Because some of these waters are inside the BWCA, not all of the water north of the Divide is directly available for use.

Annual average flow for 12 streams studied by the U.S. Geological Survey for the Study ranged from 23 to 1,027 cubic feet per second (cfs). High flow generally occurs after heavy precipitation and following the spring snowmelt. Average low flow for seven days is 2 to 186 cfs compared to an average high flow of 87 to 4,763 cfs.

Ground water yield is generally low, limited by the low permeability of the Area's bedrock and the often shallow overlaying glacial deposits. Yields generally average less than 5 gallons/minute. Three relatively small areas have high volume aquifers yielding up to 1,000 gallons/minute: the Embarrass Sand Plain, the Dunka River Sand Plain, and the local fractured and leached bedrock areas in the Biwabik Iron Formation.

Current industrial use of surface water is primarily for electric power generation. Mine-pit dewatering is the greatest groundwater use. At current levels, water use does not cause significant impacts on the region's water resources, although withdrawal from some streams must be reduced during low flow. Surface water, including some of the large on-channel lakes (e.g. Birch Lake), could supply large water users, although storage may be required for certain streams. The Embarrass River Valley aquifer is the only identified groundwater source in surficial materials that could supply large water users.

Water Quality (Volume 3-Chapter 4). Because of the large number of streams and lakes in the Study Area, the value of high quality water which supports a significant recreational and wilderness resource of the state and the nation, and the recognized historic relationship between base-metal mining and water pollution, a major responsibility of the Regional Copper-Nickel Study was the collection of baseline surface and ground water quality data.

The surface water quality of the Water Quality Research Area (Figure 2) was monitored from November, 1975, through September, 1977. Thirty-two stream sites and 26 lakes were monitored periodically for over 40 parameters that relate to human health and the stability of aquatic resources. Median values for relatively undisturbed streams are shown in Table 4.

Table 4

The quality of the region's water resources is generally very good except for several streams with watersheds affected by extensive taconite mining activities, and for groundwater either from glacial till or wells near the Duluth Gabbro Complex sulfide mineralization. Streams draining largely undisturbed watersheds can be described as containing soft water, having low alkalinity, low total dissolved solids, low nutrients, high color, very low trace metals concentrations, and low fecal coliform counts. Streams draining disturbed

Table 4. Median values of various water quality parameters in relatively undisturbed streams in the Study Area. (November, 1975, to September, 1977).

PARAMETERS	MEDIAN STREAM VALUE
Al (ug/l)	90
As (ug/l)	0.8
Ca (mg/l)	6.0
Cd (ug/l)	0.03
Cl (mg/l)	1.6
Co (ug/l)	0.4
Cu (ug/l)	1.3
Fe (ug/l)	560
F (mg/l)	0.181
Hg (ug/l)	0.08
K (mg/l)	0.6
Mg (mg/l)	3
Mn (ug/l)	35
Na (mg/l)	1.6
Ni (ug/l)	1.0
Pb (ug/l)	0.5
Zn (ug/l)	2.0
Alkalinity (mg/l)($CaCO_3$)	19
TOC (mg/l)	15
P-total (ug/l)	20
NO_2 NO_3 (ug/l)	80
SO_4 (mg/l)	6.6
pH	6.9
Specific conductance (umhos/cm)(25°C)	55
Color (Pt-Co)	90.2
Silica (mg/l)	6.3

watersheds (Partridge, Embarrass, Upper St. Louis rivers south of the Laurentian Divide, and the lower Dunka River and Unnamed Creek north of the Divide) would be considered to contain moderately hard to hard waters, with elevated dissolved solids, nutrients, and trace metals concentrations relative to undisturbed watersheds. Color and fecal coliform concentrations are not significantly different in the two watershed classifications. Most water quality parameters tend to be much less variable in undisturbed streams as compared to disturbed streams.

The quality of the lakes studied is variable though similar to the quality of undisturbed streams. However, lake values may be less meaningful for determining baseline concentrations than values in streams because of the limited number of samples.

In general, concentrations of most chemical constituents are higher in the groundwater than in streams and lakes of the area. Groundwater from wells proximate to the Duluth Gabbro contact were found to have higher levels of trace metals and sulfate than wells located at a distance from the contact.

Phosphorus and nitrogen are the major nutrients in aquatic systems. Concentrations of both nutrients in study streams are at the low end of the range of values for U.S. streams. Variations in nutrient levels exhibited no clear trends between headwater and downstream stations or between small and large watersheds. Highest concentrations of nitrogen were found downstream from mining operations where blasting compounds containing nitrogen are used.

In lakes, nutrient parameters are closely associated with the activities of aquatic organisms. Higher levels of available nutrients encourage greater biological productivity. The ratio of nitrogen (N) to phosphorus (P) can be used to evaluate which of these nutrients limits algal productivity. Lakes with a N:P ratio greater than 14 are considered to be limited by phosphorus. Within the Study Area, median N:P ratios ranged from 14 to 60, and half the lakes studied had ratios greater than 25. Overall concentrations of both nutrients were at the low end. Median values for both nutrients were higher south of the Laurentian Divide than north of it. The most productive lakes were all headwater lakes, usually shallow, and surrounded by extensive bog and marsh areas.

A major concern related to copper-nickel development is levels of heavy metals in surface waters. At background stream stations, copper, nickel, and zinc levels are generally very low, with median concentrations of copper and zinc in the range of 1-2 ug/liter and nickel around 1 ug/liter. Other trace metals of biological importance (As, Cd, Co, Hg, and Pb) have median concentrations significantly below 1 ug/liter. There is little variability in the levels of arsenic, cobalt, cadmium, mercury, titanium, selenium, and silver across almost all surface waters monitored. Variability of metal levels does not appear to be related to watershed size. As expected, iron, manganese, copper, nickel, zinc, lead, fluoride, and chromium concentrations in streams are significantly higher in disturbed watersheds than in undisturbed areas.

The dynamics of metals in lakes are somewhat different from those in streams because the large surface area of bottom sediments with their varying oxidation reduction potentials complicates the picture. Lakes can act as sinks for metals (as is the case with iron at Colby Lake) so that the chemistry of outflowing waters is different from that of inflowing waters. Large lakes may exhibit variability in the concentration of metals within the lake itself (as is the case with nickel in Birch Lake). Similar to streams, iron, aluminum, and manganese were the most elevated metals in the Study Area lakes. Copper, nickel, and zinc have median levels between 1 and 2 ug/l, whereas arsenic, cobalt, and lead have median levels of 0.6, 0.4, and 0.4 ug/l, respectively. Cadmium levels were an order of magnitude (10 times) lower than those for arsenic, cobalt, and lead. The greatest variabilities in concentrations were exhibited by manganese, zinc, cadmium, and aluminum, with arsenic the least variable metal.

Water quality standards and criteria for many parameters have been adopted or are proposed for adoption by the Minnesota Pollution Control Agency or the U.S. Environmental Protection Agency (EPA). Recommended levels for cadmium, color, copper, iron, lead, manganese, mercury, nickel, nitrogen (as NO_2 + NO_3), pH, specific conductance, sulfate, and zinc were exceeded in one or more of the streams monitored. In most cases, these elevated levels occurred in Unnamed Creek, which is affected by mining (see discussion of Unnamed Creek below). The region's streams and lakes have naturally high color levels.

All streams which were monitored exceeded the EPA water quality criteria for mercury (0.05 ug/liter). The median concentration of mercury for all streams monitored was 0.08 ug/liter with a range of 0.01-0.6 ug/liter. Standards for mercury are based on U.S. Food and Drug Administration guidelines for edible fish. Certain freshwater species concentrate mercury by a factor in excess of 10,000. High mercury levels have been found in fish from some of the area's lakes and streams. The source(s) of this mercury in the region is currently unknown.

Because acid precipitation is a potential problem, the quality of precipitation in the Study Area was monitored at several sites. Seventy-seven percent of the samples (41) had a pH less than 5.7, which means that most of the precipitation measured can be considered acidic. Fifty percent of the samples had a pH of 3.6 to 4.4. The geometric mean pH of samples collected in the area was 4.6. These values are comparable to, or even less than values measured in areas of the world where ecological damage has already occurred. Measurements by the Regional Study indicate that the present annual sulfate deposition rate (wet plus dry) across the Study Area is from 10 to 20 kg/ha/yr (9 to 18 lbs/acre/yr). Atmospheric dispersion modeling indicates that regional sources of SO_2 are not major contributors to depressed acidity of precipitation and sulfate deposition in the region. This in turn indicates that out-state and out-of-state sources, possibly as far away as St. Louis, Chicago, and Ohio Valley areas, are likely the major cause of acid rain and sulfate deposition in northeastern Minnesota.

If the patterns of increasingly acidic precipitation continue, it is likely that many of the poorly buffered small streams will have noticeable decreases in aquatic populations (such as fish) during and following spring melt (Volume 4-Chapter 1). Stream systems are very sensitive because the flush of water from spring snowmelt can represent a majority of the water that the stream may carry through the whole year. Recovery from these episodes may be expected to be fairly rapid (i.e. within months) unless or until the sources of recolonizing organisms are themselves affected (i.e. well buffered lakes or large unaffected streams). Recovery would be very slow once the source areas are affected. The effects of acid precipitation on vegetation range from damage to leaves to increased susceptibility to disease and death (see Volume 4-Chapter 2). A direct causal relationship between acid precipitation and reduced forest productivity measured by growth remains to be demonstrated. However, research suggests that acid precipitation is probably a cause of reduced forest growth.

Because acidic precipitation and sulfate deposition are primarily related to air pollution sources outside the region and are projected to increase significantly over the next 10-20 years, acidification may represent a serious threat to the ecosystems of northeastern Minnesota, even if copper-nickel development does not occur. Long-term changes in the aquatic communities are probably already underway due to the general decrease in the pH of precipitation and thereby of surface waters in the Study Area. Because the decrease in pH will likely be slow, measurement of biological effects would require intensive long-term monitoring. During this period of decreasing pH, the overall productivity and diversity of the aquatic communities can be expected to decrease.

One crucial parameter that was monitored is the water's buffering capacity--its ability to regulate pH changes due to acid inputs from atmospheric deposition or leaching. The resistance to pH change is a function of the type of acid input (i.e. strong or weak acids) and the type of chemical components in the receiving water which can assimilate or bind the hydrogen ions. Calcite saturation indices (CSI) were calculated for all study lakes and 30 lakes in the BWCA to measure this buffering capacity. Lakes with a CSI less than 3.0 are well buffered; lakes with an index between 3.0 and 5.0 are poorly buffered with the possibility that acidification may already be occurring; and an index over 5.0 indicates lakes with little or no buffering ability and a strong possibility that severe acidification has already occurred.

The poorly buffered lakes in the region are with few exceptions headwater lakes. This may be explained by the fact that buffering is a function not only of atmospheric processes, but also of watershed geology. The chemistry of headwater lakes often reflects that of precipitation, with watershed contributions to lake chemistry assuming secondary importance. As one proceeds from headwater to downstream lakes in the Study Area, the ability of the lakes to assimilate hydrogen ions generally increases. Headwater areas of the region (which include half the BWCA lakes studied) are generally not well buffered and have limited capacities to assimilate existing acid loadings. Some of the lakes sampled during the study which may be the earliest to be affected by acidic precipitation include: Clearwater, August, Turtle, One, Greenwood, Perch, and Long lakes. These lakes have Calcite Saturation Indices above 3.0. Headwater streams are generally poorly buffered, in part because their water quality is also dependent upon the quality of precipitation.

Two unique water quality conditions have been identified in the Study Area which are directly related to the presence of copper-nickel sulfide mineralization. In one of these cases, human disturbance of this mineralization has accelerated the chemical/physical weathering (leaching) of this material. Filson Creek, located in the northeastern part of the Study Area adjacent to the BWCA, flows naturally over exposed mineralized gabbro. Within the Filson Creek watershed, total concentrations of copper and nickel in the year 1977 generally increased from headwater locations to Filson's point of discharge into the South Kawishiwi River. Total nickel concentrations measured in Filson's headwaters were, except for one sample, less than 1 ug/liter, while the mean nickel concentration near the mouth of the watershed was 3 to 5 ug/liter. The smaller copper and nickel concentrations at Filson Creek headwater locations reflect the smaller percentage of sulfide bearing material in the till and the greater distance from the mineralized contact zone.

The elevated metal values measured in Filson Creek may not be completely due to natural weathering of sulfide minerals. Prior to 1977, considerable mineral exploration activities occurred, including the taking of a bulk surface mineral sample. Subsequently, a small volume surface discharge was discovered at the foot of the bulk sample site with elevated metals levels (10,000 to 13,000 ug/l Ni, 360 to 1,000 ug/l Cu, and 190 to 5300 ug/l Zn). This discharge enters a small tributary of Filson Creek and raises the nickel and copper concentrations by about 9 ug/l and 5 ug/l, respectively. This change in trace metal concentrations is not sufficient to result in measureable biological changes in the Creek.

In the other unique case, a small watershed (Unnamed Creek) which drains into Birch Lake at Bob Bay contains several wastepiles containing mineralized gabbro from a nearby taconite mining operation (Erie Mining Company's Dunka Pit). The large surface area of the wasterock facilitates the chemical weathering process. Surface seeps containing elevated concentrations of sulfates and trace metals (especially nickel) are present. The seeps flow into Unnamed Creek where the influence of this disturbance on water quality is obvious. Median nickel levels in Unnamed Creek were 85 ug/l, compared to 1 ug/l in undisturbed streams (Table 4). Extensive field studies conducted in this watershed have demonstrated that extensive disturbance of the mineralized gabbro without corrective mitigation can result in significant water quality degradation. The magnitude of the potential impacts in this specific case is largely mitigated by natural chemical processes involving adsorption, chemical complexation, and precipitation due largely to the presence of a bog in the watershed. The metal concentrations measured at Bob Bay would be significantly higher if not for the effect of the bog. However, the bog is showing some signs of stress and its beneficial effect on water quality may not continue for long.

