EFFECTS OF WATER POLLUTION CONTROL COSTS ON MINING ECONOMICS: THE CASE OF THE BASE METAL SECTOR IN CANADA.

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ECONOMIC EFFECTS OF WATER POLLUTION CONTROL COSTS.-

To the two little monsters, Andonis and Marina

ABSTRACT

This study examines the impact of water pollution control costs on mining economics. The analysis focuses on the base metal mining sector in Canada for which economic data have been assembled. Three levels of water pollution control regulations are defined. Wastewater treatment systems are designed to provide an effluent quality complying with the regulations. These treatment systems are subsequently costed and the impact of water pollution control costs is assessed.

The economic characteristics of the base metal mining sector have been assessed both on a before-tax and after-tax basis. On a before-tax basis, the costs related to water pollution control are found to be an important part of total capital and operating costs. On an after-tax basis, however, these costs do not appear to have a particularly adverse effect on the economics of the base metal mining sector. To the extent that the second control level defined in this study represents current regulations it has been found that most of the economic impact has already been absorbed. Therefore, a change to more stringent regulations would not have a very significant effect on the economics of the base metal mining sector.

RESUME

Cette étude examine l' impacte économique du coût de contrôle de la pollution des eaux. L' analyse porte sur le secteur minier des métaux de base, pour lequel des données ont été assemblées. Trois nivaux de contrôle de qualité sont definis. Des systèmes de traitement sont établis de façon à donner une qualité des effluents conforme aux règlements. Les coûts de ces systèmes sont estimés et leur effet sur les caractéristiques économiques du secteur des métaux de base est ensuite évalué.

Les caracteristiques économiques du patrimoine minéral sont évalués avant et après l' imposition des taxes et droits miniers. Avant imposition fiscale, les coûts associés au contrôle de qualité des effluents représentent une partie importante des investissements de mise en valeur et des coûts de production. Ces coûts, d' ailleurs, dependent plutôt de la capacité de la mine que du type de minerai. Cependant, après imposition, ces coûts ne semblent pas affecter sérieusement les caractéristiques économiques du secteur minier étudié. En considérant que le deuxième niveau de contrôle défini dans cette étude répresente les règlements actuels, il est démontré que la majeure partie de l' impacte économique a déjà été absorbée. Par consequence, un changement vers des règlements plus sévères n' affecterait pas très sensiblement les caractéristiques économiques du patrimoine minéral Canadien.

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CHAPTER 1. INTRODUCTION

1.1 Environmental Impact of Mining

In this study, mining is defined to comprise the mining and milling stages of mineral supply. The product of mining is metal concentrate.

Mining distrubs the environment in several ways:

- Surface mining creates aesthetic problems and land devaluation.
- Tailings disposal may be a source of waters contaminated with toxic substances.
- Acid mine and tailings waters affect the pH of receiving watercourses.
- Surface mining and ore transportation disseminate dust in the air.
- Tailings dams represent potentially dangerous structures.

Water pollution is the single most important type of environmental damage created by mining. In general, water pollution is the main environmental problem in the mining and transformation stages of metals production. In the smelting and refining stages, the main problem is air pollution.

Increased scale and intensity of exploitation of mineral resources, increased population and social developments have resulted in concern over the side effects of mining, mainly in terms of aesthetic and pollution effects. This concern is reflected by the establishment of regulations for prevention or elimination of damage to the environment. These regulations result in better environment for men and life and higher costs for the mining industry.

1.2 The Objective of the Study

More stringent environmental regulations result in additional costs for the mining industry, over and above traditional production costs. In the case of water pollution, regulations specify the maximum amount of pollutants permitted to be released in the environment through mine and mill waters. Compliance with the regulations means for the mine operator installation of additional treatment facilities. The additional capital and operating costs associated with pollution control affect the economics of mineral supply.

The focus of this study is the Canadian base metal sector, for which economic data have been assembled (Section 1.4). The objective of the study is to evaluate the impact of water pollution control costs on the economics of the base metal mining sector. This task is accomplished in two steps:

- Estimation of capital and operating costs associated with water pollution control.
- Assessment of their effect on the economics of the base metal mining sector.

In the first step of the analysis, costs relevant to pollution control are estimated for each base metal deposit included in the existing data base. The particular characteristics of each deposit (technical, regional, geological) must be estimated if the results are to be realistic. Average values have been used whenever these characteristics are not known.

Although the costs estimated for each deposit are uncertain, it is suggested that they provide a meaningful basis for estimating overall economic effects.

In the second step of the analysis, the impacts of the estimated water pollution control costs are assessed with respect to the following economic characteristics:[1]

On a before-tax basis:

- The potential number of economic deposits for a particular endowment shows the number of deposits that can potentially realize a total revenue of more than $20 million and a rate of return higher than 8% (cost of capital).
- The potential value to society is the increase in society's wealth which results from the exploitation of all economic deposits. The potential value to society is the difference between total revenues and total direct costs and represents the available surplus value prior to mining taxation considerations.

Taxation is a profit-sharing mechanism. It aims to distribute the potential value between the government and the mining industry. After taxation, however, some economically marginal deposits will not satisfy

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[1] Evaluations are made using discounted cash flow methods; the most common are:
- Net Present Value (NPV) = sum of present values of positive and negative cash flows over the operation's life, discounted at the investor's cost of capital;
- Rate of Return (ROR) = rate of interest realized by the investor over the operation's life considering his investment and returns; the ROR is the discount rate that equates the total present value (PV) of investments to the total PV of returns.

economic deposit criteria. These deposits will not be exploited and their potential value will not be realized. On an after-tax basis, the endowment value is evaluated with respect to society, the mining industry as investor and government as tax collector.

The value to society is represented by:

- The actual number of economic deposits, i.e., the number of deposits that satisfy economic deposit criteria on an after-tax basis.
- The actual value to society, i.e., the surplus value to society that can be realized from exploitation of the after-tax economic deposits.

The value to the mining industry is represented by:

- The rate of return to the investor, realized from exploitation of the after-tax economic deposits.

The value to the government is represented by:

- The total present value of tax payments, resulting from the exploitation of all after-tax economic deposits.

It must be noted from the outset that the endowment as described in Section 1.4, is considered for the purposes of this study to be a closed system. The focus of the study is the reactions of this system to changes in its environment (pollution control regulations). Broader issues are not incorporated into the analysis, such as the better environment resulting from compliance with the regulations, and the indirect effects of the additional expenditures on the economy.

1.3 Terms of Reference for the Analysis

The effluent discharge possibilities for a mining operation range from the indiscriminate discharge of all effluents and residues to a state of complete elimination of discharge. For the purposes of this analysis, three discharge levels have been defined:

Control Level 1: Absence of regulations. No consideration is given to pollution. All effluents are freely discharged to the surrounding receiving media.

Control Level 2: Existing federal regulations, briefly shown in Table 1 (Bragg, 1975). Descriptions of these regulations are given in Appendix 1.

Control Level 3: Complete elimination of discharge if possible. When this is not achievable with existing technology, the best possible technology is applied.

The approach consists of estimating the capital and operating costs associated with water pollution control for each mining operation, as a function of each of the three control levels. The water treatment applicable is defined for each mine designed to operate under each of the three control levels. The particular characteristics of each mine are taken into account in this definition.

The water treatment operations are subsequently costed. The results are three sets of capital and operating costs per deposit, each set representing the costs of compliance with one of the pollution control levels.

Parameter	Control Level* (Total Metals)
lead	0.2 mg/ℓ
copper	0.3 mg/ℓ
arsenic	0.5 mg/ℓ
nickel	0.5 mg/ℓ
zinc	0.5 mg/ℓ
suspended solids	25.0 mg/ℓ
pH	6.0 minimum
acute toxicity	not less than 50% survival in a 96-hour bioassay test (in guidelines only)
Ra 226	10 pCi/ℓ (dissolved)

*The control level represents a monthly arithmetic mean for the parameter listed.

TABLE 1. Summary of acceptable effluent levels as set out in regulations and guidelines. (For base metal, uranium and iron mines.)

Until now, costs have been estimated for mines designed to operate under each of the defined control levels. When, however, a mine already operating at Level 1 is required to comply with Level 2, the situation is different. Some facilities already exist, since some pollution control measures are exerted. New complementary measures have to be taken, but the design flexibility is limited by existing operating facilities. The additional facilities and control measures that have to be incorporated into an existing process in order to conform to the next higher control level, are called an 'increment'.

Within the scope of this analysis, three increments can be assumed:

Increment A: Upgrading of an operating mine from Level 1 to Level 2.

Increment B: Upgrading of a mine designed for and operating at Level 2, to Level 3.

Increment C: Improvement to Level 3 of a mine, presently operating at Level 2. This mine, originally designed to operate at Level 1, has subsequently been upgraded to Level 2 by Increment A.

The relationship of increments to the defined control levels is shown in Table 2.

New Mine	Upgraded Mine	
Level 1		
Level 2	Level 1 + In A	
Level 3	Level 2 + In B	Level 1 + In A + In C

TABLE 2. Relationship of defined levels and increments.

Incremental costs are used to complement the assessment of the impact of control level change on economic characteristics of the endowment.

1.4 The Canadian Base Metal Mining Sector[2]

The base metal sector is defined to include copper, zinc, lead and molybdenum deposits together with any associated gold and silver content. The data base used for evaluations includes cash flow estimates for all 131 significant discoveries made during the 1951-74 period. Appendix 2 gives a list of these 131 deposits. The list includes the name of each deposit, its discovery date, the controlling organization and the name of any parent or affiliate organization.

Each deposit is evaluated at the mine development decision point, on the basis of current economic and technological outlook conditions. In addition, the exploration cost and time required to find and delineate the deposits are included. Thus, assessments are made of the exploration, development and production phases of the base metal mining sector. All monetary values are expressed in constant 1979 dollars.

General market estimates are applied to evaluate the time distribution of revenues for each of the deposits. Metal price is both the most important and the most uncertain variable in the assessment of cash flows. Therefore, cash flows are evaluated as a function of price. An expected or mean price outlook is bounded by upper and lower limit prices for each mineral commodity. The prices used are shown in Table 3.

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[2]Further details concerning the data base and methodology applied may be found in Effects of Taxation on Base Metal Mining in Canada, B.W. MacKenzie and M.L. Bilodeau, Centre for Resource Studies, 1979.

Commodity	Lower Limit	Expected Value	Upper Limit
copper ($/lb)[1]	0.70	1.05	1.50
zinc ($/lb)	0.40	0.50	0.70
lead ($/lb)	0.32	0.42	0.62
molybdenum ($/lb in concentrate)	4.50	7.00	10.00
silver ($/oz)[2]	6.00	8.00	72.00
gold ($/oz)	200.00	270.00	450.00

TABLE 3. Metal prices (1979 dollars).

The assessment of costs and revenues assumes that a metal concentrate is produced at each possible mine. Individual estimates of recoverable ore reserves, mine and mill capacity, development capital costs, operating costs and development period are made for each of the base metal deposits, based on present-day economic and technological conditions. The distributions of these estimates are shown in Appendix 3. In the estimation of each deposit's capital and operating costs, compliance with the actual federal regulations (defined as control Level 2) is assumed.

For the purpose of estimating water pollution control costs, the deposits are categorized into various types and sizes. Tables 4 and 5 outline the criteria for these definitions. Table 6 shows the number of deposits belonging to each type and size category.

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[1] 1 lb = 453.59 grams

[2] 1 oz = 31.10 grams

Type of Deposit	Deposit Characteristics
1	Cu-Zn-Pb or Zn-Pb deposit; complex milling circuit; high sulfur content
2	Cu-Zn-Au-Ag, Cu-Ag-Au deposit; simple milling circuit; medium sulfur content
3	Cu, Cu-Mo, Mo deposit; simple milling circuit; low sulfur content

TABLE 4. Definition of deposit types.

	Annual Mill Capacity (tons/year)[3]	
Mine Size	From	To
1	0	1 million
2	1 million	5 million
3	5 million	up

TABLE 5. Definition of mine size

[3] 1 ton 0.907 metric tonne

Mine Size	Type of Deposit			
	1	2	3	Totals
1	19	53	9	81
2	9	10	10	29
3	2	-	19	21
Totals	30	63	38	131

TABLE 6. Number of deposits in each mine size and deposit type category.

CHAPTER 2. AN OVERVIEW OF THE STUDY

Regulations concerning protection of the natural environment from pollution are a part of the legal framework of the mining industry. This particular field of government authority has become increasingly stringent in recent years. This study is an attempt to examine the impact of these increasing pollution control burdens on the economic characteristics of the base metal mining sector in Canada.

The study focuses on water pollution, which is the single most important aspect of environmental quality related to mining activities. Three levels of water pollution control have been defined.

- Control Level 1: free discharge
- Control Level 2: compliance with existing federal regulations
- Control Level 3: complete elimination of discharge

Economic evaluations are made for 131 deposits discovered during the 1951-74 period. These deposits contain copper, zinc, lead and molybdenum, as well as associated gold and silver. Technical and economic characteristics of these deposits have been estimated, compiled and used to assess the economic value of the base metal Canadian endowment with respect to different taxation systems (Mackenzie, Bilodeau 1979).

Within this study, the costs of compliance associated with each control level are evaluated for each deposit. These costs are then introduced in the database and economic criteria are evaluated for each deposit and for the total base metal sector. Potential values prior to mining taxation considerations and actual values on an after-tax basis are assessed. Potential value assessments are made on the basis of:

- Potential number of economic deposits.
- Potential value to Canadian society, expressed as the net present value and the rate of return of cash flows generated by the potential economic deposits..

Actual value assessments are made on the basis of:

- Actual number of economic deposits.
- Actual value to society, expressed in terms of net present value.
- Actual incentive to the mining industry, expressed in terms of rate of return to the investor.
- Actual value to government as the tax collector, expressed in terms of present value of tax payments.

The most common causes of water pollution problems associated with mining, examined in Chapter 3, include:

- Acids generated from exposure of pyrites to the atmosphere; these acids affect the pH of receiving waterstreams and leach toxic heavy metals from tailings.
- Contaminants arising from ore processing; frothers, thiosalts and suspended solids.

It appears that in current mining practice, suspended solids and thiosalts are seldom a problem. Tailings ponds usually provide enough retention time for thiosalts to be oxidized and suspended solids to be settled out. Frothers can either be eliminated by inducing oxidation conditions or recycling to the mill. The most important problem is created by acid metal-bearing waters. These waters are usually treated with lime in order to be neutralized and to precipitate leached heavy metals in the form of hydroxides. This can be accomplished by controlling the pH between 9.5 and 10. Lime treatment is usually carried out in the tailings pond.

The facilities currently used for wastewater treatment and pollution control are also examined in Chapter 3. The tailings pond is typically the central element in the water treatment system. It provides permanent storage for tailings and precipitates and also provides the required conditions for acid neutralization, heavy metal removal and reagent stabilization. All contaminated water in the system may be treated in the tailings pond. Sometimes, though, acid mine and surface waters are treated in a separate holding pond. A recent development in the treatment of acid waters is the mechanical treatment system. The water treatment system includes a network of channels for the collection of acid or uncontaminated surface waters.

Chapter 4 presents waste water treatment flowsheets for the various control levels and types of deposit. It also presents the cost estimating procedure for these treatment systems. Higher effluent quality is achieved with more advanced effluent treatment. The flowsheets of wastewater treatment systems include all operations affected by a change in control levels. At Level 1, only the operating requirements of the mine-mill complex are considered. At Level 2 all mine, mill and surface waters are treated with lime in the tailings pond. The tailings dam is constructed so as to meet structural requirements and minimize seepage. Reclaimed water is recycled at the industry's average recycling rate.

At Level 3, acid mine and surface waters are treated in a separate holding pond, except in the case of type 1 deposits (producing Cu, Zn and Pb). In these cases, acid waters are mechanically treated. Reclaimed water is recycled at the highest rate technically possible.

Flowsheets for incremental systems are also considered in Chapter 4. An increment is the improvement of the treatment system for an operating mine, in order to comply with a higher control level. Usually, the flexibility in the design of an increment is limited by the existing facilities.

Chapter 4 also outlines the computer simulation model used for the evaluation of water treatment costs. In the first stage of the analysis, the technical characteristics of the operations pertinent to each control level are evaluated for each deposit. In this evaluation, individual deposit characteristics are used, as well as average industry values. Technical characteristics include volumes of recycled and fresh water, dam dimensions, amount of lime for effluent treatment and volumes of surface waters. In the second stage, operations relevant to water treatment are costed on the basis of their technical characteristics. The capital and operating costs related to each control level are the total cost of the facilities and treatments involved for the specific control level.

The estimated pollution control related costs are presented in Chapter 5. These costs reflect economies of scale in pumping and piping facilities. Type 3 deposits have consistently lower costs per ton than deposits of the other types.

This is a result of their nature which is the least problematic and their typically large size. Type 1 and Type 2 deposits have approximately equal costs at Levels 1 and 2. Type 1 deposits involve a more advanced wastewater treatment but are larger on average. At Level 3, type 1 deposits have significantly higher costs because of the introduction of mechanical treatment in the system. Increment A involves the most important incremental costs. According to Scott and Bragg (1975a), "the incremental cost of waste treatment to upgrade old facilities appears to be approximately 10-20¢/ton of ore with an extreme of 35¢/ton." This range approximates the distribution of operating costs of increment A. Increment A costs, however, are higher because they represent total costs related to pollution control. Pollution control related capital and operating costs represent a sizeable portion of total costs at control Levels 2 and 3 and increment A.

Since metal prices are the most uncertain and most important economic factor in this analysis, assessments are made for lower limit, expected value and upper limit prices at the three control levels. Potential value assessments are sensitive to metal prices. The number of economic deposits and the potential Net Present Value to Society are sensitive to changes from control Level 1 to Level 2 at lower limit and for expected value metal prices.

Deductibility of pollution control costs for tax purposes results in tax credits, which ease the burden to the mining industry. The actual number of economic deposits, net present value to society and rate of return to the investor assessed on an after-tax basis, show an important sensitivity to changes from control Level 1 to Level 2 at all metals price variants. Tax payments decrease substantially with control level changes. The decrease represents the government's contribution to the higher costs associated with higher levels of pollution control.

The following points outline the results of this study.

- Pollution control related costs represent important components of total capital and operating costs.
- Potential value and after-tax assessments are mainly sensitive to changes from control Level 1 to Level 2. To the extent that control Level 2 represents the current regulations, most of the total economic impact has already been absorbed.
- Taxation eases the burden to the mining industry by transferring a part of the costs to government, through reduced tax payments.
- Small deposits of the shield region are generally the most vulnerable to changes in control levels. If Level 3 controls were to be implemented as a national regulation, it is suggested that some measures be taken to cushion the impact of this change on smaller mineral deposits and mining operations.

CHAPTER 3. WATER POLLUTION IN MINES

This chapter, based on the work of Scott and Bragg (1975), outlines the actual situation relevant to water pollution in the Canadian mining industry. Section 3.1 presents the origins of environmental problems related to the use and discharge of contaminated waters from the mine and mill. Possible mechanisms to control these problems are presented in Section 3.2. Section 3.3 outlines the facilities currently used for effluent treatment in mining.

3.1 The Origins of Water Pollution Problems in Mining

The sources of water pollution from base metal mining operations can be classified into two groups:

i) Acid generated from the exposure of pyrite minerals to the atmosphere. This acid affects the pH of receiving streams and dissolves heavy metals present in the tailings. These toxic substances are then carried to the receiving watercourses.

ii) Contaminants resulting from processing the ore to separate concentrate and tailings products. Contaminants include milling reagents, thiosalts and suspended solids. They are toxic and alter the environment of aquatic life.

Acid Generation

Acid waters are produced from the oxidation of metallic sulphide minerals, particularly those containing iron. In theory, this oxidation can occur either chemically or by biological means. The relative importance of these two mechanisms remains uncertain. In practice, the bacterium thiobacillus ferrooxidans is always present in acid mine waters and there is considerable evidence which suggests that the biological mechanism is significant, if not predominant.

Thiobacillus ferrooxidans is a unique bacterium which obtains its energy for growth from the oxidation of reduced sulphur compounds and ferrous iron. It is the only organism known that has the ability to oxidize sulphide minerals. In order to perform the oxidation, the bacterium requires water, oxygen, carbon dioxide, ammonia, phosphorus and trace amounts of other nutrients. The acid generation process is complex and the subject of disagreement. Considering, however, the net reactions, it can be illustrated as follows, for the case of pyrite:

$$4FeS_2 + 15O_2 + 14H_2O \rightarrow 4Fe(OH)_3 + 8H_2SO_4 \qquad (3.1)$$

Not all the iron precipitates as hydroxide; some iron forms a basic iron sulphate jarosite type material. This reaction may be represented by the following equation:

$$6FeS_2 + 22\tfrac{1}{2}O_2 + 15H_2O \rightarrow 2HFe_3(SO_4)_2(OH)_3 + 8H_2SO_4 \qquad (3.2)$$

In practice, neither of these reactions apply completely. The actual amount of acid produced is between 1.33 and 2 moles per mole of pyrite.

The acid generation may take place in the mine itself, where natural seepage comes into contact with the broken sulphide ore, or in the tailings area, both during the mining operation and after closure.

After its formation, acid is available to leach metals from the minerals. The characteristics of a range of typical acid waters associated with mining is given in Table 7 (Scott and Bragg, 1975a). In this untreated form, such wastes are extremely toxic to fish and other forms of aquatic life and do not comply with many basic requirements for potable water.

Contaminants Arising from the Processing of Ores

Milling reagents modify a property of a particular mineral or class of minerals, thus permitting the separation of that mineral or class from the gangue. Most reagents are toxic. They also vary in stability. Some of them are persistent and will escape from a tailings pond, while others are unstable and will break down in the tailings area. Generally, frothers (reagents) are undesirable in the effluent. Their presence can be reduced or eliminated by:

- Increasing the retention time of the frother-containing waste.
- Applying mechanical aeration to the waste.
- Selecting a frother with appropriate breakdown properties.

It should be noted here that, in some cases, the recycling of frother-containing waters to the mill results in substantial savings in reagent costs. In these cases, appropriate measures have to be taken in order to prevent a frother breakdown.

Contents	Type of Mine					
	Cu-Zn-Pb (Mine Surface Waters)	Cu-Zn-Pb (Mine Water)	Uranium (Seepage)	Cu-Zn (Active Mine)	Base Metal (Abandoned Mine)	Uranium (Abandoned Mine)
pH	4.0	2.0	2.0	3.0	2.6	2.0 - 2.8
suspended solids	8.8	690	nil	-	-	25
total less solids	79	24,000	-	-	9,200	13,440
hardness	293	2,960	-	-	1,390	-
Ca	-	-	416	-	454	-
Mg	-	-	106	-	178	-
Cu	17	11	3.6	0.0	2.5	2.2
Zn	118	1,090	11.4	0.4	34	9.4
Pb	0.4	58	0.7	0.11	0.5	-
Fe (total)	79	1,830	3,200	11.7	1,300	300
Mn	21	0	5.6	0.4	8.2	3.6
SO_4	36	16,560	7,440	885	4,050	6,900
COD	-	245	270	-	110	-

TABLE 7. Typical assays of acid waters in Canada. (All concentrations are in mg/ℓ except pH. pH is the negative logarithm of hydrogen or acid ion concentration.)

Thiosalts can originate from:

- Grinding operations. During grinding and flotation operations, a small amount of sulphur from the mineral dissolves in the water. Through a series of reactions, polythionates ($S_3O_6^{=}$, $S_4O_6^{=}$, $S_5O_6^{=}$, etc) are formed. These compounds are subject to oxidation with time and generate sulphuric acid.
- Reducing sulphur compounds. These compounds (generally in the form of alkaline sulphides, hydrosulphides, sulphites, etc) are used to enable selective flotation of certain minerals and result in increasing polythionate concentrations.

Suspended Solids

In order to recover the valuable constituents, ore must be finely ground. The fine tailings are generally deposited into a tailings pond. In recent years, finer grinding requirements associated with the treatment of more complex and lower-grade ores have resulted in substantially finer tailings. Finer tailings are more difficult to settle, and there are special problems associated with the settling properties of colloidal sized particles. Suspended solids present in discharged effluents alter the physical properties of receiving watercourses and can have a direct effect on aquatic life.

3.2 Possible Control Mechanisms

Factors Influencing Acid Generation

Theoretically, whenever a sulphide mineral is exposed to the atmosphere, the potential for acid generation exists. However, there are numerous interrelated factors which influence the nature and extent of this process, including the following:

i) Restricting the supply of chemical requirements to the oxidation process will slow down or even stop the reaction completely. These requirements include oxygen, water, carbon dioxide and other micronutrients. The supply of oxygen can be restricted through revegetation, flooding and sealing the surface. The latter is a high cost method. The supply of water to the oxidation process can be effectively restricted by providing a vegetative cover over the pyrites to be isolated. Tailings dumps can be isolated in this way, but contact of mine waters with the ore cannot be prevented.

ii) Controlling the pH. The influence of pH on the oxidation process is complex and imperfectly understood. It is suggested that at high pH values the process slows down because of reduced bacteria activity and neutralization of the sulphide materials. pH control using lime inhibits the acid generation process more than any other method, as shown in Table 8 (CIM, 1978). It is accomplished through the dissemination of lime or limestone in the tailings or the mine waters.

Water Treatment Practice	%
lime treatment	23
other treatment	10
no treatment	55
not applicable	12
	100

TABLE 8. Water treatment practice in Canada.

iii) Isolating the sulphide components is not generally possible. In specific cases, most reactive tailings could be buried under less reactive and preferably less permeable components to minimize oxidation. For the same reasons, it is undesirable to construct the embankment of the tailings dam from reactive materials.

Other techniques used to influence oxidation include:

- reducing ferric iron, and
- limiting the area of reactive surfaces.

Acid Neutralization and Heavy Metal Removal

Any process used to neutralize acids will also remove dissolved heavy metals through the formation of insoluble metal hydroxides.

Heavy metal precipitation occurs as a result of the reaction

$$M^{++} + 2OH^{-} \rightarrow M(OH)_2 \qquad (3.3)$$

where M is the metal cation. Precipitation is affected by pH. There is a pH level where the solubility of the metal cation is minimized. Solubility increases as the pH is shifted in either direction. It is very difficult to derive values for the best residual levels of heavy metal ions. However, the ranges of metal concentrations shown in Table 9 (Scott and Bragg, 1975a), appear to be theoretically feasible if total precipitate removal from the effluent can be achieved.

	Residual Concentration (μg/ℓ per litre)	pH
Cu	1-8	9.5
Zn	10-60	10
Pb	< 1	8
Fe (total)	< 1	8[1]

TABLE 9. Lowest metal concentrations theoretically achievable.

If the theoretical relationships apply, it is probable that better overall results would be achieved by closely controlling the pH at 9.5 to 10. In this way, good copper and zinc precipitations would be achieved with only slightly less efficient removal of iron and lead.

Reagents used to control pH include limestone, lime, sodium carbonate and sodium hydroxide. Lime is the most commonly used. Although lime is more expensive than limestone, it is usually preferred because of its higher purity.

Thiosalt and Reagent Stabilization

Bacterial action can convert sulfur and its reduced compounds to sulfate.

[1]If Fe is totally oxidized to ferric.

The optimum conditions for bacterial oxidation are a pH of 3.5, a temperature of 35°C and the presence of adequate nutrient supply. It must be noted that while thiosalts may be found in many mining wastes, their concentrations may not be sufficiently high to justify installation of specific treatment facilities to stabilize them. In many cases the oxidation provided by normal retention times in a tailings pond is sufficient without seriously affecting the pH of the system. Water quality problems are rarely attributed to process reagents. Most of these compounds are subject to biological and/or chemical degradation under the conditions usually existing in a tailings pond.

Suspended Solids Removal

Special problems associated with settling and effective retention of colloidal sized particles may be encountered. Usually, however, several limiting factors in an impoundment design such as topography and reagent stabilization, result in substantial safety margins for the settling of suspended solids. If necessary, settling characteristics can be improved through pH adjustment or addition of flocculating agents.

3.3 Currently Used Effluent Control Facilities

Basically, three kinds of waste water flows may be encountered in mining operations: acid mine waters, mill process effluent, and contaminated surface waters including tailings pond seepage. By far, the most common method of treating these wastes is to discharge them into a tailings pond. In the pond, suspended solids are settled out, heavy metal ions in the water are precipitated and settled out, and the solids retained in perpetuity. Since a basic assumption in this study is that each mine is developed with its own milling facility, the tailings pond is the central element in effluent control. Other facilities complementing the tailings pond when needed are holding ponds, surface contaminated water control channels, surface uncontaminated water diversion channels and mechanical treatment of acid waters.

The Tailings Pond

Originally, the only purpose of a tailings pond was to provide an appropriate space where mill tailings could be permanently stored. While this remains a main requirement of a tailings pond, other considerations have accompanied the growing concern about damage to the environment from mine and mill effluents. Nowadays, a typical pond may be required to perform some or all of the following functions:

- removal of tailings solids by sedimentation;
- acid neutralization;
- formation of heavy metal precipitates (hydroxides), and sedimentation of these precipitates;
- perpetual retention of settled tailings and precipitates;
- stabilization of oxidable constituents, e.g. thiosalts and flotation reagent residuals;
- balancing action for fluctuations in influent quality and quantity; and
- storm water storage and flow balancing.

Tailings dams may be constructed by the upstream or the downstream methods, as illustrated in Figure 1. In most cases, the tailings pond is a natural concavity closed by a dam on the downstream side. The tailings dam may be constructed of coarse tailings or of excavated or waste rock and other inert materials (overburden is used when available). When tailings are used as construction material, acid is generated in the dam itself, resulting in increased seepage through the dam and deterioration of the dam with time.

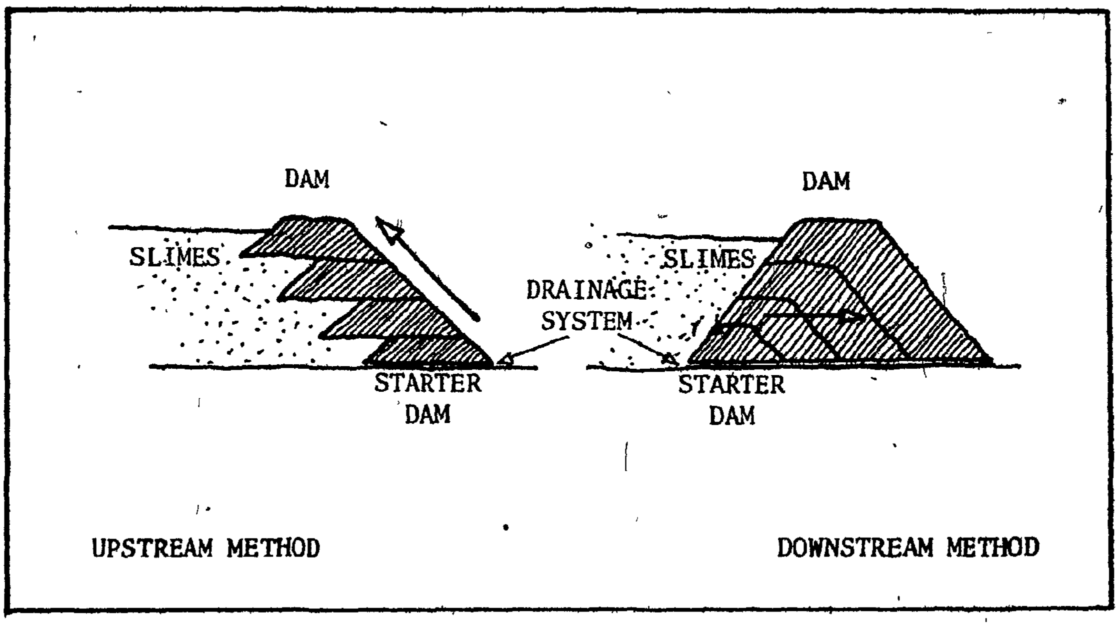

Figure 1. Dam construction methods.

The upstream method has been extensively used in the past and is still acceptable for low dams. In most cases, however, the more rigorous structural characteristics required today can only be met by using the downstream construction method. The tailings dam has become an expensive, highly engineered structure.

In the tailings pond, the effluent is subject to treatment. The most commonly used is pH control, achieved through addition of lime. pH control slows down acid generation and allows maximum precipitation of hydroxides. Moreover, during the time period effluent is retained in the pond, reagents are oxidized or stabilized. To allow maximum retention, the effluent is admitted in the pond at the most distant point from the dam.

The tailings pond is a large, simple system, performing many operations and lacking responsive means of control. However, a well-monitored tailings pond has usually the capacity to provide an effluent of high quality (A. Bell, 1974).[2]

Holding Ponds

Holding ponds are treatment facilities similar to tailings ponds. The basic wastewater treatment operations may be performed in holding ponds: addition of lime to neutralize acids and precipitate hydroxides, bio-oxidation and reagent stabilization. Holding ponds are used for treatment of effluents free of tailings, and thus, are not required to provide any tailings retention.

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[2] "A recent study of mine waste management in New Brunswick (EPS,1973) determined that mines in that region which treated their effluent using well-controlled tailings ponds systems were able to consistently achieve effluent metal levels equal to or better than the following:

copper	30 μg/ℓ
zinc	150 μg/ℓ
lead	100 μg/ℓ
Total Iron:	1 mg/ℓ."

Holding ponds can be used to separately treat acid mine and surface waters containing high concentrations of leached heavy metals. The tailings pond seepage is sometimes also treated together with mine and surface waters in the holding pond. Another disposition of a holding pond may be downstream of the tailings pond in which all effluents are treated. In such a case, the holding pond provides additional retention time, thus improving effluent quality.

Drainage System for Control of Surface Waters

Surface waters may become contaminated when flowing through tailings dumps or areas where mineral or waste rock is exposed. These acid waters should be treated together with the other effluents. Collecting ditches lead these waters to the treatment facility.

Uncontaminated surface waters may, because of topographic contour, flow into the tailings pond, thereby increasing the volume of water to be treated. To prevent this, uncontaminated run-off may be diverted into the neighbouring receiving streams before it enters the effluents circuit.

Mechanical Treatment of Acid Waters

Mechanical treatment of acid metal-bearing mine waters is a technique that has been recently introduced in Canada. It provides a practical means of reducing heavy metal concentrations to the low levels now required by Canadian jurisdictions and overcoming the problem of sludge accumulation. It is, however, important to maintain a proper perspective, particularly with respect to the use of tailings ponds when they are available. It has been demonstrated in many instances that tailings ponds in which the pH is well controlled and in which good sedimentation conditions are maintained, will provide an effluent of an acceptable quality (Bell, Phinney and Behie, 1975).

In the framework of this study, the mechanical treatment system should be regarded as a method of handling acid metal-bearing mine drainage in special cases where segregated treatment is preferred.

CHAPTER 4. MODELLING THE WATER POLLUTION CONTROL SYSTEM

Effluent quality is directly affected by the degree of wastewater treatment. The higher the control level desired, the more complete the treatment that must be applied to the effluent. In order to model water pollution control systems, typical water circuit flowsheets are constructed. These flowsheets show various levels of wastewater treatment assumed to produce an effluent quality complying with the control levels described in Chapter 1. Incremental flowsheets are designed, as well, for the increments defined in Chapter 1. The technology currently available to deal with mining water pollution problems, as presented in Chapter 3, is considered. This technology utilizes the tailings pond as the central element of the wastewater treatment system. Two different sets of flowsheets are presented. The first set, presented in Section 4.1, includes flowsheets for new mines designed to operate at each of the three control levels. The second set, presented in Section 4.2, shows the improvement necessary in existing flowsheets, in order for an operating mine to comply with a higher level of control. In Section 4.3, capital and operating costs associated with each flowsheet are assessed based on current costing procedures.

Given the number of deposits and the complexity of their individual characteristics, it is not easy to correlate specific operations with the expected effluent quality result. It is believed, however, that the flowsheets presented would, in most cases, result in an effluent quality complying with the specifications of each control level.

4.1 Water Treatment Systems for New Mines

Level 1

The characteristics of this level of treatment are:

- Tailings are stored in a tailings pond.
- Pond effluent and mine waters are freely discharged into the receiving watercourses.
- Only fresh water is used as mill process water, i.e. no water is recycled.

Figure 2 shows the water treatment circuit assuming compliance with control Level 1. The following operations are performed:

- Tailings slurries are pumped to the tailings pond.
- Mine water is pumped out of the mine.
- All necessary mill process water is provided from a fresh water source.

The sole use of the tailings pond is tailings retention. All tailings pond overflow and dam seepage are freely discharged. The tailings dam is constructed of coarse tailings with no concern about acid seepage. The upstream construction method is assumed to be used for small dams and the downstream method is assumed for large dams. Mine water is discharged as soon as it is pumped out of the mine. Surface waters are not collected. At Level 1 only the operating requirements of the mine-mill complex are considered and environmental aspects are neglected.

