BuMines OFR 101-80

PB81-106783

ENVIRONMENTAL ASSESSMENT OF IN SITU MINING

PREPARED FOR

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF MINES

Bureau of Mines Open File Report 101-80

BY

PRC TOUPS
ORANGE, CALIFORNIA

FINAL REPORT

CONTRACT NO. J 0265022
ENVIRONMENTAL ASSESSMENT OF IN SITU MINING

DECEMBER, 1979

PRC Toups

50272-101

REPORT DOCUMENTATION PAGE

1. REPORT NO. BuMines OFR 101-80

2.

3. Recipient's Accession No. PB 81-106783

4. Title and Subtitle

Environmental Assessment of In Situ Mining

5. Report Date December 1979

6.

7. Author(s) Dennis R. Kasper, Harry W. Martin, Larry D. Munsey, Roshan B. Bhappu, and Clement K. Chase

8. Performing Organization Rept. No.

9. Performing Organization Name and Address

PRC Toups
972 Town & Country Road
Orange, California 92667

10. Project/Task/Work Unit No.

11. Contract(C) or Grant(G) No.

(C) J0265022

(G)

12. Sponsoring Organization Name and Address

Office of the Director--Mineral Resources Technology
Bureau of Mines
U.S. Department of the Interior
Washington, D.C. 20241

13. Type of Report & Period Covered

Contract research,
June 1976-December 1978

14.

15. Supplementary Notes

Approved by the Director, Bureau of Mines, for placement on open file, August 11, 1980.

16. Abstract (Limit: 200 words)

This study evaluates selective environmental impacts of two distinct in situ mining techniques. In situ leaching of uranium, porphyry copper, and native copper and in situ borehold slurry mining of uranium, sandstone, and pebble phosphate ores are the techniques and minerals investigated. The potential impacts onsite in the desert southwest (porphyry copper), Michigan (native copper), Texas and Wyoming (uranium), and Florida and North Carolina (phosphate) are discussed. The study emphasizes those impacts that are unique to in situ solution leaching and borehole slurry mining. Impacts that are characteristic of all construction projects in the general geographical areas investigated, such as socioeconomic effects on surrounding communities, and site-specific impacts such as rare and endangered species, are beyond the scope of this study. For each of the in situ processes and associated ores investigated, the physical and chemical characteristics of the systems are described, the toxicity of the leaching solutions are presented, and the potential impacts on the environment are developed.

17. Document Analysis a. Descriptors

Mining
Borehole slurry mining
copper mining
Environmental impact

In situ mining
In situ regulations
Phosphate mining

Solution leaching
Urnium mining

b. Identifiers/Open-Ended Terms

New mining techniques

c. COSATI Field/Group 08I

18. Availability Statement

Unlimited release by NTIS.

19. Security Class (This Report)

20. Security Class (This Page)

21. No. of Pages 294

22. Price

(See ANSI-Z39.18)

See Instructions on Reverse

OPTIONAL FORM 272 (4-77)
(Formerly NTIS-35)
Department of Commerce

FOREWORD

This report was prepared by PRC Toups under Bureau of Mines Contract number J0265022. The contract was initiated under the Advancing Metal and Nonmetal Mining Technology Program. It was administered under the technical direction of the Twin Cities Research Center, with William H. Engelmann acting as Technical Project Officer. William P. Battle was the Contract Administrator for the Bureau of Mines. This report is a summary of the work recently completed as a part of this contract during the period June, 1976 to December, 1978. This report was submitted by the authors on December 22, 1978 and in final form December, 1979.

No patentable features were developed during the conduct of this study.

CONTENTS

CONTENTS (CONTINUED)

CONTENTS (CONTINUED)

CONTENTS (CONTINUED)

CONTENTS (CONTINUED)

CONTENTS (CONTINUED)

CHAPTER 1

EXECUTIVE SUMMARY

DESCRIPTION OF INVESTIGATION

This study evaluates selective environmental impacts caused by two distinct in situ mining techniques. In situ leaching of uranium, porphyry copper and native copper, and in situ borehole slurry mining of uranium, sandstone, and pebble phosphate ores are the techniques and minerals investigated. The potential impacts on sites in the arid southwest (porphyry copper), Michigan (native copper), Texas and Wyoming (uranium), and Florida and North Carolina (phosphate) are addressed and discussed. The study emphasizes those impacts which are unique to in situ solution leaching and borehole slurry mining. Impacts characteristic of all construction projects in the general geographic areas are not investigated (see abstract). These include socioeconomic effects on surrounding communities. Site specific impacts and impacts on rare and endangered species are beyond the scope of this study.

For each of the in situ processes and associated ores investigated, the physical and chemical characteristics of the systems are described, the toxicity of the leaching solutions are presented, and potential impacts on the environment are developed.

The developmental states of the solution leaching and borehole slurry mining techniques differ significantly. Currently, there are more than twenty-five pilot solution leaching projects recorded for uranium and four to eight projects for copper. There are only two to four documented demonstration sites of the borehole technique. At the present time, the major interest in in situ processes is in the recovery of uranium from sandstones.

For solution leaching of uranium, the adopted monitoring programs are generally adequate for detection of excursions (1). Presently, restoration of groundwater quality techniques are in an infancy stage, and appear to be capable of generally restoring water quality of the leached ore body and aquifer to near original levels. Several pilot sites in Texas have been successfully restored, thus enabling production scale operations. Future improvements should result in more effective groundwater quality restoration techniques that may be more economical and effected in a more timely manner.

A major environmental factor of solution leaching involves the disposal of waste process and other solutions generated during groundwater quality restoration activities. Commonly used disposal methods are deep well injection and evaporation ponds.

An evaporation pond depends on direct solar evaporation for concentration of waste solutions. Recent regulations generally require that such ponds be lined with impervious materials. Closed, sealed ponds will require future monitoring to assure that leaching and leakage do not occur. Wells are used to inject waste solutions into non-potable water bearing strata which can occur at deep depths.

Borehole slurry mining has a less significant potential impact on the water environment since the minerals are not solubilized and are not in a state which can be transported into the environment. The borehole slurry technique does produce tailings, the majority of which can be backfilled into the borehole unless subsidence occurs first. Additional demonstration and documentation studies are required before more definite conclusions regarding environmental impacts can be made.

Reviews of Federal and State environmental laws and regulations having direct and indirect jurisdiction over the in situ methods are presented in Chapters 13 and 14. The complexity of permitting processes for approval of in situ mining operations varies greatly from state to state, depending on which specific mineral is being recovered. Many states have no experience with in situ mining and tend to adopt conservative environmental protection approaches. Due to the overlap of State and Federal regulations there is often a duplication of efforts in obtaining permits. In many instances, different levels of input data are required for the cognizant agencies.

The regulatory requirements for mining are being revised and redeveloped at the present time. The information in Chapters 13 and 14 was prepared in the latter half of 1978. Readers are cautioned that such information is rapidly outdated.

PRIMARY CONCLUSIONS

General

In general, in situ mining techniques do not remove vast quantities of overburden and/or ore. This results in significantly less disturbance of the environment than is caused by conventional mining techniques.

Application of the in situ techniques enables recoveries of lower grade ores which previously were economically unrecoverable. The availability of additional quantities of uranium could have significant future environmental effects; such indirect considerations are beyond the scope of this report.

Disturbances to the environment by in situ construction and operational activities are relatively small and of short duration when compared to conventional mining methods. Many environmental disturbances of conventional operations arise from the disposal of tailings and overburden in the surface environment. Both in situ techniques greatly reduce the volumes of materials requiring surface disposal.

In Situ Leaching

For in situ leaching the major potential impact would be on the water resources. Adverse impacts can be minimized or even eliminated by proper monitoring and by groundwater quality restoration activities.

The lixiviants applied to three types of ore amenable to solution leaching may be generally undesirable due to high salinities, presence of mobilized trace metals, and/or low pH.

The current monitoring techniques appear to be adequate for detection of excursions in sandstones. It is highly improbable that similar monitoring (developed for sandstone strata) would suffice in areas surrounding porphyry or native copper ores since these are generally hard rock. Excursions could flow in crevices, fractures, faults, etc., and would be detected only if the monitoring well intake intersected the fault. Monitoring techniques specific to porphyry ores will have to be developed.

Limited studies on a small scale indicate that aquifer restoration in uranium bearing sandstone for mine closure or excursion control is technically possible. The economics of aquifer restoration are specific and must be evaluated for each site.

A properly designed and operated in situ leaching operation will avoid surface discharges of liquid effluents. This should eliminate adverse impacts to surface waters. Discharge caused by excursions via faults and fissures may still be possible, but are controlled by monitoring requirements. Nevertheless, a "properly designed operation" may discharge to an evaporation pond.

Evaporation ponds will probably be used for retention of process wastewaters. Resulting residual solids will ultimately be disposed of in accordance with State and Federal regulations. Seepage from unlined ponds can transport toxic solutions to the surrounding environment. Such seepage will generally cause unacceptable levels of environmental degradation, and it is highly probable that all evaporation ponds will require impervious liners.

Any mining operation in the arid Southwest impacts the available water supplies. In situ operations have relatively low consumptive water usages, because of recycling and treatment of process water.

The qualities of native groundwaters in most uranium ore deposits often do not meet drinking water standards. In many instances the waters are also unfit for consumption by livestock. The waters in the vicinity of the roll front deposits generally have total dissolved solids (TDS) concentrations in excess of 500 mg/l which exceed proposed National Secondary Maximum Contaminant levels for public water systems (40 CFR part 143, Federal Register <u>42</u> No. 62, March 31, 1977, pp. 17143-17146).

The possibility of undetected, long-term excursions is extremely small if: 1) adequate premining hydrologic studies are performed to define the characteristics of the ore deposit; 2) mass balances on the leaching solutions are performed on a routine and frequent (monthly) basis. If such excursions do occur, dispersion will dilute the levels of all constituents as the solutions migrate from the leaching site. Insufficient general data exists for prediction of the maximum contaminant concentrations as functions of distances from the plant sites located in the study areas. Such analyses can be performed for specific sites and specific lixiviants.

A special problem exists in restoration of ore bodies leached with lixiviants containing ammonium ions. Ammonium ions generally adsorb on the contained clays in the sandstone strata, and require large volumes of pore-flushing water to achieve groundwater quality restoration. Alternatives to the ammonium ion in the lixivants and various aquifer restoration techniques are currently being evaluated. Results now indicate that restoration of most aquifers can be restored to water quality levels consistent with baseline or starting conditions.

Impacts on air quality are very small and will generally be negligible if proper control measures are adopted. Emissions requiring control measures are sulfuric acid mists (porphyry copper) and ammonia gas and ammonium chloride particulates (uranium). The atmospheric radiological emissions from in situ uranium leaching operations are significantly less than from those of conventional uranium mills. It is estimated that the radon gas and uranium 238 dust would produce a dose of only 0.009 millirems/year at a distance of 6.4 kilometers (4 miles) from the mine. This is only 0.002 percent of the annual maximum whole body dose recommended by the Nuclear Regulatory Commission (NRC).

Borehole (Slurry) Mining

The borehole (slurry) mining technique is currently in its infancy and analytical data documenting its environmental impacts have not been developed.

The technique has been established only recently as a viable mining method for the softer, more friable ores and appears to also have a potential for significantly fewer environmental impacts than conventional mining methods.

One potential advantage of the borehole technique is that after segregation of coarse and fine ore fractions, the coarse sands can be backfilled in slurry form into the borehole. This proposed backfilling will eliminate disposal of large volumes of solid wastes on the surface and protect against subsidence. In the case of uranium ore tailings, burial of the sands in the borehole effectively will dispose of a major fraction of the radium.

Disposal of the finest fractions of tailings (slimes) has not been demonstrated. It is known that these fine fractions are most difficult to dewater. Slimes constitute a significant environmental problem in the conventional pebble phosphate industry (2). Uranium ore slimes will contain a major fraction of radium and other radionuclides.

There is a potential for solubilization of trace metals from ores during the borehole mining operations. However, the short duration of mining and the use of water without additives provide little opportunity for transport of solutions to the environment.

With regards to the potential impacts of borehole mining on the surface environment, compaction of backfilled solids in boreholes could occur and allow surface subsidence. The magnitude of any subsidence depends on particular site conditions. While damage to structures such as buildings or pipelines could occur, the overall combined effects on the environment will probably be minimal. Site specific conditions such as a shallow groundwater table could result in ponding of subsided areas. This could result in minor changes in the surface ecology.

CHAPTER 1 REFERENCES

1. William Taylor, Personal Communication. January 1978. Texas Department of Water Quality, Austin, Texas.

2. Bartos, Michael J. Containment Area Management to Promote Natural Dewatering of Fine-Grained Dredged Material. Tech. Rpt. D-77-19. Vicksburg, Miss 86 pp. 1977. U.S. Waterways Experiment Station, Army Corps of Engineers.

CHAPTER 2

INTRODUCTION

GENERAL

Worldwide improvements in standards of living and overall population increases have greatly increased demands for minerals, metals and energy. These increased demands occur at a time when high grade, easily recoverable ore reserves are dwindling. Recently discovered reserves generally tend to have lower mineral values and are more difficult to extract by conventional mining techniques. Environmental protection measures have become a necessity as man has developed an understanding of the fragility of most parts of his ecosystem.

Mining developments typically require movement of very large volumes of overburden and/or low grade ores. Environmental awareness which has matured over the last two decades has resulted in the establishment of numerous Federal and State agencies which have jurisdiction over various mining operations, including processes of in situ mining. Development of all types of mining operations is directly affected by the requirements of the various regulatory agencies. In situ mining techniques are methods for extracting minerals without removing or disturbing the overburden or the ore matrix. In this report, two in situ mining techniques are evaluated to determine their potential environmental impacts. The investigated techniques are in situ leaching and in situ borehole (slurry) mining.

In situ leaching is a method that is currently being applied to uranium and copper mining. The method has potential application to any mineral which can be solubilized from its host ore. The current (1979) markets for uranium and copper have resulted in almost all in situ leaching shifting to uranium. The technological approach of in situ leaching is general and is applicable to extraction of metals other than uranium and copper.

In this study, in situ leaching is evaluated for: 1) porphyry copper ores in the desert southwest; 2) native copper in Michigan; 3) uranium-bearing sandstones in Texas and Wyoming. Many characteristics affecting the environment are related to the process and certain conclusions can be applied to other geographical settings.

Borehole (slurry) mining is a method for hydraulically eroding and pumping ores (slurried) to the surface without removal of overburden. The technique has been proposed and tested for certain phosphate and uranium ores. In this report, the environmental impacts of the application of the technique to phosphate ores in Florida and North Carolina and to uranium ores in Wyoming and Texas are analyzed. The technique has much broader potential application and, as with in situ leaching, many of the findings of this study are applicable to other locations and minerals.

OBJECTIVES

The objectives of this investigation are to assess and summarize the environmental effects of two in situ mining techniques and to assess the regulatory requirements presently affecting the industry. Both State and Federal regulatory agencies are considered. Emphasis is placed on determining chemical and radiation hazards of specific leaching solutions at typical geographical settings.

A major factor affecting the scope of this study is that it is primarily concerned with environmental effects unique to the in situ processes investigated. No attempt is made to identify all factors which are site specific. For example, the socioeconomic impacts on surrounding communities are not unique for the in situ processes. Ore recovery by surface or underground mining, or any other conventional mining technique, would produce basically the same type of socioeconomic impact on surrounding communities. In situ development would probably result in reduced magnitudes of socioeconomic impacts due to the smaller labor forces required for in situ operations. Such impacts have been summarized in a matrix format for each scenario and are presented in Appendix A.

REPORT ORGANIZATION

This report is divided into three parts, each of which comprises a complete unit. Part I evaluates in situ leaching processes for porphyry and native copper and for uranium-bearing sandstones. It consists of an introductory chapter (Chapter 3), three separate chapters on the three ores of importance, a chapter on general environmental considerations and a chapter summarizing environmental effects of in situ leaching.

Part I represents the major part of the study in view of the further advances of in situ leaching over that of borehole (slurry) mining. Many of the environmental considerations presented in Chapter 7 are general in scope but have potential application to certain aspects of borehole (slurry) mining.

Part II evaluates the borehole (slurry) mining technique for phosphates and uranium-bearing sandstones. The four chapters included in this section of the report are: 1) an introduction and general description of the technique; 2) analysis of potential borehole phosphate mining operations in Florida and North Carolina; 3) analysis of potential uranium borehole operations in Texas and Wyoming; 4) conclusions.

Federal and State regulations are presented in the final two chapters which comprise Part III of the report.

Environmental Impact Assessment matrices for typical geographical settings of the principle ores discussed for the in situ processes are presented in Appendix A. Appendix B is a glossary of terms used in the report and in the in situ mining (leaching and borehole) industry.

APPROACH

The lack of definitive data documenting environmental effects or certain characteristics of the in situ techniques under consideration necessitated extrapolation of limited data and application of general analytical techniques. This approach resulted in the identification of both real and potential environmental effects. Additional studies should be performed to determine the extent of certain potential environmental effects identified.

For each of the ores and techniques investigated, a "typical" physical setting is developed to enable evaluation of general effects on the environment. Specific emphasis is given to those impacts which are unique to the in situ processes under consideration. The general mineral or ore extraction method and the processing required for concentrating the product is described for each ore system investigated. Definition of process variables thus resulted in the environmental impact analysis.

CHAPTER 3

IN SITU LEACHING

Leaching is mining and beneficiation processes combined, applicable to recovery of such metals as uranium, copper, nickel, and potash. Two above-ground leaching techniques are heap and vat leaching. These techniques are controlled processes in that a known amount of leaching solution is applied and recovered. The conventional vat and heap leaching techniques require that the ore be placed in vats or in heaps on impervious pads. The mineral typically constitutes only 0.03 to 1 percent of the ore and vast amounts of ore are transported for each pound of product recovered. In many instances the ores are crushed or pulverized to increase surface areas exposed to the lixiviants thus speeding up the leaching process. Agitation in vats is also practiced to promote rapid mineral solubilization as the lixiviant or leaching solution percolates through or around the ore. Chemical or biochemical reactions occur which solubilize the metal being recovered. The pregnant or mineral-bearing solution is then recovered from the ore and transported to the beneficiation plant where additional treatment and product concentration is performed. The leached ore or tailings are typically disposed of into tailing ponds or dumps.

A third leaching technique is dump leaching. Beneficiation processes employed today have greater efficiencies than those previously used. Many of the tailings and overburden set aside in previous years contain economically leachable quantities of metals in terms of current values and process efficiencies. Leaching solutions have been applied to such dumps to recover the low grade minerals for many years.