5.2 Environmental Impact Analysis

Land Use. Increases in the amount of land consumed by mining, and the amount required to house and service a large population will heighten competition for uses of the land. On the other hand, a decision to restrict use of some land for purely recreational activities or wilderness preservation would effectively exclude mining operations.

In the event of any copper-nickel mine development in the Study Area, both the general types of man-made features that cover the land and the uses to which land is put will change depending on the size, siting, type, and number of mining operations. Other factors, such as the height and number of waste dumps and lean ore stockpiles, the ratio of waste rock to lean ore, the depth and number of tailing basins, and allowances for spaces between facilities will also determine the actual land requirements of a mine operation.

Land requirements of the three mine/mill/smelter/refinery models were discussed in Chapter 4 (Figure 7). Because of the location of copper-nickel deposits, the land required for these uses will likely have to come from land not presently being used as mineland (Volume 5-Chapter 3). The area where direct impacts are expected to occur (Figure 1) is roughly a six mile wide corridor (the Development Zone) which includes an 88,600 acre inner zone called the Copper-Nickel Resource Zone. This is the zone which, in addition to the pits and mineshafts, would be the most likely location for ore processing facilities such as crushing, grinding, and flotation plants. The remaining 86,320 acres of the Copper-Nickel Development Zone extends one and one-half miles beyond the resource area and represents the area within which the bulk of waste materials such as waste rock, tailing, and lean ore would be stored or disposed. Over 90 percent of all land consumed by new mining and associated development is projected to occur in areas currently classified as forest.

Reclamation activities are becoming an integral part of most domestic mining operations (Volume 2-Chapter 2). The term "reclamation" as used here includes all potential post-production uses of minelands, as well as those measures not inherent in the mining process that are used by the industry or others to mitigate adverse environmental impacts created during the course of mining. Because after-uses are not restricted to the establishment of natural plant and animal communities, reclamation should be distinguished from "restoration", which attempts to return the land to its previous ecological condition (including agriculture or other previous uses) and "revegetation", which may be restricted to mere provision of plant cover.

Restoration and possibly reclamation (depending upon desired reclamation goals) include regeneration of soils comparable to those formerly in the area, reconstitution of hydrologic characteristics, and return of former or comparable species diversity, structural attributes, nutrient pathways, and productivity of the ecosystem. Such complete restoration is an unlikely goal for most mineland areas and an impossible goal for areas where physical conditions have been altered beyond the normal range of variability of the natural landscape (such as steep slopes of poorly designed waste rock piles or walls of open pit mines). Because restoration seeks a return to former levels of ecosystem function associated with mature communities, its success cannot be measured until adequate time has elapsed--probably 40 to 70 years for the revegetated areas to revert to their former state.

The desired post-operational use of minelands should be determined during the pre-construction planning phase. Not all lands and facilities are likely to become available for permanent reclamation at the same time. For tailing basins and waste rock piles, reclamation can be an ongoing process beginning whenever a portion of a basin or pile is completed. Other areas, such as a plant site, can be reclaimed or restored only when the entire operation is completed.

Abandoned pits will eventually fill with water and could be used as lakes. However, there is a long lag-time between abandonment and complete filling, perhaps several hundred years. Contamination of groundwater is a concern where open pit mines are converted into lakes because they may exhibit elevated levels of heavy metals.

Access to shafts in underground mines must be controlled for safety purposes after abandonment. Because of the competence of the Duluth Gabbro, surface subsidence is not expected in areas overlying underground mines. Should such subsidence occur, the overlying landscape could develop irregular and broken surfaces requiring stabilization and revegetation by methods similar to those discussed for waste rock piles and tailing basins.

Lean ore and waste rock piles share several characteristics that inhibit the growth of vegetation, including nutrient deficiencies, water deficiencies, heat stress, and adverse physical conditions for rooting. Final reclamation goals for waste rock and lean ore piles are likely to be heavily influenced by water quality considerations.

Almost all effective methods for revegetation of metalliferous wastes involve cover with a layer of overburden or soil. The choice of material and depth of top dressing are dependent on the physical and chemical characteristics of the waste rock, the reclamation goal, the availability of borrow material, and relative costs. Chemical conditions of the waste rock and the final reclamation goals may influence the choice of one type of overburden over another for top dressing. If control of leaching is an important reclamation goal, loamy topsoil may be favored as top dressing on piles where waste materials are easily leached.

There is some evidence to suggest that revegetation of piles may not always have the expected positive effect of diminishing the leaching of heavy metals. Seasonal cycles of wetting and drying caused by seasonal photosynthetic activity have been suggested as the cause of increased leaching in sanitary landfills and could cause similar effects on waste rock. Organic acid production and physical exposure of deeper surfaces by root penetration are additional mechanisms by which plants could enhance leaching. Land reclamation practices and other passive methods which do not require frequent human intervention may help. Currently, very little information is available on the long-term effectiveness and degree of pollution reduction these methods will provide. Passive methods that work are preferred for this development phase because problems of economic liability are reduced. If water treatment plants are the only demonstrated method of solving post-production copper-nickel water pollution problems, then the long-term economic responsibility (ten to several hundred years) for maintaining such treatment works is a major issue.

In order to reduce their visual impact, waste piles could be contoured to reflect the mass and form of existing man-made and natural topographic features. If final reclamation goals are taken into account during waste pile design, excessive earthmoving costs may be avoided.

Methods for the reclamation of tailing basins are well understood and generally make use of standard agricultural practices that modify tailing to resemble normal soils. Before soil alteration can begin, the basin must be dewatered, dried, contoured, and stabilized against erosion. Tailing materials generally exhibit deficiencies of nitrogen, phosphorous, and potassium. The use of ponded areas in tailing basins for wildlife has been successful on taconite tailing, but may not be possible on copper-nickel tailing (which are comparatively high in sulfur and heavy metals) because of the possible contamination of migratory waterfowl.

The major reclamation issue affecting smelter/refinery sites is the effect of heavy metal contamination from particulate emissions. If poor housekeeping procedures or frequent breakdowns occur, revegetation of disturbed areas immediately surrounding a smelter may involve major steps including mechanical loosening of soils, addition of organic matter to raise the cation exchange capacity, liming, and fertilization with inorganic nitrogen, phosphorous, and potassium fertilizers to compensate for slowed nutrient cycling caused by heavy metal loading. Siting of smelters away from young, sensitive conifer plantations and in areas having soils with a high cation exchange capacity can reduce potential impacts.

Water Use. Water is required in significant quantities in the processing operation as a transport medium for the ore during concentration and for tailing disposal. Additional water is required in the smelting and refining phase for cooling and other purposes. Precipitation partially offsets the major water losses coming from evaporation from tailing basins and water trapped between particles in tailing basins. However, fresh makeup water (estimated to average 0.76-1 billion gallons per year) will be required for all three integrated copper-nickel development models (Volume 2-Chapter 5). Water requirements will vary significantly on a seasonal and annual basis.

A good water management system is designed to manage and store runoff and seepage on the site (around waste piles, tailing basins, and elsewhere). The specific site and the design of the system will determine whether periodic discharges of waste water will be necessary during periods of above average precipitation.

Because of the fairly continuous demand for water and the varying supply of water in lakes and streams in the area, it is estimated that significant water storage (10,000 to 15,000 acre-feet) will be necessary for use during dry periods. This water storage could be supplied by the tailing basin and/or reservoirs. Storage requirements for makeup water supply and containment of polluted water could increase land requirements by 2,000 to 3,000 acres.

Increased demand for water could become a source of conflict if waters tributary to the BWCA are appropriated for copper-nickel development and if the waters are also diverted for taconite development, such as the Upper St. Louis and Partridge river watersheds. These issues could be considered prior to issuance of a DNR permit which is required for water appropriation. However, if both taconite expansion and copper-nickel development proceed in northeastern Minnesota, a regional comprehensive water management plan and perhaps a cooperative industrial water supply system may need to be considered.

Sulfur Oxides and Acidification. The major pollutant emitted by the copper-nickel industry is sulfur dioxide (SO_2), which is produced in smelting operations by the burning or oxidation of sulfides in the concentrate. For example, an operation producing 100,000 metric tons of copper plus nickel per year would generate on the order of 200,000 to 400,000 metric tons of SO_2 each year (Volume 2-Chapter 4). If released to the environment, this gas could cause serious impacts.

Since the enactment of clean air laws in the United States, Japan, and other countries, considerable advances have been made in the control and treatment of air pollutants. Sulfur dioxide pollution control development and application has concentrated on three factors:

- Increasing the SO_2 concentration in gases from furnaces and converters by reducing infiltration of dilution air and by reducing the content of gases such as nitrogen and hydrocarbons in combustion air.
- Increasing the efficiency of gas collection devices to reduce leakage of fugitive SO_2 emissions.
- Improving the performance of high concentration and low concentration SO_2 removal systems, especially those which produce a marketable byproduct such as sulfuric acid.

Implementing these procedures enables a modern smelter to control from 95 to 99+ percent of potential SO_2 air pollution emissions under normal operating conditions. Instead of emitting between 200,000 and 400,000 metric tons of SO_2 each year, the level of emissions would be significantly lowered to between 1,000 and 20,000 metric tons.

A series of hypothetical models were created in order to investigate the impacts of a copper-nickel development. Principal interest with regard to air quality focused on short-term (24-hour) SO_2 concentrations with the smelter as the most important source. A series of three smelter models were developed which represented varying degrees of SO_2 control (Volume 2-Chapter 4). Table 5 summarizes the fugitive and controlled stack emission rates used for the three models.

Table 5

Atmospheric dispersion modeling was performed on the emissions from the smelter models (Volume 3-Chapter 3). Concern was focused on 24-hour average concentrations which may occur in the region under meteorological conditions unfavorable to rapid dispersion of the SO_2. Figure 13 is shown on an expanded scale to place a typical result for one of the smelter models into perspective in the context of the ambient air quality standards. Even for the smelter model with the least amount of SO_2 control, the Class II PSD increment is not predicted to be exceeded. The ambient standards are not threatened since they are much higher than the allowed Class II increment. However, in every case the Class I increment is predicted to be exceeded out to a considerable distance from the smelter. The fugitive emissions (which are the same for all the models) cause high SO_2 concentrations close to the smelter. These fall off rapidly with distance as the emission plume disperses. The stack emissions, by contrast, have little effect close to the smelter, but become quite important some 1 to 2 miles (1.6-3.2 km) downwind when they have diffused to ground level. Here the value of increased SO_2 control on stack emissions is apparent in the form of reduced ambient concentrations far downwind of the smelter, with significant reductions below the levels shown in Figure 13.

Figure 13

Long-range air quality modeling techniques were developed by the Study to estimate the distances which the various smelter models would have to be removed from Class I areas to prevent exceeding the increments in these areas. Figure 14

Table 5. Summary of SO_2 emissions from three control models for a smelter complex producing 100,000 mtpy of copper plus nickel metal[a].

MODEL VARIATIONS	ANNUAL SO_2 EMISSIONS IN mtpy (and gm/sec) Fugitive Emissions mtpy (gm/sec)	Stack Emissions mtpy (gm/sec)	Total Emissions mtpy (gm/sec)
Base[b]	990(31)	11,284(358)	12,274(389)
Option 1[c]	990(31)	4,512(143)	5,502(174)
Option 2[d]	990(31)	1,002(32)	1,992(63)

MODEL VARIATIONS	SHORT-TERM SO_2 EMISSIONS (based on 350 operating days/yr) Fugitive Emissions gm/sec	Stack Emissions gm/sec	Total Emissions gm/sec
Base	33	373	406
Option 1	33	149	182
Option 2	33	33	66

[a]All models assume normal operating conditions (see Volume 2-Chapter 4 for further details).

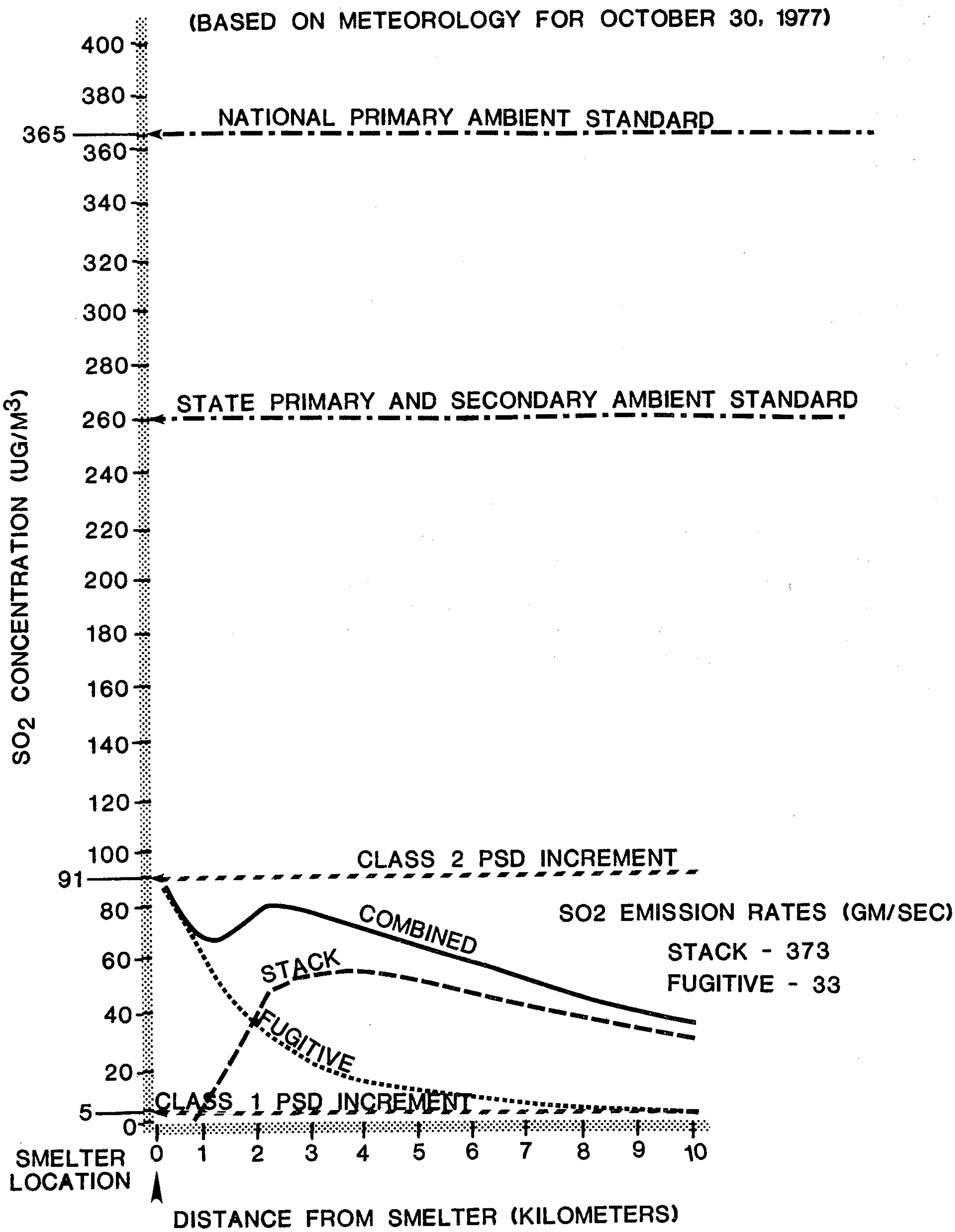
[b]Acid plant control for strong SO_2 gas to 650 ppm SO_2.

