OPTIMUM MINE ENVIRONMENTAL PLANNING

by

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INTRODUCTION

Many actions have been taken by the United States to cope with those problems which arise when man interacts with his environment. Legislative action has evolved continuously over seventy years beginning with the Rivers and Harbors Act of 1899 and culminating in the National Environmental Policy Act of 1969, NEPA. NEPA is now famous for requiring environmental impact statements for projects with significant and major federal action. Court decisions have extended NEPA, so that in virtually any federal action, the government agency involved is forced to incorporate environmental considerations into the total planning process.

A wave of public sentiment has evolved along with the establishment of this definitive national environmental policy. Probably small, but vocal, groups have fostered the "ecological" or "environmental movement." Through the NEPA-required public review of environmental impact statements (EIS), such groups have stimulated legal action against some existing and proposed developments. Avid support for this environmental protection stand, combined with further federal action and the pattern of courts' decisions, has entrenched national environmental policy and kept it in the spotlight.

Along with policy expansion, a large-scale technological expansion has occurred in the environmental sciences. The environmental sciences are, in reality, no more than extensions of the traditional fields of knowledge. However, an understanding of the interrelationships requires

a breadth of comprehension only possible from multidisciplinary studies. In such multifaceted investigations, distinct relationships are still often difficult to identify. A shift of relationships is present, from the quantitative, hard facts of engineering and science, through intermediate regimes characterized by economics, to the qualitative and subjective bases of knowledge found in the humanities and social sciences. The efforts of a team of specialists from several general disciplines, and detailed expertise in a given planning situation, may be needed for proper assessment.

Coordinating the components of interdisciplinary studies can be complex. A specialist frequently has no clear idea of his field's relation to the overall effort. Engineers, scientists, economists and social scientists have such different professional backgrounds, with different technical jargons, that meaningful communications may be hindered. A full exchange of values may require a very forceful coordination and leadership or even be impossible.

Mining as an industry is severely influenced by the environmental movement. Surface mining is capable of extreme alterations to topographical and biological conditions. The total restoration of surface-mined land is often very difficult or impossible. Achieving that which is expected in most regulations, even with the best applicable technology, can result in some illegal and irreversible changes in the environment. However, even the worst effects of mining can be balanced by positive aspects related to the national and local needs. Increased employment and production and their corresponding sociological benefits is an example.

Mining engineering is unique in that this discipline has few explicit technical distinctions from other engineering disciplines. Mining engineering combines aspects of other fields with its own philosophy and method. The education and experience required for analyzing environmental interrelationships and their indirect effects on the mining situation are not usually considered. From a limited data base, the mining engineer acheives, through a total-systems analysis, specific definition of a complex operation from many viewpoints. Yet despite an excellent effort, a lack of knowledge in a few closely related fields may severely hinder the achievement of a comprehensive, interdisciplinary and systematic assessment which integrates environmental concern with the planning process.

Technological expansion to support national environmental policy requires that mine planning be pursued concurrently with environmental planning and operations related to mining. While the details of neither function are separately unique, there is a uniqueness to their combination. This combination, while apparently simple, is still not the approach which is practiced today. Extreme benefits can be achieved by the mining operation which chooses to integrate production of environmental quality with the production of other natural resources for consumption. The first part of this investigation will review the general aspects of environmental concerns and include some relevant details. Mining engineering aspects will then be surveyed. Following this, a subjective approach to the optimization of mine-environmental concerns will then be developed by which the mining engineer can analyze and plan for the utilization and production of mineral values and

environmental quality. A case study follows which presents a typical mining engineering analysis and then an integrated, mining-environmental analysis, emphasizing additional benefits which the mining company may identify through the composite analysis. In conclusion, an evaluation is presented of the logical extensions of this approach to more complex mining situations.

THE PERSPECTIVE OF THE ENVIRONMENT

In any investigation, the first steps are to review and identify the sources and types of data available and the manner in which these may be used for solving the problem. The sources and types of data for environmental analysis have become more complicated over time, as man has recognized more fully his complex interaction in the environment. It is first necessary to review environmental planning and then to review the basics of mining before specific approaches to optimizing the mine-environmental system can be identified. A prerequisite is to understand environmental concerns as they are viewed from an array of disciplines. This chapter introduces these perspectives, the aspects and perspectives which will be stressed in further discussion.

There are several basic concepts which occur repeatedly throughout such a discussion and require definition. Environment itself is defined in Webster's New Collegiate Dictionary as: surroundings and influences. Specifically an environment is a definite set of circumstances and conditions, physical, chemical, biological and social, in which a person or thing lives, resides or works. Ecology, which is often confused with environment, is derived from the Greek word for "home." Ecology is a specified field of biology, dealing with the study of life in the home, or more specifically, with the study of the relationships of an organism, community or population with its environment. Communities are groups of organisms. A community is a common study group said to reside

in an ecosystem. One of the basic goals of ecology is to define a niche. A niche is a specific set of surroundings and influences unique to the animal or plant being studied. A niche could be described by a list of all characteristics of the environment within which something resides.

Broadly, this study deals with human ecology, the effects of man's actions on his environment, and more specifically, it deals with the control and avoidance of contamination and pollution. Contamination is any action which alters a component of the environment. Pollution is an act of contamination which alters a component to such a degree that the environment is fouled, or a given use in contravened. Pollution may also be thought of as removing some element from a niche. Large-scale occurrences of pollution may be referred to as pollution episodes.

Many vogue terms have developed to express the environmental effects of an action. These terms are outgrowths of environmental impact statements and include impact, type, level, degree and importance. an impact, the effect of an action, may be positive, negative or null in type, depending on whether the effect is beneficial, adverse, or has no influence. Level of impact refers to either direct impacts, which are straightforward consequences of an action, or to indirect impacts, which are side-effects or spillover consequences. Degree and importance relate the extent of the impact. Mowing a lawn is of high importance to the lawn. The entire "ecosystem" of the lawn is affected. But the small amount of grass actually removed makes the act low in degree. In the same system, pulling a weed is of low importance to the lawn-system while the degree is quite high to the weed.

Internality and externality are primarily terms in environmental economics; however, it is fashionable to use them in many environmental contexts. These terms relate to the directness of effects. In an economic context, internalities are viewed as costs or benefits wholly borne by the firm. Externalities "arise when the voluntary economic activities of economic agents affect the interests of other economic agents in a way which does not set up a legally recognized right of compensation or redress," (Keating, Barry, 1976, letter).

Bases of Environmental Considerations

Ever since man has sought to win the resources of the earth and to put them to his use, he has had to realize the consequences of contamination and pollution. There is an almost instinctive drive for man to expand his natural resource technology. There is also a moral instinct to deal with the consequences of his actions. Man must use natural resources in a manner which optimizes protection of the environment, conserving and preserving such of his natural resources as he can.

Environmental concern is founded in five general areas: (1) the natural sciences (biology, physics, chemistry), (2) the humanistic and social sciences, (3) economics, (4) law, and (5) engineering. Each, in turn, has its own sub-disciplines and specific environmental aspects. Criteria and standards related to optimizing environmental concern are found in each of these five areas. Factors are often determined as characteristic of particular situations. These factors, when they relate to an ideal condition, are regarded as criteria. When criteria are accepted

throughout a discipline, or established by the government through legislation as requirements to be met for the general welfare, they become standards.

The Nature of Criteria of the Sciences

Applying a rational approach to a given question is not always purely rational. Subjectivity is often required even to recognize that there is a problem. Certain disciplines are more rational than others and these are the sciences. Criteria of the sciences, the natural theories and laws, are the base for investigations in other fields and should be understood to assist in understanding other fields.

Many environmental planning criteria, concerning the effects of actions on life, are derived from biology. These criteria may have been accepted and legislated as environmental quality standards. Information about organisms, their relationships with their surroundings, and the study of associated physical, chemical and social interactions serve as measures in analyzing the effects of contamination. It may be important to consider combinations of two or more contaminants and their combined or synergistic effects. (Synergy refers to individual items which greatly enhance individual effects when combined.) The study of individual and synergistic effects requires a study of the total environment and the total life system, an integration of individual criteria to achieve a composite assessment.

Distinctions can be drawn between the quality of one contaminant, or <u>effluent</u> criteria, and the quality of a combination of contaminants,

or system criteria. Such a distinction is quite common in water quality analysis, where actual standards are developed for individual items as effluent standards, and total system standards are developed as stream standards.

Chemistry and physics provide few direct criteria linking the surroundings to the quality of life. Both of these fields, however, are extremely important since they provide investigators with methods by which contaminants are detected and measured. They also suggest approaches for the removal, reduction or neutralization of contamination. Physics also serves as the foundation for radiological health and control.

The geosciences deal with the fundamental physical and chemical nature of the earth. These disciplines link physics and chemistry to the non-living or abiotic aspects of the environment. Specific disciplines of geology address the gross environment, while other areas such as agronomy, meteorology, or hydrology discuss natural processes and cycles. These delineate the physical limits of natural systems and the chain of natural cycles.

The Nature of Criteria of the Humanistic and Social Sciences

Some of the more important considerations of environmental planning are in the less objective area of the humanistic and social sciences. Many of the subtly positive effects of technology are indirect, or economically external. An unwritten doctrine of public trust, that regards mankind's welfare as the ultimate of his endeavors, should be present

in any planning philosophy. The doctrines of the socio-humanistic fields are the bases for planning future technological advances.

The behavioral aspects of human ecology are developed in the field of sociology, the study of the nature, origin, and development of society. The social reactions of man must be predicted if the full impacts of a proposed action are to be determined. The ability and desires of a population to accept any project will limit the speed and degree of technological advance possible. Usually, tradeoffs are necessary, such as balancing the benefits of increased employment and income against the social change from agrarian to an industrial culture. These analyses can become crucial in assessing the benefits of a proposed action.

History can be important in two ways. Many disciplines of engineering and particularly mining rely heavily on past practice with the traditional approach being preferred to a new and untried one. Historical records are limited concerning the environmental consequences of mining. Industry's preference to follow traditional practices must be carefully reviewed and integrated into a revised mining-environmental planning process. A second aspect of historical consideration is that mining must, of course, respect the value of sites unique to both national and local heritage.

Mine planning has to recognize the bargaining and collective-action mechanisms by which governmental policies and practice are determined. This is the field of political science. The processes by which laws and regulations are established are both specific and also fairly idiosyncratic. The planner who understands this should be more capable

of negotiating within such a framework. He should also find that this understanding aids him in interpreting the specific regulations which affect his operation.

Various aspects of philosophy, and religion, affect most of the other fields of sciences, humanities, engineering, etc. A general conceptual foundation should underlie technological endeavors and serve to direct the planner in achieving his goals. The presence of such a philosophy of work alone does not justify actions, but is necessary to justify further action.

The Law

Laws dealing with the environment and mining are concerned with distributing benefits and costs through a system of property rights. The major law of property rights is common law, or the accumulated decisions of specific cases. Since environmental quality can be transient and intangible, and since mineral values may be separated from other property values, common law cannot always resolve all conflicts. Statutory laws and regulations are meant to handle these extreme conflicts. Economists and political/social commentators, however, agree that regulation is imperfect as compared to the bargaining system of the pure, property-right system.

The individual who owns the surface owns everything "*ad coelum et ad infernos*," (to the heavens and to the depths) according to the Roman common laws, (Goldberg and Power, 1972). These property rights include minerals, water, surface, access, etc., and can be separated and rented

or sold at the discretion of the owner. Settling the conflicts of a multitude of various owners trying to exercise their various rights is the crux of legal evolution.

Surface owners have the riparian right to use water, so long as they do not interfere with the rights of others. Industry-prejudiced court cases in the late 1800's muddled the common law of riparian rights, so that now many water quality laws are in force to clarify the relationships. Land-use disputes involve the responsibility for cave-ins (subjacent support) and landslides and slope failures (adjacent support). Major disputes occur over the right to surface mine where the right to the minerals has been established. In many of these cases, responsibility can only be established by a law suit unless it is very specifically covered in the deed or lease.

Mining responsiblities can be shared by many property owners at the same time. Responsibility can be divided between surface and mineral owners according to the time the problem occurs, unless the owners have specifically agreed upon some other way. Prior to mining, and then at the expiration of the lease, the miner is not responsible. Unless responsibility is otherwise specified in the lease, the landowner must make good any damages which occur after mining is over.

Regulation of many mining activities is divided between federal and state agencies by law. Regulatory state agencies pertinent to mining and to environmental affairs may be in one department or spread over many. In most states, there is an office concerned with summarizing reports of mining production, supervising health and safety under federal acts, and controlling mineral acquisition under federal claim and lease

laws. Often, these offices also coordinate compliance with state and federal regulations for permits and licenses to mine. In other instances, the mine operator must contact a multitude of different state offices and achieve coordination through his own efforts. A single agency or a set of closely related ones will also often exist to cover various aspects of water, air and solid waste management, either because of federal regulations or as suggested by federal policy. Finally, mining activities must be coordinated with some state functions which exist in an advisory capacity, such as those for agriculture, game and fish.

Considerations in Economics

If a proposition is to be optimized, there must be some common basis on which alternatives can be compared. Ultimately, the common basis for measuring tangibles and intangibles is dollars. Positive and negative effects of an action must be reduced to quantitative values, the sum of which is combined to produce an economic value for the proposed project alternative. This is known as benefit-cost analysis. The field of economics is the hinge point of mining-environmental analysis. Economics provides the framework for analyzing the large-scale or macroeconomic relationships, and the mine level or microeconomic ones. The key in these analyses may be in determining relationships of real dollar values and intangible aspects of a mining operation.

Macroeconomic analysis is all too often limited to conjecture. Specifically, its role is to define two aspects of the system, maximization of public welfare, and public choice. Maximizing public welfare implies

that all of the smaller economic subsystems are close to, or are approaching, an optimum level on their own. Public choice is the mechanism by which the public develops constraints for each subsystem, and analyzes the total system.

Microeconomic analysis covers the large majority of engineering economic studies. The classic relationships of supply, demand, utility, equity and efficiency, as related to the private market economy, are all considered. These relationships are developed in an analysis which treats environmental quality as a scarce good, which can be purchased. For a scarce good, in an economic sense, the demand exceeds the supply if the good is free (i.e., at zero price). Usually, the price which is paid for clean air, clean water, and other environmental commodities is considered as an indirect, opportunity cost. The price is not paid for in real dollars but in benefits foregone to achieve quality, (Seneca and Taussig, 1974).

For example, clean air may be achieved by foregoing the opportunity to drive. However, clean air may also be obtained by paying another direct cost, for air pollution control mechanisms. The costs paid for environmental quality can be divided into two categories of waste disposal costs. Some costs are for avoiding or preventing pollution (smog controls), others are for cleaning up pollution which has already occurred. This latter class can also be divided into existing welfare damage costs and pollution damage avoidance costs. An example of the former is physical damage to buildings or plants, and of the latter is efforts taken to avoid contact with pollution, such as locating where there is no pollution or taking trips to find clean air.

This relationship is shown in Figure 1, (Seneca and Taussig, 1974). The analysis of the actions of man and their resulting costs and benefits can become very involved, since many factors of environmental quality are also indirectly influenced. It is in considering these indirect relations that the concepts of internalities and externalities arise. The consideration of an individual mining operation, the traditional realm of the mining engineering economist, is no longer sufficient. Too many of the relationships of mining "spill over" into areas which are economically external to the mining operation. If a meaningful analysis is to be realized, the view of the planner must be expanded to include a larger system to which all of the costs of mining become internal. All resources can then be recognized as proceeding through a series of transformations, not merely use and consumption, starting with their extraction from the earth through, to and including ultimate and residual disposal. Along this path, the several spillover areas can be identified. This approach is a specific example of the total-system type of solution, which will be discussed in more detail in a following section.

Considerations in Engineering

Engineering provides the techniques needed in mining and in environmental planning and operation. The engineering approach is a refinement of the scientific method, and a further refinement of the engineering approach is the total-systems approach. Engineering seeks to develop approximate solutions which are close enough for technologically

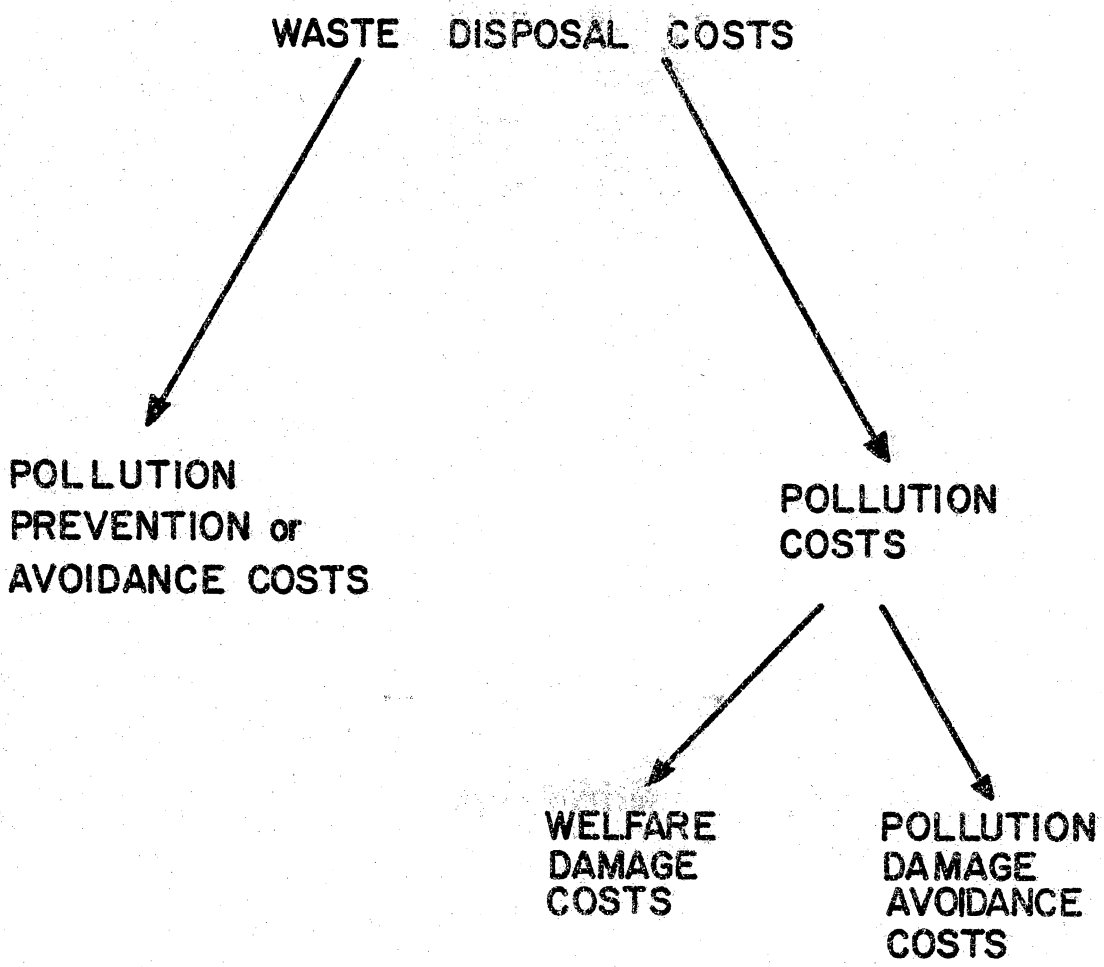


FIGURE 1: RELATING THE COSTS OF POLLUTION

practical purposes. Many engineering problems have no exact solution, but present an array of alternative solutions, each with its own positive and negative aspects. These are analyzed separately to determine their efficiency and economy. Efficiency implies compatibility with the appropriate laws of science, while economy implies a maximum output for a given input of value.

The total-systems approach was developed to handle obvious, as well as subtle, interaction between the components of a problem which might otherwise be lost in a traditional approach. If a problem is so involved as to defy solution in total, there may be a set of subproblems which can be solved. If these sub-problems are solved, and their interrelationships are considered, a composite of these can be used as the solution to the main problem. The difficulties of such an approach are that detailed division into subsystems may lose the general problem concept, and the time and effort of analysis must be justified by the specific problem. If the forest is lost in considering the individual trees, the time and effort required to achieve a total solution expands at an exponential rate. Dividing a problem one step further than is absolutely necessary can expand the analytic effort several times, as observed in personal experience. Despite drawbacks, the total-systems approach often serves as the basis for the comprehensive analysis of extensive, complex, and interrelated projects, such as mine-environmental ones.

A Systematic, Comprehensive, and Interdisciplinary Approach

The National Environmental Policy Act of 1969 directs that "... a systematic, interdisciplinary approach which will insure the integrated use of ... sciences and ... arts in planning and decision making ..." should be incorporated into planning processes, (National Environmental Policy Act, 1969). This can usually be achieved only through use of a properly coordinated total-systems approach. In such a multi-disciplinary involvement, an open mind is necessary and preconceptions must be identified and eliminated. Communications between participating disciplines must remain open. The adherence to a commonly accepted, strict methodology and philosophy becomes important. This methodology involves six phases: (1) formulation of the problem; (2) identification of sources and types of data for assessment; (3) assembly of data; (4) assessment of data; (5) an interdisciplinary review and discussion; and (6) generation of the solution. These activities are termed a flow process, and at any stage, it may be necessary to go back to a previous stage for further work as it becomes apparent.

The formulation of the problem and the adherence to a systematic routine are the heart of the process. Once the scope, depth, components, paths and interactions are known, the routine leads to a solution. This approach also identifies the disciplines, and hence the personnel, which must be employed.

Once the problem-solving team is formed, an interdisciplinary effort should identify the sources and types of data and the techniques to be used. Format requirements must be met for communication between

disciplines, and all of the necessary parameters and measures must be identified. All conceivable major areas should be covered at this stage, so participants can recognize the contact areas in their investigation.

Once the proper techniques have been established, the assessment of data should be routine. Too often, however, a solution may be forced to fit the data, or data may be forced to fit the solution technique. It must be emphasized that the appropriate formulation and identification of data types and analysis techniques is necessary to ensure that assessment is directed along the right path.

As results of individuals must be related to the entire group, interplay and discussion become crucial. As interplay and discussion near an end, conflicts are near resolution. After a "cleanup" phase, one final review should confirm that the solution is acceptable to all parties.

Such an approach is that which has been selected for use in optimizing mine environmental planning. This problem will consist of three major subsystems: (1) mine planning and operation; (2) environmental planning and operations; and (3) regulatory compliance. The real problem is to develop an optimum mine planning approach, since the mining operation and the production of environmental quality are not actually separable within this context.

Characteristics of Environmental Planning

This section is a general review, not a detailed compilation of

approaches to environmental control. Its purpose is to begin to fill in the previously developed framework for the total-systems approach to mine environmental planning. Aspects of general policy and practice will be identified. Discussion of air, land and water quality management will follow.

General Aspects of Environmental Policy and Practice

Environmental concern in planning can be varied according to the constraints of the problem and the statutory laws and policies which cover the operation. A variety of statutory requirements exist among the states. Many of these are directed by federal laws (which establish requirements) or philosophy-establishing policies, such as the National Environmental Policy Act, the Federal Water Pollution Control Act, and the Clean Air Act.

NEPA is a statement of policy. A goal of national environmental quality is established by the act. A practice is further defined by the act, the practice of producing environmental impact statements. Many specific requirements for these statements are directed not by the act, but by the regulations published by the Administrator of the Environmental Protection Agency pursuant to the act. These regulations establish what is to be included in planning processes at the federal level. Such practices are also suggested, by the nature of NEPA as a policy act, to be followed at state, local and private levels as well. Since NEPA does not cover private citizens or states, its effect is simply that of policy and philosophy.

The Federal Water Pollution Control Act of 1972 (FWPCA) is a federal law and set of regulations which suggest state laws and regulations. The Act enables the EPA to administer regulations which it establishes. The goal is to achieve a zero-discharge of pollutants into the nation's waterways by 1985. Various sponsored programs of research and development, and many types of restrictions and penalties, are included in the act. FWPCA also recognizes states' rights, and allows the states to be involved to a variety of degrees.

The act provides that anyone making a discharge into a navigable waterway must first have a permit to do so. A state must approve this permit before federal approval is granted. A state may be delegated the authority to approve this application and to enforce the regulations if it has its own law and regulations, as strong as the federal act, and approved by the EPA. The Administrator of the EPA has the right to revoke any specific discharge permit or to withdraw the approval of a specific state's authority at will. These last two provisions assure that state compliance will be more than token.

The Clean Air Act of 1970 (CAA) presents a third class of legislation by explicitly directing the states to establish air quality regulatory programs. The goal is to clean up the nation's air and to coordinate the activities of the states. Various air quality goals and standards for the nation have been established. Each state is required to set up a regulatory commission, and to have their laws and regulations, as well as an implementation plan, approved by the EPA. Control of the states is, as with water, by permits to discharge air contaminants. A variety of penalties are presented for non-compliance.

Again, the Administrator of the EPA has the power to revoke specific permits and state plans, Additional power is added to the CAA, however, through the provision that a state plan which is not approved may be revised and structured by the EPA -- the Administrator may direct the formation of state laws and regulations if they are not acceptable. A final point of the CAA is significant. The transient nature of air is recognized. Since air does not divide itself at state lines, the power is given for states to join into interstate compacts to control air quality. Such a step is important in that it recognizes the universal nature of environmental affairs, and may serve as a guide to the development of policy and practice in other areas as well. Table I presents a summary of the characteristics of the three classes of acts.

Federal agencies have developed policies and practices which are consistent with NEPA. They are developing the ability to pursue comprehensive, interdisciplinary and systematic approaches to the resolution of six main requirements of NEPA: (1) describe the action, (2) identify probable environmental impacts, (3) identify adverse effects which cannot be avoided, (4) develop a set of alternative actions and the data to assess their impacts, (5) relate short-term use to long-term productivity and (6) state the resources which may be irreversibly or irretrievably committed. Hopefully, the federal agencies' practices will continue to evolve in this fashion which incorporates environmental concern in the total planning process.

State agencies fall into three categories: (1) well-established agencies, which existed prior to NEPA to meet the needs of a state and not because of federal demand. The California Air Quality Board is an

TABLE I: THREE CLASSES OF FEDERAL ACTS

CLASS	EXAMPLE	ARE REGULATIONS ISSUED ?	FOR WHOM ?	STATE CONTROL ?
POLICY	N.E.P.A.	YES	FEDERAL AGENCIES	NO
ENABLING	F. W. P. C. A.	YES SUGGESTED	NATION STATES	YES, WITH APPROVED LAW & REGS.
ESTABLISHING	C. A. A.	YES	NATION & STATE	REQUIRED, LAW MUST BE APPROVED

example, and these agencies generally meet NEPA criteria. (2) Newly created agencies, patterned after, or established as a result of, environmental-era legislation. These are often still in the process of growth and expansion. While compliance with NEPA on paper is simple, time is required to become fully consistent with its and the state's goals. (3) A third category exists, that in which no agency is established. In time, the need for these may become apparent, and then these agencies will hopefully meet the needs expressed in state and national policy.

Industry is commonly attacked for ignoring the National Environmental Policy by failing to develop its own environmental policy. The major cause is not a lack of technology, for which many place the blame, but the lack of a proper incentive structure to propagate policy past the federal and state government levels.

The government's task is to establish policy and practices while industry's is to maximize wealth. While these two ultimately relate to the same, classic economic goal of maximum total welfare, government subjectively strives for the most good for the most people, and industry objectively works at generally maximizing dollar profits. An observation can be formally presented, then, that a company will only incur those costs which are necessary. Regardless of ethics, the planner in industry must relate expenditures for environmental concern directly to the economic incentive of increased profits.

The approach of government policy-makers is to achieve incentive by regulation. While the limited success of regulatory acts has often been attributed to a lack of time and technology, actually these could

be overcome if the incentive existed. Government sponsorship of research is useful, but the application of these results belongs in industry, which often chooses to ignore them because there is insufficient incentive.

The ultimate objective is to foster the development of industry environmental policy. Legislation alone seems futile in this endeavor. The key appears to be the development and propagation of approaches by which the positive, indirect and external benefits (which can be brought about by a properly conceived and coordinated program of environmental concern) can be realized by a company as a real return on its investment. Only when industry recognizes that benefits are to be gained, and that wealth is to be increased, will concern for the environment be included in its planning process.

Although this propagation through the industrial level will probably occur, the realization of this at a personal and individual level seems unlikely. The ultimate success of environmental efforts depends on the individual in society. Consistent industry policies require that existing social and external costs be shifted within the industry framework. In a free-market system, these costs, once so internalized, must shift to the consumer, a shift of economic scope, not of domain. What the average private consumer usually does not realize is that while market costs are rising, they are merely shifting costs from foregone benefits to a cash basis. Until government, industry, and the concerned public can educate the consumers, the final realization of a true national environmental policy will exist only as a goal.

Environmental Impact Analysis

Policy is essentially recognizing a problem and formulating a method of solution. The attention of this section turns from policy to actual methods. The first to be considered is the analysis of environmental impact.

In the first years after NEPA, research was often directed to finding a perfect method for environmental impact analysis. Many excellent advances were made, all falling short of this quest, but firmly establishing that there is nothing that is certain, and that the uniqueness of any situation dictates that the solution be unique. Various approaches were developed which, when used in combination, offer tremendous potential.

Four distinct methods for environmental impact assessment prevail, (Warner and Preston, 1974). These are: (1) checklist, (2) overlay, (3) matrix and (4) network or system. Checklist, as shown in Figure 2, is a popular method, which incorporates a simple, linear train of thought. A list of parameters are covered, one at a time, and the impact is related to each parameter. In general, a checklist will fit any project, but the results are not necessarily conclusive.

Overlay methods, as shown in Figure 3, provide graphic interpretation of impact on overlay maps. These give a good visual characterization of concentrated sensitivities. Sophisticated approaches have been developed for computerized production of overlays. While the results are dimensional and spatial, there is little quantification of expected impact.

RESOURCES	IMPACT + = BENEFIT 0=NONE — = ADVERSE
PHYSICAL	+
CHEMICAL	—
PLANTS	0
ANIMALS	+
SOCIOLOGICAL	—
AESTHETIC	—
ECONOMIC	+

FIGURE 2: A SAMPLE CHECKLIST ENVIRONMENTAL ANALYSIS

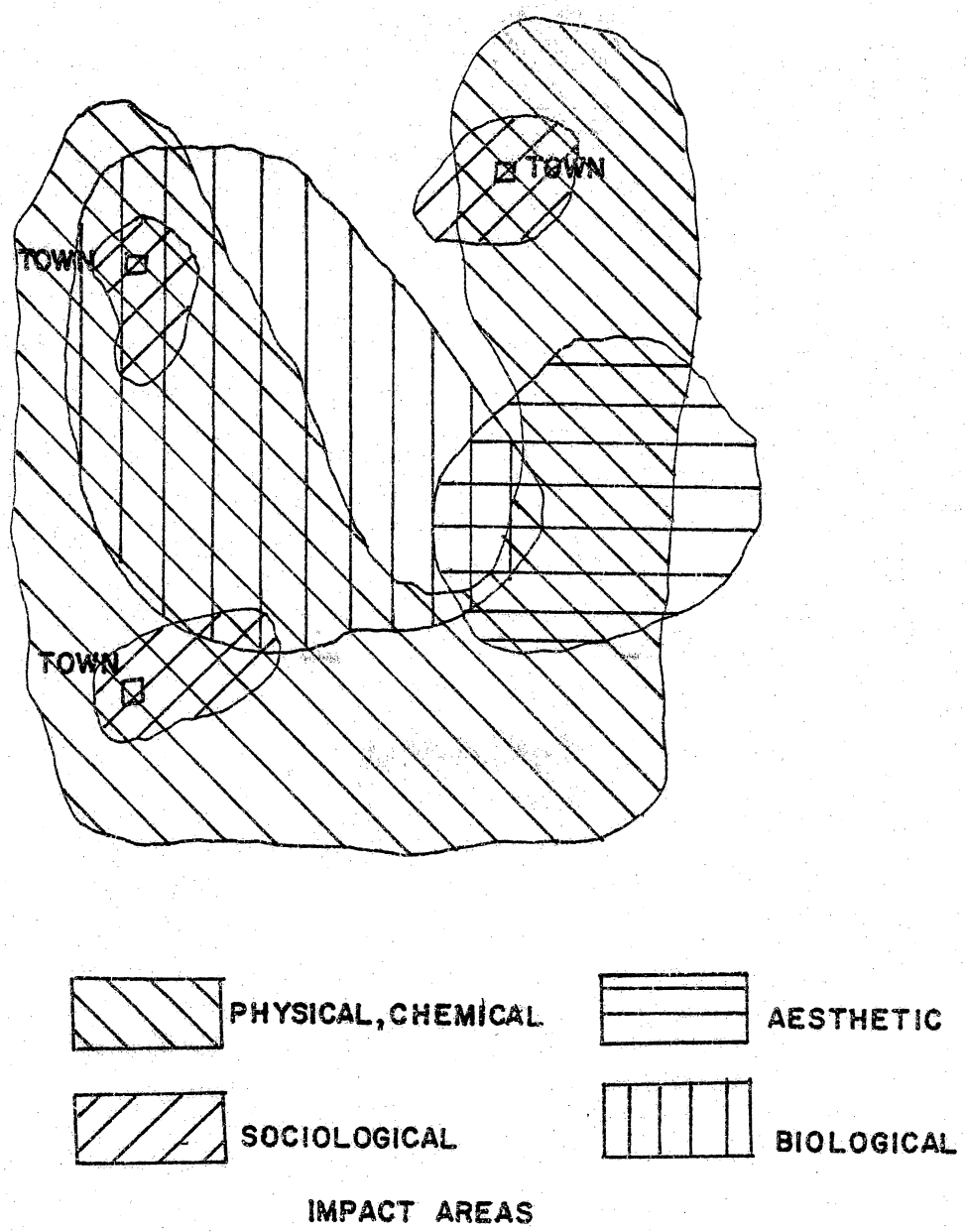


FIGURE 3: A SAMPLE OVERLAY ENVIRONMENTAL ANALYSIS

Matrix approaches, as shown in Figure 4, relate anticipated activities to environmental characteristics through cause-effect relations. These approaches display the list of activities at one side of a matrix, a list of characteristics at the other side, and provide many little boxes which can be checked or in which calculations can be performed. However, little if anything is ever done besides checking little boxes or doing some specific calculation. Overall interpretation is still limited and little quantification results.