Level 2

Level 2 assumes compliance with current federal regulations (shown in Table 1 and described in Appendix 1). The effluent quality specified by federal regulations is achieved when:

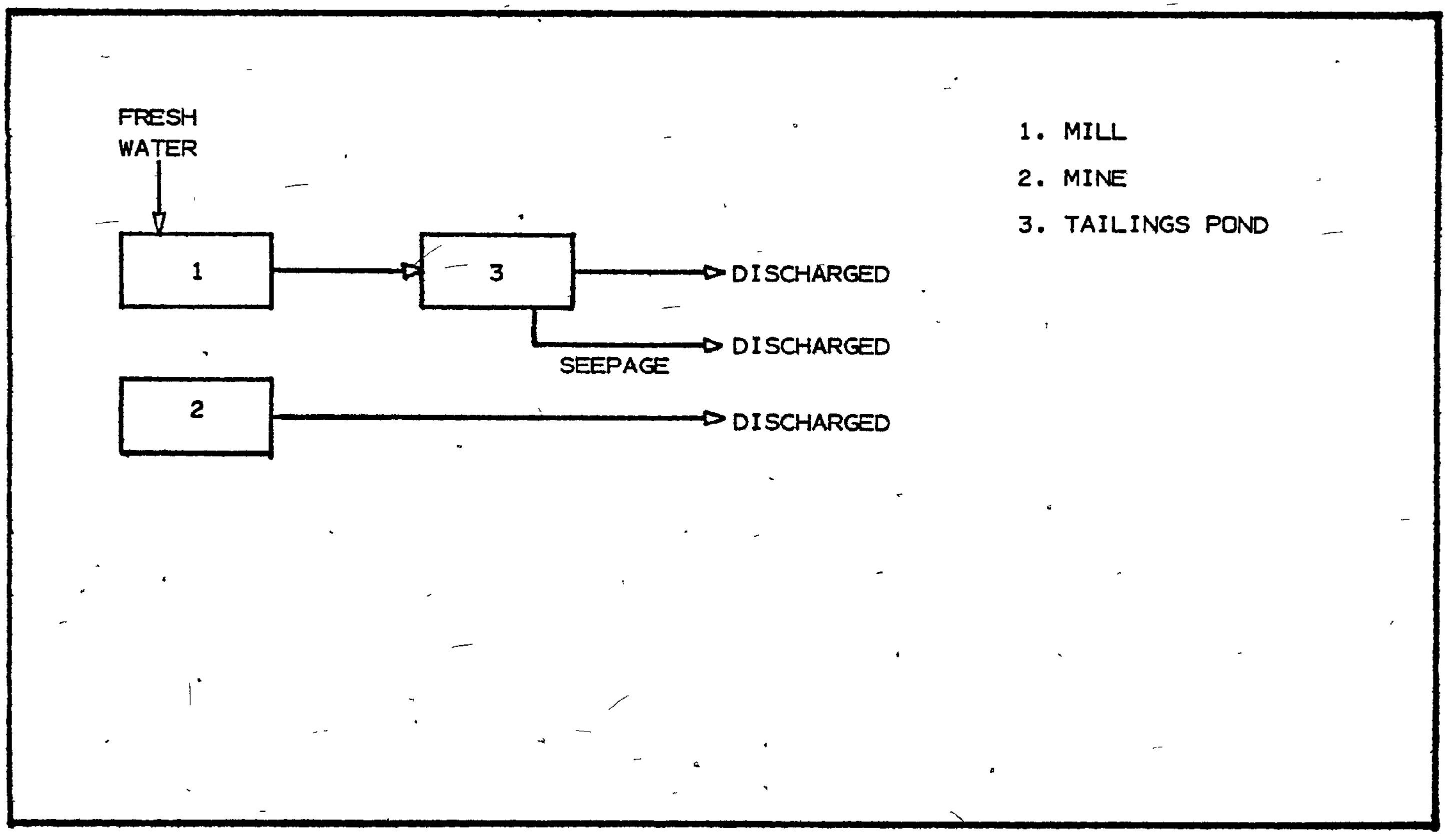

Figure 2. Flowsheet for level 1 of wastewater treatment

- The tailings pond, besides retaining the tailings, is used as a treatment facility. Mill effluent as well as mine and surface waters are treated in the tailings pond.
- The tailings pond overflow is recycled to the mill at the average rate observed in the Canadian mining industry. Average recycling rate varies with the type of deposit.[1]
- Fresh water is added to recycled water to satisfy the mill process water requirements.

The flowsheet for treatment Level 2 is shown in Figure 3.

The following operations yield an effluent quality complying with control Level 2:

- Tailings slurries are pumped to the tailings pond.
- Mine waters are pumped out of the mine.
- Surface acid waters are collected.
- All effluents are treated with lime in the tailings pond, in order to control pH, precipitate heavy metals and neutralize reagents and thiosalts.
- Reclaimed water is recycled to the mill.
- Necessary fresh water is pumped in to complement the needs of mill process water requirement.

The tailings dam is constructed of waste or excavated rock and overburden in order to prevent any acid formation through the dam and

[1]Recycling rate for type 1 deposits: 30-40% of mill process water requirements. Recycling rate of type 2 and 3 deposits: 78% of mill process water requirements. For further details, see Section 4.3.

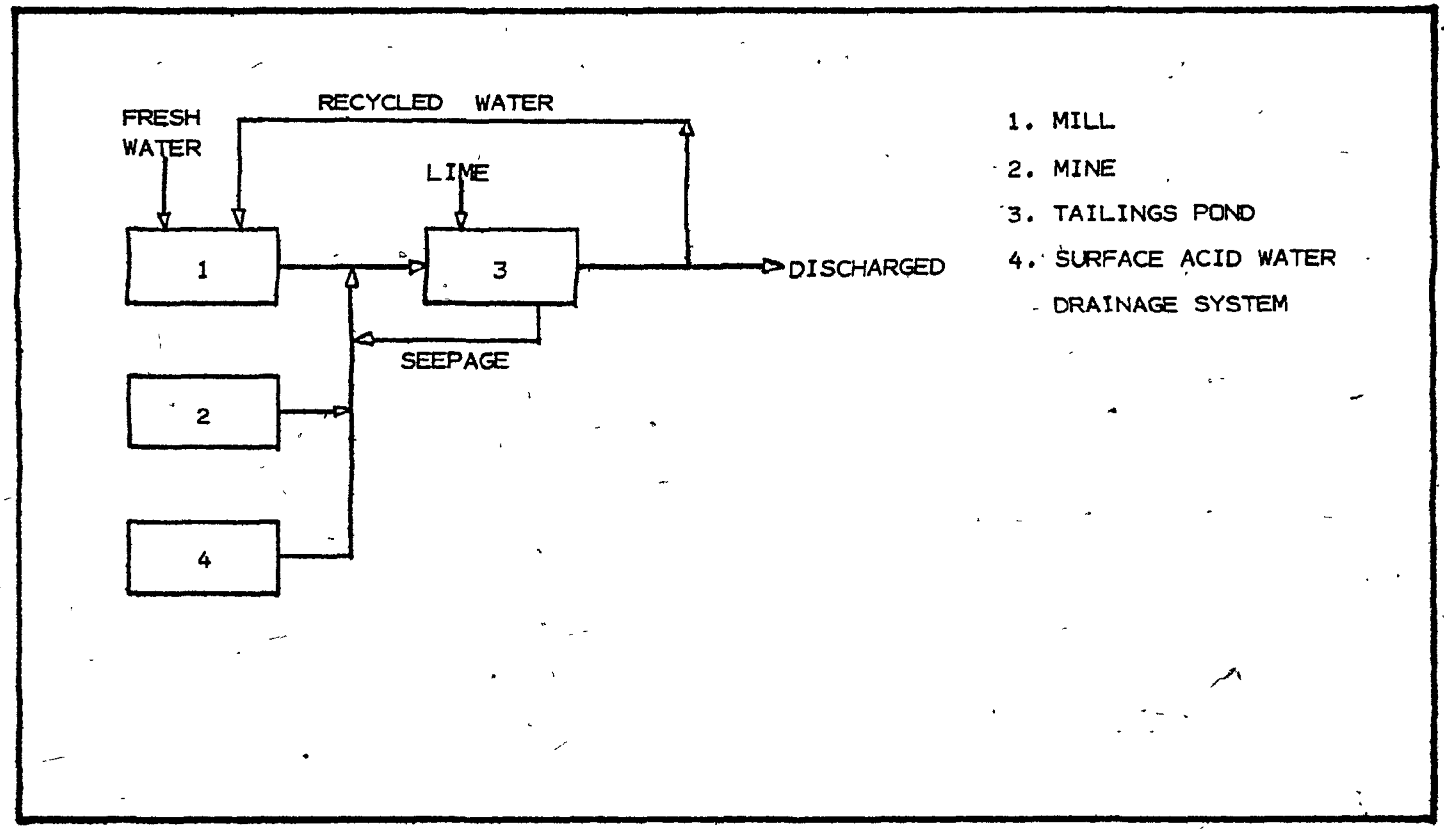

Figure 3. Flowsheet for level 2 of wastewater treatment

reduce the volume of seepage. The tailings pond provides sufficient water retention time to allow for completion of wastewater treatments.

Level 3

Control Level 3 represents the complete elimination of discharge obtained by recycling all the reclaimed water. In general, this practice is technically achievable, except when milling type 1 sulphide ores containing Cu, Zn, Pb, or Zn, Pb. In this case technical problems are associated with the reuse of recycled water in the flotation cells (Scott and Bragg, 1975b). The recycling rate at Level 3 is considered to be the highest achievable rate given present technology.[2]

Type 1 Deposits

In the case of a type 1 deposit, compliance with control Level 3 is achieved when:

- Mill effluent is treated in the tailings pond.
- Pond overflow is retained in an aging pond downstream of the tailings pond, for a complete control of reagents.
- Acid metal-bearing mine waters together with acid surface waters and tailings pond seepage, are treated in a mechanized treatment system.
- Uncontaminated surface waters are diverted into receiving streams before entering the acid waters system.

[2] For type 1 deposits, this rate is 75% of mill process water. For further details, see Section 4.3.

- Reclaimed water is recycled to the mill at the highest achievable rate.
- Fresh water complements recycled water to cover total mill process water requirements.

The water treatment circuit for this case is shown in Figure 4. The necessary operations are:

- Tailings slurries are pumped to the pond.
- Mine waters are pumped out of the mine.
- Mill effluent is treated with lime in the tailings pond.
- Pond overflow is treated with lime in an aging pond.
- Surface acid waters are collected.
- Mine waters, surface acid waters and tailings pond seepage are treated in a mechanical treatment system.
- Reclaimed water is recycled to the mill.
- Fresh water is pumped in to complement for total mill process water requirements.
- Uncontaminated surface waters are collected and diverted before entering the wastewater circuit.

The tailings dam is constructed using the technique described for Level 2. This system does not eliminate discharge; it is assumed, however, that separate treatment of mill effluent and acid waters, accompanied with a close control of treatment conditions, can yield a discharged effluent of very high quality.

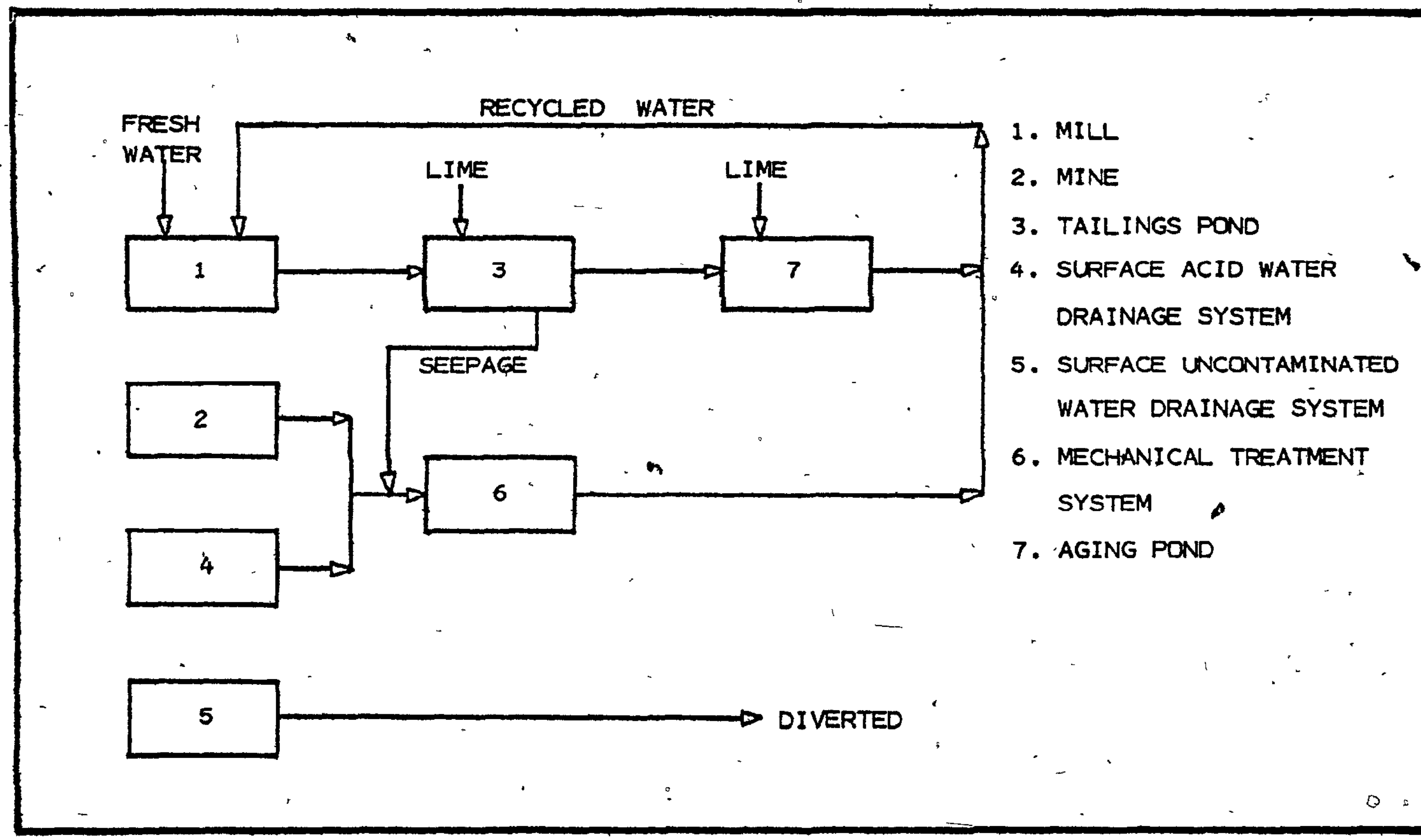

Figure 4. Flowsheet for level 3 of wastewater treatment; type 1 deposits

Deposits of Type 2 or 3

When the ore milled originates from type 2 or 3 deposits, reclaimed water can be fully recycled to the mill. The treatment system is simpler than the one for type 1 deposit ores and is presented in Figure 5. In dealing with a type 2 or 3 deposit, control Level 3 is achieved when:

- Mill effluent is treated in the tailings pond. Pond overflow is recycled to the mill and tailings dam seepage is recycled to the pond.
- Acid mine and surface waters are treated in a holding pond.
- Uncontaminated surface waters are diverted.

The required operations for the system shown in Figure 5 are:

- Tailings slurries are pumped in the tailings pond.
- Acid mine waters are pumped out of the mine.
- Mill effluent is treated with lime in the tailings pond.
- Acid mine and surface waters are treated with lime in the holding pond.
- Tailings and holding pond overflow is recycled to the mill.
- Any necessary additional fresh water is pumped to the mill.
- Uncontaminated surface waters are collected and diverted.

4.2 Upgrading Effluent Control at Operating Mines

Improving to Level 2 the effluent control of a mine designed to operate at Level 1 : Increment A

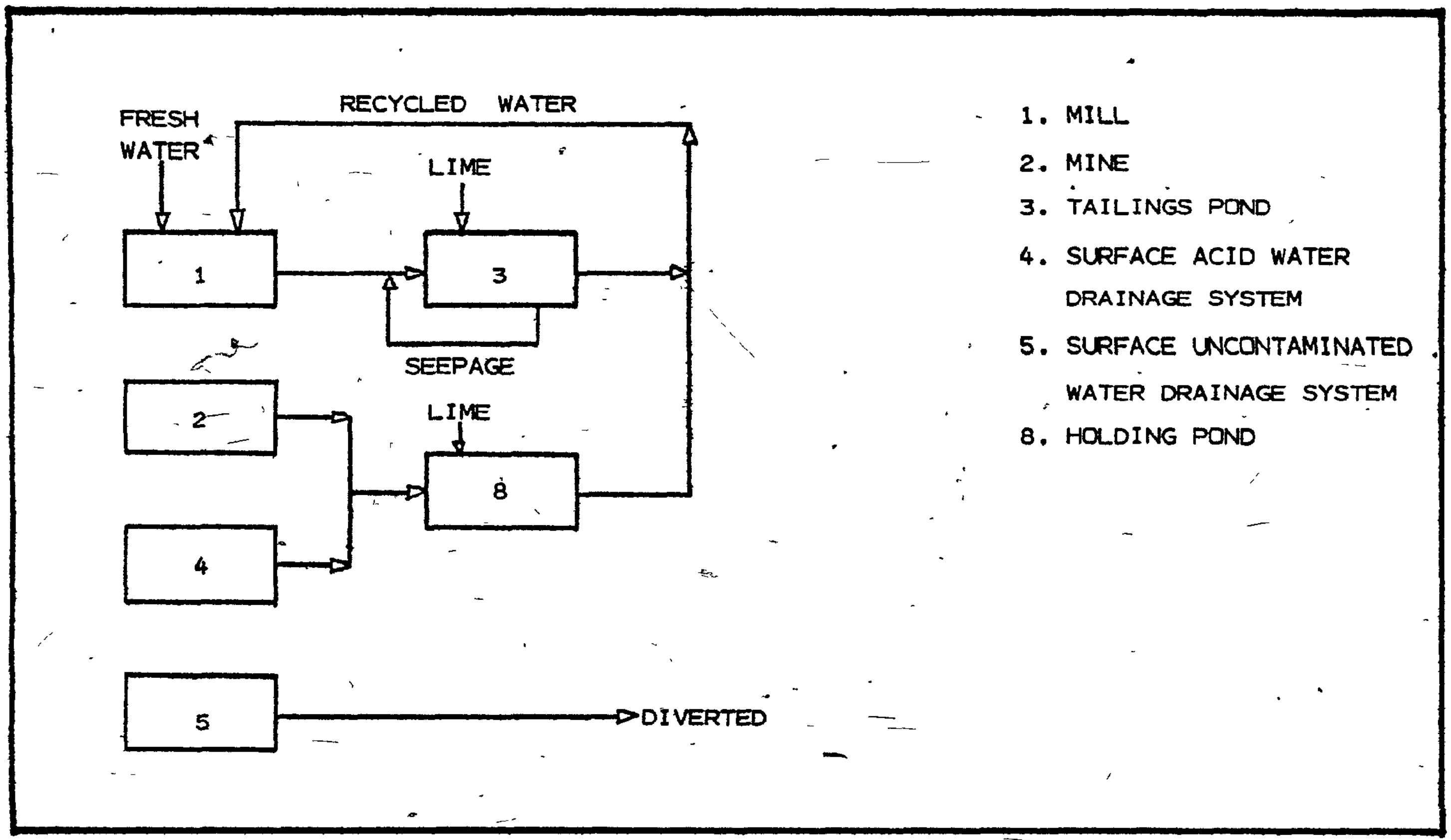

Figure 5. Flowsheet for level 3 of wastewater treatment; type 2 or 3 deposits

This increment involves the following operations:

- The existing tailings dam is upgraded in order to improve impermeability, seepage control and stability.
- Mill effluent is treated with lime in the tailings pond.
- Surface acid waters are collected.
- A holding pond is added to the system. Acid mine and surface waters are separately treated with lime in this holding pond. This new facility is required because the tailings pond, originally designed as a tailings storage area, is unable to provide sufficient control of treatment conditions for all effluents.
- Reclaimed water is recycled to the mill as in Level 2.

Figure 6 shows the flowsheet for control Level 2 posterior to upgrading the wastewater treatment system. Incremental operations are shown by dotted lines.

Improving to Level 3 the Effluent Control of a Mine Designed to Operate at Level 2: Increment B

Two different wastewater treatment flowsheets have been constructed for Level 3, depending on the type of ore processed. Thus, two different increment B flow sheets are considered.

Deposits of Type 1

To derive the flowsheet shown in Figure 5, the following changes are introduced to the flowsheet in Figure 4:

- An aging pond is added to the system downstream of the tailings pond.

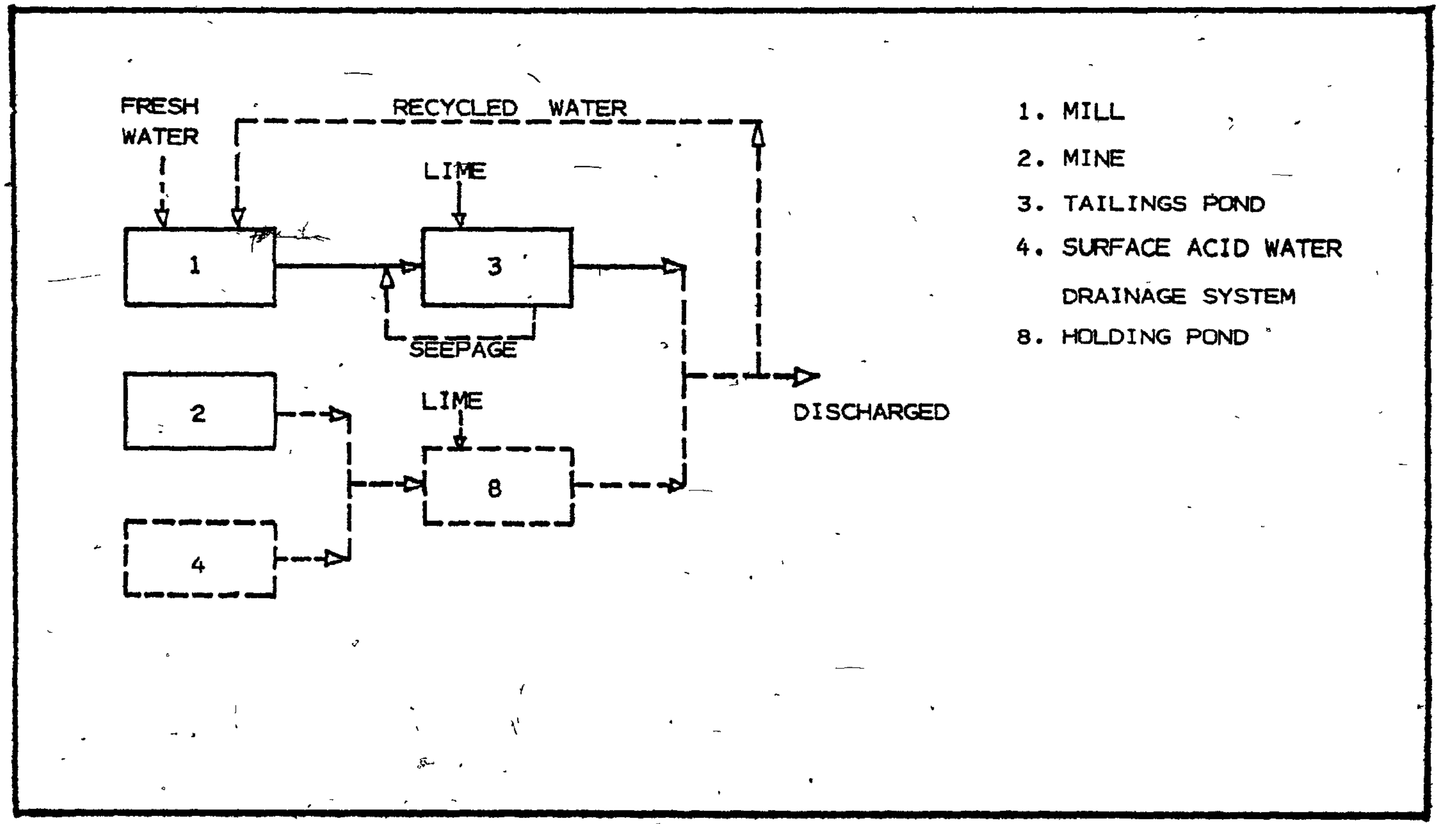

Figure 6. Flowsheet for increment A of wastewater treatment

- A mechanical acid water treatment facility is added to the system. Acid mine and surface waters are treated in this facility.
- The recycling rate is increased to the rate of Level 3.
- Uncontaminated surface waters are collected and diverted.

Increment B is shown by the dotted lines in Figure 7.

Deposits of Type 2 or 3

The Level 3 flowsheet for these deposit types is shown in Figure 5. The incremental operations are shown by dotted lines in Figure 8. The increment involves:

- The addition of a holding pond in the system. Acid mine and surface waters are treated with lime in this holding pond. The separate treatment of acid waters provides better treatment control in both the tailings and holding ponds.
- Uncontaminated surface waters are collected and diverted.
- Reclaimed water is recycled to the mill at the Level 3 rate.

Improving to Level 3 the effluent control of a mine designed to operate at Level 1 : Increment C

The effluent control of the mine has been upgraded from Level 1 to Level 2 by the addition of increment A. Increment C improves that effluent control to Level 3. With respect to deposit type, two different flowsheets are considered for increment C.

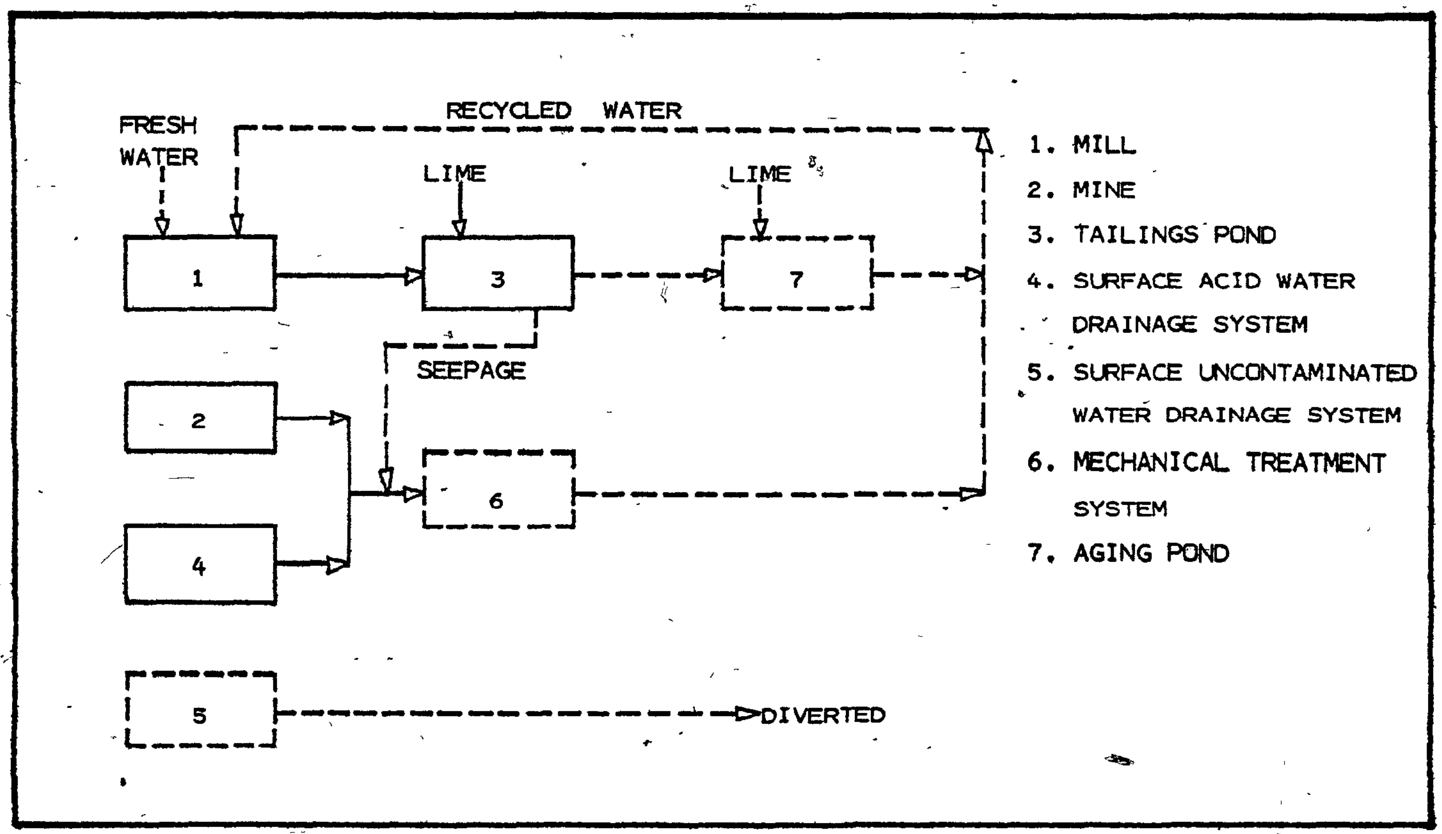

Figure 7. Flowsheet for increment B of wastewater treatment; type 1 deposits

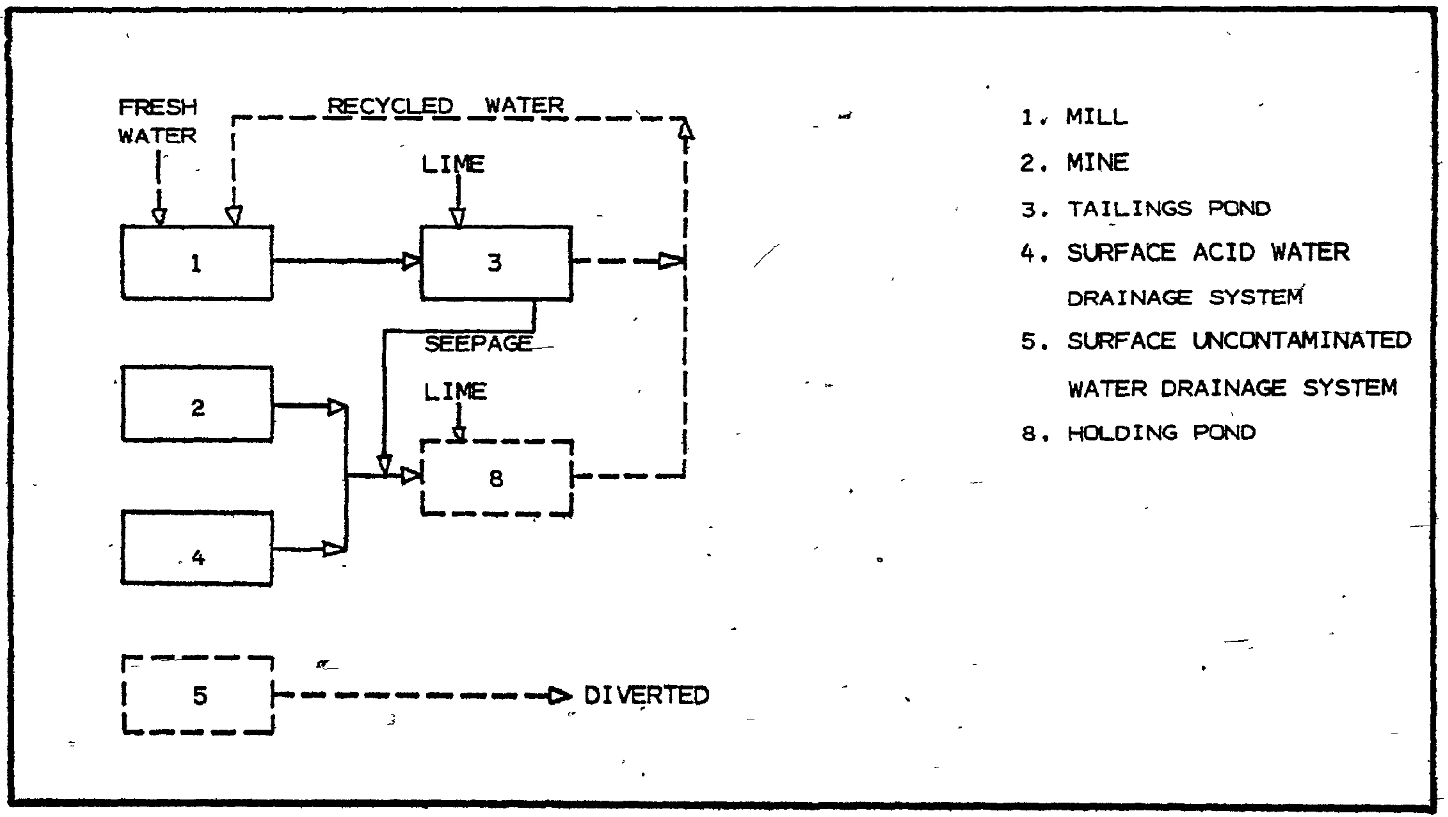

Figure 8. Flowsheet for increment B of wastewater treatment; type 2 or 3 deposits

Deposits of Type 1

The initial treatment system is the one shown in Figure 6. The increment required is shown by dotted lines in Figure 9. The holding pond of Figure 6 is used as aging pond for complete control of the tailings pond overflow. Increment C involves the following operations:

- A mechanical treatment facility is added in the system. Acid mine and surface waters are treated in this facility.
- Uncontaminated surface waters are collected and diverted.
- Reclaimed water is recycled at the Level 3 rate.

Deposits of Type 2 or 3

With respect to the Level 2 flowsheet shown in Figure 7, the required increment involves two additional operations:

- Uncontaminated surface waters are collected and diverted.
- Reclaimed water is fully recycled to the mill.

The tailings and holding ponds used for wastewater treatment at Level 2 are sufficient to ensure effluent quality control. Increment C is shown by dotted lines in Figure 10.

4.3 The Cost Estimating Procedure

The Methodology

There are two alternative ways to estimate pollution control costs:

1) All operations relevant to pollution control are costed and a percentage of the costs is allocated to pollution control. Thus, the

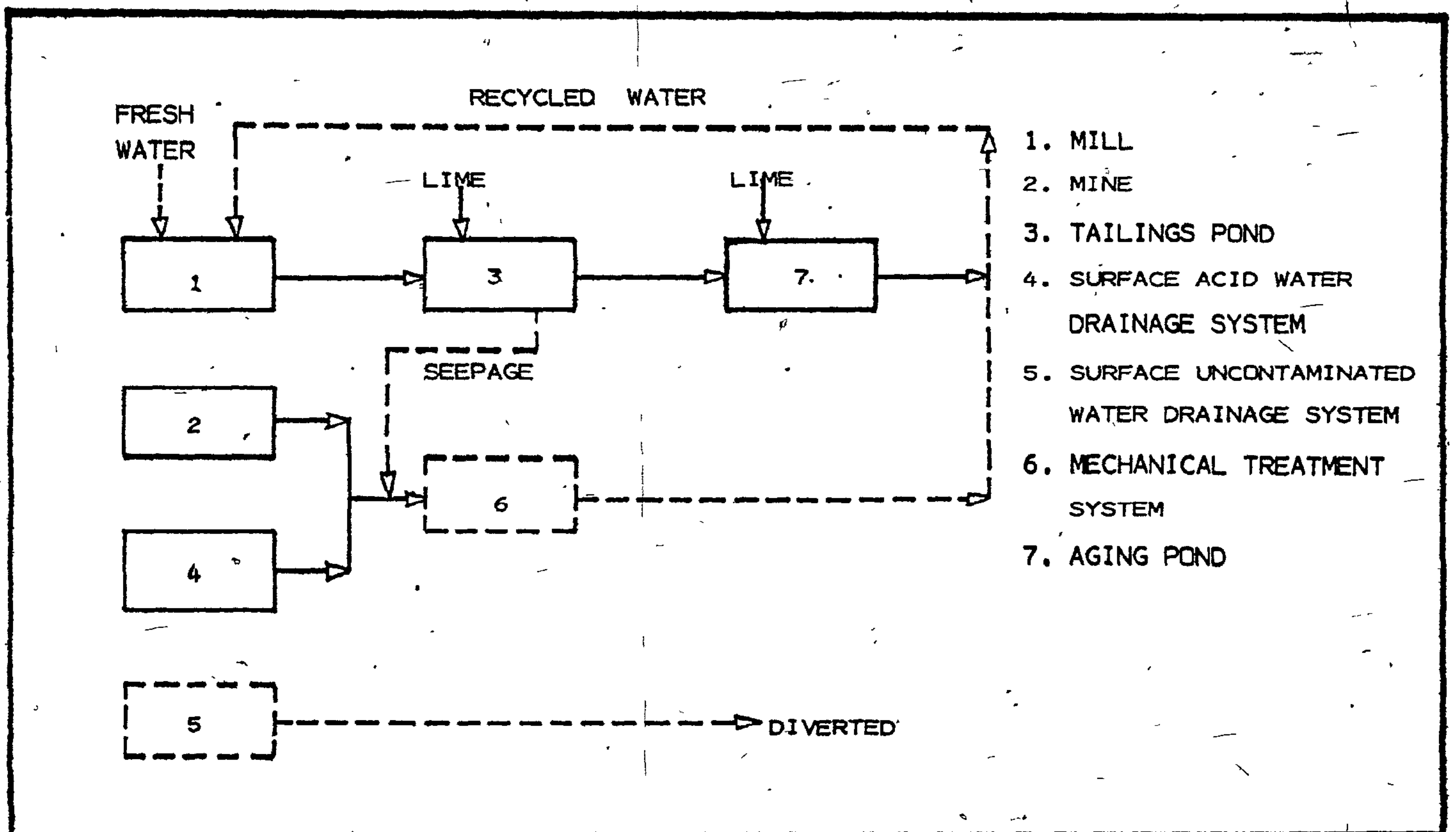

Figure 9. Flowsheet for increment C of wastewater treatment; type 1 deposits

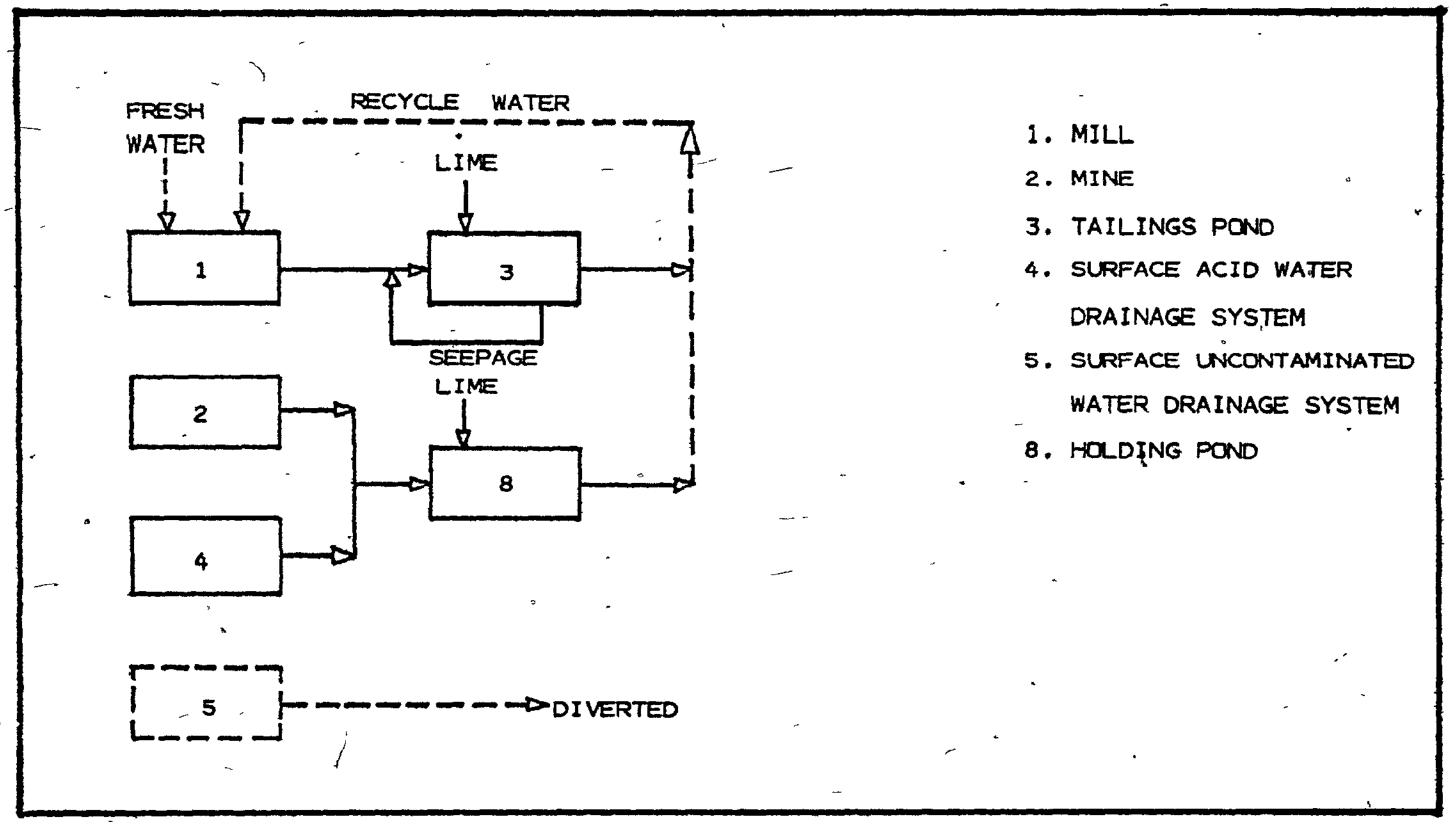

Figure 10. Flowsheet for increment C of wastewater treatment; type 2 or 3 deposits

cost of the tailings dam would be arbitrarily divided into two parts: the first considered to be a component of the mine's production costs and the second considered a requirement for compliance with the specific control level. The total cost of pollution control would then be the sum of all cost components allocated to pollution control.