[c]Same as b plus scrubbing of collected weak SO_2 gas to 650 ppm SO_2.

[d]Same as c with acid plant control of strong SO_2 gas to 300 ppm SO_2, plus scrubbing of acid plant tail gas and collected weak SO_2 gas to 143 ppm SO_2.

FIGURE 13

MAXIMUM PREDICTED 24-HOUR SO_2 CONCENTRATIONS ALONG THE COMBINED PLUME CENTERLINE FOR THE BASE CASE SMELTER MODEL



presents the results of these analyses. Note that results are based on the smelter models as the only sources of SO_2 when, in reality, the PSD increment must be shared by all new sources.

Figure 14

The sensitivity of northeastern Minnesota's environment to the problems associated with acid precipitation raises serious issues regarding decisions to site a copper-nickel smelter in the region. The emission of sulfur dioxide from a copper-nickel smelter, while significant, is not projected to be a significant regional factor in the area's acid precipitation problem by itself; but it will aggravate the existing problem.

During normal operating conditions, no vegetation damage is expected from SO_2 released by the smelter. However, the air dispersion models used by the Study indicate the possibility for 3-hour average SO_2 concentrations of 1,000 to 2,000 ug/m^3 within a distance of 3 miles (5 km) and concentrations of 500 to 1,000 ug/m^3 at distances up to 5 miles (8 km) if stack emissions should increase due to pollution control equipment failure for a period of 3 hours. These results are shown in Figure 15.

Figure 15

Such levels would be potentially injurious to all major forest species except white spruce (Table 6) (Volume 4-Chapter 2). About one-half of the pollution control device breakdowns expected during summer might result in acute injury to vegetation in a narrow band within an estimated 6 miles (10 km) downwind of the

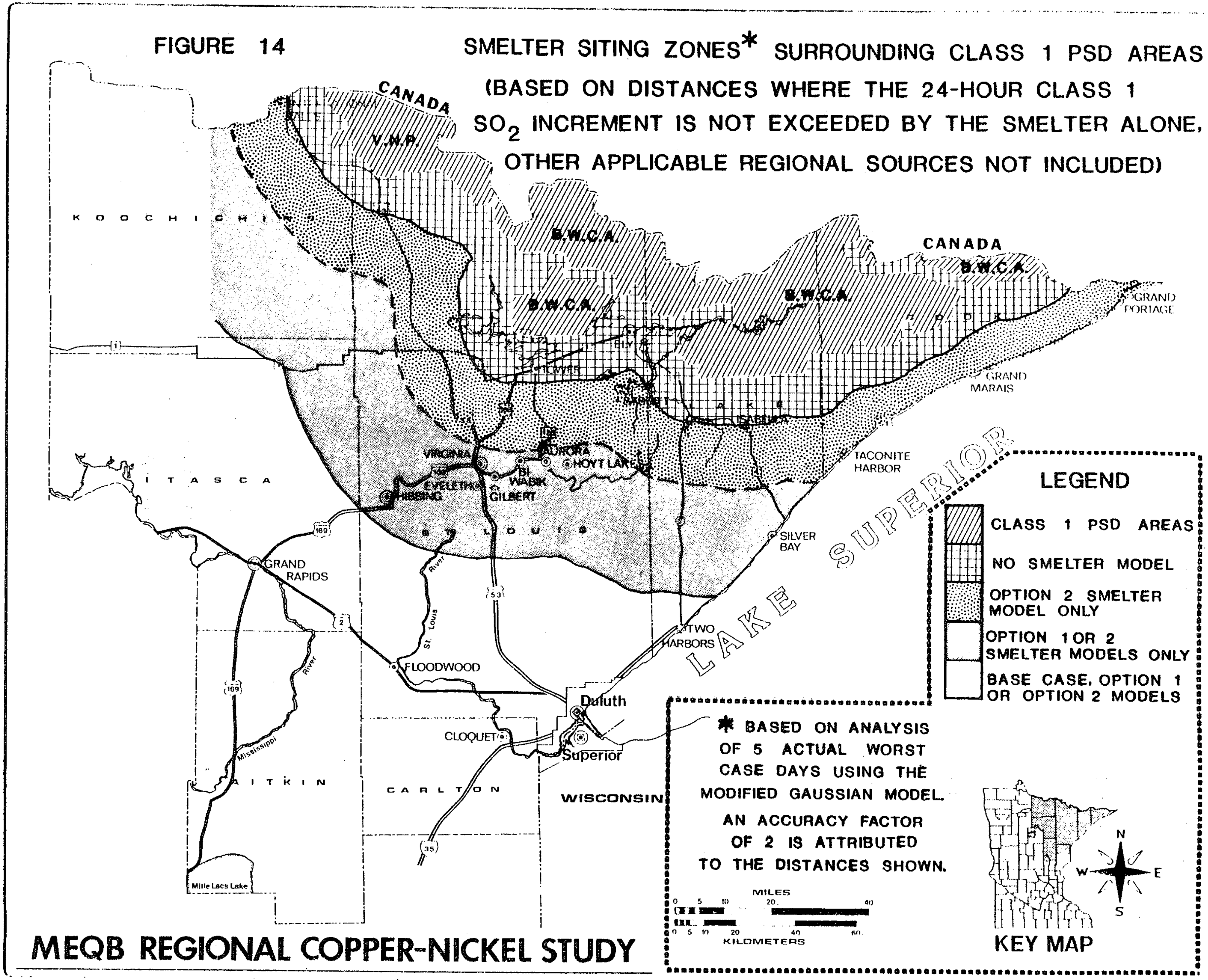
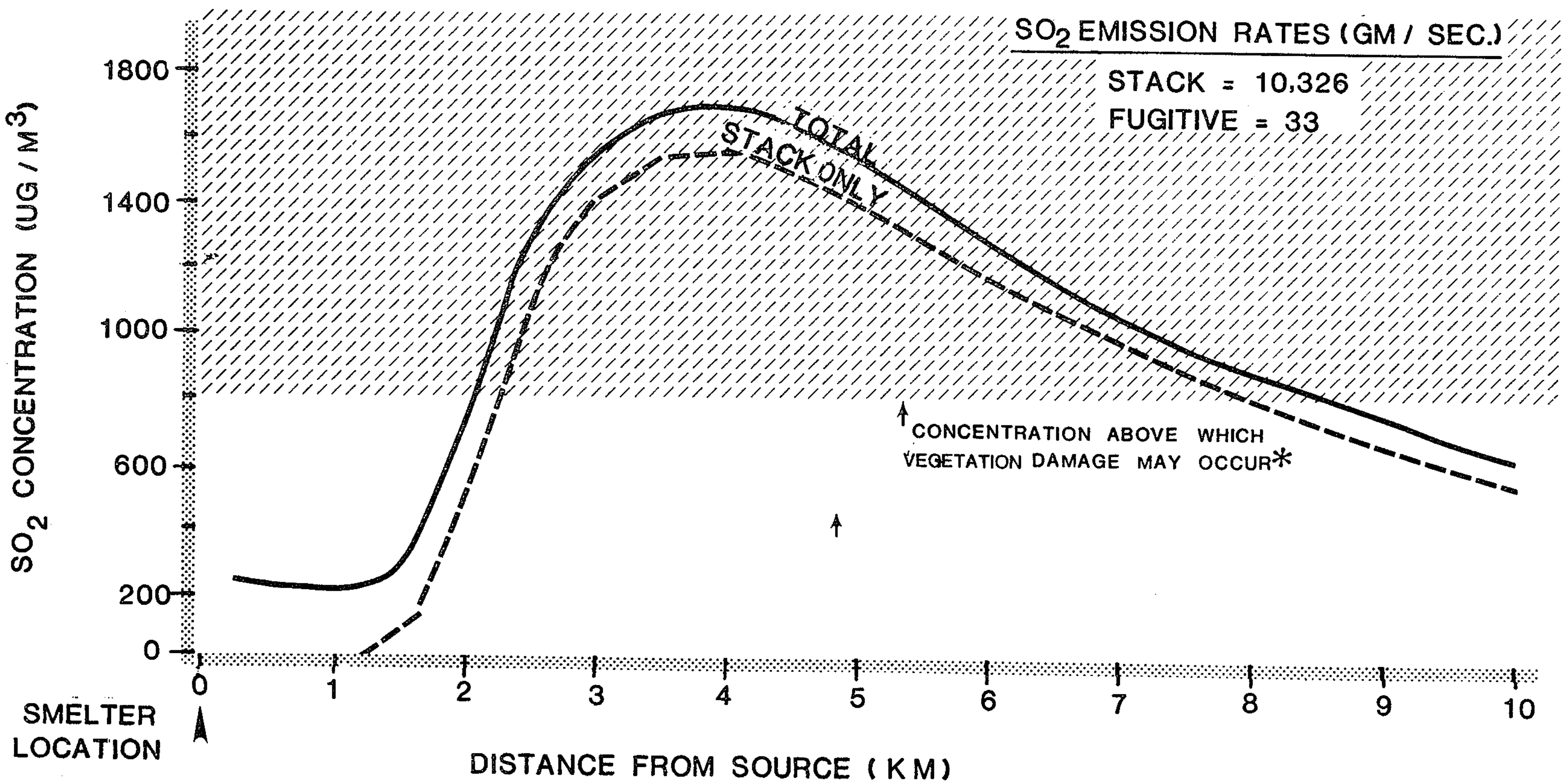


FIGURE 14 SMELTER SITING ZONES* SURROUNDING CLASS 1 PSD AREAS (BASED ON DISTANCES WHERE THE 24-HOUR CLASS 1 SO_2 INCREMENT IS NOT EXCEEDED BY THE SMELTER ALONE, OTHER APPLICABLE REGIONAL SOURCES NOT INCLUDED)

FIGURE 15

PREDICTED MAXIMUM 3 - HOUR SO_2 CONCENTRATIONS ALONG THE COMBINED PLUME CENTERLINE FOR THE STACK UPSET SMELTER SCENARIO WITH STABILITY C CONDITIONS



*BASED ON THE OCCURRENCE OF VISIBLE DAMAGE FOR A 3-HOUR EXPOSURE FOR A SELECTED NATIVE SPECIES (SEE VOLUME 4, CHAPTER 2) smelter. Because of changing wind conditions, the probability of damage occurring repeatedly in the same area is low. Therefore, long-term impacts (Type III--see Table 7) are not expected from air pollutants during normal operation or infrequent breakdowns resulting in increased stack emission rates. Type I and II impacts on vegetation may occur, but knowledge of these impacts is so limited at the present time that it is not feasible either to predict the extent of potential change or to measure this damage if and when it does occur.

Table 6,7

Animals are not expected to experience any direct impacts from potential air pollution, although they are subject to indirect impacts. If air pollution results in significant changes to terrestrial habitats (vegetation and soils), associated animals will be influenced. If local patterns of forest growth or succession are modified, the population of species which use mature habitats (e.g. fisher and marten) may decrease. The populations of deer and other species which use disturbed habitats would probably increase in the impacted areas.

Predicted sulfate deposition rates for the various smelter models were estimated and compared to the present rates without copper-nickel development (Volume 3-Chapter 3). Averaged across the region, the base case smelter model is expected to increase current sulfate deposition rates by ten percent. Because of the increased deposition expected from outside sources by the time a smelter could be operational in the Study Area, the percentage increase would be even less. However, deposition rates in the immediate vicinity of the smelter may be substantially elevated. For example, the base case smelter model would create a 50 percent increase over the bulk sulfate deposition rate at a location 3 miles

Table 6. Sulfur dioxide concentrations causing threshold injury to various sensitivity groupings of vegetation. Also shown are the sensitivities of Minnesota species.

MAXIMUM AVERAGE CONCENTRATION	SENSITIVITY GROUPING Sensitive ug/m^3	Intermediate ug/m^3	Resistant ug/m^3
Peak[a]	2,620 to 3,930 (1.0 to 1.5 ppm)[c]	3,930 to 5,240 (1.5 to 2.0 ppm)	5,240 (2.0 ppm)
1 hr[a]	1,310 to 2,620 (0.5 to 1.0 ppm)	2,620 to 5,240 (1.0 to 2.0 ppm)	5,240 (2.0 ppm)
3 hr[a]	786 to 1,572 (0.3 to 0.6 ppm)	1,572 to 2,096 (0.6 to 0.8 ppm)	2,096 (0.8 ppm)
8 hr[b]	262 to 1,310 (0.1 to 0.5 ppm)	524 to 6,550 (0.20 to 2.5 ppm)	unknown

Sensitivities of Minnesota Species

Sensitive	Intermediate	Resistant
Jack pine	Balsam fir	White spruce
Red pine	Balsam poplar	Black spruce
White pine	Basswood	White cedar
Paper birch		Red maple
Black ash		Red oak
Quaking aspen		Bur oak
Bigtooth aspen		

[a]Peak, 1-hour, and 3-hour concentrations based on observations of visible injury occurring on over 120 species growing in the vicinities of SO_2 sources in the southeastern United States and on other field observations.

