AN ASSESSMENT OF CAPITAL INVESTMENT IN MINERAL EXPLORATION IN MANITOBA (1976-2000)

by

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In Partial Fulfillment of the Requirements for the Degree of Master of Natural Resource Management

NATURAL RESOURCE INSTITUTE
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ABSTRACT

The system of mineral supply in Manitoba is a dynamic one requiring a constant stream of capital inputs. One of these inputs is capital investment in mineral exploration.

Forecasting future levels of capital investment in mineral exploration is made difficult by both the lack of relevant data, and the theoretical nature of the problem. The statistical concept of expected payoffs can be used to formulate a methodology for forecasting exploration expenditure based on total reserve estimates and past exploration history. The resulting forecasts must be interpreted with appropriate caution.

Exploration expenditure in Manitoba between 1976 and 2000 is expected to be sensitive to both mine output and exploration success rates. If the historic growth trend of Manitoba's mine output is to continue, the exploration effort (in terms of expenditure) is expected to be of the same magnitude as that of the past 30 years. An increase in the growth rate of mine output is expected to require a corresponding increase in the exploration effort. It is expected that the maitenance of current levels of mine output can be achieved with a decrease in exploration effort. Advances in exploration technology will decrease the expected expenditure requirements.

Further research into the theoretical basis and data requirements of the problem is necessary to improve the quality of forecasting in this area.

ACKNOWLEDGMENTS

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GLOSSARY OF TERMS

Constant Dollars	- 1976 dollars. 1976 was chosen as the base year of the study since the 1976 data was the most complete and recent.
Exploration	- The activity of searching for and defining ore reserves occuring prior to a decision to develop the reserves to the productive stage.
Exploration Expenditure	- The costs associated with exploration activity.
Mineral Deposit	- A naturally occuring concentration of rock material containing a metal of some economic value
Ore	- That part of a mineral deposit from which the valuable constituents could be profitably extracted under prevailing economic conditions.
Ore Reserves	- Ore tonnage that can be reasonably assumed to exist.

CHAPTER I

THE PROBLEM AND ITS SETTING

Introduction

Mineral exploration in Manitoba has led to the development of a primary mineral production industry consisting of several operations, most being parts of large national and multi-national corporations.* The ability of this industry to continue primary production in the province is dependent on both the physical distribution of mineral deposits in the province, and the industry's ability to locate and define these deposits through exploration.

Mining in Manitoba contributes to the provincial economy by providing employment and income, and payment to the provincial government in the form of taxes and royalties. These benefits will occur as long as the industry is active and has sufficient knowledge of economic mineral deposits to continue its activity. This knowledge is acquired through mineral exploration expenditure.

The Problem

The basic problem is the forecasting of the level of capital investment in mineral exploration in Manitoba between 1976 and 2000. The objective of this research is to use a simplified theoretical framework of the

* Manitoba primary mineral production operations are presented in Appendix 1.

mineral supply system in Manitoba to develop a methodology for forecasting the level of this investment. This methodology will then be used with the available data to forecast mineral exploration expenditure in Manitoba between 1976 and 2000. This forecast will take the form of a range of values defined by contingent sets of assumptions regarding future states.

The study is limited to the analysis of mining activity occuring within the geographical limits of the province of Manitoba, and the three main mining products, in terms of the value of production, nickel, copper, and zinc. The study is also limited to forecasting production for the period 1976-2005 and forecasting exploration expenditure for the period 1976-2000. The forecasts are based on a survey of the currently known resource endowment, exploration history, and assumed growth rates of output. Other factors which influence the level of exploration expenditure, such as political conditions, international trading patterns, and energy availability are not considered in this study.

Assessment of future capital investment in mineral exploration is made difficult by both the lack of sufficient relevant data, and the theoretical nature of the problem. Both the complexity of, and the uncertainties involved in the mining industry make any assessment of the industry in a future time frame subject to difficulties.

The problem under consideration involves the analysis of the behavior of a large and complex industry. The capital expenditure pattern of the industry is developed in response to an array of both internally generated and extraneous forces such as metal market conditions, political circumstances, environmental and safety concerns, social conditions of the communities affected, technical and geological considerations, and energy availability.

To identify and define the influence of the relevant forces on the level of exploration expenditure would be a task well beyond the capacity of the resources allocated to this study.

The necessity of predicting the behavior of the influencing forces introduces an additional element of uncertainty which must be carried through the analysis.

The approach chosen for this study is to develop a simplified theoretical framework describing the mineral supply process. This framework is then used to place mineral exploration expenditure in a proper perspective and formulate a specific problem statement.

This simplified interpretation of the mineral supply system and the role of capital investment in mineral exploration is necessary before any specific methodology can be developed. A theoretical simplification of the mineral supply system is described below.

<u>The Mineral Supply System</u>

The mineral supply process can be described as a multistage series of activities by which minerals are converted from unknown geologic resources to marketable commodities. (Mackenzie and Bilodeau, 1977) The system can be viewed as a succession from stimulus to activities to results. It is a dynamic process in two ways. Firstly, all levels of activity involved are sensitive to continual changes in the operating environment. Secondly, mineral deposits are continually being depleted and abandoned, while others are being developed to the productive stage.

The world mineral supply system is illustrated diagramatically in Figure 1. Note that it is a cyclical process, as the initial operating environment is influenced by the end product, mineral supply.

The initial stimulus for the mineral supply system is provided by the existence of the opportunity to produce mineral supply at a cost-price ratio of less than one. This is referred to as economic opportunity. Four factors in the

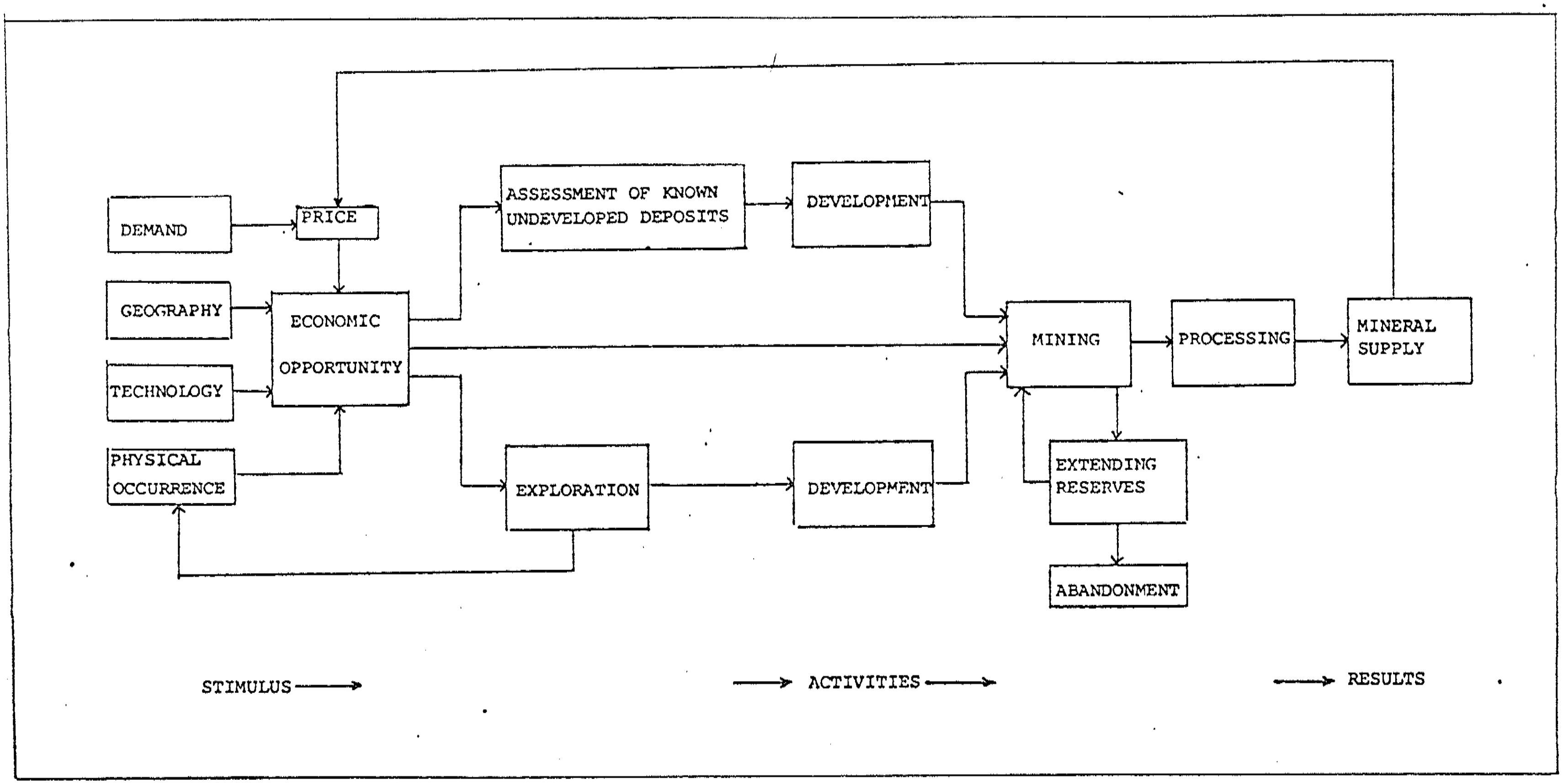

Figure 1: The World Mineral Supply System

operating environment have been identified as having an influence on the extent of economic opportunity at any given time. These are, world demand for mineral output, world geography, technology available, and the physical occurence of mineral deposits in the earth's crust.

The world demand for mineral output is directly related to the world-wide level of economic activity and the intensity of mineral consumption per unit of economic activity. (Energy, Mines and Resources Canada, 1976a)

The world-wide level of economic activity is influenced strongly by the growth in Gross National Product (GNP) of the industrialized nations, as they represent the most intensive consumers and producers of goods and services. Economic growth of the industrialized nations, as expressed by real growth in G.N.P., is an approximate indicator of the growth of demand for mineral output. This is assuming a constant rate of mineral consumption per unit of economic growth.

There are indications that the intensity of mineral consumption per unit of economic growth may be shifting downwards in the industrialized nations in recent years. (Energy, Mines and Resources Canada, 1976a) This can possibly be explained by the shift in proportionate contribution to total G.N.P. from the primary and secondary sectors to the tertiary sector. Because of this tendency, the intensity of mineral consumption per unit of economic growth must also be considered when analyzing world mineral demand in terms of growth in G.N.P. of the industrialized nations.

The world demand for mineral output together with the world mineral supply establishes a market equilibrium price for mineral commodities at any given time. This price becomes the price component in the cost-price ratio.

The cost component of the cost-price ratio is determined by two other factors in the operating environment, geography and technology.

The two most important geographical factors influencing economic opportunity are the transportation infrastructure and political institutions in place at any given time.

Transporting mineral output to the market is a major factor in the total costs involved in the mineral industries, as the spatial distribution of mineable mineral deposits has little relationship with the spatial distribution of the market. This is true in Canada as most mineral production comes from the sparsely populated Shield and Cordilleran regions, while the markets are either foreign or in the southern industrialized region.

The proximity of an established transportation corridor is often the key determinant in the development decision of many mineral deposits where the cost-price ratio is close to one before transport costs are considered. The construction of a new transportation link will increase the level of economic opportunity if it passes through previously remote regions containing sub-economic deposits.

Political institutions, through their royalty systems and legislation governing mining activities, have a strong influence on total costs and, therefore, economic opportunity. Other geographical factors such as population distribution, cultural attitudes, and political alliances may also affect the level of economic opportunity, but their influence is usually uncertain and difficult to analyze. Therefore, transportation infrastructure and political institutions can be considered to be the most important geographical factors.

The level of technology available is another important factor in determining total costs. Technological breakthroughs can increase the level of economic opportunity through the lowering of production costs. The history of the development of new mining and metallurgical techniques and subsequent increases in the development of new productive capacity serves to illustrate this effect. Cost-lowering technological innovation at any stage of the mineral supply process will serve to increase economic opportunity.

The physical component of the operating environment consists of the total number of mineral deposits in the earth's crust. This physical resource base must be qualified on the basis of the extent of knowledge concerning its existence. The physical component of the operating environment can be divided into two groups of mineral deposits, known deposits and speculative deposits.

Known deposits are all deposits from which presently existing mines are producing plus all deposits discovered and assessed, but not considered to be economically exploitable under present conditions.

Speculative deposits are those which have not yet been discovered. They may or may not be economically exploitable under the present conditions. The existence of these deposits can only be estimated on the basis of the application of past exploration and geological knowledge. The physical component of the operating environment is strictly an interpretation based on the experience and intuition of the individuals involved. It is subject to constant change as exploration procedes and new geological insights are gained.

The level of economic opportunity can be defined as the physical quantity of mineral output from all existing mineral deposits which can be produced at a cost-price ratio of less than one. For any given operating environment, this value can only be estimated, as the physical component of that operating environment is itself an uncertain value subject to the extent of geological knowledge and individual interpretation.

The existence of this economic opportunity is the stimulus of the entire system. It initiates the activities leading to the production of mineral supply.

Exploration will occur if the existence of economic opportunity is, in part, based on mineral deposits which are speculative. This activity discovers and deliniates new mineral deposits, thereby continually changing the physical component of the operating environment as deposits are moved from the speculative to the known class.

It must be emphasized that the term "exploration" as used in this study refers to the search for new mineral deposits outside the immediate environment of operating mines. This is sometimes referred to as "grassroots exploration" in the literature. The search for areas of mineralization within operating mines is not considered exploration for the purposes of this study, and is discussed below as "extending reserves".

Exploration involves an element of risk in two ways. Firstly, the existence of speculative deposits is not assured. If they do exist, they may not be discovered through the exploration program. Secondly, if a discovery of mineralization is made, it may not be economically exploitable under prevailing economic conditions. Both of these possibilities make risk an important factor in assessing the activity of exploration.

The extent of an exploration program is dependent on the on-going results. As new geological insights are gained, and the physical component of the operating environment changes, the economic opportunity which had initiated the exploration activity in the first place may disappear and the activity will cease. If the economic opportunity continues to exist as more geological insights are gained, the exploration will continue to a point where enough information has been gathered to make a rational decision regarding the development of the discovered deposits. The development of new productive capacity and subsequent mining will occur if the cost-price ratio of producing from the deposit over a relevant time period is believed to be less than one.

A certain amount of risk is involved in the development of new productive capacity because neither the cost-price ratio nor the exact physical nature of the deposit can be known with precision at the time the decision must be made.

A second type of activity initiated by the existence of economic opportunity is the assessment of known undeveloped deposits. The feasibility of developing known deposits is constantly being re-assessed as the level of economic opportunity changes. This re-assessment will lead to a decision regarding the development of the deposit. As in the assessment of new discoveries, development and subsequent mining will occur if the cost-price ratio is felt to be less than one over a relevant time period. Development risks are again associated with this activity.

Mining is the central activity in the mineral supply system whether stimulated directly or indirectly through preliminary exploration and development.

The existence of economic opportunity stimulates the continuation of mining operations in mineral deposits which are developed. This is a relatively low risk activity because the producing portions of mineral deposits are usually well explored and defined, and the costs of mining are known from past experience.

Mining will take place only as long as the mineral deposit can be mined at a cost-price ratio of less than one in the long run.* The size of the orebody may change over time as the economic component of the operating environment changes. In some cases, the lowering of commodity prices may force an end to mining operations

* In depressed periods, some mines may continue to operate with a cost-price ratio below one. This is, however, strictly a short run situation.

as the ore becomes sub-economic. A recovery of prices may induce a resumption of activity as the orebody will again be economic, if the development is left intact.

In some instances, factors other than economic ones come to bear on the closure decision. The economy of the mining community and the livelihood of the people dependent on the industry is often at stake in such decisions. These factors may result in pressure on the company to continue producing beyond the point where purely economic considerations would suggest closure.

As ore is mined out, the delineated portion of the mineral deposit is depleted. This leads to another important activity closely related to mining, the extension of reserves.

Reserves are that part of an orebody which can be mined without further delineation. Reserves include what is referred to as proven or measured reserves in some literature.

There is no economic justification for the detailed study of an orebody too far in advance of its date of exploitation. This would tie up capital from which there is no return until the ore is mined. At present, there is no way of knowing whether that part of the deposit will even be considered mineable under the uncertain future economic conditions. If it is, the present value of the return approaches zero if the lead time is in excess of about twenty years. However, a certain amount of delineation must be done in advance of production in order to plan operations effectively. Most mining companies find a balance between these two effects and define approximately fifteen to twenty years supply of ore at the present production rate. (McDivitt, 1957)

As the reserves of developed mineral deposits are mined out, new reserves must be found to replace them and maintain the desired supply level for future production. The activity of delineating new reserves from developed mineral deposits is referred to as extending reserves.

It is important to note the distinction between this activity and the activity of exploration discussed above. Although both activities involve the search for new ore and, for this reason, are not distinguished by some, a basic theoretical distinction has been made for the purposes of this study. Expenditure on extending reserves is considered to be part of the cost of mining the deposit and is closely related to the mining activity. This activity will cease once the deposit nears exhaustion. Exploration is an on-going process, not directly related to mining. Exploration expenditure is considered to be capital investment necessary for the long term survival of the industry. In more practical terms, exploration is considered to have ended once the decision to develop a particular deposit is made. Once the development decision has been made, the activity of searching for new ore can be considered as extending reserves.

Extending reserves usually occurs simutaneously with mining. However, complete delineation may occur prior to production when the mineral deposit is relatively small and easily outlined. Also, when the mineral deposit has been mined extensively and is nearing exhaustion, replacements for mined out reserves may not exist and the mine is eventually closed or abandoned.

The final activity in the mineral supply system is the processing of mine output. In this stage, mine output is converted into various forms of a more concentrated product. The processing stage can include various combinations of milling, smelting and refining techniques depending on the particular ore and product involved.

An important aspect of this system is the effect of time lags on the pattern of development of new productive capacity. The time lag between the initial stimulus and the first production may be several years in those cases where mineral supply is produced through a sequence of activities involving exploration and the development of new productive capacity. By this time, the economic opportunity which initiated the process in the first place may no longer exist due to subsequent changes in the operating environment. Conversely, a newly existing economic opportunity may not be manifested as mineral supply for several years due to the same time lag in the development process. This time lag makes the system insensitive to short term fluctuations although mineral supply is directly related to economic opportunity in the long run. A market equilibrium is difficult to attain due to this effect and the cyclical nature of the system. Price fluctuations are common, and development tends to occur in periods of high prices only. This creates an irregular pattern of development which tends to be self-perpetuating. Small scale changes in world demand can, in this way, set off amplified fluctuations in commodity prices and the corresponding irregular pattern of development. This tends to continue even if world demand stabilizes.

The Manitoba Mineral Supply System

An important modification must be made when applying the world mineral supply system, as outlined above, to a small, geographically defined part of the total world mineral industry, such as the Manitoba mineral industry. If the mineral output of that particular part of the total world industry is sufficiently small relative to total world output, that part can be considered a perfect competitor in the economic sense. This part of the industry is then a price taker and has no influence on the world market equilibrium position. This would eliminate the link between mineral supply and the operating environment, making the process linear as opposed to cyclical. This is assumed to be the case for the Manitoba mineral industry. The Manitoba mineral supply system is illustrated diagramatically in Figure 2.

The Role of Exploration Expenditure in the Mineral Supply System

Exploration expenditure is one of many expenditures involved in sustaining the activities of the mineral supply system. It can be regarded as a component of the total cost of production of mineral supply.

The total cost of production can be divided into fixed costs and variable costs, using the conventional economic distinction.

Fixed costs or capital expenditures are the costs associated with developing productive capacity. These costs are fixed in the sense that they are sunk costs which cannot be changed in the short run no matter what the level of production is. They can vary in the long run as they are sensitive to on-going exploration results and the level of economic opportunity.

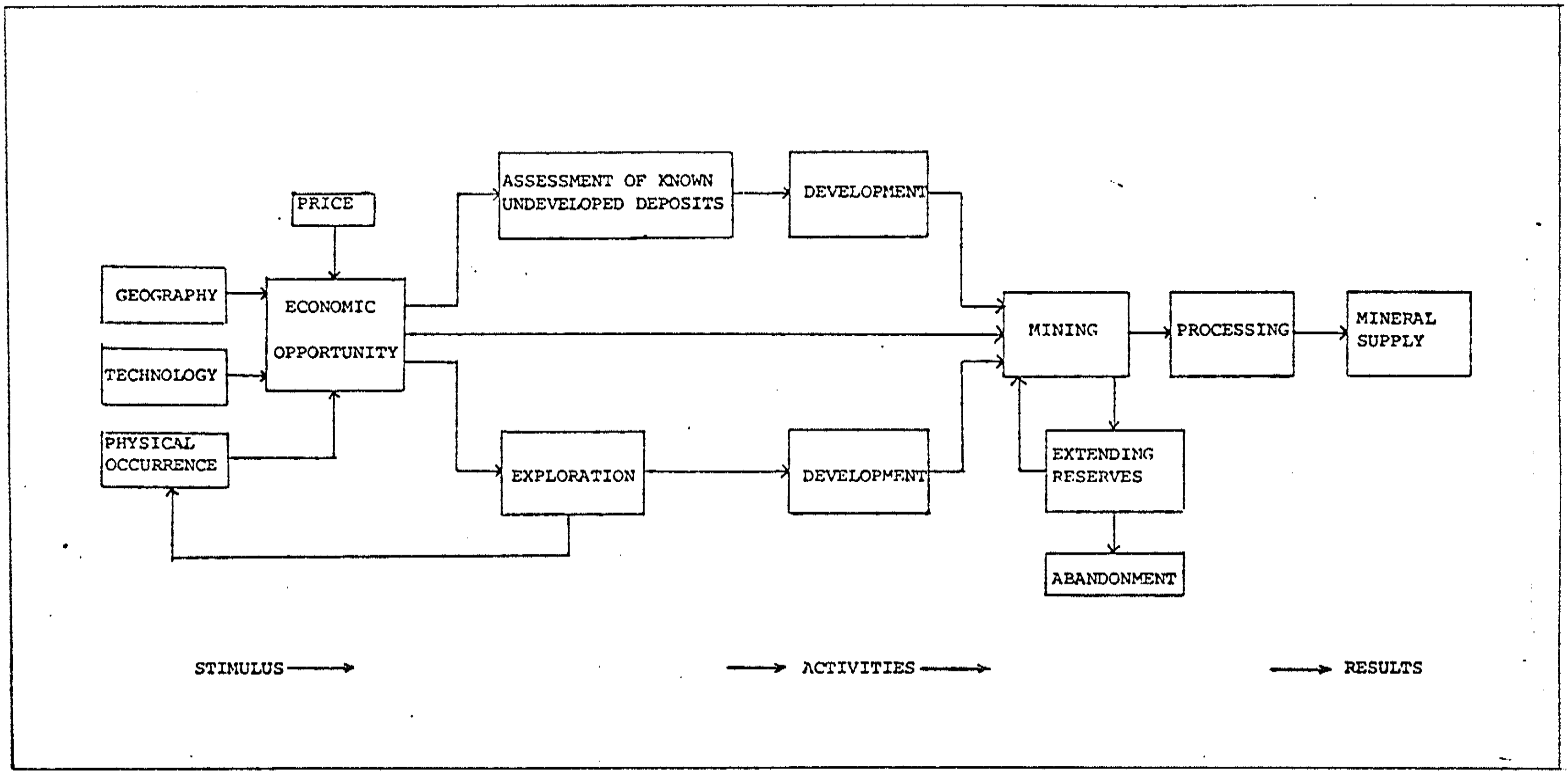

Figure 2: The Manitoba Mineral Supply System

Included in the fixed costs are the costs of exploration as this is a necessary first step in the development of new productive capacity.