2) All operations affected by changes in the level of wastewater treatment are costed. Total capital or operating costs at any specific level would then be:

$$TC_{\ell} = NC + C_{\ell} \tag{4.1}$$

where:

TC_{ℓ} = total capital or operating costs at Level ℓ.

NC = capital or operating costs of all operations not affected by changing treatment levels. Hereafter, these costs will be called <u>unrelated</u> costs.

C_{ℓ} = capital or operating costs of all operations affected by changing treatment levels. Hereafter, these costs will be called <u>related</u> costs.

ℓ = pollution control level.

The first method shows the cost of pollution control for the specific control level. This cost, however, is based on the arbitrarily chosen percentage rate used to allocate a part of every relevant cost to pollution control. Moreover, this method does not allow a direct comparison of the costs at different control levels. The second method results in a value showing the related costs at the specific control level. This value cannot be called pollution control costs, since it comprises operating requirements as well. This value, however, can be used to evaluate economic characteristics of individual deposits and of the endowment at different control levels. These evaluations are possible since total capital and operating costs for each control level can be computed by applying formula (4.1). Because of this ability, the second method has been selected for the purposes of this study.

The costing procedure used is built around five basic assumptions:

1) The producing unit at every deposit is a mine-mill complex, in which all mined ore is processed by the milling facility. This assumption is representative of isolated mines. It is less representative of the case where many small mines operate in the same district and large mills custom process their outputs. Even in these cases, however, the situation from a total cost point of view is not seriously affected. Higher costs resulting from more stringent controls will be passed to the mine operators through higher processing fees, ultimately affecting their economic characteristics.
2) The tailings pond is the basic water treatment system. Apart from very few cases where tailings are deposited in lakes and one case of deep sea disposal, the tailings pond is standard practice throughout the Canadian mining industry and the studied database. Tailings ponds handle both tailings disposal and effluent treatment. They have enough flexibility to perform several treatment processes resulting in an acceptable effluent quality in most situations.
3) All tailings are stored in the tailings area. They are not used as backfill nor are they recycled in any other way.

4) The basic relationship governing the water volumes in the circuit is:

$$F + P + M = E + T + D \qquad (4.2)$$

where:

F = fresh input process water.

P = precipitation within the dam controlled area.

M = mine waters.

E = evaporation from tailings pond and other ponds.

T = water retained in tailings.

D = discarded effluent.

The left side of equation (4.2) represents the inputs of water in the system and the right side represents the outputs. Discharge is eliminated ($D = 0$), when:

$$F + P + M = E + T \qquad (4.3)$$

If, however, $P + M > E + T$, discharge cannot be eliminated and $D = P + M - (E + T)$. For the purposes of this study, it is assumed that at Level 3, the equation (4.3) is satisfied by keeping to the necessary minimum the area which contributes surface runoff to the water balance.

5) It is possible to recycle reclaimed water before complete elimination of frothers. In such a case, some frother concentration is recycled. Operating cost savings may result from the reduced need of new frother introduction in the process water. This potential reduction in operating costs is not considered in this study.

Within the mine-mill complex, control level changes are expected to affect all operations connected with water supply, water usage and tailings disposal. Consequently, all of them should be costed. Two operations, however, remain unaffected by control level changes. These are:

- Pumping mine waters to surface.
- Pumping or otherwise transporting tailings slurries to the tailings pond.

All the other operations defined in Sections 4.1 and 4.2 are considered and their capital and operating costs are estimated. These operations include:

- Construction of tailings ponds.
- Construction of holding ponds.
- Supply of fresh water to the mill.
- Supply of recycled water to the mill.
- Collection of acid surface waters.
- Collection and diversion of uncontaminated surface waters.
- Treatment of effluents with lime in the tailings or holding pond.
- Treatment of acid waters in the mechanical treatment system.

The Computer Model

The computer modelling process is carried out in three steps.

In the first step, program MINPOL computes the capital and operating pollution control related costs for each of the three levels and increments described in Section 1.3. These costs are computed for each of the 131 Canadian base metal deposits of the database.

In the second step, an intermediate program computes the total capital and operating costs at each level or increment, as follows.

The database includes estimates of total capital and operating costs for each deposit. In estimating these costs, compliance with the current federal regulations is assumed. The unrelated costs for each deposit are calculated by applying equation (4.1); thus,

$$NC = TC_2 - C_2$$

where:

TC_2 is the cost specified in the database and C_2 is the pollution control related cost computed by program MINPOL for level 2. Total costs for Levels 1 and 3 are also derived applying equation (4.1):

$$TC_1 = NC + C_1 \text{ , and}$$

$$TC_3 = NC + C_3 \text{ .}$$

The output of this program is three datasets containing the information necessary for the economic evaluation of all 131 deposits at each pollution control level.

In the third step, the datafiles are processed by program MINDEC[3], in order to assess the economic characteristics of the endowment under each control level and permit comparisons of results between different levels.

Program MINPOL : Estimation of Pollution Control Related Costs for Each Control Level and Increment

Organization of the Model

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[3]For further details, see "Effects of Taxation on Base Metal Mining in Canada", B.W.Mackenzie, M.Bilodeau, Centre for Resource Studies, 1979.

For each deposit, the model first determines the technical characteristics of the operations involved with each level. Subsequently, it costs each operation based on the technical characteristics relevant to the specific deposit. The costing procedure used is the one presented by Scott and Bragg (1975a). The curves used are shown in Appendix 4. Technical characteristics mostly depend on the particularities of the specific operation as well as on its environment. It is sometimes impossible to obtain all the necessary data relevant to each operation. Extrapolations or average industry values are used in these instances. Total capital costs are computed by adding all capital expenses as well as a 15% contingency. A 5% contingency is added to total operating costs. The inflation multipliers shown in Appendix 5 are used to convert current to constant dollar values. The flow-chart of program MINPOL is given in Appendix 6.

Input Data

The following data are supplied for each deposit:

- location: flat or mountaineous relief
- type of deposit
- mean annual precipitation in the deposit's region
- number of ore reserve categories[4]
- recoverable tonnage for each ore reserve category
- annual mill capacity
- mine type: open pit or underground

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[4] Any change in a major factor during the mine life delineates a different ore reserve category. Such factors are grade, mine type and mill capacity.

Simulation of Technical Characteristics and Costs of Wastewater Treatment Related Operations

i. Tailings Dam Dimensions and Costs

The tailings pond is assumed to have the shape ABCDA shown in Figure 11. BC is the length of the tailings dam when completed and DE is its height. (AE and BC are horizontal). Moreover, the relationship between AE and BC is assumed to depend on whether the mine is located in a flat or in a mountainous region.

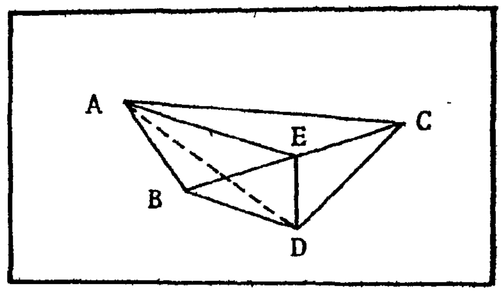

Figure 11. Assumed shape of the tailings pond.

In the first case, AE = 2 x BC, showing a short and wide tailings pond. In the second case, AE = 4 x BC, showing a long and narrow pond.

The tailings pond is expected to permanently hold all tailings resulting from exploitation of total reserves.[5] The dam height is assumed to be a function of location and total recoverable reserves, ranging from 30 ft[6] to 110 ft for a flat relief and from 50 ft to 250 ft for a mountainous relief. For every deposit, the model determines the tailings dam dimensions. The dam construction technique may change depending on control level. Dam dimensions, however, determined on the basis of tailings volume, remain constant. In the case of Level 1, the construction method may be upstream or downstream, depending on dam height. For

[5]The tailings density used is 20 cu ft/ton (0.624 m^3/metric ton).

[6]1 ft = 0.3048 m.

Level 2 and 3, however, because of structural requirements only the downstream method is considered. Starter dam height is assumed to be a function of location and main dam height. It can vary from 10 ft to 25 ft when the mine is located in a flat relief and from 15 ft to 40 ft if the mine is located in a mountainous relief. Cyclones are used to classify the tailings used for dam construction at Level 1. Cyclone sizes of 300 tons, 1,000 tons and 5,000 tons[7] per day are considered. Cyclone size selection depends on mill daily capacity, as shown in the chart below.

Mill Daily Capacity in Tons		Cyclone Size in Tons/Day
From	To	
0	2,000	300
2,000	10,000	1,000
10,000	up	5,000

The costs of wastewater treatment operations are estimated using the curves in Appendix 4. Figure 22 shows the cost per foot run of a dam constructed of tailings. This method is used for Level 1. Figure 23 shows the cost per foot run

[7] 1 ton = 0.907 metric tonne.

of a zoned dam, constructed as to comply with control Levels 2 and 3. Cyclone capital costs are derived from the graph in Figure 24 and starter dam costs from the graph in Figure 25. For the purposes of dam costing, an adjustment is made with respect to dam dimensions. This adjustment compensates for the assumed triangular elevation of the dam (maximum height occurs only at the center). The same procedure is used to estimate holding pond dimensions and costs. Holding ponds are designed on a 5-day effluent retention basis.

ii. Process Water Volume Estimation

Accurate estimation of the water volumes in every mining operation requires an assessment of the variables of equation (4.2). Because of the lack of detailed data for each operation, a simplified approach has been taken. For all deposits of the same type, the following average values have been used for total mill water requirements and recycling rates (Scott and Bragg, 1975b).

Type 1 Deposits

average water usage:	403 gpm/1000 tpd[8]
current average recycling rate:	30-40%
target recycling rate:	75%

[8] 1 gpm/1000 tons per day (1 gallon per minute per 1000 tons of daily capacity) = 7.21 ℓ/metric tonne per day.

Type 2 and 3 Deposits

average water usage: 668 gpm/1000 tpd

current average recycling rate: 78%

target recycling rate: 100%

Mill water requirements and recycling rates relevant to each deposit are defined on the basis of deposit type. At Level 1, it is assumed that all required water is pumped in from a fresh water source. At Level 2, the recycling rate is assumed to be the current average. At Level 3, the recycling rate is considered to be the industry's target rate. Additional mill water requirements are covered by fresh water. Incremental recycling rates are the difference between initial recycling rates and final recycling rates.

iii. Pumping and Piping

Two important design factors missing from the data base are the length of tailings line and fresh water supply line. The length of tailings line is assumed to be equal to the length of recycling line. Average industry values (Canadian Mining Journal, 1978) have been used for these factors. These values are 6,300 ft for the recycling line and 8,000 ft for the fresh water supply line. A head of 150 ft has been assumed for the calculation of pump and motor requirements. Figure 26 shows how the approximate break horsepower and pump costs are determined. The motor costs are determined from Figure 27. Installed costs are obtained by multiplying total purchase costs by 1.43. The costs of transmission lines and pumphouses are added to installed costs. Pipes are assumed to be made of stainless steel and installed on grade. Pipe diameter and cost are determined from the nomograph in Figure 28 and are a function of slope and water flow. Extra costs for grade preparation and pipe installation are added to materials costs. An overall adjustment is made to compensate for unaccounted seepage recycling installations, inter-pond connections, etc. Operating costs for pumping and piping include power, labour and maintenance.

iv. Contaminated and Uncontaminated Runoff Control

The area that contributes acid waters to the system is assumed to be 0.04 acres per ton[9] of daily capacity for underground mines[10] (Scott and Bragg, 1975b). For open pit mines this value is assumed to be 0.05 acres per ton of daily capacity. These assumptions are made for Levels 2 and 3. The contributing area is assumed to be 0.08 and 0.1 acres per ton of daily capacity for increments B and C. These latter values are greater because existing facilities do not allow an arrangement to minimize the contributing area. The 24-hour design storm is assumed to be 25% of annual rainfall. Figure 29 gives the flow in cu ft/sec,[11] and the excavation cost per foot run (earth excavation). Total length of collecting ditches is also related to the contributing area ($4 \times \sqrt{\text{contributing area}}$). Annual operating costs are considered to

[9] 1 acre/ton = 4,472.5 m^2/metric tonne (t).

[10] For new underground mines located in Northeastern New Brunswick, it is recommended that the area contributing contaminated surface waters be limited, where feasible, to 0.04 acres/ton of daily mill capacity.

[11] 1 cu ft/sec = 28.32 ℓ/sec.

be 6% of capital costs.

v. Lime Treatment

Lime treatment costs are a function of residual effluent acidity which varies with the deposit type. Residual acidity is assumed to be 3,000 mg/ℓ of $CaCO_3$ for type 1 deposits, 500 mg/ℓ for type 2 deposits and 50 mg/ℓ for type 3 deposits. Cost calculations are based on Figure 30 and on the estimated total water volume. A capital expense of $30,000 is associated with handling facilities at each point of lime introduction.

vi. Mechanical Treatment of Acid Waters

Residual acidity is again assumed to be 3,000 mg/ℓ. Capital and operating costs for mechanical treatment are derived from Figure 31.

CHAPTER 5. ANALYSIS OF RESULTS

The estimated costs related to pollution control are presented in Section 5.1. The distributions of costs are analyzed with respect to mine size and deposit type and they are broken down into their major components. Finally, the relationship of these costs to total capital and operating costs is examined.

Section 5.2 analyzes the effects of the estimated pollution control costs on the potential value to society. This potential value reflects the fundamental value of the Canadian base metal endowment. It includes all direct costs and revenues and represents the surplus which is potentially available prior to mining taxation considerations.

In Section 5.3 assessments on an after-tax basis are made assuming current Canadian mining taxation conditions. These assessments are made from the viewpoints of Canadian society, the mining company as investor and government as the tax collector.

Finally, the results are discussed in Section 5.4.

5.1 Estimated Costs Related to Pollution Control

Selected lists of estimated capital and operating costs related to pollution control are shown in Tables 10 to 12 for each of the three control levels. Complete distributions of costs are presented in Figures 12 to 15. These distributions are presented in the form of histograms. The last class of every histogram represents the number

L E V E L 1 COST OF CAPITAL= 8%

ECONOMIC CHARACTERISTICS

1	2	3	4	5	6	7	8	9
	*1000 TONS	$/T	$/T	$/T	$/T	$/T	1000$	$/T
[redacted]	3000.	0.13	0.15	0.02	0.00	0.01	955.	0.03
[redacted]	4000.	0.10	0.11	0.01	0.00	0.01	955.	0.03
[redacted]	750.	0.10	0.40	0.05	0.00	0.03	433.	0.09
[redacted]	750.	0.10	0.40	0.05	0.00	0.03	433.	0.09
[redacted]	750.	0.10	0.40	0.05	0.00	0.03	433.	0.09
[redacted]	2000.	0.12	0.22	0.02	0.00	0.02	781.	0.04
[redacted]	300.	0.14	0.81	0.05	0.01	0.07	327.	0.14
[redacted]	250.	0.14	0.97	0.06	0.01	0.09	318.	0.17
[redacted]	750.	0.16	0.35	0.07	0.00	0.03	437.	0.11
[redacted]	1500.	0.18	0.20	0.03	0.00	0.02	653.	0.05
[redacted]	3000.	0.09	0.15	0.01	0.00	0.01	820.	0.03
[redacted]	350.	0.14	0.69	0.05	0.01	0.06	335.	0.12
[redacted]	250.	0.15	0.97	0.10	0.01	0.09	323.	0.20
[redacted]	400.	0.14	0.61	0.04	0.01	0.05	344.	0.11
[redacted]	400.	0.14	0.61	0.04	0.01	0.05	346.	0.11
[redacted]	400.	0.12	0.65	0.05	0.01	0.06	355.	0.12
[redacted]	800.	0.10	0.38	0.03	0.00	0.03	439.	0.07
[redacted]	800.	0.10	0.38	0.03	0.00	0.03	439.	0.07
[redacted]	250.	0.15	0.97	0.06	0.01	0.04	322.	0.16
[redacted]	500.	0.16	0.52	0.06	0.01	0.05	395.	0.12
[redacted]	350.	0.15	0.75	0.04	0.01	0.07	361.	0.12
[redacted]	500.	0.11	0.52	0.04	0.01	0.05	365.	0.10
[redacted]	200.	0.18	1.21	0.10	0.01	0.11	321.	0.23
[redacted]	200.	0.18	1.21	0.10	0.01	0.11	321.	0.23
[redacted]	600.	0.09	0.50	0.04	0.01	0.04	412.	0.09
[redacted]	350.	0.11	0.75	0.05	0.01	0.07	346.	0.13
[redacted]	2200.	0.07	0.20	0.03	0.00	0.02	606.	0.05
[redacted]	4500.	0.04	0.12	0.02	0.00	0.01	841.	0.04
[redacted]	4500.	0.04	0.12	0.02	0.00	0.01	841.	0.04
[redacted]	10000.	0.05	0.08	0.02	0.00	0.01	1485.	0.03
[redacted]	6500.	0.06	0.12	0.03	0.00	0.01	1317.	0.04
[redacted]	6500.	0.06	0.12	0.03	0.00	0.01	1317.	0.04
[redacted]	6500.	0.06	0.12	0.03	0.00	0.01	1317.	0.04
[redacted]	6500.	0.06	0.12	0.03	0.00	0.01	1317.	0.04
[redacted]	500.	0.09	0.52	0.03	0.01	0.05	353.	0.08
[redacted]	9500.	0.05	0.08	0.02	0.00	0.01	1377.	0.03
[redacted]	9500.	0.05	0.08	0.02	0.00	0.01	1377.	0.03
[redacted]	250.	0.11	0.97	0.04	0.01	0.09	310.	0.14
[redacted]	1800.	0.07	0.25	0.03	0.00	0.02	668.	0.06
[redacted]	1800.	0.07	0.25	0.03	0.00	0.02	668.	0.06
[redacted]	250.	0.10	0.97	0.04	0.01	0.09	307.	0.14
[redacted]	8500.	0.06	0.09	0.02	0.00	0.01	1479.	0.03
[redacted]	8500.	0.06	0.09	0.02	0.00	0.01	1479.	0.03
[redacted]	13400.	0.05	0.09	0.02	0.00	0.01	2120.	0.03
[redacted]	13400.	0.05	0.09	0.02	0.00	0.01	2120.	0.03

1. DEPOSIT CODE
2. ANNUAL CAPACITY
3. COST OF STARTER DAM (CAPITAL COST)
4. FRESH WATER PUMPING AND PIPING CAPITAL COSTS
5. TAILINGS DAM CONSTRUCTION (OPERATING COST)
6. CYCLONE COST (OPERATING COST)
7. FRESH WATER PUMPING AND PIPING OPERATING COSTS
8. TOTAL CAPITAL COSTS
9. TOTAL OPERATING COSTS

*CAPITAL COSTS ARE EXPRESSED IN $/TON OF ANNUAL CAPACITY

Table 10. Estimated costs associated with pollution control for selected deposits; level 1 of control

LEVEL 2 COST OF CAPITAL= 8%

ECONOMIC CHARACTERISTICS

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	1000 TONS	$	$/T	$/T	$/T	$/T	$/T	$/T	$/T	$/T	$/T	$/T	1000$	$/T
[redacted]	3000.	348192.	0.13	0.11	0.04	0.00	0.37	0.02	0.30	0.01	0.02	0.12	2982.	0.28
[redacted]	4000.	464255.	0.10	0.08	0.03	0.00	0.28	0.02	0.23	0.01	0.01	0.12	2954.	0.24
[redacted]	750.	43286.	0.10	0.18	0.04	0.00	0.81	0.06	1.22	0.06	0.07	0.06	1925.	0.38
[redacted]	750.	43286.	0.10	0.18	0.04	0.00	0.81	0.06	1.22	0.06	0.07	0.06	1925.	0.38
[redacted]	750.	43286.	0.10	0.18	0.04	0.00	0.81	0.06	1.22	0.06	0.07	0.06	1925.	0.38
[redacted]	2000.	232128.	0.12	0.11	0.03	0.00	0.38	0.03	0.37	0.02	0.03	0.12	2120.	0.29
[redacted]	300.	34819.	0.14	0.31	0.04	0.00	2.02	0.14	1.89	0.12	0.17	0.12	1469.	0.73
[redacted]	250.	29016.	0.14	0.39	0.04	0.00	2.06	0.16	2.27	0.14	0.20	0.12	1353.	0.84
[redacted]	750.	87048.	0.16	0.19	0.03	0.00	0.87	0.06	0.91	0.05	0.07	0.12	1753.	0.44
[redacted]	1500.	174096.	0.18	0.17	0.03	0.00	0.50	0.03	0.50	0.03	0.03	0.12	2139.	0.37
[redacted]	3000.	348192.	0.09	0.09	0.03	0.00	0.37	0.02	0.30	0.01	0.02	0.12	2811.	0.25
[redacted]	349.	40622.	0.14	0.29	0.04	0.00	1.74	0.12	1.62	0.10	0.14	0.12	1479.	0.67
[redacted]	250.	29016.	0.15	0.35	0.04	0.00	2.06	0.16	2.27	0.14	0.20	0.12	1358.	0.80
[redacted]	400.	46426.	0.14	0.26	0.04	0.00	1.52	0.11	1.42	0.09	0.13	0.12	1485.	0.60
[redacted]	400.	46426.	0.14	0.25	0.04	0.00	1.52	0.11	1.42	0.09	0.13	0.12	1492.	0.60
[redacted]	400.	23086.	0.12	0.20	0.04	0.00	1.29	0.10	1.80	0.10	0.13	0.06	1577.	0.56
[redacted]	800.	11543.	0.10	0.18	0.03	0.00	0.76	0.05	1.14	0.06	0.06	0.01	1927.	0.33
[redacted]	800.	11543.	0.10	0.18	0.03	0.00	0.76	0.05	1.14	0.06	0.06	0.01	1927.	0.33
[redacted]	250.	29016.	0.15	0.34	0.04	0.00	2.06	0.16	2.27	0.14	0.20	0.12	1357.	0.79
[redacted]	500.	58032.	0.16	0.22	0.04	0.00	1.22	0.09	1.14	0.07	0.10	0.12	1524.	0.52
[redacted]	350.	20200.	0.15	0.27	0.04	0.00	1.47	0.11	1.94	0.11	0.14	0.06	1500.	0.58
[redacted]	500.	28850.	0.11	0.24	0.03	0.00	1.22	0.09	1.49	0.08	0.10	0.06	1697.	0.49
[redacted]	200.	2886.	0.18	0.38	0.05	0.00	2.58	0.19	3.40	0.19	0.25	0.01	1483.	0.83
[redacted]	200.	2886.	0.18	0.38	0.05	0.00	2.58	0.19	3.40	0.19	0.25	0.01	1483.	0.83
[redacted]	600.	8657.	0.09	0.24	0.03	0.00	1.01	0.07	1.24	0.07	0.08	0.01	1700.	0.41
[redacted]	350.	5050.	0.11	0.33	0.04	0.00	1.47	0.11	1.94	0.11	0.14	0.01	1492.	0.59
[redacted]	2200.	31743.	0.07	0.08	0.03	0.00	0.30	0.02	0.67	0.03	0.02	0.01	2740.	0.15
[redacted]	4500.	64930.	0.04	0.06	0.02	0.00	0.17	0.01	0.43	0.02	0.01	0.01	3453.	0.11
[redacted]	4500.	64930.	0.04	0.06	0.02	0.00	0.17	0.01	0.43	0.02	0.01	0.01	3453.	0.11
[redacted]	10000.	144288.	0.05	0.05	0.03	0.00	0.11	0.01	0.26	0.01	0.00	0.01	5318.	0.09
[redacted]	6500.	93787.	0.06	0.07	0.03	0.00	0.17	0.01	0.29	0.01	0.01	0.01	4194.	0.11
[redacted]	6500.	93787.	0.06	0.07	0.03	0.00	0.17	0.01	0.29	0.01	0.01	0.01	4194.	0.11
[redacted]	6500.	93787.	0.06	0.07	0.03	0.00	0.17	0.01	0.29	0.01	0.01	0.01	4194.	0.11
[redacted]	6500.	93787.	0.06	0.07	0.03	0.00	0.17	0.01	0.29	0.01	0.01	0.01	4194.	0.11
[redacted]	500.	7214.	0.09	0.17	0.03	0.00	1.22	0.09	1.49	0.08	0.10	0.01	1684.	0.37
[redacted]	9500.	137073.	0.05	0.06	0.02	0.00	0.12	0.01	0.28	0.01	0.01	0.01	5127.	0.09
[redacted]	9500.	137073.	0.05	0.06	0.02	0.00	0.12	0.01	0.28	0.01	0.01	0.01	5127.	0.09
[redacted]	250.	3607.	0.11	0.27	0.04	0.00	2.06	0.16	2.72	0.15	0.20	0.01	1472.	0.63
[redacted]	1800.	25972.	0.07	0.09	0.02	0.00	0.36	0.03	0.81	0.03	0.03	0.01	2697.	0.17
[redacted]	1800.	25972.	0.07	0.09	0.02	0.00	0.36	0.03	0.81	0.03	0.03	0.01	2688.	0.17
[redacted]	250.	3607.	0.10	0.28	0.04	0.00	2.06	0.16	2.72	0.16	0.20	0.01	1469.	0.63
[redacted]	8500.	122645.	0.06	0.06	0.03	0.00	0.13	0.01	0.31	0.01	0.01	0.01	5275.	0.10
[redacted]	8500.	122645.	0.06	0.06	0.03	0.00	0.13	0.01	0.31	0.01	0.01	0.01	5275.	0.10
[redacted]	13400.	193346.	0.05	0.05	0.07	0.00	0.10	0.01	0.20	0.01	0.00	0.01	6557.	0.08
[redacted]	13400.	193346.	0.05	0.05	0.07	0.00	0.10	0.01	0.20	0.01	0.00	0.01	6557.	0.08

1. DEPOSIT CODE
2. ANNUAL CAPACITY
3. ANNUAL COST OF LIME
4. COST OF STARTER DAM (CAPITAL COST)
5. TAILINGS DAM CONSTRUCTION (OPERATING COST)
6. SURFACE ACID WATER DRAINAGE SYSTEM CAPITAL COSTS
7. SURFACE ACID WATER DRAINAGE SYSTEM OPERATING COSTS
8. FRESH WATER PUMPING AND PIPING CAPITAL COSTS
9. FRESH WATER PUMPING AND PIPING OPERATING COSTS
10. RECYCLED WATER PUMPING AND PIPING CAPITAL COSTS
11. RECYCLED WATER PUMPING AND PIPING OPERATING COSTS
12. LIME TREATMENT CAPITAL COSTS
13. LIME COST (OPERATING COST)

CAPITAL COSTS ARE EXPRESSED IN $/TON OF ANNUAL CAPACITY

Table 11. Estimated costs associated with pollution control for selected deposits; level 2 control

L E V E L 3

ECONOMIC CHARACTERISTICS

COST OF CAPITAL= 8%

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
	1000 TONS	$/T	$/T	$/T	$/T	$/T	$/T	$/T	$/T	$/T	$/T	$/T	$/T	$/T	$/T	$/T	100C$	$/T
[redacted]	3000.	0.13	0.08	0.04	0.09	0.03	0.26	0.49	0.52	0.11	0.00	0.01	0.17	0.02	0.02	0.36	5627.	0.72
[redacted]	4000.	0.10	0.07	0.03	0.07	0.03	0.23	0.37	0.37	0.08	0.00	0.00	0.17	0.01	0.01	0.25	5753.	0.57
[redacted]	750.	0.10	0.15	0.04	0.08	0.13	0.82	1.22	0.00	0.18	0.00	0.00	0.09	0.05	0.06	0.00	2191.	0.39
[redacted]	750.	0.10	0.15	0.04	0.08	0.13	0.82	1.22	0.00	0.18	0.00	0.00	0.09	0.05	0.06	0.00	2191.	0.39
[redacted]	750.	0.10	0.15	0.04	0.08	0.13	0.82	1.22	0.00	0.18	0.00	0.00	0.09	0.05	0.06	0.00	2191.	0.39
[redacted]	2000.	0.12	0.09	0.03	0.06	0.05	0.39	0.46	0.45	0.11	0.00	0.00	0.17	0.02	0.02	0.26	3789.	0.63
[redacted]	300.	0.14	0.24	0.04	0.08	0.33	2.06	2.26	0.89	0.31	0.00	0.00	0.17	0.13	0.13	0.41	2085.	1.22
[redacted]	250.	0.14	0.26	0.04	0.08	0.40	2.47	2.72	0.98	0.39	0.00	0.00	0.17	0.16	0.15	0.47	2040.	1.41
[redacted]	750.	0.16	0.15	0.03	0.06	0.13	0.97	0.99	0.62	0.19	0.00	0.00	0.17	0.06	0.05	0.29	2689.	0.81
[redacted]	1500.	0.18	0.11	0.03	0.06	0.07	0.49	0.61	0.50	0.17	0.00	0.00	0.17	0.03	0.03	0.26	3517.	0.70
[redacted]	3000.	0.07	0.08	0.03	0.07	0.03	0.26	0.49	0.39	0.09	0.00	0.00	0.17	0.02	0.02	0.25	4964.	0.58
[redacted]	350.	0.14	0.22	0.04	0.07	0.29	1.77	1.94	0.83	0.29	0.00	0.00	0.17	0.11	0.11	0.41	2129.	1.15
[redacted]	250.	0.15	0.26	0.04	0.08	0.40	2.47	2.72	0.98	0.35	0.00	0.00	0.17	0.16	0.15	0.47	2044.	1.37
[redacted]	400.	0.14	0.21	0.04	0.07	0.25	1.54	1.70	0.78	0.26	0.00	0.00	0.17	0.10	0.10	0.35	2173.	1.03
[redacted]	400.	0.14	0.21	0.04	0.07	0.25	1.54	1.70	0.78	0.25	0.00	0.00	0.17	0.10	0.10	0.35	2175.	1.03
[redacted]	400.	0.12	0.17	0.04	0.07	0.25	1.54	1.86	0.00	0.28	0.00	0.00	0.09	0.10	0.10	0.00	1866.	0.57
[redacted]	800.	0.10	0.12	0.03	0.06	0.13	0.77	1.14	0.00	0.18	0.00	0.00	0.02	0.05	0.06	0.00	2166.	0.32
[redacted]	800.	0.10	0.12	0.03	0.06	0.13	0.77	1.14	0.00	0.18	0.00	0.00	0.02	0.05	0.06	0.00	2166.	0.32
[redacted]	250.	0.15	0.26	0.04	0.08	0.40	2.47	2.72	0.98	0.34	0.00	0.00	0.17	0.16	0.15	0.47	2043.	1.36
[redacted]	500.	0.16	0.19	0.04	0.07	0.20	1.24	1.36	0.73	0.22	0.00	0.00	0.17	0.08	0.08	0.32	2291.	0.92
[redacted]	350.	0.15	0.19	0.04	0.08	0.29	1.77	2.13	0.00	0.27	0.00	0.00	0.09	0.11	0.11	0.00	1866.	0.59
[redacted]	500.	0.11	0.16	0.03	0.07	0.20	1.24	1.49	0.00	0.24	0.00	0.00	0.09	0.08	0.08	0.00	1897.	0.49
[redacted]	200.	0.18	0.25	0.05	0.09	0.50	3.09	3.40	0.00	0.38	0.00	0.01	0.02	0.19	0.19	0.00	1737.	0.80
[redacted]	200.	0.18	0.25	0.05	0.09	0.50	3.09	3.40	0.00	0.38	0.00	0.01	0.02	0.19	0.19	0.00	1737.	0.80
[redacted]	600.	0.09	0.14	0.03	0.07	0.17	1.03	1.52	0.00	0.24	0.00	0.00	0.02	0.06	0.07	0.00	2109.	0.41
[redacted]	350.	0.11	0.19	0.04	0.08	0.29	1.77	2.13	0.00	0.33	0.00	0.00	0.02	0.11	0.11	0.00	1849.	0.53
[redacted]	2200.	0.07	0.14	0.03	0.06	0.05	0.33	0.67	0.00	0.08	0.00	0.00	0.02	0.02	0.03	0.00	3380.	0.15
[redacted]	1500.	0.04	0.09	0.02	0.05	0.02	0.16	0.43	0.00	0.06	0.00	0.00	0.02	0.01	0.02	0.00	4216.	0.11
[redacted]	4500.	0.04	0.09	0.02	0.05	0.02	0.16	0.43	0.00	0.06	0.00	0.00	0.02	0.01	0.02	0.00	4216.	0.11
[redacted]	10000.	0.05	0.06	0.03	0.06	0.01	0.08	0.26	0.00	0.05	0.00	0.00	0.02	0.00	0.01	0.00	6380.	0.09
[redacted]	6500.	0.06	0.08	0.03	0.05	0.02	0.12	0.40	0.00	0.07	0.00	0.00	0.02	0.01	0.01	0.00	5653.	0.11
[redacted]	6500.	0.06	0.08	0.03	0.05	0.02	0.12	0.40	0.00	0.07	0.00	0.00	0.02	0.01	0.01	0.00	5653.	0.11
[redacted]	6500.	0.06	0.08	0.03	0.05	0.02	0.12	0.40	0.00	0.07	0.00	0.00	0.02	0.01	0.01	0.00	5653.	0.11
[redacted]	6500.	0.06	0.08	0.03	0.05	0.02	0.12	0.40	0.00	0.07	0.00	0.00	0.02	0.01	0.01	0.00	5653.	0.11
[redacted]	500.	0.09	0.25	0.03	0.07	0.20	1.24	1.49	0.00	0.17	0.00	0.00	0.02	0.08	0.08	0.00	1938.	0.35
[redacted]	9500.	0.05	0.06	0.02	0.05	0.01	0.08	0.28	0.00	0.06	0.00	0.00	0.02	0.00	0.01	0.00	5994.	0.10
[redacted]	9500.	0.05	0.06	0.02	0.05	0.01	0.08	0.28	0.00	0.06	0.00	0.00	0.02	0.00	0.01	0.00	5994.	0.10
[redacted]	250.	0.11	0.33	0.04	0.08	0.40	2.47	2.72	0.00	0.27	0.00	0.00	0.02	0.16	0.15	0.00	1764.	0.61
[redacted]	1800.	0.07	0.15	0.02	0.05	0.06	0.34	0.81	0.00	0.09	0.00	0.00	0.07	0.02	0.03	0.00	3119.	0.17
[redacted]	1800.	0.07	0.12	0.02	0.04	0.06	0.34	0.81	0.00	0.05	0.00	0.00	0.02	0.02	0.03	0.00	3040.	0.17
[redacted]	250.	0.10	0.33	0.04	0.08	0.40	2.47	2.72	0.00	0.28	0.00	0.00	0.02	0.16	0.15	0.00	1760.	0.61
[redacted]	8500.	0.06	0.07	0.03	0.06	0.01	0.09	0.31	0.00	0.06	0.00	0.00	0.02	0.01	0.01	0.00	6212.	0.10
[redacted]	8500.	0.06	0.07	0.03	0.06	0.01	0.09	0.31	0.00	0.06	0.00	0.00	0.02	0.01	0.01	0.00	6212.	0.10
[redacted]	13400.	0.05	0.06	0.07	0.14	0.01	0.07	0.31	0.00	0.05	0.00	0.01	0.02	0.00	0.01	0.00	10562.	0.10
[redacted]	13400.	0.05	0.06	0.07	0.14	0.01	0.07	0.31	0.00	0.05	0.00	0.01	0.02	0.00	0.01	0.00	10562.	0.10