[b]Average concentrations over an eight-hour period.

[c]Parts per million SO_2 converted to micrograms per cubic meter (ug/m^3) by the multiplication of ppm X 2,620.

Table 7. Levels of air pollution impacts.

Type I	- low dosage effects where vegetation and soils act as a sink for pollutants.
Type II	- subtle detrimental effects caused by moderate dosages and resulting in such symptoms as nutrient deficiencies, reduced photosynthesis, lower growth and/or reproductive rates, and increased incidence of stress-related insect and disease damage.
Type III	- severe damage causing acute morbidity (illness) and mortality (death) of specific plants, increased erosion, reduced nutrient cycling, and structural simplification of the ecosystem.

(5 km) away. This increase could create significant water quality problems, as poorly buffered streams and lakes nearby might experience serious impacts from acidification. During the spring melt, when sulfate which has accumulated in the snowpack during the winter is released with the first part of the runoff, these effects would be particularly important. Noticeable decreases in fish populations could occur. The severity of this problem depends on the water quality in the vicinity of any potential smelter location and must be investigated on a site-by-site basis. If sulfur emissions are controlled more strictly (such as Options 1 or 2 in Table 5), corresponding impacts would be substantially reduced.

Sulfates are also a major product of sulfide mineral chemical weathering (chemical leaching) and are a documented primary constituent of waste waters produced by the mining and processing of sulfide minerals. Most sulfates are very soluble in water and require sophisticated and very costly treatment systems for their removal. It is unlikely that such systems would be economically feasible for large-scale application to mining operations. Therefore, the primary mitigation measures for this pollutant are the elimination of release and/or dilution of any necessary discharge by receiving waters to levels consistent with the applicable management goal.

Acid waste from waste rock piles (if it occurs) is not expected to cause biological damage directly, but will likely aggravate heavy metal problems. The pH of water from a smelter may be below 3 due to waste water from the sulfuric acid plant. If water with a pH this low is released without treatment, it could cause serious damage to the aquatic environment. Current regulations require treatment of such waters to within a pH range of 6 to 9. Compliance should not be a problem and would provide protection against environmental impacts. Decreases of pH in waters may in turn increase the toxicity and availability of heavy metals in the aquatic environment. The leaching of the metals from waste rock/lean ore stockpiles would likely increase as a result of acidic precipitation. At the present time, there is no consensus as to the relationship between pH and toxicity of metals.

Particulates/Fugitive Dust. Potential particulate emissions from copper-nickel development include point sources from the mill and smelter, and non-point sources from haul roads, blasting, and blow-off from waste rock piles and tailing basins. These emissions were modeled in detail (Volume 3-Chapter 3). Although these facilities will increase TSP concentrations, no serious new ambient concentration problems are foreseen provided they are not sited too close to a Class I area. It may be difficult for an open pit operation to be located less than 6 to 9 miles (10-15 km) of a Class I area without exceeding the 24-hour Class I PSD increment for particulates. However, effective dust control measures are available and if used could significantly reduce the distance over which the Class I increment is jeopardized. Fugitive dust presents less of a problem in the case of an underground operation, although Class I standards may still be exceeded within several miles of the operation as a result of emissions from the tailing basin and mill site areas. Reasonable dust control measures should allow the Class I increment to be met beyond the immediate (0.5 mile or 1 km) vicinity of an underground operation.

Heavy Metals. Heavy metals released by copper-nickel development present the potential for long term impacts on terrestrial and aquatic biota. Expected effects on human health are not clearly predictable. These impacts may continue long after active mining ceases, particularly in the case of heavy metals leaching from waste rock/lean ore piles, tailing basins, and other disturbed areas.

Airborne heavy metals will be released by the smelter. A certain amount of the metals present in the concentrate may be released from the dryer, smelting furnace, or converters as either vapors or small particles in the exit gas. Copper, nickel, and cobalt are of principal concern since large amounts of these metals are present in the concentrate. Other metals (such as arsenic, cadmium, lead, and mercury) are also of concern, but of a lesser degree because they are not expected to be present in large amounts.

The Regional Study's air quality modeling suggests that deposition of heavy metals is probably the most severe potential impact of air pollution on terrestrial ecosystems that can be expected from a copper-nickel smelter in northeastern Minnesota (Volume 4-Chapter 2). Modeling estimates indicate that, for a smelter facility with a moderate degree of particulate emission control, the deposition rates for copper and nickel within a few miles of the facility may increase from 10 to 100 times over existing rates. This could eventually result in metals buildup in the soil with long-range (25-50 years) effects on the soil and the vegetation it supports.

For a location 12 miles (20 km) from a smelter, it is estimated that after 25 years of operation of a base case smelter, metals buildup in most Study Area soils could reduce decomposition rates of leaves by roughly 25 percent. Slowed decomposition of leaves on the forest floor could produce deep leaf layers that are poor seedbeds for species which require mineral soil for establishment, such as red pine, jack pine, and other conifer species. The decreased rates of nutrient recycling may affect forest growth and productivity. Areas managed for conifer production by the U.S. Forest Service may be particularly vulnerable, since leaf litter layers are often removed before planting to uncover mineral soils. Forest stands with no leaf litter layer will be most susceptible to heavy metals deposition.

Metals deposition onto the soil may have significant effects on germination and the growth of seedlings of native species of vegetation. Experiments conducted by the Regional Study indicated reduced growth rates for germinating seeds of several indigenous shrub and tree species when they were exposed to high levels of heavy metals in their growth medium. If metal loadings reach levels where they decrease growth or germination, natural patterns of succession (the pattern of forest growth and species change) may be altered.

Results from other studies suggest that the toxicity of heavy metals to existing plants is minimal at levels typical of tailings processed from ore taken at the INCO test site.

To reduce the size of the area subject to metals deposition, it would be necessary to reduce smelter stack and fugitive emissions. The areal extent of significant metals deposition could be reduced to within 1.5 miles (2.5 km) if emission rates are reduced to between 10 and 20 percent of the levels projected by the Regional Study's smelter model with the least control of particulates. As with control of sulfur dioxide, the technology exists to remove the majority of these elements from smelter gases prior to emission to the environment. Good gas collection systems can be used to minimize fugitive releases, and devices such as fabric filters and electrostatic precipitators can remove 99+ percent of the particles in a gas stream. Devices used to remove sulfur dioxide (such as sulfuric acid plants and wet scrubbers) also remove particles and metallic vapors.

Heavy metals are also released to waters through leaching from metal sulfide bearing rocks and waste water discharge. There are four significant potential sources: waste rock/lean ore stockpile runoff, seepage from tailing basins, mine dewatering, and smelter/refinery discharges.

The production of heavy metals and sulfate from waste piles containing natural mineral sulfides involves the chemical breakdown by oxygen in the presence of water to sulfate and elemental sulfur with the concomitant release of heavy metals. (Acidity, which enhances heavy metal leaching, is also generated by this process, but theoretical data suggest that the acidity will be buffered by the silicate materials present in ore rocks. The accuracy of this assumption is discussed later.)

The amount of heavy metals released depends upon the concentration of the metal sulfides in the waste, the thermodynamic characteristics of each metal, and other factors including the chemistry of the waters in direct contact with the rock. Lean ore stockpiles could present a greater potential for leaching than waste rock piles, because of their greater sulfide content. The waste rock pile runoff could be a continuous source of heavy metals during mining and long afterwards, since these stockpiles would remain after mining operations cease.

The tailing basin may also be a significant source of heavy metals. However, the expected low sulfide concentration of tailing (less than 0.1 percent) combined with its expected high buffering capacity could prevent acid conditions from occurring which could reduce heavy metal leaching. Tailing basin waters may also contain residual chemicals used in the concentrating process which can be toxic to aquatic systems. In some cases, these chemicals are a nutrient source, causing excessive growth of algae.

Quality of tailing water during the operating phase is primarily controlled by the concentrating process water. This water is largely recycled and should not be a significant heavy metal pollution source. Seepage can also be collected and recycled if necessary. Elevated levels could occur during the post-operating phase or if more sulfides are deposited in the basin than projected. Local variation in ore mineralogy could result in pockets of tailing having much higher sulfide concentrations which could cause localized leaching problems. Due to limited research on tailing water quality, the unknowns involving the quality of runoff and seepage from a tailing basin are greater than those associated with waste rock piles and create another source of significant risk involving future copper-nickel water management decisions. The Minnesota Department of Natural Resources is conducting research on this topic.

Mine dewatering can also contribute heavy metals, the amount depending upon the quantity of water from precipitation and groundwater sources that must be removed and the metal sulfide content of the mine. No precise conclusions can be made about expected levels of heavy metal release from this source.

Smelter and refinery waste water is not as significant an issue as waste piles. Production of these waste waters is dependent on facility design and operation, and there appears to be no significant post-operational concerns. Treatment methods are available to reduce heavy metal concentrations in these waste waters to levels where biological impacts are not expected.

Effluent water quality models for impact assessment purposes were developed (Volume 3-Chapter 4) based on the best data available from field and laboratory results, but this information is not sufficient to allow precise statements on the quality of water produced from copper-nickel water pollution sources or on the effectiveness of reclamation practices for specific effluent parameters (e.g. sulfates, trace metals, processing reagents). For example, information strongly suggests that runoff from waste piles will contain elevated heavy metals and dissolved solids concentrations as compared to background surface water quality. Heavy metals could be 500 to several thousand times higher than natural water quality levels and sulfates could be ten to several hundred times higher.

These models reflect an assumption that acid mine drainage problems will not occur because of the natural buffering capacity of the waste materials. If this assumption is wrong and acid conditions do occur, then projections of water pollution will be significantly underestimated because, as the pH becomes acid, there are dramatic increases in the amount of heavy metals leached from the waste materials and the mobility of these metals in the aquatic environment. The pH significantly affects whether a metal will be in an aqueous phase (and highly mobile) or in a solid phase.

Laboratory studies have indicated that low-grade material which would likely make up lean ore/waste rock stockpiles has more than sufficient buffering capacity to maintain the pH of the leachate at neutral values (pH=7). However, some field data indicate different results. Recent data from the gabbro stockpiles at Erie

Mining Company's Dunka Pit and at the Amax exploration site have indicated that the pH in leachate may in fact drop below 7.0 and be acid. Average pH values at Erie's Seep 3 were 7.2 in 1976, 7.1 in 1977, and 6.7 in 1978. At the present time the cause of this pH reduction is not understood.

Treatment of large amounts of runoff to remove heavy metals to existing background levels may be prohibitively expensive. Additional research is necessary in order to make accurate predictions about effluent quality and the effectiveness of various controls. Cost and time constraints will likely require that the first mining activities proceed without this predictive capability.

Heavy metals have adverse effects on aquatic organisms, the extent depending upon the type of metal (or combination of metals), organism tolerance, and water chemistry (Volume 4-Chapter 1). For example, cold water fisheries are generally more susceptible to heavy metal pollution than warm water fisheries. To assess the impacts of heavy metals on the aquatic environment, a simple system was developed to quantify the combined impacts of the four metals which may be released in the largest quantities by copper-nickel operations: copper, nickel, cobalt, and zinc. Toxicities relative to copper were estimated for each metal and added, in order to translate all potential impacts into what could be expected at an equivalent copper concentration. Because of the significant variability among toxicity data and the differential influences of water chemistry on the toxicants, the relative toxicity of metals were fixed within orders of magnitude. The formula for "copper equivalent units" (CEU) is: 1(copper) + 0.1(nickel) + 1(cobalt) + 0.1 (zinc) = CEU. For this formula, it is assumed that the toxicities are additive. However, in reality they may be either more or less than additive. Table 8 summarizes the impacts of various CEU concentrations on algae, invertebrates, and fish. This table was developed using all available data from the literature and the Study's experiments with Research Area waters and potential leachate mixtures.

Table 8

To explain the impacts of heavy metal release from copper-nickel development, two cases are discussed: lean ore stockpile runoff and tailing basin discharge. It is assumed in the following discussion that the metals have equivalent mobility and that this represents a relatively conservative picture of transport and toxicity of potential heavy metal release. Waste water discharge models presented in Volume 3-Chapter 4 indicate that the CEU concentrations in a direct discharge from a lean ore pile could be 8,300 ug/l. A discharge of this quality without any dilution would be acutely toxic to all aquatic organisms. All organisms downstream of this discharge would move to other areas in the watershed where the discharge would be diluted by at least a factor of 3 to 4, or would die. At that point some species of fish would still survive, but long-term exposure would probably eliminate all fish reproduction and few if any invertebrates would be available as a food source. When the dilution factor approaches 10-20, some species of invertebrates could be expected to survive short-term exposure and more would remain alive. When the lean ore pile runoff is diluted by a factor of 25-30 (to 300 ug/l CEU), a greater number of fish and invertebrate species would be observed although little algal growth could be expected. As the dilution factor approaches 80-90, a relatively large number of fish species and several species of invertebrates would be found. Dilution by a factor of 200-300 would be necessary before it would become difficult or impossible to measure the chronic impacts of this discharge.

Table 8. Impacts of copper equivalent units (CEU) on aquatic organisms.[a]

COPPER EQUIVALENT UNITS (CEU in ug/liter)	ALGAE	INVERTEBRATES	FISH
10,000-			
2,5000-			-Major fish kills and species losses irrespective of WQ
1,000-			
600-		-Major decrease of population size and diversity, indirect loss of fish due to lack of food, irrespective of WQ	
300-	-Acute population and density losses irrespective of WQ		-Chronic impact, loss of some population irrespective of WQ, acute impacts dependent on WQ
100-	-Chronic impact on species diversity irrespective of WQ	-Acute losses of some species and population size, dependent on WQ	
30-	-Potential chronic impact on species diversity dependent on WQ	-Chronic impact, loss of diversity, limited acute effects	-Chronic impacts dependent on WQ
10-			
5-	-No measureable impact irrespective of WQ	-No measureable impact irrespective of WQ	-No measureable impacts irrespective of WQ
2.3-	--	BACKGROUND WQ	--
1-			

WQ = water quality

[a]CEU toxicity will vary greatly from the above depending upon species affected and chemistry of the impacted waters.