In situ leaching is the process in which leaching solutions are applied to ores in their naturally occurring location. A significant advantage of the technique is that the metal values can be recovered without removal of the bulk of the ore. A significant economic advantage results from not having to move 100 to 3,000 pounds of ore (1 to 0.03 percent mineral contents) for each pound of mineral recovered. There is also an environmental advantage since there are no large volumes of tailings which would require disposal in surface ponds or heaps. The in situ liquid wastes generated are similar to those generated in the liquid circuit of conventional vat or heap leaching, that is, concentrated solutions containing toxic species.

The application of any technique which can recover minerals from lower grade ores than economically minable or accessible by conventional techniques extends the recoverable ore reserves. This is a significant advantage when the uranium ore produces energy which can reduce the need to mine coal deposits or reduce oil imports.

In situ leaching can be used to recover any metals or minerals which can be solubilized from the ore. Primary factors which affect the economics of the process are the rates at which solubilization occur and the magnitude of leach solution consumption by the gangue material. The rate of solubilization is

affected by the surface area exposed to the lixiviant, the strength and composition of the lixiviant and the rate of lixiviant circulation through the ore, among other factors. It is necessary for the ore deposit to be permeable so that the leaching solution can be injected and recovered. Sandstone hosts for copper- or uranium-bearing minerals are prime candidates for the technique. Porphyry copper, or any other hard rock deposits, require fracturing for development of voids which would enable fluid to pass through the processed ore body.

Candidate deposits for in situ leaching include both undisturbed ore bodies and low-grade materials backfilled into former underground mine workings. A classic example of low-grade ores buried, in former workings, are the native copper mines in upper Michigan. Stopes at depths exceeding 3,000 meters (10,000 feet) have been backfilled with low-grade copper ores.

In any new developing technology, standardization of terminology does not occur immediately. In this report, the term "in situ leaching" is used instead of other common terms such as in situ solution mining, in situ mining, in situ leach mining, or solution leaching.

CHAPTER 4

PORPHYRY COPPER

INTRODUCTION

Over the last 100 years, the grade of economically minable copper has declined from 20 percent copper to the present lower economically minable limit of about 0.4 percent (1). Greater than 80 percent of the world's copper production is currently derived from porphyry copper deposits. These deposits are usually large with many individual ore deposits and exceeding 3 billion tons. One of several methods of extracting copper from these low-grade reserves is by in situ leaching, a technique discussed herein, with emphasis on its application to southwestern United States deposits.

Porphyry copper is defined as a disseminated replacement deposit in which the copper minerals occur as discrete grains and veinlets throughout a large volume of rock, which commonly is a porphyry. It is a large tonnage, low-grade deposit. In the commercial sense, the term is not restricted to ore in porphyry but is applied to deposits characterized by huge size, particularly with respect to horizontal dimension, uniform dissemination, and low average per ton copper content. It should be noted that this commonly accepted definition of porphyry is in part geological and in part economic and thus lacks precision. The ore includes the oxide copper minerals which are most readily solubilized by leaching solutions.

PHYSICAL SETTING

Geographic Location

Porphyry copper deposits are distributed worldwide. In the Western Hemisphere, the preponderance of the deposits are distributed along the Cordilleran Belt which includes the mountainous western portions of both the Northern and Southern Hemispheres. In North America, the porphyry belt passes from Alaska southward through western Canada and the United States into Mexico and Central America (Figure 4-1). The southwestern United States component of the porphyry province comprises portions of the States of Arizona, Nevada, New Mexico, and Utah.

Nature of Deposits

Porphyry copper deposits range from small veins, usually mined underground, to the huge porphyry coppers--currently the prime source of copper and also an important source of associated metals such as gold, silver, and molybdenum. Both veins and the large disseminated porphyry deposits occur in various conditions and are found in a wide range of geologic environments. Felsitic igneous rocks (quartz, monzonite, granodiorite, etc.) predominate as hosts but significant deposits may also occur locally in sedimentary strata, metamorphic rocks, and more basic igneous types.

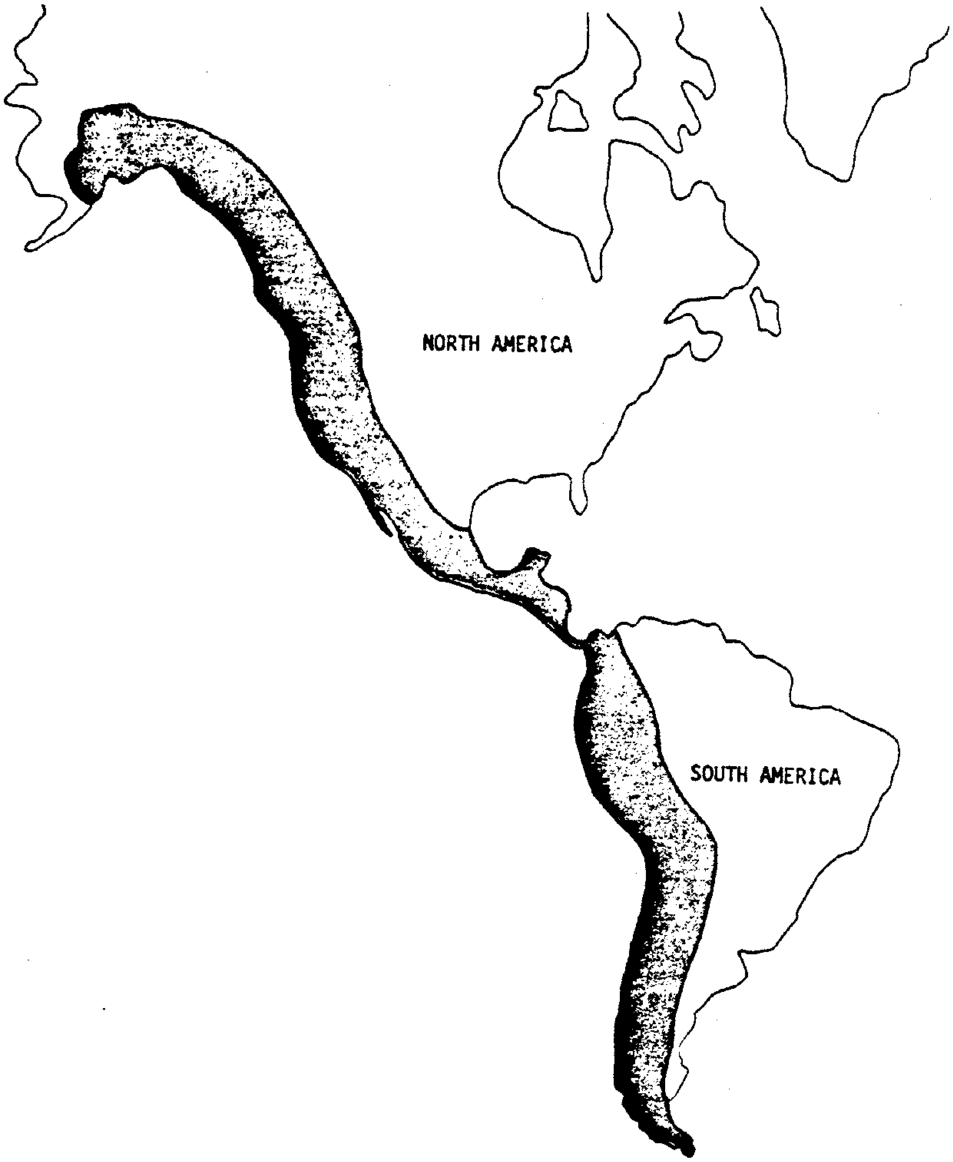


FIGURE 4-1. OCCURRENCE OF PORPHYRY COPPER DEPOSITS IN THE WESTERN HEMISPHERE

The principal copper-bearing mineral in porphyry coppers is chalcopyrite which is disseminated in large volumes of rock as blebs or small veinlets. Because copper porphyrites are also susceptible to secondary enrichment, the basic copper level in many has been enhanced with deposition of secondary chalcocite. Many southwestern United States porphyry deposits have been rendered economically minable by such enrichment.

Most porphyry copper deposits contain small amounts of other metals such as molybdenum and uranium. The composition of a typical porphyry copper ore is presented in Table 4-1. The ranges in values indicated for various constituents are based upon analysis of several samples taken from different parts of the same ore body. The magnitude of the variation of composition illustrates that it is difficult to make generalizations concerning the amounts of minor constituents in a given ore body. Thus, it is impossible to generalize minor constituent levels for specific minerals located in different ore bodies.

Table 4-2 presents the results of a more thorough analysis performed on a copper ore obtained from a boring near Safford, in southeast Arizona. This was accomplished in the course of a feasibility study (2) conducted by the Lawrence Livermore Laboratory to evaluate the potential for nuclear explosive fracturing followed by in situ leaching and recovery of copper. Specific attention was addressed to those elements that might be affected by the action of the nuclear explosive. (Due to environmental, social and economic considerations, nuclear fracturing was not conducted, and the technique is not considered further in this report.)

Nature of Surface Conditions

Soils

Materials overlying domestic porphyry copper deposits in the western United States range from outcrops of bedrock, typical of higher elevations, to thick accumulations of alluvium over deposits situated below the valley floors. In the arid and semiarid southwestern United States, climate is probably the dominant soil forming influence. Soils formed in an arid environment constitute the aridsol, a major class in soil science. Caliche is a common soil constituent and is caused by the accumulation of lime. Intermediate phases of calcification are reflected by the incomplete removal of alkali elements and compounds from bedrock and the conversion of alkaline earths to carbonates. A relatively low percentage of insoluble residue in these lime-rich soils is common. With the exception of climate and time, the effects of other standard soil-forming factors are minor. Topographic relief can be important locally. Parent material (bedrock), vegetation, and organisms generally play subordinate roles in the formation of arid and semiarid soils.

Hydrology

Southwestern United States porphyry copper deposits generally occur in the low and intermediate elevation deserts, which are semiarid. Both the surface and subsurface hydrology of the region differ between the alluvial fills, which

TABLE 4-1. - Typical Composition of Porphyry Copper Ore Deposits (3)

Constituent	Range in Composition (Percent by Weight)					
	Granite Porphyry	Quartz Monzonite	Quartz Monzonite	Quartz Monzonite	Granodiorite	Quartz Diorite
SiO_2	69-79	63-71	65-78	60-72	60-81	52-60
Al_2O_3	10.2-13.4	12.1-16.1	9.2-17.4	13.6-17.6	10.6-17.6	15.3-17.0
K_2O	3.1-6.4	3.2-5.5	1.9-7.5	3.0-8.0	0.65-7.6	2.3-17.0
Na_2O	0.5-2.9	1.4-4.3	0.05-5.2	1.6-4.0	0.07-4.3	2.2-3.6
CaO	0.1-1.4	0.9-3.9	0.01-3.3	0.08-2.4	0.10-5.0	2.4-6.6
FeO	0.01-4.6	1.5-4.4	0.04-9.0	0.02-4.6	0.23-5.2	2.2-6.6
MgO	0.33-1.3	1.2-2.5	0.20-1.2	0.13-1.8	0.03-2.3	2.6-4.3
MnO	0.01-0.04	0.01-0.04	0.01-0.04	0-0.04	0-0.26	0.04-0.09
TiO_2	0.17-0.67	0.33-0.67	0.17-0.67	0.17-0.83	0.33-0.67	0.67-1.17
S	0-2.6	0-2.9	0.04-5.0	0.02-1.70	0-3.4	0.04-6.3
Fe_2O_3	0-4.0	0-4.2	0-8.2	0-3.7	0-5.4	0-4.1
CO_2	0-0.95	0-2.6	0-1.2	0-1.6	0-2.1	0-0.7
CuS	0.002-1.5	0.002-1.5	0.04-3.6	0.03-0.9	0-1.5	0.06-0.60
MoS_2	0-0.03	0-0.17	0-0.17	0-0.10	0-0.10	0.001-0.002
PbS	0.002-0.006	0-0.0023	0.001-0.03	0.001-0.006	0-0.006	0-0.006
ZnS	0	0	0-0.21	0	0-0.04	0
NiO	0.001-0.003	0.0006-0.004	0.0013	0.0013-0.0025	0.006-0.002	0.001-0.006
Cr_2O_3	0.03-0.06	0.03-0.06	0.006-0.06	0.02-0.06	0.01-0.06	0.02-0.06
V_2O_5	0.02-0.04	0.02-0.04	0.01-0.04	0.02-0.06	0.02-0.06	0.04-0.07

TABLE 4-1. - Typical Composition of Porphyry Copper Ore Deposits (3) - Continued

Constituent	Range in Composition (Percent by Weight)					
	Granite Porphyry	Quartz Monzonite	Quartz Monzonite	Quartz Monzonite	Granodiorite	Quartz Diorite
ZrO_2	0.02-0.04	0.02-0.04	0.01-0.04	0.02-0.06	0.006-0.023	0.011-0.035
BaO	0.03-0.16	0.05-0.22	0.008-0.17	0.02-0.11	0.11-0.22	0.081-0.17
BeO	0-0.003	0.0006-0.001	0.0006-0.003	0-0.0028	0-0.0014	0.006-0.0019
SrO_2	0.01-0.02	0.03-0.12	0.01-0.18	0.01-0.08	0.02-0.11	0.035-0.059
Cl	0.002-0.02	0.005-0.02	0.001-0.019	0.003-0.033	0.005-0.061	0.007-0.040
F	0.03-0.2	0.03-0.09	0.03-0.20	0.05-0.10	0.02-0.16	0.07-0.19
Number of Samples	25	41	40	27	40	16

TABLE 4-2. - Complete Chemical Analysis of Safford, Arizona, Copper Ore [a]

Constituent	Concentration[b]	Constituent	Concentration[b]	Constituent	Concentration[b]
Lithium	10	Gallium	20	Samarium	9.3
Beryllium	5	Germanium	1.4	Europium	1.1
Carbon	300	Arsenic	8	Gadolinium	6.0
Nitrogen	20	Selenium	0.05	Terbium	2.5
Oxygen	480,000	Bromine	1.7	Dysprosium	2.8
Fluorine	220			Tantalum	3.5
Sodium	26,000	Rubidium	687	Holmium	2
Magnesium	5,000	Strontium	300	Erbium	4
Aluminum	77,000	Yttrium	34	Thulium	0
Silicon	330,000	Zirconium	200	Ytterbium	4
Phosphorous	800	Niobium	20	Lutetium	1
Sulfur	120	Molybdenum	141	Hafnium	1
Chlorine	210	Rhodium	0.01	Tungsten	1.5
Potassium	34,000	Palladium	1.0	Rhenium	1
Calcium	14,000	Silver	150	Gold	15
Scandium	3	Cadmium	2.0	Mercury	0.08
Titanium	2,300	Indium	0.26	Thallium	1.5
Vanadium	17	Tin	45	Lead	20
Chromium	150	Antimony	0.26	Bismuth	0.01
Manganese	900	Tellurium	0.001	Thorium	0.4
Iron	24,000	Iodine	6	Uranium	3.5
Cobalt	6	Cesium	5		
Nickel	154	Barium	830		
Copper	10,000	Lanthanum	60		
Zinc	60	Cerium	100		
		Praseodymium	4		
		Neodymium	54		

[a] Lawrence Livermore Laboratory, Livermore, California. Analytical technique - spark source mass spectrography. Arranged in order of increasing atomic numbers.

[b] Values expressed in ppm by weight.

predominate in the region, and the mountains that border the basins. Generally, the mountains are composed of crystalline granitic rocks and relatively impervious sedimentary and volcanic rocks. Aquifers usually do not occur in the mountain regions.

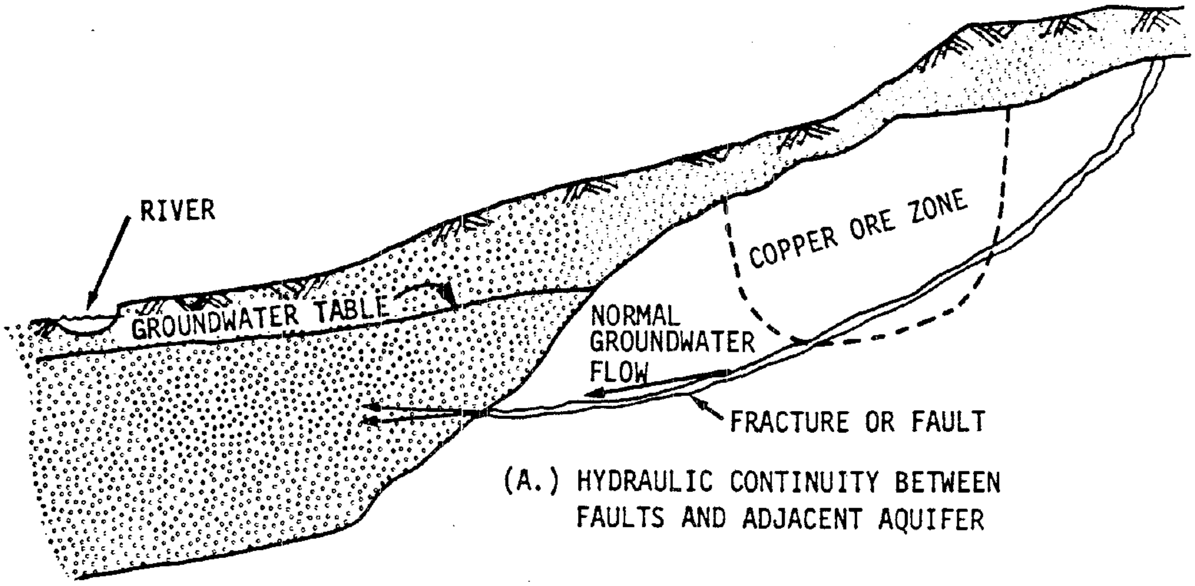
The alluvial fills in the basins or valleys are composed of poorly consolidated gravel, sand and silt with certain amounts of clays and caliche. These alluvial fills are the principal aquifers of the region and, in general, constitute the major water supplies.

The annual potential evaporation and transpiration greatly exceeds the annual precipitation in the area under consideration. Precipitation occurs primarily during the winter and summer seasons. Winter storms originate over the Pacific ocean and are characterized by low-intensity precipitation of several days duration. Relatively little runoff or streamflow is produced during these storms because the ability of the soil to absorb the moisture exceeds the precipitation rates.