1. DEPOSIT CODE
2. ANNUAL CAPACITY
3. COST OF STARTER DAM (CAPITAL COST)
4. HOLDING DAM COST (CAPITAL COST)
5. SURFACE ACID WATER DRAINAGE SYSTEM CAPITAL COSTS
6. SURFACE UNCONTAMINATED WATER DRAINAGE SYSTEM CAPITAL COSTS
7. LIME TREATMENT CAPITAL COSTS
8. FRESH WATER PUMPING AND PIPING CAPITAL COSTS
9. RECYCLED WATER PUMPING AND PIPING CAPITAL COSTS
10. MECHANICAL TREATMENT CAPITAL COSTS
11. TAILINGS DAM CONSTRUCTION (OPERATING COST)
12. SURFACE ACID WATER DRAINAGE SYSTEM OPERATING COSTS
13. SURFACE UNCONTAMINATED WATER DRAINAGE SYSTEM OPERATING COSTS
14. LIME TREATMENT OPERATING COSTS
15. FRESH WATER PUMPING AND PIPING OPERATING COSTS
16. RECYCLED WATER PUMPING AND PIPING OPERATING COSTS
17. MECHANICAL TREATMENT OPERATING COSTS
18. TOTAL CAPITAL COSTS
19. TOTAL OPERATING COSTS

CAPITAL COSTS ARE EXPRESSED IN $/TON OF ANNUAL CAPACITY

Table 12. Estimated costs associated with pollution control for selected deposits; level 3 control

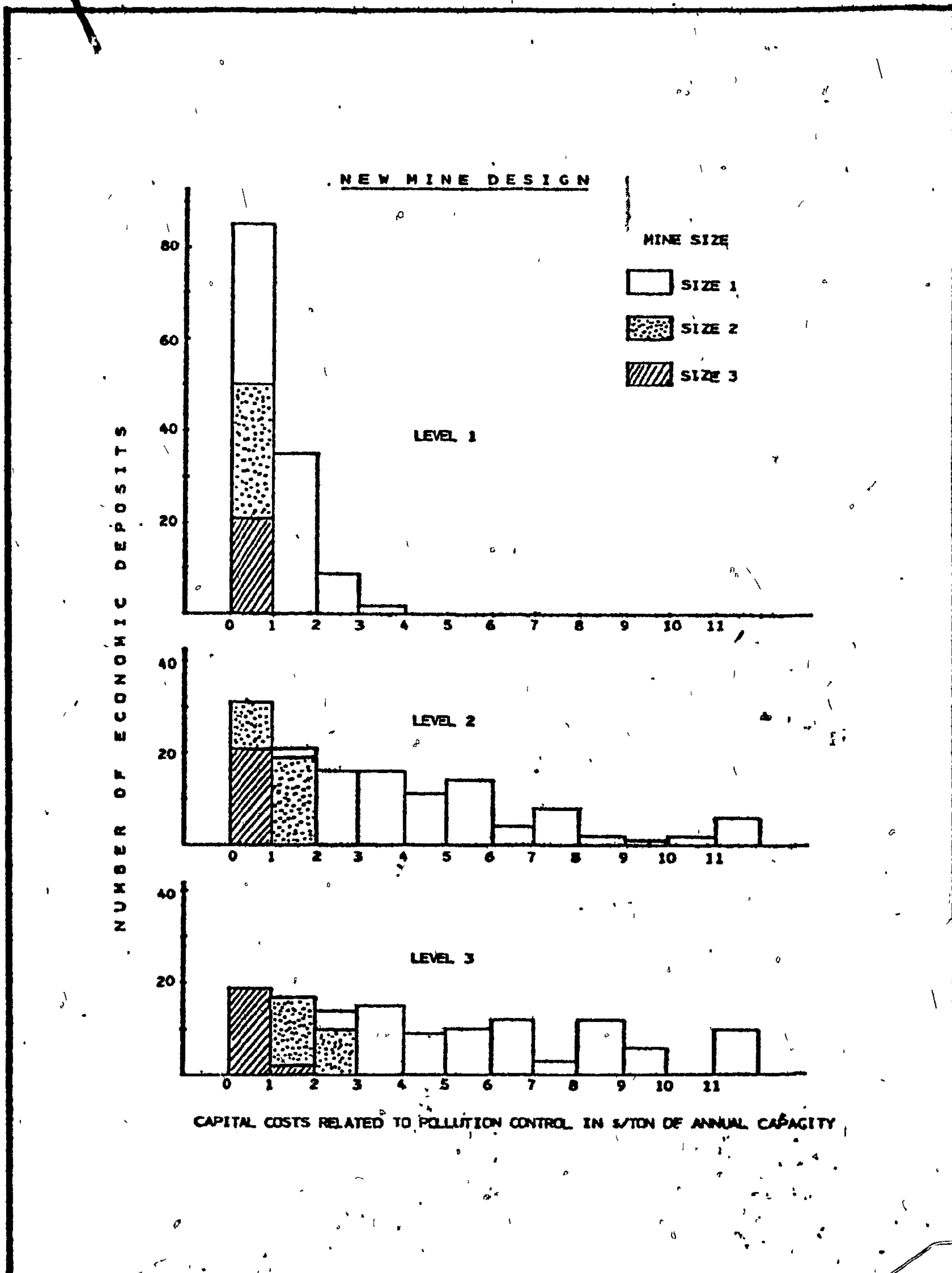

Figure 12. Distribution of capital costs related to pollution control for new mines

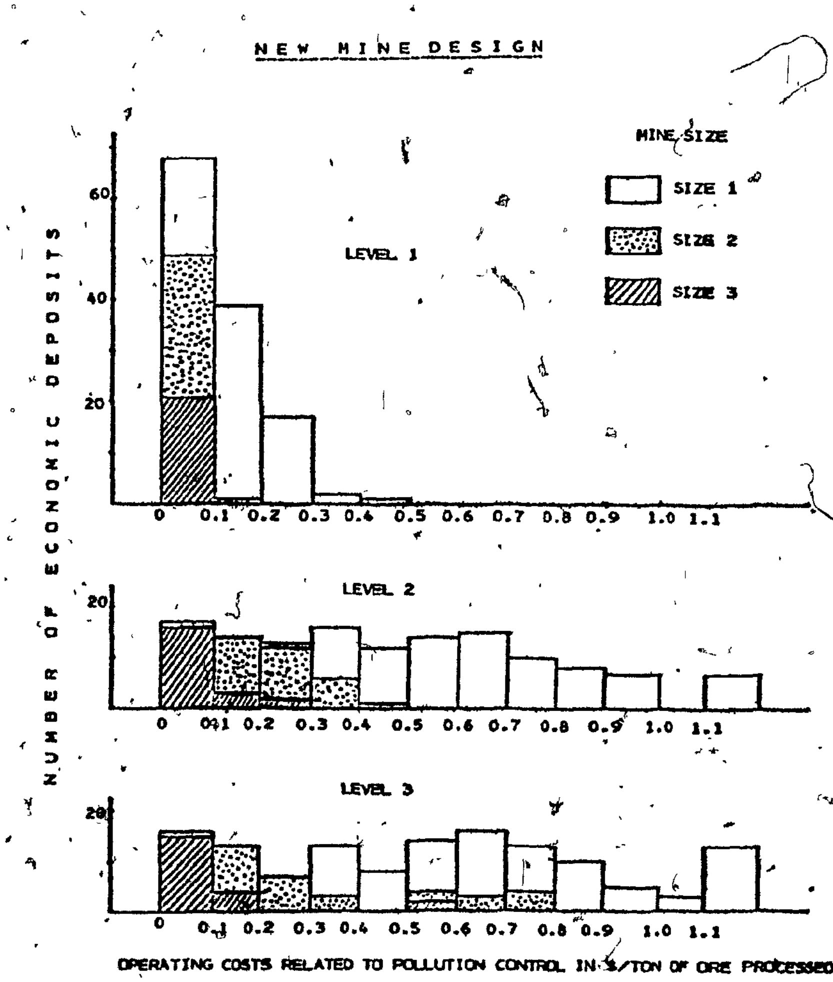

Figure 13. Distribution of operating costs related to pollution control for new mines

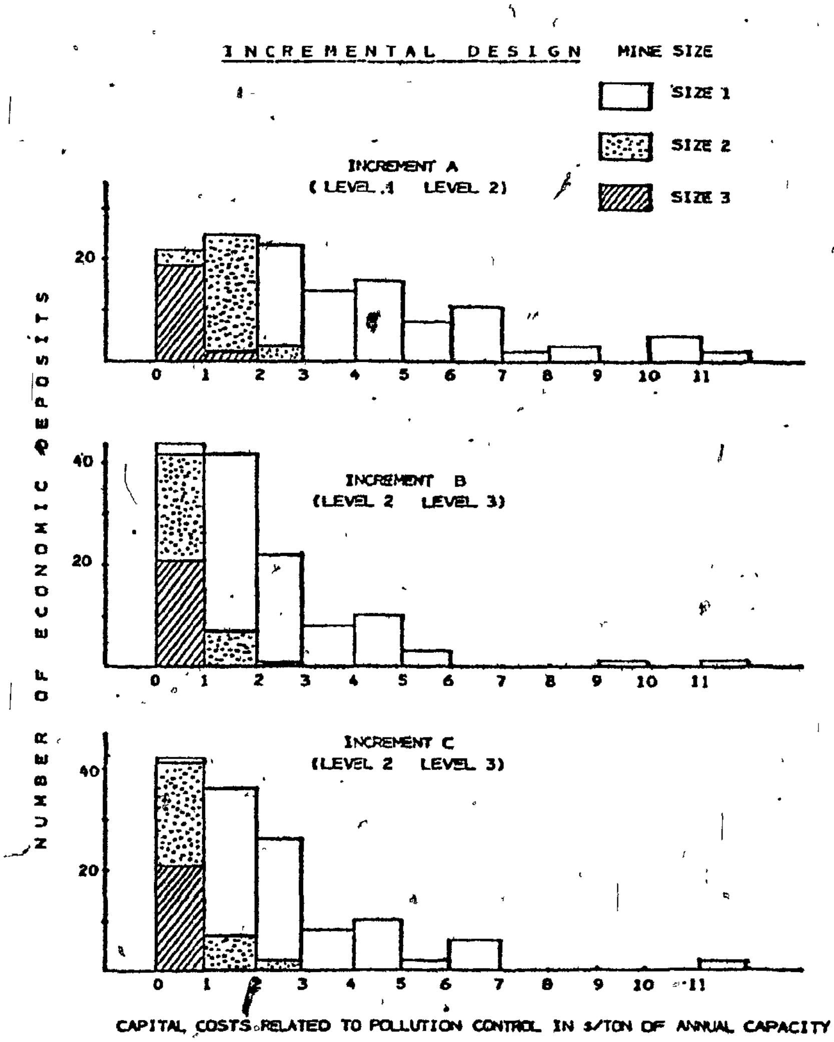

Figure 14. Distribution of capital costs related to pollution control for upgrading operating mines

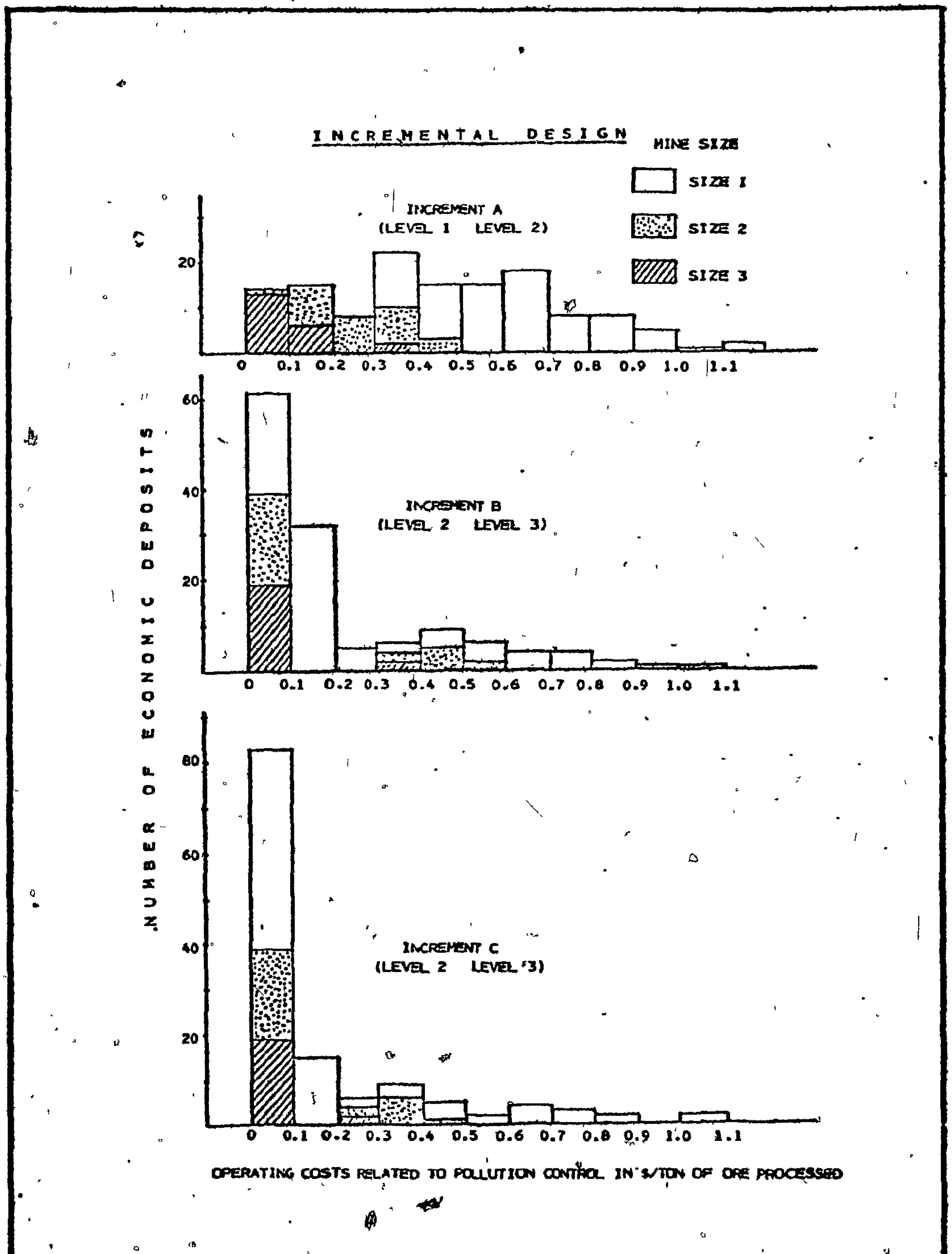

Figure 15. Distribution of operating costs related to pollution control for upgrading operating mines

of deposits having costs above the upper limit of the previous cost class. Each distribution shows a deposit size breakdown. Capital and operating costs assessed on a new mine design basis for each control level are presented in Figures 12 and 13. Figures 14 and 15 show the distributions of capital and operating costs assessed on an incremental basis, for each control increment. Tables 13 and 14 present the average capital and operating costs of all the deposits included in the database, with respect to mine capacity and deposit type. These averages can be used to show the relative magnitude of the estimated pollution control related costs with respect to the total figures.

Figure 12 shows the distributions of the related capital costs per ton of installed capacity for the three levels of pollution control. These costs are low for Level 1, because very few operations are performed. At Level 2, the related capital costs are significantly scattered. At Level 3, the distribution shifts to the right, typically showing an increase of about $1/ton compared with Level 2. The distributions of pollution related operating costs per ton for the three control levels are shown in Figure 13. The large deposits present in the high cost brackets are type 1 deposits. As shown in Figure 43 of Appendix 7, these deposits may have higher operating costs. The distributions of incremental capital costs are shown in Figure 14. It appears that Increment A involves higher capital costs. Increment A also involves higher operating costs, as shown in the distributions of incremental operating costs in Figure 15. The results clearly reflect economies of scale. Capacity has a significant effect on costs of small operations. This results in more variable costs for these operations.

The cost distributions are broken down by deposit types for each control level and increment in Appendix 7. Generally, type 1 deposits incur higher costs due to larger process water volumes, higher lime costs and additional treatment facilities. Pollution control related operations are simpler in the case of type 2 deposits. However, the overall small mine size of type 2 deposits results in high unit costs, comparable with those of type 1 deposits. Type 3 deposits pose less problems with respect to water pollution. This effect, combined with generally large mine sizes and the consequent economies of scale, results in low costs for these deposits.

Mine Capacity ('000 tons/year)	CC/ton of annual capacity ($)	OC/ton of ore processed ($)
0-1,000	59.22	14.49
1,000-5,000	38.75	9.33
more than 5,000	16.12	3.18

TABLE 13. Average capital and operating costs of all deposits as a function of mine capacity.

Deposit Type	CC/ton of annual capacity ($)	OC/ton of ore processed ($)
Cu-Zn-Pb, Zn-Pb	56.15	15.58
Cu-Zn-Ag-Au, Cu-Ag, Au	57.86	13.00
Cu, Cu-Mo, Mo	24.47	5.91

TABLE 14. Average capital and operating costs of all deposits as a function of deposit type.

		Cost Breakdown								
				Level 3			Incr. B		Incr. C	
		Level 1	Level 2	Type 1	Type 2,3	Inc. A	Type 1	Type 2,3	Type 1	Type 2,3
Size 1	struct.	15-30%	8-12%	13-17%	15-21%	30-40%	15-25%	40-55%	3-8%	8-15%
	pump.	70-85%	88-92%	63-73%	79-85%	60-70%	45-55%	45-60%	60-75%	85-92%
	mech. tr.	-	-	20-25%	-	-	25-35%	-	20-30%	-
Size 2	struct.	25-35%	15-23%	20-25%	25-30%	40-50%	20-35%	50-60%	5-15%	20-30%
	pump.	65-75%	77-85%	50-55%	70-75%	50-60%	30-45%	40-50%	45-55%	70-80%
	mech. tr.	-	-	27-30%	-	-	40-50%	-	40-60%	-
Size 3	struct.	35-45%	18-25%	25-30%	32-37%	50-60%	15-35%	60-70%	3-8%	30-40%
	pump.	55-65%	75-82%	45-50%	63-68%	40-50%	20-35%	30-40%	10-20%	60-70%
	mech. tr.	-	-	27-30%	-	-	40-50%	-	75-90%	-

TABLE 15. Breakdown of related capital costs as a function of mine size.

		Cost Breakdown								
				Level 3			Incr. B		Incr. C	
		Level 1	Level 2	Type 1	Type 2	Inc. A	Type 1	Type 2,3	Type 1	Type 2,3
Size 1	struct.	45-60%	45-50%	25-30%	40-45%	45-50%	1-5%	1-15%	1-5%	10-30%
	pump.	40-55%	30-40%	15-25%	30-40%	20-30%	5-20%	25-50%	15-25%	70-90%
	lime tr.	-	10-20%	15-20%	15-25%	20-30%	15-25%	45-75%	-	-
	mech. tr.	-	-	35-40%	-	-	60-70%	-	70-85%	-
Size 2	struct.	50-75%	40-55%	15-20%	45-50%	40-50%	1-5%	1-15%	1-5%	40-50%
	pump.	25-50%	20-25%	5-10%	15-25%	10-20%	3-15%	10-50%	10-20%	50-60%
	lime tr.	-	20-25%	25-30%	20-35%	30-40%	20-40%	40-70%	-	-
	mech. tr.	-	-	40-45%	-	-	60-70%	-	70-90%	-
Size 3	struct.	65-80%	55-65%	15-20%	60-65%	55-65%	1-5%	10-50%	1-5%	30-50%
	pump.	20-35%	20-25%	3-8%	18-23%	10-20%	3-15%	1-10%	1-5%	50-70%
	lime tr.	-	10-15%	30-35%	15-20%	20-30%	20-40%	40-80%	-	-
	mech. tr.	-	-	40-45%	-	-	60-70%	-	85-95%	-

TABLE 16. Breakdown of related operating costs as a function of mine size.

In Tables 15 and 16 the related capital and operating costs are broken down into their components. In this way the importance of each component and its behaviour under different control regulations may be examined. Capital costs are broken down into costs related to structures[1], pumping and piping costs and mechanical treatment costs where applicable. Operating costs are broken down into structure costs[2], pumping and piping costs, lime treatment and mechanical treatment where applicable. Pumping and piping costs realize the most important economies of scale with respect to both capital and operating costs. For Level 1 in Table 15 for example, the increase in structure costs from 15-30% (size 1) to 35-45% (size 3) typifies the economies of scale in pumping and piping costs, since structure costs per ton do not vary considerably with size. Structure cost is the most important component of operating costs. This cost is more sensitive to control level and topography than to mine size. Lime treatment cost is also insensitive to size. This cost depends upon the type of deposit.

Another aspect of the estimated pollution control costs is their relationship with total capital and operating costs. As has been set forth in Chapter 4, total costs in the database include the costs of compliance with current water pollution regulations (control Level 2). Tables 17 and 18 show the related capital and operating costs at all levels as a

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[1] Structures include the starter dam, holding (or aging) ponds, ditches for the collection of contaminated or uncontaminated surface runoff and lime handling facility. The capital costs of structures may include some or all of the above cost items, depending on the operations performed at the specific treatment level.

[2] They include the gradual construction of the tailings dam and maintenance of the surface runoff collecting network. Structure costs are mostly dam construction costs; the maintenance component is very small.

	Pollution Control Related Costs											
	Level 1		Level 2		Level 3		Incr. A		Incr. B		Incr. C	
Size	CC	OC	CC	OC	CC	OC	CC	OC	CC	OC	CC	OC
1	1.5-3.0	0.8-1.5	6-13	3-6	7-17	3-10	6-14	3-6	2-9	1-5	3-12	0.5-5
2	1-3.5	0.5-1.5	4-12	2-5	3-15	2-6	3-12	2-5	1-8	1-4	1-7	0.2-3
3	1-1.5	1-2	2-6	3-5	2-7	3-6	4-8	3-9	2-4	1-6	2-4	0.5-4

TABLE 17. Pollution control related capital and operating costs as percentages of total costs, as a function of mine size.

	Pollution Control Related Costs											
	Level 1		Level 2		Level 3		Incr. A		Incr. B		Incr. C	
Type	CC	OC	CC	OC	CC	OC	CC	OC	CC	OC	CC	OC
1	1-2.5	0.8-1.5	2-10	2-4	3-15	5-10	4-9	3-9	3-9	3-6	3-11	2-5
2	1-3	0.4-1	3-13	2-5	3-16	2-5	3-13	3-5	2-3	0.7-2	2-6	0.5-1.
3	1-3	1-2	2-12	3-5	4-15	3-6	4-15	3-5	1-2	1-2	2-5	0.3-1

TABLE 18. Pollution control related capital and operating costs as percentages of total costs, as a function of deposit type.

percentage of total costs at Level 2. The relationship between pollution control related costs and total costs is a function of size (reflecting economies of scale), rather than a function of deposit type. The deposit type, however, does have some significance in the relationship. In Table 17, the higher cost brackets correspond to type 1 deposits, both for capital and operating costs. It is also of interest to note that size 3 mines, characterized by type 3 deposits, show the lowest percentage with respect to capital costs.

5.2 Effects on Potential Value of Base Metal Mineral Endowment

Potential value assessments are made for various metal prices and control levels. Metal price is the most important and the most uncertain variable in assessing the endowment's economic characteristics. Lower limit expected value and upper limit prices shown in Table 3 are used for these assessments. The pollution control related costs at different control levels are added to the database costs and potential value assessments are made for each combination of price variant and control level. For each combination, the following criteria are evaluated:

- The potential number of economic deposits.
- The potential net present value to society from the exploration, development and production phases of the base metal mining sector, discounted at 8 percent.
- The potential rate of return to society.

Results are presented in Table 19. These results indicate that potential value to society is highly sensitive to control level changes at lower limit metal prices. The number of economic deposits is particularly sensitive to control level changes at lower limit and expected value prices. Table 19 also indicates that the potential value criteria are more sensitive to changes from Level 1 to Level 2 than from Level 2 to Level 3. To the extent that the endowment is actually subject to control Level 2, the results indicate that the main part of society's losses has been absorbed in the change from Level 1 to Level 2. The results suggest that a further change to Level 3 would have a relatively small impact on the potential value of the endowment.

5.3 After-tax Effects of Costs Related to Pollution Control

This section examines the after-tax effects of the estimated costs related to pollution control on the base metal mining sector. The results are based on the current Canadian mining taxation system.

The value to society is shared between investors and government through corporate and mining taxes. Considered as an additional cost to the mine operator, taxation can affect the viability of economically marginal deposits. It can decrease the number of economic deposits thereby reducing the value to society. Taxation, however, eases the burden of additional costs, by sharing them between investors and government. This is accomplished through tax allowances, resulting in tax credits to the investor. As a result, the after-tax impact of additional costs is smaller than the before-tax impact of these costs.

Price and Control Level Variants	Potential Number of Economic Deposits	Potential Value of Endowment to Society ($ millions)	Rate of Return on Endowment to Society
Lower Limit Prices			
Control Level 1	56	905.6	10.75%
Control Level 2	48	554.2	9.81%
Control Level 3	47	454.1	9.52%
Expected Value Prices			
Control Level 1	95	5,956.8	18.37%
Control Level 2	87	5,272.0	17.54%
Control Level 3	86	5,060.9	17.22%
Upper Limit Prices			
Control Level 1	124	18,004.6	28.56%
Control Level 2	124	17,499.3	27.85%
Control Level 3	124	17,254.3	27.55%

TABLE 19. Potential value assessments.

The variants used for after-tax assessments consist of the different combinations of price and control levels. Costs related to pollution control are added to the database costs and current taxation rules (federal and provincial) are applied. Then, the actual number of economic deposits, the actual value to society discounted at 8% and the actual rate of return to the investor are assessed for each variant. Tax payments which represent the government's share of the actual value to society are discounted at 3%. Results are presented in Tables 20 and 21. With respect to control level changes, variations in after-tax criteria are usually smaller than variations in before-tax criteria. This effect illustrates the transfer of part of the additional pollution control costs to government through taxation. Table 20 also shows that for all three metal price variants, most of the impact is associated with changes from control Level 1 to control Level 2. To the extent that control Level 2 represents current federal regulations, it can be concluded that most of the impact has already been taken.

From the government's viewpoint, the transfer of part of the additional pollution control costs results in reduced tax payments. Table 21 shows the total present value of tax payments discounted at 3%. For all metal price variants, a change in control level results in substantial reductions of tax payments. The reduction of government income resulting from a change in control level represents the government's share of the additional costs associated with the higher control level.

	Actual Number of Economic Deposits	Actual Value to Society ($ millions)	Actual Rate of Return to Society (%)
Lower Limit Prices			
Control Level 1	48	291.1	9.8
Control Level 2	39	105.2	8.7
Control Level 3	38	61.6	8.4
Expected Value Prices			
Control Level 1	86	2,566.7	16.3
Control Level 2	81	2,303.6	15.7
Control Level 3	81	2,223.3	15.4
Upper Limit Prices			
Control Level 1	123	8,425.3	24.7
Control Level 2	119	8,044.3	24.1
Control Level 3	119	7,923.2	23.8

TABLE 20. After-tax assessments as a function of metal price and control level.

	Present Value of Tax Payments ($ millions)
Lower Limit Prices	
Control Level 1	3,074.0
Control Level 2	2,555.2
Control Level 3	2,395.0
Expected Value Prices	
Control Level 1	9,787.7
Control Level 2	9,222.1
Control Level 3	9,030.1
Upper Limit Prices	
Control Level 1	24,581.7
Control Level 2	23,777.4
Control Level 3	23,513.9

TABLE 21. Tax payments from all economic deposits, as a function of metal price and control level.

5.4 Discussion of Results

In absolute terms, the estimated pollution control related costs represent important expenditures both in the form of capital and operating costs, as set forth in Table 17. The sensitivity of the economic characteristics of the base metal mining sector to these additional expenditures vary. The potential and actual numbers of economic deposits as well as the potential and actual values to society are sensitive to control level changes for lower and expected metal prices. For all metal prices, rates of return are less sensitive to control level changes.

At expected metal prices, a change in water pollution regulations from the present situation[1] to complete elimination of discharge would, according to this study, have the following effects:

- The actual number of economic deposits would remain the same.
- The actual value of the endowment to society would decrease by 3.5%.
- The rate of return to the investor would decrease by 1.7%.
- The tax payments to government would decrease by 2.1%.

The rate of return to the investor, which represents the mining industry's incentive, merits further consideration. At expected value prices and control Level 2, the investor's rate of return is 15.7%. It decreases to 15.4% at control Level 3. When these rates of return are compared to the cost of capital of 8%, the decrease attributed to changing control levels appears inconsequential.

[1] Control Level 2, current federal and provincial mining taxation systems.

In this analysis, the economic characteristics of the base metal sector have been evaluated under the assumption that all mines and mills are designed to operate at a particular control level from the start of production. The effect of incremental costs (costs of upgrading an existing operation to comply with the higher control level) has not been evaluated in detail. It is expected, however, that incremental costs would have similar effects. Two factors support this conclusion:

- The magnitude of incremental costs is similar to the magnitude of original design costs.
- Incremental capital costs would be spent at some future point in time and incremental operating costs would be incurred afterwards. At the mine development decision time, the present values of these expenditures are relevant. These present values would depend upon the timing of the expenditures. They would become less significant in the discounted cash flow analysis, as the time at which higher control standards are imposed is deferred.

Of interest in the evaluation results is the type and size of deposits most sensitive to changes in control levels. Figure 16 shows the size distribution of deposits which become uneconomic because of higher control levels at expected metal prices. Out of a total of fourteen deposits affected, nine were small Cu-Zn-Ag-Au or Cu-Ag-Au deposits, characteristic of the shield region. For the same conditions, Figure 16 also shows the deposits that become uneconomic because of taxation. Thirteen of the twenty deposits affected have medium to large mine sizes. Twelve of these are low grade copper producers characteristic of the cordilleran region. The reason for the differential effect of these

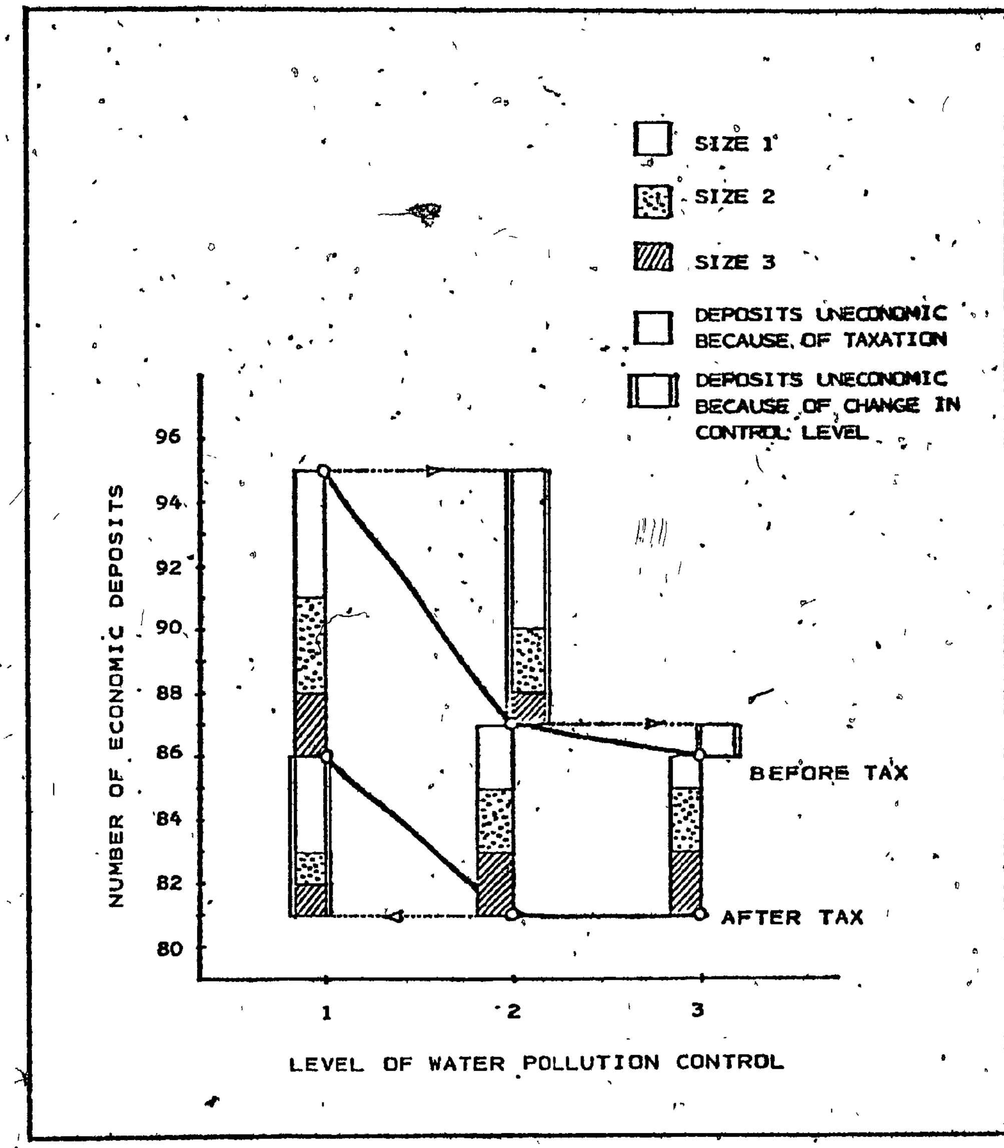

Figure 16. Comparison of the effects of pollution control costs and taxation on the number of economic deposits.

policies with respect to mine size appears to result from the different ratios of additional costs to total costs. As shown in Table 17, the ratio of pollution control related costs to total costs for small deposits is about twice as large as the same ratio for large deposits. Another factor which is likely to influence this differential effect is the different economic characteristics expressed in terms of revenues and costs per ton of ore for the two different deposit types. Within the scope of this study, the differential effect of pollution control and taxation on mines of different sizes is not further examined. This effect, however, can be the subject of additional research.

CONCLUSIONS

The following points may summarize the findings of this study:

i) Pollution control related costs associated with changing control levels represent important portions of the actual capital and operating costs. These costs show economies of scale and thus, their impact is particularly strong in the case of smaller deposits.

ii) The impact of costs related to pollution control on economic characteristics of the base metal mining sector is rather modest overall, to both society and the investor. Some degree of sensitivity is observed in the potential and actual number of economic deposits, as well as the potential and actual value to society at lower metal prices. Other criteria of desirability remain relatively stable over the various control levels and metal prices examined.

iii) Costs related to pollution control are not generally harmful to the mining industry. They do, however, show a tendency to adversely affect small sulphide deposits typical of the shield region. It is suggested that protective measures should be taken to offset the increased costs smaller operations will incur, if higher control levels were implemented.

The results of this study may be used as a basis for further research in the following suggested areas:

i) Elucidation of the reasons for the differential effects of pollution control costs and taxation on mines of different sizes.

ii) Analysis of the effects of incremental costs on the economic characteristics of the endowment. One aspect of this analysis would be the detailed examination of the effect of incremental costs at the mine development decision time. Another aspect of this analysis would be the effect of incremental costs on operating mines.

APPENDIX 1. Metal mining liquid effluent regulations

9/3/77 Canada Gazette Part II, Vol. 111, No. 5 Gazette du Canada Partie II, Vol 111, N° 5 SOR/DORS/77-178

Registration
SOR/77-178 25 February, 1977

FISHERIES ACT

Metal Mining Liquid Effluent Regulations

P.C. 1977-388 24 February, 1977

His Excellency the Governor General in Council, on the recommendation of the Minister of Fisheries and the Environment, pursuant to sections 33 and 34 of the Fisheries Act, is pleased hereby to make the annexed Regulations respecting deleterious substances in liquid effluents from metal mines.

REGULATIONS RESPECTING DELETERIOUS SUBSTANCES IN LIQUID EFFLUENTS FROM METAL MINES

Short Title

1. These Regulations may be cited as the *Metal Mining Liquid Effluent Regulations.*

Interpretation

2. In these Regulations,

"Act" means the *Fisheries Act*; (*Loi*)

"arithmetic mean" means the average value of the concentrations in composite or grab samples collected over the time period required by section 7; (*moyenne arithmétique*)

"composite sample" means

(*a*) a quantity of undiluted effluent consisting of a minimum of three equal volumes of effluent or three volumes proportionate to flow that have been collected at approximately equal time intervals over a sampling period of not less than 7 hours and not more than 24 hours, or

(*b*) a quantity of undiluted effluent collected continually at an equal rate or at a rate proportionate to flow over a sampling period of not less than 7 hours and not more than 24 hours;

(*échantillon composite*)

"deposit" means to deposit or permit the deposit into water frequented by fish; (*rejeter*)

"effluent" includes mine water effluent, mill process effluent, tailings impoundment area effluent, treatment pond or treatment facility effluent, seepage and surface drainage; (*effluent*)

"existing mine" means a mine that came into commercial production before the date of coming into force of these Regulations and that operated on a commercial basis for at least two months in the twelve months immediately prior to that date; (*mine existante*)

Enregistrement
DORS/77-178 25 février 1977

LOI SUR LES PÊCHERIES

Règlement sur les effluents liquides des mines de métaux

C.P. 1977-388 24 février 1977

Sur avis conforme du ministre des Pêcheries et de l'Environnement et en vertu des articles 33 et 34 de la Loi sur les pêcheries, il plaît à Son Excellence le Gouverneur général en conseil d'établir le Règlement relatif aux substances nocives présentes dans les effluents des mines de métaux, ci-après.