Variable costs or operating costs include the cost of actually mining and processing the ore once the productive capacity has been developed. Variable costs are directly related to the level of output, and can range in the short run from zero, if nothing is produced, to a maximum value determined by the capacity limitations of the operation.

Included in variable costs are the costs associated with extending reserves once a mineral deposit is in production, since this activity is directly related to the level of mining output.

Figure 3 illustrates the role of capital in the mineral supply system. Exploration expenditure is one part of the total capital expenditure involved.

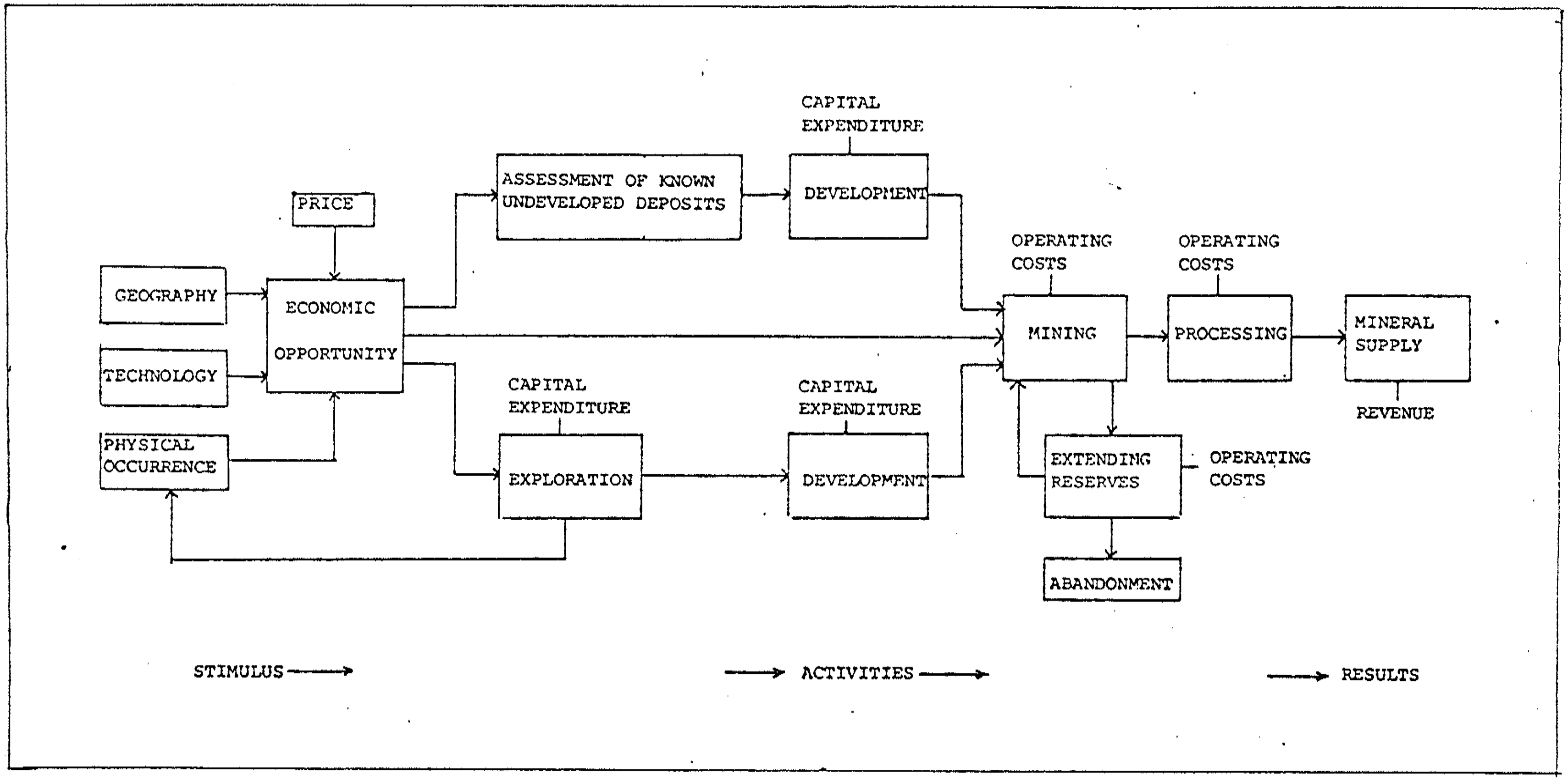

Figure 3: The Role of Capital in the Manitoba
Mineral Supply System

CHAPTER II

REVIEW OF THE RELATED LITERATURE

The literature relating to this study covers a range of topics pertaining to the mining industry. In this review, some of the most relevant pieces have been chosen to provide a representative sample of the related literature. This sample has been divided into four groups: literature relating to the study in a general sense; literature relating to forecasting in the mineral industries; literature relating to resources and reserves; and literature relating to exploration.

General

Literature relating to the study in a general sense covers topics such as economic theory relating to minerals, public minerals policy, and mineral planning studies.

Perhaps the most comprehensive single work dealing with the theoretical aspects of the economic analysis of the mineral industries is the text Economics of the Mineral Industries (Vogely, 1976). This text consists of a series of articles by specialists grouped into five major subject areas. These are:

1. The economic role of minerals.
2. Central problems arising in the analysis of resources.
3. Functions and structure of the minerals industry.

4. Public policy in the minerals industry.
5. Minerals and man's future.

The stated objective of this text is to help bridge the perceived gap between professionals involved in the technical and economic aspects of the industry. The emphasis is on the integration of economic concepts and theories with the technical realities of the mining industry.

The article within the text entitled "Mineral Supply as a Stock" (Brooks, 1976), is of particular interest to the theoretical aspects of this study. In this article, the concept of mineral supply is examined, first from a geologic, and then from an economic viewpoint. The geologic and economic basis are then integrated in a two-diminsional resource classification scheme. Ore reserve classification systems are then discussed with reference to both the geologic and cost-price dimensions of resources.

The article also covers the topic of the estimation of reserves and resources. Again, the two-dimensional nature of mineral resource evaluation is emphasized in a discussion of the extension of reserves along the geologic and cost-price dimensions.

The relationship between mineral stocks and productive capacity is also discussed in order to introduce some dynamic considerations to the essentially static concept of mineral stock.

The treatment of the subject matter is theoretical. The concepts developed provide a theoretical basis upon which approaches to practical problems within the mining industry can be developed.

Manitoba's minerals policy, although not directly under consideration in this study, is an important component of the exploration environment. This matter has been dealt with in some detail by many studies. The Report on Natural Resources Policy in Manitoba (Kierans, 1973) (the Kierans Report) reviews historically Manitoba's mineral policies, and analyses in depth the concept of economic rent as applied to the Manitoba minerals industry. The report concludes that private mining companies are receiving significant economic rents in Manitoba, and states that these rents should accrue to the owners of the resource- the people of Manitoba. On this basis, recommendations for change are presented.

The Kierans Report is critically reviewed in An Analysis of the Kierans Report (Hedlin, Menzies & Assoc., 1973). This report consist of two books. Book one is an analysis of the tables of figures used to substantiate the conclusions reached in the Kierans Report. Book two is an in depth review of some of the major topics discussed in the Kierans Report. This report uses additional confidential information to re-evaluate the figures used in the Kierans

Report, and questions the existence of the economic rents described in the Kierans Report.

A third important work dealing with Manitoba's minerals policy is the Report of the Task Force on Manitoba's Minerals Policy. An outline of the historical development of mining in Manitoba is presented along with a discussion of the geology and important mineral occurrences of the province. Individual producers are listed and the nature of their operations is described.

Acts and regulation governing the mining industry are outlined followed by discussion of taxation, both federal and provincial. Some of the information presented here may not be accurate, as changes in this area have occurred since the publication of the report.

Economic aspects are dealt with, first through a product by product discussion of mineral markets, and then through a detailed economic analysis of the nickel and copper industries of Manitoba.

The findings are summarized and mineral policy options are presented, followed by conclusions and recommendations.

Although the primary purpose of the report is to investigate questions relating to provincial minerals policy, the report contains a great deal of information describing the details of the Manitoba minerals industry.

An important piece of literature which provides a framework in which data essential to the consideration of minerals policy can be generated is Economic Characteristics of Base Metal Supply in Canada (Mackenzie & Bilodeau, 1976). The Canadian base metal mining experience is examined over a relevant historical period in order to determine the economic characteristics relating to the costs and revenues of exploration, development and production. The assessment is made on a pre-tax basis as one of the objectives of the study is to provide base data for the determination of revenue sharing arrangements between industry and government.

The study also does the assessment for specific regions and provinces within Canada and discusses some of the variations. It is concluded that the overall economic characteristics are reflecting the diminishing geological returns over time inherent in the mineral supply process.

Relating more specifically to this study, but still on a general level are numerous pieces dealing with planning in the mineral industries. An overview of the problems associated with planning mineral resource development is presented in "Resource Development, Regional Planning, and Ore Reserves" (Watson, 1977). This paper presents socio-economic objectives which mineral development should strive for and stresses the need for effective regional planning to realize these objectives. Problems relating to the incompatability of governmental and industrial planning objectives are then discussed. These problems often result in barriers to the free flow of information between these two parties. Ore reserve estimates are singled out as an important data input to the planning process which is not normally available on account of these problems. The paper concludes that more co-operation between industry and government is necessary if effective regional planning is to occur. More specifically, the development of widely accepted standards for the classification of ore reserves is necessary inorder to facilitate the flow of information required for this co-operation.

A specific mineral planning study which is particularly relevant to this study is the Mineral Areas Planning Study (MAPS) (Energy, Mines and Resources Canada, 1975). This report is part of a series prepared to contribute to the formulation of Canadian minerals policy. The report deals with five major questions:

1) What are the forecast domestic and export requirements for key metallic mineral commodities mined in Canada?

2) What is the forecast availability of each of these minerals to the year 2000?

3) What quantities of additional reserves will have to be generated in Canada and when to meet these requirements?

4) In what regions of Canada will mineral productive capacity expand or contract?

5) What efforts could be directed towards developing mineral potential?

Questions one, two, and three relate directly to the objectives of this study. The methodology used in the MAPS study provided a framework in which the general methodology for this study was developed. This study will take one subproblem of the MAPS study (exploration expenditure) and apply it in a Manitoba context.

A series of maps showing mineral deposits, mineral potential, and flows of products are also presented. Since the MAPS study involved a Canada-wide aggregation of data, the conclusions reached do not necessarily apply to Manitoba.

Adapted from parts of MAPS is <u>Metal Mining in Canada 1976-2000</u> (Martin, Cranstone, and Zwartendyk, 1976). This report deals with only forecast exploration and capital investment and labour requirements of the Canadian mining industry from 1976 to 2000. Although the figures used are identical to those used in MAPS, it is emphasized that forecast requirements for metal output have been revised downward since the publication of MAPS. Because of this, it is believed that the estimates derived in the study are "at most" estimates. As in MAPS, it is concluded that the exploration and capital investment and labour requirements of the Canadian mining industry between 1976 and 2000 are well within the reach of Canada.

Forecasting

A general discussion of trends in the growth of the Canadian mineral industry is presented in Mineral Industry Trends and Economic Opportunity (Energy, Mines and Resources Canada, 1976a). This publication is intended as an aid in determining mineral development patterns with the emphasis on Canadian development objectives. Events since 1973 and their effects on the observed trends are considered in detail.

The concept of life cycles as applied to the Canadian mineral industry is discussed along with a historical review of mineral production in Canada.

Factors affecting the growth trend of mineral output are then discussed. These include economic growth trends, population growth trends, intensity of mineral consumption, and changes in the international trading system. The position of the minerals industry in the overall Canadian economy is also examined.

Growth options for Canadian mine output are presented and the economic implications of each are discussed. Policy implications for the realization of the growth options are examined for all stages of the mineral supply system.

It is concluded that a viable target for the growth of mine output is somewhere between slow and moderate growth. The actual rate will depend on the particular policies chosen. Economic opportunities also exist in the secondary stages of mineral production. Increased benefits to the economy can occur through diversification of the mineral industry in Canada without an actual increase in mine output.

A discussion of forecasting techniques relevant to the mineral industries is included in the text, Economics of the Mineral Industries. In "Projecting and Forecasting Methods" (Morrison, 1976), general methodologies for application to practical problems are outlined. Four important methods are discussed in detail.

Trend extrapolation is the simplest technique, with the only influencing variable being time. Predictions are made, based on the assumption that past continuities will influence the future in a predictable manner.

Trend correlation is a further refinement of trend extrapolation. Here, several inter-related variables influence the dependant variable.

Intuitive forecasting involves the use of knowledge and judgement to make predictions without the mathematical rigor of the first two techniques. It is very important where information on past trends is limited.

Contingency forecasting is prediction on the basis of assumed states or scenarios. This method provides an opportunity to use judgement and knowledge to avoid the rigidity of trend projection. It can be used to define ranges of expected values based on extremes of related variables.

The method to be used in this study is a variation of contingency forecasting.

Reserves and Resources

An introduction to the concept of reserves as generally used in the mining industry is provided in the article, "The Meaning of Published Ore Reserve Figures...an Economic Interpretation" (McDivitt, 1957). This article discusses some of the factors involved in the determination of exactly what the proven ore reserve figure will represent. The specific amount of ore to be proven is determined by the interplay of two factors. The uncertainty of future economic conditions and the low present value of revenue from production in the distant future combine to influence mining companies to prove up as little ore as possible for future production. On the other hand, the need for effective planning of investment, development, and production makes the knowledge of some level of future ore supply necessary. A compromise between these two influences usually determines the nature of the published ore reserve figure.

The effect of changes in economic conditions on ore reserve figures is also discussed. Significant changes in ore reserves can occur without any work in the mine, as economically marginal ore is either included or excluded from ore reserve figures, depending on the movement of commodity prices and mining costs.*

The concepts developed are then applied to new, old, and mature mines. The article concludes that there is no relationship between proven reserves and total reserves.

The publication What is Mineral Endowment and How Should We Measure It? (Energy, Mines, and Resources Canada, 1972), further analyses the concepts of reserves and resources. Problems and inconsistencies in the evaluation of mineral endowment arising out of the lack of a consistent set of concepts and terms applicable to the problem are emphasized. The two-dimensional nature of resource classification is emphasized and the varying spheres of interest of the professionals involved in mining within these two dimensions are discussed.

The publication concludes that any evaluation of mineral endowment must:

1) Go beyond proven reserves.
2) Be divided into categories of certainty of existence.

* This effect is less important in Manitoba where most orebodies have distinct rather than gradational boundries.

3) Be further sub-divided into categories of certainty of economic exploitation.

An illustration of a scheme for such an evaluation is also presented (see Figure 4).* It is emphasized that widespread adoption of such a theoretical framework is necessary if the current ambiguity in the measurement of mineral endowment is to be avoided in the future.

An applied methodology for one type of mineral endowment evaluation is presented in A Quick-Look Method for Monitoring the Adequacy of Metal Supplies from Canadian Mining for Domestic Needs (Energy, Mines and Resources Canada, 1976b). The methodology described takes mine by mine information on reserves and production levels and future domestic requirements to calculate a "basic timespan". This is essentially the time that will elapse before domestic requirements exceed projected mine output for a particular metal. The central idea is to monitor this "basic timespan" over time in order to observe any changes in the supply system for that metal. Further in-depth analysis may be warranted if significant changes are observed. A constant "basic timespan" over time would suggest that the supply system is dynamic, and that exhaustion of economically mineable deposits of that particular metal is not immenent.

* See Appendix 2 for other resource classification schemes.

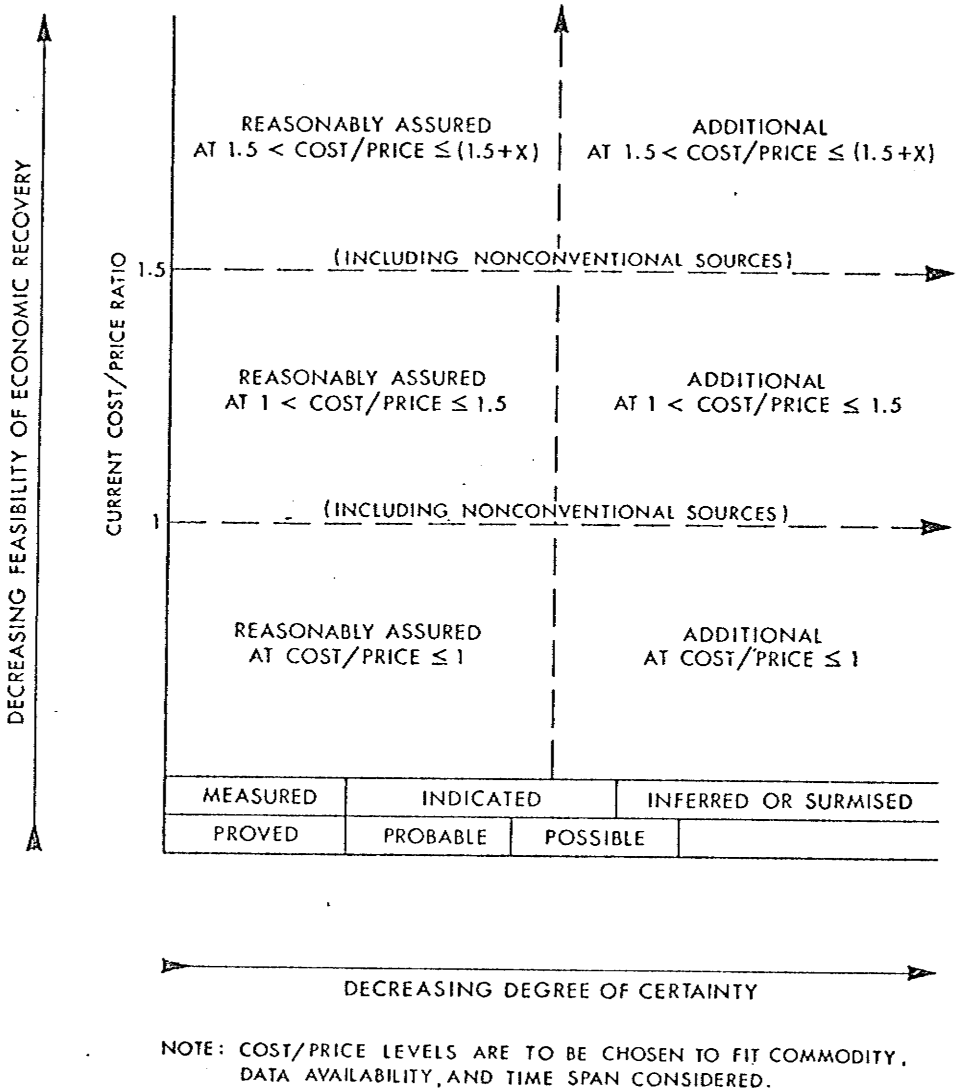

Figure 4: Classification of Resource Endowment

Source: Zwartendyk, 1972.

This methodology applies the concept of the flow of resources along two dimensions (as developed in the previous article) to a practical problem. For illustrative purposes, the methodology is applied to the analysis of the copper, zinc, and lead supply systems of Canada.

Two publications from Energy, Mines and Resources Canada deal specifically with quantitative descriptions of the mineral resources of Canada.

Canadian Reserves of Copper, Nickel, Lead, Zinc, Molybdenum, Silver and Gold (Energy, Mines, and Resources Canada, 1977) is a compilation of quantitative information on ore reserves in Canada as of January 1, 1977. The data sources were company publications, industry journals, production and revenue reports received by the federal government, and mining company officials. Some subjective judgements by commodity speciatlists within the federal government were also incorporated where the available information was not too clear.

Ore reserve information is presented for each commodity on a mine by mine basis with provincial and national totals. Included as ore reserves were all materials reported as either measured or indicated ore reserves as well as material interpreted to be in these classes by the commodity specialists. In addition to ore reserves in producing mines and deposits being developed for production, ore reserves in undeveloped deposits for which, by the judgement of commodity specialists, production is foreseen, are also presented.

Undeveloped deposits are analysed in more detail in A Survey of Known Mineral Deposits in Canada that are not Being Mined (Annis, Cranstone, and Vallee, 1976). This publication is a compilation of known mineral deposits in Canada not presently producing or announced for production. Included are both deposits which are considered to be economically exploitable some time before the year 2000, as well as deposits considered unlikely to become economically exploitable before the year 2000.

For each deposit, a brief summary of the geology, exploration and development history, published tonnage and grade, and comments on specific economic or technical problems hindering the development of that deposit are presented.*

The stated purpose of the compilation is to provide a reference for use in regional planning and development, and as a guide towards the solution of the problems hindering development.

* Since the publication of this report, two addendums with additional deposits have been published.

Exploration

The literature relating specifically to exploration is found mainly in mining journals and usually deals with the individual firm's viewpoint. An overall view of the exploration process, which is more relevant to this study, is presented in the following studies:

In a paper entitled "Are Ore Discovery Costs Increasing?"(Cranstone, 1972) the behavior of ore discovery (exploration) costs in Canada from 1946 to 1971 is examined. Several methods of evaluating an ore discovery success rate are presented. The particular method chosen for the analysis closely parallels the method to be used in this study.