System modelling techniques are perhaps the most effective approaches when properly conceived and developed. While most of these develop a network model of the environmental system and its impacts, only a few of the best methods then proceed to develop an explicit quantitative assessment. While expansion of a network into a model is possible, the success of the model is dependent on the appropriateness of formulation as an operations research problem. If the time and effort of an operations research type investigation can be justified, modeling approaches can satisfy the quantitative requirements of environmental analysis.

No single methodology is the best. In a total-systems perspective, it can be seen that a judicious composite of the four is perhaps most appropriate, (Warner and Preston, 1974).

Air Quality Assessment and Management

Because of the variety of uses of air, a wide variety of disciplines are used in air quality management. Although the atmosphere is constant-

RESOURCES	ACTIONS: NATURAL	ACTIONS: MAN-MADE	ACTIONS: ECONOMIC
PHYSICAL	0	+	+
CHEMICAL	0	−	+
PLANTS	+	−	0
ANIMALS	+	+	0
SOCIOLOGICAL	−	−	+
AESTHETIC	0	−	+
ECONOMIC	0	+	+

0 - NO IMPACT

− - ADVERSE

+ - BENEFIT

FIGURE 4: A SAMPLE MATRIX ENVIRONMENTAL ANALYSIS

ly moving and mixing, there are certain gases which are recognized as permanent and others as variable constituents of air. Thes appear in Table II.

Occassionally aerosols, gases and vapors become present in air at such high concentrations that they have adverse effects. Examples are: reduced visibility, odors, or respiratory distress. One of the major problems in air quality is contamination due to aerosols. Aerosols are particles suspended in the atmosphere, such as dust, pollen, mists, or bacteria. In addition to direct respiratory irritation, solid aerosols may have synergistic effects, enhancing the effect of other air pollutants such as sulfur dioxide.

The next major concerns are the two types of smog. Sulfurous smog is a byproduct of smelting sulfide ores or the combustion of fossil fuels containing sulfur. Its problems relate to the direct toxic effects of the gas sulfur dioxide (SO_2), and to the fact that it combines with water in the air to form sulfuric acid.

Although sulfurous smog has been known for a long time, more recently recognized is photochemical smog. When cars or other high-combustion sources operate, nitrogen is burned at high temperatures to form nitrous oxide (NO). NO is then oxidized to NO_2 and still further oxidized in sunlight to form nitrous oxide and atomic oxygen. Atomic oxygen combines with molecular oxygen to form ozone, and the energy loss passes to an unburned hydrocarbon. Ozone reacts to form NO_2 and O_2 by reacting with the nitrous oxide. The hydrocarbons compete for the free oxygen. Although the process is complex, it is essentially a buildup of NO_2 and

TABLE II

COMPOSITION OF CLEAN AIR NEAR SEA LEVEL

CONSTITUENT & FORMULA		PERCENT (VOLUME)
NITROGEN	N_2	78.084
OXYGEN	O_2	20.946
ARGON	Ar	0.934
NEON	Ne	0.0000182
HELIUM	He	0.0000052
KRYPTON	Kr	0.0000011
HYDROGEN	H_2	0.0000005
NITROUS OXIDE	N_2O	0.0000003
XENON	Xe	0.00000009
VARIABLE GASES		
CARBON DIOXIDE	CO_2	0.032
WATER VAPOR	H_2O	0-7
METHANE	CH_4	0.0000015
CARBON MONOXIDE	CO	0.0000001
OZONE	O_3	0.00000002
AMMONIA	NH_3	0.00000001
NITROGEN DIOXIDE	NO	0.000000001

(After Williamson, 1973)

ozone (O_3) at the expense of NO. These two gases form slowly, and in a maturing smog the nitric oxides are removed as secondary solid pollutants while ozone does not persist in high concentrations in the atmosphere, so the seriousness is minimized.

Photochemical smog not only reduces visibility, it causes physical damage to materials, plants and people due to a variety of extremely irritating compounds. These are called PAN's after one of the compounds, perozyacetyl nitrate. The intricate and involved nature of photochemical smog has complicated its understanding, (Williamson, 1973).

Nationally, air quality is to be maintained through a system of ambient air quality standards. Primary standards are established to protect people, and secondary ones to protect other factors. In meeting these standards, two limits can be reached: a maximum concentration of pollutant allowable at any specific time, and a dosage, or maximum cumulative exposure over time. Some standards, correspondingly, are established for time intervals. Table III is a list of the national ambient air quality standards. As previously mentioned, the responsibility for achieving these is left to the states, pursuant to the Clean Air Act.

Monitoring the quality of air and air pollutant sources is important to the planner. While equipment and techniques are involved, in most instances, for the reference methods which are accepted by the EPA, continous and automated instruments are available to complement these techniques.

Control of air pollution is classified according to differences in principles of operation. The general classes of air pollution control

TABLE III: AMBIENT AIR QUALITY STANDARDS

POLLUTANT NAME	TIME PERIOD	STANDARDS PRIMARY	STANDARDS SECONDARY	REASON
SULFUR OXIDES (SO_2)	YEAR	80 $\mu g/m^3$ (1)	—	REDUCE CHRONIC DISEASES, ODOR, PLANT DAMAGE
	24-hr	365 $\mu g/m^3$ (3)	—	
	3-hr	—	1300 $\mu g/m^3$ (3)	
PARTICULATE MATTER	YEAR	75 $\mu g/m^3$ (2)	60 μg m^3 (2)	IMPROVE VISIBILITY, REDUCE SYNERGISM WITH SULFUR OXIDES
	24-hr	260 $\mu g/m^3$ (3)	150 $\mu g/m^3$ (3)	
CARBON MONOXIDE	8-hr	10 mg/m^3 (3)	10 mg/m^3 (3)	PREVENT BLOOD PROBLEMS
	1-hr	40 mg/m^3 (3)	40 mg/m^3 (3)	
PHOTOCHEMICAL OXIDANTS	1-hr	160 $\mu g/m^3$ (3)	160 $\mu g/m^3$ (3)	ALLEVIATE PHOTOCHEMICAL SMOG
HYDROCARBONS	3-hr (6-9 a.m.)	160 $\mu g/m^3$ (3)	160 $\mu g/m^3$ (3)	same
NITROGEN DIOXIDE	YEAR	100 $\mu g/m^3$ (1)	100 $\mu g/m^3$ (1)	PUBLIC HEALTH, AIR COLOR

NOTES:
(1) ANNUAL ARITHMETIC MEAN (2) ANNUAL GEOMETRIC MEAN
(3) NOT TO BE EXCEEDED MORE THAN ONE TIME PER YEAR

equipment are filters, settling chambers, inertial collectors, electrostatic precipitators, scrubbers, adsorbers and chemical reactors. Most commonly, no single device is sufficient and a combination of devices is usually used. The basic problem with all of these devices is that they are merely "added on" in an attempt to control the pollution already generated by present processes. Successful planning for air quality depends on managers who are personally able to assess the individual control devices, since manufacturers do not warrant or guarantee these. The best control will occur when managers are able to design total systems that are inherently pollution-free, that is, when comprehensive planning incorporates environmental concern.

Many aspects of mining result in air pollution (such as dust from roads and truck exhaust). The mine planner must, therefore, be aware of air quality constraints. He should know the fundamental parameters and of the available control equipment even though mining is generally not concerned with major air pollution problems.

Water Quality Assessment and Management

Water is the one common essential for all known forms of life. Water was generally accepted as abundant until the 1800's, when the pressures of industrialization brought about the realization of its scarcity. Some of the earliest environmental legislation was to protect water quality.

Science provides the theoretical basis for water quality management, and engineering provides the practical, technological aspects. Imple-

mentation of water quality management is the synthesis and coordination of the technical aspects with philosophical, political and economic concerns.

Water quality standards relate to seven generally recognized uses: (1) water supply, (2) electrical power generation, (3) recreation, (4) irrigation, (5) navigation, (6) fish and wildlife propagation, and (7) the ultimate disposal of waste. Pollution of water is an act which contravenes one or more of these uses. Standards are developed to assure that water will be capable of supporting all of those uses to which it is being put. A biologist might look to a change in community structure as an indication of contravened use, while an engineer might relate loss of use to loss of waste disposal capacity.

Of the many parameters of water quality (Table IV), there are only three well-definable standards: (1) dissolved oxygen, (2) pH and (3) temperature. All other measurements combine to form a gross perspective of the capability of the stream. Effluent standards attempt to relate absolute integrity to one specific parameter. Those effluent standards which are established to relate overall stream quality to many parameters are stream standards. Ultimately, as the zero-discharge goal is realized, there will be no discussion as to which is the best kind of standard to follow. Currently, however, much attention is directed to stream standards as they can be a legal basis for circumventing effluent standards.

Field and monitoring techniques are divided according to two purposes, either as identification of specific parameters or as an assessment of total system quality. Specific parameters measured include

TABLE IV: WATER QUALITY MEASURES

ABBREVIATION	NAME	DESCRIPTION
—	TEMPERATURE	—
—	pH	HYDROGEN ION CONCENTRATION
—	ALKALINITY	CARBONATE & BICARBONATE CONCENTRATION
—	ACIDITY	CARBONATE REQUIRED TO NEUTRALIZE pH
—	HARDNESS	CONCENTRATION OF DIVALENT CATIONS
D.O.	DISSOLVED OXYGEN	PERCENT OXYGEN CONTAINED
$B.O.D._5$	FIVE-DAY BIOLOGICAL OXYGEN DEMAND	OXYGEN THAT IS REQUIRED OVER A 5-DAY PERIOD TO SUPPORT THE TOTAL METABOLIC SYSTEM PRESENT.
C.O.D.	CHEMICAL OXYGEN DEMAND	OXYGEN REQUIRED TO COMPLETELY OXIDIZE ALL MATERIAL CONTAINED
—	TRANSPARENCY	CLARITY WITH WHICH LIGHT PASSES
—	COLOR	FIDELITY " " " "
—	TURBIDITY	CLOUDINESS
—	TASTE	———
—	ODOR	———
	SOLIDS	
T.S.	TOTAL	SOLIDS LEFT ON EVAPORATION
S.S.	SUSPENDED	FILTERABLE
D.S.	DISSOLVED	PASSING A FILTER
V.S.	VOLATILE	DRIVEN OFF BY HEAT
	ALL COMBINATIONS, AS	
	(TOTAL) (VOLATILE) (NON-VOLATILE)	TOTAL SUSPENDED DISSOLVED SOLIDS
—	SPECIFIC IONS	ANY DESIRED, PARTICULARLY MACRONUTRIENTS MICRONUTRIENTS TOXIC HEAVY METALS OTHER TOXIC COMPOUNDS
—	BIOLOGICAL STUDIES	COLIFORMS STREPTOCOCCI VIRUSES ALGAL CHLOROPHYLL DIVERSITY— TOTAL SPECIFIC COMMUNITIES

those in Table IV. The details of these measurements are contained in Standard Methods for the Examination of Water and Waste Water, (American Public Health Association, 1971).

Biological assessment, at one time based on the concept of there being one indicator species which represented the total biological integrity of the system, is now directed to a variety of measurements, which relate to the total system. Simply stated, the sensitivity and integrity of a system relate to the number of species present, and to the number of members present in each species. Large numbers of many species imply a strong structure, while the opposite a fragile structure, (Cairns and Dickson, 1971). Such relationships are measures of diversity.

The planner strives to achieve a maximum assimilation of a discharge by a stream without altering its diversity. Five biologic communities are present in water: plankton, periphyton, macroinvertebrates, macrophyton and large rovers. Guides for assessing each area as well as the composite water quality are available.

While zero-discharge is ideally sought, there are current technological constraints which usually preclude this. Design procedures, then, attempt to minimize contamination by abatement and treatment.

Abatement reduces the level of contamination by the maximum use of water and by limiting the exposure of water to contamination. In situations where abatement is not practical, treatment may be physical, chemical or biological. These processes are familiar to sanitary and chemical engineers.

Physical processes include direct separation or gravimetric

separation. Chemical processes use direct neutralization through addition of reagents or chemical reduction prior to physical or biological treatment. Biological processes utilize the physical and chemical processes of nature to break down the waste into more inoccuous, or more separable components.

The ultimate approach to water planning and management has been implied throughout this section. Abatement or prevention through inherent process design is paramount. As treatment may be necessary, the planner should bear in mind the fundamental goals, standards and criteria in incorporating a comprehensive, total-systems approach.

Land Quality Assessment and Management

While land quality must necessarily be considered coequally with air and water, it is complicated by the different nature of land. Certain land use planning aspects are inherent in air and water management, and vice versa. Land is fixed in quantity and not mobile, it is a scarce resource, and due to its fixed nature may have a limited quantity of other resources available in its vicinity (such as water, power, etc.). Land is, however, recyclable to some degree, through a variety of uses.

The concepts to be followed by the planner are simple to state. They are: (1) conserve the land by limiting the operation to necessary areas only; (2) reclaim the land which is used to allow future equal level of use; (3) restore the land to multiple-use fashion. Optimization, however, is a technique or process to follow with the

three previous concepts serving as constraints, and is neither so simple nor so easily definable.

A simple classification of land uses is proposed in Table V. Land use planning considers the ability of land to support a given use, combined more subjectively with the desirability of that use. The constraints include both physical phenomena and social concepts, making a purely objective criterion nearly impossible. Optimization must link these to economic factors in a benefit-cost analysis. Improper mine planning can create fantastic damage, multiply the effects of air and water pollution by increasing areas of contamination, or affect more subjective relationships.

Problems of Environmental Planning and Operations

Many problems have been reviewed which inevitably relate either to an inappropriateness of the incentive mechanisms or to the shortsightedness of management. The problems of environmental pollution will probably not be handled efficiently without including a responsible, individual environmental policy. Regulation of effluents serves to achieve acceptable levels of pollution, but falls short of the goal of maximum social welfare, (Seneca and Taussig, 1974).

The influence of the public and government, contrary to its basic desires, actually fosters managerial shortsightedness. In answering to stockholders, the corporate manager is generally restricted sheerly to compliance with regulation, since current methods of accounting and analysis do not reflect the subtly positive, external benefits

TABLE V: A TYPOLOGY OF LAND USES

TYPE	DESCRIPTION
WILDERNESS	UNTOUCHED BY DEVELOPMENT OR DOMESTIC ANIMALS FOR RECREATION AND AESTHETIC USES ONLY
LIMITED AGRICULTURE	GRAZING AND FORAGE FOR DOMESTIC ANIMALS, NON-TILLED CROPS, NO SIGNIFICANT CONSTRUCTION. INCLUDES ANY DEGREE OF RECREATION FOR WHICH DEVELOPMENT IS LIMITED
DEVELOPED AGRICULTURE	CULTIVATION, BARNS AND HOUSES, MORE-DEVELOPED RECREATION
LIGHT DEVELOPMENT	SUBURBAN DWELLING, LIGHT OR WELL-PLANNED COMMERCIAL AREAS, LIGHT INDUSTRY, MOST-DEVELOPED RECREATION
EXTENSIVE DEVELOPMENT	APARTMENTS, SKYSCRAPERS, HEAVY COMMERCIAL AND INDUSTRY, TRANSPORTATION SYSTEMS MINING IS IN THIS CATEGORY

of environmental control. If the manager could restructure to achieve these and defend his balance sheet, the public would be faced with cash costs which it now ignores. With no compensation from the government, with an uninformed consumer group, the consequences of higher than competitor's prices would be a disaster for the company.

The planner must satisfy the government, the public, and his company simultaneously. All three sectors share a vital concern for the future of our natural resources. What is required is a joint venture in education to understand the nature of mining and the environment and the social responsibility of the industry. Such an understanding should include an awareness by the public and government to the economic needs of industry.

Companies must realize that external, non-cash costs can produce external, non-cash returns. While real money is spent today, the long-term results of environmental concern will be in real profits tomorrow. Comprehensive planning should yield greater returns than the mere compliance with regulations could be hoped to yield. These returns will be realized when industry's desire to optimize social welfare is earnest and proven to society. Society must then in turn recognize its own responsibilities in the optimization of social welfare. It is only in working together that the government, the public, and industry can eliminate pollution and reach this goal.

A REVIEW OF MINING AND ENVIRONMENTAL PRACTICES

For thousands of years man has dug into the crust of the earth for the raw materials to support himself. Central to his exploitation has been the technology of mining. Influenced by many factors, mining engineering must employ efficient techniques for developing and utilizing the opening through which resources can be extracted. Four mining phases will be considered: planning, development, operation and closure. These phases overlap in actual practice but represent the sequential aspects of mining engineering.

The Mine Planning Phase

Mining has been described previously as a conglomeration of various engineering sub-disciplines linked with a unifying philosophy. One of its more abstract areas is mine planning, for which an understanding must be developed for the physical, chemical and geometrical aspects of the orebody and the surrounding rock. Once the various relationships are known, a combination of technologies can be selected to form a workable mining plan. To achieve this awareness and to develop the plan, three engineering steps are followed: examination, design, and evaluation.

Mine examination defines the nature of the deposit. An history and literature survey is conducted to ascertain ownership rights, identify

legal constraints, understand the operating history of the property and its neighbors and review approaches to similar mining situations. Such office work is then finalized through visits to the mine site to verify the results and to augment them through first-hand experience.

A positive decision may require further exploration and delineation. The success of the mine will depend upon the quantity and quality of the resource available. Size, shape and spatial relationships must be understood. Geo-scientific studies, exploratory drilling, and sampling will provide much of the necessary information.

Geological and geophysical studies endeavor to develop a gross-perspective view of the deposit. While the presence of many soft-rock, non-metallic deposits is inferred from the stratigraphy and surface characteristics, many disseminated and massive metallic orebodies can be detected only be geochemical or geophysical indications.

Drilling programs are correlated with the type of deposit (Figure 5) being investigated. Continuous or horizontal deposits may require few holes to define. Vein deposits are generally explored by down-dip holes, to determine extent, and piercing holes, to determine grade at various locations. Massive or disseminated deposits require extensive drilling programs, both to determine the shape and to determine the grade (Figure 6).

Alternative approaches can be taken to calculate the value of ore reserves in place. The specific methods depend on scope of the project and resources available, and involve extensive calculations by hand or by computers. Ore grades are inferred through statistical analysis of assay values. Areas of interest are identified on geologic sections of

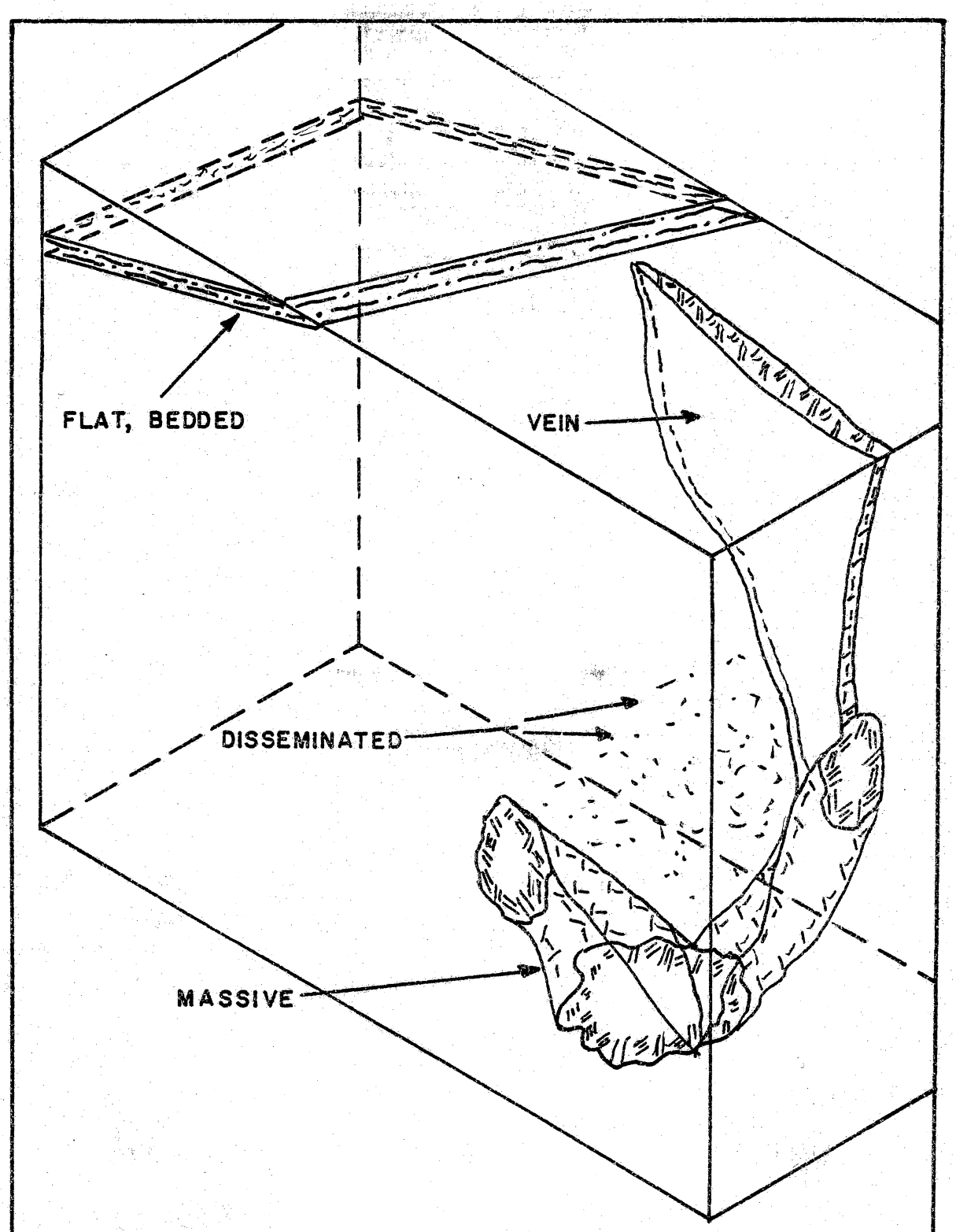


FIGURE 5: TYPES OF ORE DEPOSITS

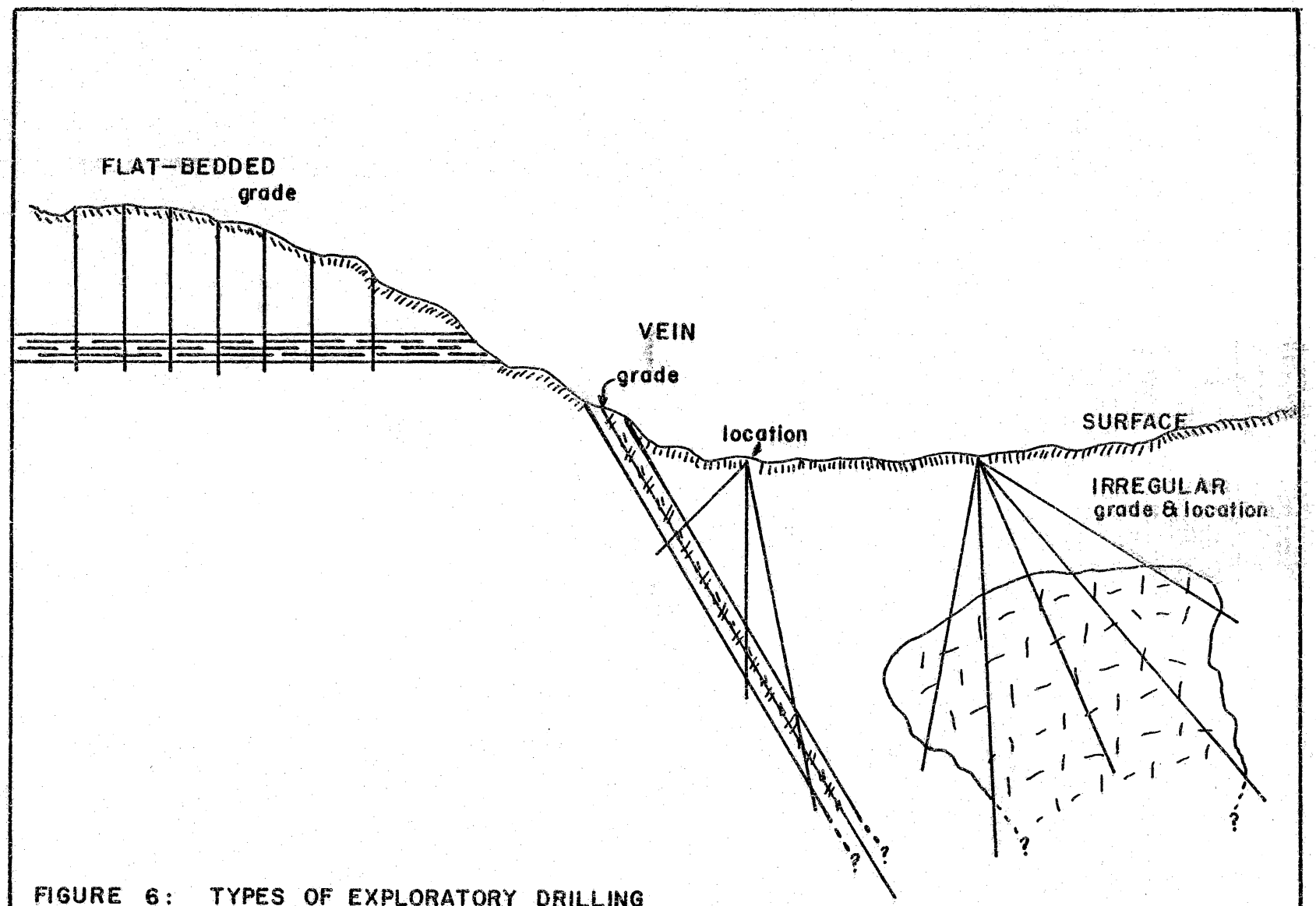


FIGURE 6: TYPES OF EXPLORATORY DRILLING

the orebody. These areas may be laid out according to many geometrical schemes, as indicated by the type of deposit being examined. These schemes range from simple rectangular gridworks to complex curve- and surface-fitting relationships expressed through a sophisticated approach known as geostatistical analysis.

Since ore deposits are three dimensional, areas of interest are multiplied by the thickness of influence to determine a volume of interest. The thickness of influence is generally the distance between the geologic sections being investigated. Variation between geologic sections may be assumed to be linear, or may be expressed in a variety of non-linear fashions. Having determined volumes of influence, tonnage can then be calculated from the unit weights of the ore and gangue (associated waste). A weighted average grade can be calculated and adjusted to reflect unavoidable losses in mining and inadvertent inclusion of waste material in the mining process.

From such a resource estimate, the actual ore reserves can be estimated. Ore implies that a mineral resource, which has value, can be extracted and sold at a profit. Experts generally classify ore as proven, probable and possible. A definition of these classes of ore reserves has been at least partially accepted. This is:

> Reserves — Mineralized material in an identified deposit which may be shown by exploration to contain ore under certain economic conditions. Reserves may be described as proven, probable or possible, depending upon the degree to which dimensions, grade, metallurgical characteristics, and continuity have been established by sampling. When used in context with ore deposits, the terms "ore reserves" and "reserves" are synonymous.
>
> Proven Ore — An ore reserve so extensively sampled

> that the tonnage, grade, geometry and recoverability of the ore within the block or blocks of ground under consideration can be computed with sufficient accuracy so that the uncertainties involved would not be a factor in determining the positive feasibility of a mining operation.
>
> Probable Ore — An ore reserve for which sufficient continuity of dimensions and grade can be assumed for preliminary financial planning, but for which the risk of failure in continuity is greater than for proven ore.
>
> Possible Reserves — Mineralized material of which the dimensions and grade are based on geologic correlation between samples so widely spaced or so erratic that additional exploration is required to establish whether ore reserves are present.
>
> (Banfield and Havard, 1975, p. 75)

The establishment of a reserve base, tonnage and grade, and estimates of the mining and milling costs and market conditions may be used to establish an economic basis for selection of a mining method.

The design of a mining method has several distinct objectives. A production rate must be maintained, at a given purity and perhaps a given fragment size. The operation must be safe, economical and offer conservation (by recovering a high quantity of the material in place). Several subsystems must be designed within these guidelines: ground control, materials handling, excavation, auxiliary and plant functions, and concern for public trust. Traditionally, the combination of ground control, excavation and materials handling defines the mining method. The synthesis of the mining method with the other subsystems forms the mining system.

Excavation includes the unit operations which actually separate the rock from the ground. These are drilling and blasting and digging.

Materials handling covers unit operations which carry the material from the face to the final loading point. A combination of the two is generally considered to be the focal point of mining design. The system is constrained by the geometry of advance, which is the size and shape of the production blasting round. This advance geometry is further constrained by ground control and also requires a logical physical division of the mine into working zones. The system is developed to achieve flexibility, although some rigidity is always present due to the limitations of geology, equipment and power sources.

While only one or two methods may be feasible, a hybrid system is the usual practice. The cost must match the value of the ore, with a production rate to maintain that value relationship. Underground mining methods are explicitly limited to various geometry/strength relationships as summarized in Table VI. Some of the typical costs of various mining methods are summarized in Table VII.

Ground control factors define three general classes of underground mining methods. These are: (1) unsupported methods, which require little or no external support for the roof, ribs or men; (2) supported methods, which require timber, fill or other support; (3) caving methods, which rely on the weakness of the rock and its natural failure as an excavation technique. These will be discussed later.

If preliminary analyses are favorable, a more detailed evaluation is conducted. The size and timing of necessary capital and labor expenditures are fixed, profits are estimated, and the return on investment is determined. Since equipment and buildings in mining have little

TABLE VI: MINING METHODS AND THEIR APPLICATIONS

TYPE OF DEPOSIT	STRENGTH OF ORE AND COUNTRY ROCK: STRONG	MODERATE		WEAK
VEIN				
FLAT, THIN OR THICK	OPEN STOPING	OPEN STOPING WITH RANDOM PILLARS	ROOM AND PILLAR	LONGWALL
DIPPING, THIN TO MODERATE	SHRINKAGE	SHRINK AND FILL	CUT AND FILL	TIMBERED STOPING
THICK	SUBLEVEL STOPING			TOP SLICING SUBLEVEL CAVING
MASSIVE, IRREGULAR, OR DISSEMINATED				TIMBERED STOPING, BLOCK CAVING

TABLE VII: COSTS OF VARIOUS MINING METHODS

METHOD	COST PER TON, $	TONNAGE PER MAN-SHIFT
SURFACE MINING	0.30— 3.00	250 - 500
OPEN STOPING	2.00— 4.00	10 - 30
ROOM & PILLAR	2.50— 7.50	5- 20
CUT & FILL	5.00— 25.00	10 — 30
SHRINKAGE	3.00- 12.00	15 - 40
SUBLEVEL STOPING	2.00- 8.00	15 - 40
TIMBERED STOPING	10.00-50.00	10 - 20
TOP SLICING	7.50-20.00	10- 20
SUBLEVEL CAVING	5.00-15.00	15 - 30
BLOCK CAVING	2.00- 3.00	20- 50

other value, they are viewed as a depreciation base. A method of mining is preferred which will yield a maximum of unit ore values at a minimum capital cost. Other fixed costs must be included to cover pre-production excavation, working capital, and miscellaneous investments in securing water, power, timber, labor and the living community or townsite, if necessary.