A discharge from the tailing basin is expected to pose fewer problems than the lean ore pile runoff. The CEU concentration in the basin is modeled to be 54 ug/l. In this case, a discharge could possibly cause chronic effects on the aquatic ecosystem, but it is not possible to project these effects on the basis of current knowledge.

There are no distinct regional patterns for sensitivity to heavy metal water pollution. Lakes and streams in the Study Area with relatively high total organic carbon (TOC) content or high hardness values will be less sensitive to heavy metals stresses. It is most important to avoid areas which have low TOC or hardness because the organisms in these areas would suffer greater damage if exposed to equivalent concentrations of heavy metals.

Mineral Fibers. Existing information indicates that the concentration of asbestiform amphibole minerals in Duluth Complex ore is expected to be quite low (about 0.1 ppm by weight). On the other hand, amphibole minerals in non-asbestiform habits are expected to be much higher, possibly ranging as high as 13 percent by volume and averaging up to 3 percent by volume. Concern thus focuses on the possibility that processing copper-nickel ore will result in the release of fiber-like cleavage fragments of amphibole which might constitute a hazard to health.

As currently defined by the Minnesota Department of Health, mineral fibers will most certainly be present in the products of mineral processing. Typical copper-nickel tailing slurries may contain from 10^{12} to 10^{13} fibers per liter, of which some 20 to 30 percent or more may be amphibole fibers. These levels are about six orders of magnitude greater than background levels in surface waters in this region. Processing of Duluth Complex material may produce roughly one-third the concentration of amphibole fibers present in the tailing material produced by Reserve Mining at Silver Bay. These fibers do not originate from amphiboles occurring in asbestiform habits (an occurrence expected to be rare). Instead, a large fraction of the fibers are plagioclase which is a common mineral in the earth's crust and occurs naturally in most areas. There is considerable disagreement concerning the potential hazard to health of fibers produced from amphibole minerals in non-asbestiform habits.

Possible changes in ambient air concentrations of mineral fibers in the atmosphere around a copper-nickel development were investigated (Volume 3-Chapter 3). Present concentrations in the area generally range from 10,000 to 40,000 fibers/m^3. Modeling estimates by the Study suggest that ambient fiber concentrations in air may double within 0.5 miles (0.8 km) of a tailing basin and may increase by a factor of ten within five miles (8 km) of a smelter. Although the health implications of these fiber releases are poorly understood at present, there is the possibility that they pose a significant hazard to health.

<u>Noise</u> (Volume 3-Chapter 5). Noise is a significant factor in determining environmental quality, particularly in wilderness, recreational, and residential areas. The occupational hazards due to noise in a copper-nickel operation seem minimal if existing practices to reduce sound levels and protect workers are followed. Therefore, primary attention was given to the effect of sounds created by mining on the wilderness values of areas in and adjacent to the copper-nickel development zones. Major mining sound sources of concern include blasting, haul trucks, sirens, and train horns. Ventilation fans are major potential sources of sound for underground mining operations.

The Regional Study conducted a noise monitoring program which showed that a major portion of the region is very lightly impacted by man-made sounds at any level. The relative quiet in the region makes it particularly sensitive to new sound sources.

In order to investigate the extent of possible noise impacts on the region, a noise model was developed, using data on meteorology, vegetation, and the major sources likely to be present in a mining operation. The model indicates that these potential new sources would be audible over extremely large areas of the now quiet region. For example, under some conditions an 85 ton haul truck would be audible over areas ranging from 110 to 690 square miles (280 to 1,800 km^2). At least half of the time that is is operating it would be audible over areas ranging from 3 to 120 square miles (8 to 320 km^2). A ventilating fan would be audible over areas ranging from 190 to 360 square miles (480 to 940 km^2). Careful equipment selection and the use of noise barriers can significantly reduce the extent of noise impact.

Resource zones 3, 4, and 5 (see Figure 1) are already affected by taconite mining and are not expected to suffer major new noise impacts. This is not the case in 1, 2, 6, and 7. Zones 1 and 2 are of particular concern since activity here will likely be audible a significant fraction of the time in portions of the BWCA.

Human Health (Volume 5-Chapter 2). Workers are the population group most likely to have their health affected by copper-nickel development. Accident rates in underground mines have historically been three times as high as those for other stages of development. Nickel dusts from nickel refineries have been a cause of lung cancer. Because the time interval between first exposure to nickel and development of cancer is so long (20-30 years), the effectiveness of existing controls is unknown. Dusts, sulfur dioxide, and sulfuric acid mist have caused chronic respiratory diseases in workers at other U.S. copper developments.

Because the actual emission levels and characteristics of a copper-nickel development may be highly variable and there are no comprehensive epidemeological data available from the vicinity of modern developments, the Regional Study gathered information from communities surrounding existing developments to identify the potential for public health risks. This information indicated that the populations in almost all of the seven U.S. counties studied, where copper or nickel mines and/or smelters are currently operating, are experiencing increased death rates from respiratory cancers, accidents, and cardiovascular diseases. The actual causes of these increases are not understood at this time, but these results indicate that there is a potential for effects on human health.

The release of sulfur dioxide and sulfates at the concentrations predicted is not expected to have significant effects on human health. During the most extreme breakdown conditions, SO_2 concentrations of 20-70 mg/m^3 are possible for 3-hour periods with 0.15 miles (0.25 km) and, although these levels dissipate rapidly, and people downwind of a smelter may experience some discomfort and coughing. Since people with chronic respiratory disease would be especially susceptible to such emissions, it would be wise not to site a smelter near hospitals, rest homes, or other such places. This type of short-term exposure is not expected to have any long-term effects once the stack gases are again under control. The effects of breakdown episodes on human health are therefore directly related to the size and health of the nearby population.

Release of heavy metal particulates from a copper-nickel smelter could result in increased levels of these in the hair, blood, and/or urine of people living nearby. Those living within 1 mile (1.6 km) of existing smelters (not equipped with current air pollution control systems) have experienced the greatest exposure to heavy metals but increased biological concentrations of metals have been found in people living out as far as 4 miles (7 km). Children aged 1-4 years have shown the greatest increases in body metals. The health implications (if any) of these increased body concentrations are not well understood, except in the case of lead.

A new smelter constructed to process Minnesota copper-nickel concentrates would be required to comply with the laws, rules, and regulations of the Environmental Protection Agency and Occupational Health and Safety Administration. As a result, many of the occupational and public health problems documented to occur around existing smelters may not occur near a new smelter.

Boundary Waters Canoe Area. The Boundary Waters Canoe Area (BWCA) (Figure 1) is a critical issue because of a proposal (INCO) to develop a large open pit copper-nickel mine directly adjacent to it in resource zone 1.

Development in the BWCA itself is highly unlikely because state and federal laws currently prohibit mining within the BWCA unless Congress declares a national emergency. Still nickel and cobalt are strategically important minerals and currently are derived principally from foreign sources. Although sulfide minerals are known to exist in the BWCA, an accurate estimate of the quantity and quality of these minerals is not available due to exploration limitations.

Congress recently extended the boundaries of the BWCA to include a portion of resource zone 1 and established a Mining Protection Area consisting of several road corridors located adjacent to the BWCA where mining is prohibited. The Mining Protection Area does not include any of the Duluth Gabbro Complex in the resource area (Figure 1), but does include a portion of the Greenstone formations near Ely. It also includes the northern Gunflint Trail region which may have significant mineral resources.

Congress has placed the BWCA under the highest air quality protection category (Class I PSD), thus forbidding activities anywhere that would cause measurable changes in the concentrations of sulfur dioxide and particulates over the BWCA. Except for these two cases, there are no state or federal criteria to protect the BWCA from environmental degradation caused by activities outside its boundaries.

Air quality changes resulting from copper-nickel mining and smelting are not expected to cause significant biological impacts within the BWCA if the developments are designed and operated so that they conform with present state and federal air quality regulations. Air pollutants from copper-nickel development could indirectly impact on the BWCA in four principle forms: 1) fugitive dust from open pit mines, haul roads, and tailing basins; 2) very high concentration sulfur dioxide emissions from a smelter caused by breakdowns of pollution control equipment; 3) aggravation of existing and projected acid precipitation conditions in northeastern Minnesota by smelter SO_2 emissions; and 4) deposition of heavy metals resulting from a smelter operation.

Increased dust deposition in the BWCA from fugitive dust emissions would be greatest if development occurred in zones 1 and 2 (see Figure 1) where 65 percent of Minnesota's estimated copper-nickel resources are located. Impacts could be greatly reduced if state-of-the art control methods are utilized and if dust sources are not sited in zone 1.

Emissions of sulfur dioxide from a smelter using state-of-the art emission control systems and sited far enough from the BWCA (Figure 14) should not cause significant changes in its air quality and precipitation acidity under normal operating conditions. However, a smelter should not be sited less than 6-12 miles (10-20 km) of the BWCA to guard against significant risks of damage during breakdown conditions. Since the probability of risk depends on the frequency of wind direction, risk of damage can be greatly reduced by not siting a smelter in a northwesterly, or south, southeasterly direction from the BWCA.

Increasing acidification of surface water is also a concern for the BWCA, because the lakes have limited capabilities to assimilate and neutralize acid input. Water discharge models developed by the Regional Copper-Nickel Study indicate that sulfate concentrations 100 times greater and nickel concentrations 1,000 times greater than background concentrations are possible in waste waters. Only copper-nickel development north of the Laurentian Divide (zones 1-3 and part of zone 4) would affect BWCA waters (Volume 3-Chapter 4). Development within a small watershed in zone 1 which drains directly into the BWCA would have the highest potential for impacting the BWCA (Figure 16). Water discharges from copper-nickel operations located in the moderate impact zone would be diluted by receiving waters produced by a 1,347 square mile (3,490 sq km) watershed before it reaches the BWCA. Assuming a 4.5 cfs waste water discharge containing from 2,400 to 4,700 ug/liter nickel and 550 mg/liter sulfate, the quality of the Kawishiwi River as it reenters the BWCA northeast of Ely would be 11 to 21 ug/liter nickel and 9 mg/liter sulfate during annual average flow conditions and assuming conservation of chemical mass in the aqueous phase. This represents a 1,000 to 2,000 percent increase (10-20 times) in nickel concentrations and 29 percent increase in sulfate concentrations over median background levels. The predicted nickel concentrations are clearly higher than the range of nickel values recently measured at this location, but the predicted sulfate concentration is within the range measured at this same location.

Figure 16

Nickel is toxic to aquatic organisms in trace concentrations. Research conducted by the Regional Copper-Nickel Study indicates that high concentrations of nickel could occur in discharge waters and that nickel is very mobile in aquatic systems as compared to other metals (e.g. copper). High levels of nickel can be removed from waste waters using conventional methods; but removal to background levels would require more sophisticated and costly methods. Discharge prevention and dilution would have to be considered to achieve a management goal of no measurable water quality change from existing conditions.

If a criterion of two standard deviations above the mean concentration of background measurements (95 percent confidence interval) is used to determine measurable change from existing conditions, then a concentration of 3.38 ug/liter nickel and 11.17 mg/liter sulfate should not be exceeded at the Kawishiwi River where it enters the BWCA. Using the conservative mass balance model, a 4.5 cfs discharge having a nickel concentration not exceeding 560 ug/liter and a sulfate concentration not exceeding 990 mg/liter would meet this criteria, if copper-nickel development was located in the moderate impact zone (Figure 16). If more than one copper-nickel operation occurred in this area, the above maximum concentrations would have to be reduced accordingly in order to meet the management goal. The present MPCA ambient water quality standard for sulfates is

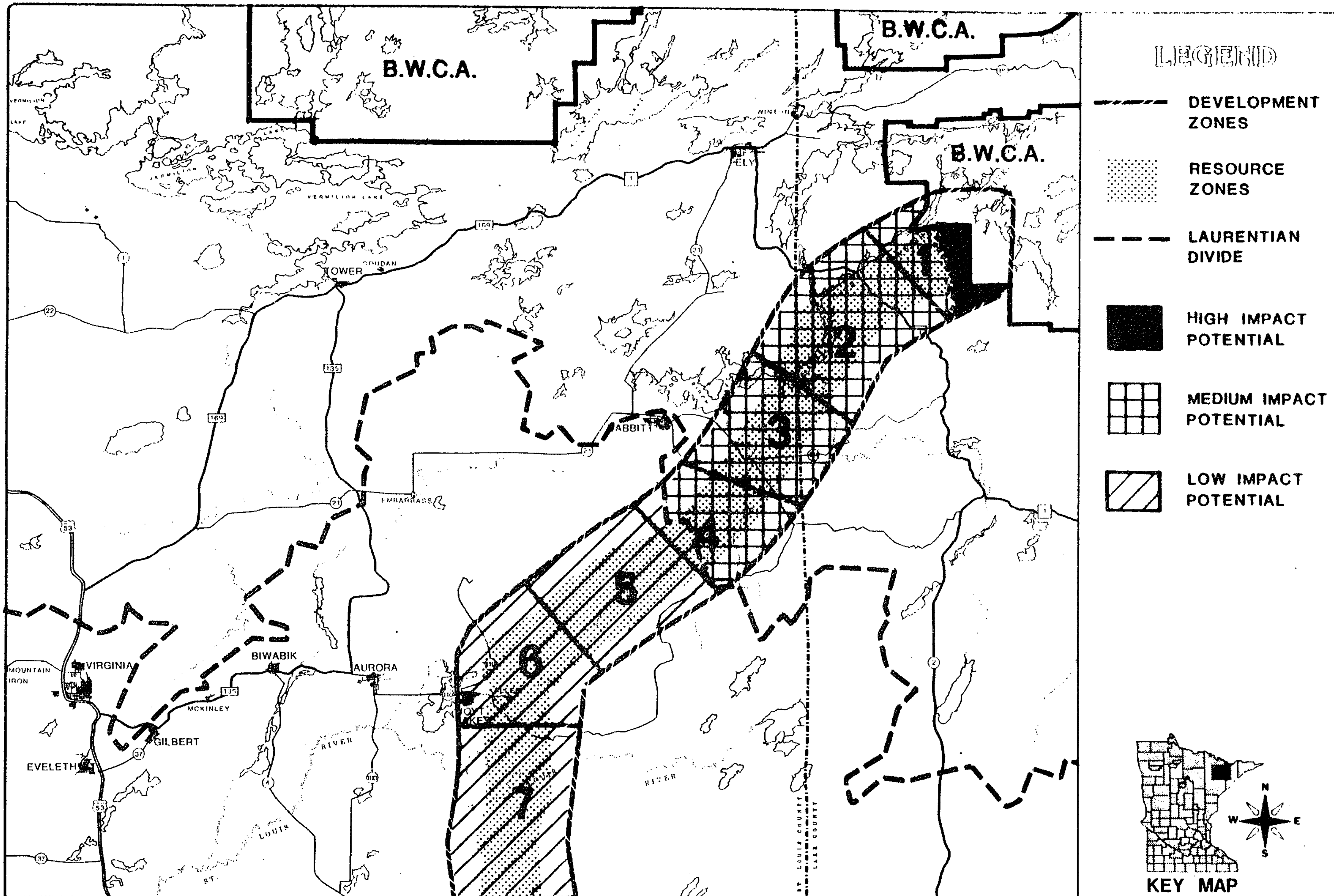


FIGURE 16 **MEQB REGIONAL COPPER-NICKEL STUDY**

B.W.C.A. WATER QUALITY IMPACT POTENTIAL OF DEVELOPMENT ZONES OUTSIDE THE B.W.C.A.