Problems in obtaining high quality data relating to exploration success rates are discussed in some detail. Certain mineral commodities are excluded from the analysis, and quite often the associated exploration expenditures could not be excluded due to the aggregative nature of the statistics available.

Exploration programs often span over many years, and the actual date of discovery used will often cause distortions in the relationship between the expenditure and discovery rate.

Much of the data available is based on response to questionaires. Distortion may occur due to variations in the interpretation of the questions asked. Also, a major change in the form of the questionnaire occured in 1967 which may cause problems in correlating data from before 1967 with data from after 1967.

With these problems in mind, an analysis of the data is made to determine the trend of ore discovery costs. It is concluded that the costs are increasing, but the problems in the quality of the data preclude the possibility of more quantitative and specific conclusions.

The analysis and discussion of problems relating to data provide a framework for developing a specific methodology for analysing the trend in ore discovery costs in Manitoba.

The methodology used in this paper was also used in the Mineral Areas Planning Study.

Two other papers, also dealing with the question of ore discovery costs appear in the Canadian Mining and Metallurgical (CIM) Bulletin.

In "Exploration Expenditure, Discovery Rates and Methods" (Derry, 1970) information on Canadian exploration expenditure, major discoveries and exploration methods responsible for the discoveries is presented. It is concluded that the rate of exploration expenditure is rising and that the ratio of exploration expenditure to production value must be increased if sufficient reserves for the future are to be provided.

In "Probability of an Exploration Discovery in Canada" (Roscoe, 1971) the data in the previous article is used to develop a probabilistic approach to analyzing exploration expenditure. It is calculated that the probability of making a discover, assuming a $30,000 exploration expenditure (based on 1968 dollars), has decreased tenfold between 1951 and 1969. This paper illustrates how the problem can be approached in a different way, and adds new meaning to the data presented in the previous paper.

The individual firm's viewpoint is examined in "An Industrial Analysis of Exploration Activity" (Going, 1973). The analysis was done with data obtained from Statistics Canada surveys of mining companies.

The relationships between the level of exploration activity and size, the expenditure behavior, and the financing methods are discussed for various types of companies.

The study concludes that, due to economics of scale in new exploration techniques, the concentration of capital among middle and large sized companies, and increased market control through integration, the trend towards concentration of exploration expenditure in the hands of a few large companies will continue at an increasing rate.

CHAPTER III

METHODOLOGY

General

The approach to the stated problem is to simulate the mineral supply system for the time period under consideration using varying sets of assumptions regarding the operating environment and exploration success rates.

In order to facilitate this, a Fortran Watfiv computer program designed to perform the numerical analysis has been developed. The program inputs basic information regarding the presently known mineral resource base and productive capacities, along with assumptions regarding future economic opportunity, development and possible extensions of known mineral deposits, reserve-capacity relationships, and exploration success rates. The program uses this information to estimate future exploration expenditure levels.

The program has been run a number of times, using the same basic reserve information, but different assumptions in each case. In this way, each estimate of future exploration expenditure is qualified by the assumptions used in the analysis. A range of what are considered to be reasonable assumptions have been used to define a range of probable answers.

It must be emphasized that the real answer does not necessarily lie within this range even if all the assumptions used turn out to be accurate. Due to the risk and uncertainty involved in exploration, any given expenditure does not guarantee success. However, estimations of future success rates are essential in estimating future expenditures. These estimations of future success rates can be based on the statistical concept of expected payoffs.

It is assumed that the future exploration activity in Manitoba will be of sufficient scale to ensure that the expected success rate will have a high probability of being a reasonable estimator of the actual success rate in mineral exploration. However, the results will still remain as statistically expected results and must be interpreted as such.

The basis of the analysis is a yearly assessment of economic opportunity, existing productive capacity, and possible production from known undeveloped deposits. It is assumed that production from new, as yet undiscovered, deposits will only occur if the economic opportunity is greater than the productive capacity of known developed and undeveloped deposits for which development is foreseen.* This production from new sources will be equal to the difference between economic opportunity and the productive capacity of known deposits. Production from

* This assumption is used to simplify the problem. In reality, production from newly discovered deposits may occur before production from known deposits if the new discoveries are of sufficient grade.

new deposits will then be expressed as discovery requirements using a given development time delay and reserve-capacity ratio. Using an appropriate exploration success ratio, these discovery requirements can be expressed in terms of required exploration expenditure.

A more detailed account of the methodology must be preceded by a discussion of the derivation and meaning of the variables involved.

Base Economic Opportunity

As defined, the level of economic opportunity is the physical quantity of mineral output from known and speculative mineral deposits which can be produced at a cost-price ratio of less than one. This value can be expressed for each metal for each operating environment.

The base economic opportunity will represent the economic opportunity existing in Manitoba in 1976, the first or base year of the period under study. Using actual production figures to determine this value presents many problems as, in the mining industry, wide variations in the actual output levels from year to year make the selection of one particular year as a base very unrealistic.

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For the purposes of this study, the base economic opportunity for each metal is assumed to be equal to the summation of the productive capacities of each individual mine producing that metal in 1976. The matter of choosing a value to represent the productive capacity of each mine is discussed later. This value is expressed in terms of thousand short tons of contained metal in ore production for each metal. This approach avaids the introduction of complications resulting from the consideration of metal recovery factors.

Growth of Economic Opportunity

It is assumed that, in the past, the level of mine output or mineral supply has been equal to the level of economic opportunity at any given time. Therefore, the growth trend of mine output can be used to evaluate the growth trend of economic opportunity.

The growth trend of mine output in Manitoba is difficult to analyze due to the limited scale of the mining industry in Manitoba. This trend is distorted by fluctuations caused by production decisions made by individual major producers.

It is assumed that the growth trend of mine output in Manitoba parallels that of Canada as a whole. The growth trend of the Canadian mineral industry along with future possible growth options are presented in Figure 5. These growth options which also represent growth of economic opportunity are assumed to be applicable to Manitoba. These growth options are discussed in more detail below:

i) High Growth (8%)

This growth rate is representative of rapid exansion as experienced by the Canadian minerals industry from the mid forties until the early sixties. Future expansion at this rate would appear unlikely in light of the expected rates of growth in world consumption and the associated marketing and competetive problems.*

ii) Moderate Growth (4%)

This growth rate is representative of steady growth as experienced by the Canadian minerals industry from the early sixties to the early seventies. Further expansion at this rate would mean a sharp upturn in current activity. This rate is assumed to be close to the maximum growth rate in economic opportunity which can realistically be expected to occur during the period under consideration.

* In a limited area, such as Manitoba, high growth can occur if there is a sharp rise in demand for the region's major product, or a large discovery of exceptional grade is made.

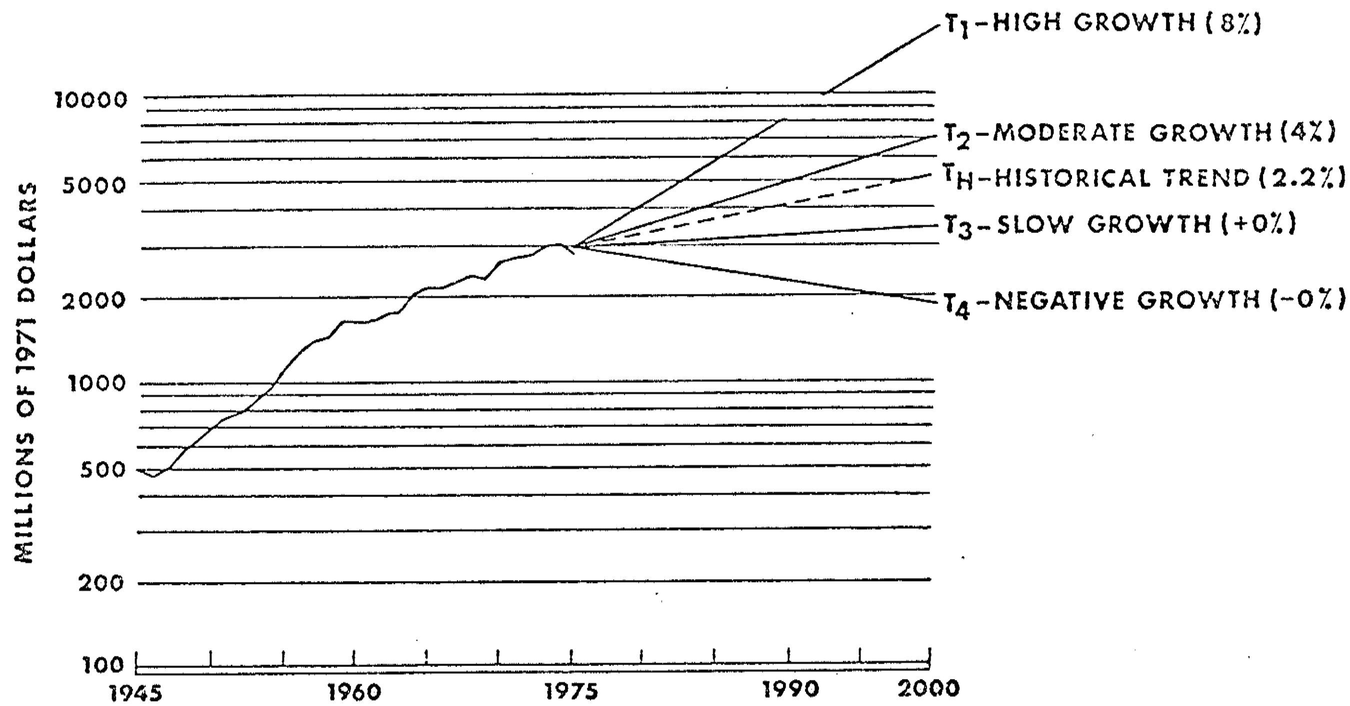

Figure 5: Growth Options for Mine Output

Source: Energy, Mines, and Resources Canada, 1976a.

iii) Historic Trend (2.2%)

This growth rate is derived from data on the growth of Canadian minerals output between 1945 and 1975 as presented in Figure 6. It is assumed that this growth rate is an approximate indicator of the historic trend in Manitoba as well. Present indications are that growth will tend to be somewhat below this historic trend as the overall tendency is towards a continually decreasing rate of growth over time.

iv) Slow Growth (+0%)

This growth rate represents a generally constant level of mine output with little expansion and development. Current indications suggest that the long-term situation may be one of slow growth where the growth rate will be near zero, but positive.

v) Negative Growth (-0%)

This growth option represents a declining level of output over time. This situation could arise from a sharp decrease in world demand for mineral commodities and the corresponding weakening of commodity prices, or from a loss of competetive position in the world market. Depletion of the mineral resource base can also contribute to a decline in economic opportunity. Negative growth is recognized as a possibility for the mineral industry in Manitoba, although it will not be considered for copper and zinc production in the analysis.

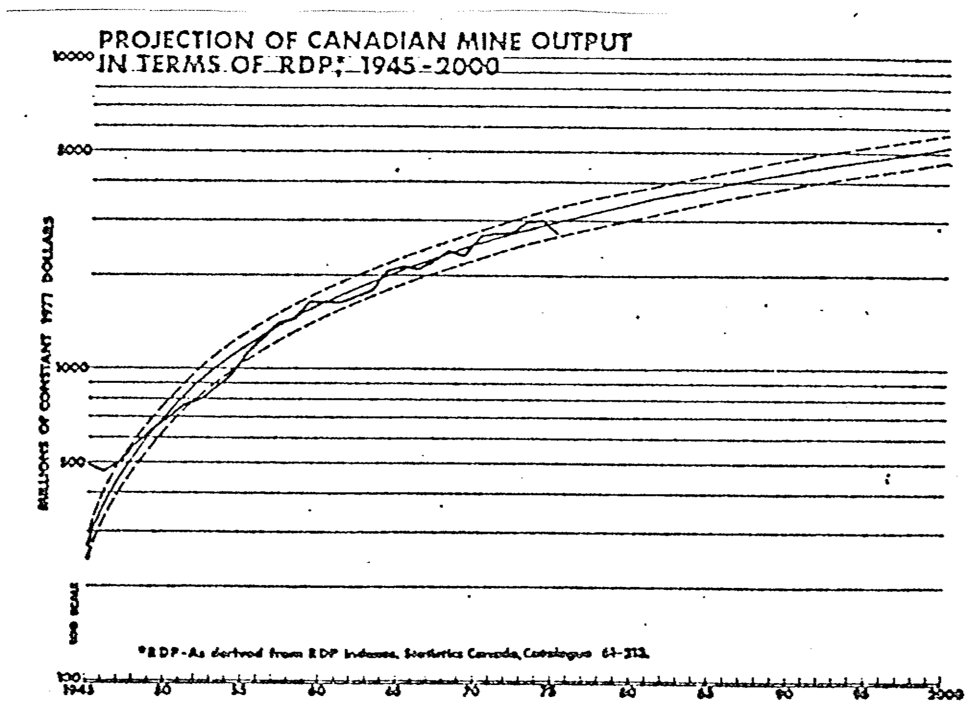

Figure 6: Projection of Canadian Mine Output

Source: Energy, Mines, and Resources Canada, 1976a.

Growth of economic opportunity for each metal consists of a set of thirty values, each representing the growth of economic opportunity during each corresponding year. It is expressed as a proportion of the previous year's economic opportunity. The specific growth rates to be used in the analysis are discussed later when the individual scenarios are developed.

Production From Proven Reserves of Presently Operating Mines

The annual production (in terms of short tons of contained metal mined) of any given mine is dependant on a number of factors including the rated capacity, development activities, commodity prices, labour relations, and availability. The actual level of production for any given mine will vary from year to year in a pattern determined by the prevailing economic conditions and technical considerations. This pattern is difficult to predict.

For the purposes of this study, the productive capacity of the producing mines is expressed in terms of thousands of short tons of contained metal in annual ore production. One value for each metal for each mine is used to estimate the annual production throughout the period under consideration. This value is chosen subjectively, and based on the past production record, rated productive capacity, and anticipated capacity expansions.

The number of years that any particular mine will be producing from proven reserves (as of 1975) is referred to as the proven reserves life index. This value is equal to the total proven reserves divided by the annual productive capacity. This is not necessarily equal to the anticipated life of the mine, as reserves are being added to the proven category continuously as the mine is producing. Although this value does not relate directly to the real life index of the mine, it does indicate the planning horizon of the company involved, and may become more significant as the mine nears exhaustion.

Production from proven reserves of presently operating mines for each metal consists of a set of thirty values each representing the summation of the productive capacities of all Manitoba mines producing that metal in the corresponding year. It is assumed that production will continue at the chosen productive capacity for a number of years equalling the proven reserves life index.

This variable has little significance as it does not consider the process of extending reserves. It is included to illustrate the planning horizon of the companies involved.

Production from Extended Reserves of Presently Operating Mines

This variable differs from the above in that it represents a realistic estimate of what the mines will be producing during the period under consideration by taking into account the process of extending reserves. The productive capacities for each mine is the same as in the previous variable, but a real life index instead of the proven reserves life index is used to estimate the life of the mines.

The real life index of any particular mine refers to the number of years that the mine will be producing from its total reserves. If the rate of production is constant over time, the real life index is equal to the total reserves divided by the productive capacity. For the purposes of this study, this is assumed to be the case.

The estimation of the total reserves of any particular mine in terms of contained metal presents difficulties. Any quantification of ore reserves is dependant on both the geological and economic dimensions of the mineral deposit. The geologic dimension, or extent of knowledge concerning the physical nature of the mineral deposit is usually expressed as a division of ore reserves into three categories or classes; measured, indicated, and inferred reserves.* The distinction is made on the basis of the degree of certainty of existence. Quantitative descriptions of reserves in the inferred and indicated classes involve large margins of error. This uncertainty makes the utility of total reserve estimates questionable.

* These categories of ore reserve classification are elaborated upon in E.M.R. Interim Document "Departmental Terminology and Definitions of Reserves and Resources", January 1975.

The economic, or cost-price, dimension of a mineral deposit is usually manifested as a minimum cut-off grade which is determined by the mining method being used and the prevailing cost-price conditions. This cut-off grade combined with the geological knowledge of the mineral deposit defines the size of the total reserve.

Since the cost-price conditions are subject to continual change, the size of the orebody will not remain constant. This effect is more pronounced for certain types of deposits than others.

As a hypothetical example, a small, high-grade vein type deposit may have grades ranging from 2 to 4 percent metal within distinct veins of mineralized material. At the contact of the orebody with the host rock, the grade may drop from 3 percent in the mineralized zone to close to 0 percent in the host rock over a few inches. In this case, a change in the cost-price conditions which lowers the cut-off grade from 1.5 to 1.0 percent will not significantly affect the size of the total ore reserve.

With another type of mineral deposit, the situation may be different. As a hypothetical example, a large disseminated type deposit may have grades varying from .1 to 3 percent metal. The deposit may contain 20 million tons of material grading between 1.5 and 3.0 percent metal, 40 million tons of material grading between 1.0 and 1.5 percent metal, and 60 million tons of material grading between .1 and 1.0 percent metal. In this case, the same change in the cut-off grade (1.5 to 1.0 percent) would increase the total reserves threefold from 20 to 60 million tons. Unlike the small vein type deposit or the massive sulfide type, the size of this deposit is sensitive to change in the cost-price conditions.

A total reserve estimate is an instantaneous evaluation which must be qualified by the prevailing economic conditions and the extent of geological knowledge. The ore reserve estimate to be used in this study must be based on the current state of geological knowledge and qualified by certain cost-price conditions. A problem arises in determining which cost-price conditions to use in the estimation as the period under consideration is 30 years in length. Significant variations in both mining costs and commodity prices can occur within a 30 year period.

For the purposes of this study, it is assumed that, despite short term fluctuations, current (1970-1976) economic conditions will prevail throughout the next 30 years, and that ore reserve estimates qualified by current cost-price conditions can be used to quantify the total ore reserves in known deposits which will be economically exploitable some time during the period under consideration.

Production from extended reserves of presently operating mines for each metal consists of a set of thirty values, each representing the summation of the productive capacities of all Manitoba mines producing that metal in the corresponding year. It is assumed that production will continue at the chosen productive capacity for a number of years equalling the real life index for each mine.

Production From Known Undeveloped Deposits

The decision of whether or not to develop any given mineral deposit to the productive stage is dependent on the current and anticipated economic conditions and the known size and grade of the deposit. The decision regarding which deposits will be brought into production and their corresponding productive capacities and year of opening must, for the purposes of this study, be made subjectively as insufficient information in this regard is available.

This variable is largely dependent on the growth of economic opportunity and therefore will be closely linked to it when individual scenarios are developed.

Production from known undeveloped deposits for each metal consists of a set of thirty values each representing the summation of production from all deposits in Manitoba not currently producing, but expected to be producing that metal in the corresponding year. This includes presently known, but undeveloped deposits.

Production From Known Sources

This variable for each metal consists of a set of thirty values each of which are the sum of production from extended reserves of presently operating mines and production from known undeveloped deposits in each corresponding year.

Production From New Sources

This variable, for each metal, consists of a set of thirty values which are the difference between economic opportunity and production from known sources in each corresponding year.

Reserve-Capacity Ratio

The developement of a certain productive capacity must be backed by a certain level of assured reserves. The reserve-capacity ratio represents the total ultimate reserves of a mine divided by the annual productive capacity. This value is, theoretically, equal to the number of years the mine will be in production. It also determines the specific relationship between production requirements and reserve requirements.

When estimating possible reserve-capacity ratios to be used in the study, the effect of deposit size and grade must be considered. Table 1. presents data on the size, grade and productive capacity of three hypothetical types of copper mines to illustrate this effect. * The important thing to note is that, although either three large, six medium, or ten small sized mines have a productive capacity of 135,000 tons of Cu/year, their total ultimate reserves and therefore, reserve-capacity ratios are not equal. The largest reserve-capacity ratio exists for mines described as medium sized (40.0), and the smallest is for those described as small sized (22.2). Therefore, the immediate discovery requirements, in terms of contained metal, would be a maximum if all new production were to come from medium sized mines. In this example, the medium sized mines will also have the longest life, continuing to operate until all the contained metal is mined out. The net effect is that long term discovery requirements are not affected by mine size and grade.

The mine size and grade do affect the rate at which the discovered metal is mined. The large reserve-capacity ratio of medium sized mines implies that the discovered metal will be mined at a slower rate that of a small or large sized mine. More contained metal must

* Although it is the case in this example, it should be noted that grade is not necessarily a function of size.

Table I: Relationships Between Metal Production Capacity and Required Metal Reserves in Hypothetical Copper Mines of Three Types (in million tons)

Number and Size of Mines	Lifetime Ore Reserves		Grade	Contained Metal	Production of Ore (annual)		Annual Metal Production
	Per Mine	Total			Per Mine	Total	
3 large	250	750	.5%	3.75	9.0	27.0	.135
6 medium	60	360	1.5%	5.40	3.0	9.0	.135
10 small	10	100	3.0%	3.00	1.5	4.5	.135

Source: Energy, Mines, and Resources Canada, 1975.

must be discovered initially to assure the needed productive capacity. This will affect the distribution of, but not the total exploration expenditure involved in the long run.

It is assumed that for new developments, the summation of all new reserves divided by the summation of all new productive capacity can be approximated by the reserve-capacity ratio of one hypothetical operation. This hypothetical reserve-capacity ratio will be assumed and used in the analysis.

For the purposes of this study, two types of mines applicable to the Manitoba industry have been hypothesized. They are described in Table 2. Large mines are representative of the large scale Manitoba operations such as Ruttan, Thompson, Birchtree, and Flin Flon. This type of mine has a hypothetical reserve-capacity of 40.0. Small mines are representative of most of the other operation in Manitoba. They have a hypothetical reserve-capacity ratio of 15.0.

Both these reserve-capacity ratios will be used in the analysis to illustrate the varying magnitudes and distribution of exploration expenditure attributable to differences in mine size and grade.