Table VIII presents the general unit cost structure of mining which may be highly variable. Explicit information is available from manufacturers and in the literature. Actual operating costs in mining involve economies of scale, so a range of plant and mine sites should be considered to optimize unit cost. In general, higher production rates result in lower unit costs, but require greater capital investment. Several levels of development, plant size and production may result in an equal total return on investment over time, so there may be several acceptable alternatives.

A corresponding range of involvement exists in the marketing of mineral commodities. Base metal markets are steady to generally rising while scarce commodities, such as silver and copper, exhibit fluctuating markets. The mine planner must consider these and determine which development alternative works best with his market.

Total evaluation requires the estimation of a series of costs and profits for periods in the mine's life. Traditionally, the ultimate valuation of a mine is determined as a net present value according to two interest rates. One rate is the return desired by the company and the second is a "safe" rate which would always be available for the redemption of capital. These practices are almost a century old, and

TABLE VIII: UNIT COST STRUCTURES IN MINING ENGINEERING

DIRECT COSTS		INDIRECT COSTS	
FIXED	VARIABLE	FIXED	VARIABLE
CAPITAL	PRODUCTION	TAXES	INSURANCE
DEPRECIATION	LABOR	TOWNSITE	PAYROLL TAXES
AMORTIZATION	SUPPLIES	UTILITIES	SUPERVISION
	MAINTENANCE		CLERICAL
	DEVELOPMENT		ENGINEERING
	LABOR		
	SUPPLIES		
	MAINTENANCE		
	CAPITAL		
	DEPLETION		

with the advent of computers, many mining companies have chosen to use new engineering economic methods for evaluation. Presently, discounted cash flow is widely used, although net present value, net future value, and equivalent annual cost are equally acceptable approaches.

The mine planning phase is often conducted through several iterations. Preliminary analyses lead to several more-refined analyses, and through succeeding steps, the complexities of design are refined by additional details. Usually, one detailed system stands out as that to be employed.

Mine Development and Operation

After planning, a certain amount of excavation, or development work, is generally required before the deposit can be tapped. Once the deposit is reached, the work of extraction is termed production. Since every mining method has unique development requirements, a concurrent description of development and operation is appropriate. Some aspects are related to all mining situations, while others must be separated into four broad areas: (1) surface coal mining; (2) underground coal mining, (3) surface non-coal mining; and (4) underground non-coal mining. These terms are not absolute, however, as the coal-non-coal distinction is more one of soft-rock vs. hard-rock and deposit geometries.

One feature common to any mining method is access. In surface mining, this is by road. In underground mining, access may be by near-vertical entry (shaft), inclined entry (incline or slope), or near-horizontal entry (adit or tunnel), depending on the deposit's

location and depth.

Development after the main access may consist of driving horizontal openings parallel to the strike of the deposit, which may be termed drifts in hard-rock mining, and other flat entries, at right angles to the strike, which are termed crosscuts. Vertical openings, if driven downward from the surface, are shafts, or if driven down from underground are called winzes, or if driven upward from underground are called raises. A place of work is called the working place in hard-rock or a section in coal mining. Other division of the mine into blocks, panels, drifts and stopes (hard-rock) or into sub-mains, panels and rooms (coal), proceeds from the framework of drifts, crosscuts, raises and winzes. All such development must proceed in a systematic order, to assure that entries are developed early enough to allow production areas to function.

Surface Coal Mining

The surface mining of coal is commonly referred to as strip mining, since the material covering the coal, or the overburden, is removed in strips to prepare the coal for removal. The differences between strip mining methods are in the overburden handling, since the practices of coal handling are quite similar. The methods are area mining and contour mining, depending on the topography.

Area mining predominates in the Interior Coal Province (Illinois, Indiana, Iowa, Kansas, Oklahoma) and the Far West, (Grim and Hill, 1974). In area mining, a box cut or trench is made through the overburden to

expose the coal seam. This cut usually extends to the limits of the property. As the overburden is removed, it is placed on adjacent unmined land. As the coal is removed from the bottom of the first cut, a second cut is started immediately adjacent and parallel to the first cut. Overburden removed in this second cut is placed in that portion of the first cut from which the coal has been removed. When the coal has been entirely removed from the first cut, the stripping of spoil from the second cut is completed. Cut by cut, the mining proceeds across the property. The final cut leaves an open trench, bordered on one side by the spoil and on the other side by an unbroken face of overburden called the highwall. If no restoration is effected, the spoil banks from stripping resemble a giant washboard or the ridges of a plowed field. Reclamation concurrent with mining, being environmetnally preferable, includes the grading and planting of the spoil. The phases of reclamation-concurrent area mining are depicted in Figure 7.

Area mining, if limited by capital restrictions, is small-scale. Otherwise it is characterized by giant earthmoving equipment. What is an uneconomical prospect to a small operator may, if combined with several other such prospects, prove quite attractive to a giant coal company.

Contour mining (Figure 8) is practiced where the limitations are not those of ownership boundaries, but are those of economics related to topography. Mining is typically on hillsides, where the increasing depth of overburden as the seam is worked into the hillside restricts the operation, but the mining may proceed around the hillside, at a fixed stripping ratio, and along a given elevation or contour line. This

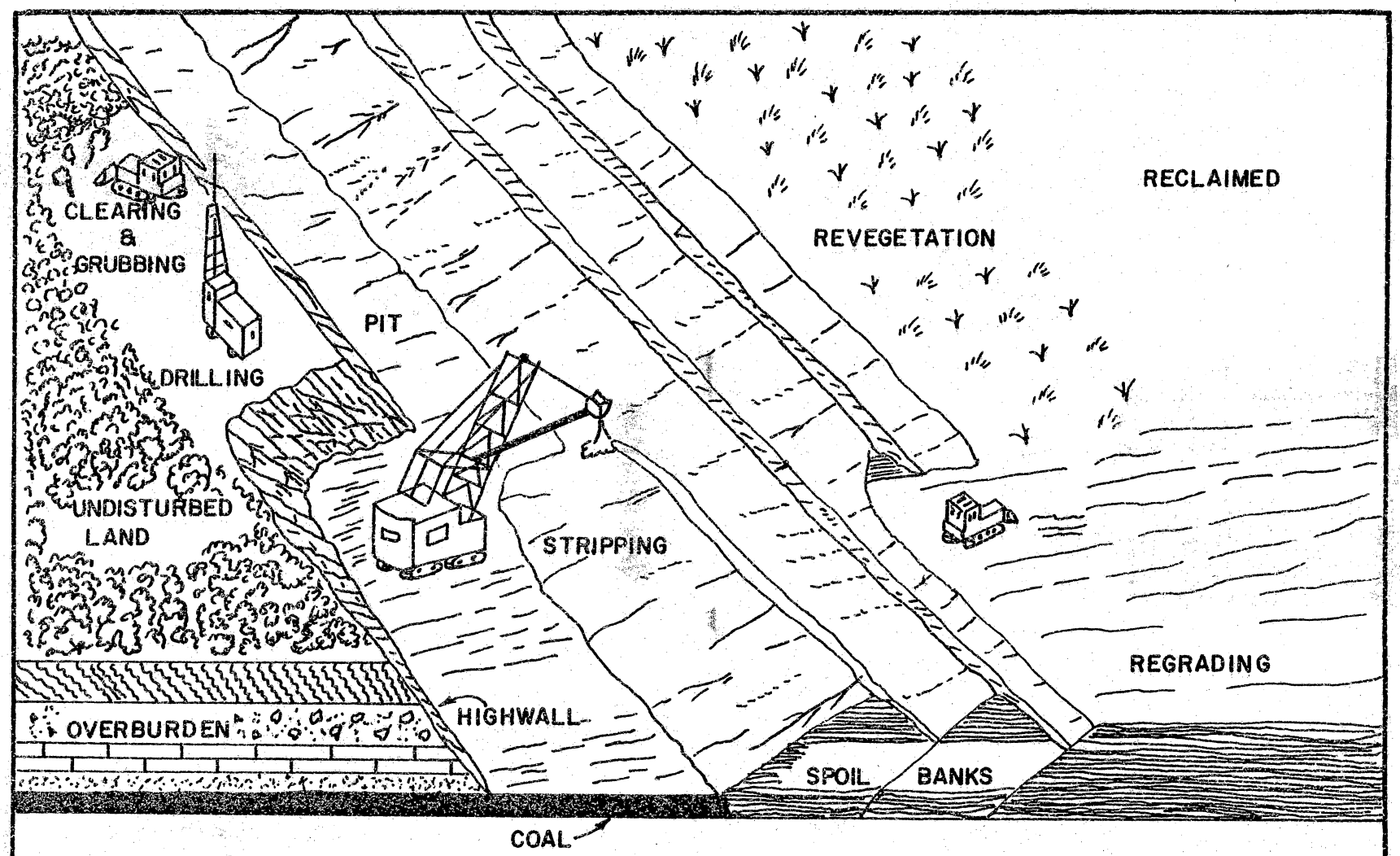


FIGURE 7: AREA MINING WITH CONCURRENT RECLAMATION (After Grim & Hill, 1974)

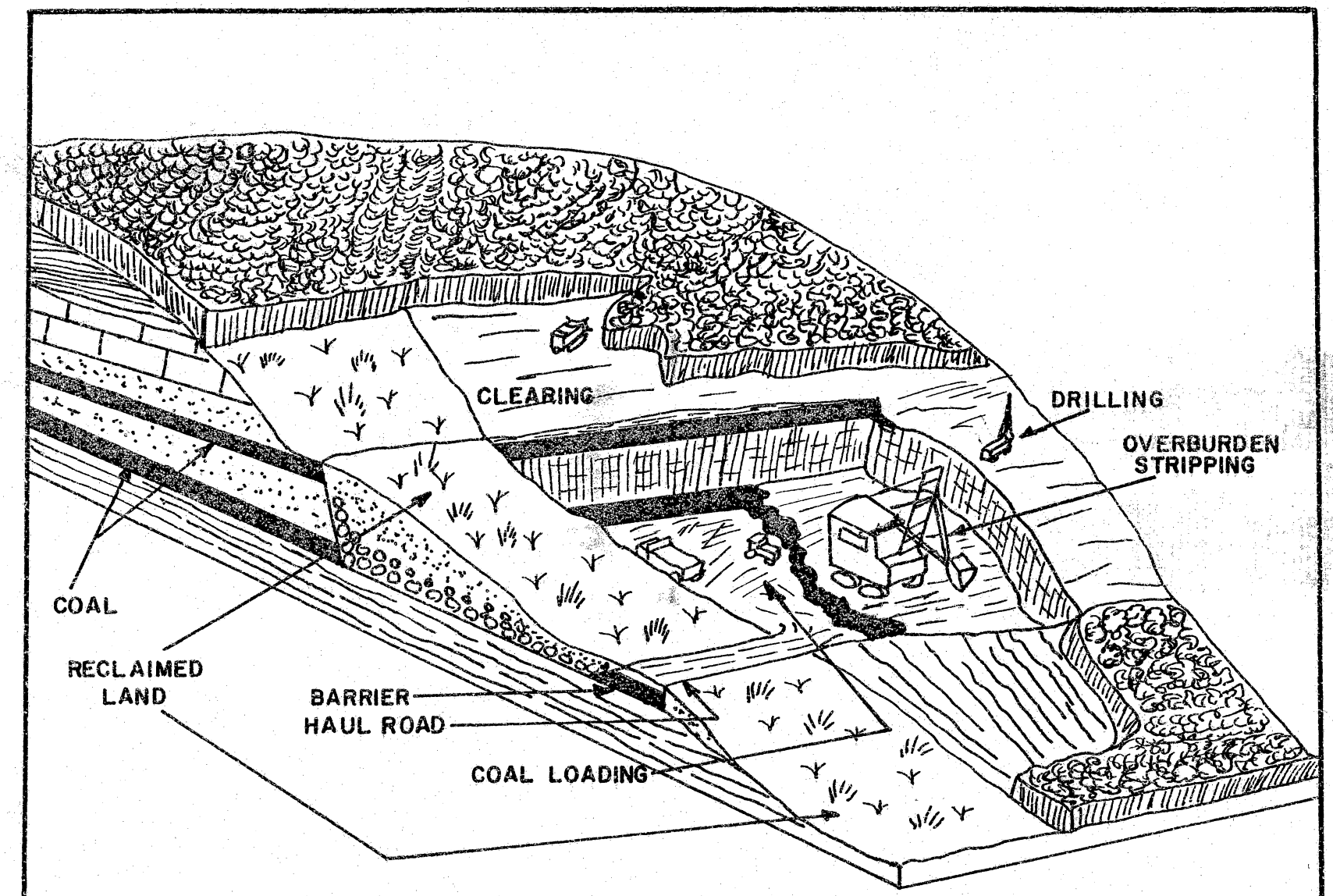


FIGURE 8: CONTOUR MINING

mining has provided the name of "contour mining" to any operation which takes place in steep (>12°) terrain and in which the stripping ratio varies as the physical or economic limits of machinery are exceeded. A range of methods are encountered, including outslope disposal, outslope reduction, box-cut, haulback, block-cut, modified area, mountain top removal and longwall stripping, as well as the head-of-hollow fill method of spoil disposal, (Grim and Hill, 1974).

Outslope disposal has been the traditional approach. For obvious reasons it is scarcely practiced today due to its environmental consequences. Waste material is simply pushed over the edge of the working bench. A logical progression of mining methods has developed from this seemingly unconcerned approach.

Slope reduction and box-cut (Figures 9 and 10) were developed to provide more control in the placement of spoil. While they do provide this, they still have the common drawback that spoil disposal is still outside of the working bench. Further developments were necessary to realize environmental protection.

One such concept was the head-of-hollow or valley fill for spoil disposal. Figure 11 depicts this. The method is a logical, controllable alternative to outslope disposal. Although disposal is technically downslope and outside the solid bench, a specific, controlled situation developed.

Once the head-of-hollow fill method had been developed, the techniques of block-cut, haulback, modified area, and mountain top removal mining could be developed. These methods are depicted in Figures 13-16. They all represent applications of selective replacement of spoil, and

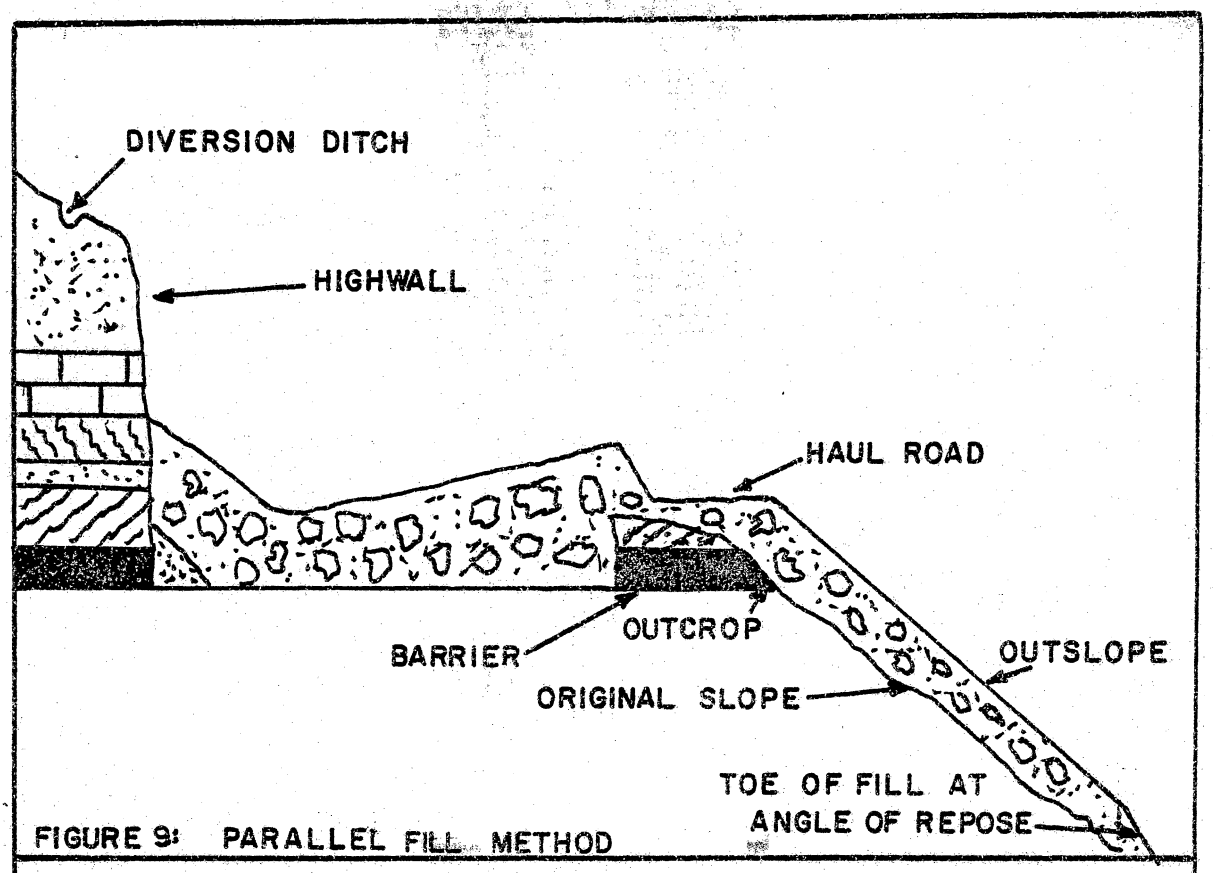


FIGURE 9: PARALLEL FILL METHOD

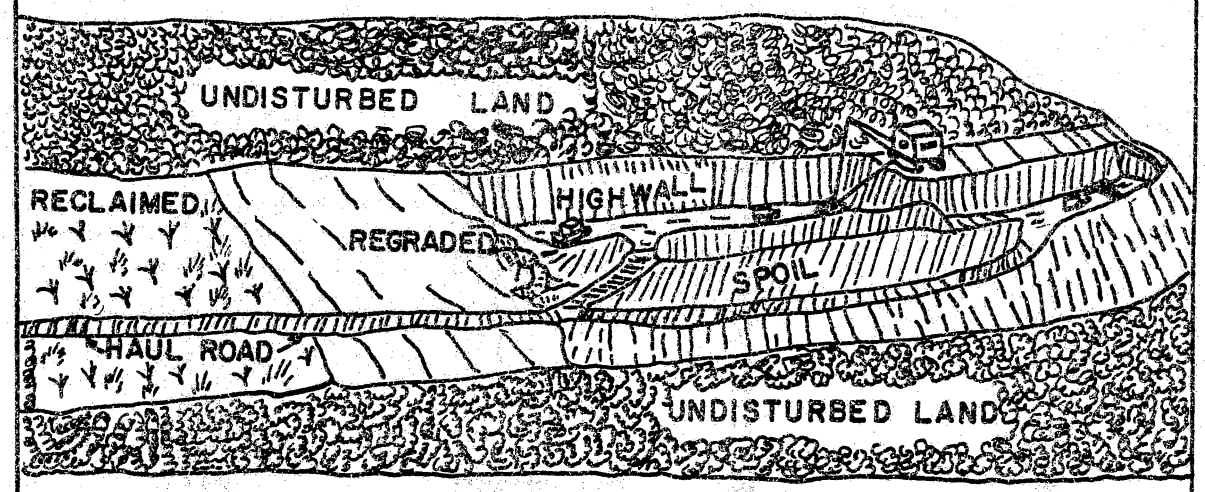


FIGURE 10: BOX-CUT METHOD

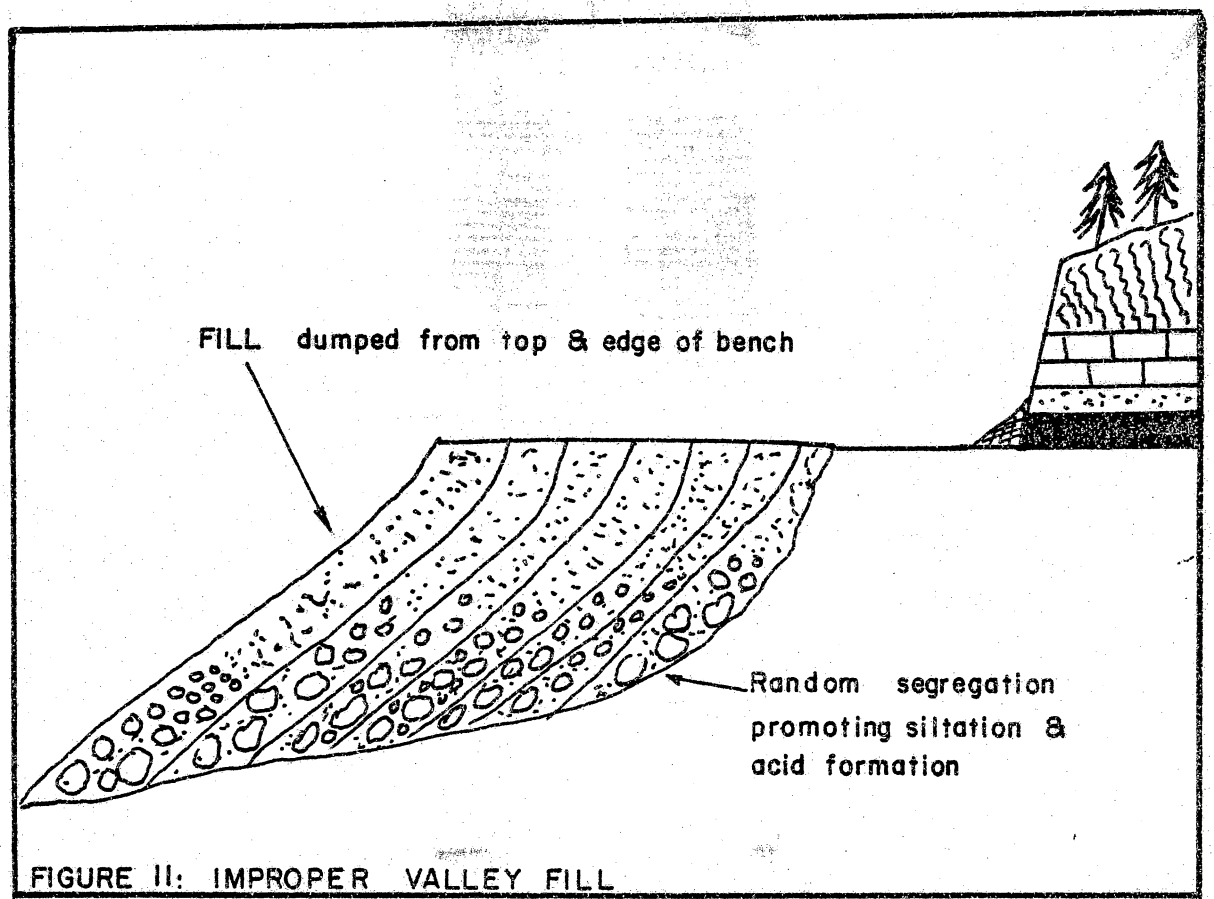


FIGURE 11: IMPROPER VALLEY FILL

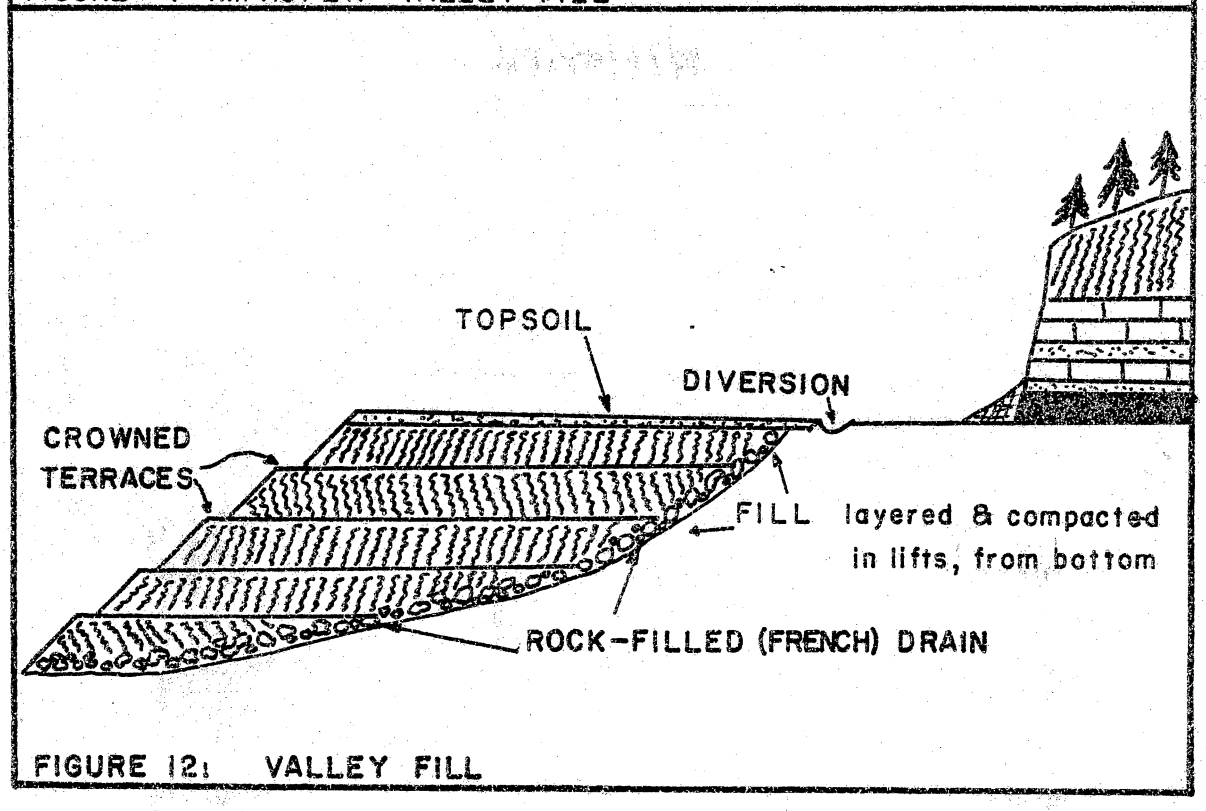
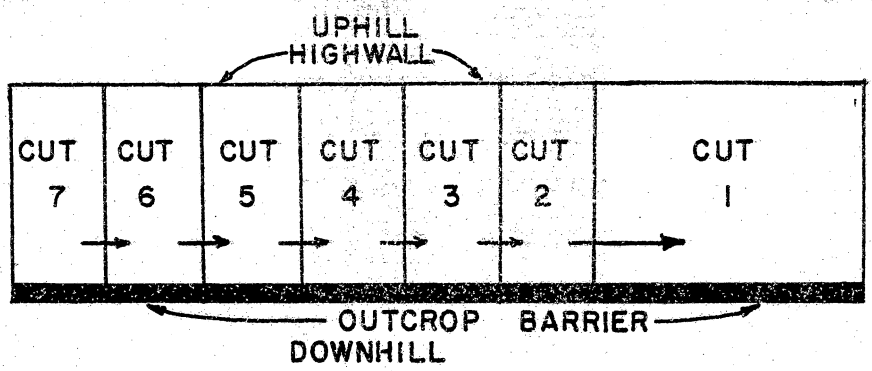


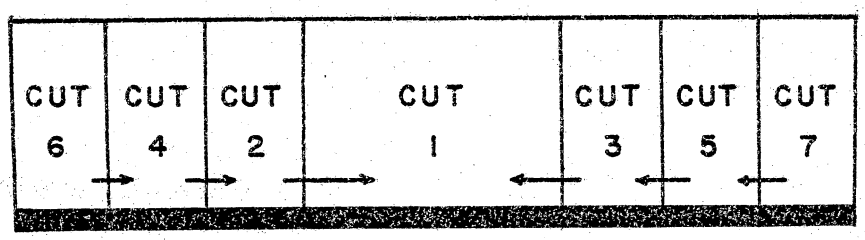
FIGURE 12: VALLEY FILL



FIRST CUT IS BOX-CUT, SPOIL TO VALLEY FILL.

REMAINING CUTS SUCCESSIVELY BOX-CUT, SPOIL TO PRECEDING CUTS.

FIGURE 13: BLOCK-CUT METHOD



(A TWO-DIRECTION BLOCK-CUT)

CUT 1 IS TYPICALLY AT THICKEST OVERBURDEN

FIGURE 14: HAULBACK METHOD

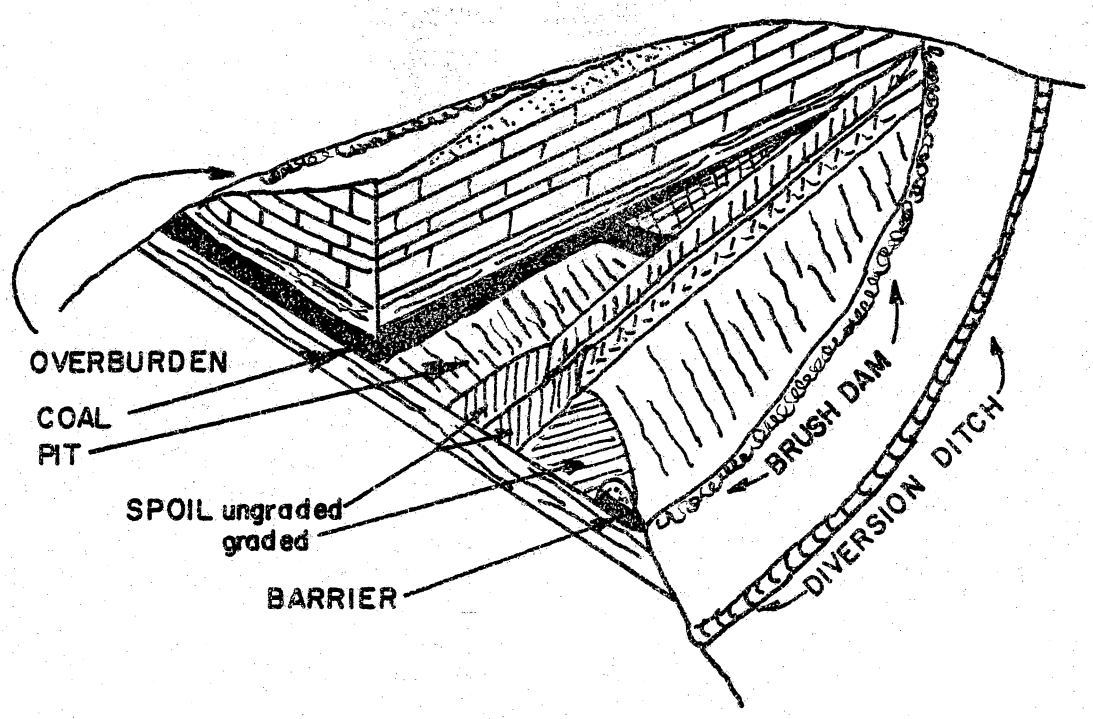


FIGURE 15: MOUNTAIN-TOP-REMOVAL MINING

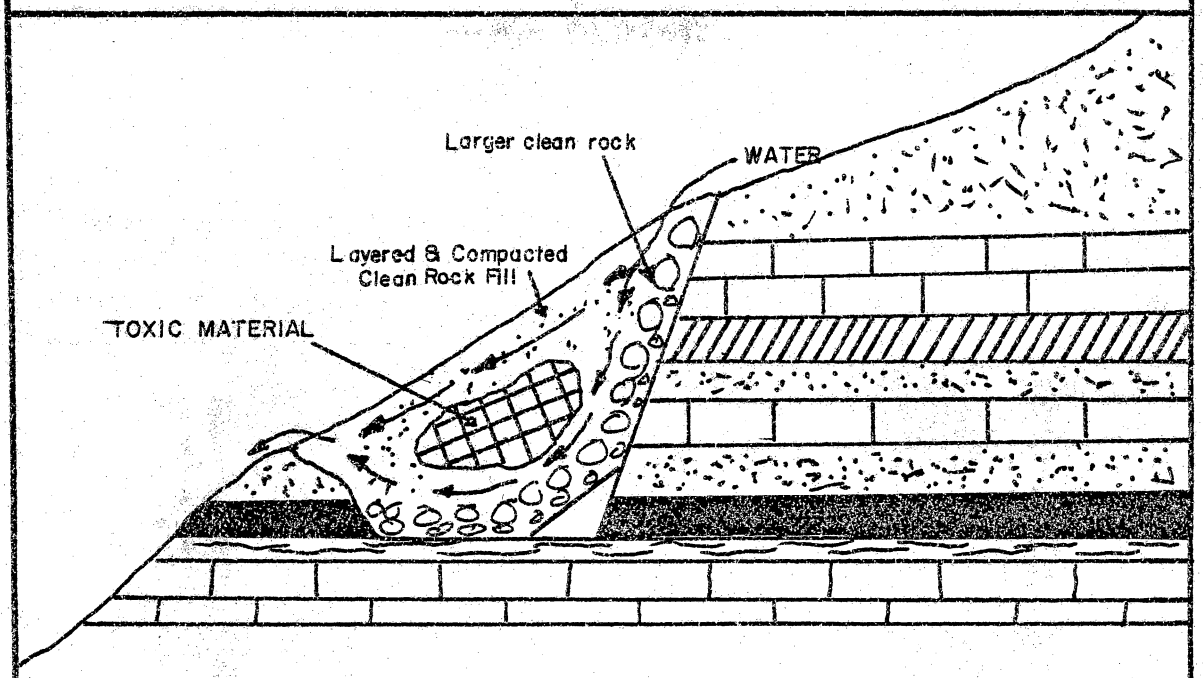


FIGURE 16: TOXIC MATERIAL BACKFILL

restoration to the approximate original contour in a variety of topographies.