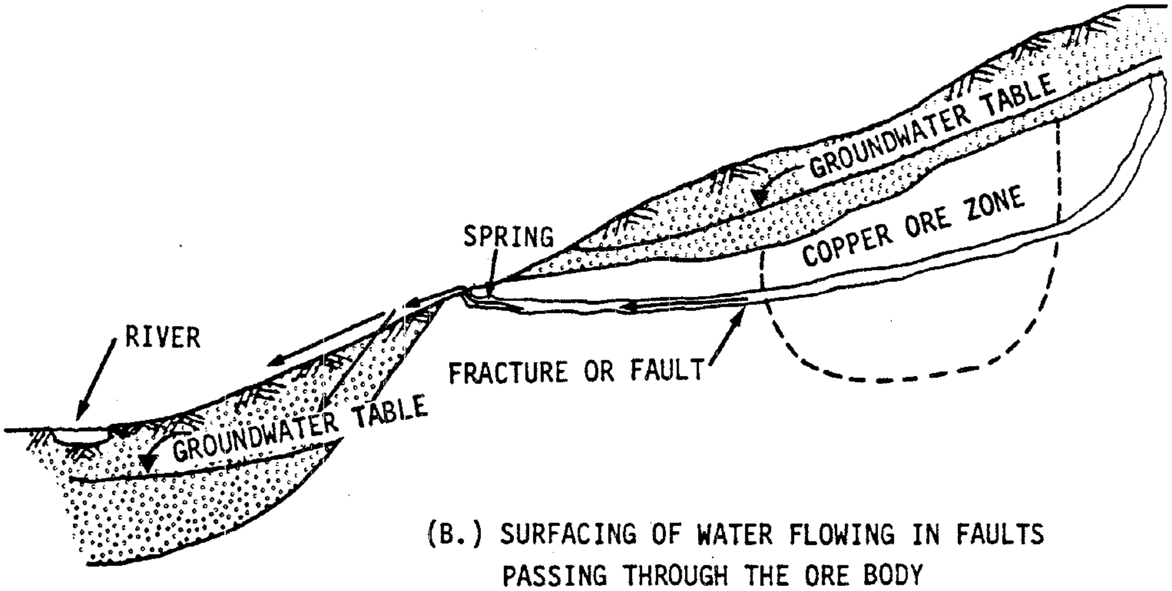
Summer precipitation usually occurs as thunderstorms originating from moisture masses formed over the Gulf of Mexico. These thundershowers are characterized by high intensities and short durations and frequently result in flash floods. Many of the arroyos traversing much of the low mountain areas and the alluvial fills contain runoff only during, and for several hours after, these summer thunderstorms. Diversion and retainment structures for the control of surface streams in most of the porphyry ore areas should be designed for the summer thunderstorm runoff.

The porphyry ore deposits generally occur in rock of little or no permeability. Aquifers composed of porous media do not usually exist directly adjacent to porphyry ores. Flow of water through or in the vicinity of ore bodies, if existent, usually occurs only in fractures and faults. The hydrologic properties of rock types typical to the porphyry region are presented in Table 4-3. Transmission of water through a region occurs only if the rock is fractured to a degree so that faults intersect each other. These intersections provide hydraulic interconnections between faults which permit the continuous flow of water.

Figure 4-3 illustrates the groundwater hydrology typical in rock zones bearing porphyry copper deposits. In both illustrated examples, alluvial fill overlays the ore deposit. It is possible, however, that the ore deposit could outcrop and no porous deposits would lie directly adjacent to the ore. If the ore deposit is overlain with alluvium, an aquifer could be present depending upon local physical and hydrologic characteristics. Generally, any overlying aquifers contain only limited amounts of water. Mining in an alluvial valley floor is becoming very controversial for coal mining which is regulated by the Office of Surface Mining. The total mineral industry could be affected by similar regulations in the coming years.



(A.) HYDRAULIC CONTINUITY BETWEEN
FAULTS AND ADJACENT AQUIFER



(B.) SURFACING OF WATER FLOWING IN FAULTS
PASSING THROUGH THE ORE BODY

FIG 4-3 TYPICAL HYDROLOGY OF PORPHYRY COPPER ORE DEPOSITS

TABLE 4-3. - Rock Types and Hydrologic Properties

ROCK TYPES	DESCRIPTION	FEATURES	GROUNDWATER
Crystalline and Metamorphic complex	Coarse crystalline granite to fine-grained schist and dikes	Highly fractured at some locations	Limited amounts of groundwater in weathered zones and at fractures.
Pre-tertiary sedimentary rocks	Conglomerates, quartzites, shales, sandstones, and limestones	Folded and faulted and highly fractured in many places	Groundwater where faulted or where solution channels have developed in limestone
Cretaceous and tertiary sedimentary	Conglomerates, sandstones, gypsiferous beds and fresh-water limestones	Limited faulting	Many contain groundwater in small quantities
Tertiary or Quaternary terrace deposits	River gravels	Granular	Not known to carry groundwater
Cretaceous and tertiary volcanic rocks	Rhyolite, latite, dacite, trachyte, and esite	Interbedded with sedimentary materials. Fault blocks are common	Limited quantities of water in fissures and in porous pyroclastic materials - springs
Quaternary volcanic	Basalt flows	Extensively jointed. Generally above groundwater table	Minor importance in the storage and transmission of water

Biology

The subject porphyry copper area lies principally within the Sonoran Desert of the southwestern United States, with its southeastern portion extending into the Chihuahuan Desert. The only major perennial stream traversing this area is the Colorado River, which exerts a very restricted influence upon the desert vegetation. Portions of its meandering course, which are flat and subject to inundation, are covered with emergent swamp plants or cottonwood forests. There are few places where the width of palustrine (marsh) vegetation exceeds 3 kilometer (2 miles).

Two major vegetational associations comprise the portion of the Sonoran Desert under consideration: the Lower Colorado Valley microphyllous (small-leaved) association and the Arizona Upland crassicaulescent (large-stemmed) association. The Lower Colorado Valley embraces the lower drainage of the Colorado and Gila Rivers and the Salton Basin, and is one of the most arid portions of the Sonoran Desert. Surface features are diverse and include volcanic and granitic mountains, sandy plains and dunes, and alkali flats. The greatest percentage of the area is characterized by the flat sandy plains. The vegetation of the Lower Colorado Valley is distinguished by its simplicity, with two shrub species, creosotebush and white bur-sage, forming 90 to 95 percent of the plant population in low open stands covering the intermontane plains. On the upper slopes and pediments and along drainageways, small trees occur, notably honey mesquite, paloverde and ironwood. A large variety of ephemeral herbaceous species produce dramatic flowering displays annually following winter rains.

The Arizona upland community characterizes the eastern portion of the designated porphyry copper area and consists of several species of small-leaved trees as well as shrubs and numerous cacti. Principal non-riparian trees are foothill paloverde, sahuaro, ironwood, elephant tree, crucifixion thorn, desert-olive, ocotillo, holocantha, the tree-like chollas, and the columnar organ-pipe cactus and senita. Principal riparian trees of the arroyos and washes include blue paloverde, honey mesquite, catclaw, smoketree, desert willow, jumping bean and hackberry.

Creosote bush is an important member in the upland community as are a large variety of cylindropantia and platyopuentia cacti, and several perennial grass species.

The Chihuahuan Desert is essentially a shrub desert and lies mostly above 1,070 meters (3,500 feet) in the designated porphyry copper area. The four major plant association-types of the desert, occurring within the designated area, are dominated by tarbush, creosotebush, sandpaper bush, or white thorn. In various areas these dominants are associated with such species as desert sumac, senna, ocotillo, honey mesquite, and others. Grasses are in greater abundance in the more highly elevated Chihuahuan Desert than in the Sonoran.

Wildlife inhabitants of the subject porphyry copper area are typically small, arid-adapted species, many of which are nocturnal. Due to their moisture conserving adaptations, or lack thereof, reptiles and small rodents display the greatest species diversity of the vertebrate groups in this area, and amphibians, the least.

MINING AND MILLING

Ore Body Preparation

The primary objective in preparing a porphyry copper ore body for in situ leaching is fracturing the ore into rock sizes less than several centimeters (inches) in diameter, creating increased permeability and permitting a leaching solution (lixiviant) to flow at a sufficient rate to effect an economically viable mining operation. Leaching of copper from the ore by the lixiviant is basically a dissolution process. Large surface areas increase the rate of copper recovery; therefore, the smaller the original rock sizes, the more rapid the copper leaching process. Figure 4-4 illustrates a leached zone, a reaction zone and a virgin zone within a single rock. Blasting and block caving are the two fracturing techniques utilized for ore body preparation.

Blasting

Blasting is the most commonly used fracturing technique applicable to ore preparation for in situ leaching. Table 4-4 describes the recent large in situ blasting operations. The Zonia No. 1 blast holds the record as the largest non-nuclear blast.

Development of the permeability required for leaching is accomplished by providing void spaces within the ore body. A typical ore body expansion of up to 15 percent is generally sufficient to provide the required void spaces in most porphyry copper ores. Expansion of the ore body may result in the formation of a mound immediately above the deposit. The actual increase in surface elevation depends upon the depth of the ore fractured and the resulting porosity. Typical mound heights are 3 to 9 meters (10-30 feet) for previous large blasts.

Currently, tests are underway at sites in Arizona and New Mexico of blasting in deep ore bodies approximately 600 meters (2,000 feet) in depth. In these tests, small glass beads are forced into the blasted ore body to prevent collapsing of the newly formed fissures. These blasts have reportedly caused no noticeable uplift of the ground surface.

There are several techniques for setting the explosives, and various types of explosives are normally considered for each site. Factors such as rock characteristics, slope of ore body, the presence of groundwater, existence of previous mine tunnels, and topography dictate the design of the blast. Proper design of a blast, incorporating basic field data from test blasts, such as the frequency of ground movement, the ground transmission constant and the wave amplitude, can minimize both environmental and structural damage. In general, charges are set in holes drilled for the blasting operation, or in abandoned mine tunnels located beneath the ore body, if previous mining operations existed. Thorough descriptions of the design of large blasts have been presented in Porter and Carlevato and Ward (5-6).

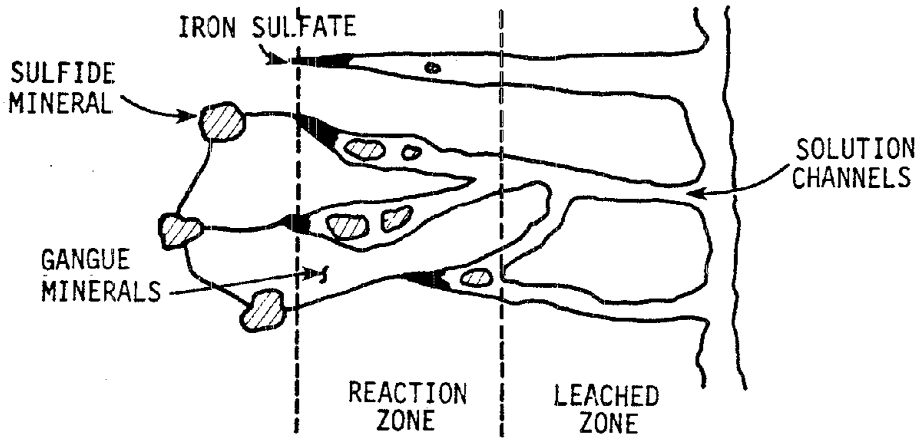


FIG. 4-4 - MODEL OF A SULFIDE BEARING ROCK BEING LEACHED. FLOW IS PERPENDICULAR TO PLANE OF DRAWING.

TABLE 4-4. - Copper Ore Body Fracturing by Blasting for In Situ Preparation

Location	Date	Charge	Ore Fractured (tons)	Swell	Fractured Rock Size
Big Mike Nevada	July 1973	182,000 Kg 400,000 lbs ANFO [a]	[b]	[b]	50% < 22 cm
Old Reliable Arizona	March 1972	1,818,000 Kg 4,000,000 lbs ANFO	5 million	7%	85% < 22 cm
Zonia No. 1 Arizona	April 1973	1,826,000 Kg 4,150,000 lbs ANFO	5 million	6%	[b]
Zonia No. 2A Arizona	March 1974	405,000 Kg 890,000 lbs ANFO Gel-ANFO	1 million	[b]	[b]
Zonia No. 2B Arizona	May 1974	200,000 Kg 1,540,000 lbs water gel-ANFO	2 million	[b]	[b]

[a] Ammonium Nitrate-Fuel Oil
[b] Information not presented in articles analyzed for preparation of this table.

Block Caving

The second method for ore fragmentation is block caving. This method has been employed for many years in the removal of relatively low grade ores which are too deep for conventional surface mining operations. In a block caving operation, tunnels are excavated below or within an ore body and the rock ceiling, directly above specially constructed draw points, is repeatedly blasted and removed which affects a gradual caving and downward movement of the entire ore body. As the ore body proceeds downward, progressive fracturing occurs. The degree of ore body fragmentation achieved is a function of vertical distance traveled, which is a function of the amount of ore withdrawn at the draw points. Ore samples from certain ore bodies, block caved during deep mining operations, have displayed average fragment diameters of a few centimeters (inches), a size amenable to in situ leaching.

The only ore body that has been block-cave fractured exclusively for in situ leaching is at Mountain City, Nevada. It was necessary to remove approximately 12 percent of the ore to achieve the required degree of fragmentation in the remainder of the ore body. It is possible that ore bodies with different structural characteristics would require removal of a greater percent of the ore to achieve adequate fracturing. The Mountain City ore body was 60 meters (200 feet) thick and covered by 60 meters (200 feet) of overburden. Removal of 12 percent of the ore body resulted in fracturing of the overburden and some surface subsidence.

An inherent product of in situ fracturing by block caving is the surface deposition of large quantities of ore or spoil withdrawn to promote caving. A sulfide milling plant would not be required to process this ore if it were amenable to dump or heap leaching. The size of the dumps or storage areas occupied by the withdrawn material can be predicted from the ore body fraction required for removal (usually 5 to 20 percent) and the expected expansion factor of the material when placed in the surface (usually 15 to 30 percent).

At Miami, Arizona, in situ leaching has been employed following conventional block caving. In this deposit recovery by deep tunnel, block caving became uneconomical as the copper concentration of the ore decreased. Thus, in situ leaching was implemented rather than abandoning the low grade ore.

From a mining viewpoint, there is little difference between in situ leaching a virgin ore body prepared by block caving fragmentation and leaching a previously mined area fragmented by block caving. There are, however, considerable differences in the environmental implications of mining virgin, as opposed to previously mined, areas. Previously mined areas typically have extensive disruption of surface flora and fauna, such as waste dumps, tailings ponds, access roads, shops and office buildings.

Leaching Facilities and Processes

Lixiviant Application and Recovery Facilities

Following fragmentation by controlled blasting or block caving, a lixiviant may be introduced into the fractured ore body in a number of ways which include:

1. Surface spray application above the ore body;
2. Flooding a small rather than a large surface area by a staggered grid system of ponds;
3. Strip or ribbon flooding as commonly used in agricultural irrigation;
4. Injection into wells thus facilitating lixiviant application directly to the ore without percolating through an overburden.

Spraying and injection are the more common application methods. Spraying is effective for even solution application where permeabilities are equal over a large surface area. However, evaporative losses are high and windblown spray may be hazardous. Injection is effective in placing the lixiviant under overburdens with low permeabilities or high percentages of alkaline material. It is also effective in introducing lixiviant into ore pockets not accessible through gravity application.

Presented in Figure 4-5 and 4-6 are typical leaching scénarios for a blasted and a block caved ore body. Figure 4-5 depicts a block caved ore body overlain by an alluvial cap with an injection lixiviant application system. Figure 4-6 depicts a block caved ore body with no alluvial cap and a sprinkler application system. It should be recognized that several other potential scenarios may be construed by recombining the variable conditions presented in each illustrated scenario.

In all types of application systems, the lixiviant flows through an ore body which is in an unsaturated condition except for an area around the collection area. It is therefore unlikely that lixiviant will escape from the ore body along faults unless they intersect the saturated flow zone at the bottom of the fractured ore body. In unsaturated conditions, lixiviant could escape through faults, while in saturated conditions, a hydraulic gradient toward the leach zone can be maintained.

Chemistry of Leaching

Two principal leaching solutions are currently used for in situ copper leaching: 1) dilute sulfuric acid; 2) dilute oxidizing sulfuric acid. Details of the chemical compositions of the leaching solutions are presented in the following two paragraphs. The solution choice depends upon the composition of the copper ore. Copper in completely oxidized ores can be dissolved by any dilute acid; partially reduced or reduced ores (sulfides) require oxidation before dissolution will occur in dilute acids. There is little difference

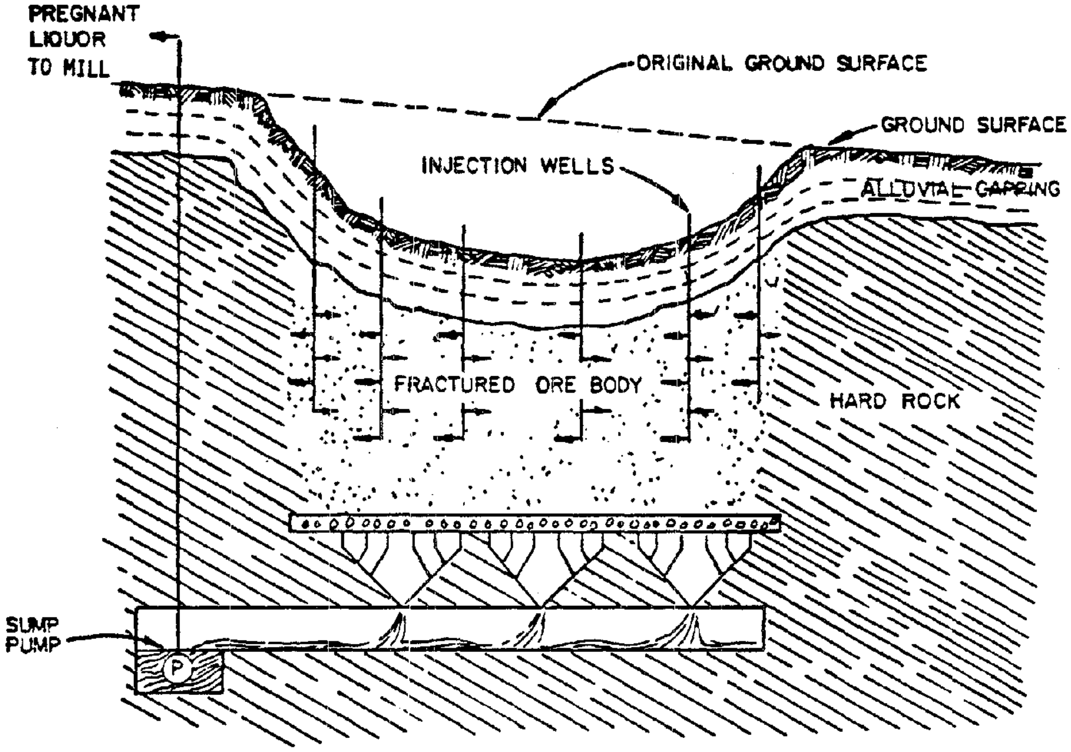


FIG 4-5 IN SITU COPPER LEACH - BLOCK CAVED ORE BODY
INJECTION APPLICATION - WITH ALLUVIAL CAP

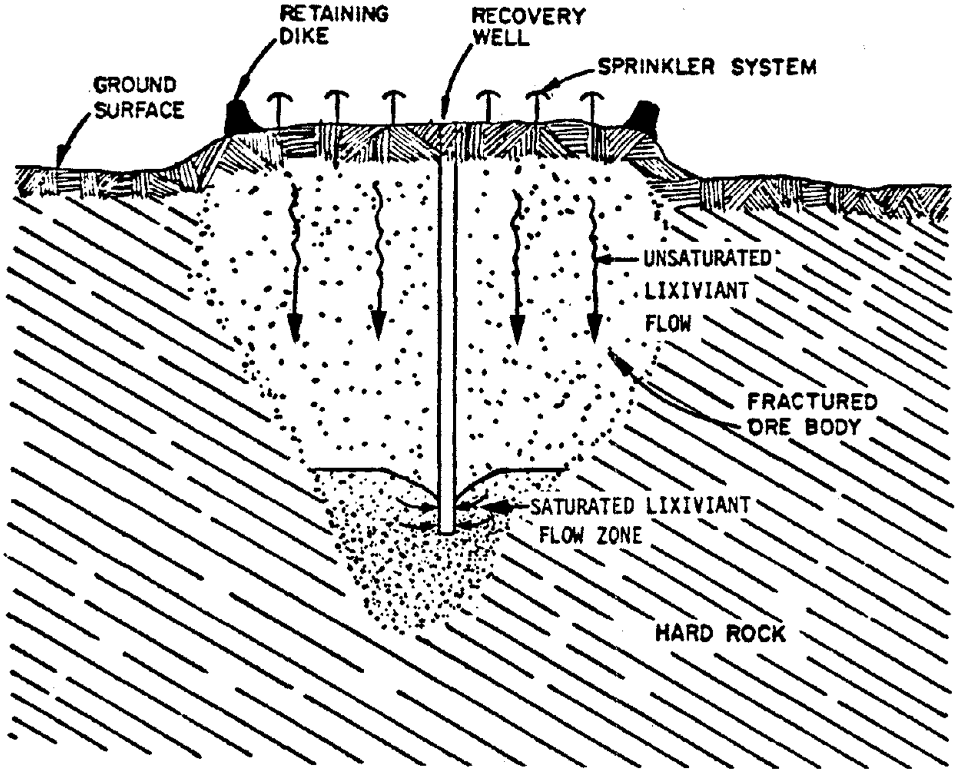


FIG 4-6 IN SITU COPPER LEACH BLASTED IMPERMEABLE ORE BODY WITH SPRINKLER APPLICATION-NO ALLUVIAL CAP

between the two lixiviant systems in terms of potential environmental effects. A discussion of ore deposit characteristics affecting lixiviant selection and action follows.