Table II: Relationships Between Metal Production Capacity and Required Metal Reserves in Hypothetical Manitoba Metal Mines (in million tons)

Number and Size of Mines	Lifetime Ore Reserves		Grade	Contained Metal	Production of Ore (annual)		Annual Metal Production
	Per Mine	Total			Per Mine	Total	
3 large	89	267	1.5%	4.00	2.22	6.67	.100
10 small	5	50	3.0%	1.50	.33	3.33	.100

New Discovery Requirements

It is assumed that the time lag between discovery and first production will be approximately five years. In reality, the actual time lag can vary considerably. The location of the deposit, the availability of development capital, metal market conditions, and the existing capacities of secondary processing facilities are some of the factors which determine the length of the time lag for each particular mine. A recent survey of Canadian mine development concluded that the average time lag was approximately six years. (Energy, Mines and Resources Canada, 1975)

Since expenditure requirements will be expressed as five year averages, the use of a five year time lag will imply that any discoveries in a given five year period will start producing in the next five year period. The actual time lag could be anywhere between one and ten years.*

New discovery requirements for each metal consists of a set of 25 values, each representing the total reserves required for discovery to ensure that the needed new productive capacity will be developed five years later in each corresponding year. This value will be calculated as production from new sources times the reserve-capacity ratio.

* This time lag makes it necessary to forecast production to the year 2005 even though exploration expenditure is being forecast to the year 2000.

'Value' of New Discovery Requirements

The use of the term 'value' is not intended to impart economic meaning to the discovery requirements. Rather, it is a convenient method of bringing individual commodity requirements to a common denominator of dollars so that they can be summed to obtain total discovery requirements. This aggregation is made necessary by the polymetallic nature of many mineral deposits. Thus, 'value' as used here is, in reality, a physical, not monetary quantity.

Value of discovery requirements for each metal consists of a set of 25 values, each representing the 'value' of new discovery requirements. This will be calculated using historically representative metal prices.

Total Value of New Discovery Requirements

This variable is a set of 25 values, each representing the summation of the individual commodity values of new discovery requirements for each corresponding year.

Base Exploration Success Ratio

In order to relate discovery requirements to exploration expenditure, the effectiveness, in terms of discoveries made, of exploration expenditure must be known. The specific relationship between exploration expenditure and resulting discoveries is an integral part of the analysis.

The success of an exploration program is dependent on expenditure, the technology and scientific knowledge available, the expertise of the individuals involved, and an element of chance. These variables are not totally independent of each other. Expenditure is often dependent on technological and scientific breakthroughs, while the expertise of the individuals involved is often dependent on expenditure.

Technological and geological breakthroughs are important in analyzing exploration success, particularly over a short period of time. For example, the technological development of portable ground geophysical equipment initiated a sharp increase in exploration expenditure and subsequent discoveries. The recognition of the copper-zinc-rhyolite association is an example of a geological breakthrough which also initiated an increase in expenditure and subsequent discoveries. These breakthroughs are difficult to predict and present a major problem when attempting to forecast exploration success.

The expertise of the individuals involved determine the quality of the decisions and interpretations made during the process of exploration. This plays a large part in determining the eventual success of the program.* Again, the level of expertise of the individuals involved is difficult to predict, if it can at all be quantified. This creates further uncertainty in the estimation of future exploration success.

For the purposes of this study, it is assumed that the effects of technological and geological breakthroughs and the varying levels of expertise of those to be involved in future exploration will tend to average out and not enter into the basic relationship between exploration expenditure and exploration success. These factors, although recognized as important, will only be considered when assessing the rate of change of exploration success over the period under consideration.

This assumption leaves exploration expenditures and the element of chance as the two determinants of exploration success. The specific relationship between exploration expenditure and exploration success to be used in this study has been developed through consideration of the following simplified model of exploration activity:

It is assumed that exploration effort can be quantified and expressed in terms of units of exploration effort or exploration tries. All tries are assumed to be homogenous

* An important aspect of this expertise is the range of study. Geologists who are not confined to a limited geographical region have the opportunity to apply their observations in various geological environments to the area under study.

with respect to the technological and scientific expertise, and total expenditure involved. Discoveries can also be quantified and expressed in terms of units of metal discovered. Discoveries are homogenous with respect to quantity of contained metal.

It is assumed that for every exploration try, there are two possible outcomes, discovery or failure. There exists a certain probability, P(discovery), that a discovery will be made and the corresponding probability, 1-P (discovery), that failure will occur each time an exploration try is made.

If a large number, N, of exploration tries are made, the total number of discoveries would be (N*P (discovery)). If the value of a discovery is X dollars, and the cost of an exploration try is Y dollars, the ratio of the total value of discoveries to the total cost of exploration would be $\frac{N*P(discovery)*X}{N*Y} = P(discovery)*\frac{X}{Y}$.

This ratio relates exploration expenditure to value of discoveries and can be used to represent the expected value of discoveries per dollar of exploration expenditure. Assuming that exploration has occurred on a sufficiently large scale in the past, this ratio can be estimated from historical data on the total value of discoveries in a given time period divided by exploration expenditure in that time period.

In reality, neither exploration tries or discoveries occur in homogenous units, and there is evidence to suggest that the probability of a discovery is not constant over time (Roscoe, 1971). These factors, although not affecting the basic principle developed above, tend to make the real analysis much more complex. However, the principle of using statistically expected values to estimate the total results of a large number of trials involving chance is essential in dealing with exploration success.

For the purposes of this study, it is assumed that the expected value of discoveries per dollar exploration expenditure, as derived above, can be used to approximate a workable relationship between exploration expenditure and discoveries. This relationship will be determined by the value referred to as the exploration success ratio. This ratio is equal to the total value of expected discoveries per exploration dollar. The base exploration success ratio to be used in this study will be assumed on the basis of historical exploration expenditures and discoveries in Manitoba.

The historic ratio can be calculated from historic exploration expenditure and historic discoveries. It is assumed that the total reserves of any deposit were discovered by exploration expenditure even though much of of the ore was found subsequent to the decision to go into production. As discussed earlier, this extending of reserves is considered to be part of the cost of mining the ore which was originally discovered through exploration.

In determining the base exploration ratio, the results of the known exploration expenditures, or discoveries must be determined and quantified. This presents many difficulties as the results of exploration can take many forms, not alway easily quantifiable. Also, an accurate description of discoveries is often not available, until the deposit has been mined extensively, many years after the initial development.

For the purposes of this study, discoveries must be expressed in terms of the value of contained metal in total reserves.

Discoveries have been classified as either discovered deposits brought into production, discovered deposits not brought into production, or general geological knowledge.

i) Discovered deposits brought into production.

The identification of such deposits is simple, but the quantification of these deposits presents problems. For producing deposits, the value of contained metal in total reserves is assumed to be equal to the sum of the value of contained metal in past production, and the value of of contained metal in measured, indicated, and inferred reserves. Problems arise in estimating inferred reserves, particularly in newly developed mines where the orebody has not been delineated in any detail.

ii) Discovered deposits not brought into production.

This class includes all discoveries of mineralized material. These discoveries can range in importance from one small mineralized outcrop to a well defined orebody whose development is in the planning stage.

For the purposes of this study, only those deposits in this class which, by a subjective judgement, are felt to be economically exploitable within the next thirty years will be included as discoveries.

Again, problems emerge in estimating the total contained metal in total reserves since information on tonnage and grades is limited.

iii) General geological knowledge.

This class consists of all the knowledge concerning the geological environment which is gathered during an exploration program, aside from the discovery of mineralization. It includes the results of what is usually referred to as an exploration failure. This knowledge is included in the results of exploration since future exploration strategies and discoveries are often dependent on it.

Although it is recognized as an important result of exploration, general geological knowledge cannot be quantified. It will not be considered as part of the discoveries for the purposes of this study.

A special case of general geological knowledge is the information acquired and released by governments through their geological survey programs. This information is important in the overall exploration process, as many companies base their exploration programs on preliminary government work such as this.

For the purposes of this study, this special case will not be considered. Government expenditure on geological surveys has been excluded from the exploration expenditure and the unquantifiable effect of this expenditure on discoveries has not been considered.

<u>Change in Exploration Success Ratio</u>

The exploration success ratio may not remain constant over time as it is influenced by two factors which are subject to continual change. These are advance in science and technology, and the depletion effect.

Advances in exploration technology and geological knowledge would tend to increase the exploration success ratio over time. Technology tends to advance in distinct steps occurring in an unpredictable manner. Geological knowledge is acquired continuously as long as exploration is in progress. Both these advances increase the efficiency of exploration, thus tending to increase the exploration success ratio over time.

Counteracting this effect is the effect of depletion. In a limited portion of the earth's crust, there are, theoretically, a limited number of economic discoverable mineral deposits under a given set of economic conditions. As time goes on and discoveries are made, the number of these deposits decreases. In addition, these remaining ones will tend to be more difficult to discover as the more easily discoverable deposits will be discovered first. This effect will decrease the probability of a discovery over time, thus decreasing the exploration success ratio over time.

The simultaneous existence of these two effects will cause the exploration success ratio to either increase, decrease, or remain the same over time depending on their relative strengths. It has been found that in Canada as a whole, the depletion effect has proven to be stronger as the exploration success rate has been decreasing at 23 to 27 percent per five year period of 5.6 percent per year between 1946 and 1970. (Energy, Mines, and Resources Canada, 1975) Such a trend cannot be interpreted from Manitoba based data due to the limited scale of exploration in Manitoba, and the distorting effects of single large discoveries such as Thompson.

The specific rates of change in the exploration success ratio to be used in the analysis will be discussed later when the individual scenarios are developed.

If a decreasing ratio over time is assumed, an adjustment will have to be made to the base exploration success ratio. The historic value will, in reality, be the average of the declining ratios over the historic period. (see Figure 7) For example, if the assumed change in the ratio is -5%/year, the base ratio can be calculated from this historic average as follows:

-let the historic exploration success ratio (average)=A

-let the ratio in the first year of the historic period =X

- exploration success ratio in year t=(.95)* (exploration success rate in year t-1)

- exploration success ratio in year t- $(X)*(.95)^{t-1}$

- therefore, $A=\frac{X+(.95)X+(.95)^2X+\ldots\ldots(.95)^{29}X}{30}$

- solve for $X=\frac{30*A}{1+.95+(.95)^2+(.95)^3+\ldots\ldots(.95)^{29}}=1.91A$

-exploration success ratio in the 30th (last) year of the historic period $=X(.95)^{29}=(1.91A)(.226) = .43A$

- therefore, exploration success ratio in the base year, which is the 31st year of the historic series= $.43A(.95) = .41A$

If it is assumed that the exploration success ratio is declining at five percent per year, the base exploration

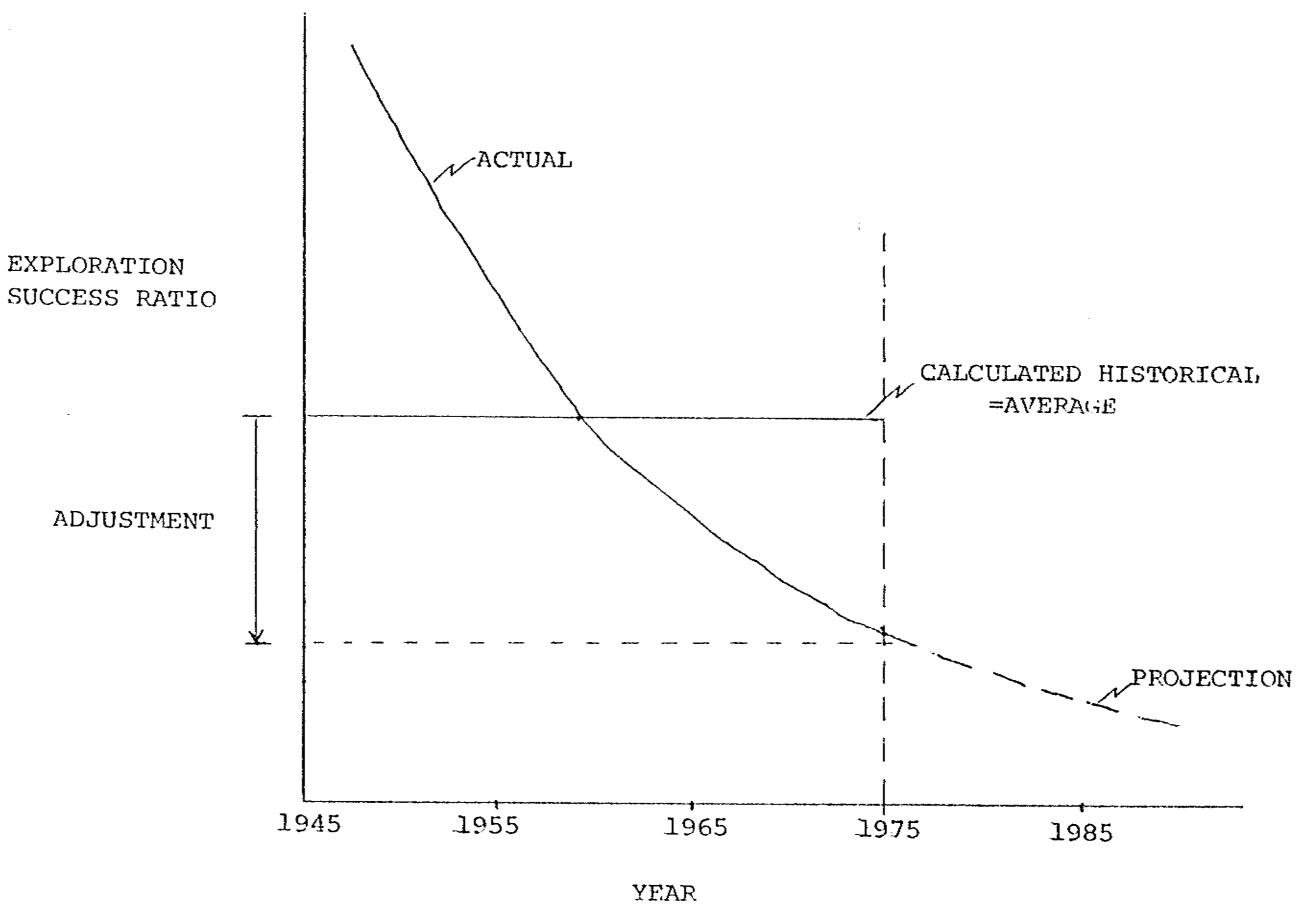

Figure 7: Adjustment to Base Exploration Success Ratio

success ratio will be .41 times the historic exploration success ratio which represents the average ratio over the past thirty years.

Exploration Expenditure Requirements

Mineral exploration expenditure requirements can be defined as the amount of money to be spent on mineral exploration which is sufficient to ensure that the expected discoveries plus presently known mineral deposits will provide a mineral resource base such that all future economic opportunities for mineral production can be taken advantage of.

This variable consists of a set of 25 values, each representing the exploration expenditure requirement in the corresponding year. It is calculated as the total value of discovery requirements divided by the exploration success ratio.

The Analysis

The data provided is the basis for the following primary calculations:

i) Economic opportunity for each metal for each year.

ii) Production from proven reserves of presently operating mines for each year.

iii) Production from extended reserves of presently operating mines for each year.

iv) Production from known undeveloped deposits for each year.

v) Exploration success ratio for each year.

Production from known sources is calculated as production from extended reserves of presently operating mines plus production from undeveloped deposits for each year.

Production from new sources is calculated as economic opportunity minus production from known sources for each year.

New discovery requirements is calculated as production from new sources (five years in advance) times the reserve-capacity ratio.

Exploration expenditure requirements is calculated as new discovery requirements divided by the exploration success ratio in each year.

The text of the computer program used, along with a detailed description of the numerical analysis performed is presented in Appendix 3.

CHAPTER IV

THE DATA

The data input required for the analysis consists of the following items:

1. Productive capacities of currently producing mines and those expected to be producing some time during the period under consideration.
2. Proven reserves of currently producing mines.
3. Total reserves of currently producing mines and those expected to be producing some time during the period under consideration.
4. Historically representative metal prices.
5. Base exploration success ratio.
   a) Historic exploration expenditure (1946-1975)
   b) Historic discoveries (1946-1975)

Productive Capacities

As mentioned in the discussion of methodology, the numerical values for the productive capacity of currently producing deposits are chosen subjectively. The choice of values for each mine is based on an assessment of the rated capacity, the past production record, and anticipated future expansions. Currently producing deposits and their corresponding productive capacities are presented in Table 3.

Table III: Currently (1976) Producing Deposits

DEPOSIT	PRODUCTIVE CAPACITY (tons X 10^3)		
	Ni	Cu	Zn
Thompson T-1	68.0	4.0	-
Birchtree	15.0	1.0	-
Pipe	10.0	-	-
Fox	-	20.0	17.0
Ruttan	-	38.0	40.0
Flin Flon	-	14.0	15.0
Chisel	-	1.0	16.0
Stall	-	16.0	2.0
Osborne	-	8.0	3.0
Anderson	-	8.0	-
White	-	2.0	5.0
Ghost	-	1.0	6.0
total	93.0	113.0	104.0

A subjective choice, based on opinions of commodity geologists was also made concerning which currently undeveloped deposits will be producers and at what time during the period under consideration they will commence production. The productive capacities of these deposits was based on an assumed reserve-capacity ratio of 15.0. The currently undeveloped deposits for which production is foreseen and their corresponding productive capacities to be used in the analysis are presented in Table 4.*

Proven Reserves

The proven reserve figures used were obtained from published sources including, federal and provincial government publications, and individual company annual reports. These values are presented in Table 5.

Total Reserves

As discussed previously, assessing total reserves of any given mineral deposit is a difficult task. The total reserve estimates to be used in this study were based on the opinions of commodity geologists. The imprecision of these estimates, stemming from the theoretical problems of total reserve estimation must be emphasized.

* See Appendix 4 for a description of these deposits.

Table IV: Undeveloped Deposits for which Production is Foreseen

DEPOSIT	PRODUCTIVE CAPACITY (tons X 10^3)		
	Ni	Cu	Zn
Bucko	4.0	-	-
Reservation 34	7.0	-	-
Hambone	2.0	-	-
Ospwagan	12.0	1.0	-
Westarm	-	5.0	-
Centennial	-	2.0	4.0
Pine Bay	-	3.0	-
Spruce Point	-	3.0	1.0
Little Stall	-	6.0	3.0

Table V: Proven Reserves

DEPOSIT	PROVEN RESERVES (tons X 10^3)		
	Ni	Cu	Zn
[a]all INCO deposits	1462.0	100.4	-
[b]all HBMS deposits	-	465.5	507.5
[c]Fox (Sherritt-Gordon)	-	167.0	181.0
[c]Ruttan "	-	632.0	632.0

Sources: a) INCO annual report (1975) and Manitoba Mineral Evaluation Branch

b) HBMS annual report (1976)

c) Sherritt-Gordon annual report (1976)

Total reserve estimates for presently producing deposits and deposits for which development is foreseen were derived from confidential information and are not presented in this report.

Representative Metal Prices

In order to aggregate the tonnages of the metals involved, representative metal prices are needed to convert these tonnages to a common denominator of dollars.

The task of determining what metal prices are likely to prevail over the period under consideration is a complex one. * No detailed attempt has been made to address the problem in this study.

The approach chosen has been to subjectively select representative prices which are within the range of prices experienced within the past ten years. It should be noted that the specific prices to be used are not critical to the outcome of the analysis. This allows for the use of this subjective approach to the selection of these values.

The prices used in this study are as follows (1976 dollars):

nickel	$2.30/lb.
copper	$ .85/lb.
zinc	$ .25/lb.

* This problem is dealt with be A. Werner and A. Azis in "Long-Term Trends in Metal Prices for Decision-Making in Industry and Government" (unpublished, EMR 1975)

Exploration Expenditure (1946-1975)

Statistics on exploration expenditure in Manitoba during the period under consideration have been compiled by Statistics Canada. Their interpretation of this data presents the following difficulties.*

The first difficulty is the incomplete coverage of the companies involved in exploration in Manitoba by the Statistics Canada survey. It is estimated that between 1946 and 1966, that 25 to 30 percent of the companies actually involved in exploration in Manitoba were not surveyed. The resulting error will tend to under-estimate the actual total. It is believed that this error may not be too large since most of the companies not included in the survey had relatively small scale exlor-ation operations with the corresponding small expenditures.

A second source of error in these figures is the presence of the double counting of some exploration expenditure by Statistics Canada between 1956 and 1962. This resulted in Manitoba exploration totals between 20% and 100% higher than expenditures actually reported by the companies.

Changes in the format and phrasing of the questionnaire during the historic period present difficulties in correlating

* This information was obtained through personal communication with D. Cranstone, Energy, Mines and Resources Canada, June 1977.

the results from before the change with the results from after the change.

From 1946-1963, the figure reported was "the cost of prospecting by metal mining companies". This was changed to the "cost of prospecting by producing metal mining companies" in 1964 and 1965. The term "producing metal mining companies" applied only to Canadian producers, thus excluding international companies exploring in Manitoba but not producing in Canada, as well as the exploration subsidiaries of major Canadian producers, which would have been included previously.

In 1967, a completely different questionnaire was introduced which asked for both "outside or general exploration" and "mine or on property exploration and development". It is not clear as to whether or not prospecting expenditure can be equated to outside or general exploration.

These changes make the correlation of pre-1967 and post-1967 data very difficult.

There is also a problem of individual interpretations of the terms "outside or general exploration" and "on property exploration". The Statistics Canada instruction manual is unclear on this point. For example, a company could hold a large (400 sq. mi.) claim block and might report all expenditure on it as "on property exploration" despite the fact that much of this expenditure can be on the search for entirely new orebodies. This would normally be considered "outside or general exploration".

The exact distinction between these two classes of exploration can vary widely from company to company, making it difficult to interpret the aggregate figure reported.

With these problems in mind, the Statistics Canada questionnaires on exploration expenditure were re-evaluated.* These results, along with the original Statistics Canada results are presented in Table 6.

For the purposes of this study, it is believed that despite the difficulties involved, the re-evaluated Statistics Canada figures for 1946-1966 plus the "outside or general exploration" expenditure figure as reported by Statistics Canada for 1967-1975 provide the best available data on exploration expenditure for the period under consideration.

The General Wholesale Price Index (GWPI) is used to convert the figures to constant 1976 dollars. ** This data is presented in Table 7.

* This re-evaluation was done by D.Cranstone, (Energy, Mines and Resources Canada)
** Source: Statistics Canada

Table VI: Manitoba Exploration Expenditure (1946-1966)

YEAR	EXPLORATION EXPENDITURE (in million current $)*	
	Statistics Canada	Re-evaluated
1946	.815	.94
1947	1.294	1.29
1948	.941	.94
1949	.945	.64
1950	.323	.46
1951	.506	.51
1952	.689	.69
1953	1.590	1.59
1954	1.995	1.99
1955	2.374	2.49
1956	9.369	7.39
1957	10.534	8.45
1958	12.286	6.17
1959	7.826	5.86
1960	8.108	5.77
1961	7.109	4.73
1962	5.375	4.38
1963	4.693	3.90
1964	.884	3.94
1965	3.318	6.15
1966	-	6.49

* 'Current dollars' refers to 'dollars of the day'. These values are not converted to constant dollars.