Longwall stripping, actually underground mining from the surface, is the latest approach to be proposed. While experimental, actual installation of a longwall stripping operation is underway. First cuts are established at both edges of the property and spoil is placed in a head-of-hollow fill. Using these cuts as access, a longwall mining system is installed and operated through the hilltop, (Grim and Hill, 1974).

Underground Coal Mining

Underground coal mining, since it is by far in thin (less than 5-meter) and relatively flat beds, is predominantly done by room and pillar mining or by longwall or shortwall methods. Such layouts, in addition to meeting the geometry of the deposit and the ground control considerations, provide critical ventilation control to handle both methane and coal dust.

Laws affect the pattern of access in coal mining. Barrier pillars are required around shafts. Entries must be driven in at least pairs, and must be interconnected at definite intervals. For this reason, plan view of coal mines often resemble gridworks or checkerboards. From the main entry, rooms are driven several hundred meters deep and 10 to 20 meters wide.

In advance mining, rooms are driven and all the coal is extracted as the room and entries are developed. In retreat mining, panel entries

are driven from the main entries, and rooms are driven from the end of the panel back toward the mains.

The actual unit operations may be classified as conventional, continuous or longwall mining. In conventional mining, undercutting, drilling, blasting and coal-loading are carried out by separate machines. In continuous mining, one continuous miner replaces the cutting, drilling, blasting and loading operations of the conventional mining system. Longwall mining originated as a caving system, but today refers to systems where the coal is plowed or sheared from a long (100 m and up) face. As the face is advanced, the back is allowed to cave, except for a small region necessary for the working face, which is supported by self-advancing hydraulic props. Figures 17 and 18 depict typical underground coal mining approaches. Shortwall mining, a new mining method, is essentially a longwall approach with the shearer or plow replaced by a continuous mining machine. If continuous conveying equipment is placed behind the miner in a shortwall, it is then sometimes referred to as a bridgewall, (Cummens and Given, 1973).

Surface Non-Coal Mining

Non-coal surface mining may be either placer mining or open-pit mining. Placer mining is applied to alluvial deposits. These deposits are generally mined by dredging or hydraulicking, but the applications are limited in the United States. Placer mining may have severe effects on the environment, and since it may become important in ocean-mining, these can become important considerations in the future.

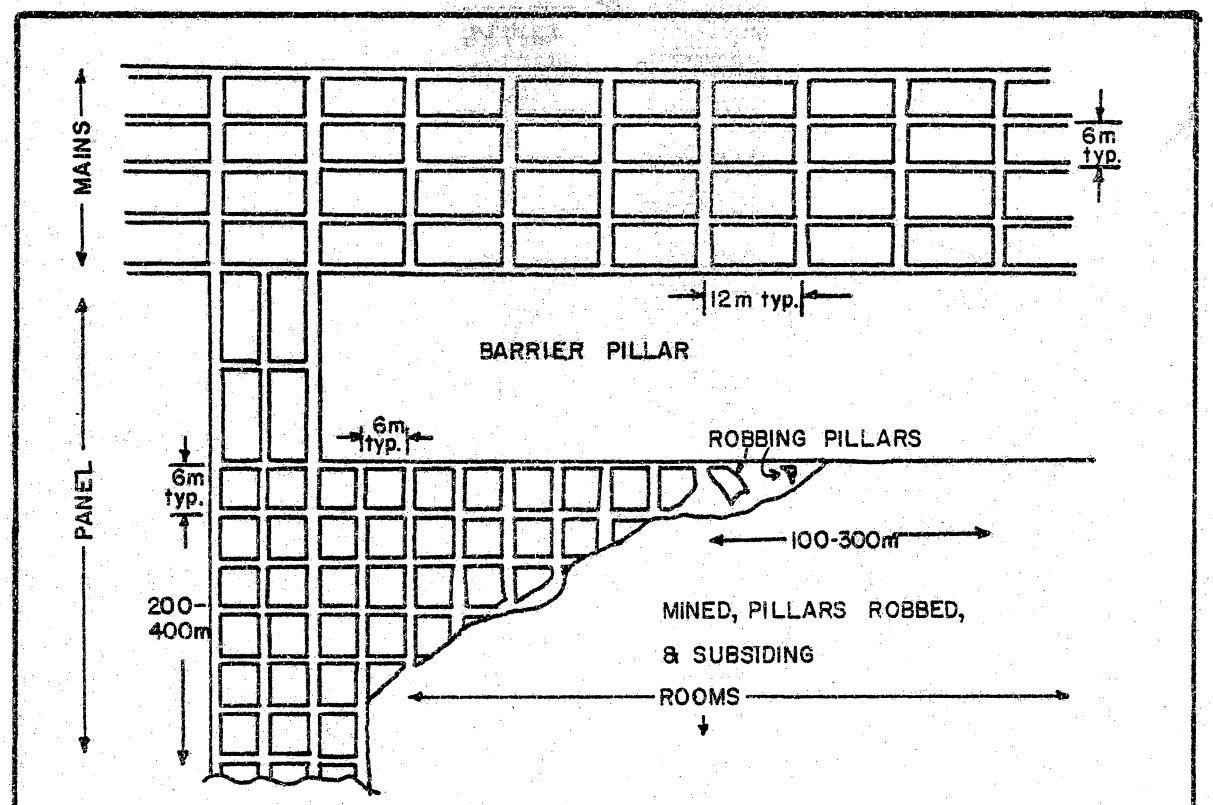


FIGURE 17: ROOM MINING IN UNDERGROUND COAL

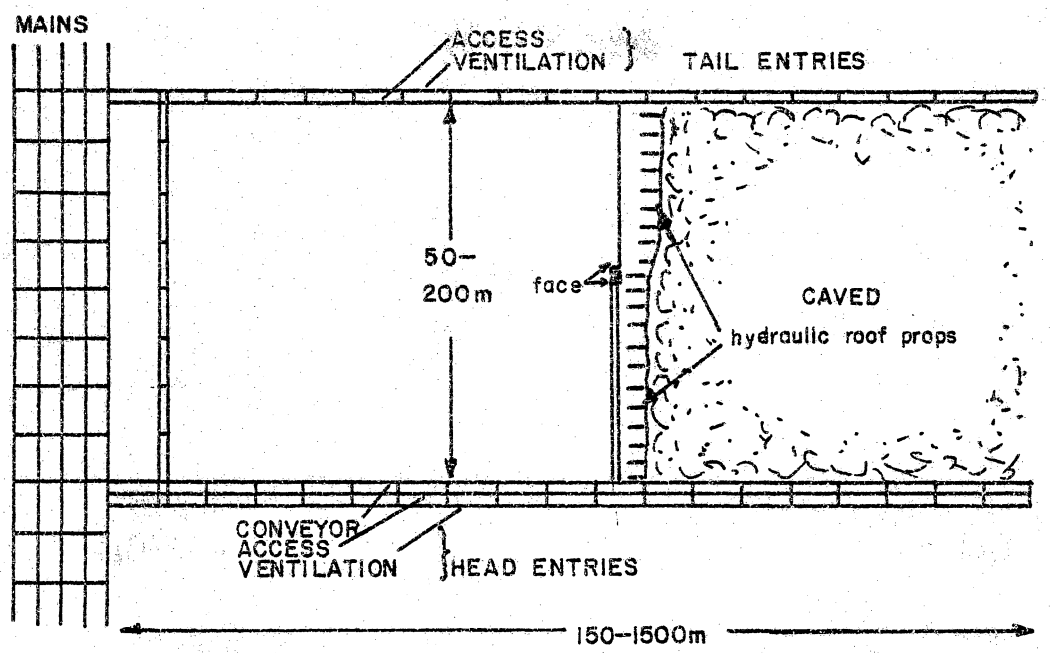


FIGURE 18: LONGWALL MINING

Open pit mining is typified by the giant deposits of copper and molybdenum in the Western U. S. Over 90% of the U. S. metal production in 1972 came from open pit mines, (Cummens and Given, 1973). Distinctions in this approach are made according to the equipment and procedures used for overburden removal and in the production and haulage units. Specifically, it is described by waste haulage method, ore haulage method, and ore and waste loading methods.

Many sophisticated operations research techniques have been applied to optimize open-pit mining. As available ores decrease in grade, large-scale open pit mining will become essential. Proper planning will be important if such efforts are to succeed.

Open pit mining operations may have extreme problems as far as land use is concerned. The Bingham Canyon mine in Utah has been in operation since the turn of the century and will likely be in operation for 100 years or more. Land masses committed to one use for such a period of time are difficult to recommit to other purposes. These problems will be discussed in the next chapter.

Underground Non-Coal Mining

Underground non-coal mining presents many development schemes to fit a variety of geometries and ground control conditions, as shown in Table VI. These, as previously mentioned, fall into roughly three categories, open, supported and caving methods.

In open breast stoping. or open room and pillar (Figure 19), advance is horizontal, and pillars are left either at random or according

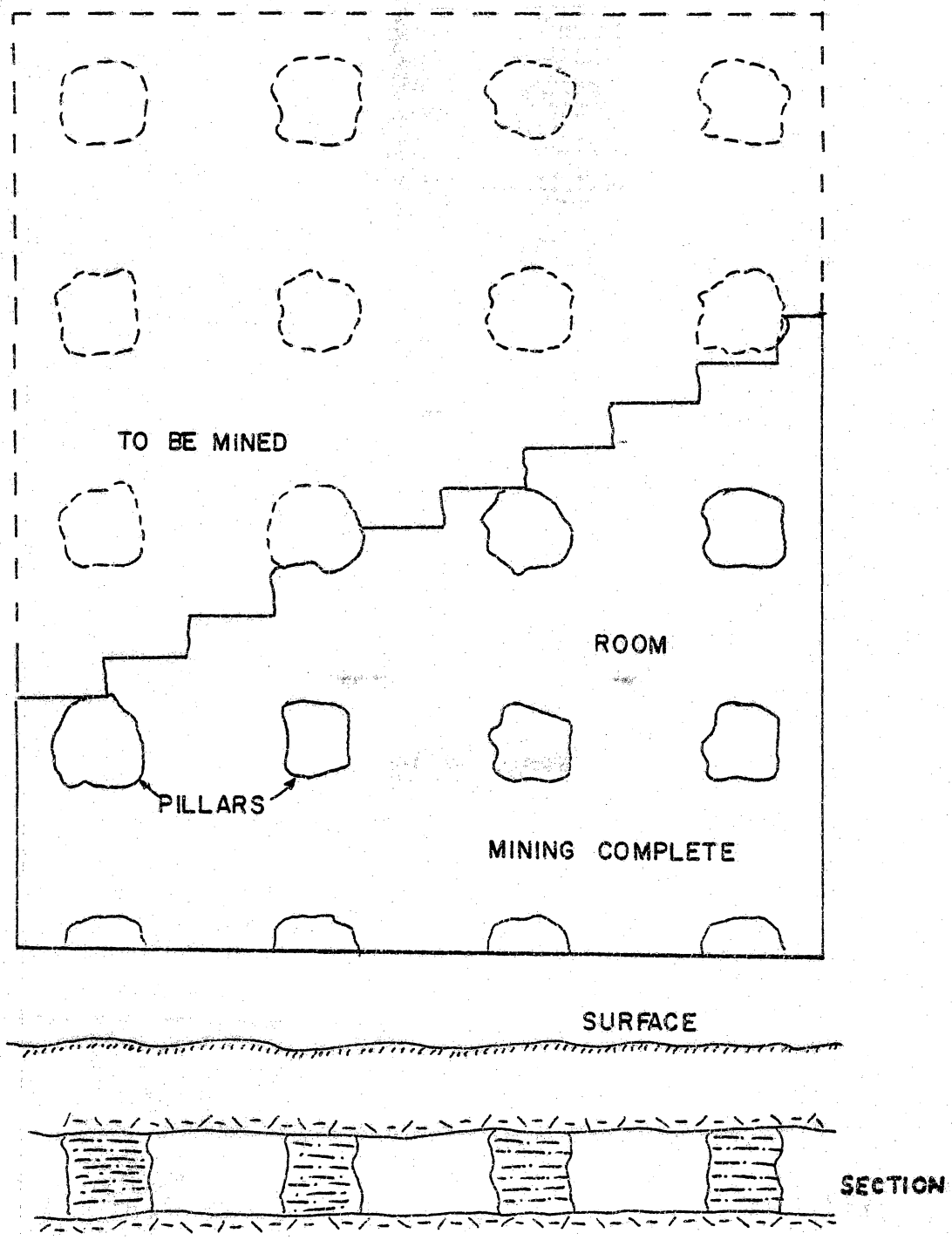


FIGURE 19: OPEN ROOM AND PILLAR MINING

to a less sporadic plan. In thick operations, faces may be advanced in several levels, through the process of benching.

Open underhand and overhand stoping, underground glory hole, and resuing, though shown in the table, are specialized techniques and will not be considered here.

Cut and fill (Figure 20) and timbered stoping are the major divisions of supported methods. In one case, support is by mine waste put into the excavation, while in the latter case, support is achieved with timber sets. Although these are high cost methods, they are applicable in almost any situation.

Certain mining methods are keyed to the movement of large quantities of material, and some incorporate the force of gravity and the inherent weakness of the ore to achieve production. These bulk methods include sublevel caving and block and panel caving, and perhaps large-scale sublevel stoping. For these, a system of drifts and raises for loading broken ore is excavated below the area to be mined. The ore is then mined either by being sliced off, by being caved out in sublevel masses, or by being caved in total, where gravity does the bulk of the work. A typical caving method is shown in Figure 21.

Shrinkage is unique, although it is sometimes classified as a supported method or as an open method. It utilizes broken ore for support while men are working in the stope, but then leaves it open after mining has been completed.

All of these methods correspond to specific geometries, ground conditions, and systematic and orderly extraction of the mass. In general, large, low grade orebodies are worked by large, bulk systems,

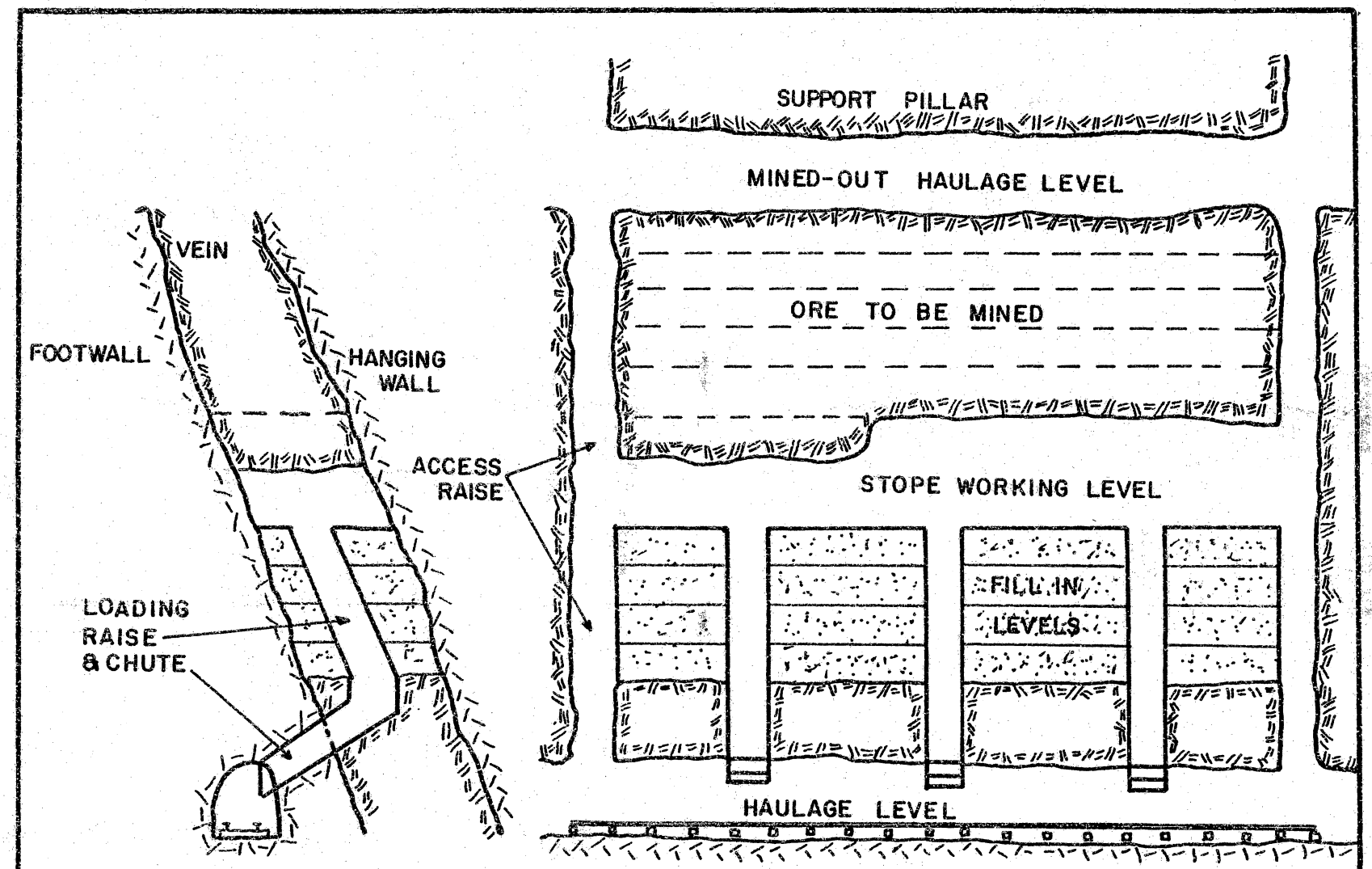
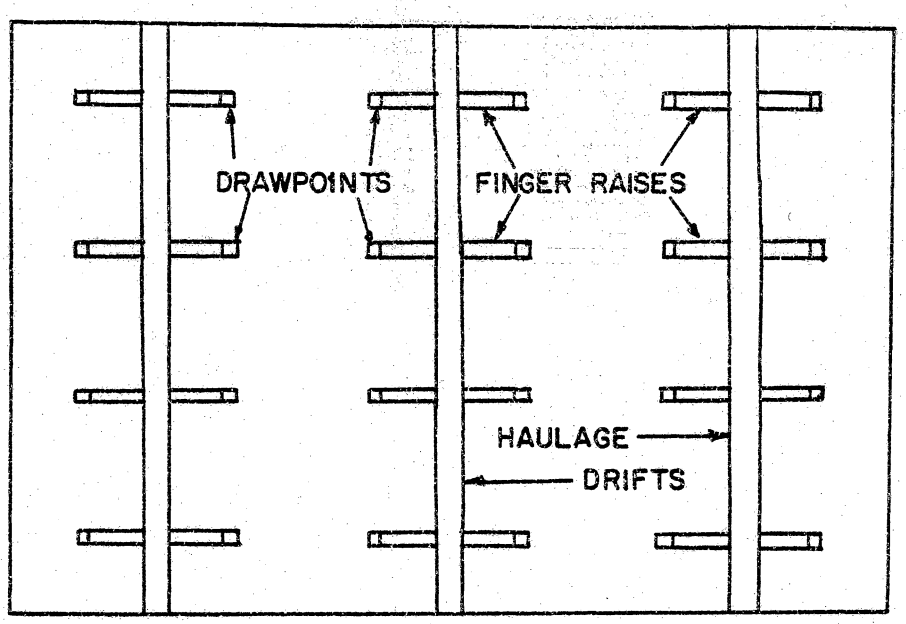


FIGURE 20: CUT AND FILL MINING



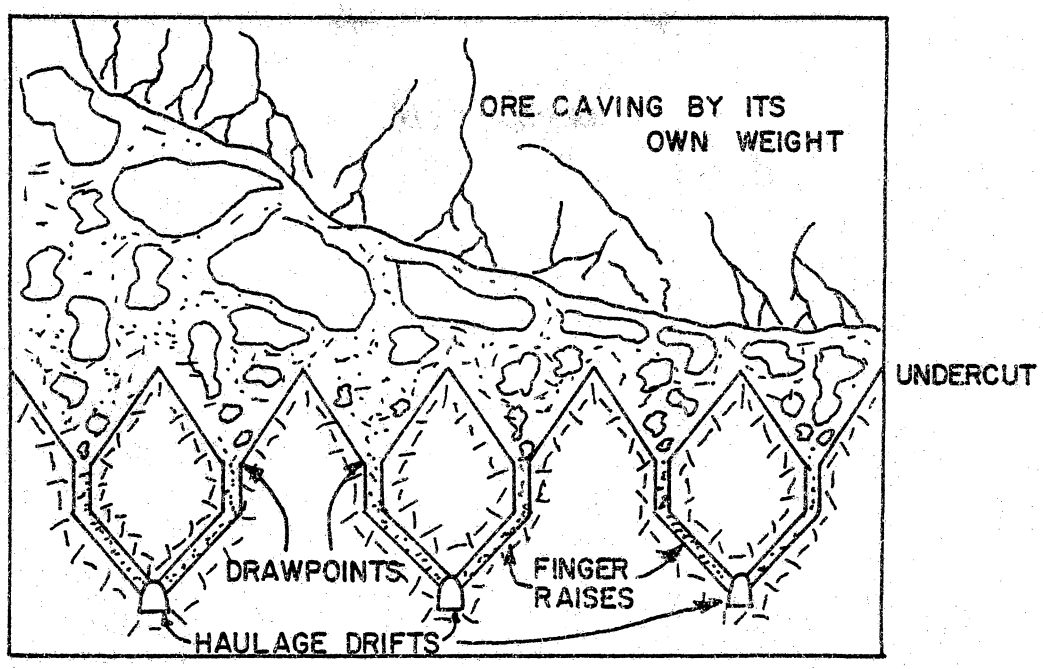


FIGURE 21: CAVING MINING

while small, high grade orebodies can be worked by small-scale, more selective systems. Further details regarding all of these methods are available in the literature, (Cummens and Given, 1973; Peele, 1941).

Mine Closure and Reclamation

Mine closure refers to removing and salvaging mine equipment and perhaps sealing or blocking the mine workings, whereas reclamation refers to rehabilitating the land after the mine is closed as well as during mining. Since closure is actually preparation for reclamation, these processes should be discussed together. Proper measures of rehabilitation and reclamation can greatly enhance the future potential of the land as well as increase its monetary value. Without such minimal considerations, the land may end up in a poor and even worthless condition.

In surface coal mining, acid mine drainage and siltation must be controlled, erosion must be checked, and the topography must be restored to a useful status. Backfilling and grading, in most instances, can provide the isolation of drainage-toxic material and topographical restoration. Rapid and adequate revegetation is the most important factor for controlling of siltation and erosion, and all of these steps must be carried out in conjunction with a capable and responsible overall mining approach, (Grim and Hill, 1974; Skelly and Loy, 1973).

Deep coal mines may cause little surface disruption, although long-term subsidence is discussed in the next chapter. Grading and backfilling is limited. The major concern in underground mining is the control

of drainage. Traditional approaches are treatment, as outlined in the control technology section. Treatment systems may require perpetual care, however, so many studies of novel treatment techniques and perhaps complete mine sealing, with rubber and plastic sealing agents, have been suggested, (Skelly and Loy, 1973).

Soft-rock surface mines are often similar to coal mines, while hard-rock mines differ significantly. Surface deposits of hard-rock minerals have various relationships of quantity of overburden removed to quantity of ore removed. Moreover, non-coal mines are less amenable to replacement of overburden than coal mines. At closure, practice is generally to reduce slopes, if feasible, fence the area, and let it be. Usually if water is present these pits will fill up. The lakes so formed may be useful for recreation, but their depth and temperature are often unfavorable. The magnitude radically increases when the giant open pits are considered. Little, if any, reclamation of Bingham Canyon could be conceived of by the average mining engineer. One of the major problems of the industry, then, is what to do with these giant operations when they are completed. This will be discussed in the next chapter.

Some similarities exist between underground non-coal and underground coal mines. As with surface metal mines, however, large quantities of mining waste and mill tailing may be left at mine closure. Today, mine planners are experimenting with the establishment of cover crops on mine waste, but there is little existing reclamation technology. The state of the art in reclamation of underground metal mines and their waste and tailing dumps is very limited.

Problems of Mine Planning and Management

Mining is broad in scope and deep in field. It is also uncertain and involves many risks. The mining practice is therefore far more empirical, traditional and intuitive than most other disciplines. In the course of its evolution, many of the interconnections of mining engineering technology have never been fully developed. Yet with each new operation, and approach, this understanding is slowly becoming more complete.

A consideration of the environment is one of the latest of these interconnections which must be handled by the mining engineer. A deeper understanding of these relationships may help to resolve these additional uncertainties in the mining process.

QUALITATIVE AND SUBJECTIVE OPTIMIZATION OF MINE-ENVIRONMENTAL RELATIONS

In a general view, there can be no separate mechanism for "environmentally optimum" mining, as environmental concerns must be an integral part of the mining process. Add-on treatment in pollution control technology is recognized as much less efficient than design of the pollution-free process. Likewise, add-on approaches to engineering design are much less efficient than an integrated and comprehensive approach. The simply stated goal of the mining engineer is to achieve an optimum mining operation, in which environmental considerations are a natural consequence. The historically narrow and shallow perspective of the profession has limited the industry's capabilities to achieve this goal. Industry has tried to conquer and subdue nature rather than cooperate with it.

Engineers, however, need to be able to distinguish between emotional viewpoints and engineering feasibility. Since mining combines various engineering disciplines with a definite operating philosophy, the solution of mine-environmental problems requires that these two areas be clearly laid out. This chapter will stress one of these, the development of definitive philosophy to link the hard-core engineering aspects of mining practice to the qualitative and subjective goals of environmental concern. The next chapter will describe a quantitative, objective approach to this problem.

The several direct, adverse effects of mining were noted previously. These deal mainly with the quality of water, land and society. It is possible to delineate the general types of impact in each of these areas, to propose goals and then to develop general approaches for achieving these. Indirect adverse impacts of mining can also be delineated. These are pervasive, subtle and difficult to handle in a typically engineering fashion. While conceptual goals can be developed for these, the total solution depends on including such conflicts in an economic analysis of the mining industry. Such a problem is one of the more classic analyses of environmental economics: the achievement of maximum social welfare. Resolution of this economic problem provides guidelines to the development of government and industry-wide philosophies which consider direct and indirect effects.

Pollution has been defined by some as a resource out of place. One new approach to analyzing the relations of pollution, which is presented in this chapter and the next, is that a three-component relationship produces environmental affects. The three parts are (1) the <u>resource</u>, a basic characteristic of the environment, (2) the <u>action</u> of man which moves that resource from its normal place, and (3) a <u>receptor</u> of the impact, a person, place or thing which realizes a value or loss from the resource relocation. The overall efforts of environmental control should be directed to assuring that resources are moved to the least offensive position possible. The use of the unique three-component relationship is helpful in pointing out that man can only alter actions: man neither can remove the resources from nature nor eliminate the receptors, he can merely revise and alter the actions which

relocate resources.

Any solution must be reasonably acceptable to both sides of the conflict, i.e., to the industry and to the environmentalist. The anticipated result should be a blend of mining engineering and the environmental and social sciences, to produce a true "marriage" of these fields.

Direct Adverse Effects of Mining

Many of these effects are local, such as haulage-road dust, blasting noise, or air pollution from processing plants or burning refuse piles, and are similar to problems in other industries. They are concerned with unit operations common to other industries. They are also point-source discharges, as they occur at one physical location, and can be controlled at that location. While their solution is required, the actual relation to the total mine-environment system is minor compared to the scale and degree of the larger problems of the deterioration of land and water.

Six major categories of impact can be identified. Three relate to water quality: (1) mine drainage, (2) siltation and erosion, and (3) thermal discharge. Three problems relate to land quality: (1) total area involved by mining operations, (2) geographic indifference of mining, and (3) the degree of land involvement by mining activity. More generally, it can be seen that these effects occur because mining (action) disturbs a particular set of physical, chemical and biological conditions (resources), and the manifestation of this is found in the water and on the land surface (receptors). Since the degree of disruption

varies with the mining methods used, (surface vs. underground, large-scale vs. small-scale), the solutions must also vary from method to method. To identify the actions involved, those which can be altered to alleviate such direct, adverse effects, each of the areas will be reviewed. General and subjective guidelines for alleviating impacts in each area will be presented in this chapter, while quantitative, engineering optimization will be presented in the next.

Water Quality Relationships

Mine drainage is often referred to as acid mine drainage, or AMD for short. The "acid" name is applied since highly acidic coal mine drainage is the most common problem, though mine drainage may also be basic and contain other ions. In coal areas, the iron sulfides pyrite and marcasite are associated with virtually all deposits. These minerals are also prominent around the major source of metallic sulfide ores.

Pyrite and marcasite, often referred to collectively a "pyrites," have the same formula, FeS_2, differing only in crystal structure. When pyrites are chemically and biologically oxidized in the presence of air and water, they react to form sulfuric acid and various ferric precipitates. Several reactions occur in the phenomenon. The rate controlling step of the reaction series proceeds very slowly at a pH less than 4, unless a catalyst is present. The bacteria Thiobacillus ferrooxidans can accelerate this reaction by a factor of up to 6 million, (Syracuse University, 1971).

In virtually any situation where sulfur-containing material is

left exposed by a mining operation, acid and metallic hydroxides will be formed. In most situations, the required bacteria are present to serve as the catalyst, and the reaction speed is increased. While all drainage situations are unique, many coal seams occur near, or as, aquifers and possess the potential for high flows and correspondingly high acid problems, (Lovell, 1973).

Even when sulfides and acid formation do not occur, the formation of adverse mine drainage is possible. Water may react with the very mineral being mined (salt or potash).

A combined problem, siltation and erosion, is of particular importance in surface mining. It may affect underground operations where high flow rates and numerous suspended solids are encountered. Salinity and suspended solids may have pronounced adverse effects on such stream life as is critical to self-purification capacity. Dissolved solids, though not directly toxic, may still exhibit chronic effects (stunted growth, reduced palatibility) on the stream life, (Skelly and Loy, 1973).

Erosion is primarily an effect on the landscape. However, since it is primarily caused by the action of water, it is usually considered as a water-related problem. The action of erosion due to surface mining places dissolved and suspended solids in the drainage.

Deep mines from which water is discharged may possess the threat of thermal contamination. As the geothermal gradient is 1.8°C per 100 m, deep mines in places such as Butte, Montana may discharge 45°C water to atmospheric temperatures of 5 to 10°C. The resulting thermal shock can be devastating to the hardiest of stream life.

In summary, any phase or aspect of the mining operation has the potential to contaminate water. Exploration activites often utilize crudely constructed access roads, contributing significant problems in erosion and siltation. The Mining Law of 1872 requires that a certain amount of development work be regularly performed to prove a claim. In many cases, such work consists of digging a pit or trench with a bulldozer, then crudely filling in the opening, in a manner which enhances siltation. Drilling operations may contaminate ground water by serving as an avenue for infiltration of outside contaminants, or may breach aquifers causing their discharge to the surface.

As the mining activity expands, more openings are created in the ground. These further enhance the transport of surface water into the ground and ground water to surface, as well as for the contamination of both surface and subsurface. The expansion of mining activity also introduces the possibility of water contamination from the ordinary refuse of mining: waste rock, tailing, sanitary waste, oil, grease, water from drilling, paper, wood and fibrous materials. Some mines have highly contaminated effluent water as a result of extensive concrete operations and stope-filling procedures.