Oxidized copper ores (copper oxides, carbonates, silicates) are readily leached by dilute sulfuric acid in concentrations of approximately 10 g/l (pH 1). Sulfuric acid is used because it is more economical and more readily available than other acids. Acid alone without an oxidizing agent will yield theoretical copper recoveries of 100 percent only if the copper is in the completely oxidized form (divalent, or cupric species) and is not combined with sulfur.

Sulfide and partially oxidized copper ores can be leached by a dilute sulfuric acid solution containing an oxidant. To date, atmospheric oxygen has been universally employed as the oxidant. Pyrite, which is naturally present in the ores, provides the sulfuric acid and ferric sulfate for the leaching cycle when it is leached. Iron oxidizing bacteria serve an important role in the leaching of copper ores by accelerating the oxidation of pyrite. Bacterial action is enhanced by suitable pH, good aeration, appropriate temperature range (35°C is optimum), absence of light, and presence of nutrients (7-8).

Other oxidants such as chlorine and nitrate (sodium, potassium nitrate) have been considered, but chlorine is expensive and causes equipment-corrosion problems. The injection of oxygen directly into leaching areas has been tried experimentally, but detailed testing and cost data are not available.

Of the important sulfide copper ore minerals, chalcocite (Cu_2S) is the most soluble in the acid ferric sulfate leach solutions. Bornite (Cu_5FeS_4) and covellite (CuS), less important as ore minerals, are less rapidly dissolved. Chalcopyrite, a most important ore mineral, is the slowest to dissolve. The dissolution reactions are not instantaneous and are slowed by intermediate coatings of sulfate formed on the mineral surfaces.

Experience indicates that fragmented chalcocite copper sulfide ore containing some oxides at maximum ore sizes up to about 1 meter (3 feet) in diameter may yield an estimated 20 percent of the copper during the first year of leaching and 5 to 10 percent per year thereafter. Chalcopyrite ore without the oxides may release only 4 to 8 percent of its copper value during the first year, depending upon the amenability to leaching of the particular local chalcopyrite, and decrease to 1 to 2 percent per year thereafter. The duration of the economic life of a leaching-recovery operation at a given site may exceed from 5 to 8 years.

As indicated earlier, typical metal ore bodies contain many minor metals in addition to the major metal. Sulfuric acid is non-selective in its action as a leaching agent. Thus, not only are most metals (including the relatively abundant iron) put into solution during porphyry copper leaching, but many gangue constituents are also dissolved and consume considerable reagent. The list of elements comprising a typical copper ore has been presented earlier (Table 4-1) and serves as an example of the trace elements which may be present in a porphyry copper body. Most of the elements listed are soluble in sulfuric acid to some extent. Many facilities are designed to recover some of these trace metals as a byproduct (particularly uranium and molybdenum). Due to the site specific nature of these byproduct operations, this chapter deals only with primary copper recovery.

It should be emphasized that compositions of pregnant leach solutions cannot be predicted completely from ore analyses. An ore analysis should be considered a list of potential constituents of leaching solutions, as many of the elements in an ore may not be solubilized by the lixiviants. Predicting minor constituent levels can be accomplished only in the laboratory in pilot scale tests.

Figure 4-7 is an example of the composition of a solution used for leaching of a primary prophyry copper ore (San Manuel Mine, Magma Copper Company, Arizona). The data in the figure was obtained in laboratory leaching studies using a sulfuric acid lixiviant by Braun, Lewis and Wadsworth at the Lawrence Livermore Laboratory (9). It is seen that the laboratory study approached a steady state within 60 to 100 days after commencement of leaching. In a full scale in situ leaching operation, the time required for attainment of a steady state would probably be substantially longer due to the longer elapsed times required for flow from the application point to the recovery point.

In examining Figure 4-7, it should be realized that the only constituents actually added to the lixiviant are the sulfate and the iron species. The other species present result from the chemical action of the lixiviant upon the ore body. The data indicate that substantial concentrations of sulfate, copper, calcium, magnesium, and aluminum occur. The total dissolved solids exceed 30,000 mg/l which is approximately the salinity of seawater. Chemical species dissolve from the ore increasing solution concentrations until equilibrium is attained whereby dissolution stops or reprecipitation occurs at a rate equal to the dissolution rate. Ions such as calcium and ferric iron achieve saturation values rapidly. Braun and others believe that iron, sodium and potassium are limited by the formation of jarosites. Calcium probably precipitates as the sulfate (9).

The continued accumulation of dissolved impurities in recycled lixiviants can inhibit copper dissolution by coating the copper minerals with scale of precipitated salts, which also reduces the permeability of the fractured deposit. This salt buildup in the recycled solutions is controlled by running a waste stream or bleed-off of the barren solution. This bleed-off has a composition similar to the pregnant solution with the exception of a much lower concentration of copper. At the present time, bleed-off is typically dumped into tailing ponds.

Beneficiation Facilities and Processes

Presently, copper is recovered from leach liquors by two processes: scrap iron cementation and solvent extraction (SX). Scrap iron cementation is still in use at older facilities but modern plants are designed with SX because this method produces cathode copper which does not require smelting, as does scrap

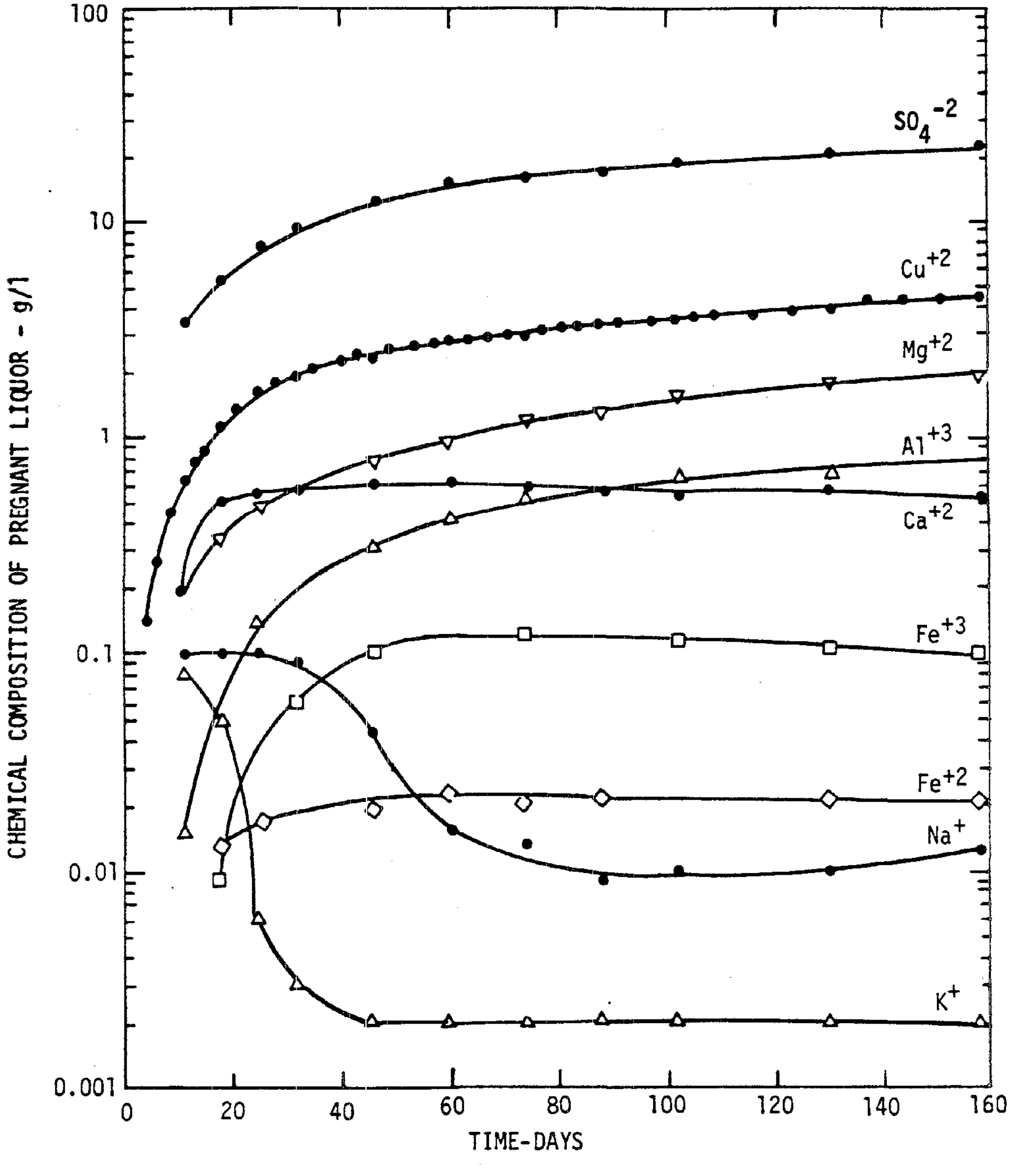


FIG 4-7 CHEMICAL COMPOSITION OF PREGNANT LIQUOR VS TIME. (9)

iron cementation copper. Due to the high cost of smelting and refining and the current very real shortage of smelting capacity, the combined techniques of solvent extraction-electrowinning (SX-EW) has become the primary beneficiation process for copper. A simplified flow sheet for a typical SX-EW plant is presented in Figure 4-8. Detailed discussions of the beneficiation processes are beyond the scope of this study. The reader is referred to Extractive Metallurgy of Copper (10) for excellent, detailed information on the beneficiation processes.

The solvent used for metal extraction in solvent extraction systems commonly consists of about 5 percent active metal extractant dissolved in a hydrocarbon diluent such as refined kerosene. This organic solvent is mixed intimately with the pregnant liquor containing perhaps 0.5 to 1.0 grams copper per liter. Next, since the mixture is essentially nonmiscible, the organic and aqueous constituents are allowed to separate in a settler. The copper has transferred from the aqueous to the organic, whence it is stripped into a purified and concentrated solution suitable for product recovery. The leaching liquor, with its copper values removed, is fortified in strength and returned to the ore.

The stripping solution with a copper concentration of between 25 to 40 g/l is fed to an electrolytic tankhouse to produce quality copper cathodes. Power consumption by electrowinning is approximately one kilowatt-hour of electricity for 0.45 Kg (1 lb) of copper. Precipitation of one unit of copper as cathode regenerates about 1.5 units of sulfuric acid, which is returned to the leach circuit. The amount of copper which is solubilized by a unit of sulfuric acid depends on the ore composition. Alkaline ore constituents can consume large amounts of acid.

Every effort is exercised to minimize losses of the expensive mixed organic via the raffinate (liquid ion exchange barren solution). Normal losses are about 0.05 liter of organic solution per 1,000 liters of leach liquor treated.

As indicated earlier, salt buildup in the lixiviant circuit is controlled by wasting from the raffinate. This is a high salt content waste with a typical constituent concentration as shown in Table 4-5.

Typical In Situ Copper Leaching Operation

To give the reader an indication of the size of the various components of an in situ leach operation, the characteristics of a typical operation are presented in Table 4-6. It should be recognized that this is a composite plant and that sizes of the components, grades of ore, flow rates and other factors will vary with each facility.

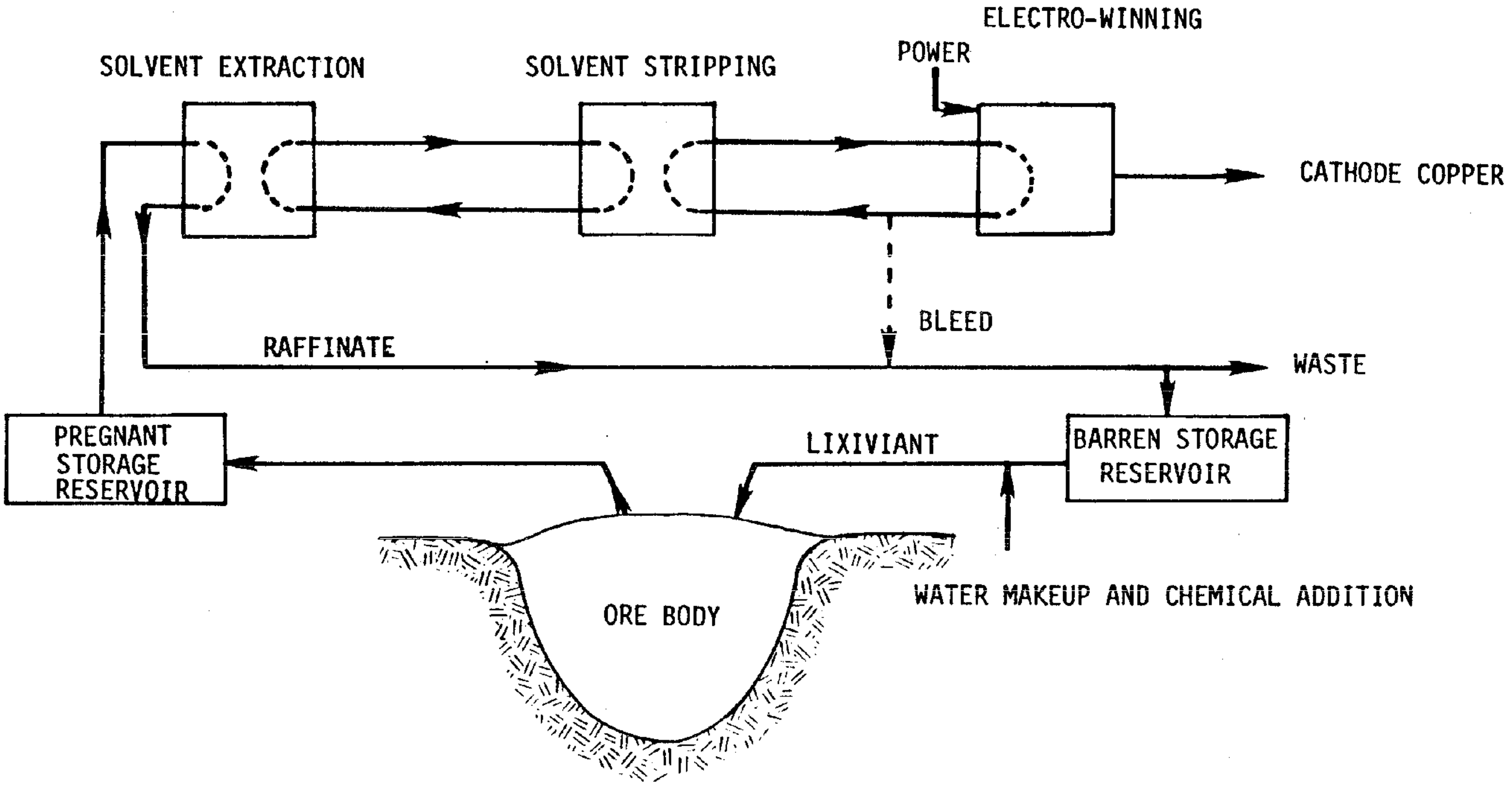


FIGURE 4-8 FLOW SHEET OF TYPICAL SOLVENT EXTRACTION ELECTRO-WINNING PLANT

TABLE 4-5. - Estimated Chemical Characteristics of a Typical In Situ Copper Waste Stream, Adapted From Sheffer and Evans (1)

Constituents	Concentrations [a]
Sulfate	20,000
Magnesium	2,000
Aluminum	800
Calcium	500
Copper	100
Iron (Fe^{++}, Fe^{+++})	100
Sodium	10
Potassium	2
Organic ion exchange media	5
Kerosene	-- [b]

[a] In mg/l.
[b] Unknown but will occur in raffinate.