Table VII: Manitoba Exploration Expenditure (1946-1975)

YEAR	EXPLORATION EXPENDITURE (mil.current$)	GWPI (1976=100)	GWPI MULTIPLIER (1976=1.0)	EXPLORATION EXPENDITURE (mil. Constant 1976 $)
1946	.94	27.1	3.69	3.47
1947	1.29	31.8	3.15	4.08
1948	.94	37.6	2.66	1.31
1949	.64	38.6	2.59	1.65
1950	.46	41.8	2.43	1.12
1951	.51	46.8	2.14	1.08
1952	.69	44.1	2.27	1.56
1953	1.59	43.1	2.32	3.69
1954	1.99	42.3	2.36	4.71
1955	2.49	42.7	2.34	5.83
1956	7.39	44.1	2.27	16.78
1957	8.45	44.2	2.26	19.11
1958	6.17	44.4	2.25	13.89
1959	5.86	45.0	2.22	13.00
1960	5.77	45.0	2.22	12.81
1961	4.73	45.4	2.20	10.41
1962	4.38	46.8	2.14	9.37
1963	3.90	47.8	2.09	8.16
1964	3.94	47.8	2.09	8.23
1965	6.15	48.7	2.05	12.60
1966	6.49	50.5	1.98	12.85
1967	6.34	51.5	1.94	12.29
1968	8.48	52.6	1.90	16.11
1969	7.90	55.0	1.82	14.38
1970	9.80	55.8	1.79	17.54
1971	9.40	56.5	1.77	16.64
1972	5.60	60.4	1.65	9.24
1973	5.90	73.5	1.35	8.02
1974	6.90	89.9	1.36	7.66
1975	5.90	95.9	1.04	6.14
total				273.75

Exploration Discoveries (1946-1975)

Exploration discoveries will be represented by the value of total reserves of deposits discovered between 1946 and 1975. This will include deposits which have been developed and those for which development is foreseen.

Total reserves of deposits which have been producing during the historic period include reserves which have been mined during the period.

These discoveries, along with their total value are presented in Table 8.

The historic exploration success ratio (i.e. contained value of discoveries/expenditure) is equal to 148.07. If it is assumed that the exploration success ratio has been decreasing at 5% per year, as will be done in the analysis, the base exploration success ratio =.41(148.07)= 60.7.

Table VIII Manitoba Mineral Deposit Discoveries (1946-1975)

Deposits which were producers (1946-75)	Deposits which are expected to become producers (1976-2005)
Thompson T-1	Bucko
Birchtree	Reservation 34
Pipe	Hambone
Soab	Ospwagan Lake
Fox	Westarm
Ruttan	Centennial
Schist	Pine Bay
North Star	Spruce Point
Don Jon	Little Stall Lake
Birch Lake	
Chisel	
Coronation	
Stall	
Osborne	
Flexar	
Anderson	
Dickstone	
White	
Ghost	
Manibridge	
Dumbarton	

Total 'value' of the metal contained in these discoveries (in millions of 1976 $) = 40533.11

CHAPTER V

THE RESULTS

The analysis was done in two parts. Part 1 is the analysis of three separate growth scenarios, which represent a range of possible growth rates of economic opportunity in Manitoba during the period under consideration. The results of this analysis are presented as five-year average exploration expenditures per year for both small and large sized mines. The average is then expressed as a percentage of the value of total production over the entire period. The same expenditure, distributed as a constant proportion of the value of production in each year, will also be presented as 'Distributed Exploration Expenditure' for each year.

Part 2 is the analysis of a single scenario under varying rates of growth and changes in the exploration success ratio. The objective is to illustrate the sensitivity of exploration expenditure to these variations. These results are presented as a matrix of exploration expenditures as a percentage of the value of production over the entire period.

The details of the scenarios and the results of the analysis are presented below:

Scenario #1: High Growth

This scenario is thought to represent the upper range of growth in economic opportunity which can realistically be expected in Manitoba during the period under consideration. Growth in economic opportunity for the production of nickel is likely to lag behind the growth rate for the other two metals due to an increasing threat of competition from non-sulfide nickel sources such as lateritic deposits and deep-sea nodules. The important points of Scenario #1 are as follows:

a) growth in economic opportunity: Nickel = 2%/yr.
Copper = 4%/yr.
Zinc = 4%/yr.

b) change in exploration success ratio: -5%/yr.

c) the following deposits will be brought into production in the corresponding year:

Bucko (Ni.)	1981
Reservation 34(Ni.)	1991
Hambone (Ni.)	1986
Ospwagan (Ni.)	1986
Westarm (Cu)	1977
Centennial (Cu-Zn)	1977
Pine Bay (Cu)	1986
Spruce Point (Cu-Zn)	1986
Little Stall (Cu-Zn)	1991

Production under Scenario #1 from currently producing mines, known undeveloped deposits, and new sources is presented numerically in Table IX and graphically in Figures 8, 9, and 10.

Under this high growth scenario, a large proportion of the required production, particularly regarding copper and zinc, will come from new, as yet undiscovered, sources. In the case of nickel (Figure 8), known sources will be capable of producing approximately 84% of the total production requirement. Only approximately 16% of the required production will come from new sources. Of the total copper production (Figure 9), approximately 38% will come from known sources. The larger proportion, approximately 63% will come from new sources. Known sources of zinc are capable of producing only approximately 32% of the total requirements (Figure 10). The remaining 68% will come from new sources.

The exploration expenditure required to expect the discovery of these new sources is presented in Table X. The average total expenditure will be 1156 million dollars(1976) or 231.3 million dollars(1976) per five year period. Expressed as a percentage of the 'value' of total production, the total exploration expenditure will be approximately 4.9%. The largest proportion of this expenditure will be in copper and zinc exploration.

Table IX: Required Production of Nickel, Copper and Zinc from Known and New Sources (1976-2005)

(thousand short tons)

		Known	New
High Growth Scenario #1	Ni (tons)	3165	608
	(% of total)	84%	16%
	Cu (tons)	2402	3968
	(% of total)	38%	62%
	Zn (tons)	1861	3972
	(% of total)	32%	68%
Moderate Growth Scenario #2	Ni (tons)	3165	70
	(% of total)	98%	2%
	Cu (tons)	2402	2182
	(% of total)	52%	48%
	Zn (tons)	1861	2358
	(% of total)	44%	56%
No Growth Scenario #3	Ni (tons)	Known sources sufficient	
	(% of total)		
	Cu (tons)	2354	1003
	(% of total)	70%	30%
	Zn (tons)	1861	1259
	(% of total)	60%	40%

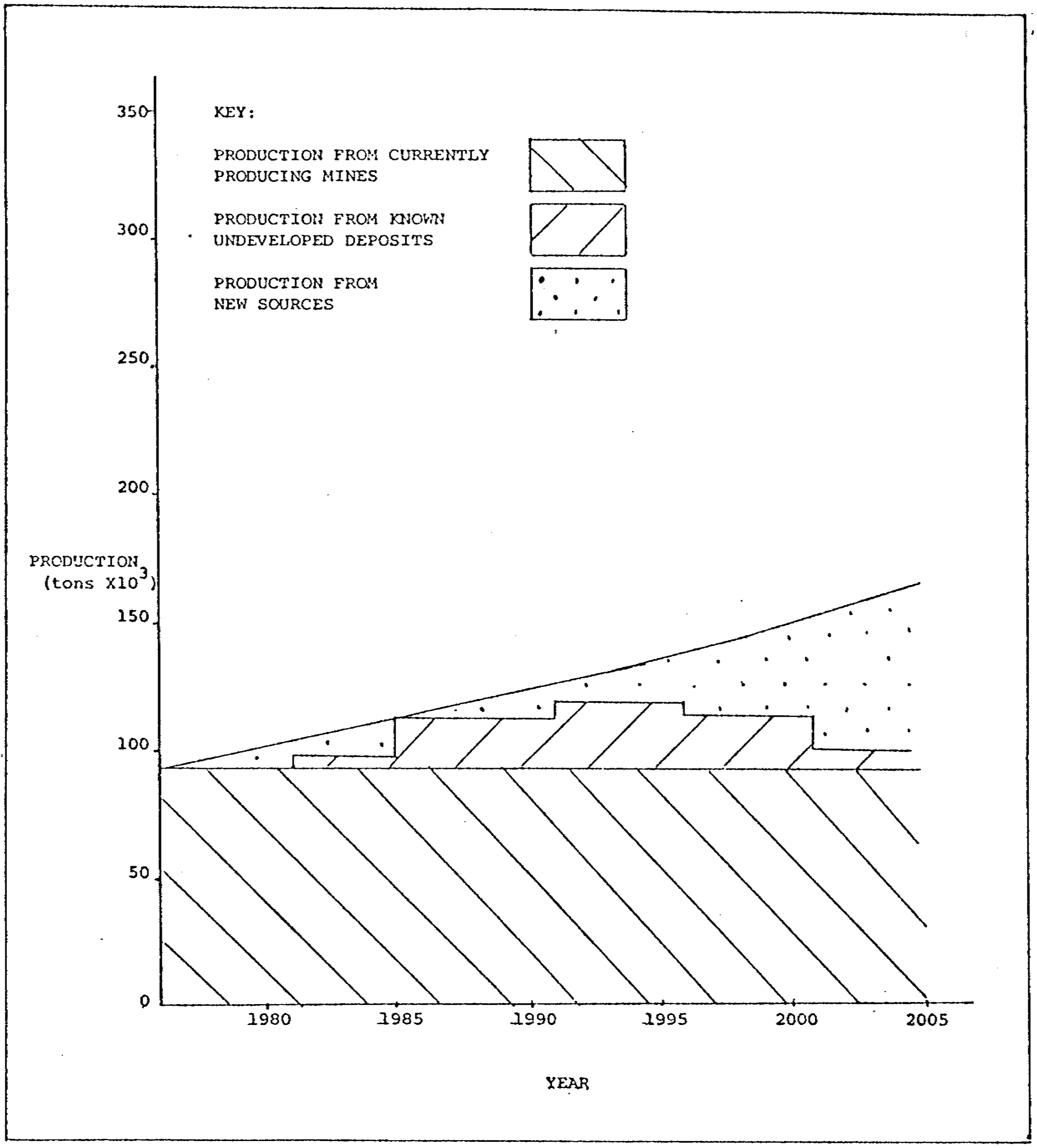

Figure 8: Annual Nickel Production Under Scenario #1 (High Growth)

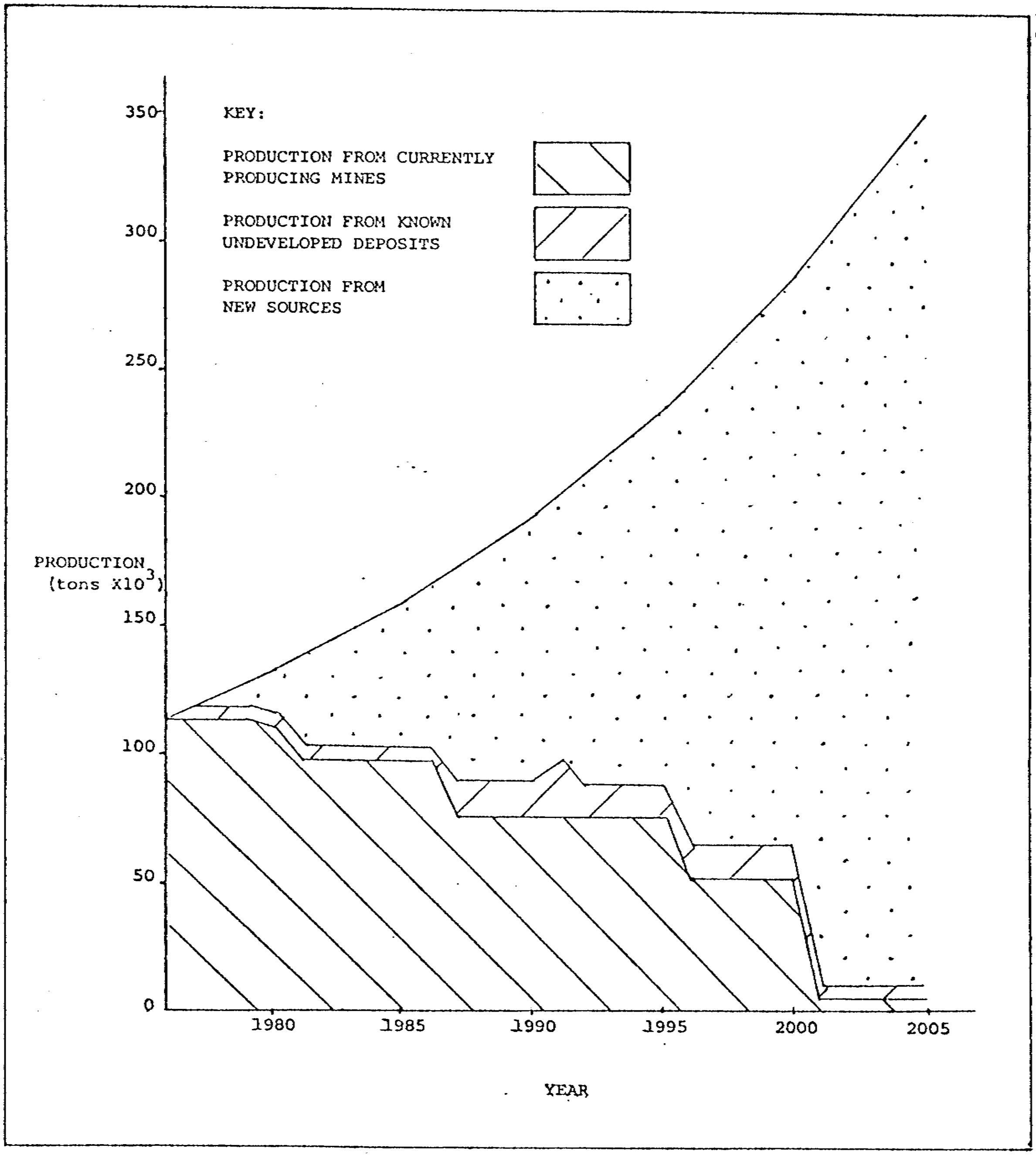

Figure 9: Annual Copper Production Under Scenario #1 (High Growth)

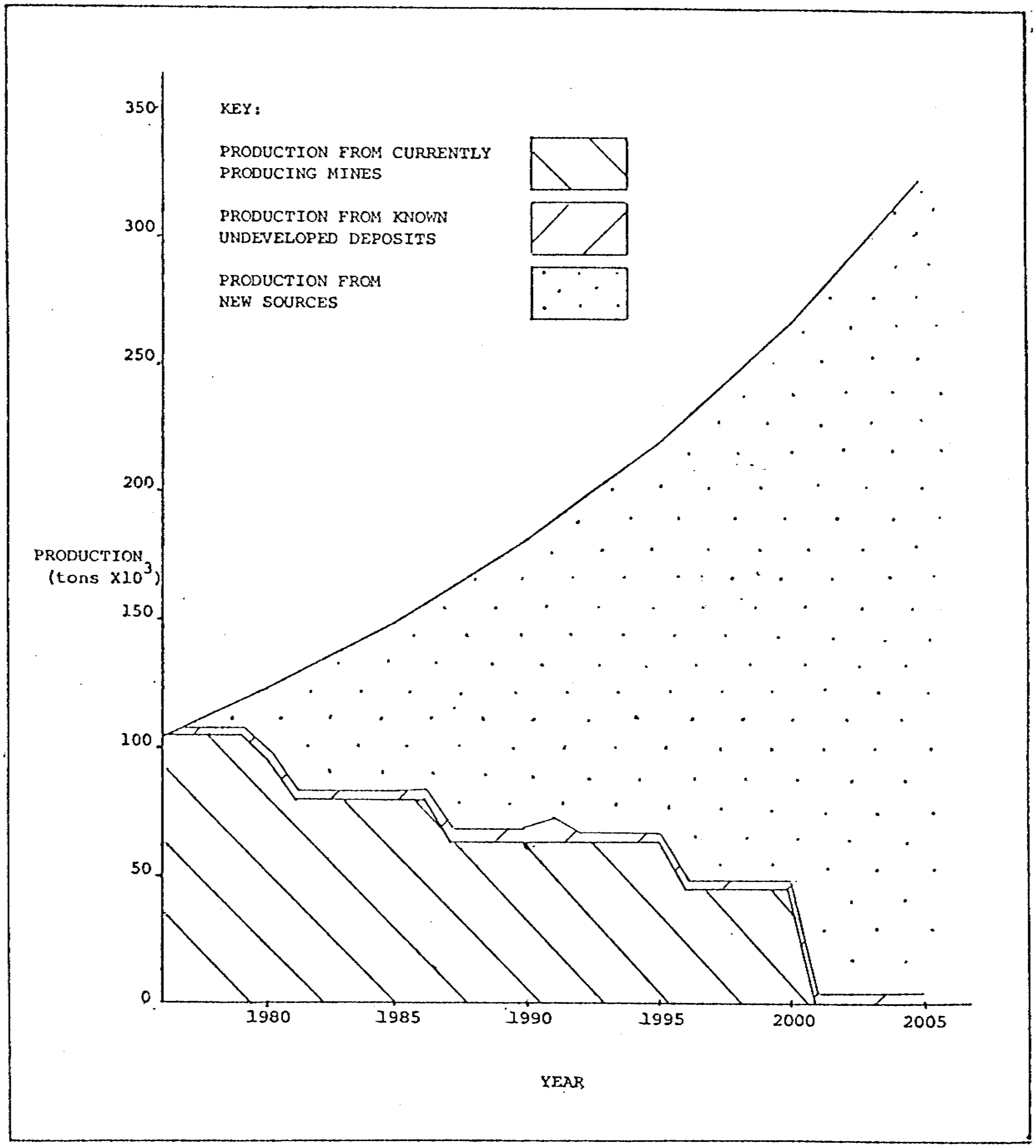

Figure 10: Annual Zinc Production Under Scenario #1 (High Growth)

Table X: Exploration Expenditure: Scenario #1 (High Growth)

PERIOD	EXPLORATION EXPENDITURE (in millions 1976$/yr.)		
	SMALL	LARGE	AVERAGE
1976-1980	7.10	19.00	13.10
1981-1985	10.60	28.30	19.40
1986-1990	17.30	35.00	26.10
1991-1995	43.60	75.70	59.70
1996-2000	76.40	149.60	113.00

EXPLORATION EXPENDITURE AS A PERCENTAGE OF PRODUCTION VALUE = 4.90

YEAR	DISTRIBUTED EXPLORATION EXPENDITURE (in millions 1976$)
1976	32.60
1977	33.40
1978	34.40
1979	35.30
1980	36.30
1981	37.30
1982	38.30
1983	39.40
1984	40.50
1985	41.60
1986	42.80
1987	44.00
1988	45.20
1989	46.50
1990	47.80
1991	49.20
1992	50.60
1993	52.10
1994	53.60
1995	55.10
1996	56.70
1997	58.40
1998	60.10
1999	61.90
2000	63.70

Scenario #2: Moderate Growth

This scenario is thought to represent a growth rate close to the center of the possible range. It is an approximation of the continuation of the historic growth trend.

The important points of Scenario #2 are as follows:

a) growth in economic opportunity: Nickel = 1%/yr.
Copper = 2%/yr.
Zinc = 2%/yr.

b) change in the exploration success ratio: -5%/yr.

c) the following deposits will be brought into production in the corresponding year:

Bucko(Ni)	1981
Reservation 34(Ni)	1991
Hambone (Ni)	1986
Ospwagan (Ni-Cu)	1986
Westarm (Cu)	1977
Centennial (Cu-Zn)	1977
Pine Bay (Cu)	1986
Spruce Point (Cu-Zn)	1986
Little Stall (Cu-Zn)	1986

Under Scenario #2, production from currently producing mines, known undeveloped deposits, and new sources is presented numerically in Table IX, and graphically in Figures 11, 12, and 13.

In a moderate growth situation, a relatively smaller, yet signifigant, portion of the total production will come from new sources, In the case of nickel,(Figure 11) known sources will be capable of producing almost all of the required production. Only an insignifigant (approximately 2%) portion of the required production will come from new sources. Of the total copper production (Figure 12), approximately 52% will come from known sources. The remainder, approximately 48% will come from new sources. Known sources of zinc are capable of producing only approximately 44% of the total requirements (Figure 13). The larger portion, approximately 56% will come from new sources.

The exploration expenditure required to expect the discovery of these new sources is presented in Table XI. The average total expenditure will be approximately 657 million dollars(1976) or 131.4 million dollars(1976) per five year period. Expressed as a percentage of the 'value' of total production, the total exploration expenditure will be approximately 3.3%. Virtually all of this expenditure will be in copper and zinc exploration.