The general aspects of mine-level control often require only common sense approaches. However, the problems occur over a large physical area; they are not so easy to control as the simple one-point discharge of a pipe. Care in siting access roads, performing required development (such as excavation) and the sealing of exploratory holes can greatly reduce the pollution. Most operating mines install settling and clarification equipment specifically to protect their pumps. It

would be relatively easy to design for an extra load to reduce the suspended and dissolved solids. Even the best of practices, however, are inefficient if continuing maintenance and monitoring are not performed through and after the mine closure period. Abandoned mining areas today and their associated poor water quality testify to this. The difficulties of perpetual care of otherwise abandoned mine operations can usually be minimized with proper approaches to abatement and prevention, though all of the problems may not be completely solved.

Land Quality Relationships

One aspect of the land quality effects of mining, which seems to be almost trivial, is the old adage, "gold is where you find it." While this may seem to be an obvious point, there are still many who do not realize that mines must be geographically located at the mineral deposit, and cannot be sited as in other industries.

Given this basic constraint, two more relationships of land quality can be discussed. While mining occupies a relatively small portion of the surface area of the United States, the industry appears as totally encompassing to those who live in the mining areas. The degree of involvement will vary depending on several factors. Underground mines are less involving than surface mines, and large scale, of course, is more than small scale. The degree of surface involvement will also vary with the relative geometry of the deposit and topography. A final distinction of land quality is in the quantity of mineral refuse produced by the mining. Minerals such as coal are typically mined in low-refuse

operations. Minerals such as the base metals may be mined in a manner which leaves 99% of the removed volume as waste. Discussion of the adverse effects on the land will be developed, then, from six points of view: the combinations of surface or underground with non-coal or coal mining and small-scale vs. large-scale geometry.

Surface Mining of Coal

Variations in land quality disturbance occur in the surface mining of coal dependent on the scale of the operation and on the actual type of involvement. Large scale contour methods, such as block-cut or mountain-top-removal with head-of- hollow fills, as well as area mining involvements may well result in minimal land-surface degradation if proper restoration and reclamation practices are followed. In these instances, the land is restored to a desirable contour, and the amendments and other efforts of rehabilitation may well result in post-mining land-use values greater than those prior to mining. Incompetent small-scale contour stripping, with improper or no backfill and uncontrolled outslope disposal, can isolate mountain tops and leave useless combinations of highwalls, benches and eroding, unstable outslope areas.

If the mining operation takes place in a forested area, the best of restoration practices cannot hope to restore the forest situation immediately. The time required for complete restoration of a forest is 50 to 250 years. However, the alternative may exist to put the post-mining reclaimed land to an economically more desirable or "higher" use, such as for farming, grazing or construction. If an area is in the

opposite status, where use, either designated or assumed, has been and likely would continue to be as a wilderness area, then the question can be raised regarding the destruction of this use by mining.

The extensive reserves of coal in the Western United States pose a different type of current use vs. future use problem. The details of these geographical areas and their problems are well-documented in the current literature. High mountains blend with vast grassland regions, and climatic extremes prevail. Current land use has been developed around the seemingly desolate nature of these areas. Grazing and forage for domestic and wild animals prevail, with some minor farming and major capabilities for recreation and tourism. Although the extraction of minerals is an historically well-developed practice in the area, mining and petroleum ventures currently comprise only a fractional percentage of total land use, (U. S. Dept. Int., 1975).

In such areas, it is argued that surface disruptions will severely alter the very fragile and unique ecosystems, and that restoration with these systems surviving is impossible. Mining companies feel that a responsible and reasonable program of reclamation can produce land suitable for the grazing, farming and recreation uses which now predominate.

Both opposing lines of reasoning are partially correct in their own right. The potential economic level of use is, indeed, perhaps higher in the post-mining case; however, the aesthetic value may be lower, and the use must relate to the availability of a variety of other necessary resources, specifically water, which are critical and limited in these unique systems. The main adverse relationship which must be addressed is the determination of that specific portion of land which is

to be mined, restored and upgraded to higher alternate economic use as balanced against that portion of the land which must be left undisturbed by the efforts of mining, at a higher natural or aesthetic use.

Surface Mining of Non-Coal Minerals

Consideration of cases other than coal mining magnifies the concern over the time frame of disturbance. Coal mining exists within a relatively short time frame, 5 to 10 years. The Bingham Canyon mine and its 100 year life have been previously mentioned. As is the typical case in non-coal mines, the deposit is vast. It is the largest mine in the world. In contrast to the coal situation, the amount of material actually shipped from the mine is very small in comparison to the amount of material excavated. Current daily production of ore and waste is in excess of 300 thousand tons, of which less than 1000 tons is extracted as metal. (In contrast, the largest of coal mines extract 3 million tons per year — less than one month's production from Bingham Canyon). Essentially all of the excavated material is disposed of as waste, either on the rock dump or as mill tailing. If the mine were shut down today, there would remain a large hole, tailing ponds and waste dumps, all devoid of any soil and on which any reclamation efforts would likely require years before success was achieved

Underground Mining

Two adverse effects of underground mining can relate to land use:

(1) the disposal of waste and (2) the effects of subsidence. The geometry of mines has changed over time, as small, detailed and selective or high-grade methods have yielded to large, bulk or low-grade methods. The extracted material has increased as has the percentage waste. Both of the problems have been magnified by this change.

The underground mining of coal, potash, trona or other non-metallic and bedded material results in the least problems. The seams are relatively flat and thin in comparison to the overburden covering them. For example, a 2-m coal seam might be covered by 200 m of overburden. In rural areas, subsidence is less controlled, and an occasional farmhouse or barn may be damaged. However, the regular nature of the deposits has permitted controlled and successful subsidence under major water impoundments or in areas of extensive surface use.

Traditional hard-rock ore mining represented a transition from the subsidence problems to waste disposal ones. Historically, thin deposits were worked as veins or beds, and by non-subsiding, supported methods. The effects of subsidence were also minimized by the relatively high proportion of overburden to mined volume. In hard-rock mining, less of the ore is extracted in processing, though, so large waste and tailing dumps appeared around the mine workings.

Recent technology has allowed the miner to extract the resources of the earth more cheaply, and to win and refine values from lower and lower concentrations of minerals. A shift has occurred from <u>selective</u> mining methods to large-scale, <u>bulk</u>, especially caving, methods of mining. The simultaneous developments in metallurgy, which allow extraction of values from high volumes of low-grade ore, combined with such an

excavation technology (high-volume production rates) approaches the same problems as those associated with open pit mines. As a specific example, the Henderson Mine of the Climax Molybdenum Co., Division of AMAX, Inc., is expected to extract 400 million tonnes of molybdenum ore by panel caving. The grade of the ore is approximately 0.4% molybdenite (MoS_2). The mining plan calls for the removal of a 1700-m cube of material from a depth of only 800 m. Over 99% of that material will be left as tailing. The surface subsidence, tailing pond and other disruption will represent significant problems in land use management.

Guidelines to the Solution of Direct Adverse Impacts

No additional steps must necessarily be added to the traditional mining approaches to accomplish a resolution of the adverse direct effects. Instead, two seemingly trivial but often neglected guidelines, if followed, will serve to direct the mining activity along the proper course. (1) In the design of any system, steps should be taken to minimize any effects at environmental interfaces. If such an abatement step is taken, then the inevitable contaminating events which do occur as a resource is misplaced at these interfaces are to be handled by the second guideline: (2) use the latest most comprehensive and inclusive engineering and scientific technology to eliminate or minimize the degree of misplacement. The appropriate application of these guidelines requires, again, a review of the mining situations by types: underground coal, underground non-coal, surface coal and surface non-coal.

Underground Coal Mining

Three major problem areas in the underground mining of coal are the land quality effects of subsidence, the disposal of solid waste, and the water quality effects of mine drainage.

The traditional approach plans for subsidence immediately following extraction or during the operation as an inherent response. Optimization of the subsidence generally implies minimization of its effects. This is often accomplished by estimating its intensity and specific location and noting the structures or features which will be affected. Relocation of structures, of drainages, and of impoundments is common practice in the industry when such effects are forecast. Few changes can be recommended to these aspects of subsidence control.

However, the effects of large-area subsidence on vast and interconnected, deep and shallow groundwater flows and aquifers is poorly understood yet can be profound. Particularly in the west, water-bearing strata are closely associated with the coal seams, or are these seams themselves. Water cannot be sealed in-place if the aquifer is to be removed, and in most cases it is equally impossible to remove the water prior to mining, save and then restore it. Explicit steps have to be taken and in order of preference they would be (1) to seal the water in place; (2) to drain the water and store it in some location for future use; (3) to seal the aquifer partially, storing part of the water underground for future use; and (4) to divert present flow to streams where best use can be made of the water, (Bisselle, et. al., 1975).

Such concerns overlap those of mine drainage. Prevention of any

noxious drainage is certainly preferable to the treatment processes. While pre-mining dewatering is obviously the ultimate solution to prevent adverse drainage, current technology will not support such a move except in rare, local and small-scale circumstances. Sealing of the active mining area to preclude any noxious flow, surface or subsurface, should be considered as a logical alternative in the total-system formulation of alternatives. A problem in such an alternative is the selection of the specific method, since many are available with varying costs and effectiveness (Table IX).

If mine drainage does occur, as is normal, there are various technological approaches aimed at neutralizing the pH and reducing suspended and dissolved solids. The efficiency and effect of such processes is generally stipulated by regulation. These effluent standards apply equally to every mining operation within a given judicial domain. The dispute of stream standards vs. effluent standards could, however, be raised. It is, therefore, difficult to select one process which most economically and efficiently meets effluent standards for a specific installation and the non-point sources found in mining.

Present practice uses hydrated lime as the treatment. Future efforts may favor novel approaches as being specifically more acceptable. These include reverse-osmosis, ion-exchange and ozone oxidation, as well as the addition of other reagents similar to lime such as potassium hydroxide, sodium hydroxide or limestone. Extremely novel approaches may be developed for individual cases. The possibility has been raised of using a trickling-filter type arrangement to take advantage of the actions of Thiobacillus sp. in a biological reactor system, (Lovell,

TABLE IX: METHODS AND COSTS OF MINE WATER SEALING (DOYLE, ET AL., 1974)

CLASS	METHOD	COSTS, $ LOW	HIGH	AVERAGE
HYDRAULIC SEAL	GROUTED DOUBLE BULKHEAD	8,300	58,000	19,600
	GROUTED SINGLE BULKHEAD WITH CURTAIN GROUTING	——	——	EST. 4,500
	QUICK-SETTING DOUBLE BULKHEAD	3,600	9,600	8,500
	EXPANDABLE GROUT RETAINER RING	——	——	3,350
	GROUTED LIMESTONE AGGREGATE	8,850	8,850	8,850
	REINFORCED CONCRETE (EST.)	15,000	20,000	——
PERMEABLE PLUG	LIMESTONE BARRIER	3,000	8,500	5,750
DRY SEALS	COMPACTED CLAY	950	2,400	1,480
	MASONRY	1,350	6,400	3,500
AIR SEALS	TIMBER, MASONRY & URETHANE	3,100	14,800	4,100

1973).

Disposal of coal mine refuse may possess the potential of acid mine drainage and the danger of combustion. Guidelines for mitigating the drainage problems of gob piles are more common sense than exact technology, since only the general, and not the technical, aspects of gob are understood. The avoidance of combustion is complicated by the spontaneous combustion capabilities of coal refuse. Pyrite can oxidize and produce sufficient heat to set the coal in the pile on fire, and cause further oxidation of adjoining pyrite and other minerals. The answer to both acid drainage and spontaneous combustion problems is the removal of moisture and oxygen. Concurrent sealing of the surface of the waste pile and design to minimize total surface area and air-water contact are steps to be taken, through an approach of (1) proper base preparation, to seal ground contact, (2) design of stable slopes that are still steep enough to minimize infiltration of rainwater, and (3) rapid sealing of the surface of the pile, covering with topsoil, and establishment of a cover crop, (Grim and Hill, 1974).

Surface Mining of Coal

While mine drainage and refuse disposal aspects of surface coal mining are quite similar to those in underground coal mining, many immense new problems arise when the land surface is massively disrupted. The treatment of drainage and refuse is similar to that for underground mining. The resolution of land-quality conflicts in surface mining, however, is much more difficult.

The mining industry is already in a poor public position. Past practices have shamed it in the eyes of the public. The industry relies on past methods and seems reluctant to remedy such poor images. Linking past, present and future land uses, merging and synchronizing disruption and rehabilitation, cannot be handled through technology alone.

NEPA requires the United States to maintain environmental quality in all endeavors. Project Independence requires that the United States become energy self-sufficient, primarily through the immediate development of coal resources. A solution to both policies requires that a total approach be developed to optimize the production of coal and environmental quality. These conflicting goals may require entirely different approaches to the surface mining of coal.

Uncontrolled contour mining without reclamation deeply scars the land. Current regulation and technology may provide effective rehabilitation if carried out concurrently with the mining operation. However, both the surface area disrupted and the amount and location of spoil must be optimized to achieve an appropriate result.

Good practice in contour mining requires that only those methods be used which place the spoil on the bench or in a stable, controlled outslope location. More specifically, the only possibly suitable methods in use today are block-cut, haulback and mountain-top-removal, as presented in a previous chapter. In these applications, excess spoil must be disposed of in a head-of-hollow fill. The total area disrupted is kept to a minimum, the working bench, and the spoil is located in a more easily controlled and central location. These methods may also be

economically feasible in comparison with other, less environmentally suitable approaches.

Auger mining should be discontinued. The practice raises too many environmental questions. Auger holes connect surface and subsurface drainage. The consequences of augering are virtually unpredictable and in most cases uncontrollable. The value of augering is also suspect from a conservation standpoint. While more coal is recovered from one operation, augering achieves this at a sacrifice of 35 to 50 percent of the augered-area's total coal. This coal is so perforated that it cannot be mined by underground methods and so little is left under so much cover that it is not likely to be re-mined by surface methods. Augering may seriously jeopardize the capability to apply novel techniques.

Area mining is that method which is classically attacked by the environmentalists. Rehabilitation of area-mined lands possesses minor problems in the east, where simple reclamation is usually sufficient to bring the previously agricultural surface back to full productivity. Most of the problems are associated with multiple seams, with thick seams at shallow depth, or with fragile surface ecosystems based on limited, almost non-existent, topsoil and scarce water supplies. Such problems prevail in the Western United States, where the multiple, inadequate alternatives present great difficulties.

Since a stripping ratio of 20 tons of overburden to 1 ton of coal is practical in some areas of the Eastern United States, it is not unreasonable to project that stripping ratios of 20 to 1, as compared to the current less-than 5 to 1, might be practiced in the west. For a 15-m coal seam, such a ratio would imply that 300 m of overburden could

be removed. Therefore, the stripping limits are the mechanical properties of the equipment, not economic ones.

However, if surface mining is started in this western region, there are depths past which underground mining becomes more feasible for today's technology. Present day "high-grading" might limit future surface mining of deeper reserves. Surface excavation may exclude access to deeper reserves for underground mining. Conversely, deep mining may extract less of the resource, since its applications to thick seams are scarcely understood and severely limited, and the act of underground mining may preclude surface mining. Such a region might well be characterized, then, as neither amenable to surface mining nor acceptable for underground mining.

In addition to immense technological considerations, the surface environment of fragile and complex, slowly developed life systems must be considered. Despite the best of efforts, actual restoration of these to their pre-mining states is difficult or impossible. There may be no real need, however, to preserve all of the western lands in their pristine state. Unique areas could be set aside as necessary, if other less-unique areas are allowed to be developed for mining.

An interesting link between the sheerly technological and the sheerly environmental aspects can be seen. Much of the prime coal land, thick seams at shallow depths, lies under the fragile surface-system areas. At the fringes, thinner seams lie under slightly thicker overburden, which underlie less-fragile surface systems. Coal development could be restricted to the less environmentally involved areas. While there would be a somewhat greater present expense, and less present

time value to the companies' investments, an environmental and mineral resource will not be wasted. The fragile ecosystems and thick-seam coal deposits will be reserved until technology will allow the exploitation at the fullest possible extent, while current coal production requirements can still be met.

Underground Non-Coal Mining

In underground non-coal mining, the importance of subsidence control and solid waste disposal are increased. As lower grade ores are mined, bulk methods, incorporating subsidence as an integral part of the process, are employed. Even room and pillar mining and sublevel stoping are being practiced on such a large scale that they can be classified as a bulk method. In these latter cases, while the subsidence is not designed or required, it is recognized as a natural consequence. The extensive subsidence over large areas which may result from bulk, underground mining may be more devastating than surface mining. The disruption is not controlled and direct, and the hole can't be filled.

Subsidence can be avoided if fill is used. The cost of such operations are up to 10 times the costs of others. If the price of the mineral can be raised, to reflect the internalization of such costs, then the damage could be eliminated. This is not an economically "elastic" situation, however, as there is no in-between situation: the mine either caves or not, so the question is one of a tenfold increase in cost.

Surface Non-Coal Mining

Surface non-coal mining is probably the most environmentally offensive method. As previously mentioned, the problems are the life span of the open pit mine and the necessity for huge volumes of material excavated to be completely dumped away from the mining area. There are, however, few reasonable alternatives; specifically, there are quite noxious and non-mitigatible aspects to the alternative underground, caving techniques as well. For this reason, surface mining may be tolerated, but should be practiced at minimal and then decreasing levels. Acceptable methods of the future will be determined by consumers, and may be a combination of bulk, open pit and controlled-subsidence approaches.

Indirect Effects of Mining

Many possible effects of mining can be identified in an indirect fashion. While their aspects can be enumerated, their values are difficult to determine. Tremendous problems must be handled. An identification of some of the benefits and costs to the total welfare will be useful.

Some indirect effects, of a scientific nature, are more direct but removed from the mining system. Mining may disrupt the habitat of a predator, or increase some particular water contamination parameter. While these are not direct pollution at the mine site, at some location removed from the mine they become direct effects.

By far the greatest number of indirect effects reside in the

socio-humanistic areas. These almost overwhelming relations are qualitatively obvious and quantitatively perplexing and involved.

The sociological side-effects of mining may be profound. Mining rarely occurs in urban locations — it is almost always in an isolated or rural setting. The development of a mine may add a structure and order to a town or community, to that which was previously present. But in time, the situation may reverse. Too many people may become dependent on mining and diversity shrinks. Concentration and dependence on mining reduces the vigor of the community and its response to stress.

Politically, the side effects of mining can also be overwhelming. The goal of the mineral producer is to regulate the market structure of the particular commodity so as to accrue the most wealth, be it government, company, individual or association who owns the minerals. In opposition, all competing producers are also manipulating the market and the political structure to concentrate power, to gain for themselves this controlling interest, and to forestall others.

It is extremely difficult to delineate specific indirect economic effects of mining, since indirect effects of many areas influence the values measured in the economic arena. Resolving conflicting relationships, balancing internal and external concerns, is the most severe problem of mine-environmental analysis because of the difficulty, if not impossibility of linking quantitative value to indirect socio-humanistic effects.

An Economic Structure for Solution

The analysis of mining and the environment hinges on the ability to derive a new structure for general mine design, a system including direct and indirect relationships. This is really one of the more classic economic problems: to maximize social welfare with regard to the provision of two resources, mineral products and environmental quality. Maximization of social welfare implies "Pareto-optimality," the classic conditions of maximum social welfare first identified by the Italian sociologist, Vilfredo Pareto. Two specific economic conditions must be met: (1) the value of the last unit of environmental quality consumed and the last unit of mineral commodity consumed must be equal for all consumers and (2) the marginal cost of the last unit of each product produced must be exactly equal to the market price of that unit. There are, however, several problems which prevent the Pareto-optimal situation from being achieved in our economy. Nonetheless, if these problems are at least partially resolved, then there may be a move towards a Pareto-optimal situation, which may be an optimizing move, (Seneca and Taussig, 1974).

Imperfect competition is one such drawback. In cases of monopoly or oligopoly, government intervention is usually suggested. The basic assumption is that private enterprise alone cannot equitably and efficiently resolve the situation. With such a limited or broad spectrum of competition as is present in the various mineral industries, efforts to perfect the competitive structure must be comprehensive and selective at the same time. The various governmental means of control, taxation,

regulation, prohibition, or intervention, while used in many ways, are still subject to debate as to their values. It is an accepted viewpoint of environmental economics that taxation and subsidy seem to be the best approach, as they establish an economic basis in right and responsibility to marketing a commodity. In a different light, taxation and subsidy place the cost of environmental protection on those who purchase or produce environmentally related products.

The mining industry is dynamic and yet uncertain. Pareto-optimality is generally regarded as being possible only in unchanging situations. However, facilities can be designed for a specific situation but to handle deviations up to a limit according to the safety factor used. A mine-environmental solution should be designed with such a safety factor or surge capacity, to make the system more stable under stress. In a dynamic and uncertain situation, the system can still respond in a reasonably predictable fashion.

Government policies regarding natural resources do not resolve equity of distribution, the question of who gets the benefits vs. who deserves them. Equity of distribution requires, in the economists' view, some establishment of ownership. The government is accepted by economists as an alternative owner of environmental quality. Its corrective and regulatory actions do not necessarily make things better, since it seems that many of the programs of government result in gains for few and losses for the general public, while total gains are only somewhat larger than the total value of losses. Clearly, then, less government bureaucracy, and more appropriate structuring of benefit-cost relationships should be developed.

A lack of understanding and, perhaps more importantly, a conflict in motives, combined with a lack of appreciation, by the public for mining and reciprocally by mining for the public, are the most serious drawbacks to economic resolution of mine-environmental problems. Education, first of the public with regard to mining, and of industry with regard to the public, will be necessary to foster responsible environmental approaches. Such programs would be stimulated if some of the pollution-control costs of mining were internalized and passed on to the consumer. The desire to know where his money is going would encourage the consumer to learn about the mining industry.

Government Level Response

The proposed solution to the mine-environmental system begins with a moderate and minimal taxation and subsidization program to make consumers and industry equally concerned. Rather than as with a price-fixing approach, the method should involve a more equitable distribution of benefits and costs. These costs would place the burden of environmental degradation, either as producer or consumer, and would conversely add economic incentive to reduction of pollution. In the long run, a concerned and informed consumer body would negotiate with a concerned and informed industry to determine the optimum supply-demand relations for mineral resources and environmental quality.

Necessarily, however, this structure would result in a decline of output, higher market prices, reallocation of property rights and a potential decrease in profits. Business generally opposes these, and

could exert opposition to its legislation. The consumers would also balk at higher prices. These incentives are viewed by environmental economists as necessary. Basic, free-market relationships must be created, (Seneca and Taussig, 1974).

For such a system to be developed, government and industry tactics would have to be reorganized and reformulated. A regulatory approach, which equitably and efficiently distributes the concerns of mining and the environment through the free-market mechanism, seems to be the most appropriate one. It would also provide the best framework within which the mine planner could function.

Industry Level Response

Two optimization procedures can be brought about on an industry level. The industry should strive to view all environmental-regulation approaches as though they were economic incentives, and try to inform the consumer group as to their specific problems and how they relate to the free market economy.

The key element in the philosophical reorganization of the mining industry is to recognize that environmental regulation need not be a police-force approach and automatically opposed, but rather it is an additional set of constraints and incentives added to an already-complex economic system. Yet the mining industry is extremely prone to regard environmental pressures as adversities only. If it could be persuaded that a given level of environmental concern not only meets the regulation but provides a reasonable return on investment, it might be willing to

accept this. In the next chapter, then, some quantitative approaches, through which such positive benefits of environmental concern can be realized, will be presented.

QUANTITATIVE OPTIMIZATION OF MINE-ENVIRONMENTAL PLANNING

The planning process is recognized as the key to success in a mining venture. Philosophical and technological re-organization is required to incorporate environmental concern in the planning process. The mine-environmental problem must be analyzed to determine both its limits and its interconnections, possible techniques for solving it must be selected, and then it must be specifically formulated and solved.

A Problem of Three Components

Mine-environmental analysis involves a situation and a proposed activity. When the activity occurs, some effect is felt by some persons, animals, or things. It is proposed that the problem and relations to be analyzed should be viewed as systems of three components: (1) a resource; (2) an action; and (3) a receptor. This approach, while seemingly obvious, has not explicitly been incorporated previously in environmental analysis.

Environmental analysis is primarily concerned with the investigation of impacts. An impact is here defined more specifically to be a change in value as a result of some action. In analyzing expected environmental impacts, some approaches consider basic characteristics of the environment, or resources, paired with proposed actions, in determining impacts. Others consider actions paired with those elements of the environment which are impacted, or receptors. However, while a

given analysis can be described about a setting and proposed activity, it is proposed that a new type of description be developed as follows.

1. There can be listed a set of resources, physical, chemical, biological, social, legal and economic, which defines that which can be altered or removed from the situation.
2. There can be listed a set of actions, natural and man-made, social and economic, which defines the proposed activity.
3. There can be listed a set of receptors, which are those living or non-living things which feel the effects of resources being either altered or consumed by the actions.
4. There can be developed, for each possible resource-action-receptor combination, a set of real and emotional values, which express the impact felt within and as a result of that particular three-component system.

Resources

The pre-mining environment is both a set of characteristics for which mining is to be designed and of constraints to the mining activity. These items can only be measured by man prior to taking any action. They cannot be removed from the environment except by man's actions.

Such items are defined as resources, for this analysis. They may be (1) living, as animals or men, (2) non-living, as rocks and water, (3) socio-humanistic, as a registered historic site or pristine, aesthetically pleasing view, or (4) economic, as the supply of money available for capital investment. A fifth class of "resource" is

appropriate in this formulation, though not intuitively obvious. This is (5) the legal resource. Although laws are usually thought of as constraints, as social mechanisms to optimize welfare they are, in some cases, capable of creating values and legal constraints do define or limit the availability of other resources.

Actions

In reality, actions are the only element which man can control. He cannot change a resource or remove a receptor except by an action. Actions can be thought of as causative pathways. They cause a resource to be altered and passed on, and further direct the path to a receptor where value is felt.

While many of the actions associated with mining are obvious, some are not, as several types of action are possible. Actions can be purely natural, physical or chemical processes, which will be classified as scientific actions. Actions will be classified as engineering if they are man-made and physical or chemical. An action may be economic, referring to the market-transfer of goods or services. Finally, an action may be social, or a non-economic action taken between men.

Receptors

A list of receptors, the factors affected by or receiving output from actions, is quite similar to a list of resources. It does not include economic receptors, as such output is received by other classes. The classes include: (1) living, (2) non-living, (3) socio-humanistic,

or (4) legal. A summary of classes of resource-action-receptor chains is given in Figure 22. Again, it is to be emphasized that receptors cannot be changed by man, except by taking action. In summary, though three components to the system are identified, there is only one controllable by man, his actions.

Values

Value is associated with a resource-action-receptor system, but is not a component of the system. Value is rather nebulous. At one time the mining engineer's system of concern was that as shown in Figure 23. He considered two chains:

(1) mineral-extraction-company

(2) mineral-marketing-public

with which the only value flows he considered were real and measured in dollars, as (1) the cost of production of mineral and (2) the revenue of marketing of mineral.

Today, however, the mining engineer could well concern himself with that system of Figure 24, a mine-public-government network including possible resource-action-receptor chains between many elements. Moreover, values are not limited to real dollars, but socio-humanistic impacts influence the public well-being by creating subjective value flows which are quite important today.

Techniques of Optimization

The formulation of the problem is to be as several three-component

RESOURCE	ACTION	RECEPTOR
ABIOTIC	SCIENTIFIC	ABIOTIC
BIOTIC	ENGINEERING	BIOTIC
SOCIO-HUMANISTIC	SOCIAL	SOCIO-HUMANISTIC
LEGAL	ECONOMIC	LEGAL
ECONOMIC		

FIGURE 22: THE RESOURCE-ACTION-RECEPTOR CHAIN

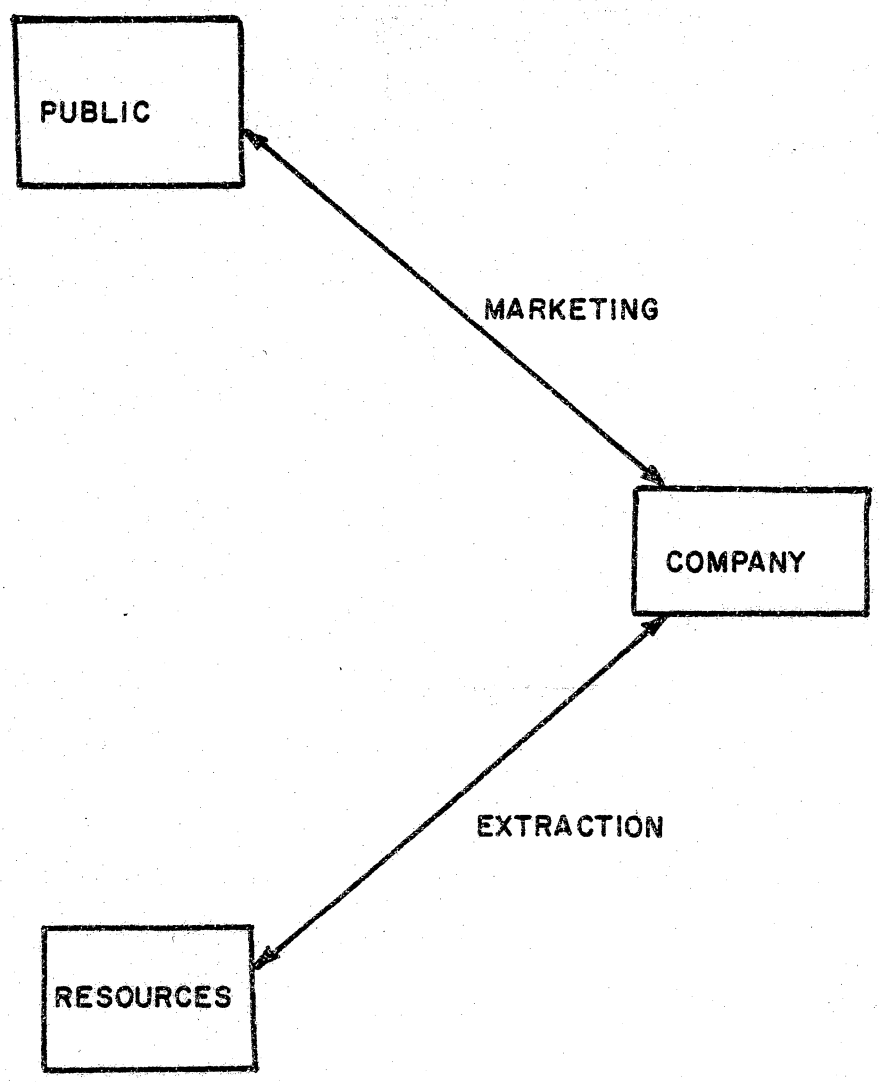


FIGURE 23: THE TRADITIONAL MINE PLANNING SYSTEM

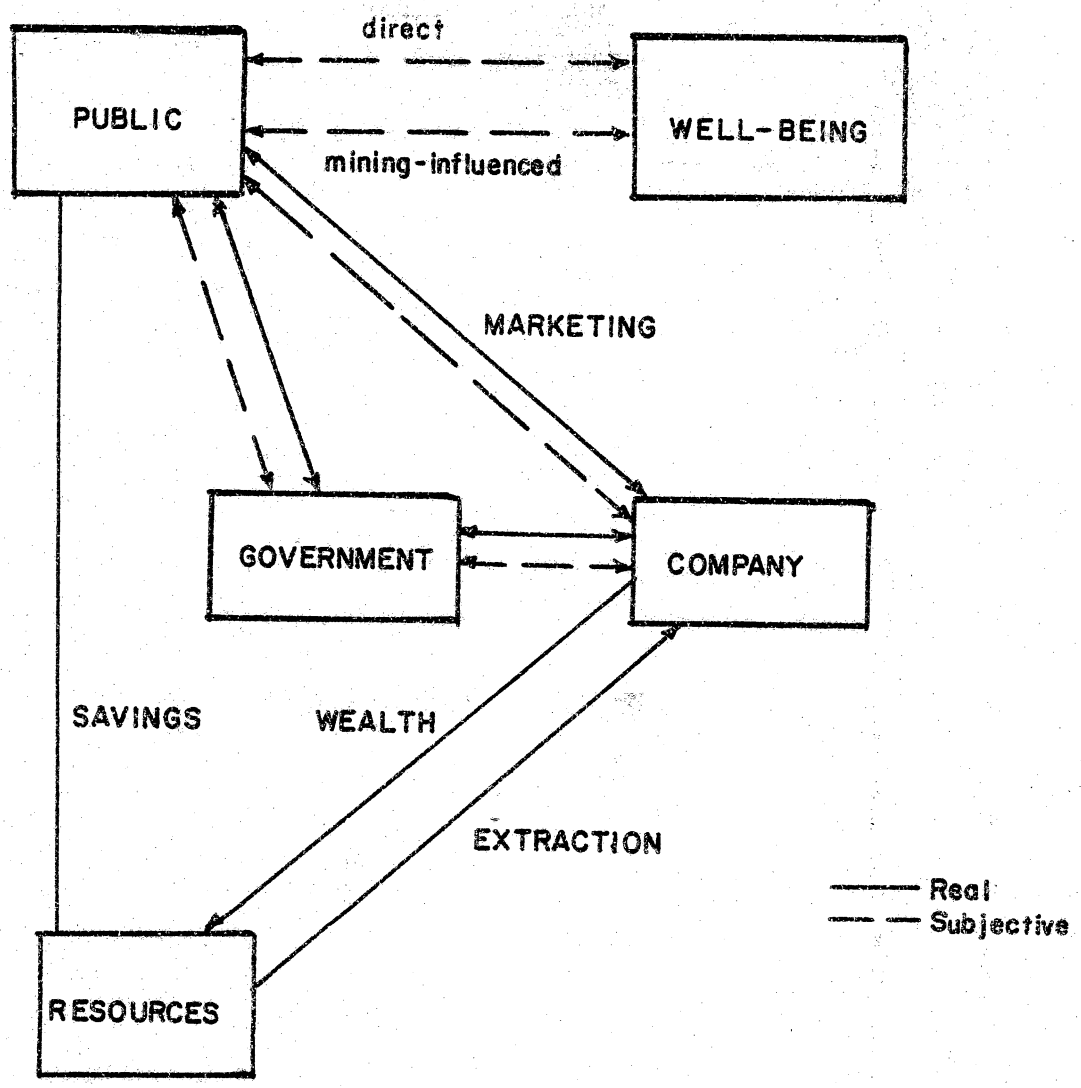


FIGURE 24: THE NEW-ERA MINE PLANNING SYSTEM

chains with which real and subjective values are associated. The techniques of environmental impact analysis should be reviewed to determine which may apply to resolving and optimizing this system.