RÈGLEMENT RELATIF AUX SUBSTANCES NOCIVES PRÉSENTES DANS LES EFFLUENTS DES MINES DE MÉTAUX

Titre abrégé

1. Ce règlement peut s'intituler: *Règlement sur les effluents liquides des mines de métaux.*

Interprétation

2. Dans ce règlement,

«chantier» comprend tout le terrain et tous les travaux servant ou ayant servi à l'exploitation minière ou à la préparation du minerai et comprend, sans limiter le sens général de ce qui précède, les mines souterraines ou à ciel ouvert, les bâtiments, les aires de stockage du minerai, les terrils, les dépôts de stériles et les étangs de traitement, abandonnés ou non, les secteurs dégagés ou perturbés adjacents à ces endroits, les fossés et les cours d'eau ou plans d'eau, dont la qualité a été modifiée par l'exploitation minière; (*operation area*)

«dépôt de stériles» désigne une aire de décharge, de superficie limitée, circonscrite par une formation naturelle ou un ouvrage artificiel ou les deux à la fois; (*tailings impoundment area*)

«eau de drainage superficiel» comprend toute eau de ruissellement qui coule sur un chantier minier ou en provient et qui de ce fait est contaminée; (*surface drainage*)

«échantillon composite» désigne

a) un volume d'effluent non dilué composé d'au moins trois portions égales d'effluent ou de trois portions proportionnelles au débit, recueillies à des intervalles de temps sensiblement égaux, pendant une période d'échantillonnage d'au moins 7 heures et d'au plus 24 heures, ou

b) un volume d'effluent non dilué prélevé de façon continue à un débit constant ou à un débit proportionnel à celui de l'effluent, pendant une période d'échantillonnage d'au moins 7 heures et d'au plus 24 heures;

(*composite sample*)

«échantillon pris au hasard» désigne un volume d'effluent non dilué recueilli à un moment quelconque; (*grab sample*) "expanded mine" means an existing mine that has increased its production rate by more than 30% of its reference mine production rate. (*mine à production accrue*)

"final discharge point" means the point beyond which the operator of a mine exercises no further control over an effluent. (*point de rejet final*)

"gold mine" means a mine where the gold produced from the mine is recovered in the operation area by the process of cyanidation and accounts for more than 50% of the value of the output of the mine; (*mine d'or*)

"grab sample" means a quantity of undiluted effluent collected at any given time; (*échantillon pris au hasard*)

"metal" includes antimony, bismuth, cadmium, cobalt, copper, chromium, gold, iron, lead, magnesium, mercury, molybdenum, nickel, niobium, silver, tantalum, tin, thorium, titanium, tungsten, uranium and zinc. (*métal*)

"mill process effluent" includes tailing slurries and all other effluent discharged from a milling operation, (*effluents des installations de préparation du minerai*)

"mine" includes all metal mining and milling facilities that are used to produce a metal concentrate or an ore from which a metal or metal concentrate may be produced and all associated smelters, pelletizing plants, sintering plants, refineries, acid plants, and any similar operation where any effluent from such operation is combined with the effluents from mining and milling; (*mine*)

"mine water effluent" means water pumped or flowing out of any underground workings or open pit; (*effluents d'eau minière*)

"Minister" means Minister of the Environment; (*Ministre*)

"new mine" means a mine that did not start commercial production prior to the date of coming into force of these Regulations and that commences commercial production on or after that date; (*mine nouvelle*)

"operation area" includes all the land and works that are used or have been used in conjunction with mining or milling activity and, without limiting the generality of the foregoing, includes open pits, underground mines, buildings, ore storage areas, active and abandoned waste rock dumps, active and abandoned tailings impoundment areas and treatment ponds, cleared or disturbed areas adjacent to those places, structures or areas and ditches, watercourses or water bodies the character of which have been altered by mining activity. (*chantier*)

"reference mine production rate" means the greater of the design rated capacity and the maximum average annual production rate ever achieved during the operating life of a mine prior to the date of coming into force of these Regulations; (*rythme de production de référence*)

"reopened mine" means a mine that resumes production on or after the date of coming into force of these Regulations and that had not been in operation for more than two months in the twelve month period immediately prior to the date of coming into force of these Regulations, (*mine remise en exploitation*)

"surface drainage" includes all surface run-off that flows over, through or out the operation area of a mine and that is

«effluent» comprend les effluents d'eau minière, les effluents des installations de préparation du minerai, les effluents des dépôts de stériles, les effluents des étangs ou des installations de traitement et les eaux d'infiltration ou de drainage superficiel. (*effluent*)

«effluents d'eau minière» désigne les eaux pompées ou rejetées par une mine souterraine ou à ciel ouvert. (*mine water effluent*)

«effluents des installations de préparation du minerai» comprend les boues stériles et tout autre effluent, rejetés à la suite de la préparation du minerai. (*mill process effluent*)

«étang de traitement» désigne un étang, une lagune ou toute autre étendue fermée autre qu'un dépôt de stériles et servant au traitement d'un effluent; (*treatment pond*)

«Loi» désigne la *Loi sur les pêcheries*. (*Act*)

«matière totale en suspension» désigne un résidu non filtré provenant de l'exploitation d'une mine et contenu dans un effluent liquide de la mine; (*total suspended matter*)

«métal» comprend l'antimoine, le bismuth, le cadmium, le cobalt, le cuivre, le chrome, l'or, le fer, le plomb, le magnésium, le mercure, le molybdène, le nickel, le niobium, l'argent, le tantale, le tin, le thorium, le titane, le tungstène, l'uranium et le zinc, (*metal*)

«mine» comprend l'ensemble des installations d'extraction et de préparation du minerai, produisant un concentré métallique, ou un minerai à partir duquel on peut obtenir le métal ou un concentré et toutes les installations connexes, fonderies ateliers de bouletage ou de frittage, raffineries, fabriques d'acide et autres du même genre, dont les effluents se combinent à ceux des installations d'extraction et de préparation du minerai, (*mine*)

«mine à production accrue» désigne une mine existante dont la productivité a été accrue de plus de 30% par rapport à son rythme de production de référence, (*expanded mine*)

«mine d'or» désigne une mine où l'or produit est récupéré sur le chantier par cyanuration et constitue plus de la moitié de la valeur de la production. (*gold mine*)

«mine existante» désigne une mine dont la production industrielle a débuté avant la date d'entrée en vigueur de ce règlement et a été maintenue pendant au moins deux mois au cours des douze mois ayant précédé immédiatement cette date. (*existing mine*)

«mine nouvelle» désigne une mine dont la production industrielle a débuté à ou après la date d'entrée en vigueur de ce règlement, (*new mine*)

«mine remise en exploitation» désigne une mine dont la production a repris à ou après la date d'entrée en vigueur de ce règlement et qui n'a pas été exploitée pendant plus de deux mois au cours des douze mois ayant précédé immédiatement cette date, (*reopened mine*)

«Ministre» désigne le ministre de l'Environnement. (*Minister*)

«moyenne arithmétique» désigne la valeur moyenne des concentrations dans les échantillons, composites ou pris au hasard, recueillis durant la période de temps indiquée à l'article 7; (*arithmetic mean*)

«non dilué» qualifie un effluent auquel aucune addition d'eau n'a été faite principalement afin de satisfaire aux limites contaminated as a result of flowing over, through or out of that area. (*eau de drainage superficiel*)

"tailings impoundment area" means a limited disposal area that is confined by man-made or natural structures or by both; (*dépôt de stériles*)

"total suspended matter" means the non-filterable residue that results from the operation of a mine, that is contained in liquid effluent from the mine; (*matière totale en suspension*)

"treatment pond" means a pond, lagoon or other confined area, other than a tailings impoundment area, used to treat an effluent; (*étang de traitement*)

"undiluted" means not having water added primarily for the purposes of meeting the limits of authorized deposits prescribed by section 5. (*non dilué*)

Application

3 These Regulations apply to every new mine, expanded mine and reopened mine, other than a gold mine.

Substances Prescribed as Deleterious Substances

4 For the purpose of paragraph (*c*) of the definition "deleterious substance" in subsection 33(11) of the Act, the following substances from the operations or processes of a mine to which these Regulations apply are hereby prescribed as deleterious substances:

(*a*) arsenic;
(*b*) copper;
(*c*) lead;
(*d*) nickel;
(*e*) zinc;
(*f*) total suspended matter; and
(*g*) radium 226

Authorized Deposit of Deleterious Substances

5. (1) Subject to these Regulations, the operator of a mine may deposit a deleterious substance prescribed by section 4 if

(*a*) the monthly arithmetic mean of the concentration in each undiluted effluent of that substance described in an item of Part 1 of Schedule I does not exceed the concentration in column I of that item and the monthly arithmetic mean pH of that effluent is not less than the value set out in column I of Part 2 of that schedule;

(*b*) the concentration in a composite sample of each undiluted effluent of that substance described in an item of Part 1 of Schedule I does not exceed the concentration in column II of that item and the pH of the composite sample is not less than the value set out in column II of Part 2 of that schedule, and

(*c*) the concentration in a grab sample of each undiluted effluent of that substance described in an item of Part 1 of Schedule I does not exceed the concentration in column III of that item and the pH of the grab sample is not less than the value set out in column III of Part 2 of that schedule.

prescrites à l'article 5 au sujet des rejets autorisés; (*undiluted*)

«point de rejet final» désigne le point au-delà duquel l'exploitant d'une mine n'exerce plus aucune influence sur la qualité d'un effluent. (*final discharge point*)

«rejeter» signifie déposer ou permettre que soit déposée une substance dans des eaux poissonneuses. (*deposit*)

«rythme de production de référence» désigne le rythme maximal de production théorique ou, s'il est plus élevé, le rythme moyen maximal de production annuelle obtenu au cours de la durée d'exploitation d'une mine, avant la date d'entrée en vigueur de ce règlement (*reference mine production rate*)

Application

3. Ce règlement s'applique à toutes les mines nouvelles, remises en exploitation et à production accrue, sauf les mines d'or.

Substances déclarées nocives

4. Aux fins de l'alinéa *c*) de la définition de «substance nocive», au paragraphe 33(11) de la Loi, les substances énumérées ci-après provenant des opérations ou des procédés d'une mine visée par ce règlement sont déclarées nocives.

a) l'arsenic;
b) le cuivre;
c) le plomb;
d) le nickel;
e) le zinc;
f) les matières totales en suspension; et
g) le radium 226.

Rejet autorisé de substances nocives

5. (1) Sous réserve de ce règlement, l'exploitant d'une mine peut rejeter les substances déclarées nocives à l'article 4, à condition que

a) la moyenne arithmétique mensuelle de la concentration dans chaque effluent non dilué de chacune des substances visées dans un article de la partie 1 de l'annexe I ne dépasse pas la concentration indiquée par cet article dans la colonne I, et que la moyenne arithmétique mensuelle du pH de cet effluent ne soit pas inférieure à la valeur indiquée à la colonne I de la partie 2 de l'annexe,

b) la concentration de chacune des substances visées dans un article de la partie 1 de l'annexe I, dans un échantillon composite de chaque effluent non dilué ne dépasse pas la concentration indiquée par cet article dans la colonne II, et que le pH de l'échantillon composite ne soit pas inférieur à la valeur indiquée à la colonne II de la partie 2 de l'annexe; et

c) la concentration de chacune des substances visées dans un article de la partie 1 de l'annexe I, dans un échantillon pris au hasard de chaque effluent non dilué ne dépasse pas la

(2) Notwithstanding subsection (1), the operator of a mine may deposit the deleterious substances prescribed by section 4 in any quantity or concentration into a tailings impoundment area designated in writing by the Minister.

ADDITIONAL CONDITIONS OF AUTHORIZATION

General

6. An operator of a mine shall

(*a*) install and maintain facilities of such type as the Minister may in writing approve for sampling and analysing effluents for the purpose of enabling the Minister to determine whether the operator is complying with the limits of authorized deposits prescribed by section 5;

(*b*) take grab or composite samples of each undiluted effluent at its final discharge point on the regular basis prescribed by section 7;

(*c*) analyse the samples referred to in paragraph (*b*) on the regular basis prescribed by section 7;

(*d*) where possible measure or in any other case estimate the volume of each undiluted effluent deposited per month at its final discharge point on the regular basis prescribed by section 9; and

(*e*) within 30 days after the end of each month, send to the Minister a report, in such form as the Minister may in writing approve, containing the information prescribed by section 10.

Frequency of Sampling and Analysis

7. (1) Subject to subsection (2), the sampling and analysis referred to in paragraphs 6(*b*) and (*c*) shall be made

(*a*) once a week, where the arithmetic mean of the concentration in undiluted effluent of a substance described in an item of Schedule 2 in the immediately preceding six months was equal to or greater than the arithmetic mean set out in column I of that item;

(*b*) once every two weeks, where the arithmetic mean of the concentration in undiluted effluent of a substance described in an item of Schedule 2 in the immediately preceding six months was equal to or greater than the arithmetic mean set out in column II of that item but less than that set out in column I of that item;

(*c*) once a month, where the arithmetic mean of the concentration in undiluted effluent of a substance described in an item of Schedule 2 in the immediately preceding six months was equal to or greater than the arithmetic mean set out in column III of that item but less than that set out in column II of that item;

(*d*) once every six months, where the arithmetic mean of the concentration in undiluted effluent of a substance described in an item of Schedule 2 in the immediately preceding six months was less than the arithmetic mean set out in column III of that item, and

concentration indiquée par cet article dans la colonne III, et que le pH de cet échantillon ne soit pas inférieur à la valeur indiquée à la colonne III de la partie 2 de l'annexe.

(2) Nonobstant le paragraphe (1), l'exploitant d'une mine peut rejeter n'importe quelle quantité ou concentration de substances nocives, visées à l'article 4, dans un dépôt de résidus que le Ministre a désigné par écrit.

CONDITIONS SUPPLÉMENTAIRES D'AUTORISATION

Disposition générale

6. L'exploitant d'une mine

a) installe et entretient les appareils d'échantillonnage et d'analyse des effluents que le Ministre a approuvés par écrit et qui permettent à celui-ci de juger si les limites de rejet prescrites à l'article 5 sont respectées.

b) prélève des échantillons composites ou pris au hasard de chacun des effluents non dilués à leur point de rejet final aux fréquences indiquées à l'article 7;

c) analyse les échantillons visés à l'alinéa *b*) aux fréquences indiquées à l'article 7;

d) lorsque c'est possible, mesure ou, dans tous les autres cas, évalue aux fréquences indiquées à l'article 9 le volume des rejets mensuels de chaque effluent à son point de rejet final, et

e) dans les 30 jours de la fin de chaque mois, envoie au Ministre un rapport, établi suivant un modèle que celui-ci a approuvé par écrit, contenant les renseignements prévus à l'article 10.

Fréquence d'échantillonnage et analyse

7. (1) Sous réserve du paragraphe (2), l'échantillonnage et l'analyse visés aux alinéas 6*b*) et *c*) ont lieu

a) chaque semaine, si la moyenne arithmétique des concentrations dans l'effluent non dilué de l'une des substances indiquées à l'annexe 2 a été égale ou supérieure, au cours des six mois précédents, à celle de la colonne I;

b) toutes les deux semaines, si la moyenne arithmétique des concentrations dans l'effluent non dilué de l'une des substances indiquées à l'annexe 2 a été égale ou supérieure, au cours des six mois précédents, à celle de la colonne II mais inférieure à celle de la colonne I;

c) chaque mois, si la moyenne arithmétique des concentrations dans l'effluent non dilué de l'une des substances indiquées à l'annexe 2 a été égale ou supérieure, au cours des six mois précédents, à celle de la colonne III mais inférieure à celle de la colonne II,

d) tous les six mois, si la moyenne arithmétique des concentrations dans l'effluent non dilué de l'une des substances indiquées à l'annexe 2 a été inférieure au cours des six mois précédents, à celle de la colonne III, et

e) chaque semaine au cours des six premiers mois d'exploitation d'une mine.

(e) once a week for the first six months of operation of a mine.

(2) The sampling and analysis of undiluted effluent to determine its pH level shall be made

(a) once a week, where the pH of the undiluted effluent was less than 5.0 at any time in the immediately preceding six months;

(b) once every two weeks, where the pH of the undiluted effluent was between 5.0 and 5.5 at any time in the immediately preceding six months,

(c) once a month, where paragraph (a) or (b) does not apply; or

(d) once a week for the first six months of operation of a mine.

Analytical Test Methods

8. (1) For the purposes of section 5, the concentration in undiluted effluent of a substance described in column I of an item of Schedule 3 shall be determined using

(a) the test method referred to in column II of that item as modified by the directions in columns III and IV for procedure and sample preservation respectively; or

(b) any other method, approved in writing by the Minister, the results of which can be confirmed by the method referred to in paragraph (a).

(2) For the purposes of section 5, the pH of undiluted effluent shall be determined using

(a) the test method prescribed by section 221 of the publication "Standard Methods for the Examination of Water and Waste Water", 13th Edition (1971), published jointly by the American Public Health Association, American Water Works Association and the Water Pollution Control Federation; or

(b) any other method, approved in writing by the Minister, the results of which can be confirmed by the method referred to in paragraph (a).

Flow Measurement

9. The measurement or estimation of volume of undiluted effluent referred to in paragraph 6(d) shall be made monthly, unless the lowest frequency of sampling and analysis prescribed by subsection 7(1) is every six months, in which case the measurement or estimation shall be made every six months.

Reporting

10. A report referred to in paragraph 6(e) shall contain the following information respecting the month in respect of which the report is made:

(a) the arithmetic mean concentrations (in milligrams per liter or picocuries per liter) of the deleterious substances in

(2) L'analyse et l'échantillonnage d'un effluent non dilué pour déterminer son niveau pH ont lieu

a) chaque semaine, s'il a été inférieur à 5.0 à un moment quelconque durant les six mois précédents.

b) toutes les deux semaines, s'il a été entre 5.0 et 5.5 à un moment quelconque durant les six mois précédents;

c) chaque mois, lorsque les alinéas a) ou b) ne s'appliquent pas; ou

d) chaque semaine au cours des six premiers mois d'exploitation d'une mine.

Méthodes d'essai analytiques

8. (1) Aux fins de l'article 5, la concentration dans l'effluent non dilué d'une des substances visées à la colonne I de l'annexe 3 se détermine

a) par la méthode d'essai visée à la colonne II, modifiée par les indications inscrites aux colonnes III et IV, relativement au mode opératoire et à la conservation des échantillons; ou

b) par toute autre méthode, approuvée par écrit par le Ministre, dont les résultats peuvent être vérifiés par la méthode visée à l'alinéa a).

(2) Aux fins de l'article 5, le pH de l'effluent non dilué se détermine

a) par la méthode d'essai prescrite à la section 221 du recueil «*Standard Methods for the Examination of Water and Waste Water*», 13e édition (1971), publié conjointement par l'*American Public Health Association*, l'*American Water Works Association* et la *Water Pollution Control Federation*; ou

b) par toute autre méthode, approuvée par écrit par le Ministre, dont les résultats peuvent être vérifiés par la méthode visée à l'alinéa a).

Mesures du débit

9. Les mesures ou les évaluations du volume d'effluent non dilué visé à l'alinéa 6d) se font mensuellement à moins que la fréquence minimale des échantillonnages et des analyses prescrits au paragraphe 7(1) ne soit tous les six mois, auquel cas, elles sont effectuées à cette fréquence.

Rapport

10. Le rapport visé à l'alinéa 6e) contient les renseignements suivants pour le mois auquel il se rapporte:

a) la moyenne arithmétique des concentrations (en milligrammes ou en picocuries par litre) des substances nocives dans chaque effluent non dilué rejeté, et la moyenne aritheach undiluted effluent deposited and the arithmetic mean pH of undiluted effluents deposited;

(*b*) the concentrations of deleterious substances in all samples used to determine the arithmetic mean concentrations referred to in paragraph (*a*),

(*c*) the pH of all samples used to determine the arithmetic mean pH referred to in paragraph (*a*),

(*d*) the volume (in Imperial gallons per month) of each undiluted effluent deposited; and

(*e*) the type of sample collection (composite or grab) used for each effluent deposited.

Permitted Variations in Additional Conditions

11. Where the operator of a mine establishes to the satisfaction of the Minister that for scientific and technical reasons a scheme of sampling and analysis, measurement or estimation or reporting referred to in sections 7, 8, 9 and 10 other than at the regular time interval frequencies required by those sections, is sufficient to enable the Minister to determine whether the operator is complying with the limits of authorized deposits prescribed by section 5, the Minister may, in writing, permit the operator to

(*a*) take and analyse samples of each undiluted effluent in accordance with the scheme on a regular basis specified in the permit,

(*b*) measure or estimate the volume of each effluent in accordance with the scheme on a regular basis specified in the permit, or

(*c*) report to the Minister in accordance with the scheme on a regular basis specified in the permit,

and sections 7, 8, 9 and 10 do not apply to the operator if he complies with the scheme on the regular basis specified in the permit.

métique du pH de chaque effluent non dilué rejeté;

b) les concentrations de substances nocives dans tous les échantillons ayant servi au calcul de la moyenne arithmétique des concentrations visée à l'alinéa *a*).

c) le pH de tous les échantillons ayant servi au calcul de la moyenne arithmétique du pH visée a l'alinea *a*),

d) le volume (en gallons impériaux par mois) de chaque effluent non dilué rejeté, et

e) le type d'échantillon (composite ou pris au hasard) utilisé pour chaque effluent rejeté.

Dérogations aux conditions supplémentaires

11. Lorsque l'exploitant d'une mine établit à la satisfaction du Ministre que, pour des raisons scientifiques et techniques, un mode d'échantillonnage et d'analyse, de mesures ou d'évaluations, ou de présentation de rapports à une fréquence différente de celle visée aux articles 7, 8, 9 et 10 suffit pour permettre au Ministre de juger si les limites de rejet prescrites à l'article 5 sont respectées, ce dernier peut autoriser l'exploitant par écrit

a) à prélever et à analyser les échantillons de chaque effluent non dilué, selon le mode et aux fréquences indiqués sur le permis,

b) à mesurer ou à évaluer le volume de chaque effluent, selon le mode et aux fréquences indiqués sur le permis, ou

c) à envoyer le rapport au Ministre, selon le mode et aux fréquences indiqués sur le permis,

et les articles 7, 8, 9 et 10 ne s'appliquent pas à l'exploitant s'il se conforme aux permis.

SCHEDULE I

PART I

AUTHORIZED LEVELS OF SUBSTANCES

Item	Substance	Column I Maximum Authorized Monthly Arithmetic Mean Concentration	Column II Maximum Authorized Concentration in a Composite Sample	Column III Maximum Authorized Concentration in a Grab Sample
1.	Arsenic	0 5 mg/l	0 75 mg/l	1 0 mg/l
2.	Copper	0,3 mg/l	0 45 mg/l	0 6 mg/l
3.	Lead	0.2 mg/l	0 3 mg/l	0 4 mg/l
4.	Nickel	0 5 mg/l	0 75 mg/l	1 0 mg/l
5.	Zinc	0.5 mg/l	0 75 mg/l	1 0 mg/l
6.	Total Suspended Matter	25 0 mg/l	37 5 mg/l	50 0 mg/l
7.	Radium 226	10 0 pCi/l	20 0 pCi/l	30.0 pCi/l

NOTE: The concentrations are given as total values with the exception of Radium 226 which is a dissolved value after filtration of the sample through a 3 micron filter.

ANNEXE 1

PARTIE I

CONCENTRATIONS AUTORISÉES DES SUBSTANCES

Article	Substance	Colonne I Concentration maximale autorisée (moyenne arithmétique mensuelle)	Colonne II Concentration maximale autorisée dans un échantillon composite	Colonne III Concentration maximale autorisee dans un échantillon pris au hasard
1.	Arsenic	0,5 mg/l	0,75 mg/l	1,0 mg/l
2	Cuivre	0,3 mg/l	0,45 mg/l	0,6 mg/l
3	Plomb	0,2 mg/l	0,3 mg/l	0,4 mg/l
4	Nickel	0,5 mg/l	0,75 mg/l	1,0 mg/l
5.	Zinc	0,5 mg/l	0,75 mg/l	1,0 mg/l
6.	Matière totale en suspension	25,0 mg/l	37,5 mg/l	50,0 mg/l
7.	Radium 226	10,0 pCi/l	20,0 pCi/l	30,0 pCi/l

REMARQUE: Ces concentrations représentent des valeurs totales, sauf pour le Radium 226 où l'échantillon ayant traversé un filtre à pores de 3 microns d'ouverture est ensuite dissous.

PART 2

AUTHORIZED LEVELS OF pH

Parameter	Column I Minimum Authorized Monthly Arithmetic mean pH	Column II Minimum Authorized pH in a Composite Sample	Column III Minimum Authorized pH in a Grab Sample
pH	6.0	5.5	5.0

PARTIE 2

CONCENTRATIONS pH AUTORISÉES

Paramètre	Colonne I pH minimal autorisé (moyenne arithmétique mensuelle)	Colonne II pH minimal autorisé dans un échantillon composite	Colonne III pH minimal autorisé dans un échantillon pris au hasard
pH	6,0	5,5	5,0

SCHEDULE 2

DETERMINATION OF FREQUENCY WITH WHICH UNDILUTED EFFLUENTS ARE TO BE SAMPLED AND ANALYSED FOR PARTICULAR SUBSTANCES

Item	Substance	Column I At least Weekly If Concentration Is Equal To Or Greater Than	Column II At Least Every Two Weeks If Concentration Is Equal To Or Greater Than	Column III At Least Monthly If Concentration Is Equal To Or Greater Than
1.	Arsenic	0.5 mg/l	0.2 mg/l	0.10 mg/l
2.	Copper	0.3 mg/l	0.1 mg/l	0.05 mg/l
3.	Lead	0.2 mg/l	0.1 mg/l	0.05 mg/l
4.	Nickel	0.5 mg/l	0.2 mg/l	0.10 mg/l
5.	Zinc	0.5 mg/l	0.2 mg/l	0.10 mg/l
6.	Total Suspended Matter	25 mg/l	20 mg/l	15 mg/l
7.	Radium 226	10.0 pCi/l	5.0 pCi/l	2.5 pCi/l

NOTE: All concentrations given are total values with the exception of Radium 226 which is a dissolved value after filtering the sample through a 3 micron filter. Radium 226 need be measured in only those mines in which there is radioactive ore.

ANNEXE 2

FRÉQUENCE D'ÉCHANTILLONNAGE D'UN EFFLUENT FINAL NON DILUÉ ET DU DOSAGE DE CERTAINES SUBSTANCES

Article	Substance	Colonne I Au moins toutes les semaines, si la concentration est égale ou supérieure à	Colonne II Au moins toutes les deux semaines, si la concentration est égale ou supérieure à	Colonne III Au moins tous les mois, si la concentration est égale ou supérieure à
1.	Arsenic	0,5 mg/l	0,2 mg/l	0,10 mg/l
2.	Cuivre	0,3 mg/l	0,1 mg/l	0,05 mg/l
3.	Plomb	0,2 mg/l	0,1 mg/l	0,05 mg/l
4.	Nickel	0,5 mg/l	0,2 mg/l	0,10 mg/l
5.	Zinc	0,5 mg/l	0,2 mg/l	0,10 mg/l
6.	Matière totale en suspension	25 mg/l	20 mg/l	15 mg/l
7.	Radium 226	10,0 pCi/l	5,0 pCi/l	2,5 pCi/l

REMARQUE Ces concentrations représentent des valeurs totales, sauf pour le Radium 226 où l'échantillon ayant traversé un filtre à pores de 3 microns d'ouverture est ensuite dissous. Le Radium 226 est mesuré dans les mines à minerais radio-actifs seulement.

SCHEDULE 3

ANALYTICAL TEST METHODS FOR DETERMINING CONCENTRATIONS OF SUBSTANCES IN LIQUID EFFLUENTS

Item	Column I Substance	Column II Test Method	Column III Procedure	Column IV Sample Preservation	Column V *References
1.	Arsenic	Colorimetric	HNO_3-H_2SO_4 digestion followed by AsH_3 reaction with silver diethyldithiocarbamate	To pH 1 with HNO_3	1
2.	Copper	Atomic Absorption Spectrophotometry	Sample is digested with HCl-HNO_3 before analysis	To pH 1 with HNO_3	2, 3, 4
3.	Lead	"	"	"	2, 3, 4
4.	Nickel	"	"	"	2, 3, 4
5.	Zinc	"	"	"	2, 3, 4
6.	Radium 226	Radon Emanation	α counting from Rn 222		5
7.	Total Suspended Matter	Gravimetric	Filter through Whatman GF/C or equivalent. Oven dry at 105°C to no further weight loss		1

*1. American Public Health Association (APHA), "Standard Methods for the Examination of Water and Wastewater", 13th Edition (1971).
2. Methods in Geochemistry and Geophysics. Atomic Absorption Spectrophotometry in Geology. E. A. Angino and G. Billings, American Elsevier Publishing Company Inc., 1967.
3. Atomic Absorption Spectrophotometry, 2nd Edition, W. T. Elwell and J. A. F. Gidley, Pergammon Press, 1966.
4. Atomic Absorption Spectroscopy, Walter Slavin, John Wiley & Sons Inc., 1968.
5. Lucas, H. F., Review of Scientific Instruments, 28, page 680 (1957).

ANNEXE 3

MÉTHODES DE DOSAGE DES SUBSTANCES DANS LES EFFLUENTS LIQUIDES

Article	Colonne I Substance	Colonne II Méthode d'essai	Colonne III Mode opératoire	Colonne IV Conservation des échantillons	Colonne V *Références
1.	Arsenic	Colorimétrie	Minéralisation dans HNO_3-H_2SO_4 suivie de la réaction de AsH_3 avec le diéthyldithiocarbamate d'argent	Ajuster le pH à 1 avec HNO_3	1
2.	Cuivre	Absorption atomique Spectrophotométrie	Minéralisation de l'échantillon dans HCl-HNO_3 avant l'analyse	Ajuster le pH à 1 avec HNO_3	2, 3, 4
3.	Plomb	"	"	"	2, 3, 4
4.	Nickel	"	"	"	2, 3, 4
5.	Zinc	"	"	"	2, 3, 4
6.	Radium 226	Émanation de radon	Comptage de la radio-activité α du Rn 222		5
7.	Matière totale en suspension	Gravimétrie	Filtration au Whatman GF/C ou l'équivalent. Séchage à l'étuve, à 105°C, jusqu'à poids stable		1

*1. *American Public Health Association (APHA), «Standard Methods for the Examination of Water and Wastewater»*, 13e édition (1971).
2. E. A. Angino et G. Billings, *Methods in Geochemistry and Geophysics. Atomic Absorption Spectrophotometry in Geology, American Elsevier Publishing Company Inc., 1967.*
3. W. T. Elwell et J. A. F. Gidley, *Atomic Absorption Spectrophotometry*, 2e édition, *Pergammon Press, 1966.*
4. Walter Slavin, *Atomic Absorption Spectroscopy, John Wiley & Sons Inc., 1968.*
5. Lucas, H. F., *Review of Scientific Instruments*, 28, page 680, (1957).

APPENDIX 2. Possible economic deposits for evaluation

Appalachian Region

NEWFOUNDLAND

Daniel's Harbour (1964)*: Newfoundland Zinc Mines (Teck-Amax)**
East (1964): Consolidated Rambler Mines
Ming (1970): Consolidated Rambler Mines
Whalesback (1961): British Newfoundland Exploration

NOVA SCOTIA

Gays River (1973): Imperial Oil
Salmon River (1962): Yara Min. (Barymin Exploration)

NEW BRUNSWICK

Brunswick (1952): Brunswick Mining and Smelting (Noranda)
Caribou (1955): Cominco (Anaconda)
Clearwater (1956): Chester Mines (Conwest)
Key Anacon (1953): Key Anacon Mines
Little River (1954): Heath Steele Mines (Amax-Inco)
Murray Brook (1955): Placer Development (Silver Standard)
Nigadoo (1953): Nigadoo River Mines (Sullivan)
Restigouche (1956): Placer Development (Silver Standard)
Stratmat 61 (1963): Cominco
Wedge (1957): Cominco

QUEBEC

Cupra (1960): Sullivan Mining Group
Madeleine (1966): Madeleine Mines (McIntyre)
Solbec (1958): Sullivan Mining Group

Shield Region

QUEBEC

Cooke (1968): Falconbridge Copper (Falconbridge)
Copper Rand (1952): Patino Mines
Corbet (1974): Falconbridge Copper (Falconbridge)
Delbridge (1965): Delbridge Mines (Falconbridge)

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* Discovery date.
** Parent or affiliate organization.

Detour A (1974): Selco Mining Corp.
Detour B (1975): Selco Mining Corp.
Henderson (1956): Campbell Chibougamau Mines
Icon (1964): Icon Sullivan (Kerr Addison)
Joutel (1958): Joutel Copper (Kerr Addison)
Kokko Creek (1953): Campbell Chibougamau Mines
Lemoine (1974): Patino Mines
Lessard (1971): Muscocho Explorations (Selco)
Louvem (1968): Louvem Mines (SOQUEM)
Magusi River (1972): Iso Mines (Noranda)
Mattagami (1957): Mattagami Lake Mines (Noranda)
Millenbach (1966): Falconbridge Copper (Falconbridge)
New Hosco (1958): New Hosco Mines (Noranda)
New Insco (1973): New Insco Mines (Noranda)
Norbec (1961): Falconbridge Copper (Falconbridge)
Norita (1965): Orchan Mines (Noranda)
Orchan (1958): Orchan Mines (Noranda)
Phelps Dodge (1973): Phelps Dodge Corp. of Canada
Poirier (1960): Mines de Poirier (Rio Algom)
Portage Island (1958): Patino Mines

ONTARIO

Copperfields (1953): Copperfields Mining (Teck)
F Group (1970): Mattagami Lake Mines (Noranda)
Geco (1953): Noranda Mines
Jamieson (1964): Canadian Jamieson Mines
Kidd Creek (1964): Taxasgulf Canada
Lyon Lake (1970): Mattagami Lake Mines (Noranda)
Mattabi (1969): Mattabi Mines (Noranda)
McIntyre (1959): Pamour Porcupine Mines (Noranda)
Pater (1954): Rio Algom Mines
South Bay (1968): South Bay Mines (Selco)
Sturgeon (1970): Sturgeon Lake Mines (Falconbridge)
Thierry (1970): Union Miniere Explorations and Mining
Tribag (1962): Tribag Mining (Teck)
Willroy (1953): Willroy Mines

MANITOBA

Anderson Lake (1963): Hudson Bay Mining and Smelting
Centennial (1969): Hudson Bay Mining and Smelting
Chisel Lake (1956): Hudson Bay Mining and Smelting
Fox (1961): Sherritt Gordon Mines
Ghost Lake (1956): Hudson Bay Mining and Smelting
Osborne Lake (1953): Hudson Bay Mining and Smelting
Reed lake (1973): Freeport Canadian Exploration
Rod (1968): Stall Lake Mines (Falconbridge)
Ruttan (1969): Sherritt Gordon Mines
Stall Lake (1956): Hudson Bay Mining and Smelting
Westarm (1973): Hudson Bay Mining and Smelting
White Lake (1963): Hudson Bay Mining and Smelting
Wim (1968): Hudson Bay Mining and Smelting

SASKATCHEWAN

Coronation (1953): Hudson Bay Mining and Smelting
Waden Bay (1952): Anglo-Rouyn Mines (Rio Algom)

NORTHWEST TERRITORIES

Hackett River (1970): Cominco (Bathurst Norsemines)
Hood River 10 (1974): Taxasgulf Canada
Izok Lake (1975): Texasgulf Canada
Nanisivik (1959): Mineral Resources International (Metallgesellschaft)

Cordilleran Region

BRITISH COLUMBIA

Afton (1971): Afton Mines (Teck)
Bell (1962): Noranda Mines
Benson (1967): Coast Copper Mines (Cominco)
Berg (1963): Placer Development (Kennco)
Bethlehem (1955): Bethlehem Copper
Boss Mountain (1963): Noranda Mines
Brenda (1966): Brenda Mines (Noranda)
Churchill Copper (1958): Consolidated Churchill Copper (Teck)
Craigmont (1957): Craigmont Mines (Placer)
Davis-Keays (1969): Davis-Keays Mining (Kam Kotia)
Endako (1962): Endako Mines (Placer)
Galore Creek (1962): Hudson Bay Mining and Smelting (Kennco)
Gibraltar (1969): Gibraltar Mines (Placer)
Goldstream River (1974): Noranda Mines
Granduc (1953): Granduc Operating (Newmont)
Granisle (1962): Granisle Copper (Granby)
Harper Creek (1967): Noranda Mines (U.S. Steel)
Highmont (1962): Highmont Mining
Huckleberry (1964): Granby Mining (Kennco)
Island Copper (1967): Utah Mines
JA(1971): Bethlehem Copper
Kitsault (1961): Climax Molycorp. of B.C. (AMAX)
Kutcho Creek (1974): Esso Minerals
Lornex (1965): Lornex Mining (Rio Algom)
Maggie (1970): Bethlehem Copper
Mineral King (1952): Sheep Creek Mines
Morrison (1964): Noranda Mines
Red Group (1974): Texasgulf Canada (Silver Standard)
Robb Lake (1971): Texasgulf Canada (Barrier Reef)
Ruby Creek (1968): Noranda Mines (Adanac Mining and Exploration)
Sam Goosly (1968): Kennco Exploration
Schaft Creek (1964): Silver Standard Mines (Liard Copper)
Similkameen (1967): Similkameen Mining (Newmont)
Sunro (1957): Jordan River Mines
Sustut (1971): Falconbridge Nickel Mines
Trout Lake (1970): Newmon (Esso)
Valley Copper (1968): Valley Copper Mines (Cominco)
Western (1962): Western Mines

YUKON TERRITORY

Anvil (1965): Anvil Mining Corp. (Cyprus)
Casino (1969): Brameda Resources (Casino Silver)
Grum (1973): Kerr Addison (AEX Minerals)
Husky (1967): United Keno Hill Mines (Falconbridge)
Howard's Pass Anniv (1973): Placer (Essex)
Howard's Pass XY (1972): Placer (Essex)
Minto (1972): Falconbridge Nickel Mines (Asarco, Silver Standard)
New Imperial (1957): Whitehorse Copper (HBM&S)
Swim Lake (1965): Kerr Addison Mines
Tom Group (1951): Hudson Bay Mining and Smelting
Vangorda (1953): Vangorda Mines (Kerr Addison)

Other Regions

NORTHWEST TERRITORIES

Coralta (1974): Cominco
Coronet (1965): Cominco
Polaris (1971): Arvik Mines (Cominco-Bankeno)
Sphinx (1965): Cominco
408 (1966): Cominco