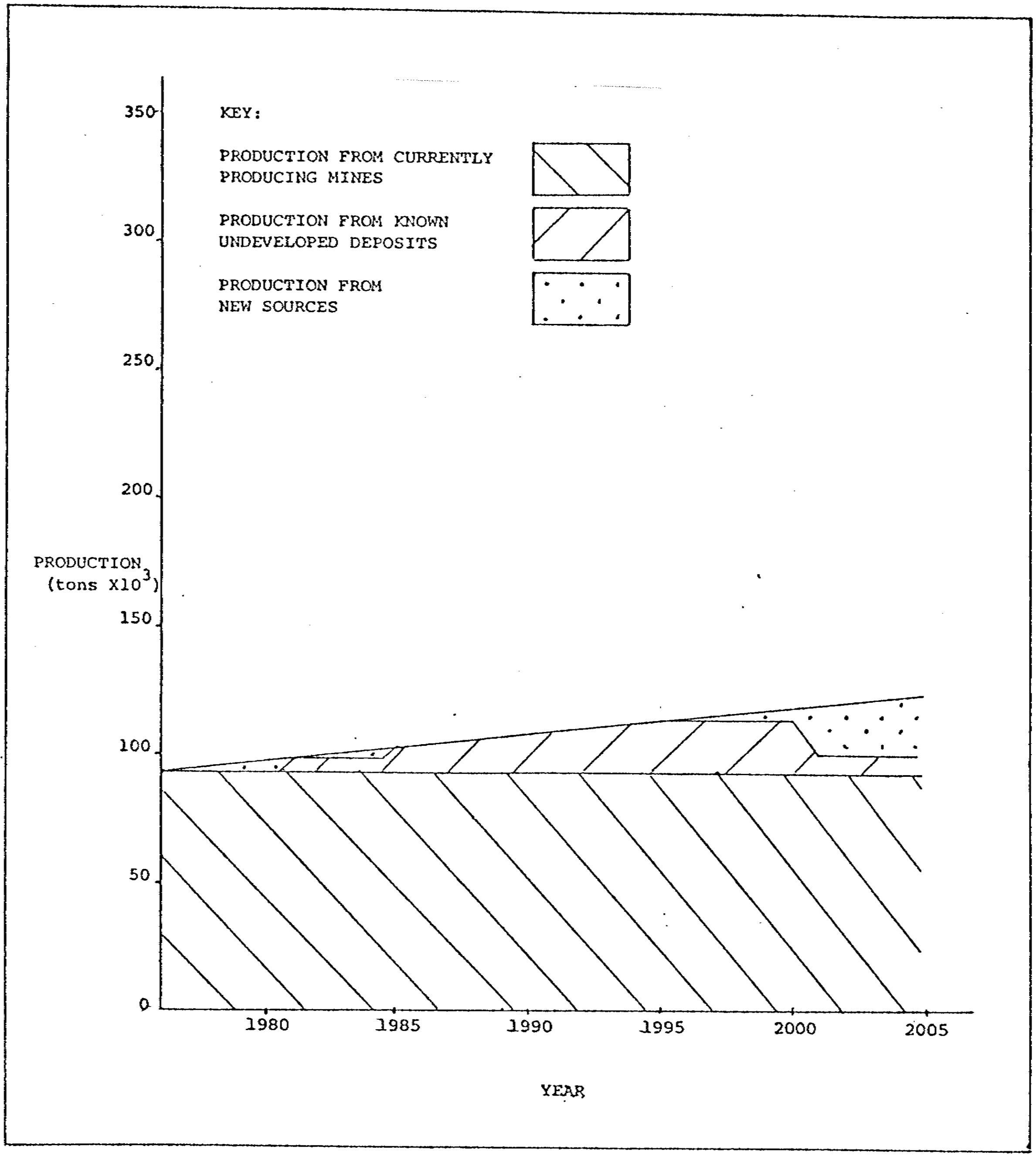

Figure 11: Annual Nickel Production Under Scenario #2 (Moderate Growth)

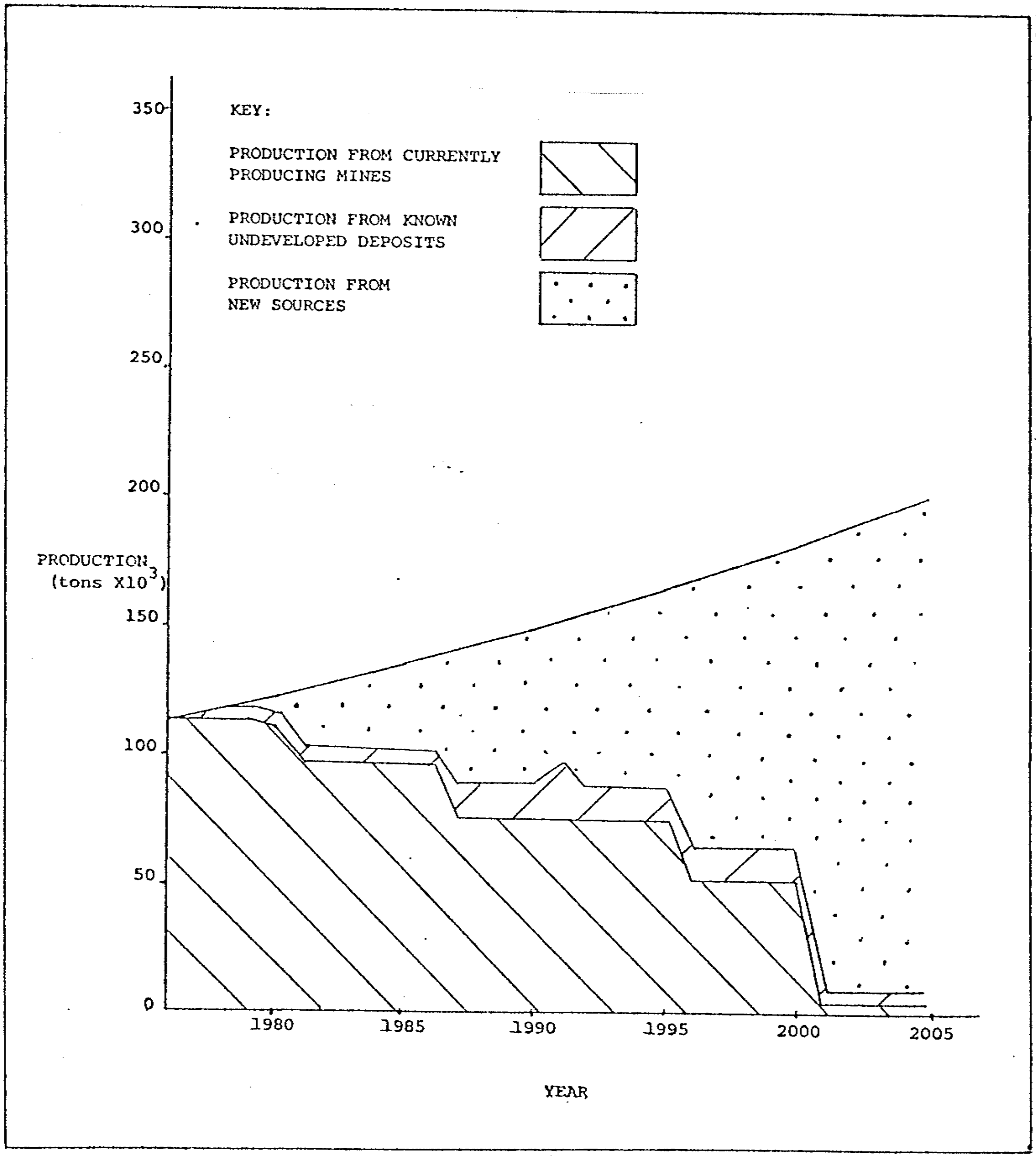

Figure 12: Annual Copper Production Under Scenario #2 (Moderate Growth)

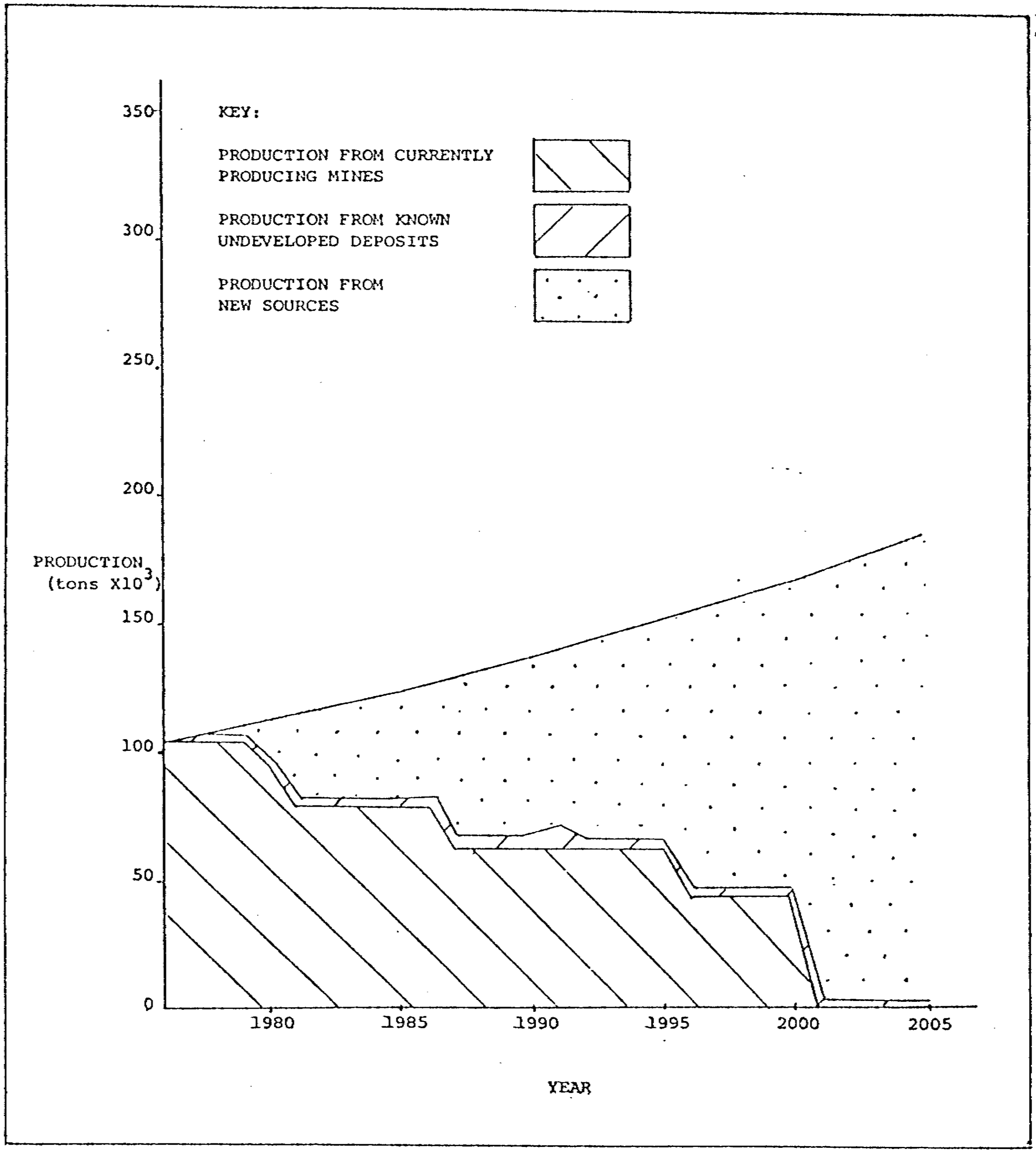

Figure 13: Annual Zinc Production Under Scenario #2 (Moderate Growth)

Table XI: Exploration Expenditure: Scenario #2 (Moderate Growth)

PERIOD	EXPLORATION EXPENDITURE (in millions 1976$/yr.)		
	SMALL	LARGE	AVERAGE
1976-1980	4.10	10.90	7.50
1981-1985	6.10	16.20	11.10
1986-1990	7.30	15.10	11.20
1991-1995	24.40	39.90	32.10
1996-2000	46.30	92.80	69.60

EXPLORATION EXPENDITURE AS A PERCENTAGE OF PRODUCTION VALUE = 3.30

YEAR	DISTRIBUTED EXPLORATION EXPENDITURE (in millions 1976$)
1976	22.20
1977	22.50
1978	22.80
1979	23.10
1980	23.40
1981	23.80
1982	24.10
1983	24.40
1984	24.80
1985	25.10
1986	25.40
1987	25.80
1988	26.20
1989	26.50
1990	26.90
1991	27.30
1992	27.60
1993	28.00
1994	28.40
1995	28.80
1996	29.20
1997	29.60
1998	30.10
1999	30.50
2000	30.90

Scenario #3 No Growth

This scenario is thought to represent the lowest growth rate in economic opportunity which can realistically be expected. It will approximate a situation where world demand for metal products will experience no growth at all, and the Manitoba industry may lose its competative position in the world market, particularly in nickel production.

The important points of Scenario #3 are as follows:

a) growth in economic opportunity: nickel = -2%/yr.
copper = 0%/yr.
zinc = 0%/yr.

b) change in the exploration success ratio: -5%/yr.

c) total Thompson area mines will operate at 75% of productive capacity during the forecast period.

d) the following known deposits will be brought into production in the corresponding year:

Westarm (Cu)	1977
Centennial (Cu-Zn)	1977
Pine Bay (Cu)	1986
Spruce Point (Cu-Zn)	1986
Little Stall (Cu-Zn)	1986

Production under Scenario #3 from currently producing mines, known undeveloped deposits, and new sources is presented numerically in Table IX, and graphically in Figures 14, 15, and 16.

Even under a no growth scenario (ie. strictly maintaining current levels of production) a signifigant portion of the total required production will come from new, as yet undiscovered, sources. In the case of nickel (Figure 14), known sources are capable of producing the entire production requirement. If the production of copper is to be maintained at a constant level, approximately 71% of the total production requirement will come from known sources (Figure 15). The remaining 29% will come from new sources. Known sources of zinc are capable of producing approximately 60% of the total production requirement (Figure 16). Approximately 40% of total zinc production will come from new sources if production is to be maintained at a constant level.

The exploration expenditure required to expect the discovery of these new sources is presented in Table XII. The average total expenditure will be approximately 299 million dollars(1976) or 59.8 million dollars(1976) per five year period. Expressed as a percentage of the 'value' of total production, the total exploration expenditure will be approximately 2.4%. This expenditure will be exclusively on copper and zinc exploration.

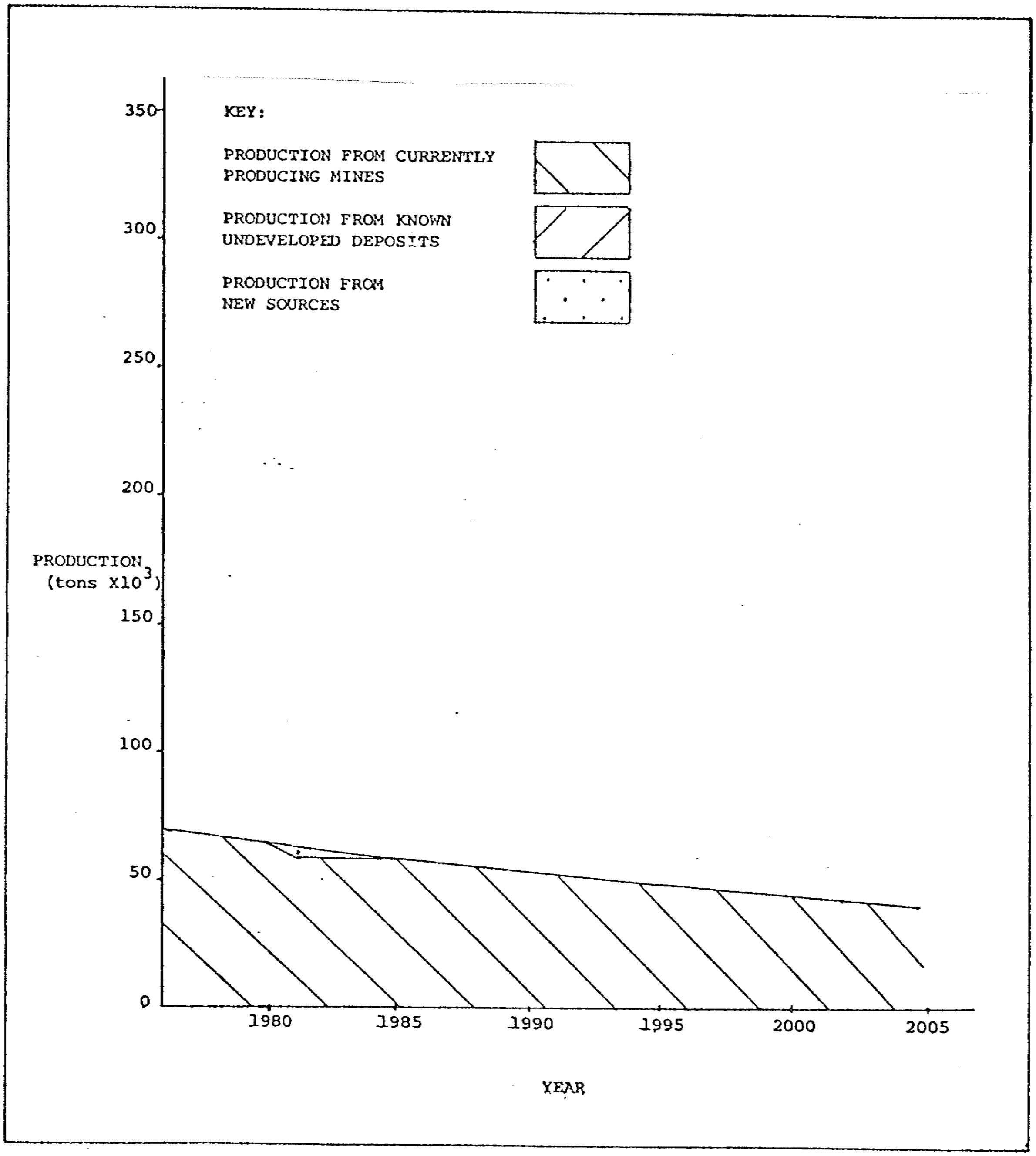

Figure 14: Annual Nickel Production Under Scenario #3 (No Growth)

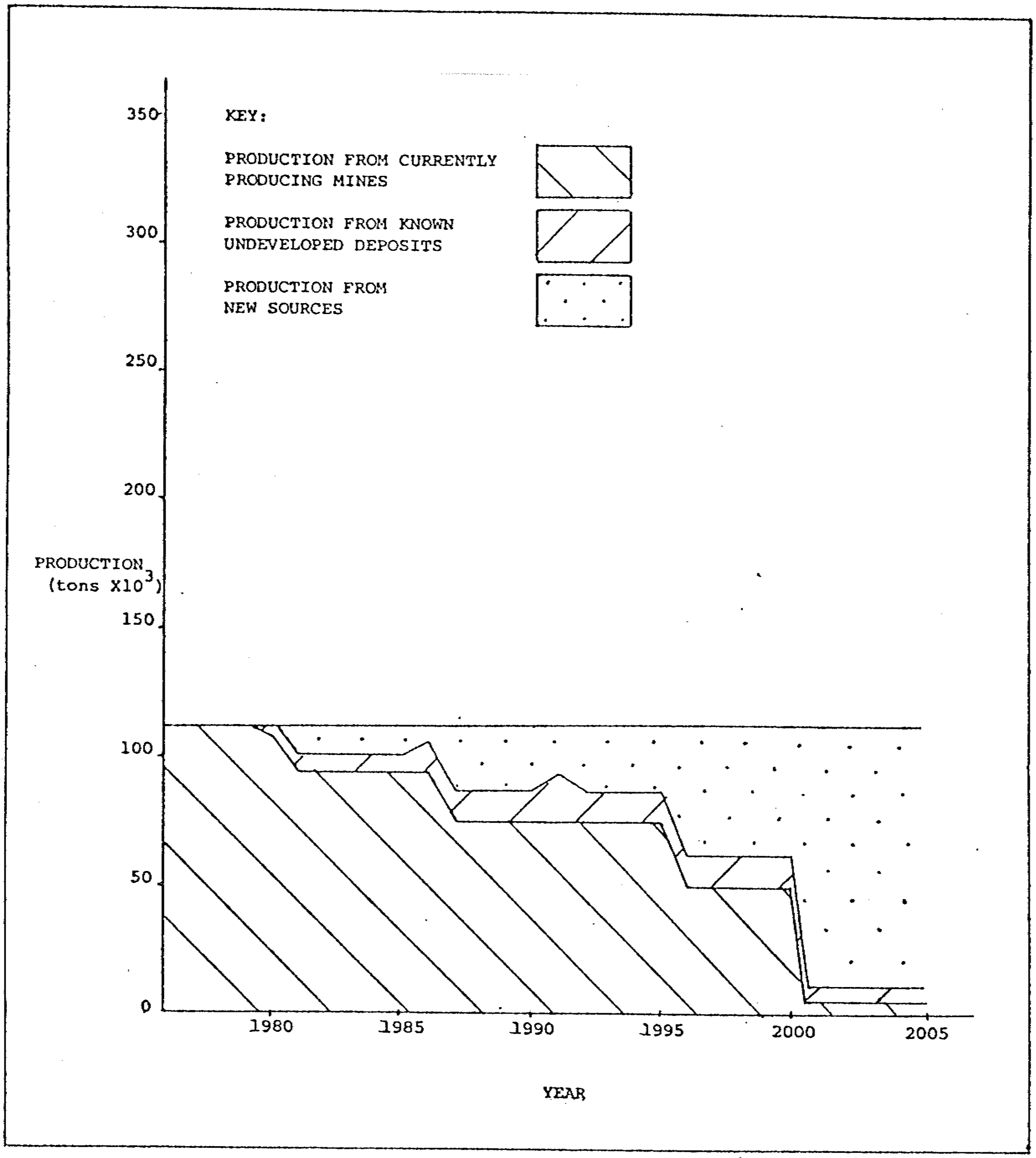

Figure 15: Annual Copper Production Under Scenario #3 (No Growth)