Checklist, Overlay and Matrix Techniques

These three classes can be quickly eliminated from consideration. The checklist is too limited in scope, and the overlay allows no quantification. The matrix approach could be expanded, as in Figure 25, to a three-dimensional display of resource-action-receptor systems. This is, in fact, an excellent means of displaying the fact that there are so many interconnections possible; however, it is just that and little more.

System Modelling

No single system-modelling approach considers the three-component chain with associated value flows. The Batelle method, (Dee, 1972), is a semi-checklist developed from a system model, and quantifies impact quite well for very explicitly restricted cases in water-resource management. The mining case is far too freely constrained for such an approach. The Resource and Land Investigation (RALI) program of the U. S. Geological Survey, (Bisselle, et. al., 1975), hints very strongly at the three-component chain, does establish a system to be modelled, but neither establishes the three-part concept nor associates both real and subjective value flows within that system.

With all possible approaches considered and eliminated, it seems

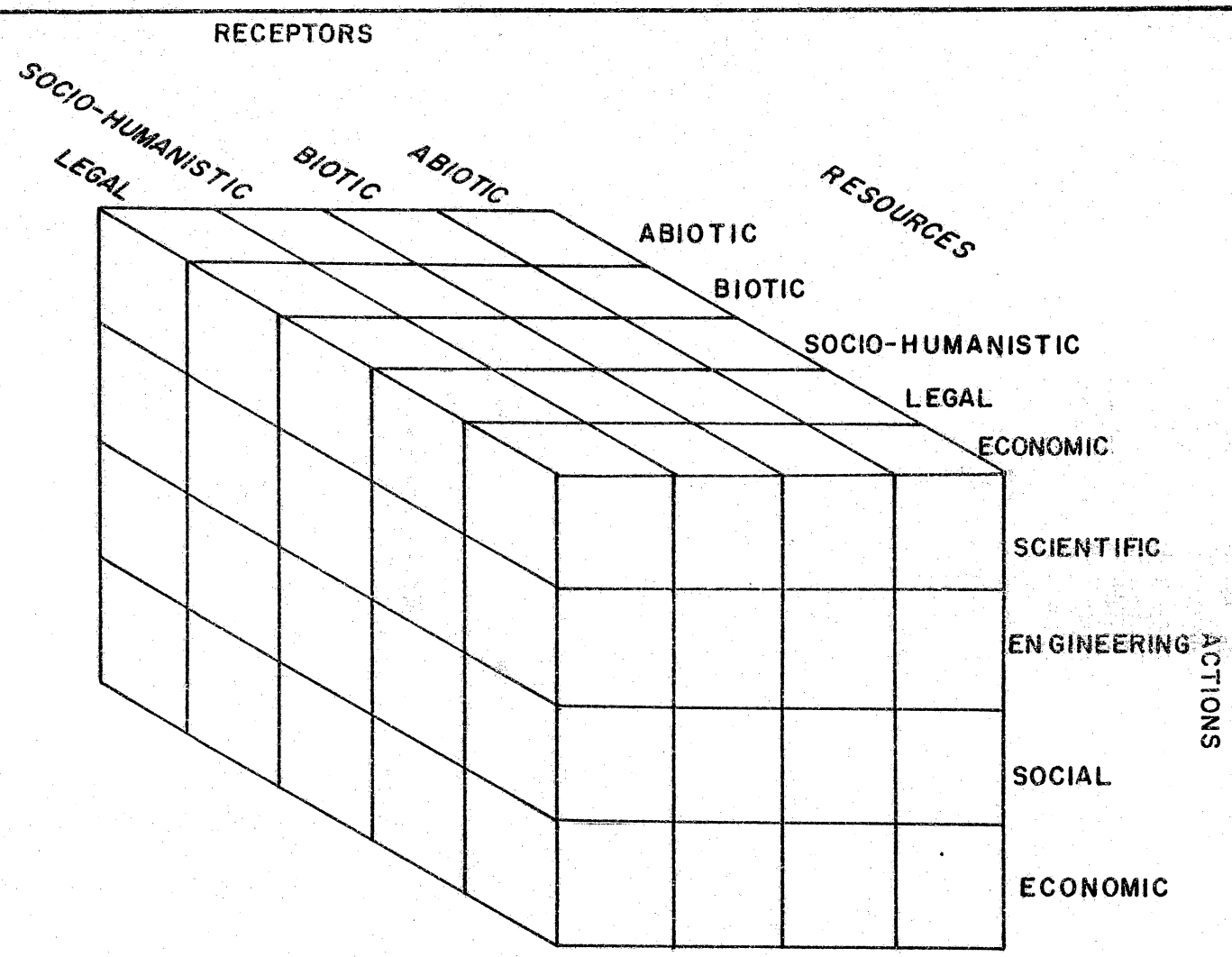


FIGURE 25. A THREE-DIMENSIONAL VIEW OF RESOURCES, ACTIONS AND RECEPTORS

apparent that a new optimization technique is required if any advantage is to be realized from the proposed formulation. Attention is directed, then, to certain techniques of operations research.

Network-Flow Modelling

In operations research, a directed linear graph or network is a set of arcs (paths) which are joined at nodes (junctions), connect a source and a sink, and through which flow passes, (Ford and Fulkerson, 1962). The mine-public-government-resource network as shown in Figure 24 could, with slight modification, become a network suitable for linear graph analysis.

Indeed, a variety of techniques are available in the field of linear graph analysis for analyzing basic flow networks. One in particular, the out-of-kilter algorithm, is the most flexible and is useful in solving any general problem of capacitated flow at a given unit cost. Attempts to use the out-of-kilter algorithm, or any other network approach, are limited, however. The resource-action-receptor chains are amenable to formulation, but linear graph analysis allows only one type of cost. In the mine-environmental planning case, there are two costs — real and subjective.

Even though network analysis is not appropriate as its own field, the suitability of the network formulation indicated that another operations research technique, linear programming, can be used.

Linear Programming

This is a mathematical technique for resolving complex alternatives which involve many interacting variables. These relations are constrained, generally by the scarce nature of some resources, and additionally by competition for their use. As implied in the name, linearity is required: an objective function, a linear equation, is maximized subject to linear constraint functions, (Driebeek, 1969).

The general form of a linear programming problem is stated as an objective function

$$\text{(Maximize or Minimize)} \quad Z = \sum_{j=1}^{n} c_j x_j \qquad \text{(I)}$$

subject to the constraints

$$\sum_{j=1}^{n} a_{i,j}\, x_j = b_i;\ i = 1,2,3,\ldots m \qquad \text{(II)}$$

$$x_j \geq 0 \qquad ;\ j = 1,2,3,\ldots n \qquad \text{(III)}$$

Translated, this shorthand notation means: (1) the objective is to maximize or minimize a function, Z, which is composed of a vector of n variables, each referred to as x, multiplied by effectiveness coefficients, c; (2) each unit of x produced requires the use of some quantity of each of a set of m scarce resources, (one unit of production of any item x_j requires $a_{i,j}$ units of resource i, which may be positive or zero), and the total quantity of resource i used is related to the absolute supply of that resource available, b_i; and (3) variables, being units of production must be zero or positive. The constraint functions [(II) and (III)] may be displayed as a set of linear equations, as follows:

$$a_{1,1}\, j_1 + a_{1,2}\, j_2 + a_{1,3}\, j_3 + \ldots + a_{1,n}\, j_n = b_1$$

$$a_{2,1}j_1 + a_{2,2}j_2 + a_{2,3}j_3 + \ldots + a_{2,n}j_n = b_2$$

$$\ldots$$

$$a_{m,1}j_1 + a_{m,2}j_2 + a_{m,3}j_3 + \ldots + a_{m,n}j_n = b_m$$

While in strict formulation equalities are necessary, constraints can be recognized as inequalities, by establishing certain artificial variables and following standard algorithmic procedures. Further details of linear programming are available in the literature.

Resources can be related to the resource constraints, j_n, and actions to the consumption equations, $a_{m,n}j_n = b_m$. For each receptor, terms can be generated in the objective function relating value flows to that receptor. In so doing, the three-component chain can be assessed by a new quantitative technique.

Graphical Analysis

A review of the characteristics of linear programming would indicate that there is one more less-involved form of analysis applicable. This approach, graphical solution, is often overlooked in engineering today, but is often valuable as a time-saving and appropriate analytical method.

Linear programming is essentially the solution of simultaneous linear equations. If the number of equations is kept sufficiently small, or if the effects of several equations can be summed to minimize the number of functions plotted, the solution can be presented as a visual analysis to determine a cost-minimum or profit-maximum point on a set of plots. The economic analysis of supply and demand is usually presented in a graphic form as the solution of two simultaneous equations. Therefore, if the

problem is small enough, graphical solution to the cost optimum point may be appropriate.

A Specific Formulation of the Problem

A specific formulation of the mine-environmental planning problem consists of the following elements:

(1) Definition of all resources in the mining system, and the maximum, and when indicated minimum, quantity of each available for consumption.

(2) Definition of all actions in the mining system, and an estimate of how each action affects, by consumption or alteration, each resource.

(3) Definition of all receptors in the mining system, and an estimate of how each action-resource pair is received by each receptor.

(4) Consideration, for each three-component combination, of the values of flow created, specifically:

(a) Is the flow of value real, subjective, or both?

(b) To whom does the flow of value accrue?

(c) For each real or subjective value flow, how do the units of value flow relate to either units of action taken or units of resource consumed?

Defining Resources

Certain quantities and qualities of basic resources are present in

the mine environment. Mining engineering practice recognizes such constraints of a resource nature as quantity and quality of ore present, physical and chemical nature of rock, limits to capital or expense money available in the company, and limits to the availability of other resources as defined by law. An inclusive, but neither exhaustive nor complete, consideration would include the following items, which are summarized in Table X.

Tonnage and purity of ore are fixed and not specifically known until the deposit is mined out. The engineer infers, at any specific time, that some total tonnage and grade is present as the resource limit. At the same time, economic value is dependent on mining costs, which are dependent on economies of scale, so a minimum quantity and quality must be mined to achieve a minimum profit.

Surface area can be recognized as a limited attribute. Alternative mining methods, production rates, and scales of operation require certain commitments of surface area. However, surface area is not necessarily removed from the environment, but is merely involved. It can usually be returned after mining through activities of restoration.

Integrity of surface, integrity of subsurface and capability for reuse are less-measurable quality items. They do represent scarce resources consumed or involved by mining. They may be partially restored by post-mining efforts, and influence the desirability and possibility of concurrent and alternative future land use.

Other mineral values may be present either as sub-ore, material not economically recoverable, or as by-product mineralization. Their presence should be considered with regard to the possibility of their future

TABLE X: A LISTING OF RESOURCES

TYPE OF RESOURCE	RESOURCE	SUBDIVISIONS POSSIBLE
ABIOTIC	TONNAGE OF ORE	PROVEN, PROBABLE, POSSIBLE
	PURITY OF ORE	PROVEN, PROBABLE, POSSIBLE
	SURFACE AREA	
	INTEGRITY OF SURFACE	
	INTEGRITY OF SUBSURFACE	
	REUSE CAPABILITIES	ALTERNATIVE USES
	OTHER MINERAL VALUES	PROVEN, PROBABLE, POSSIBLE
	WATER QUANTITY	(SURFACE AND SUBSURFACE) (SPECIFIC MEASURES)
	WATER QUALITY	
	AIR QUALITY	SPECIFIC MEASURES
BIOTIC	FLORA, FAUNA } AIR, WATER, LAND	SPECIES DIVERSITY, CATEGORIES
SOCIO-HUMANISTIC	HISTORICAL FEATURES	
	COMMUNITY STRUCTURE	
	SOCIAL HIERARCHY	
	GOOD WILL	
	AESTHETIC VALUE	
	HEALTH AND SAFETY	
LEGAL	FEDERAL, STATE, AND LOCAL LAWS AND REGULATIONS	AIR, WATER, LAND USE, SOLID WASTE, MINING, AND OTHER
ECONOMIC	CAPITAL AVAILABLE	
	EXPENSE AVAILABLE	

extraction and in an effort to improve economics. Their extraction at even marginal rate of return is attractive from the standpoint of total resource conservation.

Water may be divided between surface occurrence and subsurface, and further subdivided into quantity and quality aspects. Quantity of water present may be expressed as absolute volume or as flow rate capabilities. Quality has been related to many parameters (Table III). The resource being consumed could be thought of as the ability of the water to assimilate, or accept, additional units of such parameters as turbidity, solids, ions, and acidity as are produced by mining.

Living characteristics include plants or flora and animals or fauna. These may be further classified by habitat: air, water, or land. A specific and quantitative measure of living resources in total is provided by measurement of species diversity, such as through the sequential comparison index, SCI,(Cairns and Dickson, 1971). Further measures can be developed to relate the quality of rare and endangered, unique, predominant, fragile and economic species.

Socio-humanistic factors are difficult to quantify. Measures of quality could be derived for various features and attitudes: historical features, social hierarchy, community services, good will, aesthetic values, health and safety.

Legal constraints are important to resource definition. They may determine the use of resources, may limit quantities of certain scarce resources, or could be thought of as establishing "pollution rights" available for purchase, and their cost, through the permitting and licensing procedures.

Two final constraining areas are left -- capital and expense. The corporate structure determines the amount of these economic resources as are desirable or available, both as a minimum and as a maximum.

Defining Actions

A list of actions in mining is presented in Table XI. Certainly, these actions may be interrelated, and have been previously identified. Further discussion will relate to their use of resources and areas of impact, after receptors and value flows have been discussed.

Defining Receptors

Although receptors of impact could be listed for a sophisticated and computerized approach, such detail might muddle manual assessment. The elements of resources and actions previously identified represent a total of 1100 pairs. Of these, perhaps 50 percent are definitely involved, i.e., represent actions which consume resources with which they are paired. If only 4 classes of receptors are identified, rather than a specific listing, there are 2200 relationships to be investigated: a formidable, yet not impossible manual task. Considering a more representative number, say 40 receptors, would create 22,000 relationships. The ultimate goal, then, must yield to that practical goal which an engineer can reasonably expect to accomplish. Additionally, such interrelationships as do exist are poorly understood. Such explicit detail is not warranted. For now, then, only receptor areas, abiotic, biotic, socio-humanistic and legal, will be defined.

TABLE XI: A LISTING OF ACTIONS

TIME OF OCCURRENCE	ACTION
PRE-MINING	SECURING RIGHTS IN PROPERTY SECURING RIGHTS IN POLLUTION SITING OF PLANT AND FACILITIES SURVEYING EXPLORATION CLEARING AND GRADING PLANT CONSTRUCTION
DURING MINING	EXCAVATION MATERIALS HANDLING GROUND CONTROL WASTE DISPOSAL AUXILIARY FUNCTIONS MARKETING
CONCURRENT AND POST-MINING	STRIPPING EQUIPMENT AND RESALE DEMOLITION OR RECOMMISSIONING OF PLANT FACILITIES RESTORATION OF SURFACE REHABILITATION OF SURFACE
POST-MINING	LONG-TERM MAINTENANCE MINE SEALING FENCING AND POSTING
ALL-INCLUSIVE	PROTECTION OF RESOURCES (ABATEMENT) AVOIDANCE OF IMPACT (TREATMENT)

Determining Value Flows

Each three-component, resource-action-receptor chain must be analyzed to determine not only its relation to resource consumption but also its associated value flows. Recall that Figure 25 presented a three-sided matrix which could be used to display these relations. The process is not simple, however, as value flows may be real, subjective, or both. The quantity available for real flow is limited. No more dollars can enter the system than are produced through the extraction of resources. Since only one mining operation is explicitly considered, real dollars are viewed as occurring only through the actions of that operation. The quantity of subjective flow is probably finite, yet no practical limit can be assigned: what are the limits to abstract values such as good will? Since subjective value is a product of the human mind, it is only the public that can realize subjective value. The government and the company can neither feel nor use subjective value by themselves.

Subjective flow may be associated with actions between (1) government and resources and (2) government and people. The government has a role as mediator in the flow of subjective value. In it, the value flows of a resource-public nature accrue directly due to government actions.

Subjective value flow to the public may be brought about in several ways which correspond to certain actions with which other, real value flows are associated, namely:

(1) Restoration of resources by the company (reclamation)

(2) Payment to public by the company (wages)

(3) Payment to the company by the public (sales)

(4) Restoration of resources by the government (parks)

(5) Payment to public by the government (welfare)

(6) Payment to the government by the public (taxes)

(7) Restoration of resources by the public (by citizens' groups, such as Sierra Club, Izaak Walton League, or National Wildlife Federation)

Since the government and public do not extract real value from resources, they must, prior to paying each other, receive real value from the company's actions. The government and public must determine the disposal of the real value they receive.

Synthesizing the Formulation

There must and does exist a set of equilibrium states, presumptively infinite in number, for which all flows balance. That is, since the system being analyzed is closed, there are one or more economically balanced and optimal states, depending on the definition of "economic optimum." In further analysis, the conditions for an optimum are related to two sets of resources, (1) total subjective value retained by the public, the savings of well-being, and (2) capital accumulated by the company, or wealth. Simply stated,

(1) Subjective value flow in to the public should exceed outflow, resulting in a gain in welfare rather than a loss.

To balance flow within the system, there must be a reservoir of good feelings, the savings of well-being.

(2) The real-value, cash flow accumulated by the company, or wealth, should be maximized.

While in the ultimate solution the resolution is complex, two simple techniques are proposed, depending on the scale of the problem. These rely on certain further steps which can be taken to synthesize the components of the formulation into an integrated problem.

General Aspects of the Formulation

Income and costs of a mine balance sheet, such as gross income, expenses, capitalization, depreciation, and annual investment, are related to seven parameters. Specifically, operating expenses are a linear function of seven areas of actions, as:

Let OE = Operating expenses

GC = Ground control actions

EX = Excavation actions

MH = Materials handling actions

AX = Auxiliary function actions

PT = Public trust actions

MK = Marketing actions

GF = Ground failure and land disturbance actions

Then

$$OE = f(GC, EX, MH, AX, PT, MK, GF)$$

This function is piecewise linear, so

$$f(GC, EX, MH, AX, PT, MK, GF) = f_1\ (GC) + f_2\ (EX) + \ldots + f_7\ (GF)$$

In the problem of 22 actions, as Table XI, of mining, the equation is of the form

$$OE = f\ (a_1, a_2, a_3, \ldots, a_{22})$$
$$+ f_1(a_1) + f_2(a_2) + \ldots + f_{22}(a_{22})$$

in which each function, f_n, may be recognized as composed of several terms. The actual cost, for example, incurred in excavation is composed of (1) material costs, (2) equipment costs, (3) labor costs, (4) real payments made to public and government to ameliorate negative, real or subjective, value flows created, and (5) real payments made in reclamation or restoration of resources to compensate for the same conflicts which create the value flows in (4). The excavation cost may be reduced by public or government payments to the company if positive subjective value flows occur.

For a general case of I scarce resources, J subjective resources, K activities and L receptors, the steps of a formulation of these functions, which the analyst would follow, are given in the flow chart of Figure 26.

Specific Aspects of the Formulation

Certain more specific relationships of resource consumption and value flow can be outlined. Each action, the resources which it uses, receptors involved, and types of flows which may be created can be discussed.

Securing rights in property actually determines (1) the tonnage and purity of ore and (2) the surface area available. However, in this

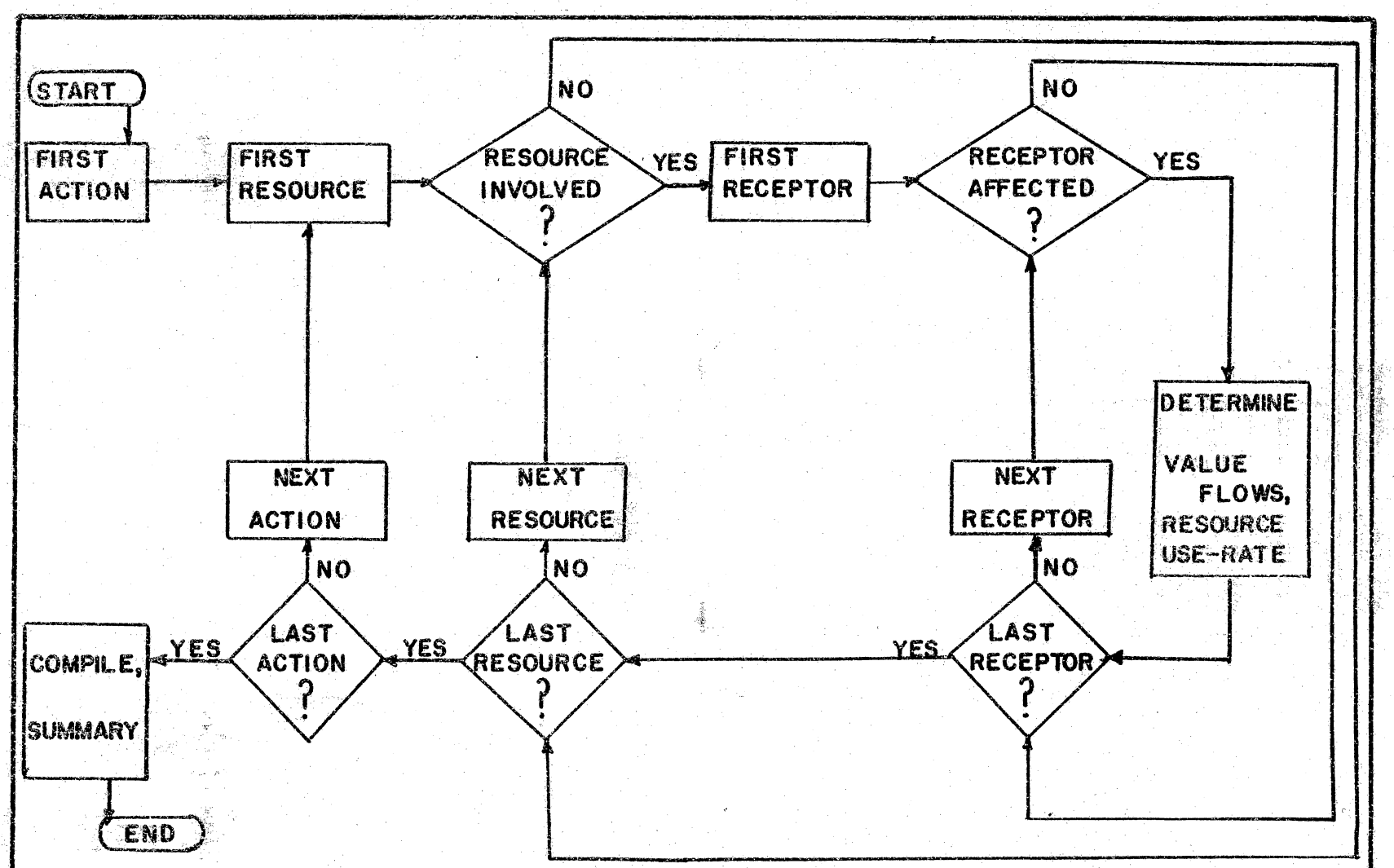


FIGURE 26. A FLOWCHART OF THE FORMULATION PROCESS

analysis it is assumed that a given area has been previously determined and that all rights are to be secured, rather than considering the probability of securing a specific right and the subsequent probability of having given levels of mineral resources present. This activity may create real flow and subjective flow from the company and to the public or government. Negotiation for rights may increase or decrease subjective feelings, and, hence, the actual purchase price. The company incurs costs, or losses of real value, through labor associated with this action.

Securing rights in pollution results in flows of real value from the company in the form of wages, as well as fees to the government. Flow to the government is then assumed to be directed either to the public or to restoration of resources. Generally, the subjective flows to the public are positive. In contrast, the exercise of these rights or pollution causes subjective loss.

Siting of plant and facilities is limited by the total area available. The action consumes no scarce resources other than expense, but may be influenced by or in turn influence subjective resources and receptors.

Surveying, exploration, clearing and grading, and plant construction are the first pre-mining actions in which scarce environmental resources are consumed, resulting in subjective and real value flows. Real flows are (1) cost of labor and supplies and (2) real value achieved by the company through development of the resource. The many associated subjective flows which can be associated with these actions depend on the quantity and type of resources consumed. Actual mining, excavation,

materials handling, ground control, waste disposal, and auxiliary functions, is an array of actions with resource consumptions and value flows similar to those of pre-mining actions.

Concurrent and post-mining actions, stripping, demolition, restoration, etc., are the first which result in a real flow of value from the company to the environment. While such activities restore certain resources, they may also consume others. Real value flow may be routed from the government or public in response to actions which restore or upgrade certain resources, through such actions as the return of performance bonds. A range of subjective value flows is likely. Two final activities are almost an afterthought. They do not relate specifically to a given phase of mining, but are abating or treating pollution which occurs as a result of any other action. These are thought of as actions to conserve scarce resources. For these actions, many types of real or subjective flows of value are possible.

Approaches to Problem Solution

Two approaches can be taken to solve the problem as it has been formulated and synthesized. For limited, small-scale problems, or for those in which the effects of many actions can be summed, a graphical solution may be appropriate. For the more complex problem, solution by linear programming is indicated.

Graphical Solution

The explanation of a simple, profit-maximizing graphical solution

shall consider several successively more complex cases. The first to be considered is presented as follows:

(1) Assume that there is only one resource involved, which may be regarded as an aggregate of resources.

(2) Assume that there are only two actions involved, mining and reclamation.

(3) Assume that the only receptors involved are the public and the company.

(4) Assume that (a) there is only one level of mine development possible, so that income to the company, excluding reclamation, is constant, and (b) the cost of reclamation is non-linear, increasing with percent restoration, due to diminishing marginal productivity of inputs.

(5) Assume a non-linear variation in subjective value for the public due to reclamation efforts, so that the value of small levels of reclamation is great but the marginal value decreases as percent reclamation increases, due to diminishing marginal utility of reclamation.

(6) Assume that subjective values can be expressed as real dollars and, therefore, plotted against the same axis as company values.

(7) Define a minimum subjective value flow for the public.

The solution is achieved by plotting the various value relationships on axes of percent reclamation and value and selecting the point at which:

(1) At least the minimum subjective value flow is realized

(2) Returns to the company are maximized.

Such a plot is shown in Figure 27.

The total net is plotted as (net receipts excluding reclamation - reclamation cost). The solution is taken from point S, which is the maximum total net in the region where subjective value is greater than or equal to the minimum level.

In one step closer to reality, the second consideration is of the case where items (1), (2), (3), (7), and (8) hold, but assumptions (4), (5), and (6) are altered as

(4) Assume that various levels of mine development are possible, and that the return to the company, exclusive of reclamation, is a linear function of the percent development.

(5) Assume that for any specific percent development, a specific, non-linear reclamation cost function can be developed.

(6) Assume that subjective value realized by the public is a function of both percent development and percent reclamation. Moreover,

(a) Losses in subjective value occur when the resource is not developed, since some level of development is necessary to provide minimum welfare (to prevent shivering in the dark)

(b) At no reclamation, the value will increase as percent development increases until the minimum level of development, as in (a), is reached.

(c) After reaching the minimum level, as percent development

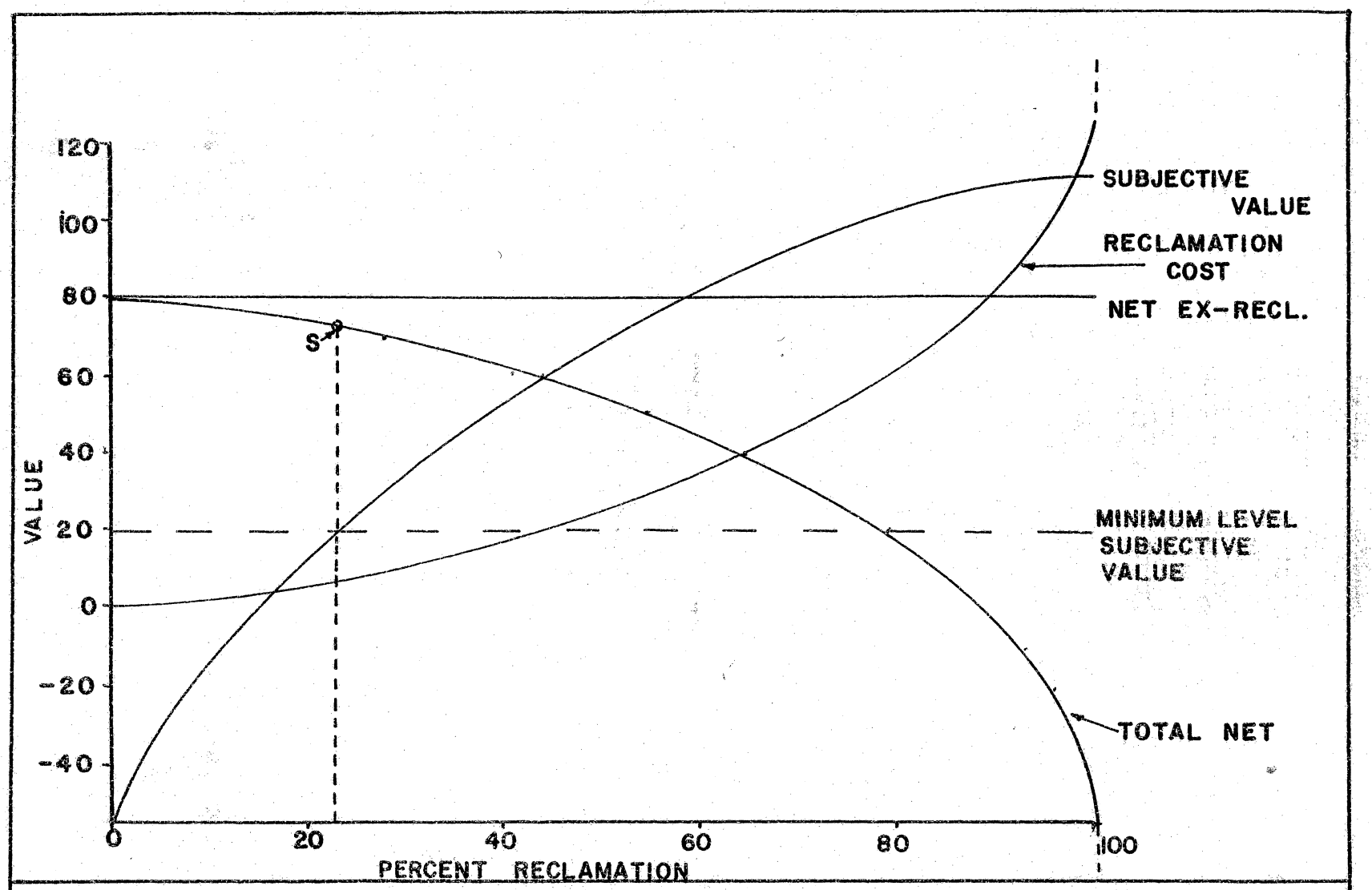


FIGURE 27: A SIMPLE GRAPHICAL SOLUTION

increases, the subjective value, at no reclamation, decreases due to the excess environmental damage occurring.