APPENDIX 3. Distributions of individual deposit estimates

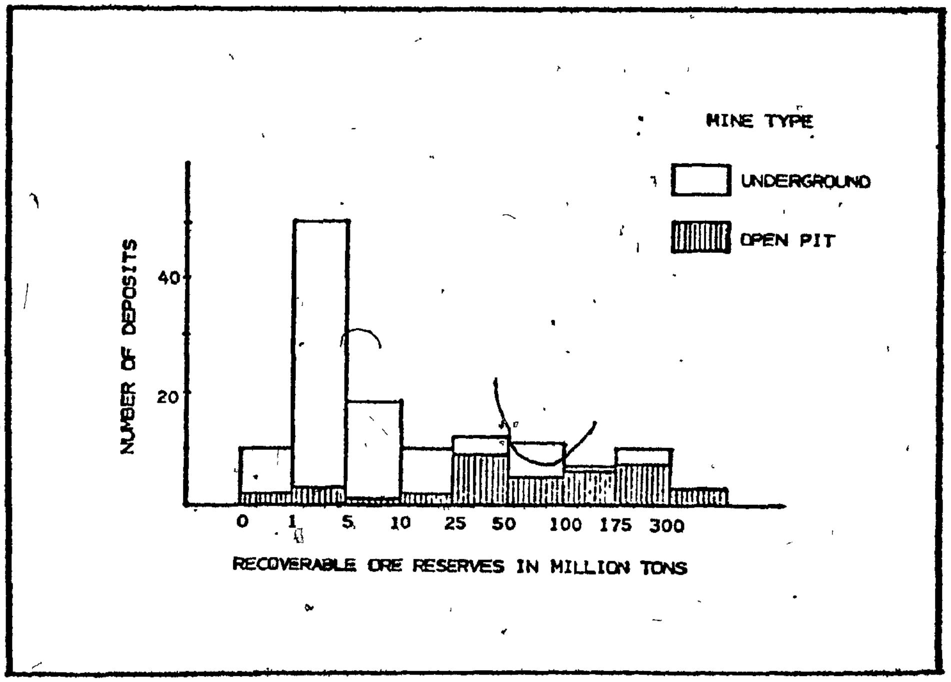

Figure 17. Recoverable ore reserves

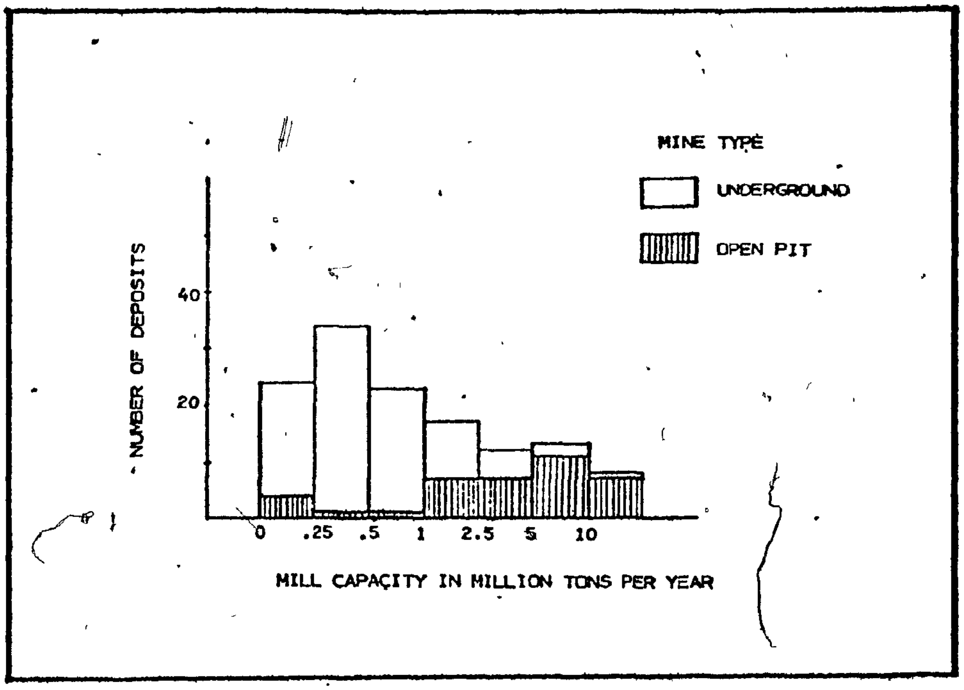

Figure 18. Mill capacity

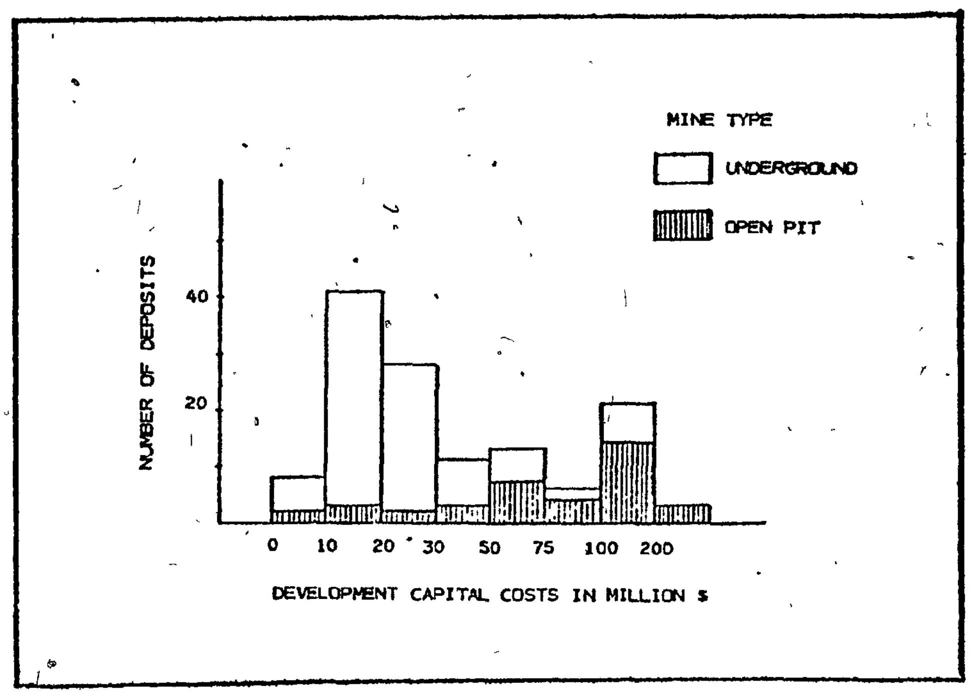

Figure 19. Development capital costs

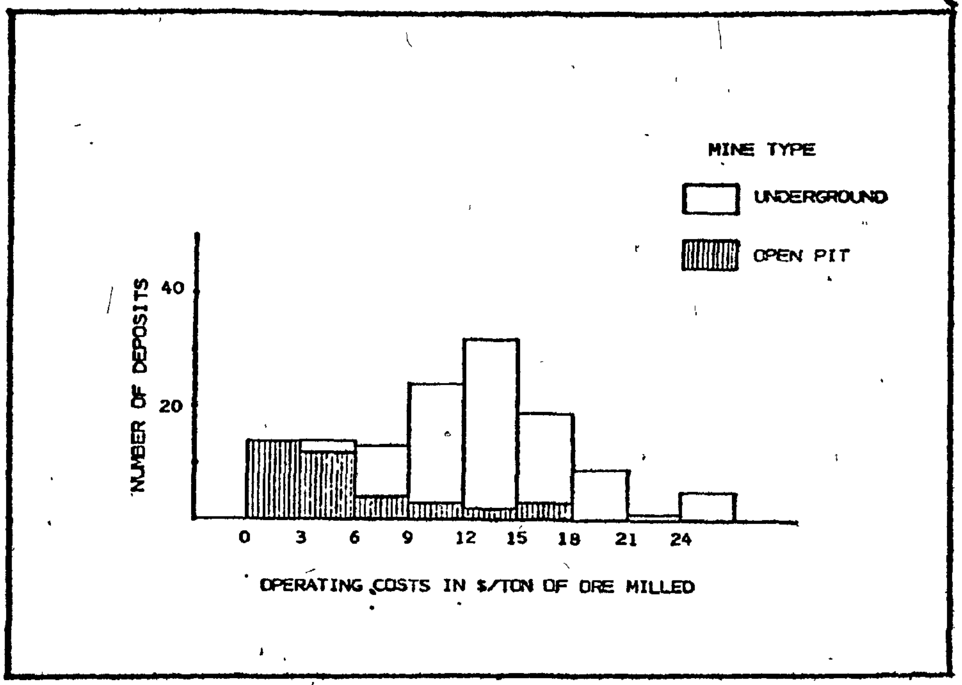

Figure 20. Operating costs

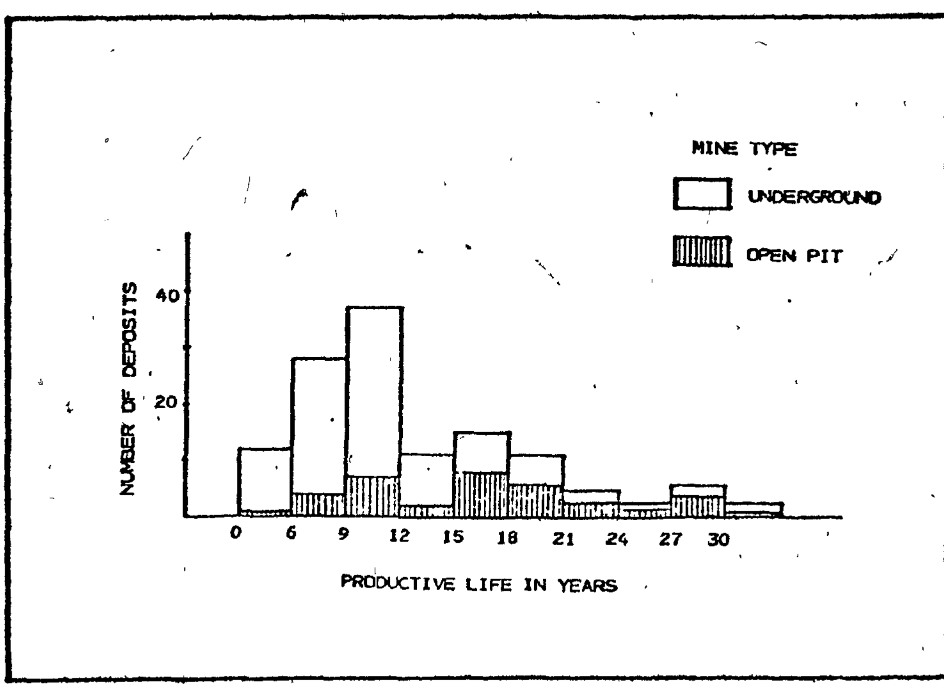

Figure 21. Productive mine life

APPENDIX 4. Curves used for the evaluation of technical characteristics and costs of operations associated with water pollution control

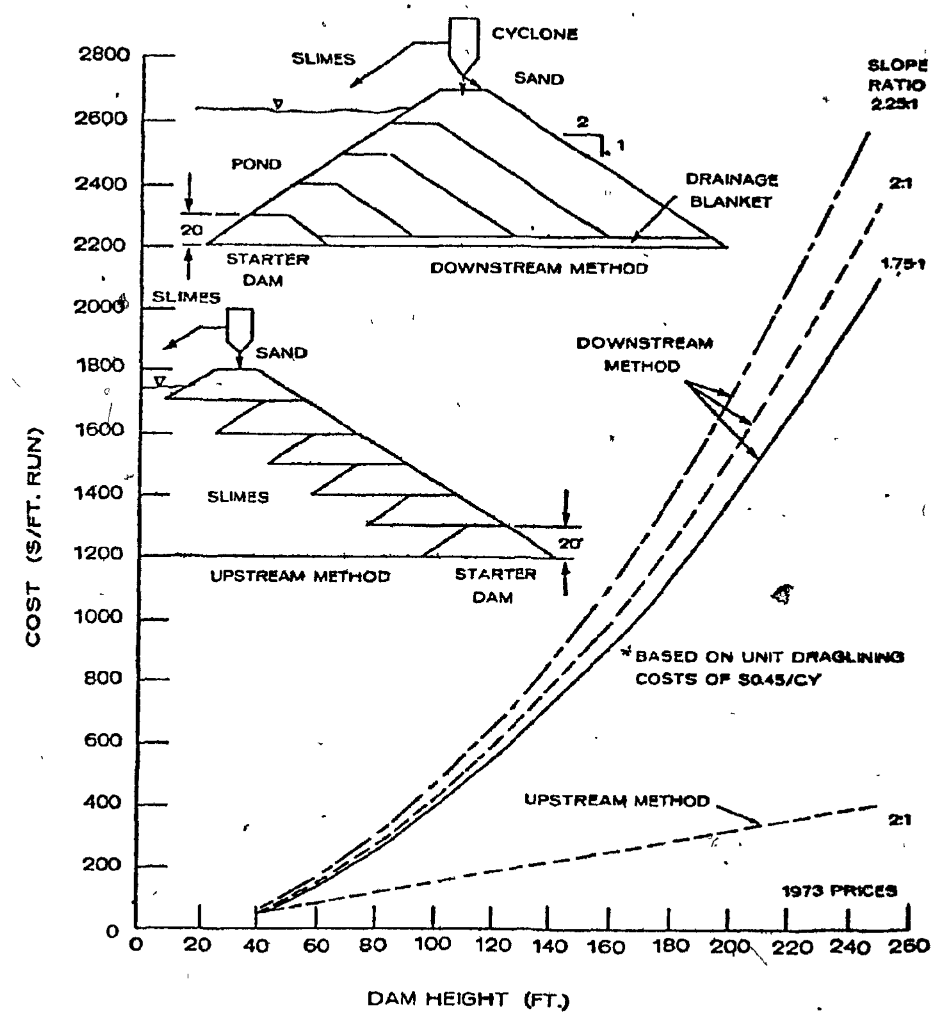

Figure 22. Cost of dams constructed of tailings.

Reproduced from Mine and mill wastewater treatment by J.S.Scott and K. Bragg, EPS 3-WP-75-5, Environment Canada, 1975.

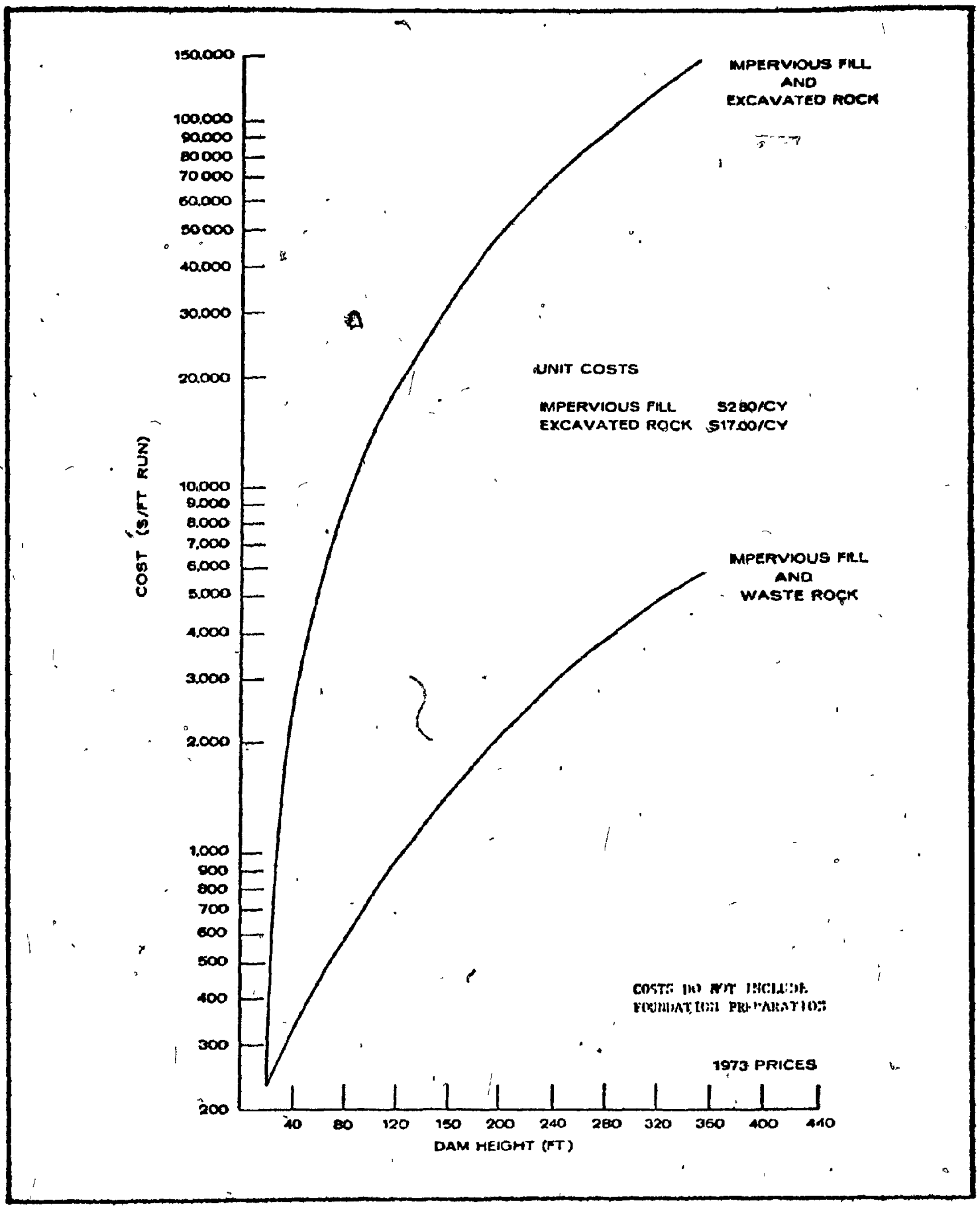

Figure 23. Cost of zoned dams.

Reproduced from <u>Mine and mill wastewater treatment</u> by J.S.Scott and K. Bragg, EPS 3-WP-75-5, Environment Canada, 1975.

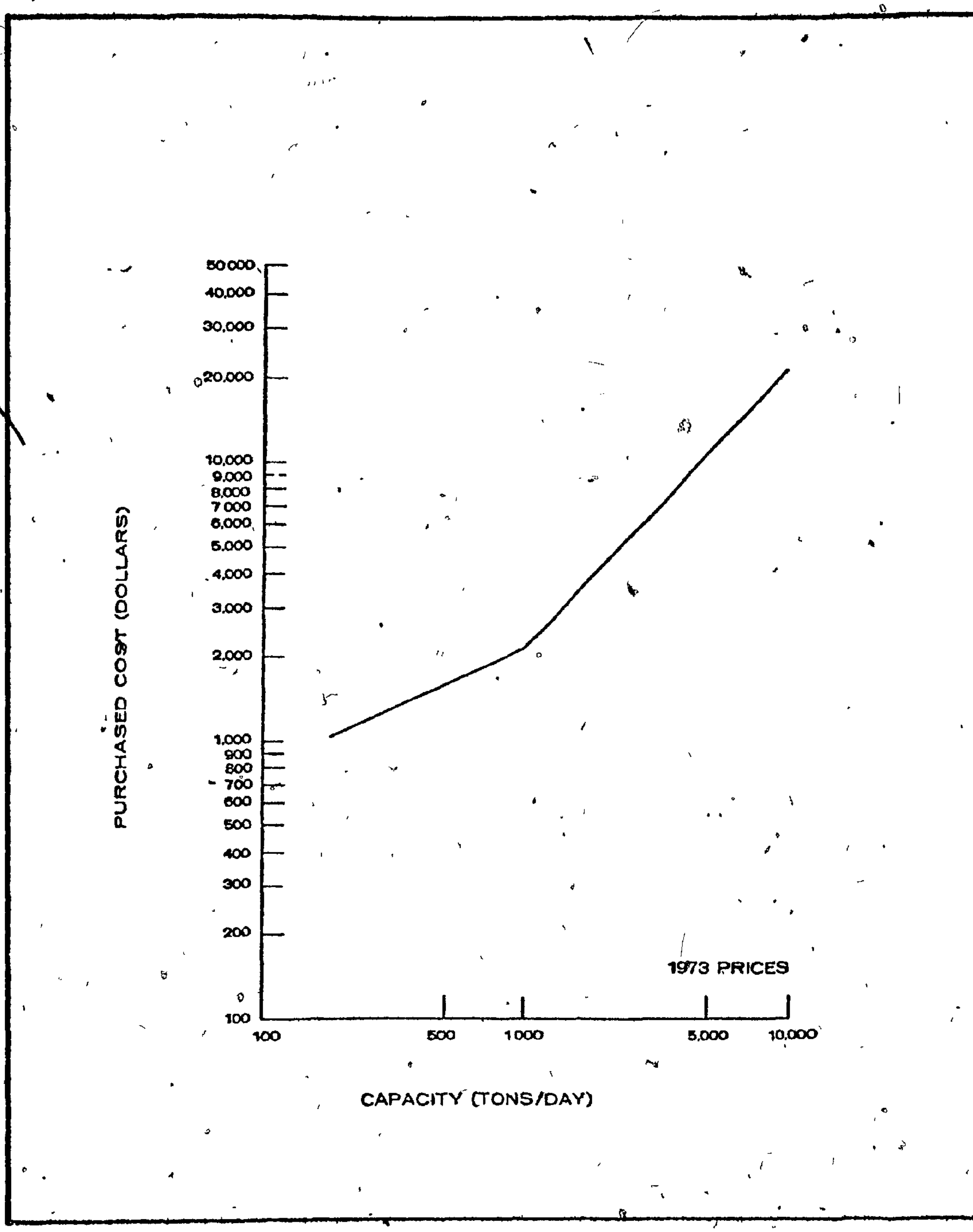

Figure 24. Cost of cyclones

Reproduced from Mine and mill wastewater treatment by J.S.Scott and K. Bragg, EPS 3-WP-75-5, Environment Canada, 1975.

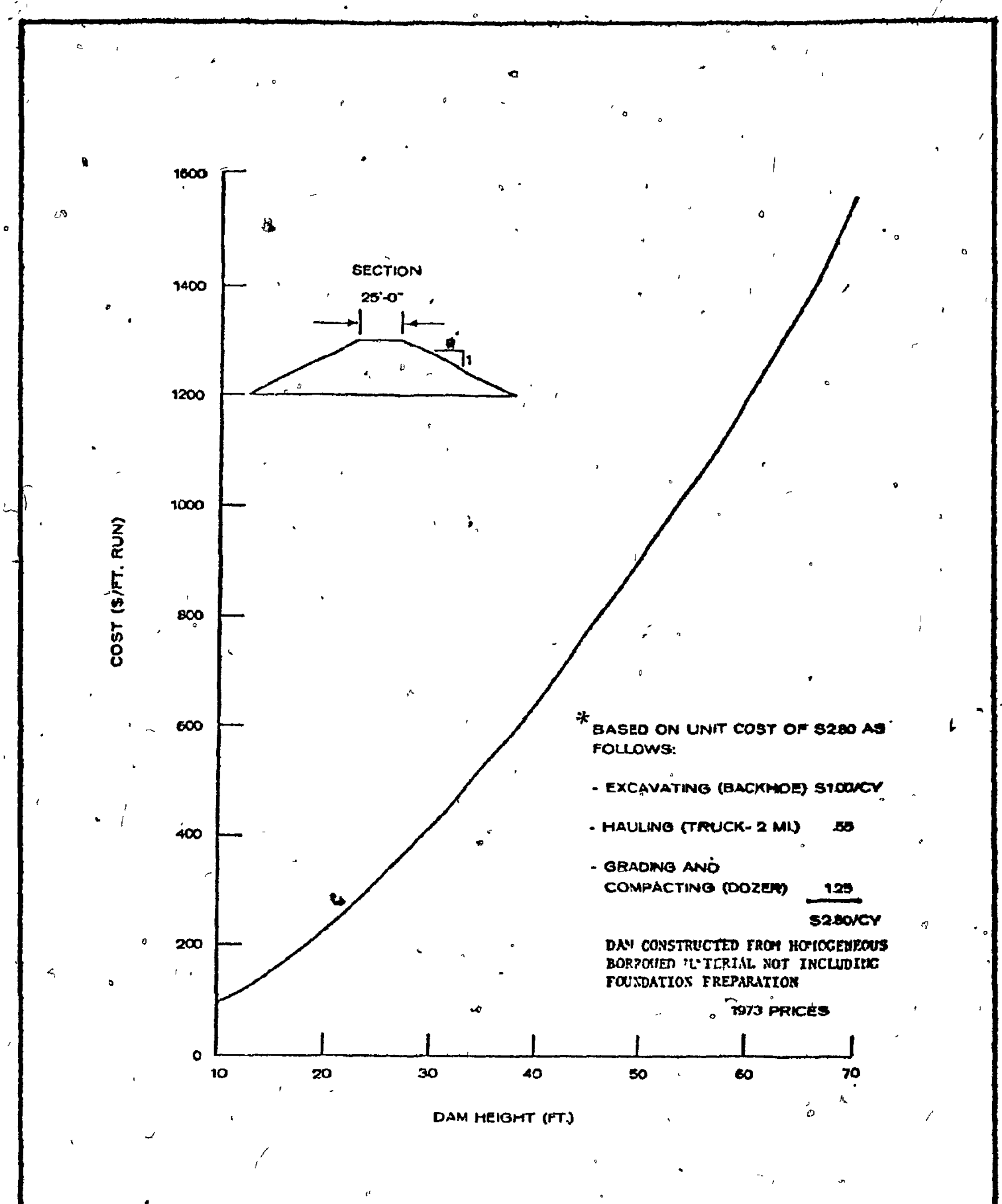

Figure 25. Cost of small dams.

Reproduced from Mine and mill wastewater treatment by J.S.Scott and K. Bragg, EPS 3-WP-75-5, Environment Canada, 1975.

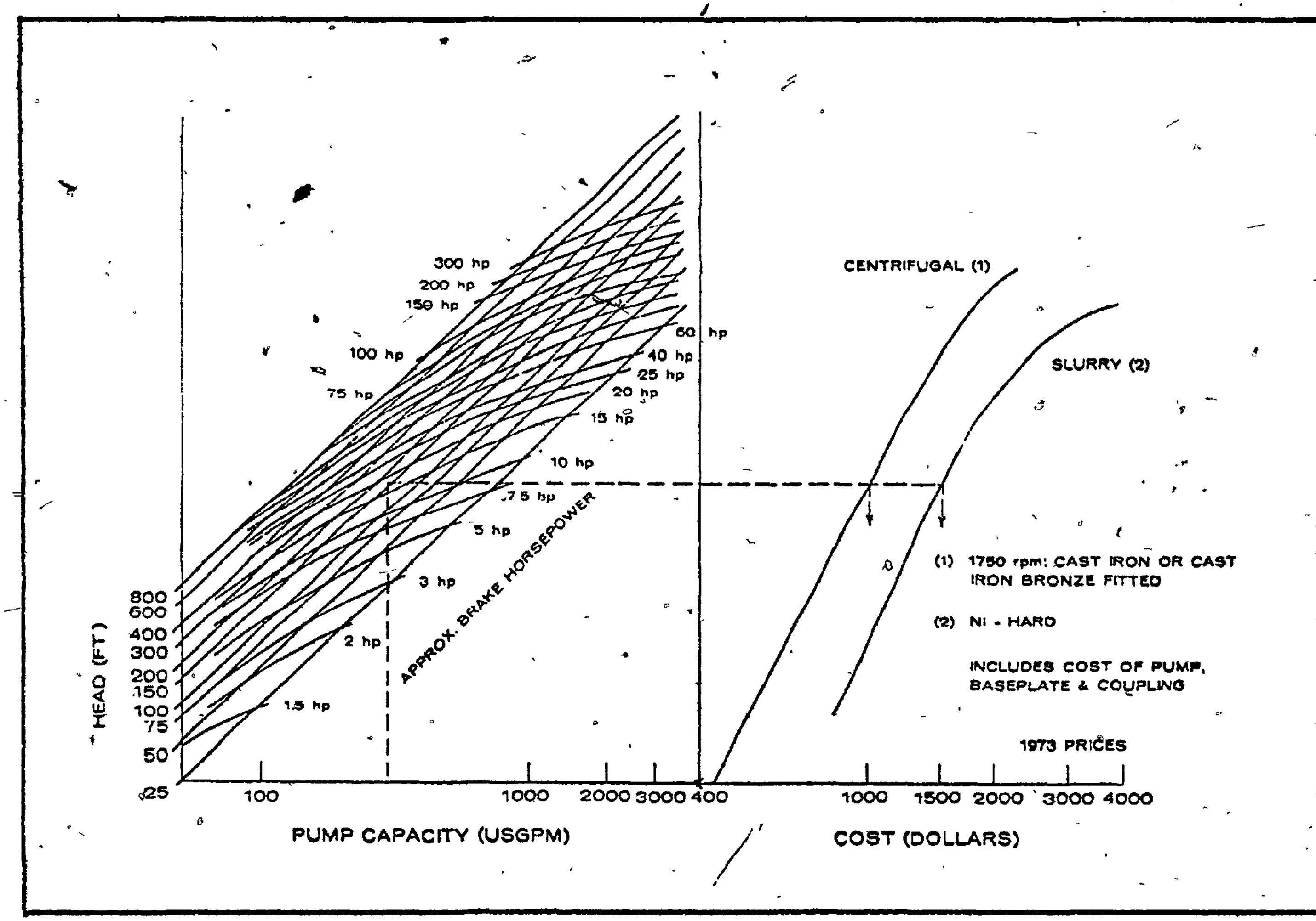

Figure 26. Cost of pumps Reproduced from Mine and mill wastewater treatment by J.S.Scott and K. Bragg, EPS 3-WP-75-5, Environment Canada, 1975.

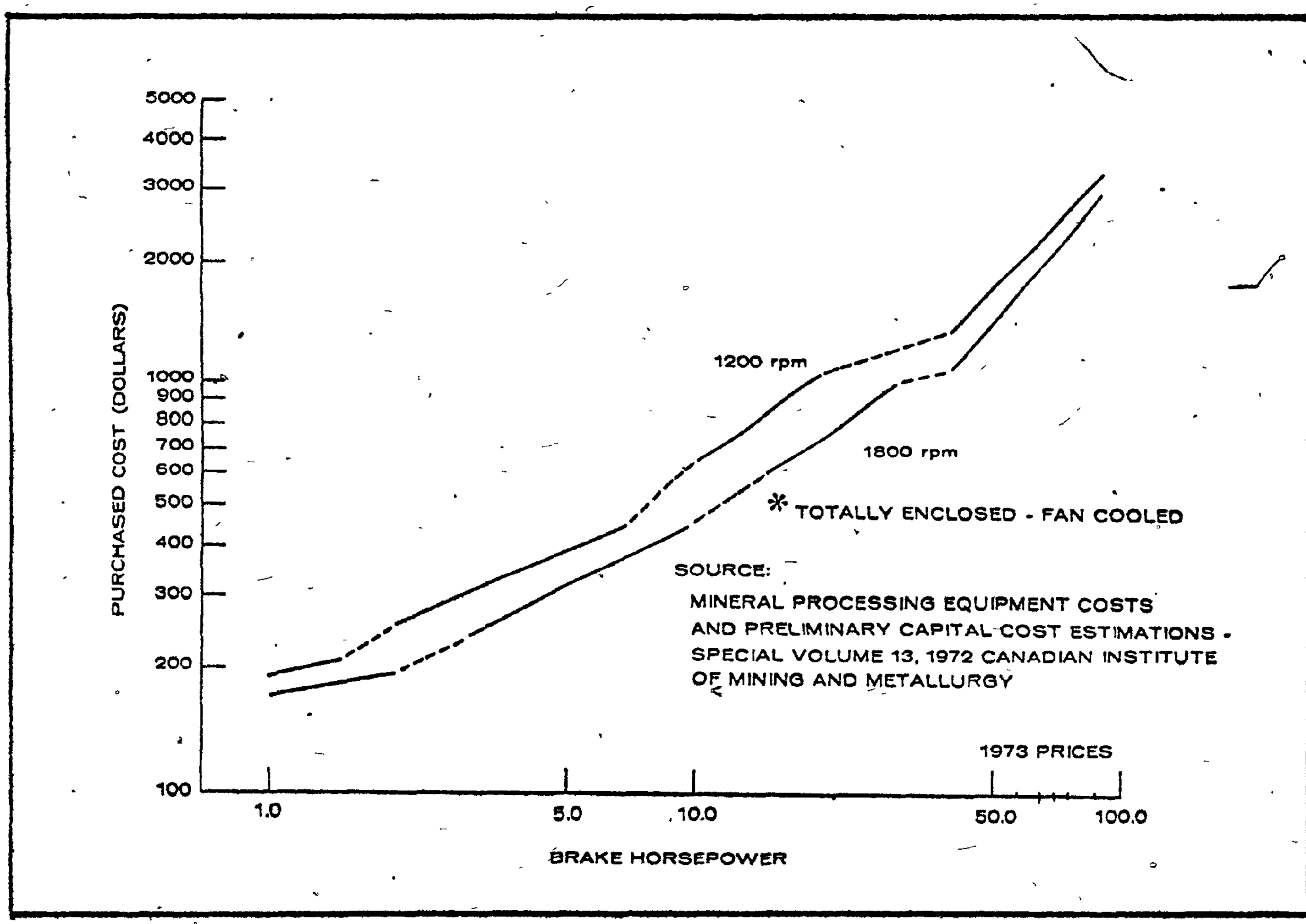

Figure 27. Cost of motors. Reproduced from Mine and mill wastewater treatment by J.S.Scott and K. Bragg, EPS 3-WP-75-5, Environment Canada, 1975.

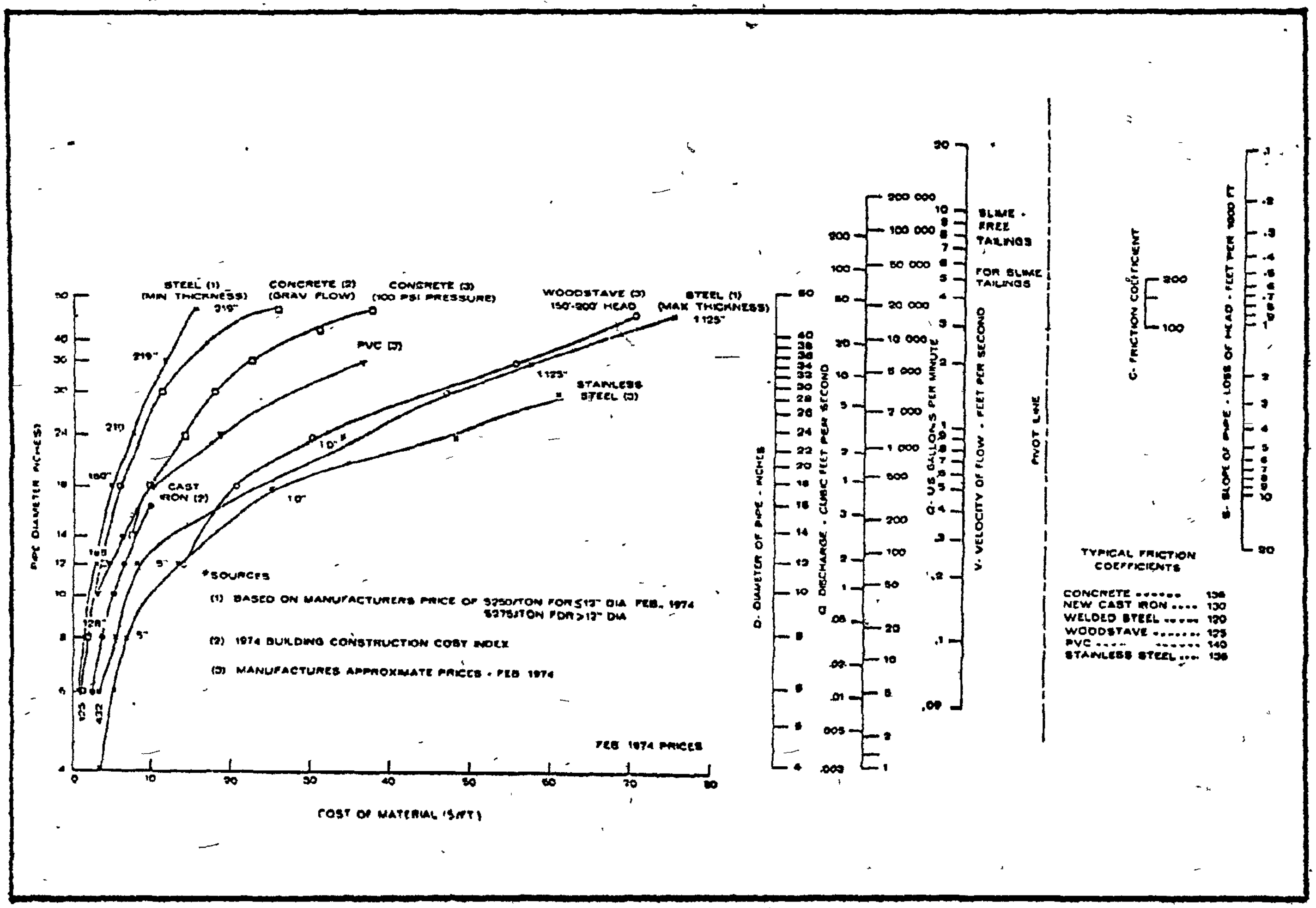

Figure 28. Pipe costs. Reproduced from Mine and mill wastewater treatment by J.S.Scott and K. Bragg, EPS 3-WP-75-5, Environment Canada, 1975.