TABLE 4-6. -- In Situ Copper Leaching Scenario

Component	Characteristics
Ore Body	
Size of ore body	5 million tons
Grade of ore	0.5 percent
Depth of overburden	15 m (50 ft)
Depth of ore	45 m (150 ft)
Plan area of ore body	4 ha (10 ac)
Ore Body Preparation	
Type of ore body preparation	Blasting
Size of charge	2,273,000 Kg (5 million lbs) ANFO
Surface expansion	6 m (20 ft)
Leaching Facilities	
Type of application	Injection and extraction wells
Flow rate	132 l/sec (2100 gpm)
Concentration of copper in pregnant liquor	1.0 g/l
Beneficiation Facilities	
Type	SX-EW
Production	10 TPD
Waste flow	6.3 l/sec (100 gpm)
Area Required for Evaporation [Assume 25 cm/yr (10 in/yr)]	
Without volume reduction	6.4 ha (16 ac)
With volume reduction (RO unit) 60% rejection	2 ha (5 ac)
Summary of Area Required	
Mine & associated roads	8 ha (20 ac)
Mill & maintenance area	2 ha (5 ac)
Waste disposal area	8 ha (20 ac)
Buffer & protective	40 ha (100 ac)

ENVIRONMENTAL REVIEW

Introduction

When considering the impact of the development of a mine operation upon the desert southwest it is important to bear in mind the uniqueness and comparative fragility of this ecosystem. The deserts of the southwestern United States comprise one of the largest unbroken sections of wilderness remaining in the continental United States, excluding Alaska. Many desert species are highly specialized to withstand extremes of aridity, temperature, and light, and are the subject of intense research to disclose adaptive mechanisms that might be of use to man.

Several unique and poorly understood habitats occur in isolated fashion throughout the desert, including springs and oases, humid mountaintops, sand dunes, and playas (flat desert basins). These habitats exist in a delicate ecological balance extremely sensitive to disturbance and harbor many specially adapted plants and animals found nowhere else. Experts contend that many invertebrate species, yet to be described, reside in these habitats, particularly in the sand dunes. Studies of the impact of recent extensive off-road vehicles' encroachment upon the desert have served to illustrate the high susceptibility of this ecosystem to damage and emphasize the importance of careful design and siting of any development therein.

Natural surface and subsurface conditions may be altered either directly or indirectly in the course of a typical in situ porphyry copper mining operation by several activities. Principal impact-producing activities in this respect are associated with: 1) establishment and operation of general mine facilities; 2) ore body preparation by blasting or block caving; 3) lixiviant application; 4) waste disposal; 5) subsurface lixiviant action. Specific impacts associated with each of these activities are discussed in the following sections. Impacts which do not directly involve physical regime modification include those associated with energy consumption and accidents and are discussed elsewhere.

Establishment and Operation of the Facility

As is true of any mining operation, a certain amount of vegetation removal and disturbance to soil and landform is incurred in the accommodation of surface facilities required to implement an in situ porphyry copper mining operation. The areal extent of this disturbance is a function of the size of the ore body and magnitude of the mining effort. Surface areas of facilities involved in a typical in situ porphyry copper mine have been discussed earlier in this chapter. As described, facilities are generally sparing and limited to fieldhouses, maintenance areas, roadways, injection wells and/or solution application equipment, recovery wells, monitoring wells, beneficiation facilities, and waste disposal (evaporation) ponds. Careful planning of the site layout in a manner that minimizes desert floor disturbance encourages optimum restoration of the mining site towards natural conditions following mine closure.

Construction activity associated with mine establishment and operation may be expected to produce dust and exhaust emissions, and noise disturbance characteristic of any construction operation. Such disruption is usually of a relatively short-term nature, although it may be of comparatively greater adverse aesthetic and biological impact than most construction operations due to the frequent impact on the pristine nature of the area. Once established, in situ leaching operations are very quiet and involve much less equipment noise, dust and exhaust emissions, and human and vehicular activity than conventional mining operations.

Most desert soils have a mantle formed by the cementing action of various carbonates or by the filaments of soil microbes, or by both in combination. There is often also a cobble, or "pavement," of close-set gravel or pebbles that have been sorted out into a surface layer by wind action occurring over the years. The delicate mantle or pavement crust acts as a lid which minimizes disturbance of the fine soil beneath.

When the surface crust is broken by vehicle passage or construction activity, the underlying soil is exposed to dessication and erosion by water and wind. Vehicular passage over the soil also results in compaction, an increase in density and decrease in air spaces within the soil. The resultant decrease in permeability and porosity reduces the ability of the soil to hold and transport water and therefore greatly limits plant growth in the compacted zone. Slow growth rates and harsh desert conditions compound the difficulty of native perennial recovery in a denuded compacted area. A compacted area also significantly increases surface runoff.

Another general impact category, which should be discussed briefly at the outset, is wildlife disturbance and eviction. This results from the establishment of mine facilities and from almost all activities associated with operation of the mine. It is often implied that when an area is disturbed by man, wildlife inhabitants can simply move to adjacent undisturbed territory. This is true only to a very limited extent. Natural biotic communities may be extremely complex and embrace very large numbers of animals within small areas. Many of these organisms are of low mobility and may be killed outright by disturbance. Other highly mobile species may simply refuse to emigrate, and still others which do move are often rapidly eliminated by predation, accidents, and unsuccessful competition for food and territory.

An adverse impact, often accompanying the advent of human activity in an undisturbed natural area, is the inadvertant introduction of alien flora. Once such exotic species are introduced, they may often take over the area around the disturbance and exclude native growth due to the exotic species' superior adaptive mechanism and the absence of native control agents. Care must be exercised during vegetation efforts to ensure that seeds of alien plant species do not accompany desired varieties.

Ore Body Preparation

As previously explained, porphyry copper ore is usually found in hard rock strata which requires fracturing to induce a permeability sufficient for desired lixiviant action. Fracturing is accomplished either by blasting or block caving.

Blasting may be conducted near the surface or at considerable depths, depending upon the location of the ore body. In the case of near-surface blasts, desert floor integrity is usually severely disrupted and vegetation completely removed either directly by the blast itself or by preparation of the area for the blast. As described earlier, ore body expansion by blasting may alter landform by producing a mound above the deposit. If the blasted area is overlain by an aquifer or if groundwater flows along fissures and faults within the ore body, blasting may severely disrupt the groundwater hydrology in the area. Some wildlife may be killed or injured by the blast, although often most will have been evicted from the area prior to the blast by site preparation. Through proper blast design, projectiles can be minimized thus restricting substantial disturbance to the general area directly above the ore body.

The extent to which animal populations may be disturbed by the sonic and vibrational properties of a blast is difficult to determine. It is well known that certain vertebrate behavior patterns are rather easily upset by foreign auditory and/or tactile stimuli, and that such disruptions may result in short-term reductions in reproductive success. If blasting were to be performed on a recurring basis, it is likely that certain species of wildlife would refuse to inhabit the surrounding affected area.

Minimizing the likelihood of property damage to wells, industrial structures, homes, and other improvements from near-surface blasts is fundamental to a successful blast design. Demonstration projects conducted in Arizona and New Mexico in extremely deep ore bodies have shown that surface disturbance from blasting at such depths is reduced to simple ground acceleration (11-12).

If block caving is employed to fracture an ore body, ground subsidence over the caved area is a long-term eventuality. With appropriate engineering measures, subsidence may be reduced or eliminated over the short term; however, the long-term effects of block caving are largely unpredictable in this respect and are specific to the site and magnitude of the operation in question. As with blasting, subsidence may have a significant impact on the groundwater hydrology depending upon the site specific geohydrologic characteristics. Progressive ground subsidence may, over a period of several years, affect dramatic changes in landform character by creating a large unstable depression. Surface depressions formed by subsidence are usually characterized by surface fractures, stepped terraces and near vertical walls. The amount of subsidence caused by a block caving operation is, of course, dependent upon the amount of underground material removed to promote the required degree of ore body fragmentation. A review of the current literature reveals no surface reclamation attempts.

Surface alterations to soil and local topography brought about by the subsidence process can be deleterious to native plant cover in several ways. Direct damage may be incurred by actual uprooting when abrupt earth slippage occurs. Surface cracking may expose root systems to injury and reduce their ability to anchor the plant and perform their natural nutrient acquisition functions. Longer term complications may arise from soil creep and general instability, increase in topsoil erodability by wind and thundershowers, removal of topsoil by small landslides during abrupt earth slippages, and decrease in moisture retention ability of substrate where subsidence has produced or increased vertical aspect of slopes.

Cracks produced by surface fracturing are usually relatively small and easily traversed or, if necessary due to size, avoided by humans and vehicles. It is conceivable, however, that the cracks might be hazardous to cattle or wildlife traversing the subsided area.

Potential degradation of vegetative cover by subsidence over the short-term is a moot consideration if surface lixiviant application is anticipated, since this procedure is necessarily preceded by surface clearing. Surface clearing will completely remove the flora in a given area and require migration of the wildlife. These impacts would usually be minor due to the small area of land directly affected.

If, on the other hand, the lixiviant is to be applied by injection, the disturbed surface of either a blasted or a block caved ore body could be reclaimed by regrading and revegetation.

The small percentage of the ore body removed during block caving may be leached (dump or heap) to recover the copper values. The resulting tailings disposal site, although smaller, will create problems similar to other tailings. These include wind and water erosion (if not stabilized or revegetated), the possibility of leaching gangue minerals, and aesthetics.

Lixiviant Application

As described earlier, a leaching solution may be introduced to a copper ore body via two basic routes: 1) through the overlying soil mantle by surface application, or 2) directly into the ore body by injection wells. A discussion of the environmental implications of each technique follows.

Leaching by application of an acid lixiviant (usually sulfuric acid) to the surface over an ore body poses both short- and long-term threats to native vegetation and wildlife. As previously mentioned, all ground cover is cleared initially from the application area in the course of its preparation. Continual introduction of a strong acid into the soil over an extended time period sterilizes it of all micro-organisms and fosters a considerable accumulation of salts and other toxic compounds. This combination of effects can be expected to produce a soil environment that is very difficult for recolonization by native plants, long after cessation of a leaching operation and the reclamation steps.

No present data are available which quantify chemical changes in soil composition promoted by extended strong acid application such as would occur in a typical full-scale leaching operation. Even if such data were available, present understanding of soil dynamics does not enable forecasting of the period after cessation of acid application for a desert soil ecosystem to return to a condition permitting colonization and establishment by native vegetation. It is reasonable to assume that the scarcity of rainfall in the desert environment would extend the recovery period since little water is provided to act as a natural mineral leaching agent. It is conceivable that certain acid-adapted halophytes (salty-soil plants) could be introduced successfully to a surface-leached site long before it became inhabitable by other desert vegetation. Other techniques, such as providing a topsoil blanket over the sterile zone, may be effective in allowing native growth to reestablish itself. However, capillary action could draw toxic minerals up into the topsoil rendering it an unsuitable habitat for revegetation. With this technique, topsoil would be removed and stockpiled prior to mining.

If lixiviant is applied to the surface by a spray or sprinkler system, the sphere of environmental hazard is extended beyond the application area itself by the potential for airborne transport of acid aerosol. While such migration and eventual deposit of acid may not occur on a scale sufficient to cause significant degradation to the soil beyond short distances, vegetation and wildlife are threatened with injury over an undetermined radius. It may be hypothesized that, in practice, wind patterns and application design act to establish a gradient of environmental damage of ever decreasing magnitude as distance from the application area increases. It is possible to minimize aerosal problems encountered with surface application by designing an application system which disseminates large droplets or by utilizing a flood application method.

Most surface damage can be avoided by introducing the leaching solution directly into, or in the proximity of, the ore body through a series of injection wells. This technique is considerably costlier at the outset, although a limited amount of this cost is recovered over a period of time through conservation of the leaching agent. Important surface effects of injection wells are limited essentially to vegetation removal in the immediate vicinity of the well. Several injection/recovery fields may comprise an in situ copper leaching operation.

A study should be conducted for each specific site to identify the most cost-effective, environmentally-acceptable method for lixiviant application. Injection wells may be cost-effective due to relatively low reclamation costs when compared to surface spraying.

Waste Disposal

The accumulation of dissolved impurities in a recycling lixiviant solution necessitates a small percentage bleed-off of barren solution and replacement with fresh solution to maintain effective leaching action. The waste then must be disposed of in some manner. Since, with the exception of certain recent pilot projects, most in situ leaching operations have been associated with deposits previously mined by conventional methods, waste disposal practice has been to discharge wastes to the tailings or evaporation ponds. It is outside the scope of this report to discuss the hydraulics of tailings ponds beyond noting that two schools-of-thought prevail regarding their hydraulic balance. One maintains that the ponds are self-sealing as a result of the fine slime discharge they receive; the other contends that such is not the case and that downward seepage of water does occur, posing the very important possibility of underlying aquifer pollution. The impacts of such pollution could be significant depending upon the present and future uses of the water. Obviously, the most negative impacts would occur if the aquifer is used for human consumption.

A porphyry copper mining operation designed exclusively for in situ leaching would likely use an evaporation pond for waste disposal. Since negligible slimes are present in barren lixiviant bleed streams, the pond definitely would not be self-sealing, and downward percolation of wastewater could occur if the pond were situated above permeable strata. Two avenues for dealing with this problem are: locating the disposal pond above an impermeable geologic member, away from potentially affected groundwater; and/or sealing the pond with an impermeable liner such as plastic or clay. Careful attention must be directed to the design of a plastic-lined earthen pond to avoid formation of large air bubbles or "whales" between the lining and earth when the pond is in use. These air bubbles can significantly reduce the capacity of a pond and, once formed, are difficult to eliminate while at the same time maintaining the integrity of the seal.

A different approach to dealing with wastes, particularly if anticipated flows are large enough to require excessive area and costs for evaporative disposal, might be to reduce the waste discharge through treatment, such as membrane desalination. However, this approach would still produce a waste, and it would be potentially very hazardous due to the concentration factor.

Subsurface Lixiviant Action

As discussed earlier, porphyry copper ore bodies in the desert area under consideration are usually not associated with aquifers. However, as noted, water may flow through, or in the vicinity of, the ore bodies through faults and fissures. Such is apparently the case at the Miami Copper Mine in Miami, Arizona, where approximately 13 l/sec (200 gpm) of groundwater, presumably flowing through a nearby fault, is being intercepted at present by a leaching operation. The water is being used in the mining operations.

Fracturing of an ore body prior to leaching may create hydraulic interconnections between the deposit and nearby faults. Such hydraulic communication between a water-bearing fault or fissure and a lixiviant leached ore body poses the theoretical threat of contamination eventually entering a water supply. Since an in situ leaching operation maintains an unsaturated flow condition in the majority of the ore body systems, it is unlikely in practice that water would escape from an ore body during leaching along faults or fissures, unless they were located near the bottom of the ore body which is saturated. Unsaturated conditions tend to retard lixiviant escape along faults.

Once a mining operation ceases, however, hydraulic conditions in the mine will slowly assume a steady state wherein one of two possible conditions will generally prevail: 1) a regional groundwater flow will occur providing saturation that sufficient water is present and that faults allow regional transmission, 2) surface evapotranspiration will balance incoming water resulting in no net regional flow. If the first condition prevails, leaching solutions, remaining in the ore body after cessation of lixiviant recovery, will be flushed out by the flowing groundwater. Since such groundwater movements in most areas in question are typically quite slow, several hundred years could conceivably expire between the time of mine closure and the theoretical migration of lixiviant contamination into a groundwater resource. During this period of time, interaction of contaminants with contacted minerals might reduce levels of contamination. Monitoring would be required to determine if and when the water becomes suitable for future usage.

ENVIRONMENTAL MONITORING

Presently there are no established groundwater quality modeling practices for in situ copper leach operations. This is possibly due to many factors including:

1. Location of an ore body in non-waterbearing strata;
2. Site specific nature of geohydraulic conditions;
3. Limited number of in situ copper leach operations;
4. Lack of known water quality problems associated with copper in situ leach operations;
5. Lack of existing state groundwater quality control regulations.

The last factor is being eliminated rapidly. The Surface Mining Act of 1977 (PL 95-87) and the Underground Injection Control regulations have jurisdiction over various aspects of groundwaters.

Water quality monitoring programs especially need to be established for leach operations where water resources are affected, which is an infrequent occurrence. Monitoring water quality in aquifers which may be effected should be done in much the same manner as is done at uranium mine sites (refer to Chapters 6 and 7 for a more detailed discussion).

The feasibility of monitoring the quality of water flowing along fissures is doubtful because their exact location would be difficult to determine. In lieu of monitoring, the escape of lixiviant may be predicted by detailed routine mass balance calculations. It would be necessary to maintain accurate logs of quantities of lixiviants injected and recovered and to make predictions of other losses such as evaporation and transpiration. This method will allow only the prediction of lixiviant excursion if an excursion is indicated by a lack of water balance; it would be necessary to make a detailed assessment of its potential effect on water resources. If nearby aquifers may be affected, observation wells should be installed to monitor groundwater quality and steps should be taken to correct any groundwater pollution.

CHAPTER 4 REFERENCES

1. Sheffer, H.W., and L.G. Evans. Copper Leaching Practices in the Western United States. Bu Mines IC 8341, 1968.

2. Lawrence Livermore Laboratory. Report UOPK-667-32, 1967.

3. Laine, R.P. Geological-Geochemical Relationships Between Porphyry Copper and Porphyry Molybdenum Ore Deposits. Ph.D. Dissertation, Univ. Calif., Irvine, Calif., 1974.

4. Rickard, R.S. Chemical Constraints on In-Situ Leaching and Metal Recovery. Pres. at Solution Mining Symposium, 103rd Annual AIME Meeting, 1974.

5. Porter, D.D., and H.G. Carlevato. In Situ Leaching: A New Blasting Challenge. Pres. at Proc. Solution Mining Symp., AIME Annual Meeting, Dallas, Texas, Feb. 25-27, 1974, pp. 33-43.

6. Ward, M.H. Surface Blasting Followed by In Situ Leaching the Big Mike Mine. Pres. at Proc. Solution Mining Symp., AIME Annual Meeting, Dallas Texas, Feb. 25-27, 1974, pp. 243-251.

7. Bryner, L.C., R.B. Walker, and R. Palmer. Some Factors Influencing the Biological and Non-Biological Oxidation of Sulfide Minerals. Pres. at AIME Annual Meeting, New York, February 1966, 19 pp.

8. Corrick, J.D., and J.A. Sutton. Copper Extraction From a Low-Grade Ore by Ferrobacillus Ferrooxidans: Effect of Environmental and Nutritional Factors. Bu Mines RI 6714, 1965, 21 pp.

9. Braun, R.L., A.E. Lewis, and M.E. Wadsworth. In-Place Leaching of Primary Sulfide Ores: Laboratory Leaching Data and Kinetics Model. Lawrence Livermore Laboratory UCRL-75044, 1973.

10. Agarwal, J.C., and J.C. Yannopoulos (eds.). Extractive Metallurgy of Copper, Vols. 1 and 2. AIME, 1976.

11. Fletcher, J.B. In-Place Leaching at Miami Mine, Miami, Arizona. Trans SME/AIME, N. 250, no. 4, 1960, p. 310.

12. ________. Ranchers Development Sets Off Blast: Will Leach at Big Mike. Mining Engineering, N. 25, no. 8, 1973, p. 10.