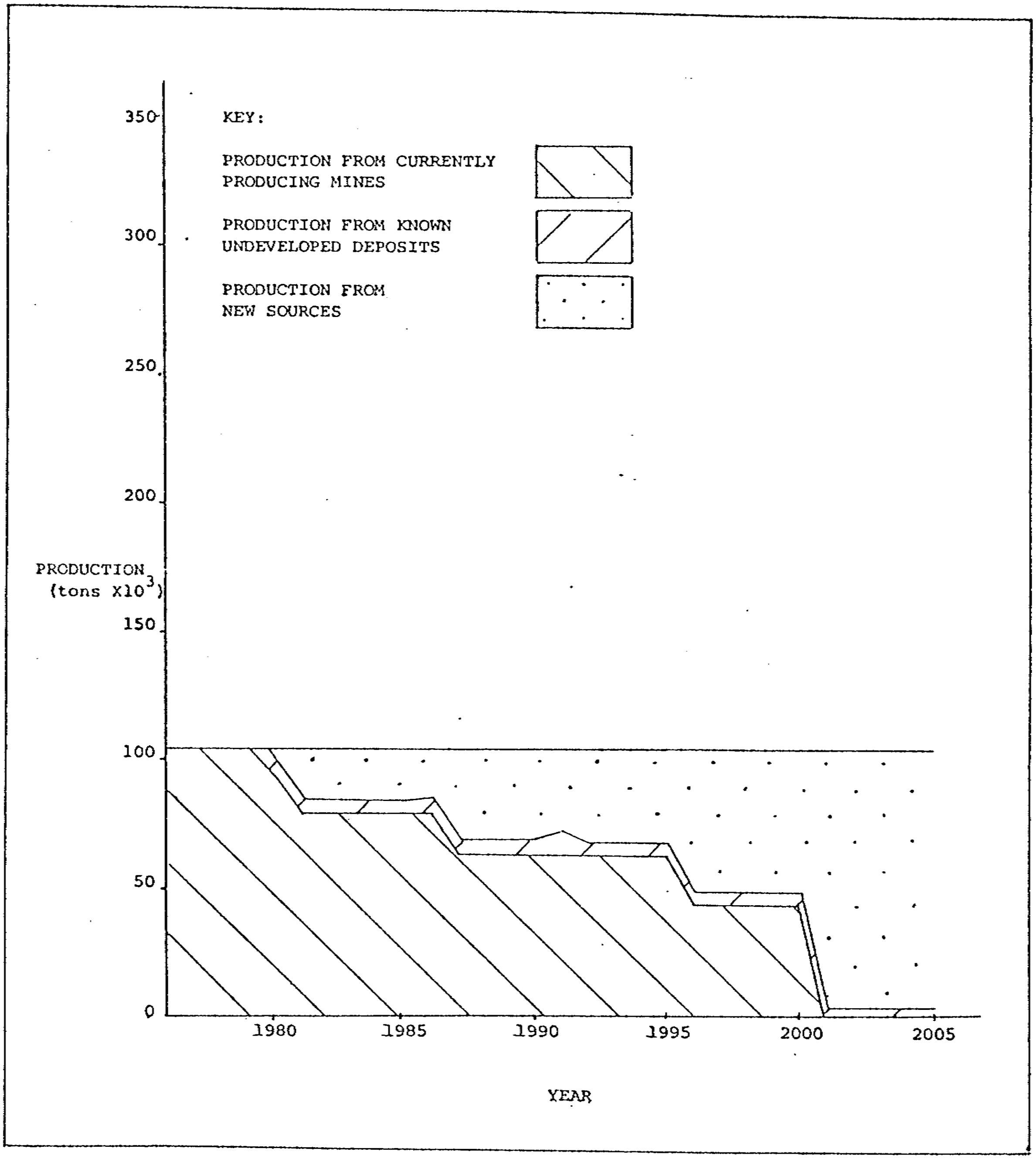

Figure 16: Annual Zinc Production Under Scenario #3 (No Growth)

Table XII: Exploration Expenditure: Scenario #3 (No Growth)

PERIOD	EXPLORATION EXPENDITURE (in millions 1976$/yr.)		
	SMALL	LARGE	AVERAGE
1976-1980	3.50	9.40	6.50
1981-1985	2.60	7.60	5.20
1986-1990	1.20	3.20	2.20
1991-1995	14.10	14.70	14.40
1996-2000	21.70	40.60	31.20

EXPLORATION EXPENDITURE AS A PERCENTAGE OF PRODUCTION VALUE = 2.40

YEAR	DISTRIBUTED EXPLORATION EXPENDITURE (in millions 1976$)
1976	13.50
1977	13.30
1978	13.20
1979	13.00
1980	12.90
1981	12.70
1982	12.60
1983	12.50
1984	12.30
1985	12.20
1986	12.10
1987	11.90
1988	11.80
1989	11.70
1990	11.60
1991	11.50
1992	11.40
1993	11.20
1994	11.10
1995	11.00
1996	10.90
1997	10.80
1998	10.70
1999	10.60
2000	10.50

Sensitivity Analysis

In conducting the sensitivity analysis, the scenario used is the same as Scenario #1 without the growth in economic opportunity and change in exploration success ratio assumptions. Different combinations of these variables are used to demonstrate their effects on exploration expenditures. Growth rates of economic opportunity are assumed to be equal for all metals.

The results of the sensitivity analysis are summarized in Table XIII. The vertical axis of this matrix represents variations in the change in exploration success ratio over time. These variations would be reflections of advances in exploration technology. The horizontal axis of the matrix represents variations in the growth rate of output for all three metals. The results are presented with exploration expenditures expressed as a percentage of the 'value' of total production for each combination of growth in economic opportunity and change in the exploration success ratio.

Table XIII: Exploration Expenditure as a Percentage of the Value of Production Under Varying Rates of Growth and Changes in the Exploration Success Ratio

Change in Exploration Success Ratio (%/yr.)	Growth in Economic Opportunity (%/yr.): -2	0	2	4
-9	5.3	4.7	8.1	13.11
-6	3.0	2.7	4.6	7.4
-3	1.8	1.6	2.7	4.3
0	1.1	1.0	1.7	2.7
3	.7	.6	1.1	1.8

CHAPTER VI

INTERPRETATION OF RESULTS AND CONCLUSIONS

Interpretation of the Results

The basic limitations of the methodology must be kept in mind when interpreting the preceding results. A number of important points should be understood before the results can be put into a realistic framework for practical application.

i) The element of chance inherent in any exploration activity must be recognized. No expenditure of any amount can guarantee a discover. The nature of the exploration process makes the assessment of future exploration expenditure a very inexact science.

It must be emphasized that the results presented are statistically expected results. The element of chance has been dealt with by assuming that long term statistically expected results will be a reasonable approximation of the actual results. The validity of this assumption increases with the scale of the exploration process under consideration.

The most serious limitation imposed by this approach is in the application of these results to anything less than a large number of exploration endeavors. The exact quantification of a 'large number' of exploration endeavors is dependant on a subjective choice of acceptable statistical margins of error. The question of whether or not the application of this approach to the analysis of exploration activity in Manitoba is valid is such a subjective choice.

A serious mis-interpretation of these results may occur if they are used as a guide in planning an exploration program given a certain desired number of discoveries. As discussed earlier, expenditure on individual exploration programs is usually planned on the basis of on-going results. Statistically expected results have little meaning when applied to individual trials. Allocating exploration funds on such a basis may result in a serious mis-allocation of such resources which would be reflected in higher discovery costs.

ii) The methodology used assumed a direct relationship between exploration expenditure and the discovery rate. Furthermore, it assumed that this relationship will, in the next 30 years, behave as it has in the last 30 years. In reality, complicating factors include not only the element of chance involved, as discussed above, but also the levels of scientific and technical expertise utilized in the various exploration programs. In fact, it can be argued that the expertise used in an individual exploration endeavor may play a more important role in determining the eventual success of that endeavor than the actual expenditure.

These results can only be considered valid if it is assumed that exploration expenditure, or size of the exploration effort, is the only important variable in determining the discovery rate. The effects of scientific and technical expertise are considered in determining the nature of any changes which will occur in the basic relationship between exploration expenditure and discoveries over time. These changes are assumed to occur at a constant rate.

This approach limits the application of these results in a time of rapidly advancing scientific and technical frontiers, as developments tend to occur in distinct steps or breakthroughs.

iii) The total reserve estimates used in the analysis can never be made with any amount of precision. As discussed earlier, reserves are an instantaneous evaluation based on the prevailing level of geological knowledge and economic conditions. The concept of reserves has limited value when extended into the future, as it must be based on the present level of geological knowledge and predictions of future economic conditions.

The uncertainty in predicting future economic conditions limits the usefulness of the total reserve estimates used, particularly in times of rapid changes in the economic conditions affecting the mining industry.

iv) These uncertain future economic conditions affect not only the size of the total reserves of known deposits, but also the rate at which they will be produced. The methodology assumes a constant rate of production from each mine throughout the period under consideration. This would be unrealistic for any period in which changes will occur in either mining costs, metal prices, labor conditions, or other factors. In addition to changes in the quantity of ore produced, variations in the tonnages of contained metal will also occur as the ore grade is usually not constant throughout the orebody.

Variations in the timing to production from known sources can also occur during the period under study. If production is below the anticipated level during the start of the period, additional reserves will be available for production later in the period. This will affect the timing and magnitude of the required new sources and, therefore, exploration expenditure.

These variations have not been considered, and their ommission limits the applicability of these results to the analysis of a mineral supply system in which the output of mines varies in response to changing economic and technical considerations.

The primary limitations of the applicability of the results stem from the fact that they are derived from a methodology based on a simplified theoretical model of the mineral supply system. The resulting imprecision, coupled with the imprecision of the primary data prohibits the application of the results from any specific quantitative analysis of exploration activity, particularly in the planning stage.

The use of exact numbers with high levels of significance in the presentation of the results has deliberately been avoided in order to emphasize the imprecision involved. It is hoped that this will help prevent potential mis-interpretation and the corresponding misuse of the results presented.

The results can be more realistically applied as aids in the qualitative assessment of the mineral supply system. An expression of the required exploration expenditure as a percentage of the total value of production indicates the magnitude of the exploration effort which is expected to be needed, given the current state of the industry and anticipated future economic opportunities. A comparison of this result with the historic exploration effort, expressed in the same manner, can indicate whether or not significant changes in the exploration expenditure patterns of the mining industry ought to be expected. This type of analysis can serve as an input into the analysis of more general questions concerning the future of the mining industry in Manitoba.

The results can also be applied in a process of monitoring the performance of the mining industry. A significant difference between the values derived through the analysis using a certain desired growth rate in mineral output, and the value derived from actual expenditure and production statistics may indicate that factors not considered in the analysis are affecting exploration expenditure. In this way, the results can be used in the process of monitoring the mineral supply system with the aim of detecting changes in exploration expenditure patterns which may warrent futher investigation. These investigations can provide input into more general mineral policy considerations.

Conclusions

The level of exploration expenditure in Manitoba between 1976 and 2000 will be sensitive to both the growth in economic opportunity for the production of nickel, copper, and zinc, and the rate of change of the exploration success ratio.

If growth in mineral output is to continue on the historic trend, exploration expenditure will average 131.4 million dollars(1976) per five year period between 1976 and 2000. This is approximately 2.9 times greater than the average expenditure of

45.5 million dollars(1976) per five year period over the historic period (1946-1975). Virtually all of this expenditure will be on copper and zinc exploration.

If the growth in mineral output is to be higher than the historic trend, returning to the steady growth rate experienced by the industry during the sixties, exploration expenditure will average 231.3 million dollars(1976) per five year period between 1976 and 2000. This is approximately 5.1 times greater than the average five year expenditure over the historic period. This expenditure will be on exploration for all three metals with the emphasis on copper and zinc.

If no growth in mineral output, or the maitenance of constant production levels, is to occur, exploration expenditure will average 59.8 million dollars(1976) per five year period between 1976 and 2000. This is approximately 1.3 times greater than the average five year expenditure over the historic period. This expenditure will be exclusively on copper and zinc exploration. It should be emphasized that this expenditure is necessary just to maintain production levels with no growth in output.

These results indicate that exploration expenditure will be greater, in absolute terms, than exploration expenditure over the historic period if output is to at least be maintained at current levels. Exploration expenditure will be sensitive to any growth in output, and up to 5.1 times greater than in the historic period if high growth in output is to occur.

This absolute increase in exploration expenditure can also be assessed in the context of the increases in production. Exploration expenditure, expressed as a percentage of the 'value' of total production, is an indicator of the magnitude of exploration effort. This value was approximately 3.8% over the historic period.* The results discussed above can also be expressed in this manner.

Under the high growth scenario, exploration expditure as a percentage of the 'value' of total production will be 4.9%. This suggests that an increase in exploration effort relative to the historic period would be required to achieve high growth. Moderate growth could be achieved with exploration expenditure of 3.3% of the 'value' of total production. This is approximately the same magnitude of exploration effort as that over the historic period. The maitenance of current production

* This figure was calculated using Statistics Canada data on nickel, copper, and zinc production in Manitoba between 1946 and 1975. A .90 recovery factor was used to convert these actual metal production figures to contained metal in ore production. This conversion is necessary to make the historic and predicted values comparable.

levels could be achieved with exploration expenditure of 2.4% of the 'value' of production. This suggests a decrease in exploration effort, even though expenditures will rise in absolute terms.

Areas for Further Research

The limitations associated with the study results emphasize the need for further study in many areas related to the assessment of capital expenditure in mineral exploration. The following specific areas requiring further research are suggested:

i) Development of scenarios

The scenarios used in this study were chosen subjectively and do not represent a detailed analysis. Research into the analysis of historic trends, relationships between the growth of economic opportunity and its influencing variables, and development planning in the mining industry may result in the development of more realistic scenarios and consequently, more realistic results.

ii) Total reserve estimates

An assessment of future discovery requirements must be based on the knowledge of the extent of presently known mineral deposits. The availability of information in this regard is limited. Further research along both the geological and economic dimensions of presently known mineral deposits is needed in order to give a clearer picture of the future sources of supply. The uncertainty in the present state of this knowledge is a significant source of error in the results. This error can be reduced through more detailed analysis of the presently known mineral resource endowment.

iii) Theoretical problems

As stated earlier, the primary limitations of the applicability of the results stem from the fact that they are derived from a methodology which is based on a simplified theoretical framework. Further research into the theoretical nature of the problem is necessary inorder to further develop this framework. This research should seek to analyze the effects of other variables involved in the overall exploration and process, and incorporate these findings into a more advance methodology.

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APPENDICES

Appendix 1: Manitoba's Mining

Appendix 2: Resource Classification Schemes

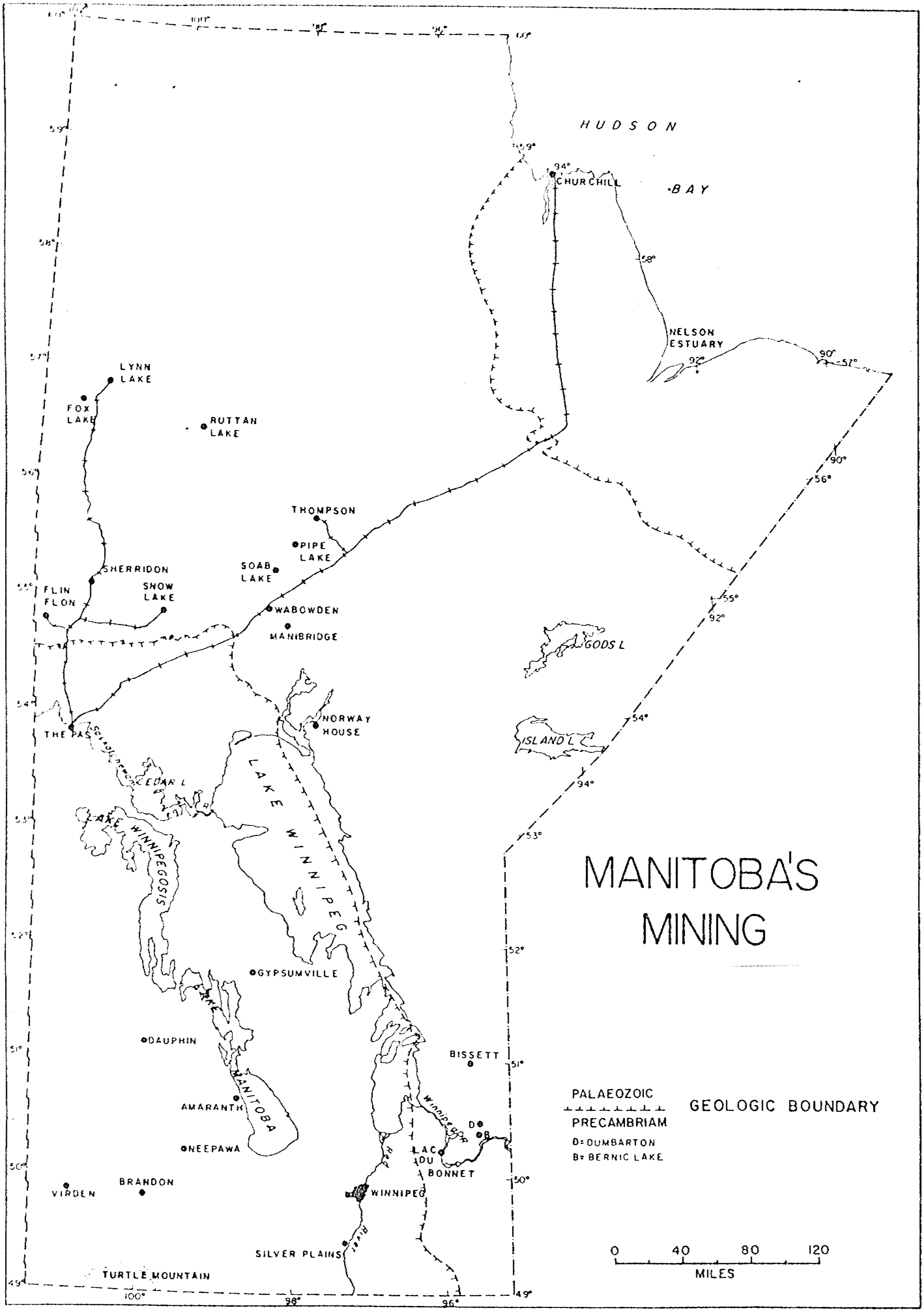
Appendix 3: Detailed Analysis

Appendix 4: Undeveloped Deposits for which Production is Foreseen

APPENDIX 1: MANITOBA'S MINING

Property Name	Property Holder	NTS Location
Thompson Area		
Thompson T-1	Inco Ltd.	63P12NW
Birchtree	Inco Ltd.	63P12NW
Pipe Open Pit	Inco Ltd.	63O08NE
Lynn Lake Area		
Fox Mine	Sherritt Gordon Mines Ltd.	64C12NE
Ruttan	"	64B05NE
Flin Flon Area		
Flin Flon	Hudson Bay Mining and Smelting Co.	63K13SW
White Lake	"	63K12NE
Westarm	"	63K12NW
Centennial	"	63K12NE
Snow Lake Area		
Stall Lake	"	63J13SW
Anderson Lake	"	63J13SW
Osborne Lake	"	63J13NE
Ghost	"	63K16SE
Chisel	"	63K16SE

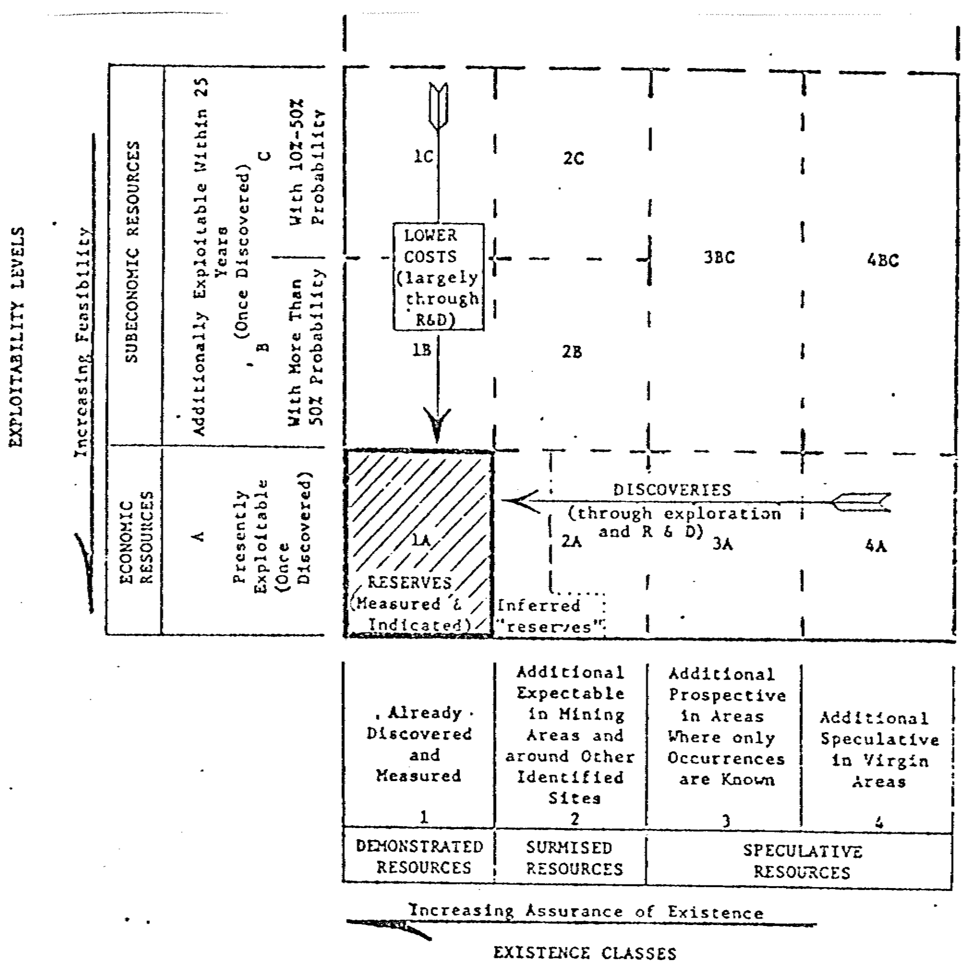
Source: Manitoba Mineral Resources Division, "Important Mineral Properties", Feb. 1977.