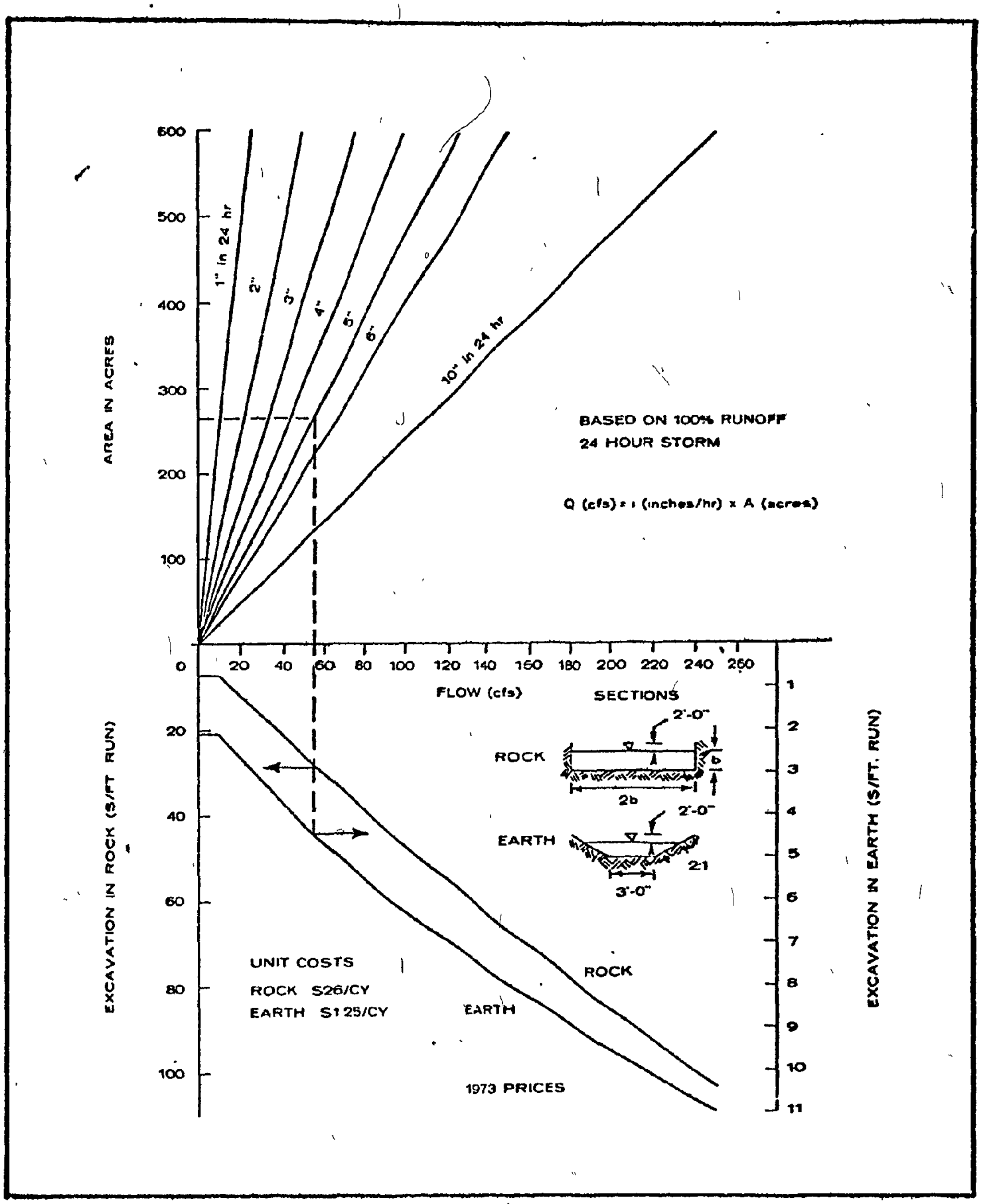

Figure 29. Surface water drainage system costs.

Reproduced from Mine and mill wastewater treatment by J.S.Scott and K. Bragg, EPS 3-WP-75-5, Environment Canada, 1975.

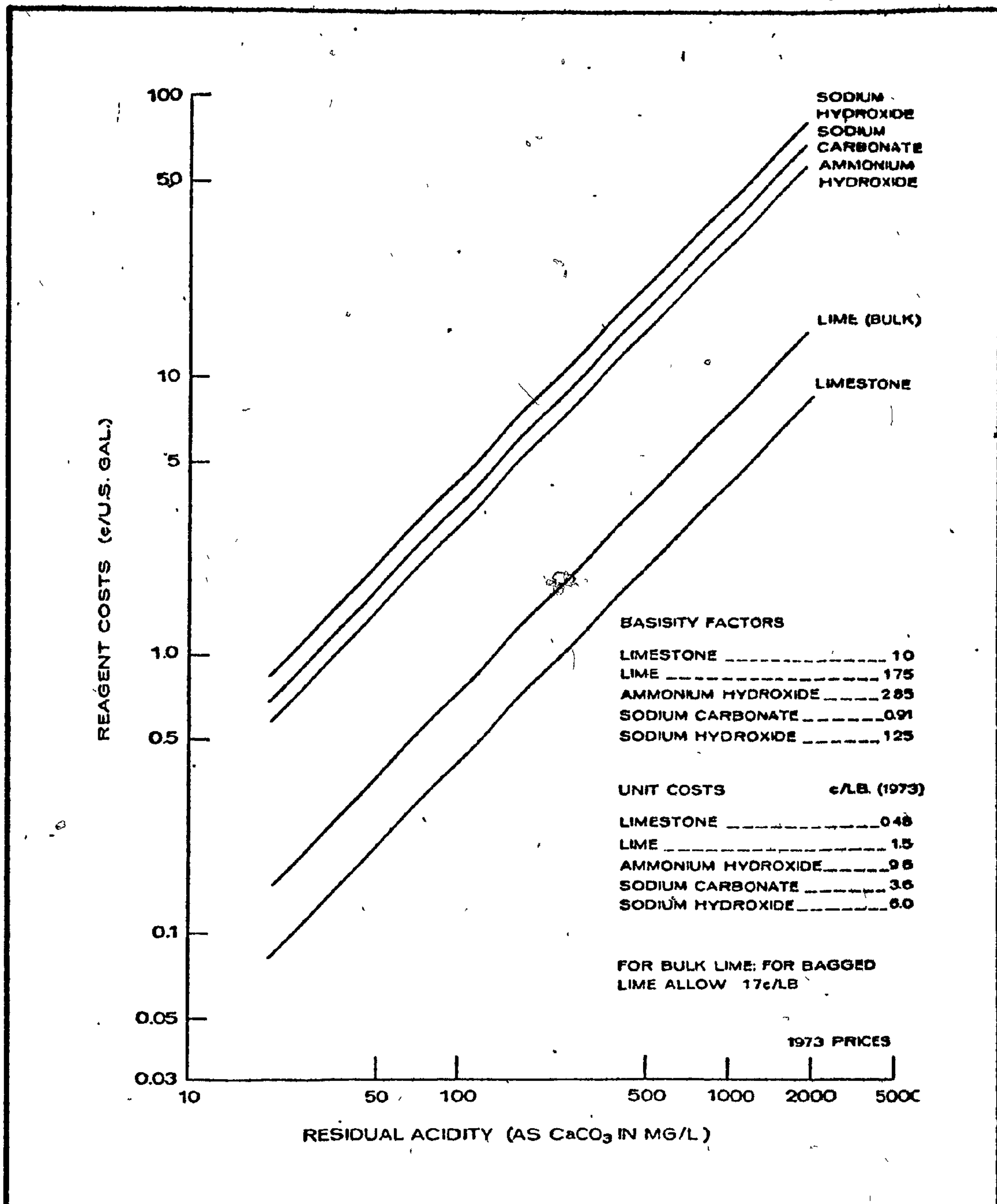

Figure 30. Neutralizing reagent costs.

Reproduced from Mine and mill wastewater treatment by J.S.Scott and K. Bragg, EPS 3-WP-75-5, Environment Canada, 1975.

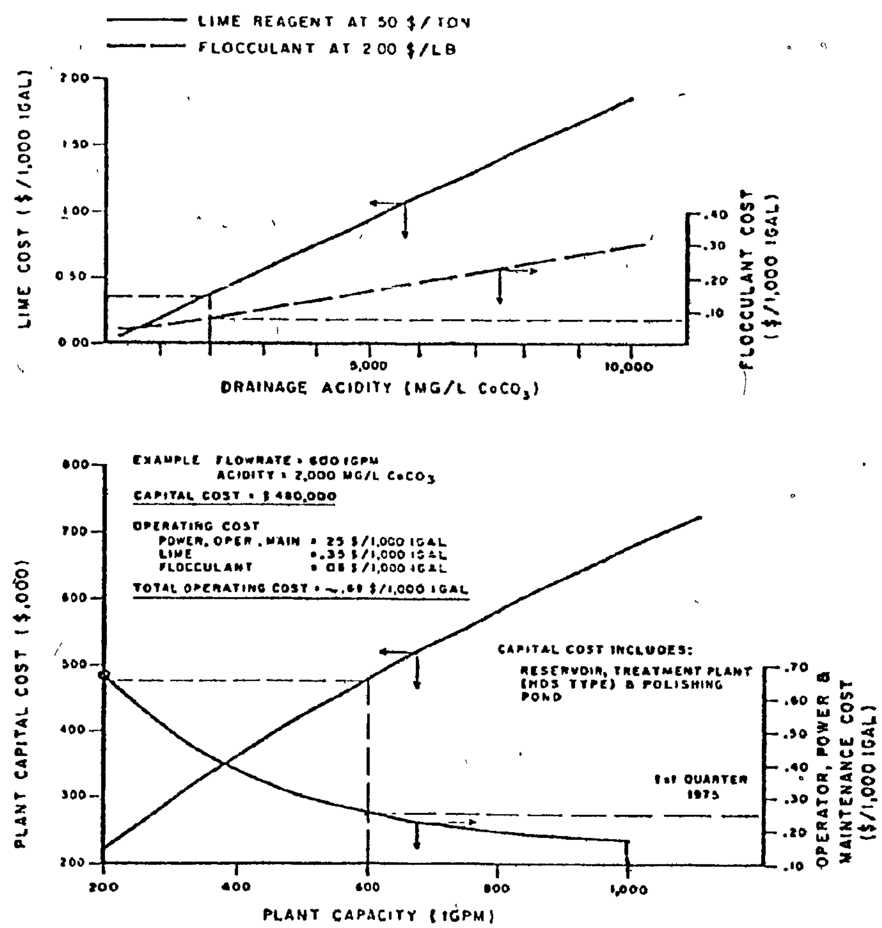

Figure 31. Cost of mechanical treatment.

Reproduced from Some recent experiences in the treatment of acidic, metal-bearing mine drainages by A. Bell, K. Phinney and S. Behie, C I M Bulletin, December 1975.

APPENDIX 5. Inflators Used in Cost Evaluations

Year	Inflation Multiplier
1970	1.92
1971	1.85
1972	1.79
1973	1.69
1974	1.47
1975	1.32
1976	1.25
1977	1.18
1978	1.10
1979	1.00

Table 22. Inflation Multiplier

Note: The inflation Multiplier is used to convert historical, current money cost data to 1979 constant money value equivalents.

APPENDIX 6. Flowchart of program MINPOL

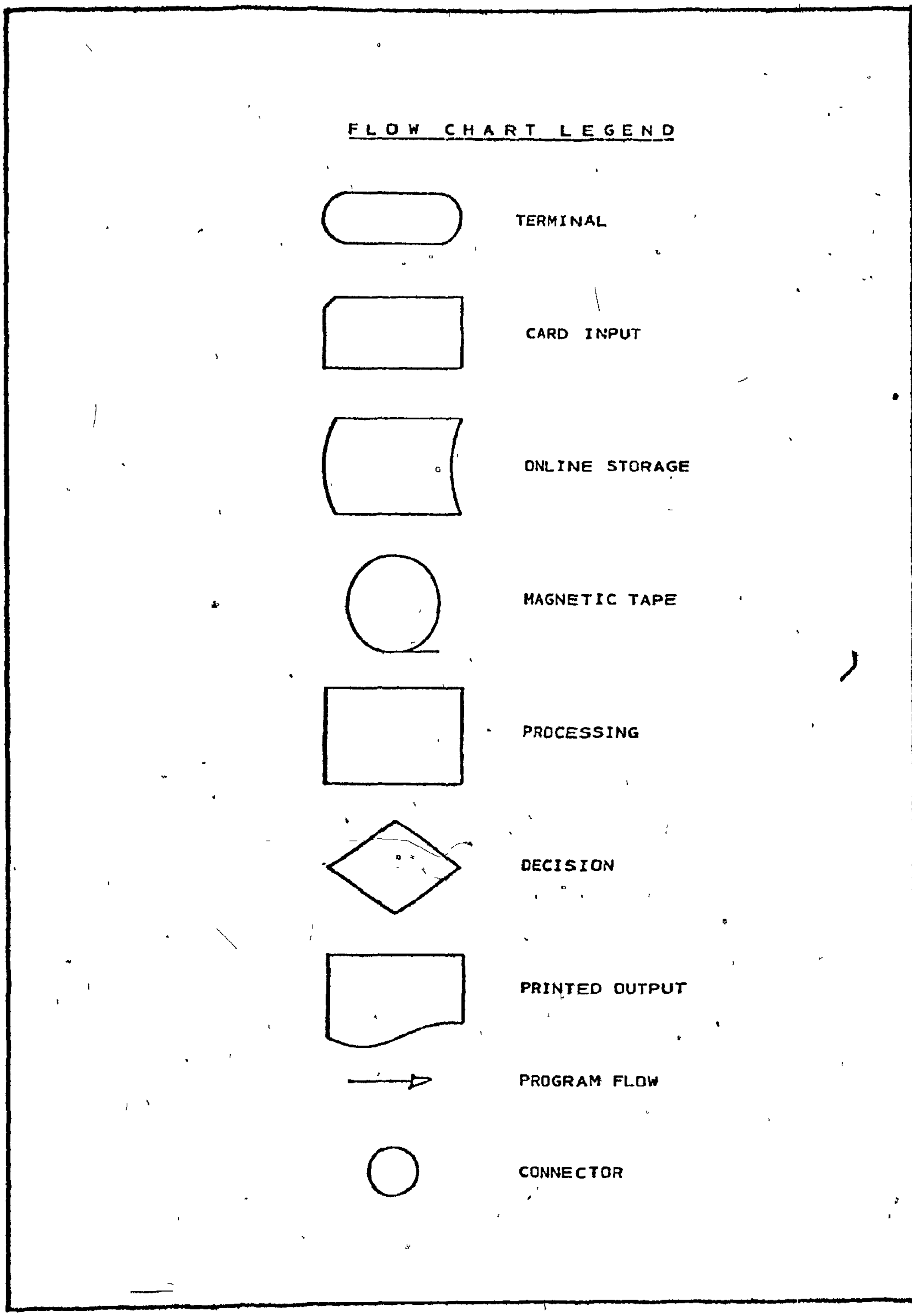

Figure 32. Flow chart legend.

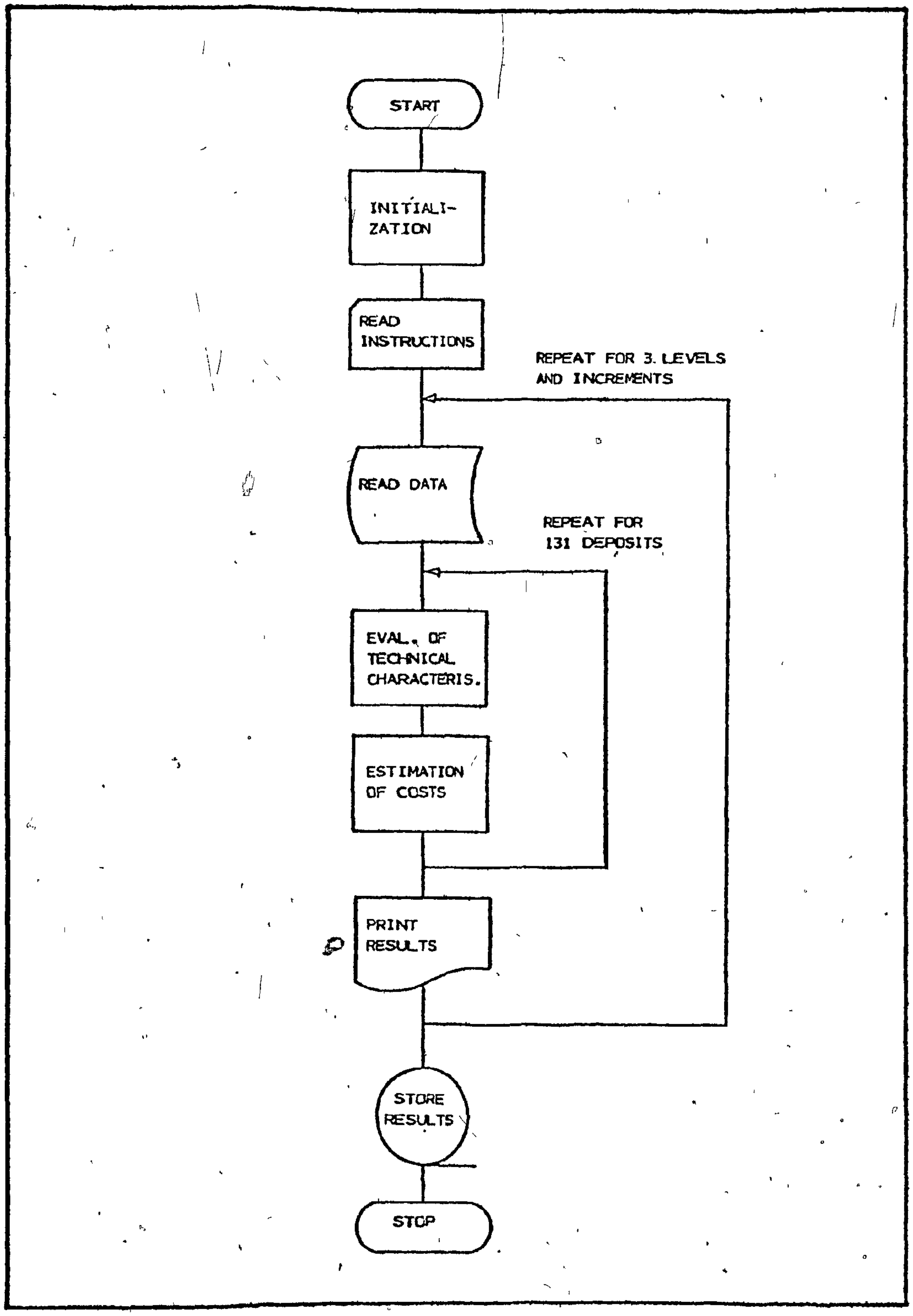

Figure 33. Flowchart of program MINPOL.

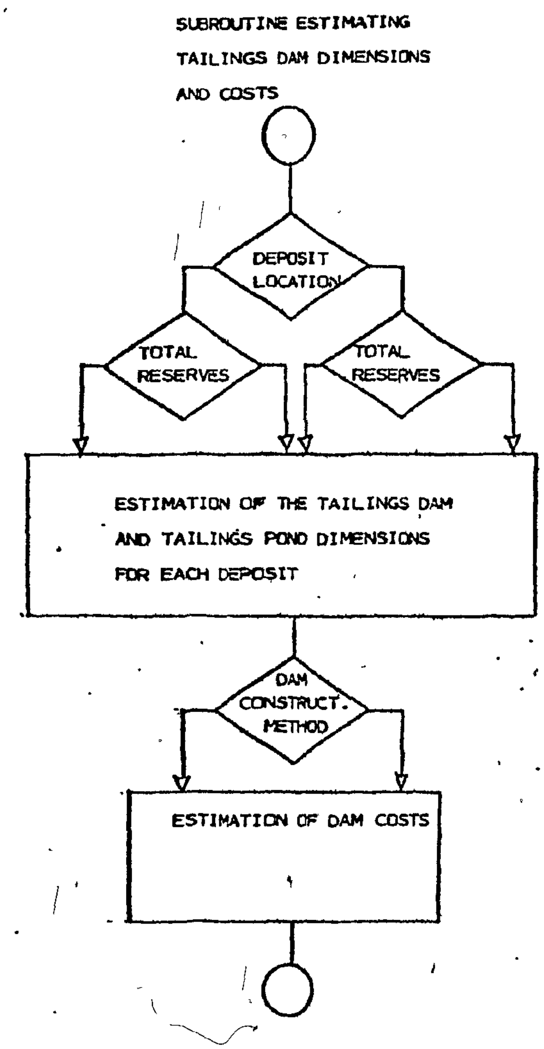

Figure 34. Subroutines of program MINPOL.

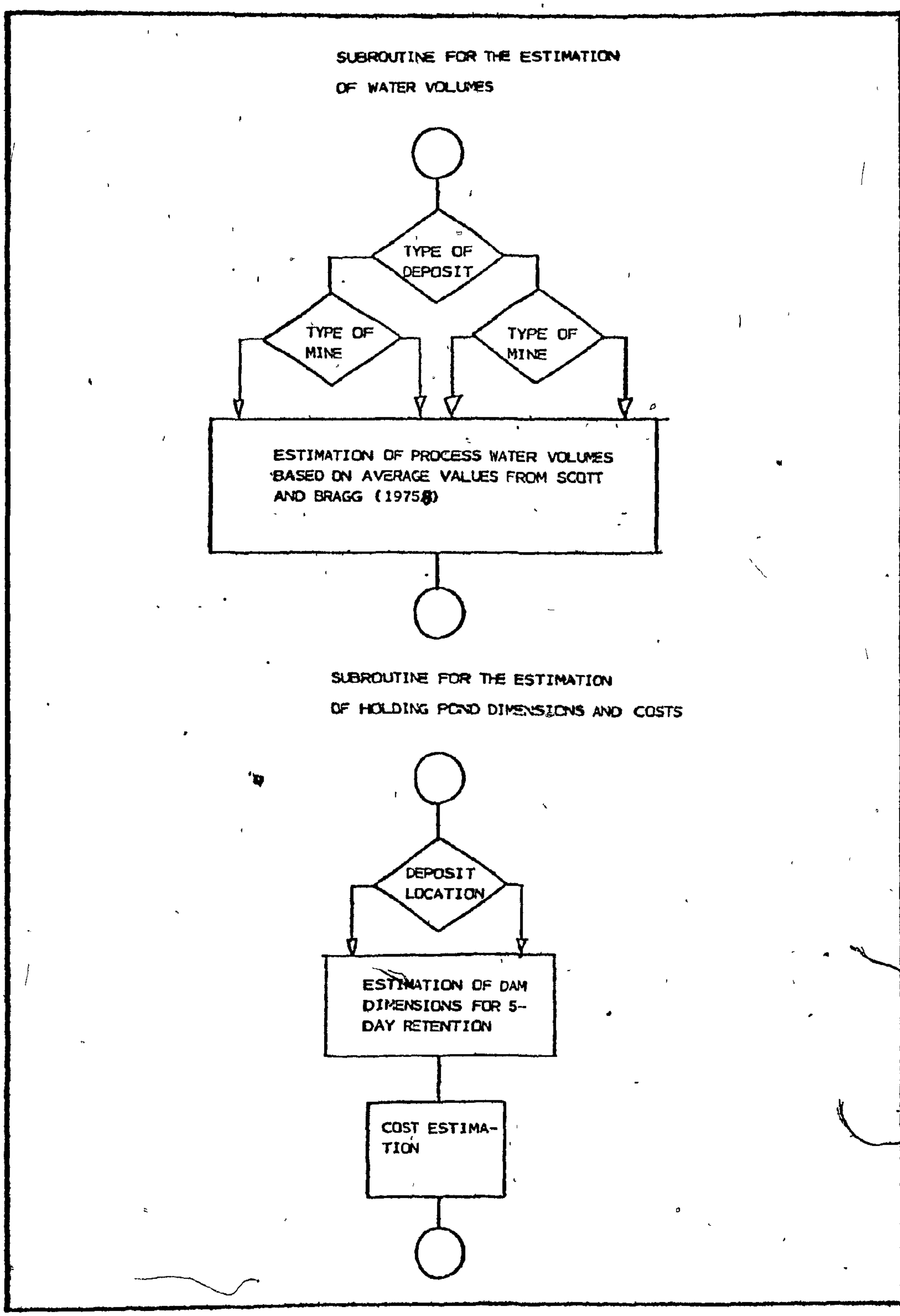

Figure 35. Subroutines of program MINPOL.

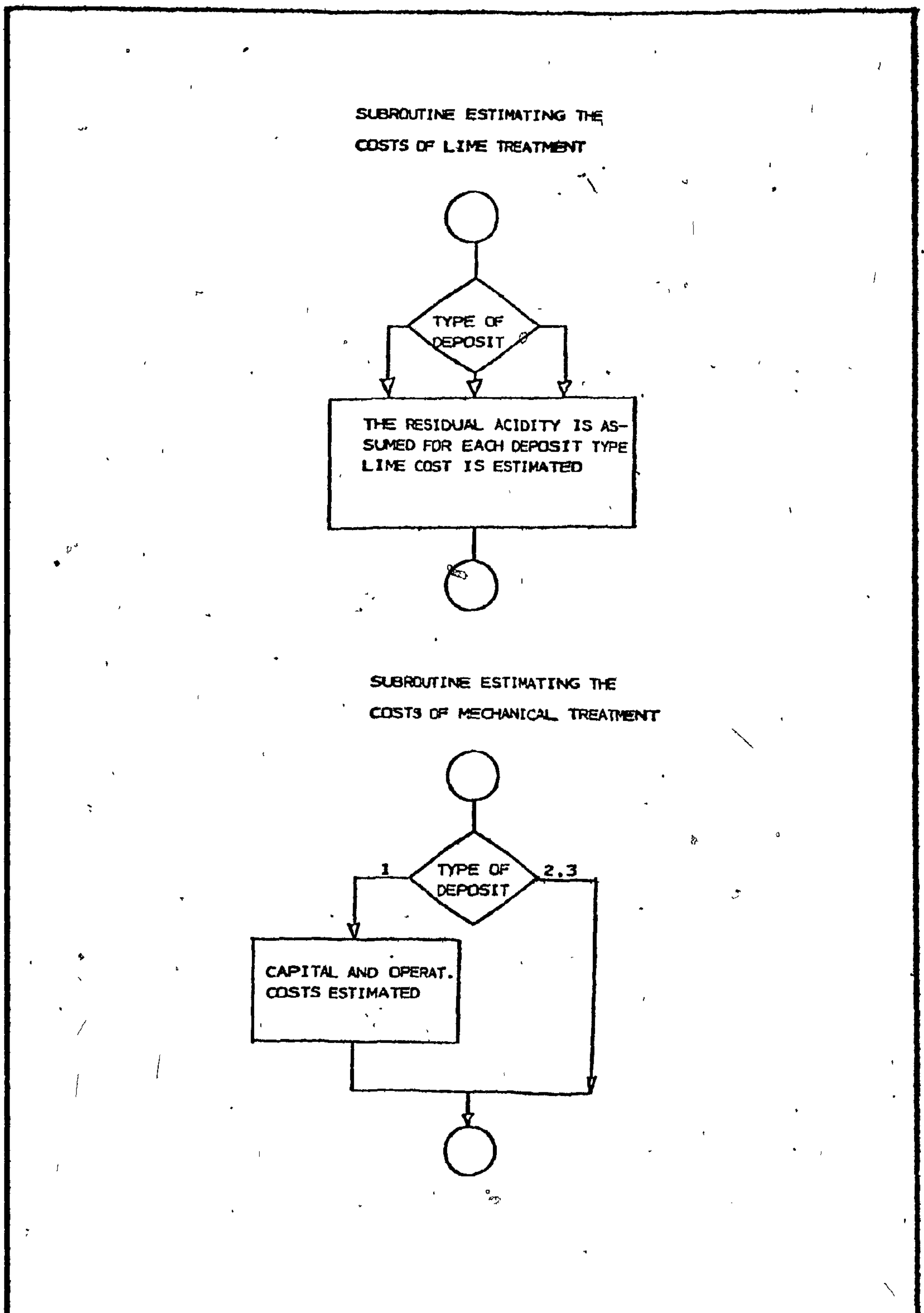

Figure 36. Subroutines of program MINPOL.

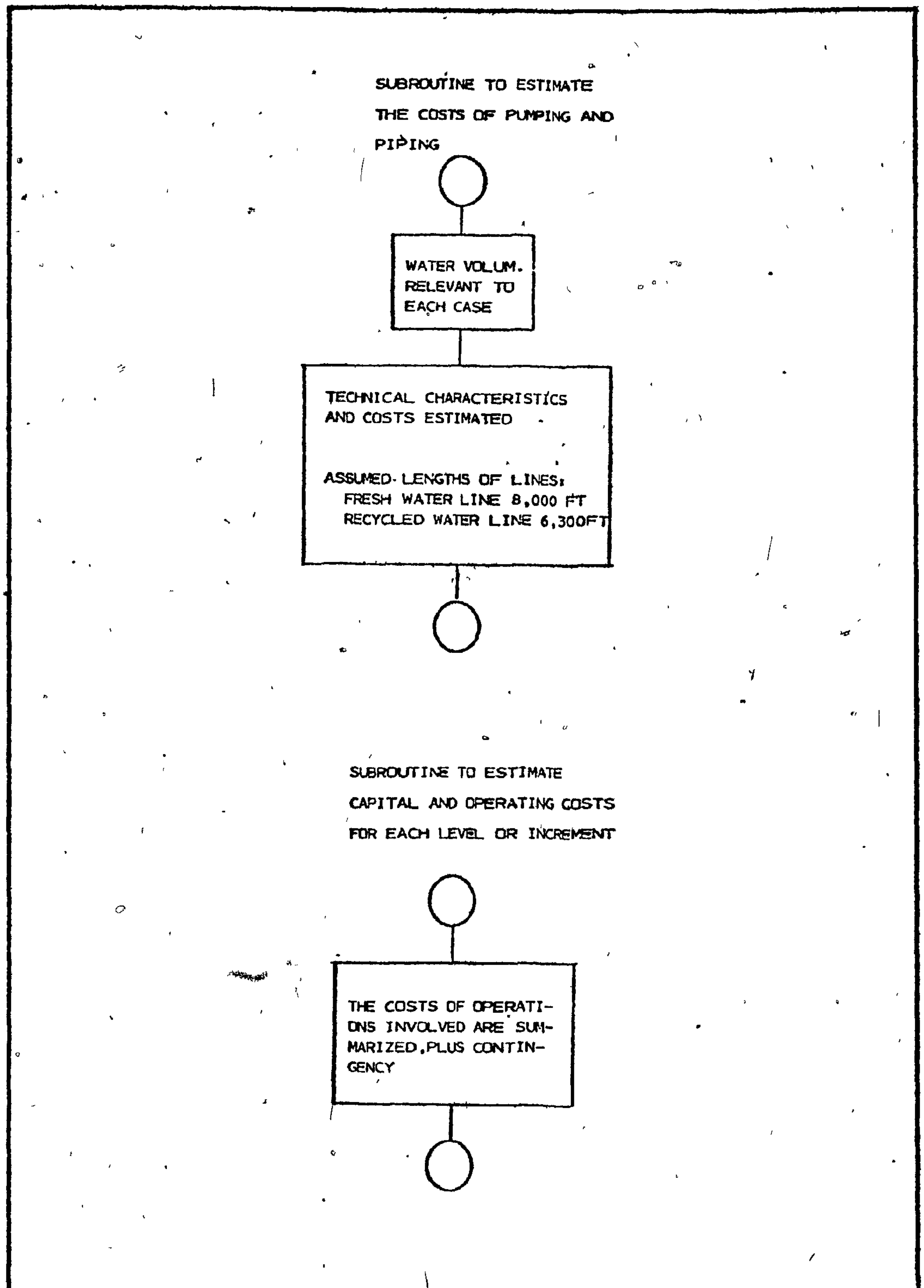

Figure 37. Subroutines of program MINPOL.

APPENDIX 7. Distributions of capital and operating costs related to water pollution control

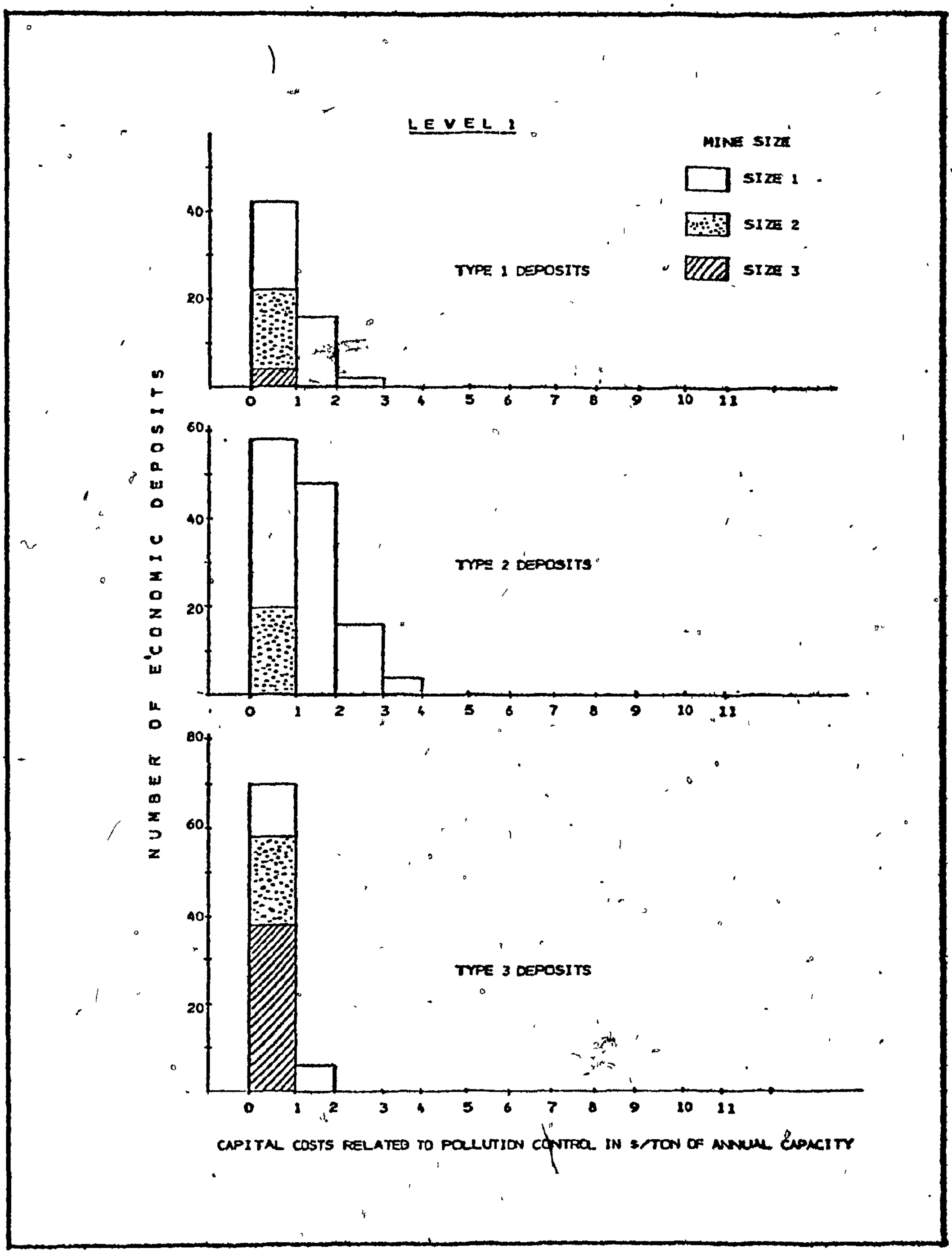

Figure 38. Capital costs for level 1 of treatment.