CHAPTER 5

NATIVE COPPER

INTRODUCTION

Native copper refers to deposits of copper which occur as particles of pure metal dispersed in gangue materials. Native copper from the Keweenaw Peninsula in Upper Michigan was one of the earliest and largest sources of copper in the United States. By 1930, copper production had exceeded four million short tons of metal, but large scale output ceased in the mid 1960's because of the high cost of conventional underground mining methods and high processing costs. There remain, however, enormous amounts of copper in both virgin and worked deposits which are believed to be recoverable by in situ leaching techniques.

PHYSICAL SETTING

Geographical Location

One of the most significant deposits of native copper known underlies portions of the igneous and sedimentary terrains within three midwestern states of the Great Lakes region. As shown in Figure 5-1, this native copper mineralization extends in a 480-kilometer (300-mile) belt from eastern Minnesota, across northern Wisconsin and into the Keweenaw Peninsula of Upper Michigan, on the south shore of Lake Superior.

Deposits with the highest potential for in situ leaching are concentrated in Houghton County, Michigan. These desposits occur in a mineralized belt between 6-10 kilometers (4-6 miles) wide and 104 kilometers (65 miles) long in the Calument-Hecla areas of Houghton County, which is shown in the shaded area on Figure 5-1. The location of the major producing mines on the peninsula are shown on Figure 5-2.

Nature of Deposits

Precambrian volcanic layers and Cambrian sedimentary beds are the primary hosts of native copper mineralization in Michigan. A geological cross-section illustrating the native copper beds at Houghton, Michigan is presented in Figure 5-3. This series of beds ranges from 7,600-9,100 meters (25,000-30,000 feet) in thickness and is comprised primarily of basaltic lava flows, with interbedded conglomerates derived from the flows during intermittent periods between volcanic activity in which early Cambrian seas eroded and reworked the volcanic rocks. In addition to the volcanic layers and conglomerates, the Keweenaw Series includes red arkosic (containing feldspar) sandstones and shales. This complete sequence of rocks trends (strikes) generally northeast-southwest and is inclined at variable degrees toward the northwest, sloping under the glacial drift near the shore of Lake Superior.

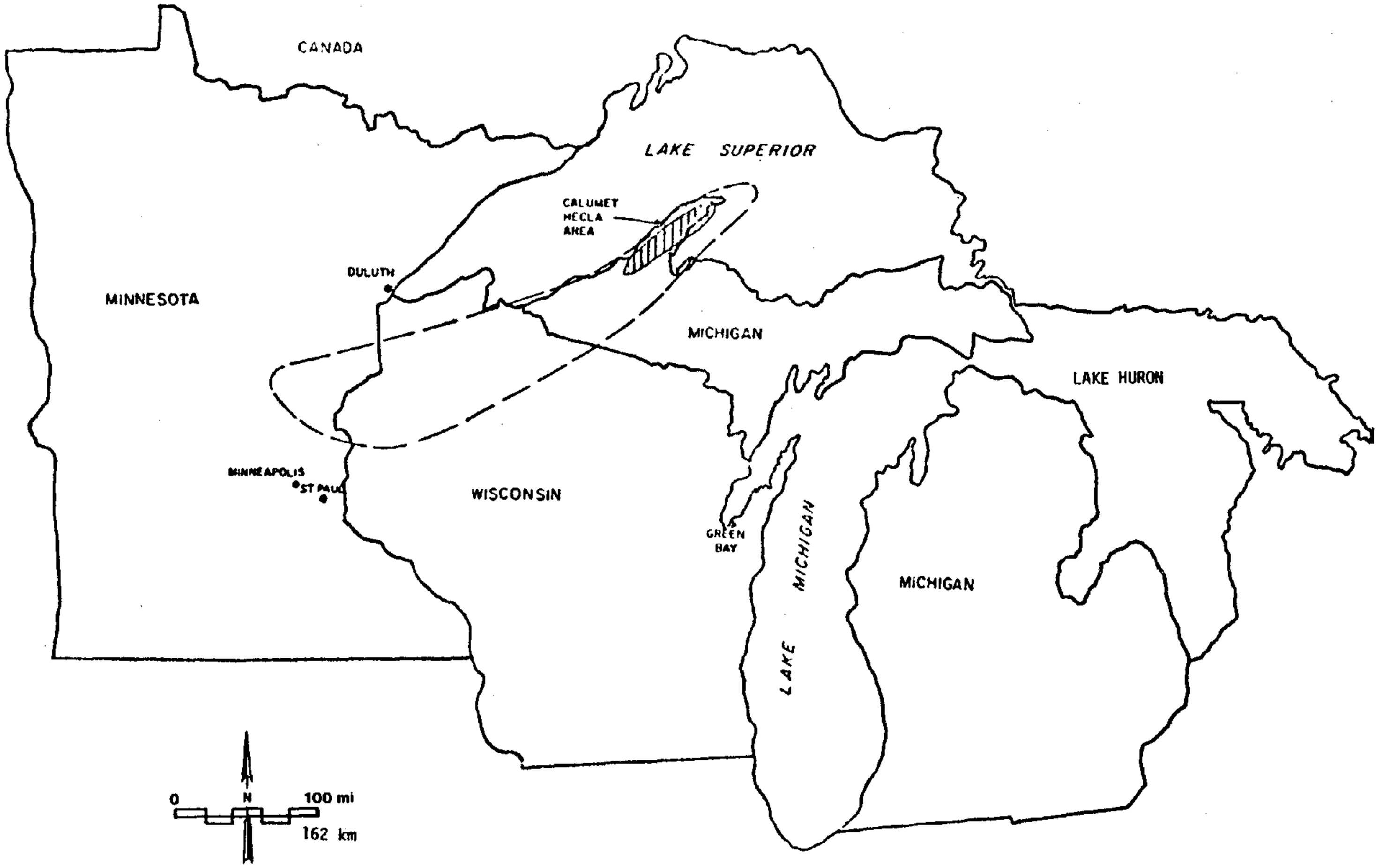


FIG. 5-1 NATIVE COPPER MINING DISTRICT

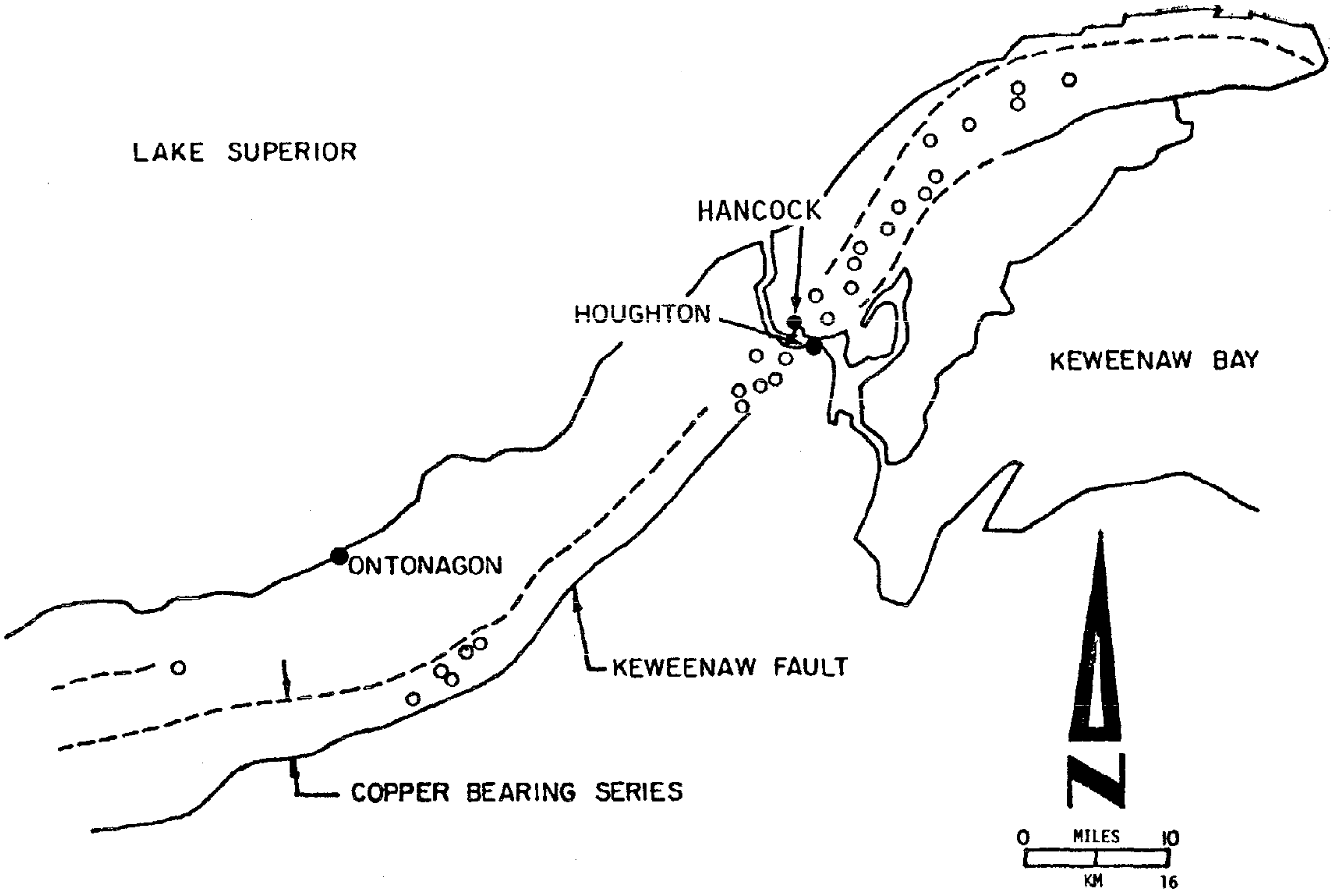


FIG. 5-2 MAJOR PRODUCING MINES IN KEWEENAW MINING DISTRICT

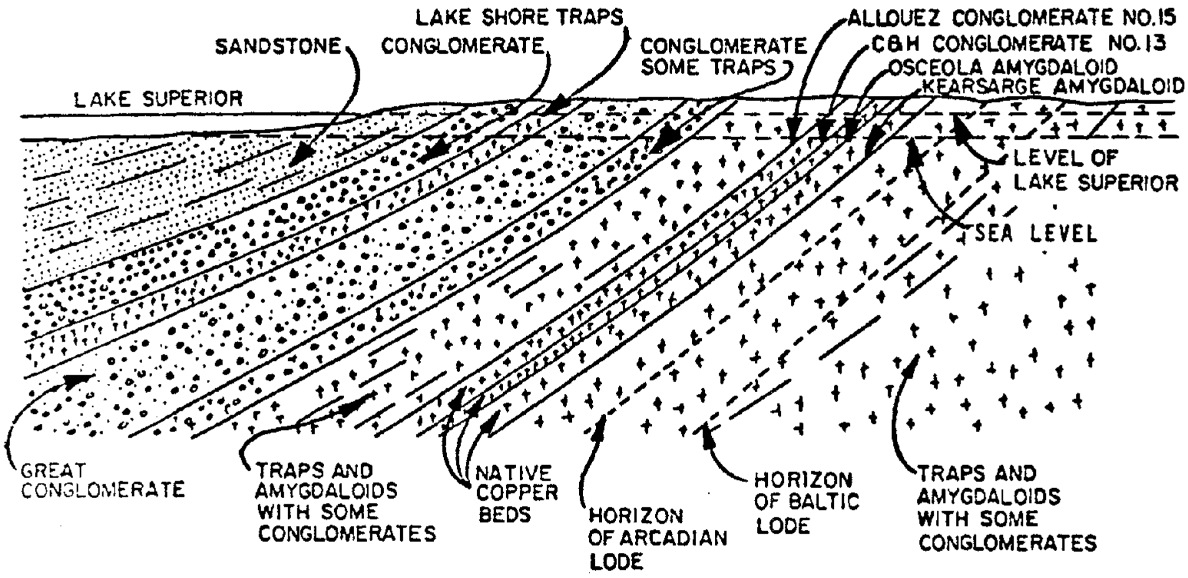


FIG. 5-3 CROSS SECTION THROUGH NATIVE COPPER BEDS
FROM (2)

Native copper in the Michigan deposits occurs in veins generally 1.2-6 meters (4-20 feet) wide in amygdaloidal basalt flows or conglomerates. The veins are typically dipping about 70 degrees at the surface, decreasing in dip to 30 degrees at greater depths. Deposits within the volcanics are most common in, or near, the vesicular and brecciated upper surfaces of certain flows. Many of the more significant deposits reflect critical phases in the probable history of their formation, with stronger copper mineralization concentrated in portions of the host rock more highly disturbed during the flow and solidification stage of the lavas. Both the angular fragments of the conglomerates and amygdaloidal (vesicular) nature of the basalts thus may contribute to naturally higher permeabilities. With these features, in addition to low percentages of soluble gangue materials, the deposits may be favorable for copper extraction by in situ leaching methods. Some care must be taken, however, to avoid portions of any deposit that may be sufficiently porous (or cavernous) to cause a loss of either the leaching or pregnant solutions.

Native copper, the dominant ore mineral, is crystalline and ranges in size from microscopic particles to masses weighing 500 tons. The deposits also contain minor percentages of chalcocite (copper sulfide) and copper arsenides. Rare amounts of native silver occur as intergrowths with the metallic copper. Gangue minerals include microcline (feldspar), chlorite, quartz, epidote, carbonates and prehnite. The chemical analysis of several native copper ores from Michigan are presented in Table 5-1.

Nature of Surface Conditions

Soils

General features of the soil mantle overlying the native copper deposits of Michigan include characteristics defined and classified within the order of alfisols, a soil typical of humid regions. Thus, they have a high percentage of insoluble residue (the elements iron and aluminum) and correspondingly lower contents of soluble materials such as lime. Locally, glacial drift is intermixed with indigent soils. In undisturbed ground, a typical profile would consist of the following horizons listed in descending order:

- Mature, zonal soils -- topsoil, influenced by climate and biological conditions;
- Intermediate, intrazonal soils -- a subsoil, primarily reflecting the chemical influence of its parent material (bedrock), and topographic relief;
- Azonal soils -- a "younger" horizon at the bottom of the soil profile, consisting primarily of immature soils mixed with rock fragments derived from the underlying bedrock.

Modifying factors in these Michigan area soils include the types of vegetation, and rate and degree of leaching and oxidation.

TABLE 5-1. - Analyses of Typical Native Copper Gangue from Michigan (2)

Constituent	Concentration[a]				
SiO_2	49.40	46.78	42.71	45.70	47.00
Al_2O_3	16.12	17.04	14.93	20.44	20.80
Fe_2O_3	11.51	7.95	7.45	9.50	6.60
FeO	2.13	6.31	3.45	8.95	4.20
Total Fe	9.71	10.46	7.92	13.60	7.88
MgO	3.52	6.31	2.70	2.24	4.30
CaO	10.90	6.94	22.76	7.46	11.80
Na_2O	3.02	3.44	0.54	0.80	2.70
K_2O	0.58	1.10	0.04	0.28	- [b]
H_2O- [c]	0.10	0.66	-	0.35	-
H_2O+ [d]	2.30	3.62	3.56	2.78	3.00
TiO_2	-	-	1.29	1.10	-
CO_2	0.59	0.08	-	-	-
Summation	109.88	110.69	107.35		108.30

[a] Concentration in percent by weight.
[b] Not available.
[c] Conate.
[d] Interstitial.

Hydrology

The Keweenaw Peninsula is surrounded by Lake Superior. A proximity of vast amounts of water causes the area to have high humidity throughout the greater portion of the year. The average annual rainfall exceeds 75 cm (30 inches), which includes an average annual snowfall in excess of 150 cm (100 inches). The precipitation in the area exceeds both the annual free surface-water evaporation rate of approximately 55-60 cm (22-24 inches) per year and the average potential evapotranspiration rate of 50-55 cm (20-22 inches). Significant amounts of surface runoff occur primarily during the spring snowmelt.

Undisturbed native copper ore bodies have extremely low permeabilities and are not considered to be developable aquifers. Naturally occurring faults and fissures, test holes, drifts and fractures, resulting from prior mining operations, are the primary channels through which water can flow. At, and before, the turn of the 20th century, there were minimal amounts of water in the mine shafts and stopes at depths as great as 3,000 meters (10,000 feet). According to Lindgren (1), at depths of 900-1,500 meters (3,000-5,000 feet), mine water was almost entirely absent. There were only small quantities of drippings which were collected and were initially hauled to the surface via the mine elevators and/or lifts. In some of the larger mines, a series of low capacity high lift pumps were installed. Immediately overlying the tilted beds of conglomerates in native copper ore, a horizontal soil mantle of intermediate permeability has developed. This nonartesian aquifer receives substantial recharge from surface streams and small ponds and continually discharges (subsurface) to Lake Superior. The shallowness of the aquifer, 6-15 meters (20-50 feet), has precluded its development as a major industrial or municipal water supply.

Abandonment of the mining operations has resulted in significant seepage of groundwaters from the surface aquifer into the inactive mine shafts and stopes. Figure 5-4 illustrates the surface aquifer and the flow of groundwater into the shafts in the native copper beds. Inactive mining operations have been filling with water for over 40 years. In 1976, it was estimated that the water level had risen to 490 meters (1,600 feet) below the surface (3).

Interconnections between the extensive mine workings permits water to flow horizontally for distances as great as 16-24 km (10-15 miles) at the lower levels of the mining activity. There are several hydraulically isolated shafts at deeper depths which did not fill with water initially. As the water rose, eventually a level was reached where water could flow horizontally to an adjacent mine and then gradually fill that mine before the overall water level in the area would rise again. It has recently been estimated that water level in the major abandoned mines is rising at approximately 30 meters (100 feet) per year. In several areas, plugs have been constructed to prevent filling areas currently used for research projects by the Bureau of Mines.