250 mg/liter (domestic consumption) and the proposed MPCA standard for nickel is 6.5 ug/liter (assuming a mean total hardness value of 28 mg/liter). Achievement of these standards would assure that no measurable change of the BWCA water quality occurs. It is unlikely that the proposed nickel standard could be met during the post-production phase of copper-nickel development; compliance may also be difficult during the operating phase.

Mine development near the BWCA may increase noise levels within the BWCA. Ore hauling trucks, blast warning sirens, explosions, underground mine ventilation fans, and railroads will generate noise that could be audible in the BWCA if development occurred in zones 1 or 2. Since the area of the BWCA which would experience increased noise levels as a result of copper-nickel development in these zones is closed to motor boats and snowmobiles by federal law, increased levels from other human activities, such as mining, may be inconsistent with this prohibition.

In summary, federal and state laws prevent copper-nickel development within the BWCA, but significant indirect impacts could occur from copper-nickel (and other development) located outside. Specific criteria for the protection of the BWCA from such impacts do not exist at the state and federal levels, except for some air pollutants. The lakes, streams, and forests of the BWCA are presently in jeopardy because of acid rain (probably caused by air pollution sources throughout the midwest). If the precipitation in the region continues its trend of increasing acidity, then the impacts on the BWCA caused by large-scale copper-nickel development will be small in comparison (both in magnitude and area affected).

A "no impact" requirement for the BWCA, if implemented, probably precludes a smelter in the Study Area (even if best available pollution control systems are used). Copper-nickel development would still be possible because a smelter can be located elsewhere. Still, a no impact requirement would probably preclude any copper-nickel mining in zone 1, and open pit mining in zone 2. Noise from underground operations in zone 2 could cause a problem, but noise suppression techniques should be able to correct this situation.

5.3 Economic and Social Impacts

The opening of a mining operation is typically accompanied by sudden population changes, housing shortages, inflation, and lack of adequate services. On the other hand, such development can mean renewed prosperity for an economically depressed area and additional tax revenue for expanded and new public services.

These considerations are addressed in the Study. Because of uncertainties involved in predicting conditions ten to twenty years in the future, the growth studies presented are not attempts to forecast precisely what will happen, but to speculate on what could happen under certain conditions if copper-nickel development occurs in the region. The problems of the mining boom towns of the past can be avoided if undesirable effects are identified and mitigative measures are designed and implemented.

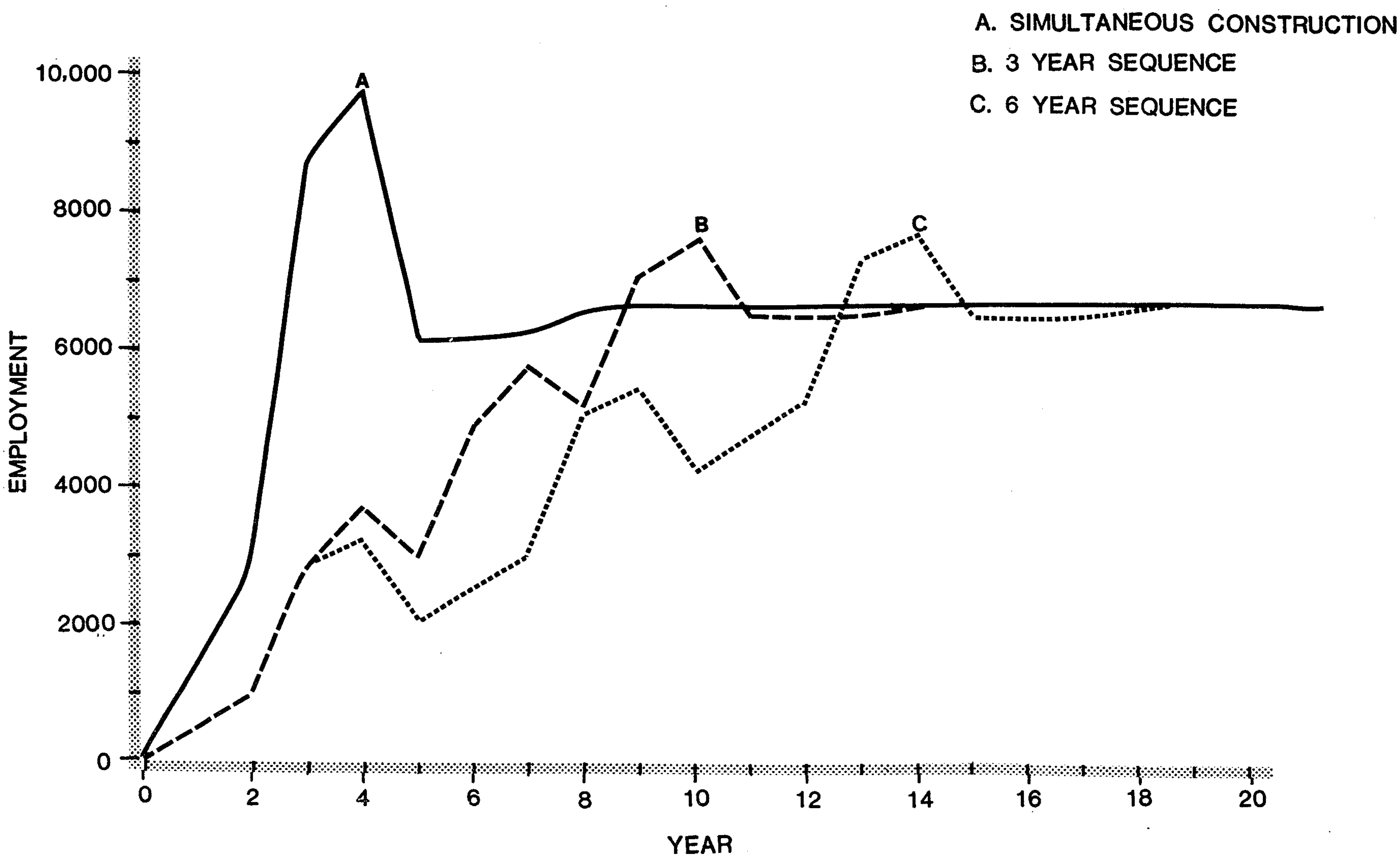
Employment. Actual employment opportunities will depend on: the type of development (e.g. open pit vs. underground mining); the size of the development; and the extent of development integration (e.g. mining, processing, and/or smelting/refining. Should copper-nickel development construction begin in the early 1980's and production start in the late 1980's, employment opportunities would increase dramatically through the rest of the century. It is expected that peak construction workforce requirements would be around 2,500 workers for a fully integrated copper-nickel development, while the peak operating workforce requirements would vary between 2,000 and 2,500 workers depending on the type and size of mine. Figure 17 shows only the construction and operating workforce jobs resulting from three different timing sequences. For example, line A, which depicts the simultaneous construction and operation of three fully integrated operations, has a peak construction workforce of almost 10,000 jobs. At the end of construction, the workforce requirement declines to about 6,000 and then gradually increases to approximately 6,800. These abrupt population changes would have a significant impact on land use, demand for housing, energy, and highways, as well as on the full range of government services (Volume 5-Chapters 1,3,8,11,13).

Figure 17

Copper-nickel development is not expected to be as rapid as was the case with taconite development in the state. A phased sequence of development would provide a greater opportunity to adjust to environmental and economic impacts. In addition, sequenced development would be more likely to provide employment opportunities to taconite workers entering the labor market between 1990 and 2000 as a result of increased productivity in the taconite industry. A sequenced development of two copper-nickel mining complexes over that period of time would help stabilize the population and provide an orderly transition from an economy dominated by taconite to one in which taconite and copper-nickel begin to assume an equal share of economic activity.

FIGURE 17

ALTERNATIVE DEVELOPMENT SEQUENCE FOR THREE INTEGRATED OPERATIONS



The transition could be made even more orderly by sequencing development of small operations as opposed to developing large operations all at once. Sequential development throughout the 50-mile (80 km) band (Figure 1) of copper-nickel resources would provide for the greatest growth related benefits and the fewest growth related detrimental impacts. Furthermore, a smelter/refinery located near Duluth could take advantage of an already established industrial infrastructure and a trained labor force while reducing the rate of growth in the Study Area.

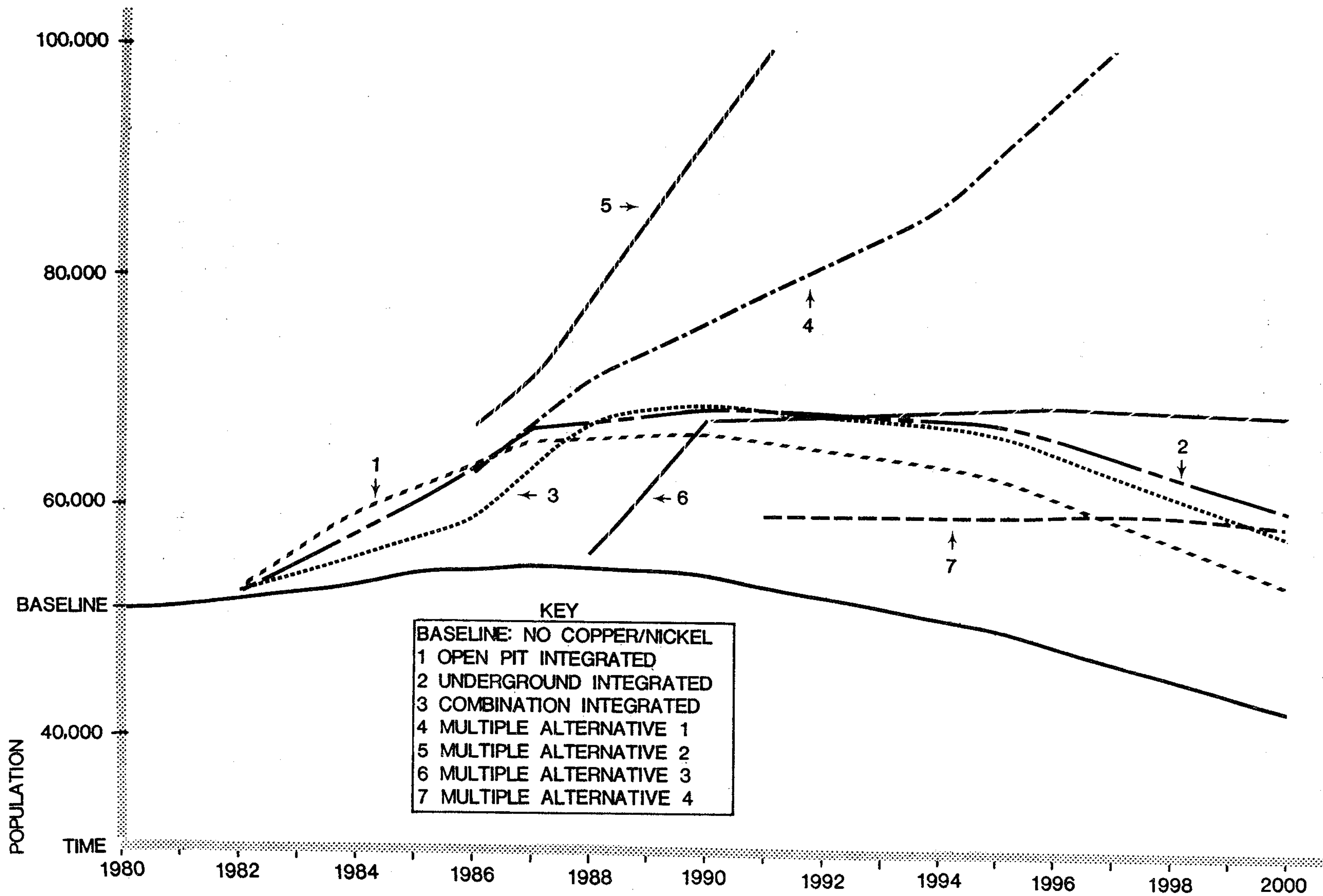
Population (Volume 5-Chapter 1). Population growth is expected to come from some construction workers that in-migrated to work on development and settled, operation workers that immigrated to work on copper-nickel, and service workers that immigrated to fill jobs in retail, wholesale, manufacturing, and service sectors resulting from copper-nickel development.

Seven alternative futures are projected to the year 2000 based on different possibilities of copper-nickel development. As Figure 18 demonstrates, there is a wide range of potential population growth impacts depending on the timing and the scale of development. The "maximum development" case shows a doubling of the Study Area's 1976 population and is demonstrated by line 3 (multiple alternative 2). This line represents the growth caused by four mine/mills and four smelter/refineries all starting production between 1985 and 1993 in the Study Area. Though the resource zone contains enough copper-nickel ore to support this degree of development, it appears unlikely to occur. Nonetheless, lines 2 and 3 on the graph do demonstrate the potential for change that development of the copper-nickel resource could induce.