(d) The same minimum development-level relations hold true at full reclamation, although as development increases, the value continues to increase.

Plotting this situation requires three axes: (1) value, (2) percent reclamation and (3) percent development. The resulting plots, which are surfaces rather than curves, for the company real flows and the public subjective flows are given as Figures 28 and 29, respectively. Figure 30 presents a composite of these surfaces, with the optimum point S again identified. In this plot, only the acceptable subjective and real regions are shown for clarity.

As a final extension, consider that real mining and reclamation costs relate to economies of scale. Figure 31 presents how the net receipts, exclusive of reclamation, might actually be plotted if five alternative mining methods were applicable depending on scale of the operation. In addition, for each level of development, each point on the plot of Figure 31, a similar type of graph could be developed for reclamation costs and their economies of scale. In other than limited cases, then, the large number of functional relationships involved defies explicit graphical analysis.

One concluding note is that such graphical analysis is dependent on the ability to plot subjective values and real values on the same axis. In a real-world situation, this would be difficult. Therefore, a more explicit solution, in which the two types of value can be separated and myriad functional relationships can be considered, is required.

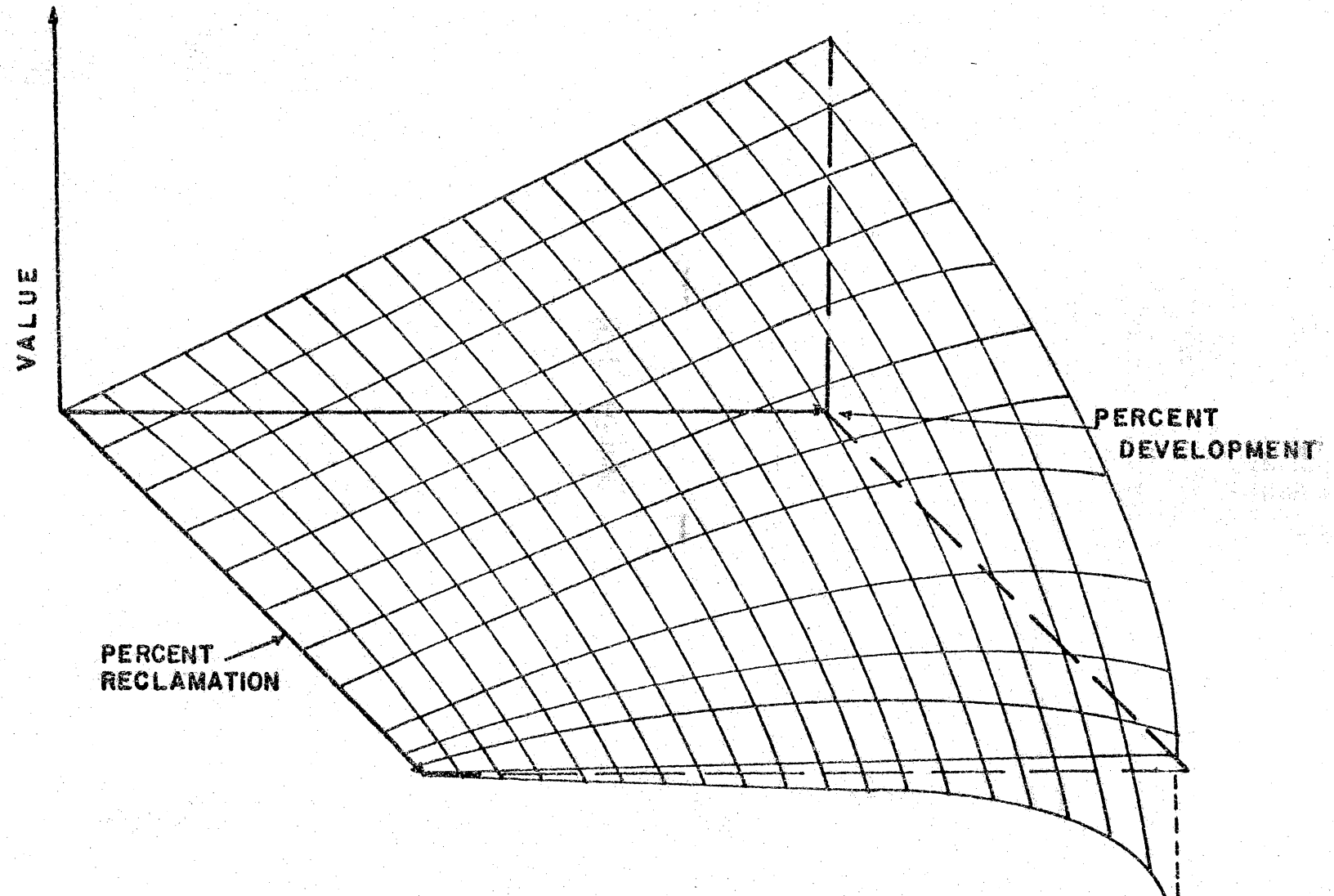


FIGURE 28: A MORE COMPLEX PROBLEM— FLOWS TO THE COMPANY

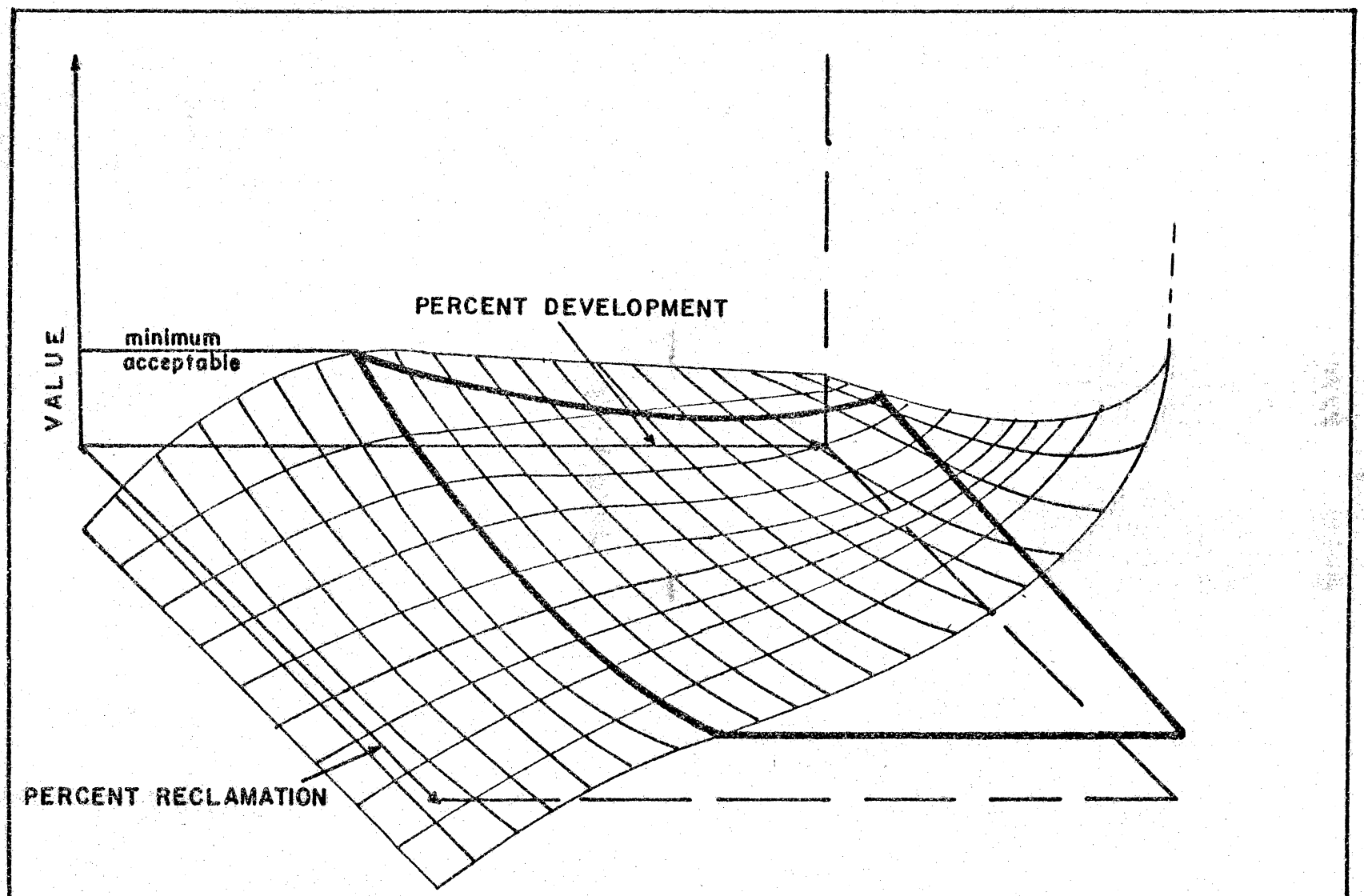


FIGURE 29: A MORE COMPLEX PROBLEM — FLOWS TO THE PUBLIC

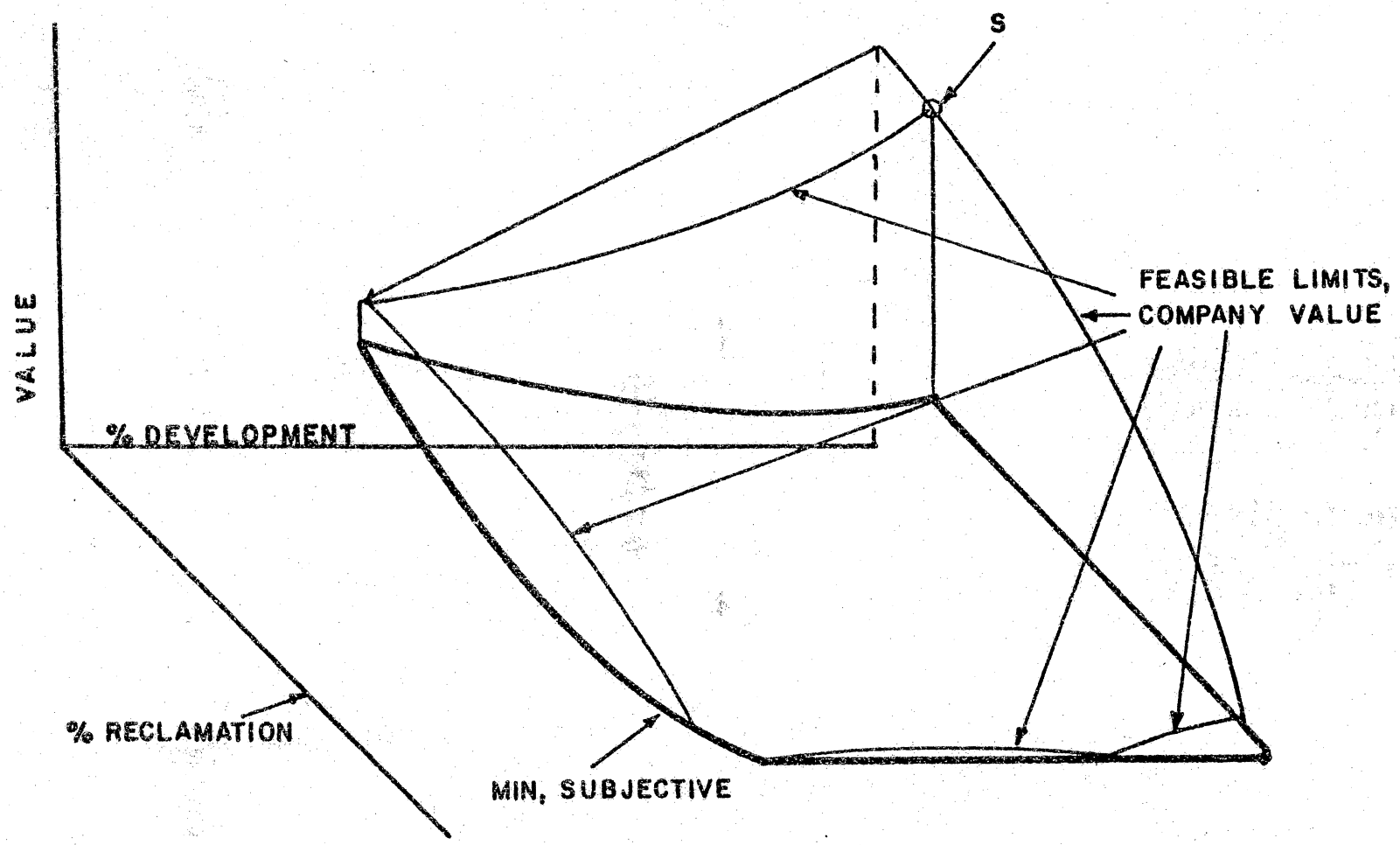


FIGURE 30: A COMPOSITE GRAPHICAL SOLUTION TO THE MORE COMPLEX PROBLEM

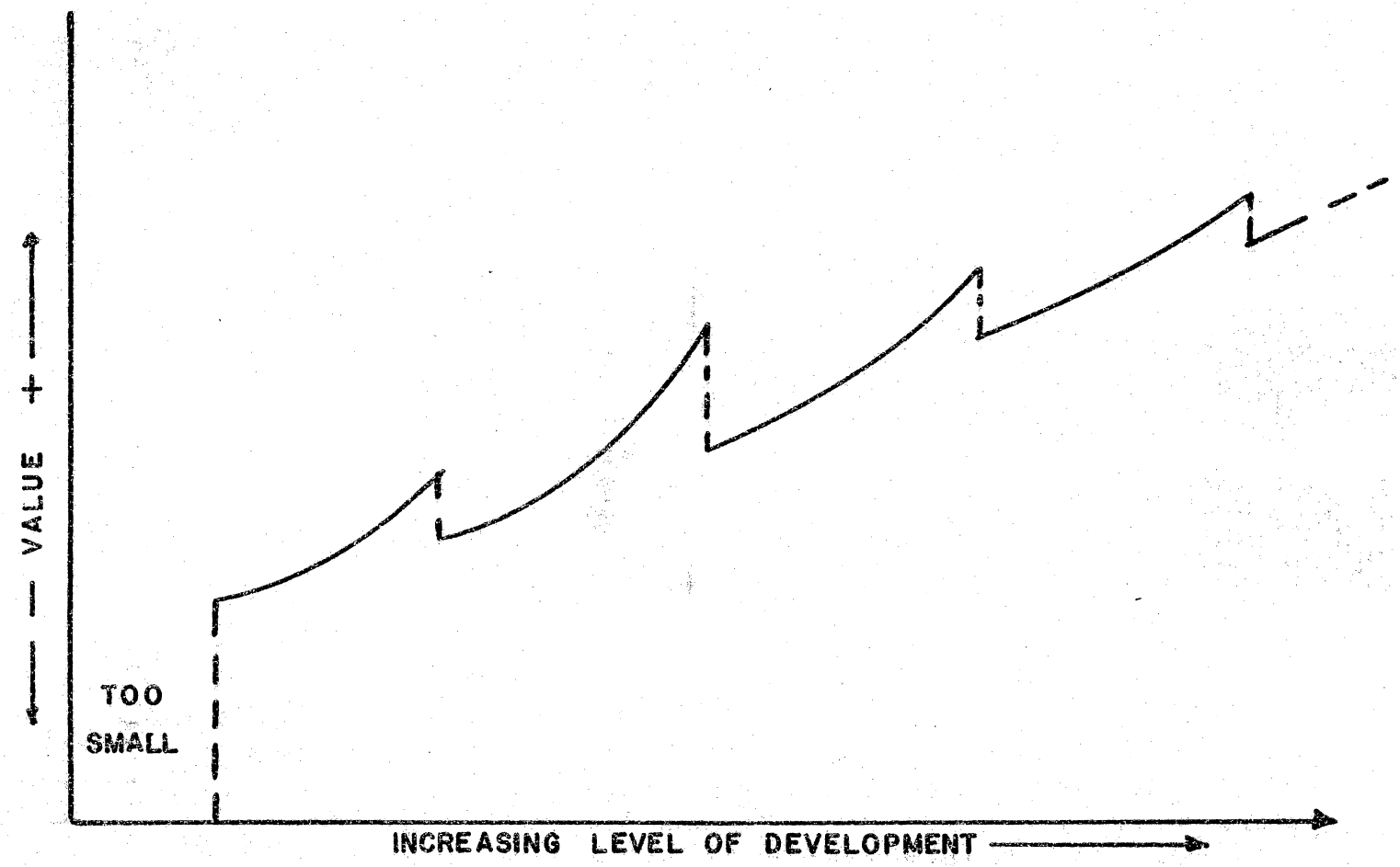


FIGURE 3b MINING VALUE CONSIDERING ECONOMIES OF SCALE

Tax and Subsidy Relationships

An observation is possible at this point regarding the appropriateness of this analytical format to the establishment of taxes and subsidies. If socio-humanistic aspects can be expressed as real dollars and plotted on the same axis as other real value flows, a technique is available to establish the tax and subsidy amounts by simple inspection. Figure 32 is essentially the simple graphical analysis of Figure 27, but company receipts are assumed to have been adjusted to allow a minimum profit as an operating cost. Given that the subjective value has been legitimately expressed in real dollar terms, then region 1 is that in which the company should be taxed (subjective value is less than the required minimum), point A is that at which no tax or subsidy is established, and region 2 is that in which the company should be subsidized (subjective value is greater than the required minimum). For these cases, it might be arbitrarily suggested that

Region 1 — Amount of tax = Minimum subjective value desired- Actual subjective value realized (but not to exceed 50% of the total net)

Region 2 — Amount of subsidy = Reclamation cost (but not to exceed one half the excess in subjective value realized)

Of course, the actual split of taxes or subsidies would be determined through some replicable and non-arbitrary decision process. In these situations, either the company shares up to half of its "excess

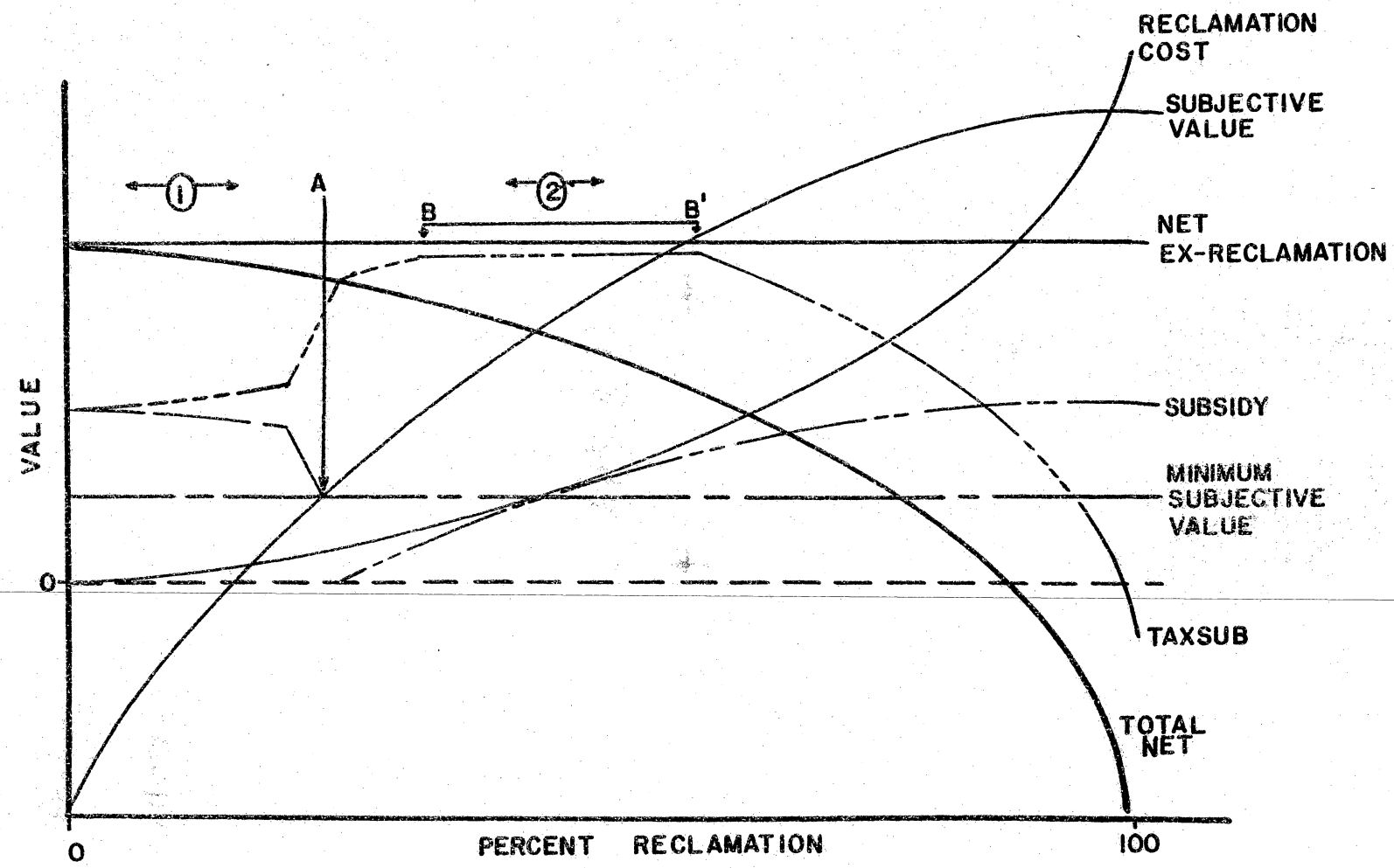


FIGURE 32: TAXES AND SUBSIDIES IN THE SIMPLE SOLUTION

earnings" due to pollution, or the public shares up to half its "excess earnings" due to the company's production of environmental quality. The resulting line, of net realized by the company under such a program, is shown as "TAXSUB" on the graph. The profit optimization point is realized by inspection as B in this case. Of course, through collective bargaining, marketing and government mediation, the 50-50 share could be altered as agreed upon by public and company.

Linear Programming Solution

Once the problem has been formulated and synthesized, the objective function in mine planning is expressed as the maximization of the company's wealth, or

Objective: Maximize Z, where

$$Z = \Sigma \text{ real flow to company} - \Sigma \text{ real flow from company}$$

Constraints related to value flow are necessary if the goal includes Pareto-optimal maximization of social welfare, as

(1) Σ real flow to public - Σ real flow from public $\geq$ minimum

(2) Σ subjective flow to public - Σ subjective flow from public $\geq$ minimum

Additional constraints are those of resources, which are:

Given: m resources and n actions

There are coefficients $a_{i,j}$ and resource limits b_m, such that for given levels, x_j, of each action:

$$\sum_{j=1}^{n} a_{i,j}x_j \geq b_i \text{ ; for } i = 1,2,3,\ldots m$$

The specific linear program for a mine-environmental planning problem has, then: (1) constraints consisting of quantities b_j of the m resources present, (2) n actions, performed at levels x_j and related to each resource m by the coefficient $a_{m,j}$, and (3) value-flow relationships for each of l receptors which are terms in the objective function or value-flow related constraint functions. This problem may be formally presented as:

Let n = number of actions present

m = number of resources present

l = number of receptors present

x_j = units of an action j to be done, $j = 1, 2, 3, \ldots n$

$a_{i,j}$ = units of resource i consumed for each unit of action j performed, $i = 1, 2, 3, \ldots m$:

$j = 1, 2, 3, \ldots n$

$FABC_{j,l}$ = flow of value, where

A = R for real flow

S for subjective flow

B = area in which receptor resides, as

R for resources

C for company

G for government

P for public

C = area in which action occurs, as R, C, G, or P above

j = action with which flow is associated

l = receptor with which flow is associated

Then,

Objective: Max Z

$$Z = \sum_{j=1}^{n} \sum_{k=1}^{n} \{x_j (FRCG_{j,k} + FRCP_{j,k} + FRCR_{j,k} - FRGC_{j,k} - FRPC_{j,k} - FRRC_{j,k})\}$$

Subject to:

$$\sum_{j=1}^{n} a_{i,j} x_j \leq b_i \ , \ i = 1, 2, 3, \ldots m$$

$$x_j \geq 0 \ , \ j = 1, 2, 3, \ldots n$$

Additional value flow related constraints (definition will vary)

The drawback to the linear programming approach is the lack of understanding of subjective and real flows related to consumption of scarce resources. Given an appropriate formulation and correct relationships, linear programming will determine an optimum solution. This approach will, however, require significant research in the future in the area of quantifying the socio-humanistic relationships. There are advantages to preparing a linear programming formulation in that it may be the basis for other techniques of operations research, including linear graph analysis, goal programming, parametric programming, mixed-integer programming and dynamic programming.

Summary

A new plan of mine-environmental assessment incorporating a three-component chain of resources, actions and receptors has been presented. Flows of value, real and subjective, have been related to these chains. Available environmental analysis techniques were reviewed, and none of

these was found to be a satisfactory approach to this new problem. However, the functional relationships involved can be analyzed by one of two techniques: graphical analysis of small problems or linear programming optimization of larger ones.

The mine-environmental planning problem was, then, specifically reviewed and formulated for the application of these approaches. The applications and some limitations for both graphical and linear programming solutions were discussed for this specific case. The common limitations concern (1) the number of functional relationships involved and (2) the quantification of subjective value flows.

The analysis to this point has been of assumed problems. In the next chapter, a simple case study will be solved by a graphical technique and by linear programming. Discussion of the inclusion of a tax and subsidy program will be included.

A CASE STUDY

In illustration of the traditional approach to mine planning and the value of the new approach to mine-environmental planning, a study is presented of an actual mining case. The data were provided by an actual mining company which choses to remain anonymous. The names are fictitious but descriptions of location and other general characteristics are as close to fact as possible without revealing proprietary information.

General Aspects

Though the data are actual, certain assumptions have been made which have little effect on the traditional analysis but are important to the combined mine-environmental analysis. These are

(1) There is only one company producing coal in the political region being studied.

(2) There is only one public involved.

(3) There is only one government structure involved.

Traditional Analysis

The traditional analysis follows the normal engineering approach. The steps followed include the description of the proposal, mining plan alternatives, capital requirements, expense requirements, market returns, estimate of worth of the project and summary.

Introduction

The proposal being considered is the re-opening of a mine. The Lion Lick No. 33 Mine of Riddle Coal Company is an underground mine located in Indiana County, Pennsylvania, southwest of Clearfield, on an unnamed tributary of Lion Lick, which flows directly into the Susquehannah River. An adjacent mine, Lion Lick No. 32, was run by Riddle until mined-out in 1972. No. 33 was to replace it, but development was canceled due to market conditions after 1500 ft of main entires and one panel-stub had been driven. Since 1972, the company has operated a custom coal-preparation plant. The question is that of increasing and rebuilding the plant to meet the increased demand for coal. The plant is capable of producing coal at the following specifications:

Moisture (surface)	4.5%
Ash	11.0%
Sulfur	1.0 - 1.2%
Heat content	13,000 Btu per lb

The parameters of plant-expansion design call for producing 500,000 tons of clean coal per year at these specifications. Historically, reject of run-of-mine coal will average 20%. Mine production must be 625,000 tons per year to supply the plant. Based on the usual five-day work week, three production shifts per day, and 250 production days per year, the production must average 2500 tons per day.

Reserves of the mine have been inferred from previous exploration work to be as follows:

	Proven Reserves		Probable Reserves		Total Reserves	
		Tons		Tons		Tons
	Acres	(000)	Acres	(000)	Acres	(000)
Under lease	313	1200	423	1625	736	2825
Under option	458	1675	761	3000	1219	4675
TOTAL	771	2875	1184	4625	1955	7500

The land option can be exercised for $1000 per acre. It is estimated that the probable reserves can be proven by a drilling program of 12 holes at an average depth of 220 ft. The thickness of the seam is 40 to 44 in.

Mining Plan Alternatives

Lion Lick No. 32 was operated on three sections: two with Wilcox Mark 20 continuous miners utilizing Lo-Low bridge conveyors, and one with a Lee-Norse CM-28 utilizing two Joy 6SC shuttle cars. Main haulage was by 30-in conveyor belt. To this equipment, Riddle can add two more Wilcox units including bridge conveyors, which he ordered in anticipation of reopening. The current lack of mining equipment restricts the plan to one incorporating this equipment which is on hand.

Practice consistent with other mines and the particular equipment would indicate the following plan:

Main entries: Five, 18- to 20-ft wide, on 60-ft centers with crosscuts on 75-ft centers

Panel entries: Three, 20-ft wide, on 50-ft centers with crosscuts on 75-ft centers

Rooms: 20 ft wide on 50-ft centers, 300 ft deep. Pillars

to be extracted as completely as possible.

At a productivity of 300 tons per shift for a Lee-Norse unit and 200 for a Wilcox, the 625,000 ton-per-year or 2500 ton-per-day target will require 3 Wilcox units on day and afternoon shifts and 2 on midnight shift, with the Lee-Norse unit operating all 3 shifts. The unused Wilcox units provide for maintenance as well as a backup capacity of 800 tons per day.

Capital Requirements

The book value of present equipment, to be considered as a capital expense, is $ 500,000. Additional capital expenses will be incurred as follows:

Mine site, dry and office — year 1, $ 75,000
years 4 and 8, $ 30,000

Main conveyor — year 1, $ 300,000
year 7, $ 60,000

Preparation plant — year 1, $ 700,000
year 6, $ 70,000

Surface substation — year 1, $ 30,000
year 3, $ 30,000

Fan station — year 1, $ 30,000
year 3, $ 30,000

Underground substations — year 1, $ 175,000
years 2-5, 7-9, $ 15,000
year 6, $ 35,000

Haulage equipment — year 1, $ 400,000

years 3, 5, 6, 8, $ 100,000

years 4, 7, $ 40,000

Mining equipment — years 2, 3, $ 250,000

Miscellaneous — year 1, $ 50,000

years 2-11, $ 7,500

The totals are:

Year 1 —	$ 1,805,000
Year 2 —	$ 272,500
Year 3 —	$ 402,500
Year 4 —	$ 82,500
Year 5 —	$ 122,500
Year 6 —	$ 212,500
Year 7 —	$ 112,500
Year 8 —	$ 152,500
Year 9 —	$ 22,500
Years 10, 11 —	$ 7,500
Total =	$ 3,200,000

Expense Requirements

Total labor requirement will be 17 salaried and 115 wage employees on an annual basis. Total payroll is $ 1,735,000, or after payroll clearing factors (wage taxes, insurance, etc.) $ 2,313,750 per year.

Production supply costs are estimated at $1.26 per ton of coal mined. Maintenance costs for the Lee-Norse unit of $1.17 per ton and

for the Wilcox of $ 0.81 per ton are prorated to an average of $ 0.94 per ton. Total production costs, including labor then, are

$$\frac{\$\ 2{,}313{,}750}{625{,}000} + \$\ 0.81 + \$\ 0.94 = \$\ 6.452$$

Other costs are itemized as:

Miner's welfare	$ 1.50 per ton
Mine power	.510
Non-payroll wage taxes	.230
Insurance	.300
Equipment Rental	.380
Royalties	.900

The grand total expenses per ton, including the labor and supply costs, is $ 9.722.

Market Returns

One customer has specified a contract would be accepted for 500 thousand tons per year over the 12-yr life of the mine. The price guaranteed is $ 16.50 per ton of clean coal, f. o. b. mine, in half-unit trains. If the contract is accepted, gross receipts will be $8,250,000 per year or $ 99,000,000 over the life of the mine.

Worth of the Project

The worth of the proposed project was analyzed by two techniques: rate of return and net discounted present value. The overall project shows a rate of return of 70.9%. The net discounted present value at

a 25% discount rate, a common rate in coal mining analysis, is $ 2,689,729.

Selection of Alternative and Summary

Clearly, the proposed project is of sufficient worth to justify selecting the alternative to mine as compared to one of no mining. In this analysis, though, no attention has been directed to reclamation or to the feelings of the public with regard to mining. It is then advisable to consider such relations in an environment-integral analysis.

Environment-integral Analysis

The operating details and obvious costs of the Lion Lick No. 33 Mine will be the same in either analysis. What differs is the method of identifying and assessing these and additional, new types of value flows. In this limited case study, certain particular categories of resources, actions and receptors are less significant than in a full application. However, the study has been particularly selected to high-light the position and value of reclamation in the new method of analysis.