The communities of Hancock and Houghton obtain their water supplies from wells located in abandoned mine shafts. The water is of relatively good quality with a TDS of less than 400 mg/l. In a recent study performed by the Institute of

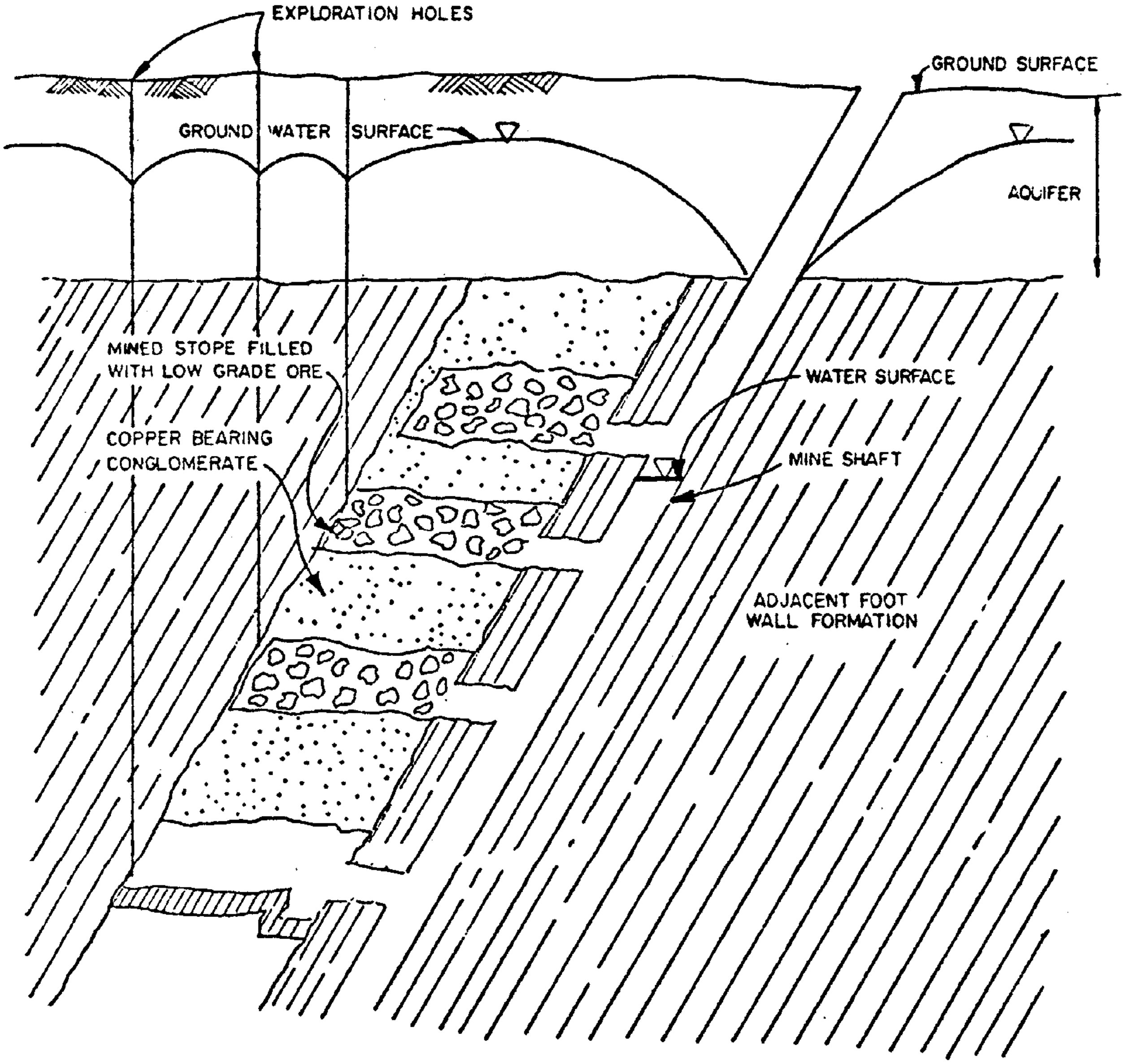


FIG. 5-4 MECHANISMS OF GROUNDWATER ENTRANCE INTO ABANDONED COPPER MINE

Mineral Research at Michigan Technological University, Houghton, Michigan, for the Bureau of Mines, various water samples from several depths of the Seneca No. 2 mine were collected and analyzed (4). The conductivity ranged from approximately 200 to 400 (μmhos/cm) which corresponds to dissolved solid levels of approximately 120 to 250 milligrams per liter (5). The primary cation present was sodium.

At deeper depths of the native copper deposits, it has been reported that brine solutions exist. Lindgren (1) presents the analysis of one sample from the Quincy mine which shows 28 percent solids. This corresponds to a brine approximately 8 times stronger than seawater. It is possible that these submerged brine fields could provide a disposal site for concentrated waste liquors and bleed-off streams from mining operations, if environmental review by the cognizant regulatory agency allowed.

Biology

The native copper area is essentially a rolling plain with no great or abrupt differences in elevation, and thus the physiographic features of greatest importance in determining vegetational character are degree and direction of slope, soil types, and presence of permanent surface water. The area under consideration is generally referable to the Wisconsin/Michigan Northern Conifer-Hardwood Forest Vegetational Province. Typically, the forest communities are characterized by the presence of coniferous trees such as pine, spruce, hemlock, fir, cedar and tamarack, although a large hardwood element is present also.

The major plant communities comprising the northern forest province may be categorized as mesic forest, xeric forest, lowland forest, and boreal forest. Mesic forest is widely distributed throughout the subject area and is the typical forest type of this section of Michigan and Wisconsin. The other forest types are much less prevalent and occur in scattered fashion only in certain portions of the area.

Throughout the subject area, northern mesic forest displays a certain similarity of character, but varies in species composition since the ranges of several important dominants do not coincide with the range of the forest type. Thus the beech is common within the area in certain parts of Michigan, but not Wisconsin. The leading dominant within the community is sugar maple with hemlock holding second position. Northern mesic forests are harvested on a selective logging basis for white pine and hardwoods. They are also used to a considerable extent in the large-scale production of maple sugar.

In addition to scattered occurrences throughout the area, northern xeric forest is present in limited development on the banks of most lakes and streams of the entire area. The most important trees comprising the community are jack pine, red pine, white pine, red maple, and red oak. Lumber yields from red and white pine forests can be quite high.

The northern lowland swamp forests are found associated largely with two types of topography -- lake beds and river flood plains. Because of these rather specialized topographic requirements, the forest type tends to be distributed as small discrete bodies and rarely covers an extensive contiguous area. The community type includes tamarack-black spruce bog forests, the white cedar-balsam fir conifer swamps, and the black ash-yellow birch-hemlock hardwood swamps. Dominant species of this community are black spruce, tamarack, white cedar, and balsam fir. Sugar maple and red maple achieve a dominant position in some swamps. Northern lowland forests are selectively harvested for white cedar and black spruce.

Boreal forest is restricted in distribution to only a few localities within the subject area. Most of the stands occur on heavy soils which are frequently wet and are located on ridges or on slopes. Dominant members of the community are balsam fir, white pine, white cedar, white birch, and white spruce. Boreal forest is of such limited extent within the subject area that it is not of great economic importance. Young stands of balsam fir are important sources of Christmas trees, and the older stands of both spruce and fir are used as sources of pulp.

Several community types of lesser importance occur within the subject area. These include pine barrens, bracken-grassland, alder thicket, sedge meadows, and various aquatic communities.

Wildlife common to the subject area include the abundant white-tailed deer, black bear, snowshoe hare, woodchuck, porcupine, beaver, red squirrel, and bobcat. A few moose and an occasional timber wolf are present in the Upper Michigan Peninsula. Waterfowl are extremely abundant in the area as are ruffed grouse. These, along with deer and snowshoe hare, are the major subjects of hunting activity in the area.

Thousands of kilometers of streams and thousands of lakes with high quality water support a valuable cold- and warm-water fishery. Most streams are designated trout streams, while the lakes embrace a wide variety of warmwater fish.

MINING TECHNIQUES

At a copper price of $1.65/kilograms ($0.75/pound) the U.S. Bureau of Mines has estimated (6) the ore reserves in the Keweenaw Peninsula area to be 482,000,000 metric tons (430,000,000 short tons) at an average grade of 1 percent copper, yielding 4,820,000 metric tons (4,300,000 short tons) of recoverable metal. Part of the mineralized rock occurs as broken and waste material left in old underground mine workings.

The advance of in situ leaching technology has created renewed interest in these native copper deposits of Michigan and possibly the remainder of the mineral deposit in Minnesota and Wisconsin. In situ leaching, using an ammonia lixiviant, is apparently the most feasible process, since it has been successfully applied commercially since 1915 to heap leaching the native copper-bearing tailing sands in the Keweenaw district.

Based upon experience in leaching operations for porphyry copper and current economic conditions, a reasonable size of an in situ native copper plant would be one capable of producing 15 metric tons per day (MTPD) or larger. This daily output could be achieved by a leach field producing a pregnant solution containing 1.0 g/l of copper at a flow rate of 180 l/sec (2,850 gpm). This section will review the three broad categories of mine operation, which include ore body preparation, leaching, and beneficiation. The latter two sections will present sizes of typical unit processes associated with a plant of the above indicated size.

Ore Body Preparation

It is possible that native copper may be leached in situ from either virgin unmined areas or the abandoned stopes of previously mined areas. Prior to leaching, these areas must be prepared to optimize the application of lixiviant and the recovery of pregnant liquor and to prevent the escape of lixiviant into other areas.

Virgin Areas

As discussed previously, the Michigan native copper deposits occur in steeply dipping tabular ore bodies having long strike distances. The native host rock is relatively impermeable but it may be fractured to permit the slow migration of fluids. This fracturing may be accomplished by blasting, but the blasting pattern must be designed to confine the breakage to the ore body itself. A brief discussion on blasting may be found in the previous chapter.

Previously Mined Areas

Unlike the virgin areas, the abandoned stopes contain significant void spaces left when the stopes were loosely backfilled with waste rock. The adjacent pillars and wall rock may also be more highly fractured than the native formation due to blasting that occurred during active mining. The many small fractures in the rock will permit the slow access of lixiviant to the copper values. The dissolution of copper particles or masses deposited in the rock increases the permeability of the host rock. As a result, it may not be necessary to prepare the mine by additional blasting.

As discussed previously, many of the old mines have become partially filled with water. Prior to leaching, the mine must be dewatered; however, wastewater discharge standards might preclude the disposal of these waters to surface streams, lakes or groundwater recharge areas depending on their qualities. The qualities of the waters are not known except for the data provided by Hockings (4) and limited other references in 1900-1935 literature. It has been reported that brines do exist at deeper depths (1) and that low salinity waters exist at higher elevations [Hockings 1976] (3). The low salinity, good quality waters could be discharged to surface waters. Similar discharge of the brines would result in significant environmental degradation due to salinity. Thus, if mines contain significant volumes of saline waters and the mine operation is to be viable, adequate treatment and/or disposal schemes must be developed.

Leaching Facilities and Processes

The chemistry of leaching has been extensively studied. However, since in situ leaching for native copper has not yet been put into commercial operation, the lixiviant application methods discussed below are based upon conceptual ideas.

Lixiviant Application and Recovery Facilities

The possible lixiviant application facilities may include either virgin or previously-mined areas. In both instances, the lixiviant must be injected below the ground surface to control the volatile loss of ammonia. Figure 5-5 presents a method by which the virgin areas could be leached. After blasting, a series of injection wells would be drilled into the ore zone and the wells cased above the point of application to prevent lixiviant excursion. One or more production wells would be drilled to the bottom of the blasted zone from which the solution would be pumped to the surface for beneficiation.

A method for in situ leaching abandoned stopes is presented in Figure 5-6. As shown, the lixiviant would be injected into the abandoned stope either through surface injection wells or possibly through injection pipes placed horizontally in the abandoned stopes. The shaft would be blocked off at a lower level and the stope at that level used for a collection gallery from which the pregnant solution would be pumped to the surface for beneficiation.

Chemistry of Leaching

Native copper may be leached either by an acid or an ammonia lixiviant solution containing suitable oxidants. However, acid systems have not seen wide use in the past due to their high cost and their nonselectivity of ionic species dissolved. Ammonia systems, on the other hand, are very selective and have been in use in the copper-bearing sands of the Keweenaw district since 1915. A drawback of the ammonia system is the volatility of ammonia which can be controlled by underground injection. Generally, it is felt that the best lixiviant system for in situ leaching of native copper is the ammonia system.

In the ammonia system, native copper is dissolved in the following manner: the surface of the copper is first oxidized; this oxide film then forms a soluble copper ammonium complex in the presence of ammonia and a suitable anion such as carbonate. The most common preferred solvent is cupric ammonium carbonate which oxidizes and simultaneously dissolves the native copper.

$$CU^{o} + \underset{\text{"cupric"}}{CU\,(NH_3)_2\,CO_3} + 2NH_4OH \qquad \underset{\text{"cuprous"}}{[CU(NH_3)_2]_2\,CO_3} + H_2O$$

The reaction will only proceed in the presence of excess ammonia. The cuprous ion also must be oxidized back to the cupric form by the addition of oxygen to regenerate the lixiviant.

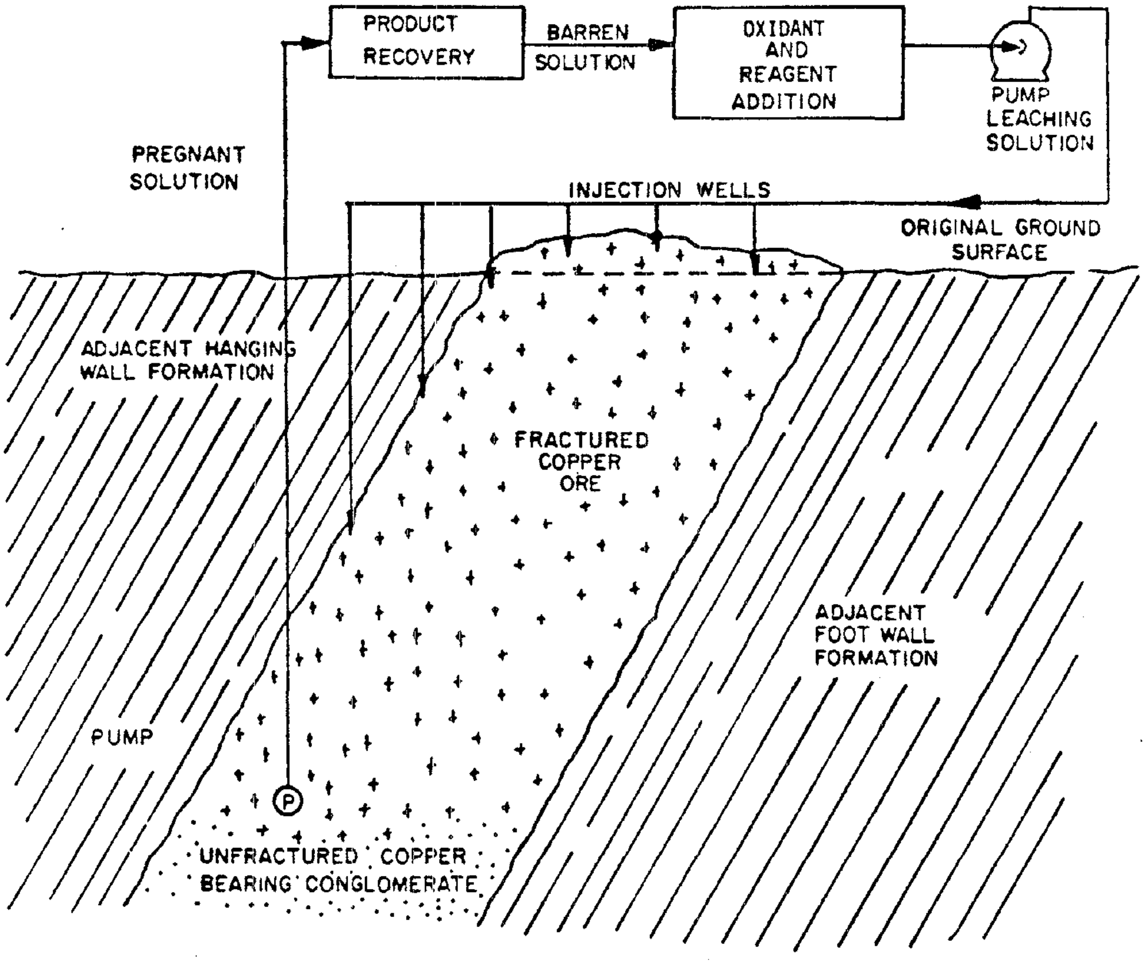


FIG. 5-5 NATIVE COPPER IN SITU MINING-BLASTED ORE BODY

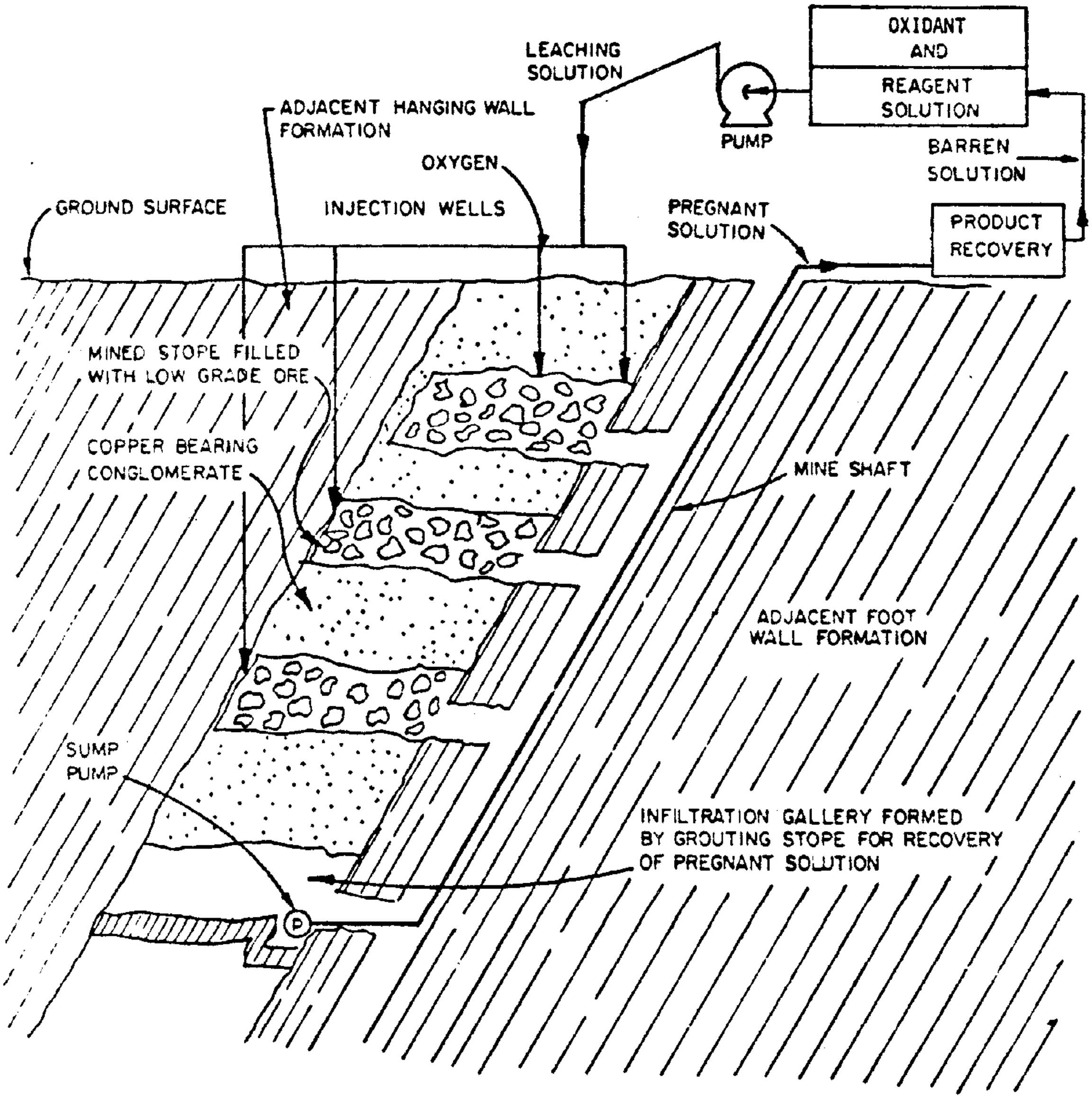


FIG. 5-6 NATIVE COPPER IN SITU MINING IN ABANDONED STOPE

$$\underset{\text{"cuprous"}}{[CU(NH_3)_2]_2\ CO_3} + 1/2\text{-}O_2 \qquad \underset{\text{"cupric"}}{CU(NH_3)_2\ CO_3}$$

In the past, strong solutions of cupric ammonium carbonate were used for leaching native copper. The solutions consisted of approximately 25-50 g/l NH_3 and 25 g/l CO_2 and contained enough cupric ion to oxidize the native copper.