Figure 18

FIGURE 18

REGIONAL COPPER-NICKEL STUDY AREA
POTENTIAL COPPER-NICKEL MINING IMPACTS ON TOTAL POPULATION
ALTERNATIVE DEVELOPMENT SCENARIOS



Line 1 on the graph demonstrates the potential impacts from a single fully integrated (mine/mill/smelter/refinery) model. This model suggests a population increase over 1976 levels of 20,000 by 1990 to a total area population of 67,000. Because the population is expected to increase to 55,000 without copper-nickel development, the copper-nickel induced increase amounts to 12,000.

The implications for housing, employment, personal income, cost of services, and income to local governments will be influenced by the timing and magnitude of copper-nickel development and could be very significant. Between 60 and 70 percent of all copper-nickel in-migrants are expected to live in and around existing urban areas such as Ely, Hoyt Lakes, Babbitt, and Virginia. The rest are expected to live in well-defined rural areas. Table 10 shows the forecasted distribution of population by the year 2000 if the following three mine models are developed: a 12.35 million mtpy crude ore underground mine/mill (no smelter) near Ely; a 16.68 million mtpy crude ore combination underground-open pit mine/mill and a 100,000 mtpy refined metal smelter/refinery near Babbitt; and a 20 million mtpy crude ore open pit mine/mill (no smelter) near Hoyt Lakes. As Table 9 demonstrates, substantial growth in individual communities and in rural areas may result from large-scale development.

Table 9

Fiscal Impacts (Volume 5-Chapter 13). Local governments must acquire and spend funds to upgrade, expand, and add new functions to satisfy the demands of a growing population and to maintain a desirable level of public services. These funds will come from taxes paid by new residents and by revenues from the new copper-nickel mining industry. However, most of the copper-nickel tax revenues

Table 9. Population distribution resulting from copper-nickel development in zones 2, 4, and 7.[a]

CITY	BEFORE CU-NI Population 1976	BEFORE CU-NI Population 1984	AFTER CU-NI Population 2000
Ely	5,250	5,550	9,810
Babbitt	2,880	3,030	5,550
Tower	750	780	1,050
Aurora	2,790	3,000	4,410
Hoyt Lakes	3,720	3,870	5,220
Biwabik	1,470	1,560	2,070
Eveleth	4,680	5,250	6,990
Virginia	11,730	13,260	17,550
Gilbert	2,610	2,790	3,540

[a]Approximately 30 to 40 percent of the total population will be distributed to rural areas and is not accounted for in this table.

only filter back to the government after being first paid to the state. These collected funds must be distributed equitably so that local government receipts are compatible with increased demand for government services induced by copper-nickel development.

Analyses based upon the 1977 tax laws and other assumptions indicate that local governments will receive adequate revenues to support growth only if one or more of the following conditions exist:

- At the time of population growth and demand for services, the community (school district) in question has a large excess of service capacity.
- The community develops adequate procedures to transfer the capital cost of service expansions to the new residents, such as through building permit fees or special assessments.
- The community has a relatively low operating cost which will not be significantly increased by new population.
- The community can provide expansion of capital and services at low costs such as through a development grant from state or federal set-aside funds.

There are eight cities and seven school districts in the Study Area. The estimated average operating cost per year ($1977) is $212 per person for the cities and $1,477 per pupil-unit (pupil-unit: a kindergarten student equals 0.5 pupil-units, an elementary student equals 1.0 pupil-units, and a secondary student equals 1.4 pupil-units) in the school districts. The range of per capita operating costs for the cities in 1977 was $156-241. The average operating cost per pupil-unit for the state in 1977 was $1,059 as compared to $1,477 for the Study Area. Six of the Study Area school districts (Eveleth excepted) ranked above the 95th percentile in operating costs per pupil-unit.

If the existing facilities of a community or school are inadequate and new facilities must be purchased or built, a community or school district usually goes into debt to expand its capacity. The average annual cost of capital expansion plus debt service is estimated to be $334 per person for the communities and $366 per pupil-unit for the school districts. Enrollment has declined in Study Area school districts over the last few years and further declines are expected unless there is a major change such as the development of copper-nickel mining.

In order to determine the fiscal impact of copper-nickel development, it was assumed that the facilities of both the communities and the school districts will be at full capacity prior to copper-nickel development, and that capital expenditures will be required to accomodate an increased demand for public services. This assumption leads to the conclusion that revenues generated by the mining operation will not balance the additional public expenditures required to meet the demands of an expanded population. The "full capacity" assumption may not be totally accurate, yet it serves to illustrate the direct relationship between demand-induced public expenditures on the one hand and additional public revenues generated by the source of the demand on the other hand. More specifically, this analysis identifies the areas and communities that are most vulnerable.

There are several taxes applicable to copper-nickel development in Minnesota, and the interpretation of some of these taxes is ambiguous. The analysis presented is based on specific interpretation which may change in the future. Of particular concern is the applicable distribution formula for the production tax, which is levied on copper-nickel mining in lieu of property taxes and the proceeds of which are partially redistributed to the local level. The distribution formula for the copper-nickel production tax was made equal to the formula fo the taconite production tax in 1965. Since then, the taconite distribution formula has been changed to reflect changing circumstances, but the coppr-nickel formula may not have changed. It is assumed in this analysis that the distribution formula is equivalent to the 1977 taconite formula. In fact, given the assumptions on capacity and population distribution, both interpretations result in similar fiscal impact conclusions. Resolution of this and other interpretation problems would be helpful.

The city and school district potential annual revenue shortfalls are indicated in the following table (Table 10). Only one instance of excess revenue is generated in the several possibilities analyzed (the Gilbert school district under the smelter/refinery scenario). The analysis indicates a need for a careful evaluation of the present copper-nickel tax generation and distribution policies.

Table 10

Expected Tax Revenues (Volume 5-Chapter 12). In addition to the aids available to all Minnesota local governments, the local governments of the taconite mining area (which includes the Study Area) are eligible to receive special state aids funded by revenue from taconite and copper-nickel production taxes. The mine/mill part of an operation would be taxed differently from a smelter/refinery under existing laws. For the most part, the copper-nickel mine and mill are subject to the same taxes as a taconite mine and mill but at different rates. (An exception is that taconite mining is exempted from state corporate income tax liability.) A smelter and refinery are treated like a manufacturing facility for tax purposes.

As a result, total government tax revenue (state and local) generated by a 100,000 mtpy smelter/refinery operation are estimated to be two to three times

Table 10. Annual cost vs. revenue figures for copper-nickel development scenarios.[a]

	UNDERGROUND MINE/MILL Resource Zone 2*			OPEN PIT/UNDERGROUND MINE/MILL Resource Zone 4			OPEN PIT MINE/MILL Resource Zone 7			SMELTER/REFINERY Resource Zone 4		
	Income	Expenditure	Diff.**	Income	Expenditure	Diff.	Income	Expenditure	Diff.	Income	Expenditure	Diff.
Cities												
Virginia	1,000	70,000	69,000	32,000	171,000	139,000	69,000	322,000	253,000	11,000	66,000	55,000
Gilbert	-1,000	6,000	7,000	4,000	16,000	12,000	26,000	72,000	46,000	1,000	6,000	5,000
Eveleth	-1,000	15,000	16,000	7,000	37,000	30,000	31,000	117,000	86,000	2,000	14,000	12,000
Ely	487,000	1,357,000	870,000	104,000	330,000	226,000	0,0	9,000	9,000	43,000	128,000	85,000
Biwabik	2,000	9,000	7,000	7,000	21,000	14,000	31,000	90,000	59,000	2,000	8,000	6,000
Babbitt	18,000	240,000	222,000	76,000	796,000	720,000	1,000	18,000	17,000	177,000	309,000	132,000
Aurora	2,000	21,000	19,000	12,000	58,000	46,000	80,000	352,000	272,000	4,000	22,000	18,000
Hoyt Lakes	-1,000	12,000	13,000	4,000	29,000	25,000	102,000	449,000	347,000	1,000	11,000	10,000
TOTAL	507,000	1,730,000	1,223,000	246,000	1,458,000	1,212,000	340,000	1,429,000	1,089,000	241,000	564,000	323,000
School Districts												
Virginia	65,000	90,000	25,000	172,000	232,000	60,000	259,000	343,000	84,000	72,000	90,000	18,000
Gilbert	11,000	15,000	4,000	30,000	39,000	9,000	164,000	216,000	52,000	16,000	15,000	-1,000***
Eveleth	18,000	26,000	8,000	54,000	63,000	9,000	178,000	247,000	69,000	19,000	24,000	5,000
Ely	2,178,000	2,551,000	373,000	601,000	711,000	110,000	15,000	18,000	3,000	256,000	276,000	20,000
Biwabik	12,000	18,000	6,000	25,000	39,000	14,000	111,000	171,000	60,000	11,000	15,000	4,000
Babbitt	418,000	573,000	155,000	1,065,000	1,642,000	577,000	84,000	144,000	60,000	585,000	638,000	53,000
Aurora/ Hoyt Lakes	29,000	59,000	30,000	76,000	149,000	73,000	578,000	1,356,000	778,000	34,000	57,000	23,000
TOTAL	2,731,000	3,332,000	601,000	2,023,000	2,875,000	852,000	1,389,000	2,495,000	1,106,000	993,000	1,115,000	122,000

*Lake County.
**Deficiency.
***Excess.

[a]Average area costs and lack of excess service capacity are assumed in these expenditure estimates. Revenue distributions are based on the 1977 taconite production tax distribution formula.

greater than the tax revenues generated by a mine/mill operation producing sufficient concentrate to support such a smelter/refinery operation. Moreover, given the direct relationship between the increased demand for government services and new jobs created, the less labor intensive smelter/refinery operation could generate seven to ten times more net tax benefit than a mine/mill operation.

Approximately 15 percent of the copper-nickel mineral rights in the resource zone are administered by the state of Minnesota (Volume 5-Chapter 4). Considering the uneven distribution of minerals and mineral ownership over the resource zone, the state's share (10.6 percent) of the total copper-nickel gross value ($50 billion based on average 1977 market pricess--see section 3) would be $5.3 billion. If an average royalty rate of 6 percent is used for state lands, the potential royalty payments to the state could amount to over $300 million. In addition, the tax on royalties which would be paid to the 32 percent of mineral ownership in the private sector could amount to $960 million.

Total direct and indirect tax revenue to school districts and city and county governments of the Study Area from mine/mill models analyzed by the Regional Copper-Nickel Study range from $63 million to $108 million over the life of an operation. Eighty percent of this total would be in the form of state aids. A large smelter/refinery complex could generate from $100 to $200 million in local revenues over its life, 15 to 30 percent in the form of state aids. The percentages differ because the smelter/refinery as a manufacturing unit is liable for local property tax, whereas the mine/mill pays the state a production tax which is redistributed to local governments in lieu of property tax.

__Tax Policy Considerations.__ Significant variations in total revenue generated over the life of an operation may occur due to changes in tax laws and the relative financial success of the mining company. For example, the open pit mine model which produces 20 million metric tons of ore per year will generate $135 million dollars in state revenues (no sales tax) under existing tax laws with copper and nickel selling at $.91 and $2.10 per pound respectively ($1977) over the life of the mine. If copper and nickel prices are increased to $1.25 and $3.00 per pound ($1977) respectively, the open pit mine/mill model will generate about $394 million ($1977) in state revenues over the life of the operation, an increase of 202 percent. If the sales tax is levied against the mine/mill model, an additional $75 million ($1977) in tax revenues would be generated.

Many factors affect the profitability of a mining operation (Volume 5-Chapter 17). The Study concluded that on a percentage basis Minnesota mineral tax rates have considerably less influence on the profitability of a copper-nickel operation than the market price of copper and the quality of ore mined. For example, it is estimated that a one percent change in property taxes is 23 times less influential, a one percent change in the state income tax is 74 times less influential, a one percent change in the production tax is 200 times less influential, and a one percent change in the occupation tax is 253 times less influential than a one percent change in the price of copper in determining profitability. However, if tax rates are changed dramatically, they will seriously affect the investment potential of any Minnesota operation. Moreover, new copper-nickel operations that are marginal investment opportunities can be made significantly more attractive or unattractive by moderate changes in existing tax law.

Minnesota's 1979 copper-nickel tax rates are close to other copper producing states. Montana, Utah, New Mexico, Arizona, and Minnesota tax rates are almost identical in their influence on the investment potential of a large open pit mine model (Table 11). However, Wisconsin's present tax rate makes that state significantly less attractive for open pit mining. Minnesota ranks third in revenues produced and a close second in investment quality because of relatively light taxes early in the mine life and relatively heavy taxes later on.

Table 11

In summary, copper-nickel development would generate significant tax and royalty revenues for the state of Minnesota. Royalty payments could be a major income source for the state depending on the state's share of the minerals that are mined. Under present tax laws, a smelter is taxed differently than a mine and mill and results in large direct payments to local government. Minnesota's present copper-nickel tax laws produce revenues comparable to other major mineral producing states, but significantly lower than Wisconsin's new tax structure. Minnesota tax policy can significantly affect the profitability of marginal copper-nickel operations, especially if taxes result in higher front end costs. In general, however, state taxes are expected to have considerably less impact on profitability than the market price of the metals and the grade of the ore mined.

Table 11. Comparison of the impact of alternative state mineral tax laws on profitability.[a]

STATE	dcfror (%)	TOTAL TAX REVENUES ($million)
Montana	12.04	797.09
Minnesota	11.93	829.03
Utah	11.88	736.43
New Mexico	11.78	807.55
Arizona	11.17	880.24
Wisconsin	9.25	1137.71

dcfror = discounted cash flow rate of return

[a]Based on a fully integrated 20 X 10^6 mtpy open pit development, and copper and nickel prices of $0.91 and $2.10 per pound ($1977), respectively.