Resources

Since the case study is limited, tonnage and purity of mineral are fixed in supply and consumption, other mineral values are assumed to be

absent, and legal constraints and incentives are assumed negligible. Capital and expense are assumed not to be limiting factors. All of the other resources, as listed in Table X, are assumed to be fixed in quantity, and capable of being consumed or altered by mining.

Actions

Of those actions listed in Table XI, "securing rights in pollution" is not to be considered, since (1) legal constraints and incentives are assumed absent and (2) no other bargaining structure for these rights has been established.

Analysis of the proposed project without reclamation would include all actions on the list through "demolition or recomissioning of plant and facilities," as well as "sealing" and "fencing and posting." Considering reclamation adds the remaining action to the list.

Receptors

Receptors identified in the case study are limited to (1) the public, (2) the company, and (3) the environment.

Alternative Approaches

Approaches to the problem will include:

(1) The traditional situation, as previously discussed.

(2) The traditional situation with varying degrees of reclamation and restoration, up to an hypothetical, "complete" reclamation process.

Value Flows

Securing rights in property consumes only capital and expense, but establishes the quantity of the several resources at hand. Exercising the options on the additional 1271 acres will, therefore, result in a flow of $ 1,271,000 from company to public. Subjective value will also flow to the public in the form of good will or well-being.

Exploration activities, aimed at increasing and/or defining tonnage and purity of minerals known to be present, would generally affect the limits of these constraints. Real payment is made directly, in the form of wages, to the public. Subjective flow may occur due to (1) the influence of the exploration activities on good will, aesthetic value and health and safety and (2) through the consumption of certain scarce environmental resources by the exploration activity. At the rate of $2500 per hole (total $30,000 for 12 holes) the degree of impact mitigation (i.e., reclamation of access, cleanup of drill site) will be nominal. It is suggested that the expense of $2000 additional per hole would hypothetically cancel these losses, real and subjective, through "complete reclamation." (While such cost rightfully falls in the categories of restoration, rehabilitation, avoidance and/or protection, it is convenient to itemize it here as an exploration cost.) It is further assumed that (1) the variation in this real cost is linear with respect to percent reclamation and (2) the level of subjective value felt by the public would range from a minimum to a maximum linearly with respect to percent reclamation achieved.

Excavation and materials handling consume tonnage and purity of ore,

capital and expense as real costs as well as a variety of scarce environmental and subjective resources. The activity, the way mining is carried out and paid for, will affect, as well as consume, good will, aesthetics and health and safety. Ground control, the third facet of the mining method, affects many characteristics consumed by these. The degree of ground control might affect the tonnage and purity of ore extracted. The careful practice of a mining method may, therefore, achieve a balance between recovery percentage and adverse effects (surface and subsurface). In the case of a 44-in coal seam at a depth of 240 ft, the surface subsidence should be minimal or non-existent (even at pillar extraction to complete failure). The variety of environmental quantities and qualities present will only be directly affected at the interface, that is, on the haulageway, between mine and surface plant. An extra expense of $10,000 in design, and likely no increase in construction cost, would generally have remarkable results in the aesthetic value of such a mine installation and mitigate other impacts. Assume again that such a measure would be linearly related, as that discussed above under exploration.

Waste disposal has, unfortunately, an extremely adverse effect. Most of the practicable technology today is included in waste disposal. However, technology is yet to be developed and applied to restoration and rehabilitation of waste areas, as is discussed below. The costs allowed in the traditional analysis will be taken, then, to include waste disposal. An array of effects, primarily adverse, occur to the environment as a receptor. In response to such subjectively valued losses, the public response is generally to limit their demand curve for

coal. Current practicable technology will not, in this case, allow "full reclamation."

Auxiliary functions are nominal and standard in approach, so much so that their evaluation, in such a general analysis as this, is immaterial.

Marketing is directly in proportion to tonnage and grade of ore and other mineral values, and is virtually the only real source of income to the mining company. A variety of subjective flows may be created through the approach to the marketing process.

The various attributes of mine closure are generally accomplished according to legal constraint. However, this analysis is to include complete restoration/rehabilitation of the mine site. The following costs are, therefore, estimated:

Refuse Pile — 40 acres	
Restoration (contouring and grading)	$ 40,000 yr 12
Soil cover	100,000 yr 12
Revegetation	12,000 yr 12
Plant Site — 20 acres	
Clearing and stripping	10,000 yr 12
Grading	20,000 yr 12
Soil cover	50,000 yr 12
Revegetation	8,000 yr 12
Mine sealing	
5 openings at $5000 each	25,000 yr 12
Drainage Treatment — 0.09 MGD capacity; 0.03 MGD flow	
Plant installations	20,000 yr 1

Operating cost	
$ 0.25/1000 gal; $7.50/day, in perpetuity	3,000 yr 1 - n
Fencing and posting — only around treatment plant	1,000 yr 12
TOTAL — year 1	$20,000
all years: $3000 x 12	36,000
year 12	266,000
	$322,000

The entire region near Lion Lick No. 33 has been extensively deep- and strip-mined. Much of the land is orphaned-mined land. Consequently, the restoration and rehabilitation activities are capable of mitigating not only the activities of this specific mining activity, but also those of the past. Assuming, then, that responsible reclamation of the land may incur a high level of sentiment, the highly positive subjective flow will be inferred as capable of increasing the subjective values of the public, from that which is prevailing prior to mining. This figure is arbitrarily accepted as the price of the coal rights, $1,955,000, which is rounded to $ 2,000,000. The changes to total subjective value are outlined with a very pessimistic outlook as:

Action	Change to Total Subjective Value at Reclamation of 0%	100%	Cost at 100% Reclamation
Exploration	-50%	+10%	$ 24,000
Mining	-50%	+10%	10,000
Drainage Treatment	-100%	+10%	56,000
Rehabilitation	-100%	+10%	268,000
TOTAL	-300%	+40%	$358,000

In addition, subjective value probably contains some term related to economic growth. In this case, assume that this term is 10% of company net.

Graphical Solution

For this solution, then, the following points are summarized:

(1) The plot is to be value versus percent reclamation.

(2) Company net cash flow will vary from $14,919,600 at no reclamation to $14,561,600 at full reclamation. (Reclamation varies from $0 to $358,000).

(3) Subjective value varies from -$7,491,960* at no reclamation, to $4,256,060† at 100% reclamation.

The solution is plotted graphically in Figure 33. Of particular interest is that mining net changes much less rapidly than subjective value. If the company is truly trying to maximize net at a given subjective value, they will choose the solution at point A — roughly 80½% reclamation.

The plot also includes the tax subsidy relations as outlined previously, with the TAXSUB plot as before. In this case, the benefit of choosing any point on the line B-C, where net = maximum, is obvious. This solution is at a slighly higher level of reclamation, approximately 81%.

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* $2,000,000 -300% x $2,000,000 + (10%) x ($14,919,600)

† $2,000,000 + 40% x $2,000,000 + (10%) x ($14,561,600)

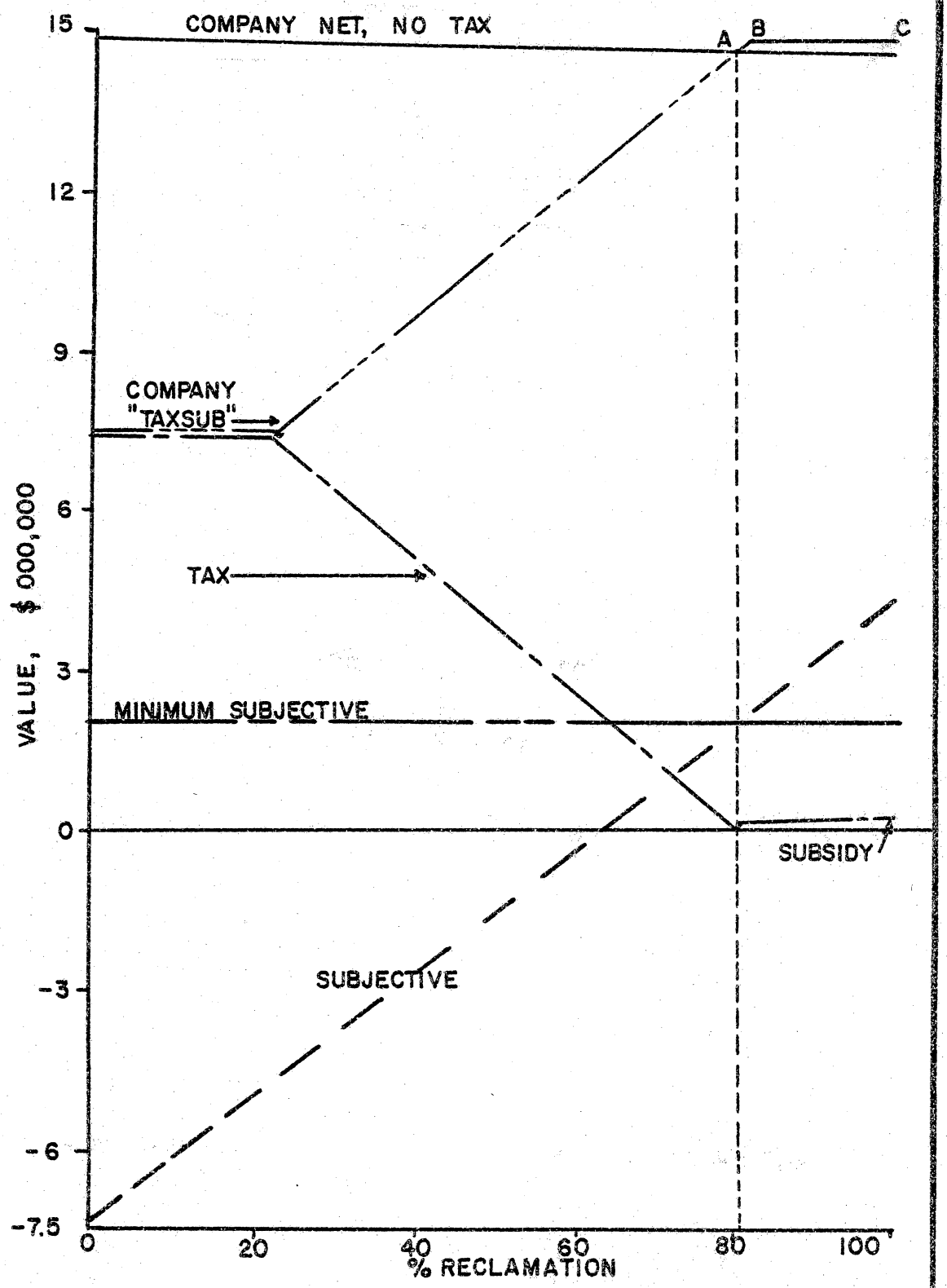

FIGURE 33: A GRAPHICAL SOLUTION TO THE CASE STUDY

Linear Programming Solution

The linear programming solution to the environment-integral problem is developed in a similar fashion to the preceding graphic analysis. The main difference is that a specific percentage environmental control accomplished for each of four categories of action will be developed. Let these be designated as:

x_1 = per cent exploration reclamation, as decimal

x_2 = per cent mining design added, as decimal

x_3 = per cent rehabilitation effected, as decimal

x_4 = per cent water treated, as decimal

The basic analysis pursuant to formulation of the linear program is as follows.

Exploration reclamation percentage may vary from 0.0 to 1.0. The cost of reclamation will vary from \$ 0 to \$ 24,000 (\$2,000 per hole x 12 holes), as:

$$\text{Cost} = x_1 \ (\ \$\ 24{,}000\ )$$

The subjective value percentage modification will vary as

$$p = (0.1 - (-0.5)\ )\ x_1 - 0.5\ , \text{ or } \ p = 0.6\ x_1 - 0.5$$

Mining design percentage may vary from 0.0 to 1.0. The cost will vary from \$ 0 to \$ 10,000, as:

$$\text{Cost} = x_2 \ (\ \$\ 10{,}000\ )$$

The subjective value percentage modification will vary as:

$$p = (0.1 - (-0.5)\ )\ x_2 - 0.5, \text{ or } p = 0.6\ x_2 - 0.5$$

Rehabilitation percentage may vary from 0.0 to 1.0. The cost of rehabilitation will vary from \$ 0 to \$ 268,000, as:

Cost = x_3 (\$ 268,000)

The subjective value percentage modification will vary as:

$p = (0.1 - (-1.0)) x_3 - 1.0$, or $p = 1.1 x_3 - 1.0$

Drainage treatment percentage will vary from ε, a very small value, to 1.0. The cost will vary from \$ 20,000 to \$ 36,000, as:

Cost = \$ 20,000 + \$ 3,000 (12) (x_4)

The subjective value percentage modification will vary as:

$p = (0.1 - (-1.0)) x_4 - 1.0$, or $p = 1.1 x_4 - 1.0$

Given these, the company net will vary as:

Net = \$ 14,919,600 - \$ 24,000 x_1 - \$ 10,000 x_2 - \$ 268,000 x_3
- \$ 20,000 - \$ 3,000 (12) (x_4)

The subjective value percentage will vary as:

Per cent subjective value change =

$\{ 1.0 + (.6 x_1 + .6 x_2 + 1.1 x_3 + 1.1 x_4 - .5 - .5 - 1.0 - 1.0)\}$ x
\$ 2,000,000 + 0.1 Net

= \$2,000,000 + \$1,200,000x_1 + \$2,200,000x_3 + \$2,200,000x_4 +
\$1,200,000x_2 - \$6,000,000 + 0.1 Net

= -\$4,000,000 + \$1,200,000x_1 + \$1,200,000x_2 + \$2,200,000x_3 +
\$2,200,000x_4 + 0.1 (\$14,899,600- \$24,000x_1 - \$10,000x_2 -
\$268,000x_3 -\$36,000x_4)

= -\$2,510,040 + \$1,197,600x_1 = \$1,199,000x_2 + \$2,173,200x_3 +
\$2,166,700x_4

The specific formulation then becomes:

Maximize Z = \$14,899,600 - \$24,000x_1 - \$10,000x_2 -\$268,000x_3 -
\$36,000 x_4

Subject to:

$$\$1,197,600\ x_1 + \$\ 1,199,000\ x_2 + \$2,173,200\ x_3 + \$2,199,700\ x_4$$

$$0 \leq x_1 \leq 1.0$$

$$0 \leq x_2 \leq 1.0$$

$$0 \leq x_3 \leq 1.0$$

$$.00001 \leq x_4 \leq 1.0$$

For which the solution is: x_1 = 100%, x_2 = 100%, x_3 = 0%, x_4 = 97.542%. Corresponding to these percentages, the subjective flow is $4,510,040 and the Objective Function is $14,830,484.92. The x_3 value stays at zero because maximization is realized without considering the most costly reclamation steps of restoration.

This solution presents the same level of subjective value as the graphical solution; whereas the graphical solution yields one general percent reclamation, linear programming optimizes the level of each of the four reclamation activities.

A Possible Extension — Midwestern Area Mining of Coal,

The midwestern (Illinois or Indiana) area mining of coal represents the next most involved consideration for mine-environment optimization. The resources, actions and receptors, as previously discussed, are the same in the problem. Variation is observed, however, in the manner by which value flows are to be established and in their scale. Therefore, these value flows will be reconsidered on a general basis.

Securing rights in property again consumes only capital and expense, while establishing the quantity of several resources at hand. In the Midwest, however, the price of the land and of the coal rights will likely be significantly greater than the cost of similar land in Pennsylvania, since the land has higher agricultural value and generally thicker coals. There may be an increase in the complexity of subjective value flows, since the farms of Southern Illinois are widespread, as are the mines, and farmers may be reluctant to part with their land if even for only a short time.

Exploration activities in the Midwest will be generally less involved than those in Pennsylvania. For one reason, the land is more or less flat and access is relatively simple — there is no need to cut new roads for drill rigs, etc. For another reason, the coal beds are more stratigraphically continuous and previously documented. The considerations of cost and of subjective value flow will be not only far less involved but far less adverse in the Midwestern situation.

Excavation and materials handling in the Southern Illinois and Indiana regions incorporate some of the largest equipment known in coal mining. Not only do these machines possess the capability of high production, they possess the capability of high rates of land disturbance at a drastic scale. The way in which mining is carried out, especially due to the extreme visibility of operations from highways and other public-access locations, is critical to the degree of adverse subjective flows which occur on an aesthetic basis. Those who see these operations from afar, and who have little knowledge of what will be done to reclaim the mine, may be sincerely upset at the sight, and all

efforts to mitigate this situation should be carefully planned and examined. However, the relationship between the costs of aesthetic protection and the percentage protection are non-linear, or more of the form.

$$\text{Cost of aesthetic protection} = e^{mx_p + b} + c\,x_p$$

where m, b and c are empirically obtained constants which relate the log-linear relationship between cost and the percent protection, x_p. Moreover, the relationship between percentage protection attempted and the actual subjective flow to the public is likely to be of the form

$$\text{Subjective flow} = e^{m'x_p + b'} - c'$$

where m', b' and c' are similar constants. In other words, two steeply sloping graphs must be analyzed for their point of intersection, while the actual standard deviation of any empirical measurements will likely be greater than the absolute value!

Waste disposal, particularly in regions of high agricultural value, would have similar relationships to those above, except the relationships would also hold true for the real dollar value of the land after mining. In certain areas of Illinois, the strip-mined lands may have as high a productivity, or even a higher one, after mining than before, particularly in the soy-bean regions. However, corn lands that have been mined do not recover so quickly as soy-bean lands. The degree of waste disposal will affect the degree to which land may be rededicated to agricultural purposes.

Of course, the real costs and subjective value flows of waste disposal are essentially the same as those of mine closure, restoration and rehabilitation. Again, for the Midwest a logarithmic

relationship would be predicted. The logarithmic relationship would be predicted both for the real costs to the mining company and for the real and subjective costs to the public.

In summary, then, the application of such an approach to Midwestern area mining would be possible. However, the exact set of equations established would be exceedingly non-linear and complex, and would be based on scarcely reliable information and conjecture. It would still be possible to optimize such a set of equations by using simulation or some non-linear programming techniques. However, the cost and time would likely be excessive and the results too inconclusive for practical use.

Conclusions

This has been a very limited and hypothetical case study although based on real data. It has been shown that analysis of resource-action-receptor chains and simultaneous optimization of real and subjective values is feasible in a simple case, and that a tax and subsidy structure could be determined from such analysis _if_ the equivalence of real and subjective values can be determined.

An application was presented of solution of this system by a linear programming approach. Discussion was then presented of a slightly more involved case, that of Midwestern area mining. In this more-involved case, the equations become complex and non-linear, and while resolution by sophisticated mathematical programming techniques might be possible, the results would likely be inconclusive as a result of the inadequacy

of data, both for the specific problem and as used in derivation of the empirical relationships.

Other conclusions are that this method of analysis:

(1) Shows the company how fractional changes in the production of environmental quality drastically affect the total social welfare.

(2) Can show the company that taxes or effluent charges, if viewed as economic disincentives and analyzed by this method, create a situation in which it is more desirable to produce environmental quality.

(3) Can be used, if sufficient socio-humanistic relationships could be determined, to establish the real economic value to the company of producing environmental quality in addition to mineral products.

LIMITING CASES OF MINE-ENVIRONMENTAL ANALYSIS

While a technique for mine-environmental planning has been developed, it is obvious that there are limitations to its current applications. These involve considerations of (1) technological costs, (2) land-use values, (3) subjective values, (4) long-term questions, and (5) short-term and local vs. long-term and total welfare. In this chapter, these areas will be considered as they relate to various mining situations.

Many of the observations in this chapter are drawn from four years' personal experience as a planning engineer for the Climax Molybdenum Co., Division of AMAX, Inc., at their Climax Mine, the second largest underground mine in the world, and with their Henderson Mine, a new, environmentally sensitive operation. Further observations are related to personal experience with The Pennsylvania State University, Department of Mineral Engineering, in an Environmental Protection Agency-sponsored research program to develop a "Manual of Practice for Pre-Mining Planning: Eastern Surface Coal Mining."

Boundary Conditions to be Considered

In a previous chapter, "Qualitative and Subjective Optimization of Mine-Environmental Relations," certain cases were recognized as typical of the boundaries of mining conditions. These will be considered

individually, and include:

(1) Underground mining with limited subsidence

(2) Caving methods

(3) Eastern surface mining

(a) Contour mining

(b) Area mining

(4) Western surface coal mining

(5) Open pit mining

The five areas of involvement, as suggested in the first paragraph of this chapter, will be discussed for each of these five boundary cases.

Underground Mining with Limited Subsidence

This category would include most underground coal mining and the hard-rock methods of cut and fill, room and pillar, shrinkage, and timbered stoping. It is that in which the case study situation would fall.

Underground mining with limited subsidence is selective rather than a bulk method. The operating costs are relatively higher than for other underground mining, but well defined. Technology is, therefore, not a constraint in planning, although the high cost may be.

These methods offer the minimum of surface involvement, so land use values are of limited concern. However, long-term land value after mining is a separate and additional question (discussed below).

As in the case study, subjective values relate to:

(1) Control of mine drainage

(2) Restoration and rehabilitation of disturbed land

(3) Aesthetic value or disvalue of the mine plant

(4) In some degree, the economic growth provided by the company

These can all be discussed relatively simply. Their quantification is, however, much more involved than as presented in the case study. Little capability exists to relate subjective value to real value.

Long-term concerns are the major boundary considerations in limited subsidence mining, related to:

(1) Eventual subsidence of surface

(2) Perpetual maintenance of drainage facilities

In Southern Illinois today there are extensive areas of suburban development on land mined approximately 70 years ago. Houses of value up to $100,000 are underlain by mine workings thought to have been safe. Recently, however, subsidence has reached the surface, to so great an extent that a bill is under consideration to require subsidence insurance of mine operators and to provide such coverage to the surface title holder. This case may prove typical of other geographical areas in the future, but it is not known for sure if it will or won't happen.

While methods are known for sealing mine openings and for treating such drainage as does occur, there are cases in which these procedures fail. Who knows how long a mine seal will last, or when it may need to be replaced? How long must a neutralization plant remain in operation? And, in both questions, who is to pay for these procedures? The responsibility for payment must be reflected in reduced prices or otherwise established with the miner, unless otherwise negotiated. But the

exact probabilities and possibilities of such long-term questions are difficult to assign and more difficult to quantify.

Fortunately, for the planner, most underground, non-subsiding mining has long-term effects on total welfare which far outweigh any impacts of short-term and local use. More importantly, the immediate short-term local welfare is monetarily greater, in most cases. Of course, for national parks and forests, wilderness areas, or suburban or urban development, the alternative short-term uses may be more important, in the long-term, than mining by these approaches, which generally involve smaller deposits, and less monetary benefit.

Caving Methods

This category includes large-scale sublevel stoping, top-slicing, sublevel caving, and block, panel or mass caving. Generally, these approaches can be thought of as non-selective, bulk mining methods with high associated waste and subsidence.

These methods are often the only economically feasible means of extracting certain lower grade ore deposits lying under such a depth of cover as to preclude their exploitation by surface mining. They rely on:

(1) Cheap, close disposal of tailing

(2) High volume rates of extraction

(3) Collapse of overlying strata, either inherently in or close after mining

Efforts to reduce either the problems in production and disposal of

waste or rapid and large-scale subsidence cannot be made, as the system cannot work when so restricted. The technological costs depend on economies of scale and disregard for the surface.

Caving methods present the most drastic form of surface disruption known in mining. In short, the land is completely removed. The value associated with the land under which mining occurs is virtually gone completely. What is left is a crumbling hole, suitable, perhaps, for use as a lake or for disposal of waste from other mining operations, but little else. The value of this loss, indeed, this establishment of negative land-use value is hard to determine.

The 1000-m wide x 1500-m long x 500-m deep "glory hole" caved at Climax, Colorado is, in some ways, pleasing to a mining engineer familiar with the 60 years of mining which it represents. However, the aesthetic value of this hole in the ground to others is questionable. In general, intense subjective value flows are associated with caving methods, and these are hard to quantify.

The main long-term question, what to do with the hole, overshadows most others; however, the disposal of waste is a close second. Concrete plans, in both instances, are difficult to envision. As a boundary condition, then, the long-term question is closely related to the technological cost.

If long-term questions and subjective values in the total welfare can be justified, it is through the appropriateness of these short-term uses. A comparison of values to total welfare of a caving mine to an open pit mine might show that real economic value was identical while subjective value was better for caving. At least caving, involving

drastic disturbances, does concentrate these in so small an area as is possible if the mineral resource is to be extracted. Further, caving and bulk methods allow the extraction of resources for which our country would otherwise be dependent on imports. The capability to equate these values in a linear program is questionable.

Eastern Surface Mining

Eastern surface mining will be considered with regard to the two different approaches: contour mining and area mining.

Contour Mining

Contour mining may be further divided into two categories:

(1) general outslope disposal

(2) in-pit disposal utilizing controlled and limited outslope disposal

Varying degrees of environmental quality can be maintained and produced depending on the cost the company is willing to pay and, subsequently, the method they use. The haulback and valley-fill combination, an environmentally more preferable approach, is cost-competitive with parallel-slope disposal, block-cut with partial outslope disposal, or box-cut with partial outslope disposal, in most situations. Mountain-top mining methods actually allow more coal to be extracted and at lower cost than by other contour methods. The costs to be assessed are the extra steps — reclamation and community relations.

The competent relcamation of contour-mined land can result in

apparently higher land use value than that prior to mining in most of the Eastern Coal Province. In mountain top mining, the resulting flat land or shallow hills and terraces may enhance future use potential for development or farming purposes. Traditional contour mining can create grazing land in the midst of previously low-use forest.

Conversely, however, in areas where predominant present use is as pristine wilderness, development will contravene that use. In this case, the development's increase of land use values is questionable, as a particular land use is destroyed forever.

Contour mining is frequently a point of great emotional conflict. A wide range of subjective values is possible depending on the specific individual circumstances related to intensity of preference. Aesthetic values are frequently reduced by the presence of contour mines and highwalls on miles of hillsides. Such subjective values may, however, for this case be more simple to quantify than in others.

Two other areas of long-term concern are present: (1) stability of slopes and fills and (2) maintenance of water quality. Although fills and water management processes are designed according to the best of engineering practices, long-term failures of valley fills or storm-water handling facilities is inevitable. The possibility of these occurrences must be balanced against the short-term relations.

In the analysis of contour mining, the apparent inacceptability of the proposal on a short-term or local basis has often been offset by considering the long-term and total welfare. The dictum "most good for the most people" is to serve as a guide, but is difficult to relate in a quantitative analysis.

Area Mining

Area mining in the east is somewhat easier to consider than contour. It has less concerns with stability and more well-defined relations to water quality.

Since Eastern area mining is characterized by the giants of earth-moving, economies of scale are the most important considerations in determining technological costs. These are well-documented, and prove to be little of a problem in analysis.

Predominant pre-mining uses in area mining regions being agricultural, the restoration of land-use values is not particularly a limiting consideration. Reclamation of area-mined land can commonly be very effective. Subjective values in area mining are simple in comparison to some other types of mining.

The primary long-term question regarding area mining is its effect on subsurface water flows. These are not particularly predictable, and this question area may quite well prove limiting to area mining analysis.

Conflicts of the nature of short-term and local uses vs. long-term and total welfare are minimal or are directly related to those as in contour mining.

Western Surface Coal Mining

Western surface coal mining in many ways resembles Eastern area mining. There are, however, several differences which make the situation almost impossible to analyze. As has been discussed previously,

Western coal deposits would support a scale of operation unknown in mining practice. The technological relationships could not be accurately and sufficiently forecast to allow quantitative optimization.

Simply stated, the current land-use values and the intensity of preference for these values at local levels cannot be quantified. Great subjective values are associated with the areas of Western coal development, but these relate primarily to land-use values as above. While many of the subjective relationships might be as easy to quantify as those in other types of mining, some will present extremely difficult cases.

There is one area in which quantification would justify Western surface coal mining. The long-term and total benefit to the public as a whole must be sufficient to offset all other effects of the short-term and local use. It is almost impossible to relate the intensity of preference to an economic consideration of total welfare. It is also difficult to consider the wishes of one local public as more important than those of the country as a whole.

Open Pit Mining

Open pit mining is the strongest limiting case to be considered. Small open pits follow the same discussion as for Eastern surface contour mining. For large open pit mines, the problems are those of caving mining and Western surface mining combined: a simply overwhelming composite.

Observations and Conclusions

The following observations and conclusions are to be offered regarding the limit cases.

(1) Underground, limited-subsidence methods are the most environmentally protective and could be practiced in any location where technically feasible.

(2) Caving methods and other bulk methods relying on subsidence and ground failure which will reach the surface should be restricted to areas of limited current and potential surface use. As an alternative, sublevel stoping, with backfill, could be used as a possible substitute.

(3) Eastern surface area mining is reasonably acceptable in its present form, except in areas of unknown subsurface water flow, wilderness areas, or heavily developed areas. However, its subjective relationships are difficult to quantify.

(4) Eastern surface contour mining should be allowed providing:

(a) All spoil is either replaced on the bench or in a well-designed and monitored valley fill.

(b) The disruption is commensurate with current land use (i.e., current land use is not wilderness).

(c) The long-term liability is established and perpetual maintenance is provided.

(5) Western surface coal mining should be allowed only in areas where the surface can definitely be restored to a productivity very similar to that prior to mining and where a high percent

Ultimate harmony or balance between man and his environment, as the penultimate in planning, requires that informed participants join in concerned cooperation, not limiting involvement to the aspects of a particular discipline but integrating all of the sciences and engineering.

CONCLUSIONS

Suggestions for Future Research

Certain areas of future research which have been implied throughout this dissertation, as well as other specific areas, include:

(1) Research in the real-dollar aspects of subjective value flows.

(2) Further identification of the scarce resources, actions, and receptors of mining and the relations of consumption and flow of value between and among them.

(3) Development of parametric, mixed-integer, and goal programming approaches to the mine-environmental planning problem.

(4) Specific relation of the constraints of value flows of the mining environment type to the mathematical approaches to the general mine planning problem and as an approach to the modelling of a total mine.

Summary

The bases for man's concern with his environment and the nature of mining and the mine planning process have been reviewed. Mining engineering has been discussed as a blend of several disciplines held together by a unique philosophy and approach. Consequently, the problems of mining, environmental or otherwise, are, in total, unique to that industry; however, upon sufficient in-depth analysis, the aspects of

any of these problems are seen to be not of themselves unique but related to problems and situations common to other disciplines.

Such a relationship was taken to suggest the total systems approach to problem solution. An in-depth review revealed that such an approach is, at least partially, present in the traditional mine planning methodology. An expansion of the formulation of the mine planning problem, through a three-component resource-action-receptor chain was presented. An optimization process, directed at maximizing certain flows of real value, as influenced by other flows of real and subjective value, was developed.

Through a case study, it was shown that the incorporation of environmental concern, although an additional cost element, may actually result in higher returns to the company if regulations are of the nature of a tax or subsidy. The conclusion was drawn that even though total costs were higher, environmental concern can be of benefit to the mining company if real returns to subjective flow occur and can be considered.

Since analysis of mine-environmental relations was shown to be feasible through a traditional and nominal engineering technique, analysis by a sophisticated management science and engineering approach, linear programming, was proposed as a possible extension. A formulation and solution of this problem was presented, and it is felt that appropriate analysis by mathematical programming may well be the key to ultimate optimization of mine environmental planning and control.

However, the resolution of these problems is in many parts. Technique is one part — one that can be solved on an individual basis. Composite solution requires team efforts of analysis and application.

Ultimate harmony or balance between man and his environment, as the penultimate in planning, requires that informed participants join in concerned cooperation, through not only environmental but all of the sciences and engineering.

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OPTIMUM MINE ENVIRONMENTAL PLANNING

by

James Moore Riddle

(ABSTRACT)

An approach and technique for optimizing mine environmental planning was developed. As a basis for discussion, the perspective of the environment was reviewed for several disciplines. The characteristics of environmental planning and some common methods in environmental planning were reviewed. As a further basis for discussion, mining and environmental practices were reviewed.

A specific discussion of various subjective and qualitative approaches to and ways of optimizing mine-environmental relations were presented, prior to development of the new quantitative approach. This approach relies on analysis of three-component resource-action-receptor chains and the real and subjective value flows associated with these. Two techniques for optimizing these chains were presented as (1) graphical solution and (2) linear programming.

A case study of a simple mining project is analyzed by the graphical and linear programming techniques. Then a discussion is presented of the various limit cases in mining and how they would be resolved in such a type of analysis.