HUDSON
BAY
CHURCHILL
NELSON
ESTUARY
LYNN
LAKE
FOX
LAKE
RUTTAN
LAKE
THOMPSON
PIPE
LAKE
SOAB
LAKE
SHERRIDON
SNOW
LAKE
FLIN
FLON
WABOWDEN
MANIBRIDGE
GODS L
NORWAY
HOUSE
ISLAND L
THE PAS
CEDAR L
LAKE WINNIPEGOSIS
LAKE WINNIPEG
GYPSUMVILLE
DAUPHIN
MANITOBA
AMARANTH
NEEPAWA
BISSETT
LAC
DU
BONNET
WINNIPEG
BRANDON
VIRDEN
SILVER PLAINS
TURTLE MOUNTAIN
MANITOBA'S
MINING
PALAEOZOIC
PRECAMBRIAM
GEOLOGIC BOUNDARY
D=DUMBARTON
B=BERNIC LAKE
0
40
80
120
MILES

APPENDIX 2: RESOURCE CLASSIFICATION SCHEMES

Energy, Mines, and Resources Canada:

Departmental Resource Classification Sheme

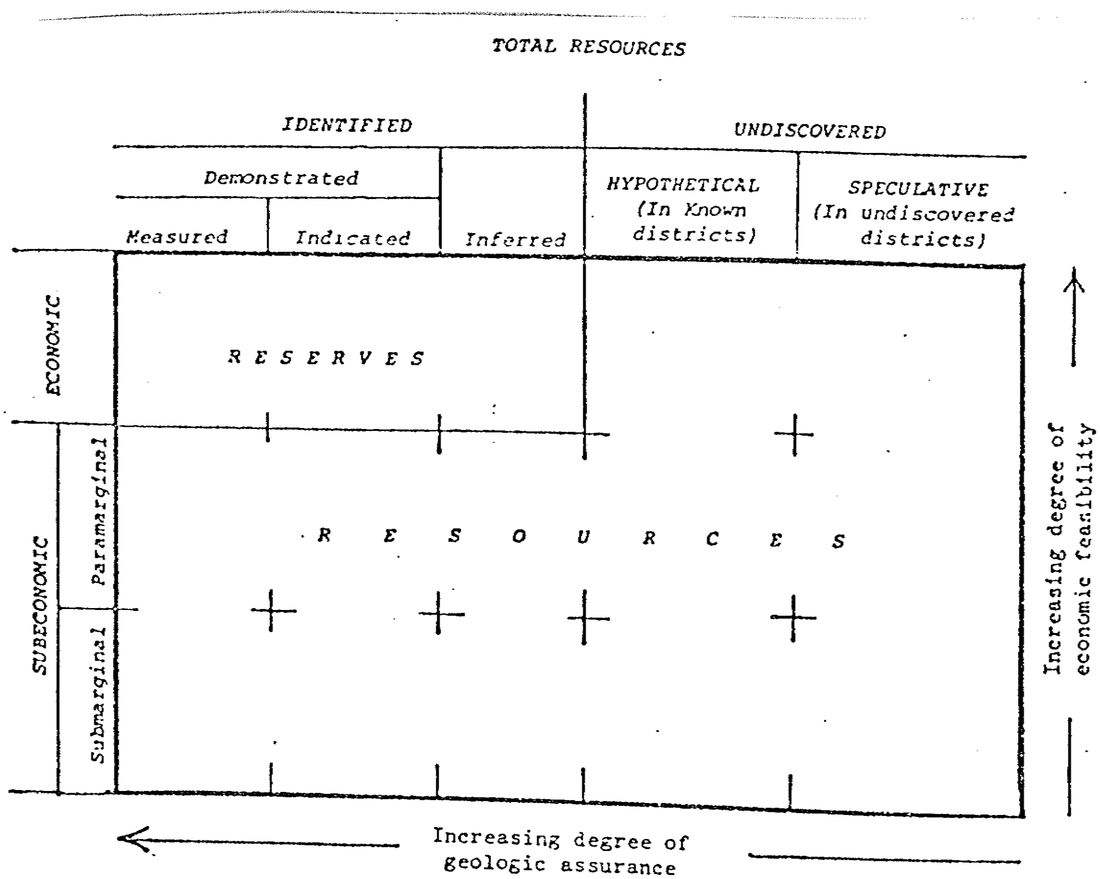


RESERVES (measured & indicated) = 1A (i.e. demonstrated economic resources)
RESOURCES = RESERVES + all other numbered areas
RESOURCE BASE = RESOURCES + indefinite area beyond top of diagram

Note: It has been found impossible in practice to make distinctions between 3B and 3C, and between 4B and 4C.

U.S.A. Bureau of Mines - Geological Survey:

Classification of Mineral Resources



APPENDIX 3: DETAILED ANALYSIS

The analysis (to be done by computer) procedes as follows:

i) Input: the following information is read in and assigned the corresponding names:

- Base economic opportunity - nickel = RPRON(1)
  " - copper = RPROC(1)
  " - zinc = RPROZ(1)
- Growth in economic opportunity in year t - nickel = GRN(t)
  " - copper = GRC(t)
  " - zinc = GRZ(t)
- Production from proven reserves of present mines:

  Production from mine I - nickel = MINE(I,1)
  " - copper = MINE(I,2)
  " - zinc = MINE(I,3)

  Proven reserves life index of mine I = LMINE(I)
- Production from extended reserves of present mines:

  Production from mine I - nickel = EXMINE(I,1)
  " - copper = EXMINE(I,2)
  " - zinc = EXMINE(I,3)

  Real life index of mine I = ELMINE(I)
- Production from known undeveloped deposits:

  Production from deposit I - nickel = SHMINE(I,1)
  " - copper = SHMINE(I,2)
  " - zinc = SHMINE(I,3)

  Production indicator for mine I in year J = LSMINE(I,J)

  (if LSMINE(I,J)=0, mine I will not produce in year J.)
  (if LSMINE(I,J)=1, mine I will produce in year J.)

NPROC(t) = RPROC(t)-EPROC(t)-SPROC(t)

NPROZ(t) = RPROZ(t)-EPROZ(t)-SPROZ(t)

Addition of new production to existing mines:

EXMINE(t+20,1) = NPRON(t)

EXMINE(t+20,2) = NPROC(t)

EXMINE(t+20,3) = NPROZ(t)

Part 3. Calculation of new reserves requirements in year t

RESN(t) = NPRON(t) * STRMN

RESC(t) = NPROC(t) * STRMN

RESZ(t) = NPROZ(T) * STRMN

Part 4. Calculation of timing of reserve requirements

TRESN(t) = RESN(t+5)

TRESC(t) = RESC(t+5)

TRESZ(t) = RESZ(t+5)

Part 5. Calculation of value of discovery requirements in year t

VTRESN(t) = TRESN(t) * PN

VTRESC(t) = TRESC(t) * PC

VTRESZ(t) = TRESZ(t) * PZ

TVTRES(t) = VTRESN(t)+VTRESC(t)+VTRESZ(t)

Part 6. Calculation of the exploration success ratio in each year t

EXEF(t) = EXEF(t-1) * GEXEF(t)

Part 7. Calculation of exploration expenditure requirements in year t

REXEX(t) = TVTRES(t)/EXEF(t)

iii) Output: the following variables will be printed for each year:

- Economic opportunity for each metal

(RPRON(t),RPROC(t),RPROZ(t))

- Reserve-capacity ratio = STRMN
- Representative metal prices - nickel = PN

  - copper = PC

  - zinc = PZ
- Base exploration success ratio = EXEF(1)
- Change in exploration success ratio in year t = EXEF(t)

ii) Calculations: the sequence of calculations procedes as follows:

Part 1: Calculation of economic opportunity in year t

RPRON(t) = RPRON(t-1) * GRN(t)

RPROC(t) = RPROC(t-1) * GRC(t)

RPROZ(t) = RPROZ(t-1) * GRZ(t)

Part 2. Calculation of production from new sources in year t

Production from known sources:

$$KPRON(t) = \sum_I MINE(I,1) \text{ if } t<LMINE(I)$$

$$KPROC(t) = \sum_I MINE(I,2) \text{ if } t<LMINE(I)$$

$$KPROZ(t) = \sum_I MINE(I,3) \text{ if } t<LMINE(I)$$

Production from extended reserves of present mines:

$$EPRON(t) = \sum_I EXMINE(I,1) \text{ if } t<ELMINE(I)$$

$$EPROC(t) = \sum_I EXMINE(I,2) \text{ if } t<ELMINE(I)$$

$$EPROZ(t) = \sum_I EXMINE(I,3) \text{ if } t<ELMINE(I)$$

Production from known undeveloped deposits:

$$SPRON(t) = \sum_I SHMINE(I,1) \text{ if } LSMINE(I,t)=1$$

$$SPROC(t) = \sum_I SHMINE(I,2) \text{ if } LSMINE(I,t)=1$$

$$SPROZ(t) = \sum_I SHMINE(I,3) \text{ if } LSMINE(I,t)=1$$

Production from new sources:

NPRON(t) = RPRON(t)-EPRON(t)-SPRON(t)

- Production from proven reserves of present mines.

  (KPRON(t),KPROC(t),KPROZ(t))

- Production from extended reserves of present mines.

  (EPRON(t),EPROC(t),EPROZ(t))

- Production from known undeveloped deposits.

  (SPRON(t),SPROC(t),SPROZ(t))

- Production from new sources.

  (NPRON(t),NPROC(t),NPROZ(t))

  - New reserve requirements

    (RESN(t),RESC(t),RESZ(t))

  - New discovery requirements.

    (TRESN(t),TRESC(t),TRESZ(t))

  - Value of new discovery requirements.

    (VTRESN(t),VTRESC(t),VTRESZ(t))

  - Tolal value of discovery requirements.

    (TVTRES(t))

  - Exploration success ratios.

    (EXEF(t))

  - Exploration expenditure requirements

    (REXEX(t))

Text of Computer Program:

```
$JOB   WATFIV   BARCHYN
C  PRELIMINARIES :  DIMENSIONS OF ARRAYS
      REAL AV(5,3)
      REAL RPRON(30),RPROC(30),RPROZ(30)
      REAL GRN(30),GRC(30),GRZ(30)
      REAL MINE(50,3)
      REAL EXMINE(50,3)
      REAL KPRON(30),KPROC(30),KPROZ(30)
      REAL EPRON(30),EPROC(30),EPROZ(30)
      REAL NPRON(30),NPROC(30),NPROZ(30)
      REAL NPCN(30),NPCC(30),NPCZ(30)
      REAL NMN(30),NMC(30),NMZ(30)
      REAL RESN(30),RESC(30),RESZ(30)
      REAL TRESN(30),TRESC(30),TRESZ(30)
      REAL VTRESN(30),VTRESC(30),VTRESZ(30)
      REAL TVTRES(30)
      REAL EXEF(30),GEXEF(30)
      REAL REXEX(30,2)
      REAL SEXEX(30)
      INTEGER LMINE(50)
      INTEGER ELMINE(50)
      INTEGER ATON,ATOC,ATOZ
      REAL SHMINE(15,3)
      INTEGER LSMINE(15,30)
      REAL SPRON(30),SPROC(30),SPROZ(30)
      REAL DPRON(30),DPROC(30),DPROZ(30)
      INTEGER LIFE
C  INPUT OF STANDARD MINE INFORMATION
      READ,RPRON(1),RPROC(1),RPROZ(1)
      READ,(GRN(I),I=1,30)
      READ,(GRC(I),I=1,30)
      READ,(GRZ(I),I=1,30)
      READ,((MINE(I,J),J=1,3),I=1,50)
      READ,(LMINE(I),I=1,50)
      READ,((EXMINE(I,J),J=1,3),I=1,50)
      READ,(ELMINE(I),I=1,50)
      READ,((SHMINE(I,J),J=1,3),I=1,15)
      READ,((LSMINE(I,J),J=1,30),I=1,15)
      READ,PN,PC,PZ
      READ,EXEF(1)
      READ,(GEXEF(I),I=1,25)
C CALCULATION OF REQUIRED PRODUCTION
      DO 91 L=1,2
      READ, STMRN
      DO 1 I=2,30
      RPRON(I)=RPRON(I-1)*GRN(I)
      RPROC(I)=RPROC(I-1)*GRC(I)
      RPROZ(I)=RPROZ(I-1)*GRZ(I)
    1 CONTINUE
C CALCULATION OF PRODUCTION FROM KNOWN MINES
      DO 3 J=1,30
      SUMN=0
      DO 4 I=1,50
      IF(J.GT.LMINE(I)) GO TO 4
      SUMN=SUMN+MINE(I,1)
    4 CONTINUE
      KPRON(J)=SUMN
      SUMC=0
      DO 5 I=1,50
      IF(J.GT.LMINE(I)) GO TO 5
      SUMC=SUMC+MINE(I,2)
    5 CONTINUE
      KPROC(J)=SUMC
      SUMZ=0
      DO 6 I=1,50
      IF(J.GT.LMINE(I)) GO TO 6
```

```
      SUMZ=SUMZ+MINE(I,3)
    6 CONTINUE
      KPROZ(J)=SUMZ
C CALCULATION OF PRODUCTION FROM EXTENTIONS
      SUMN=0
      DO 8 I=1,50
      IF(J.GT.ELMINE(I)) GO TO 8
      SUMN=SUMN+EXMINE(I,1)
    8 CONTINUE
      EPRON(J)=SUMN
      SUMC=0
      DO 9 I=1,50
      IF(J.GT.ELMINE(I)) GO TO 9
      SUMC=SUMC+EXMINE(I,2)
    9 CONTINUE
      EPROC(J)=SUMC
      SUMZ=0
      DO 10 I=1,50
      IF(J.GT.ELMINE(I)) GO TO 10
      SUMZ=SUMZ+EXMINE(I,3)
   10 CONTINUE
      EPROZ(J)=SUMZ
C CALCULATION OF PRODUCTION FROM 'ON THE SHELF' DEPOSITS
      SUMN=0
      DO 81 I=1,15
      IF(LSMINE(I,J).EQ.0) GO TO 81
      SUMN=SUMN+SHMINE(I,1)
   81 CONTINUE
      SPRON(J)=SUMN
      SUMC=0
      DO 82 I=1,15
      IF(LSMINE(I,J).EQ.0) GO TO 82
      SUMC=SUMC+SHMINE(I,2)
   82 CONTINUE
      SPROC(J)=SUMC
      SUMZ=0
      DO 83 I=1,15
      IF(LSMINE(I,J).EQ.0) GO TO 83
      SUMZ=SUMZ+SHMINE(I,3)
   83 CONTINUE
      SPROZ(J)=SUMZ
C CALCULATION OF PRODUCTION FROM NEW SOURCES
      NPRON(J)=RPRON(J)-EPRON(J)-SPRON(J)
      NPROC(J)=RPROC(J)-EPROC(J)-SPROC(J)
      NPROZ(J)=RPROZ(J)-EPROZ(J)-SPROZ(J)
      EXMINE(J+20,1)=NPRON(J)
      EXMINE(J+20,2)=NPROC(J)
      EXMINE(J+20,3)=NPROZ(J)
      ELMINE(J+20)=STMRN+J
    3 CONTINUE
C CALCULATION OF NEW RESERVES NEEDED
      DO 21 I=1,30
      NPCN(I)=NPRON(I)
      NPCC(I)=NPROC(I)
      NPCZ(I)=NPROZ(I)
   21 CONTINUE
      DO 22 I=1,30
      RESN(I)=NPCN(I)*STMRN
      RESC(I)=NPCC(I)*STMRN
      RESZ(I)=NPCZ(I)*STMRN
   22 CONTINUE
C CALCULATION OF TIMING OF RESERVE DISCOVERIES
      DO 33 I=1,25
      TRESN(I)=RESN(I+5)
      TRESC(I)=RESC(I+5)
      TRESZ(I)=RESZ(I+5)
```

```
   33 CONTINUE
C CALCULATION OF 'VALUE' OF RESERVE DISCOVERIES
      DO 34 I=1,25
      VTRESN(I)=TRESN(I)*PN
      VTRESC(I)=TRESC(I)*PC
      VTRESZ(I)=TRESZ(I)*PZ
   34 CONTINUE
      DO 35 I=1,25
      TVTRES(I)=VTRESN(I)+VTRESC(I)+VTRESZ(I)
   35 CONTINUE
C CALCULATION OF EXPLORATION $ EFFECTIVENESS
      DO 44 I=2,25
      EXEF(I)=EXEF(I-1)*GEXEF(I)
   44 CONTINUE
C CALCULATION OF REQUIRED EXPENDITURE
      DO 46 I=1,25
      REXEX(I,L)=TVTRES(I)/EXEF(I)
   46 CONTINUE
      DO 90 J=1,30
      SUMN=0
      DO 99 I=1,20
      IF(J.GT.ELMINE(I)) GO TO 99
      SUMN=SUMN+EXMINE(I,1)
   99 CONTINUE
      DPRON(J)=SUMN
      SUMC=0
      DO 97 I=1,20
      IF(J.GT.ELMINE(I)) GO TO 97
      SUMC=SUMC+EXMINE(I,2)
   97 CONTINUE
      DPROC(J)=SUMC
      SUMZ=0
      DO 95 I=1,20
      IF(J.GT.ELMINE(I)) GO TO 95
      SUMZ=SUMZ+EXMINE(I,3)
   95 CONTINUE
      DPROZ(J)=SUMZ
   90 CONTINUE
C PRINTING OF ALL OUTPUT
      PRINT50
   50 FORMAT('1','ECONOMIC OPPORTUNITY',35X,'NICKEL',20X,'COPPER'
     120X,'ZINC')
   51 FORMAT('0',I4,51X,F12.6,14X,F12.6,14X,F12.6)
      DO 53 I=1,30
      IY=I+1975
   53 PRINT51,IY,RPRON(I),RPROC(I),RPROZ(I)
      PRINT54
   54 FORMAT('1','PRODUCTION FROM PRESENT MINES',26X,'NICKEL',
     120X,'COPPER',20X,'ZINC')
      DO 55 I=1,30
      IY=I+1975
   55 PRINT51,IY,KPRON(I),KPROC(I),KPROZ(I)
      PRINT56
   56 FORMAT('1','PRODUCTION FROM EXTENDED MINES',25X,'NICKEL',
     120X,'COPPER',20X,'ZINC')
      DO 57 I=1,30
      IY=I+1975
   57 PRINT51,IY,DPRON(I),DPROC(I),DPROZ(I)
      PRINT85
   85 FORMAT('1','PRODUCTION FROM SHELF SOURCES',26X,'NICKEL',
     120X,'COPPER',20X,'ZINC')
      DO 86 I=1,30
      IY=I+1975
   86 PRINT51,IY,SPRON(I),SPROC(I),SPROZ(I)
      PRINT58
   58 FORMAT('1','PRODUCTION FROM NEW SOURCES',28X,'NICKEL',
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     120X,'COPPER',20X,'ZINC')
      DO 59 I=1,30
      IY=I+1975
   59 PRINT51,IY,NPRON(I),NPROC(I),NPROZ(I)
      PRINT60
   60 FORMAT('1','NEW PRODUCTIVE CAPACITY',32X,'NICKEL',20X,'COPPEI
     120X,'ZINC')
      DO 61 I=1,30
      IY=I+1975
   61 PRINT51,IY,NPCN(I),NPCC(I),NPCZ(I)
      PRINT64
   64 FORMAT('1','NEW RESERVES',43X,'NICKEL',20X,'COPPER',20X,'ZINI
      DO 65 I=1,30
      IY=I+1975
   65 PRINT51,IY,RESN(I),RESC(I),RESZ(I)
      PRINT66
   66 FORMAT('1','DISCOVERY REQUIREMENTS',33X,'NICKEL',20X,'COPPER'
     1'ZINC')
      DO 67 I=1,25
      IY=I+1975
   67 PRINT51,IY,TRESN(I),TRESC(I),TRESZ(I)
      PRINT68
   68 FORMAT('1','VALUE OF DISCOVERY REQUIREMENTS',24X,'NICKEL',20:
     1',20X,'ZINC')
      DO 69 I=1,25
      IY=I+1975
   69 PRINT51,IY,VTRESN(I),VTRESC(I),VTRESZ(I)
      PRINT70
   70 FORMAT('1','VALUE OF TOTAL DISCOVERY REQUIREMENTS')
      DO 71 I=1,25
      IY=I+1975
   71 PRINT72,IY,TVTRES(I)
      PRINT,'REPRESENTATIVE METAL PRICES'
      PRINT,'NICKEL',PN,'COPPER',PC,'ZINC',PZ
      PRINT73
   73 FORMAT('1','EXPLORATION DOLLAR EFFECTIVENESS')
      DO 74 I=1,25
      IY=I+1975
   74 PRINT72,IY,EXEF(I)
      PRINT75
   75 FORMAT('1','EXPLORATION EXPENDITURE REQUIRED')
      DO 76 I=1,25
      IY=I+1975
   76 PRINT72,IY,REXEX(I,L)
      SUM=0
      DO 11 I=1,5
   11 SUM=SUM+REXEX(I,L)
      AV(1,L)=SUM/5.
      SUM=0
      DO 12 I=6,10
   12 SUM=SUM+REXEX(I,L)
      AV(2,L)=SUM/5.
      SUM=0
      DO 13 I=11,15
   13 SUM=SUM+REXEX(I,L)
      AV(3,L)=SUM/5.
      SUM=0
      DO 14 I=16,20
   14 SUM=SUM+REXEX(I,L)
      AV(4,L)=SUM/5.
      SUM=0
      DO 15 I=21,25
   15 SUM=SUM+REXEX(I,L)
      AV(5,L)=SUM/5.
      DO 39 I=20,50
      EXMINE(I,1)=0
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      EXMINE(I,2)=0.
      EXMINE(I,3)=0.
   39 ELMINE(I)=0.
   91 CONTINUE
      DO 30 J=1,5
   30 AV(J,3)=(AV(J,1)+AV(J,2))*.5
      PRINT37
   37 FORMAT('1','FIVE YEAR AVERAGE',38X,'SMALL',20X,'LARGE',20X,
     1'AVERAGE')
      DO 38 I=1,5
      IB=1976+(5*(I-1))
      IE=1980+(5*(I-1))
   38 PRINT52,IB,IE,AV(I,1),AV(I,2),AV(I,3)
   52 FORMAT('0',I4,2X,'-',2X,I4,42X,F12.6,14X,F12.6,14X,F12.6)
      VSUM=0
      DO 31 I=1,25
   31 VSUM=VSUM+RPRON(I)*PN+RPROC(I)*PC+RPROZ(I)*PZ
      ESUM=0
      DO 32 I=1,5
   32 ESUM=ESUM+AV(I,3)*5.
      PEX=(ESUM/VSUM)*100.
      PRINT36,PEX
   36 FORMAT('0','EXPLORATION EXPENDITURE AS A PERCENTAGE OF
     1PRODUCTION=',2X,F12.6)
      DO 40 I=1,25
   40 SEXEX(I)=(RPRON(I)*PN+RPROC(I)*PC+RPROZ(I)*PZ)*(PEX/100.)
      PRINT41
   41 FORMAT('1','DISTRIBUTED EXPLORATION EXPENDITURE')
      DO 42 I=1,25
      IY=I+1975
   42 PRINT72,IY,SEXEX(I)
   72 FORMAT('0',I4,20X,F12.6)
      STOP
      END
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$ENTRY

APPENDIX 4: UNDEVELOPED DEPOSITS FOR WHICH PRODUCTION IS FORESEEN

Property Name	Property Holder	NTS Location
Bucko Lake	Bowden Lake Nickel Mines Ltd.	63J15NE
Reservation 34	Amax Potash Ltd.	63J03SE
Hambone-Maralgo	Inco Ltd.	63008SW
Westarm	Hudson Bay Mining And Smelting Ltd.	63K12NW
Centennial	Hudson Bay Mining And Smelting Ltd.	63K12NW
Pine Bay	Pine Bay Mines Ltd.	63K13SE
Spruce Point	Freeport Canadian Exploration Co.	63K09SW
Little Stall Lake	Stall Lake Mines Ltd.	63J13SW

Source: Manitoba Mineral Resources Division, "Important Mineral Properties", Feb. 1977.