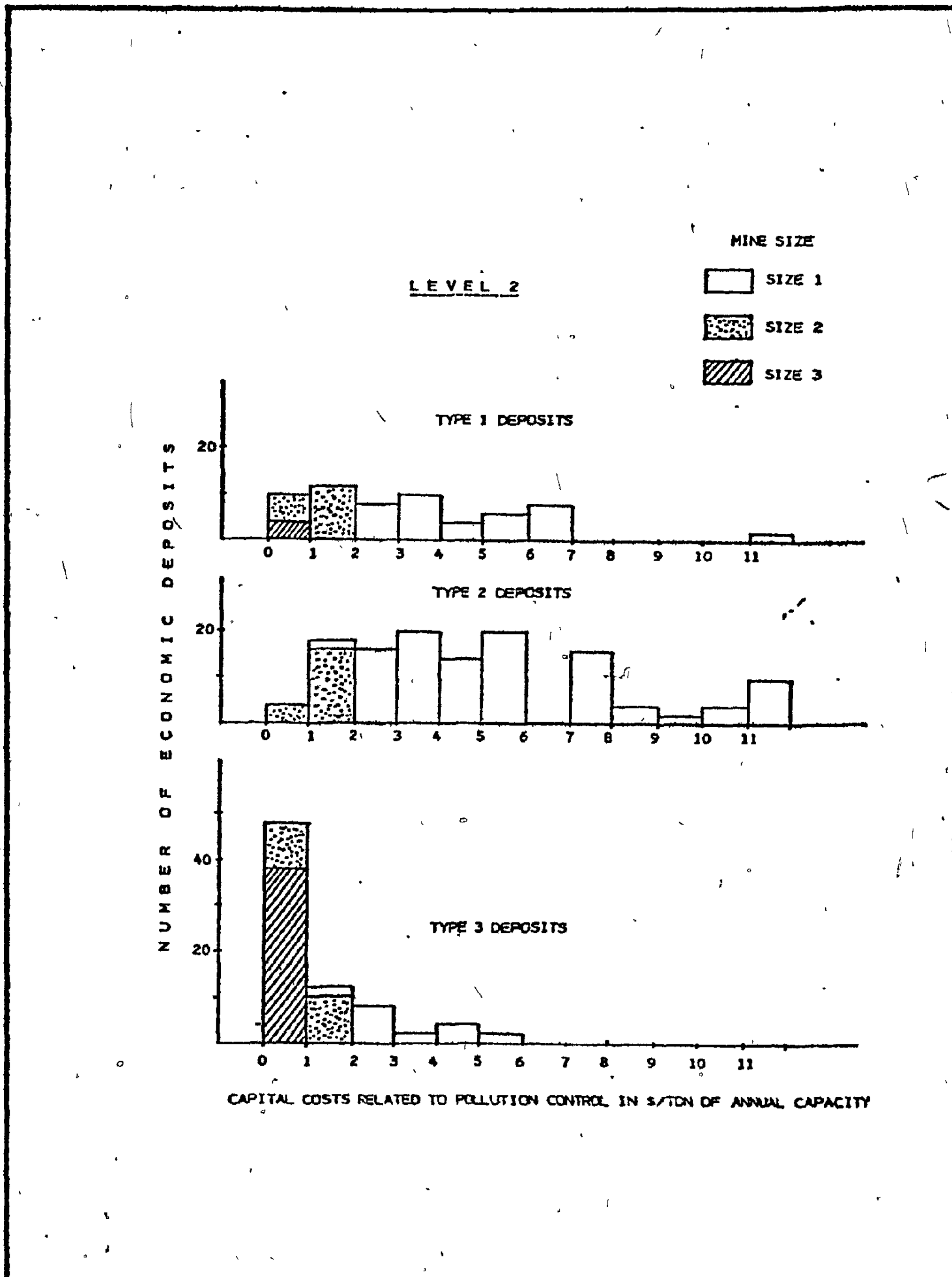

Figure 39. Capital cost for level 2

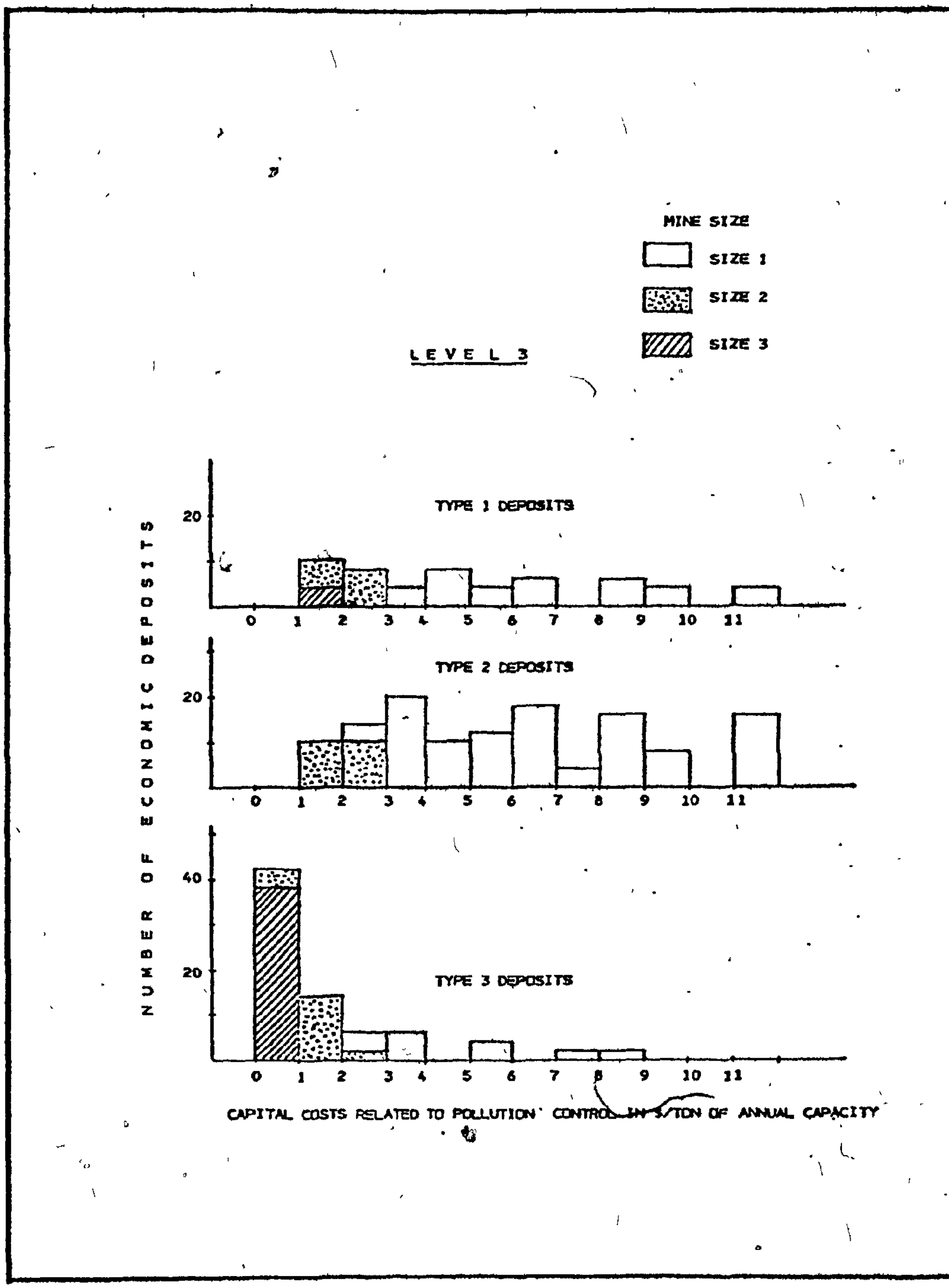

Figure 40. Capital costs for level 3

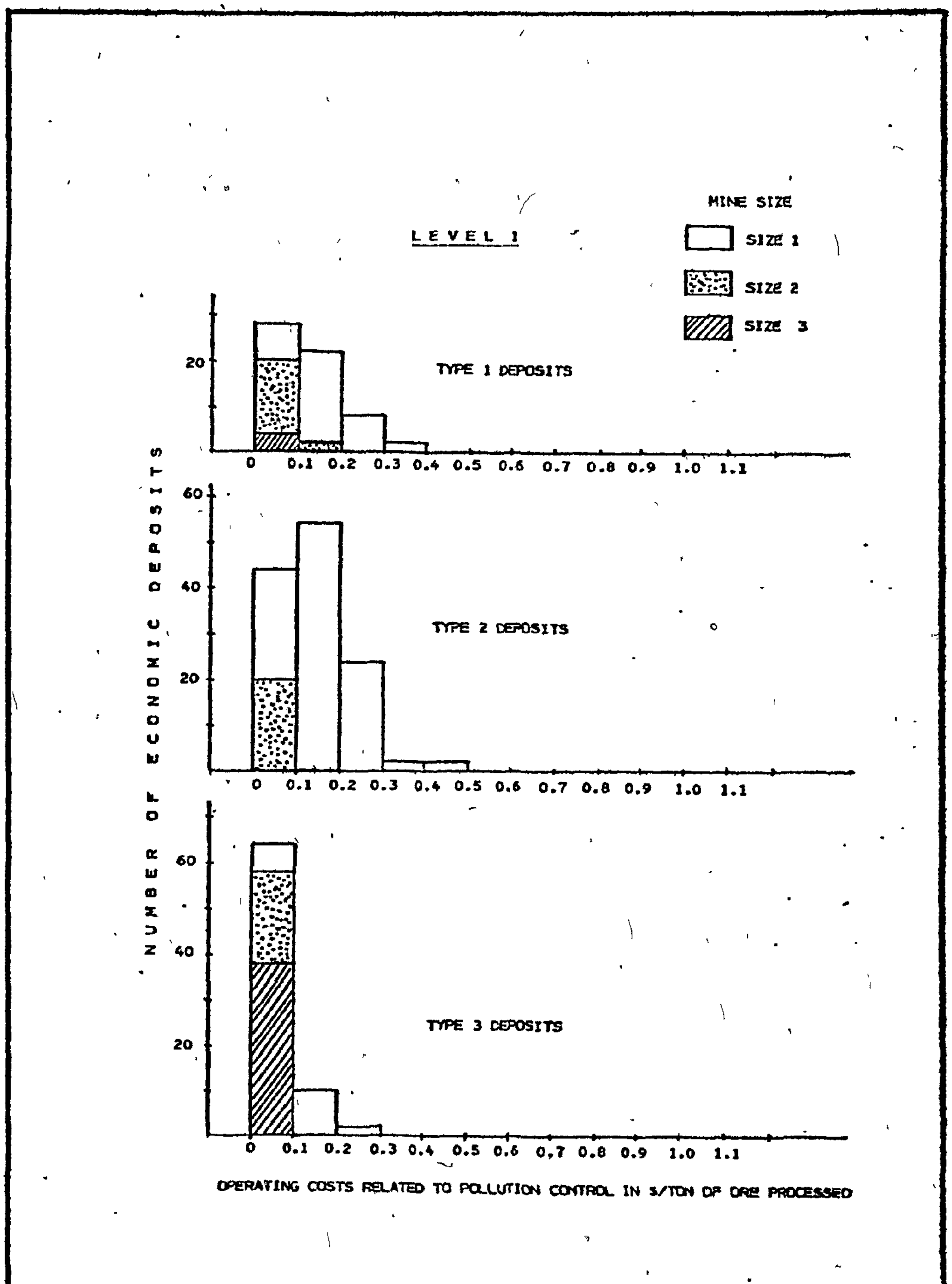

Figure 41. Operating costs for level 1

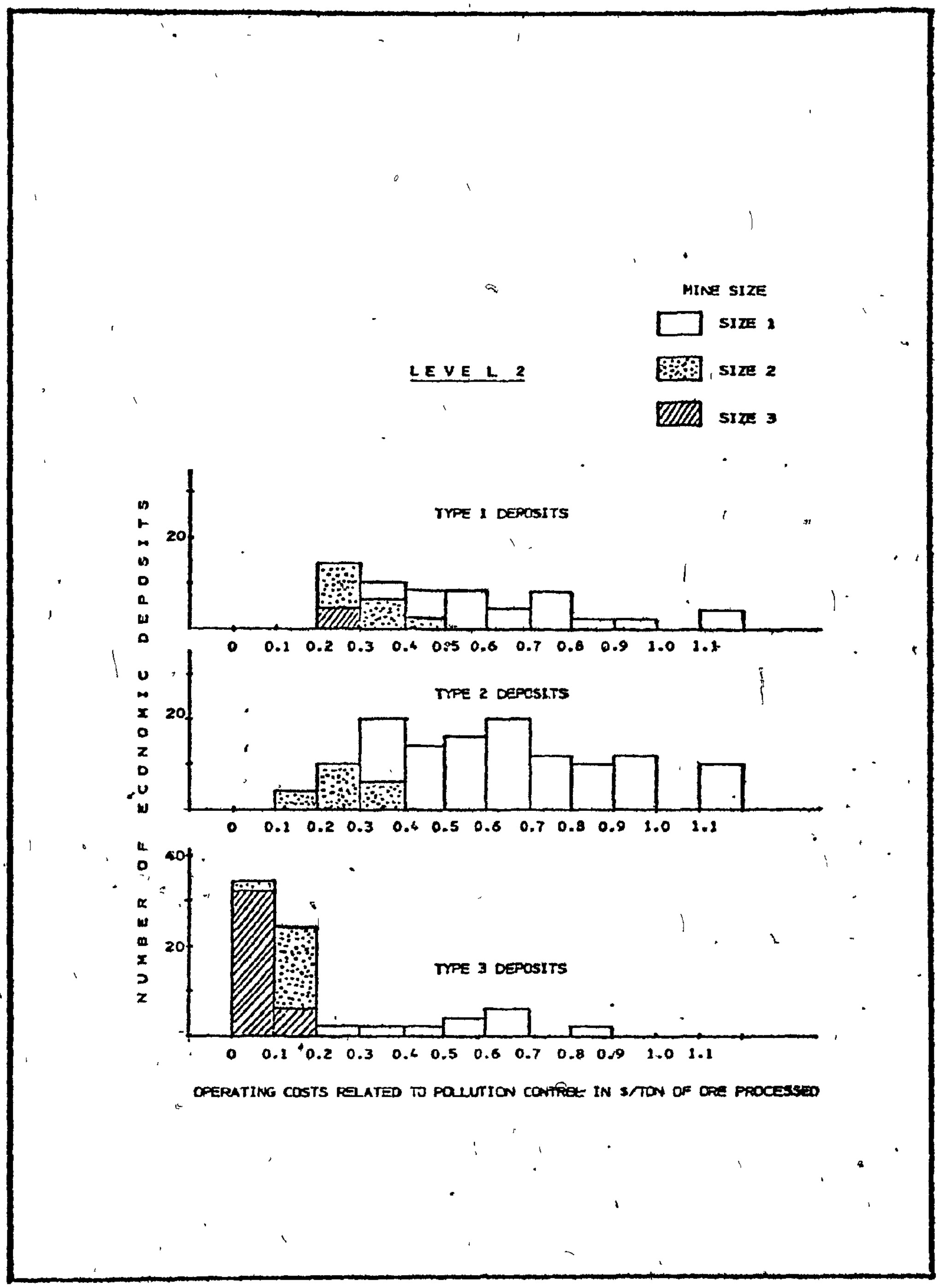

Figure 42. Operating costs for level 2

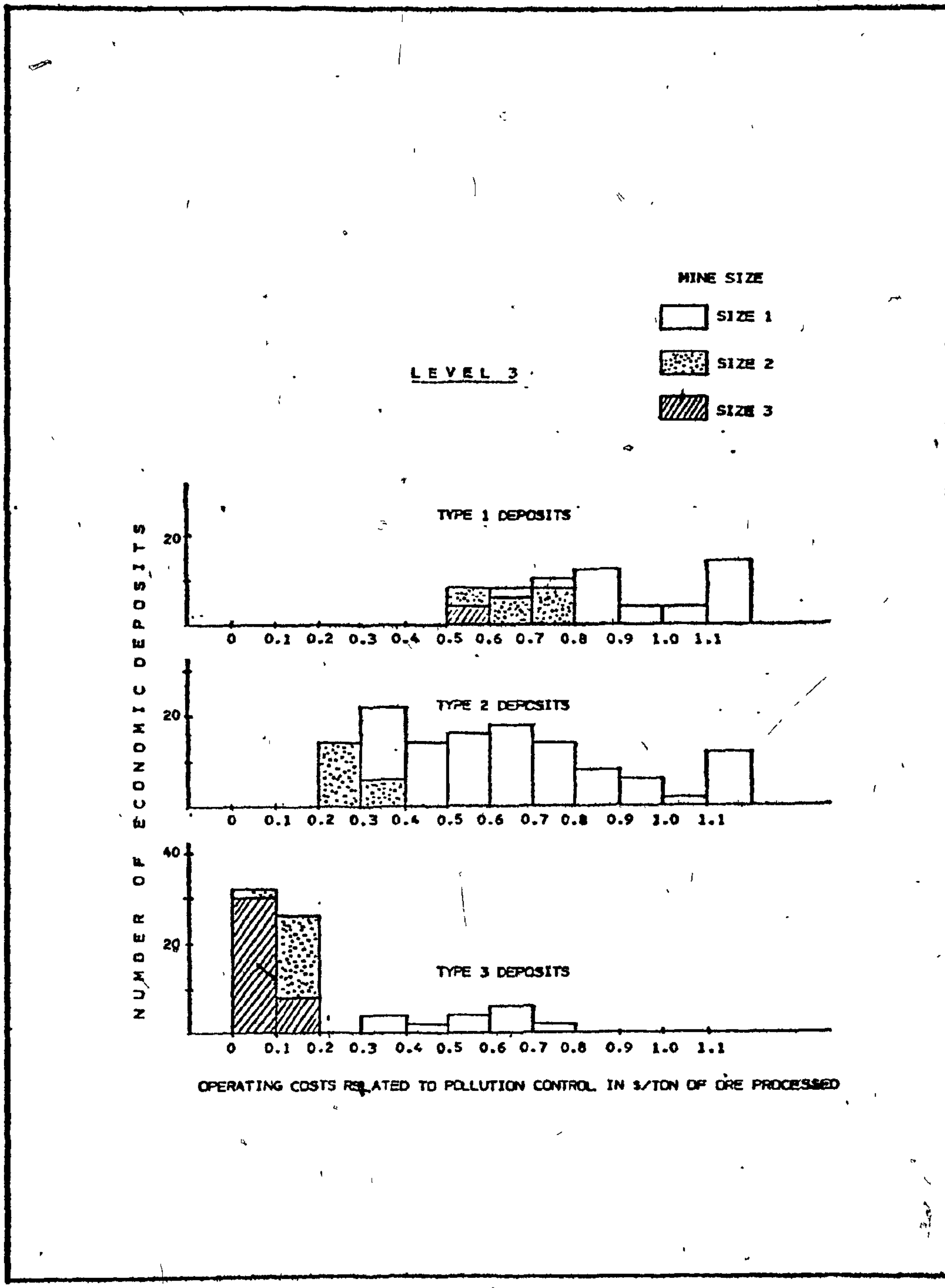

Figure 43. Operating costs for level 3

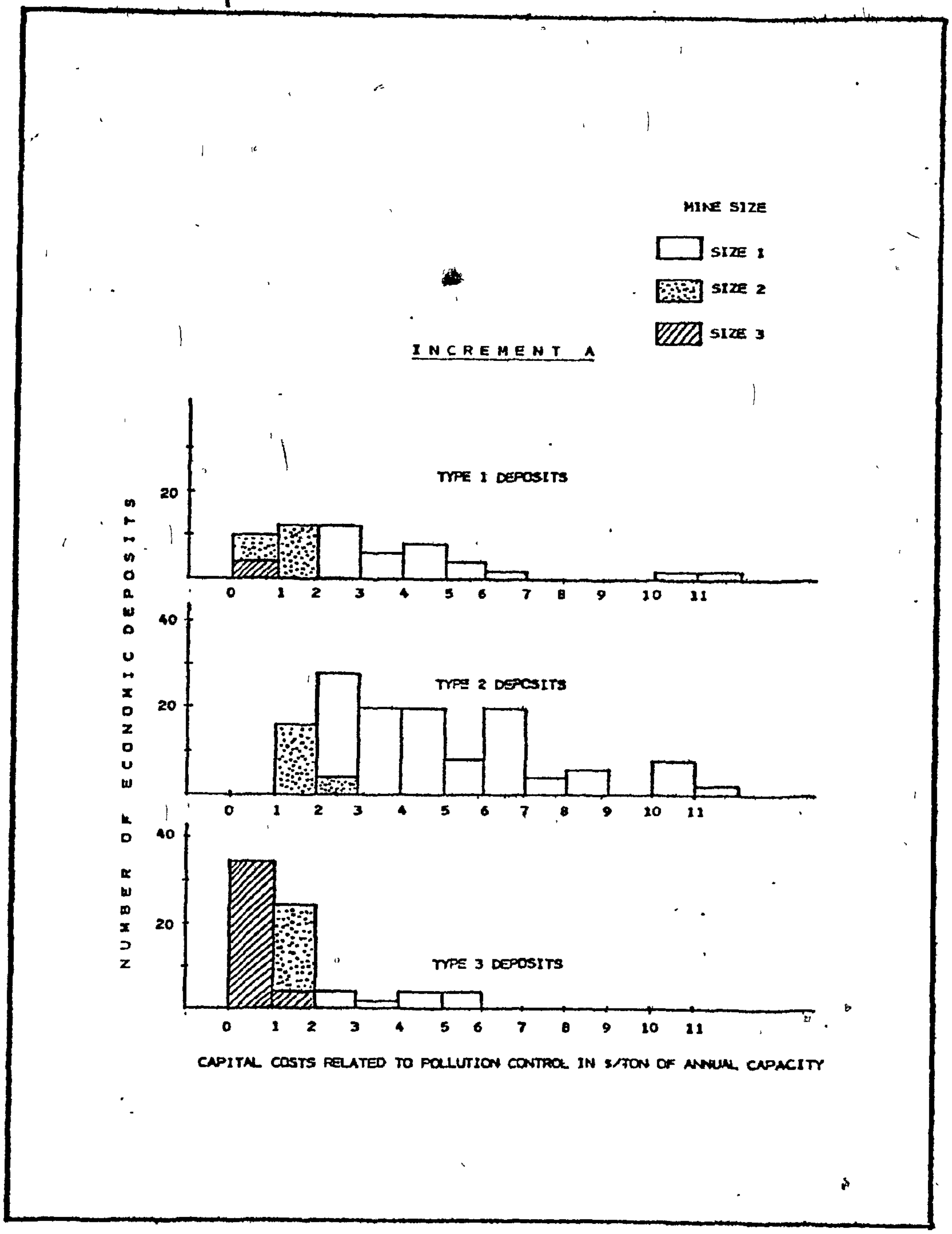

Figure 44. Capital costs for increment A

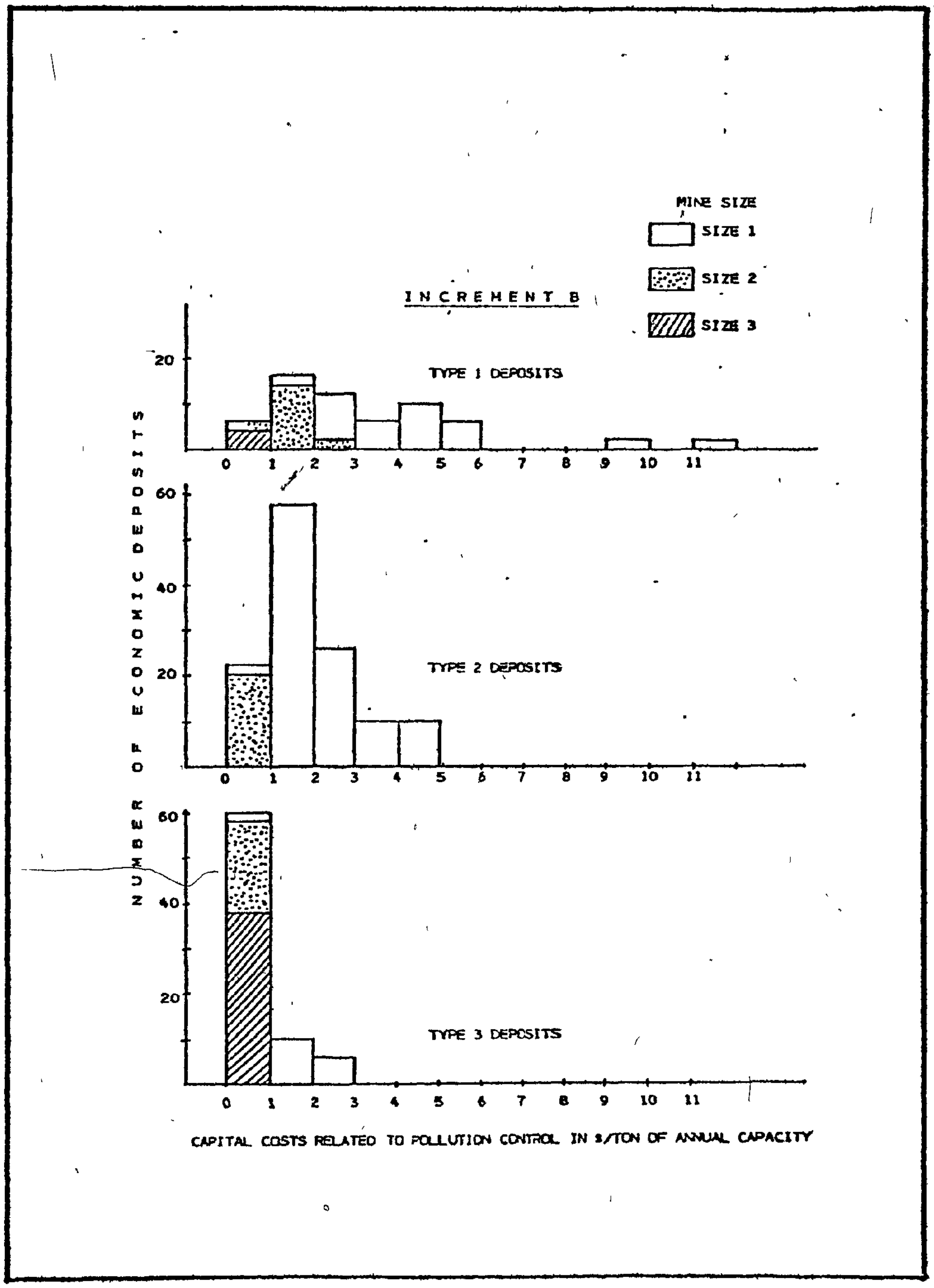

Figure 45. Capital costs for increment B

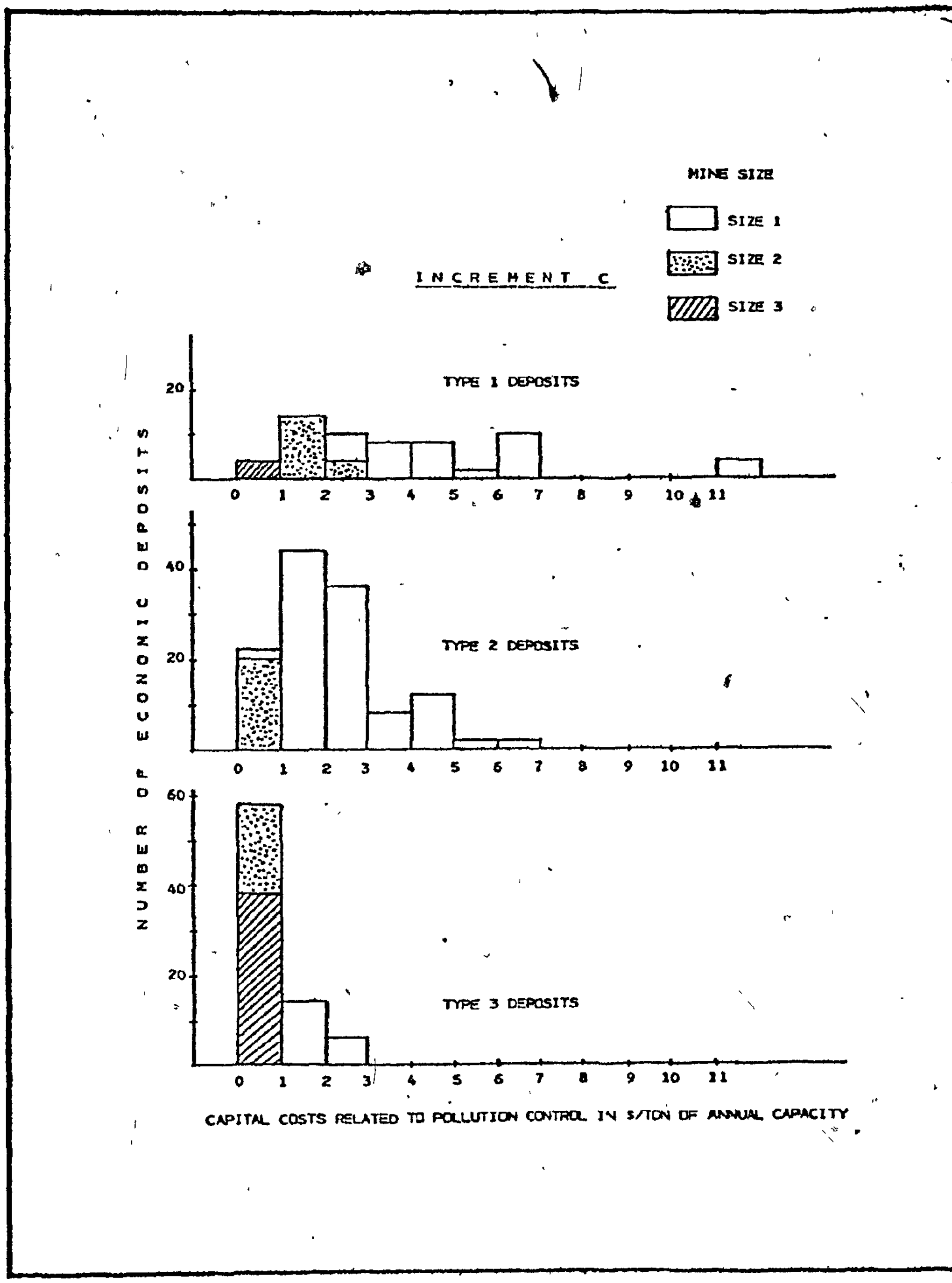

Figure 46. Capital costs for increment C

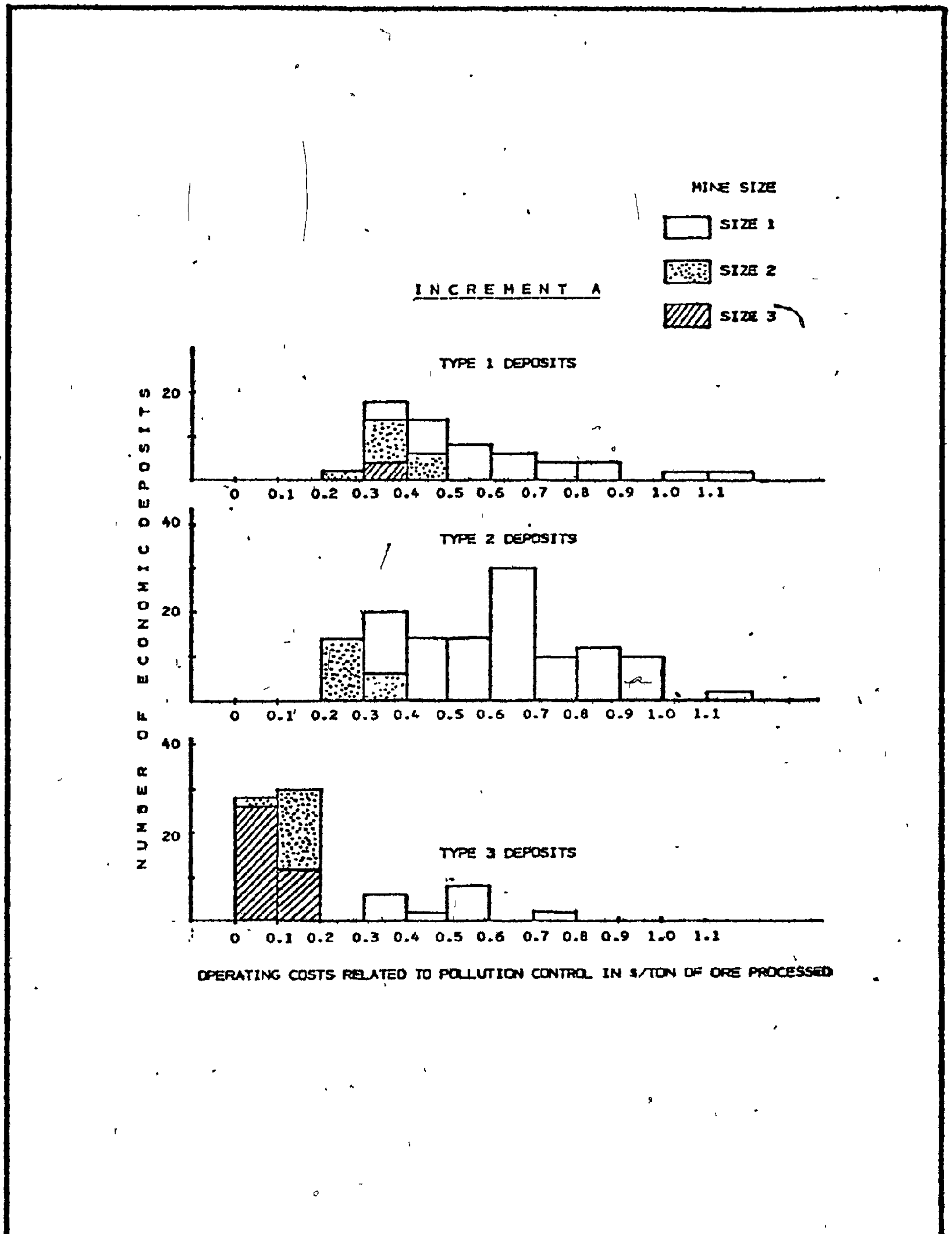

Figure 47. Operating costs for increment A

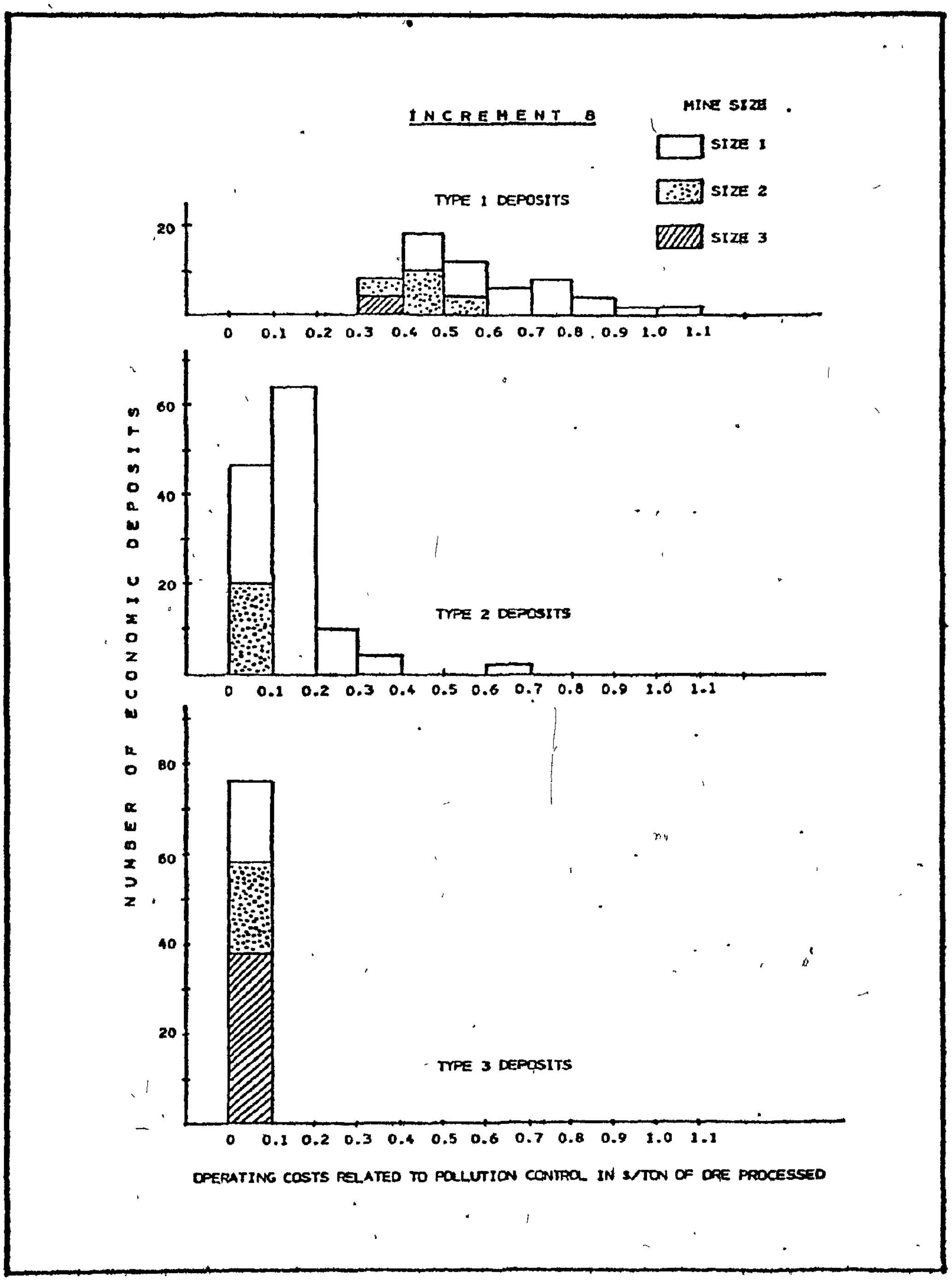

Figure 48. Operating costs for increment B

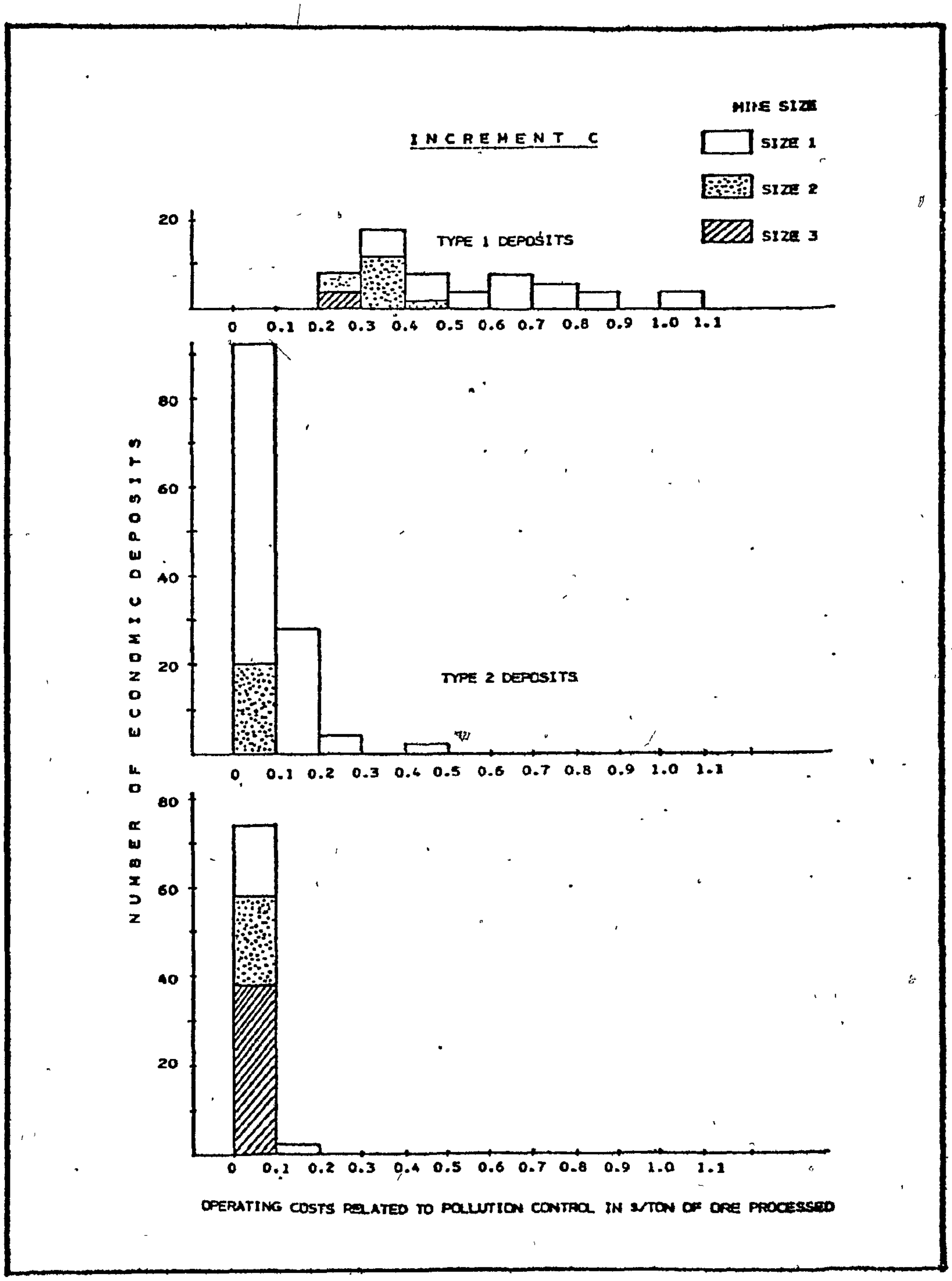

Figure 49. Operating costs for increment C

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