6. MAJOR TRADEOFF AREAS

The previous sections have discussed some of the major issues related to copper-nickel development in Minnesota. The discussion spanned a wide range of disciplines, and presented the most important findings of the Regional Copper-Nickel Study. To place this information into proper perspective, it is useful to add a discussion of some of the major tradeoffs which must be considered in deciding whether, when, where, and how copper-nickel development should proceed in Minnesota.

The following sections present a variety of alternatives to be considered during the course of any development. These alternatives will certainly be considered by mining companies interested in the development potential of the area; they may also be considered by governmental bodies, interested groups, and individuals. Inevitably, every alternative has advantages and disadvantages which must be weighed in the decision-making process. Since those who must bear the disadvantages may not be the same as those who reap the rewards of a given decision, it is useful to summarize these pros and cons so they may be juxtaposed to facilitate the decision-making process.

The major tradeoff areas considered here include:

- Mining, delayed mining, or no mining
- Open pit mining or underground mining
- Smelter in the Study Area, a remote smelter, or no smelter
- Development north or south of the Laurentian Divide

Mining,Delayed Mining,No Mining. Assuming that feasibility studies reveal that a mineable resource exists in the Study Area, the question arises whether or not to actually proceed with mining, and if so, when. If the demand for both copper and nickel continues to increase and the quality of ore being mined in the U.S. continues to decrease, there is little doubt that Minnesota's deposits will become more and more commercially attractive. The questions are when will a specific proposal be submitted, and what will be the type and location of the proposed mining operation.

Given the large investment (up to $25 million in 1977 dollars) needed to prove out a potential mine development, it is unlikely that a company will abandon all interest in any future development at the site. It will probably postpone development until economic and related conditions are favorable, while maintaining control of the resource. This is now the situation in zones 1 and 2 (INCO) and zone 4 (AMAX).

From the perspective of a mining company, the proper time to develop a resource is determined in part by the world metal prices, as well as its own position in the world metal market. For example, a company with no major copper or nickel capacity at present may wish to proceed when market prices are favorable. However, a company holding a major share of the world production capacity for a metal may find it advantageous to postpone development rather than to add new capacity which may compete with its own older, potentially more costly operations. Clearly, such considerations become quite complex and vary greatly from company to company.

Development generates direct revenues through a variety of taxes, and indirect revenues through wages along with an increased flow of capital in the region.

From the perspective of various governmental units seeking new sources of income, early development may be desirable.

On the other hand, increased population associated with development of one or more copper-nickel operations will place additional demands for services on governmental agencies at all levels. It is reasonable to conclude that these demands would be best met by allowing time for shortcomings in present services and facilities to be corrected so that the increased load can be handled prior to initiating development. Such an approach would also require that the economic and human resources needed to accomplish this upgrading be available. The services of concern here include housing, water supply, sewage treatment, roads, and a variety of social services.

Another major factor which may influence the timing of development is the status of mining technology. As new mining methods and machinery are developed and made available commercially, more resources can be economically exploited. Furthermore, the efficiency of metal recovery is likely to increase. This is particularly important in the context of Minnesota's low-grade resource. New technology may also serve to reduce or eliminate a variety of environmental problems which are difficult to deal with using current practices. One area of major concern here is the removal of low concentrations of metals (copper, nickel, zinc, and cobalt) from water prior to releasing it to the environment. If there is great concern over potential environmental impacts, consideration can be given to delaying development until means have been perfected to reduce the problems to acceptable levels.

The environmental, economic, and social impacts associated with a large-scale mining operation will be influenced by the speed at which it is developed. For example, the rapid development of copper-nickel mining would:

- Intensify social inequities of low and fixed income residents in the area who are unable to keep up with inflation induced by a major and rapid increase in demand for goods and services;

- Tax the ability of the housing market to adjust to demands of a rapidly expanded workforce;

- Strain the ability of local government resources to respond to an abrupt expansion in the demand for public goods and services; and

- Strain the capacities of regulatory and industrial controls to deal effectively with negative environmental impacts.

More moderately paced development would, on the other hand, provide greater opportunity for a more thoughtful, planned, and more adequately financed response to expected impacts on the environment, on housing, and on government services. In addition, a more moderate increase in the workforce would serve to offset somewhat the anticipated reduction in the taconite employment.

If development is not allowed, the major regional change would be a projected 16 percent decline in population and employment by the year 2000 (compared to 1976 levels) or large unemployment increases if significant out-migration does not occur.

Open Pit Mining or Underground Mining. Because an industry's decision to mine by either open pit or underground methods is dictated primarily by geological factors, adoption of a public policy to prohibit one of these methods would have the effect of excluding the development of certain deposits. For example, resource zones 3 and 7 (Figure 1) appear to contain minor open pit resources, while the underground potential is by far the most important in zone 2. Open pit resources are more important than underground resources in zones 4 and 5. Zone 1 has approximately equal quantities of each type of resource (Table 1).

Where both types of mining appear feasible (as may be the case in all but zones 3 and 7), open pit is likely to be favored by a mining company for the initial development in an area. This is principally due to a shorter development time (nominally two years) compared to an underground operation (nominally five years). The earlier startup generates early income which, coupled with lower operating costs, makes the open pit more attractive financially, even though the average ore grade would be lower and the initial capital cost per unit of contained metal capacity somewhat larger than for an underground operation.

An exception to this occurs when a higher grade deposit is discovered underground, as appears in zone 4. In this case, a small but relatively rich (2-3 percent copper, 0.5 percent nickel) underground resource may be worth developing initially to generate income that will aid in financing the remainder of the development of the lower grade of ores. While the presence of such high grade deposits has been confirmed only in zone 4, the geological continuity of the entire region associated with the Duluth Gabbro Contact suggests that such occurrences may yet be discovered in other zones as well.

Besides often being more economically attractive, an open pit mine provides advantages in worker safety. Although possibly biased by data from older operations not representative of new safety technology, available statistics worldwide indicate disabling injuries underground occur at a rate 2 to 3 times that for open pit operations handling an equivalent ore tonnage.

The relative disadvantages of open pit mining occur because usually lower grades of ore are mined and more wastes generated. The reduced grade means almost twice as much ore must be removed from the ground to recover the same amount of metal.

In addition, the production of waste rock (and possibly lean ore as well) may be 20 times or more that for an underground development. As a result, the overall land requirements for an open pit operation can be at least twice that of an underground operation producing an equivalent amount of metal. Not only does the pit itself require considerable space (on the order of a square mile), but the tailing basins would occupy twice the space and waste rock areas 20 times the space of an underground operation with comparable metal production.

Moreover, the open pit will be a potential source of fugitive dust and noise from blasting and truck traffic. The large pit collects precipitation which may become contaminated with heavy metals and suspended solids, and which must be pumped out for mining to proceed. Following abandonment, the pit will remain as a permanent landscape feature which fills with water. The resulting lake may have restricted value due to contamination by heavy metals. Underground development avoids most of these problems.

In conclusion, while open pit mining is frequently more cost effective, has greater recovery of the resource, and has the advantage of greater worker safety, underground mines would produce less severe environmental impacts. Over two-thirds of Minnesota's copper-nickel resources are more than 1,000 feet below the surface, and would probably require underground mining methods for exploitation.

Smelter in Area, Remote Smelter, or No Smelter in State. Due to the unique ratio of copper to nickel in the Minnesota deposits, it is likely that new smelting facilities will be required. These facilities could be located (1) in the Study Area close to the mines and processing facilities, (2) some distance from the Study Area but still within the state, or (3) outside of Minnesota, and possibly even outside of the U.S.

An estimated 10-15 percent savings in smelter capital and operating costs could result by locating the smelter at the same site as the processing facilities. These reductions come from savings in shared facilities such as general administration staff and facilities, maintenance facilities, electrical power substations and distribution equipment, roads and other infrastructure requirements. From the point of view of regional economics, a smelter would provide several hundred new jobs and would generate additional tax revenue. Furthermore, the concentrates from the processing plant would not have to be transported great distances, thus eliminating this transportation cost, as well as hazards that could result from a concentrate spill in transit. However, the hazards and costs associated with the additional transport of sulfuric acid (the major by-product of the smelter) would exist.

The major disadvantage of a smelter in the Study Area is due to increased air pollution. As a potentially significant source of sulfur dioxide and particulates containing heavy metals (copper, nickel, cobalt) it may be difficult to site such a facility within several miles of the BWCA without the granting of a variance or modification of existing air quality requirements. Even if the legal requirements could be met by installation of pollution control equipment, equipment failures are likely to occur during the life of the facility. Though long-term damage is unlikely, visible damage to vegetation downwind of a smelter during such upset situations would be likely. Siting a smelter in the Study Area, especially in resource zones 1-6 (see Figure 1), may be precluded because existing and planned new sources of SO_2 in the region may consume all of the Class I PSD increment (applicable to the BWCA) before any copper-nickel development occurs.

Siting a smelter outside of the Study Area (but still within the state) would eliminate the problems due to the unique aspects of the Study Area. Certainly an industrial location and population center, such as Duluth, would not be as sensitive to the added metals buildup in the soils or acidification effects from a smelter. However, new problems could be created, depending on the nature of the new site, and would have to be investigated once a proposal is in hand.

Preventing construction of a smelter within the state would also likely remove any potential smelter-related environmental impacts from the Study Area, although a smelter might still be located near the Minnesota border (such as in Wisconsin or Canada for example). In such an event the state would still experience air quality impacts but would not have jurisdiction over the facility and thus could not directly control its design, construction, or operation. Moreover, the state would lose any tax revenues from it. If the facility is remote from the state, employment advantages would be lost to Minnesota labor. If the facility were sited close to the border, some of the jobs would likely be taken by persons residing in Minnesota. In any event, the state would be subject to hazards from possible concentrate spills while in transit out of Minnesota.

Development North or South of the Laurentian Divide. The Study Area is bisected by the Laurentian Divide (Figure 1), with all waters north of the Divide flowing into the BWCA and eventually to the North Atlantic Ocean via Hudson Bay. Waters south of the Divide flow down the St. Louis River to Lake Superior and then to the Atlantic Ocean via the St. Lawrence River. Development zone 4 is bisected by the Divide, with zones 1, 2, and 3 lying entirely to the north and zones 5, 6, and 7 to the south.

Of these two regions, the area north of the Divide appears to be the most susceptible to the environmental impacts. The soils are shallower, offering less buffering to offset the effects of acid input. More of the surface is covered by water, increasing the area of surface water systems directly receiving atmospherically deposited material. The Study Area north of the Divide currently has little or no industrial development in contrast to the Study Area south of the Divide, which contains considerable taconite development.

While the susceptibility of the aquatic system may be greater north of the Divide, there is also more dilution water. Therefore, the waters south of the Divide may be as susceptible or more susceptible to biological damage.

The northern zones are close to the BWCA where there are strict air quality standards and nationally important wilderness values. Copper-nickel development to the south would not add mining noises not already present due to the taconite industry, while development in the north may extend audibility of these sounds well into currently unaffected portions of the BWCA. Development in the north is clearly less desirable from an environmental perspective than development in the south.

However, about 75 percent of the copper-nickel resource lies in zones 1, 2, and 3, north of the Divide (almost half the resources are in zone 2 alone). Zone 4 which straddles the Divide, contains almost 20 percent of the resource while zones 5, 6, and 7 together contain just over 10 percent. Clearly the major regional economic focus is on the potential for developments on and north of the Divide.

Zone 4, on the Divide, is a special case. The zone is adjacent to existing taconite development so that mining there will not be as intrusive as it would be in the other major resource zones north of the Divide. Furthermore, the zone lies 15 to 20 miles from the boundary of the BWCA--a sufficient distance to prevent significant atmospheric particulate or noise impacts on this wilderness area according to models used by the Regional Study. The surface relief in the zone is low, so that in the event of deliberate or accidental water discharges, it may be feasible to divert this water from the north side of the Divide so that it flows south, thus protecting the more fragile aquatic systems to the north. Also, the proximity of the Divide may make it possible to site major potential water pollution sources (waste rock and lean ore piles, tailing basins) south of the Divide. Because of these possibilities, development in zone 4 may be considered relatively more desirable on purely environmental grounds, provided extreme caution is taken to prevent the release of contaminated water from the site.

7. REPORT ORGANIZATION AND STUDY DOCUMENTATION (Appendix)

Copper-Nickel Study reports have been classified into three groups: 1) Executive Summary (Volume 1); 2) Second Level reports (Volumes 2-5); and 3) Technical Reports. The contents of Volumes 1-5 are listed below.

Volume 1 - Executive Summary

Chapter 1	Historical Perspective
Chapter 2	Study Goals and Objectives
Chapter 3	Study Area and Mineral Resources
Chapter 4	Copper-Nickel Development Alternatives
Chapter 5	Environmental, Economics, Social, and Fiscal Impacts Issues
Chapter 6	Major Trade Off Areas
Chapter 7	Report Organization and Study Documentation (Appendix)

Volume 2 - Technical Assessment

This volume discusses the technical aspects of all phases of mineral development including manpower, capital costs, land requirements, technology, mitigation measures, energy, water use, and time requirements. Hypothetical mine models are developed in Chapter 5.

Chapter 1	Exploration
Chapter 2	Mineral Extraction (Mining)
Chapter 3	Mineral Processing
Chapter 4	Smelting and Refining
Chapter 5	Integrated Development Models

Volume 3 - Physical Environment

This volume discusses physical aspects of the environment including characterization of existing conditions, projections of future conditions without copper-nickel development, and analysis of impacts based on copper-nickel development models.

Chapter 1	Geology and Mineralogy
Chapter 2	Mineral Resources Potential
Chapter 3	Air Resources
Chapter 4	Water Resources
Chapter 5	Noise

Volume 4 - Biological Environment

This volume discusses biological aspects of the environment including characterization of existing plant and animal communities, projected future impacts on these communities without copper-nickel development, and analysis of impacts based on copper-nickel development models.

Chapter 1	Aquatic Biology
Chapter 2	Terrestrial Biology

Volume 5 - Human Environment

This volume discusses aspects of the human environment which may be affected by copper-nickel development including a characterization of present conditions, future projections assuming no copper-nickel development, and impacts based on copper-nickel development models.

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