A relatively weak solution of 2 gm-NH_3/l and 2 gm-CO_2/l, as proposed by the U.S. Bureau of Mines, and recently studied in pilot-scale operations in the Salt Lake City Metallurgy Research Center, may be used in future in situ operations on native copper ores of the Michigan Peninsula area. The results of this test were successful and may lead the way to recovery of copper from low grade native copper sources. The concentration of these solutions minimizes the volatile loss of ammonia and reduces the need for covering all leach areas to prevent the loss of ammonia.

Some advantages of ammonia leaching are high selectivity for copper, high solubility of the copper complex, no appreciable attack on the gangue, amenability to solvent extraction, low cost, and ease of recovery of most of the ammonia from bleed streams by distillation.

The metals commonly known to form ammine complexes, and which are potentially leachable by an ammonia leach system are the following, in order of decreasing stability of the complexes: palladium, copper, nickel, cobalt, zinc, cadmium, iron (ferrous), manganese, magnesium, and silver (under some conditions) (8).

Other constituents of ammonia leach liquors may include the following:

CO_2; SO_4: carbamate; As; Pb; Sn; (8)

It should be noted that ammonia will react with gypsum, if present in the gangue, and will form ammonium sulfate. This reaction makes the recovery of ammonia incomplete. Ammonia otherwise is a relatively stable compound and is not easily oxidized by atmospheric oxygen or hydrogen peroxide.

If an ammonium carbonate leach is to be followed by a selective liquid ion exchange (IX) step for copper metal recovery, the other metals forming ammine complexes, present in most ore bodies to a variable extent, will not be removed in the IX unit but will appear in the raffinate. Raffinate is the aqueous solution remaining after copper has been removed from it. Increasing salt levels by continuous recirculation will eventually require some degree of bleed from the circuit and such a bleed will contain high levels of ammonia, and possible concentrations of such toxic metals as lead and cadmium. Improper disposal of toxic solutions can cause environmental degradation.

A recent study (9) described the buildup of dissolved impurities occurring in a recycled ammonia leach solution. The most common constituents are presented in Table 5-2. The low concentrations of magnesium and calcium are probably a reflection of the respective carbonate solubility limits. Trace amounts of zinc, nickel, and lead were also reported, but it is believed these elements were introduced from galvanized fittings and solder used in some of the bottles. Mercury occurred at a level of 152 µg/l.

TABLE 5-2. - Composition of Recycled Ammonia Leach Solution - Michigan Native Copper (4)

Constituent	Concentration (mg/l)
Sodium	182.00
Potassium	51.00
Magnesium	3.50
Calcium	2.60
Iron	0.32
Chloride	155.00

A more complete analysis of a dilute ammonium carbonate leach solution is presented in Table 5-3. This data is based on a long-term, large-scale laboratory leach test utilizing a dilute ammonium carbonate leach solution and a native copper ore from Michigan. It can be seen that the concentrations of certain constituents increase with leaching time (ammonia, carbonate) while other constituents remain at relatively constant levels after achieving steady state conditions (sodium, potassium, calcium). The source of the sulfate was the regenerant used in the mineral recovery process and could be greatly reduced by rinsing the solvent before and after regeneration. The chloride is reported to originate from the copper ore itself.

The bleed-off required to prevent excessive accumulation of salts in the leaching circuit would have a composition similar to that presented in Table 5-3 and would require treatment prior to discharge into the environment.

Beneficiation Processes and Facilities

In the past, beneficiation of an ammonia leach circuit was accomplished by steam distillation but the copper oxide product had a limited marketability. As in the porphyry copper leach circuits, it is expected that future milling operations will be by SX-EW which produces a high-grade, easily-marketed product. Figure 5-7 presents a process flow diagram for a typical ammonia leach plant using solvent extraction and electrowinning. Since the process is quite

TABLE 5-3. - Composition of a Dilute Cupric Ammonium Carbonate Solution for Michigan Native Copper (3)

Constituent	Concentration[a] 12 Months Leaching	 18 Months Leaching
Ammonia	3,500.00	4,000.00
Aluminum	1.00	1.00
Arsenic	0.11	0.50
Calcium	2.00	3.00
Carbonate	4,900.00	5,600.00
Chloride	1,000.00	870.00
Cobalt	2.00	0.01
Copper	1,140.00	650.00
Iron	0.10	0.10
Magnesium	7.10	4.30
Manganese	1.00	0.10
Nickel	1.00	0.50
Potassium	80.00	90.00
Silver	0.08	0.10
Sodium	200.00	180.00
Sulfate	1,360.00	1,300.00
Zinc	0.12	0.40
Total Dissolve Solids	12,300.00	12,800.00
pH	8.5 - 10	8.5 - 10

[a] mg/l.

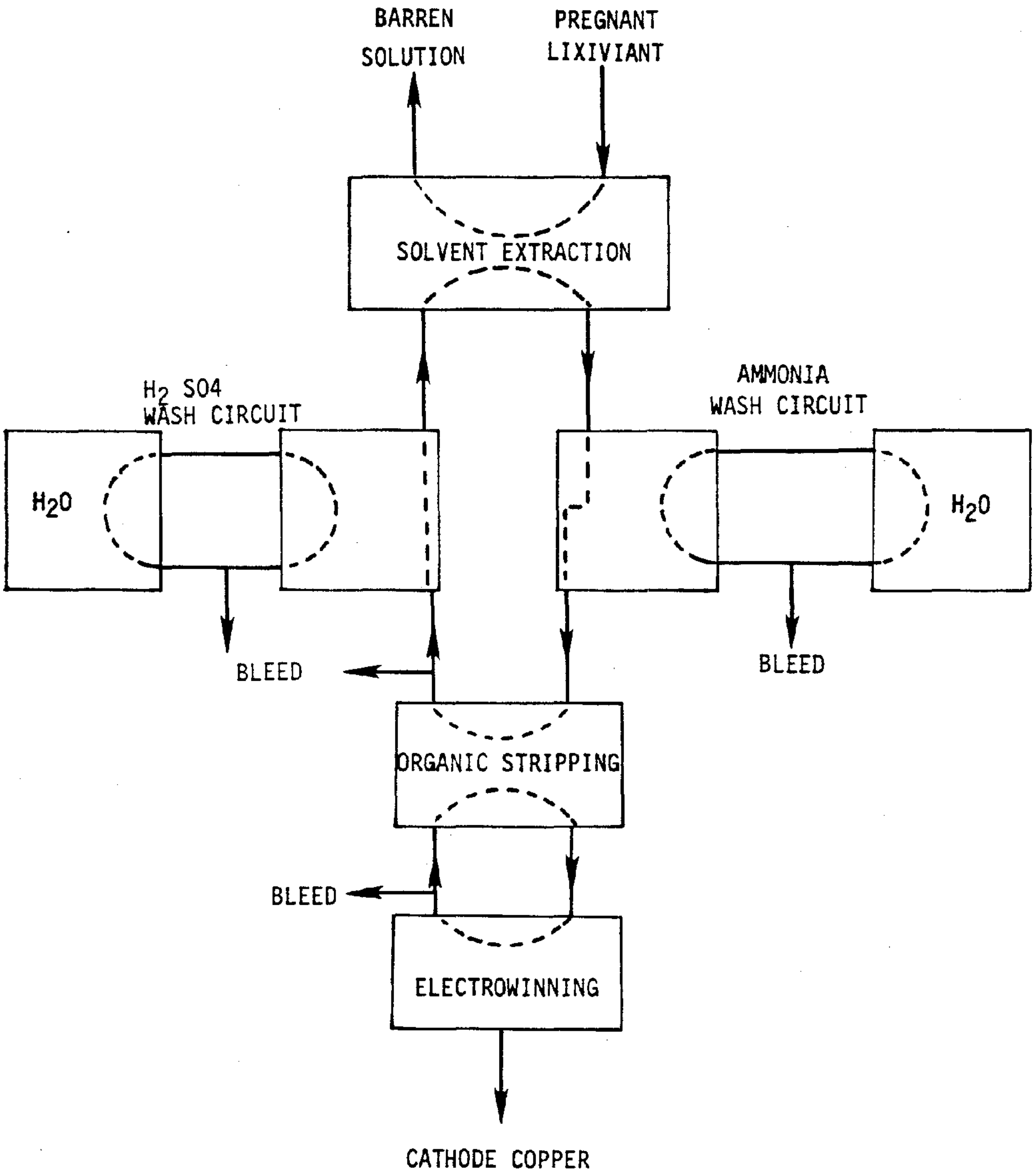


FIGURE 5-7 AMMONIUM LEACH FLOWSHEET FOR NATIVE COPPER BY SOLVENT EXTRACTION - ELECTROWINNING.

similar to that previously described in Chapter 4, a detailed description will not be given.

ENVIRONMENTAL REVIEW

Introduction

In marked contrast to the arid conditions prevailing in the southwestern United States porphyry copper region, water is plentiful in the native copper area, both as surface and groundwater. Moreover, instead of low shrubby growth, the area, in its natural state, is characterized by forests comprising several species of conifers and hardwoods.

Potential environmental impacts associated with in situ leaching of native copper may be generally categorized as related to establishment and operation of general mine facilities, ore body preparation, subsurface lixiviant action, and waste disposal.

Establishment and Operation of Facility

As indicated earlier, in situ leaching may be applied either to virgin native copper deposits or to those which have already been mined by conventional methods. In the latter case, the physical disturbance associated with establishment of the additional facilities necessary for in situ mining is rather minimal compared to that associated with establishing an operation in an undisturbed area.

Environmental impacts which might be anticipated from the establishment and operation of a new facility in an undisturbed area are generally similar to those discussed in Chapter 4 regarding porphyry copper operations. The reader is advised to refer to the discussions addressing construction impacts, wildlife disturbance, and introduction of alien flora.

From an aesthetic standpoint, a major difference exists in the overall results produced by disturbing a forested area as opposed to a desert area covered by low vegetation. In terms of sheer visual impact a denuded area within a forest appears much more dramatically altered than a similar area in a desert habitat. However, the disturbed forest area can be seen only from a limited distance due to natural tree screening, while the disturbed desert area may disrupt otherwise uninterrupted wilderness views over a distance of several miles.

Ore Body Preparation

As explained earlier, if a previously unmined native copper deposit is to be leached in situ, it is possible blasting will be necessary to produce the conditions required to facilitate fluid migration through the ore body. Should this be the case, anticipated impacts upon landform, vegetation and wildlife are like those discussed in Chapter 4, as related to blasting. Blasting may also be required to enhance the permeability of a previously mined deposit.

Subsurface Lixiviant Action

As discussed earlier, extensive mining activity in the subject native copper area has produced (or enhanced) subsurface conditions conducive to the flow of water. The distinct potential therefore exists for escape of pregnant leaching solution from an area undergoing leaching. The most immediate possibility would be migration of the lixiviant from the site of leaching to an abandoned mine or mines through naturally occurring faults and fissures or through fractures resulting from mining activity. Should the abandoned mine receiving escaped lixiviant be one from which a public water supply is drawn, a significant health hazard would result.

A less likely escape route for lixiviant would be through the walls of a faulty injection or recovery well casing. Should this occur, barren or pregnant leaching solution could conceivably reach nearby lakes or streams by travel through a shallow aquifer. Determination of the specific chemical constituents that might reach surface-waters by such a route is problematical, depending upon such variables as distance traveled, substrate/water chemical interactions, adsorption phenomena and metabolic processes. Theoretically, hazards posed to the aquatic environment by lixiviant-related contamination could exist both in the form of toxic poisoning and nutrient enrichment (by nitrogen oxidized to the nitrate form).

Measures that may be employed to prevent lixiviant excursion include proper design and construction of injection and recovery wells and sealing all hydraulic connections peripheral to the leaching site. The possibility of inadvertent fluid migration from an active leaching area is also reduced by the functional requisite of maintaining an unsaturated flow condition in the ore body.

Once a mining operation ceases, hydraulic conditions in the mine (in the absence of hydraulic sealing) may be expected to return to the general condition described earlier in the discussion of hydrology. This being the case, leaching solution remaining in the ore body after cessation of pumping may be flushed out slowly by the horizontal movement of water between mines. This points to the importance of hydraulic isolation of a leach area by appropriate sealing, even though normal leaching design discourages fluid excursion during active mining.

Waste Disposal

The proposed in situ leaching of native copper generates several waste streams which could adversely affect the environment. The adverse environmental impacts could be significant enough to prevent utilization of the technique. In general, additional studies are required to quantify the alternate waste disposal processes before final cconclusions can be made regarding the environmental acceptability of in situ leaching-recovery of the native coppers.

Mine Dewatering

The mines are likely to require dewatering prior to leaching depending on elevation. This may, in fact, pose one of the most significant problems affecting the feasibility of the process. An extensive network of bulkheads will have to be constructed to isolate the leaching zones from the surrounding flooded mines. Disposal of dewatering wastes can pose difficulties if the salinities of the waters exceed 500 mg/l. The limited data available indicate tht the upper waters have salinities lower than this value [Hockings 1976] and therefore, dewatering operations could discharge directly to the surface. A National Pollutant Discharge Elimination System Permit (NPDES) is required for surface discharges.

If dewatering produces flows with salinities greater than allowed by the NPDES, alternate techniques will have to be employed. It may be feasible to inject high salinity waters into the lower levels of the mining zone where high salinity waters were reported by Lindgren (1). Further studies are required to quantify the occurrences of brines at depths greater than 2,000 meters. Other potentially technically viable water disposal alternatives include thermal evaporation processes such as the vapor compression evaporator and membrane desalination processes. Solar evaporation ponds are not viable because the area is one of net precipitation, in other words, evaporation less than precipitation.

Process Wastes and Leach Circuit Bleeds

The ion exchange process proposed for recovery of the copper from the pregnant solutions produces only liquid wastes. These wastewaters are characterized by high salinities which preclude direct disposal to the environment. These solutions will require disposal by techniques described in the preceding section.

Ammonium sulfate waste products could possibly be recovered and used for fertilizer, contingent upon economics, availability of a local market, and product purity.

CHAPTER 5 REFERENCES

1. Lindgren, W. Mineral Deposits. McGraw-Hill Book Co., Inc., New York, 4th ed., 1933.

2. Butler, B.S., and W.S. Burbank. The Copper Deposits of Michigan. U.S. Geological Survey. Prof. Paper 144, 1929.

3. Chamberlein, P. Personal Communication, October 1977. Bureau of Mines, Twin Cities Research Center, Minneapolis, Minn.

4. Hockings, W.A. Report No. 1, Analyses of Water Samples from Seneca No. 2 Mine, Keweenaw County, Michigan. Institute of Mineral Research, Michigan Technological University, Houghton, Michigan, 1976.

5. Hem, J.D. Study and Interpretation of the Chemical Characteristics of Natural Waters. U.S. Geol. Survey WSP 1473, 2nd ed., 1970.

6. Bennett, H.J., L. Moore, and L.E. Welborn. An Economic Appraisal of the Supply of Copper From Primary Domestic Sources. Bu Mines IC 8598, 1973.

7. Groves, R.D., T.H. Jeffers, and G.M. Potter. Leaching Coarse Native Copper Ores with Dilute Ammonium Carbonate Solution. Pres. at AIME Annual Meeting, Dallas, Texas, Feb. 23-28, 1974.

8. Kunda, W., H. Veltman, and D.J.I. Evans. Production of Copper from Ammine Carbonate Systems. Pres. at EMD Copper Metallurgy Symposium, 99th Annual AIME Meeting, Feb. 16-19, 1970.

9. Hockings, W.A., and W.L. Freyberger. Laboratory Studies of In Situ Ammonia Leaching of Michigan Copper Ores. In Extractive Metallurgy of Copper, Hydrometallurgy and Electrowinning. Ed. by J.C. Agarwal and J.C. Yannopoulous, 1976.

CHAPTER 6

SOLUTION LEACHING OF URANIUM

INTRODUCTION

Approximately 2 percent of the 1976 United States uranium production was supplied by in situ leaching (1). This technique is in its infancy and significant technological advances are currently being achieved which will substantially increase future production by this method. It has been projected that a six fold increase in production by in situ leaching will occur by 1979 (1). In this chapter the characteristics of uranium leaching are described and their potential environmental effects are developed.

PHYSICAL SETTINGS

In this section, Texas and Wyoming, the two areas which have experienced the greatest development of in situ leaching, are described. The leaching technique has application in many other areas, including but not limited to Colorado, Utah, New Mexico, Arizona, Nevada and Idaho.

The uranium ores most amenable to in situ leaching are the sandstones which are referred to as the "roll front" deposits. These are the ores of primary interest today.

Wyoming Physical Setting

Geographic Location

Basin and uplift structures, with known and potential uranium deposits, occur in the eastern two-thirds of Wyoming and in small areas of adjacent states (Colorado and Montana). Figure 6-1 illustrates the study area including the important Wyoming regions of the Powder River Basin, Shirley Basin, Crooks Gap, and Gas Hills. These regions, along with deposits of lesser importance in the Baggs, Maybell, and Copper Mountain areas, contain low grade uranium reserves totaling millions of tons of uranium. There are currently in excess of nine sites undergoing evaluation for in situ leaching.

The Wyoming Basins and uplifts include the Wind River, Great Divide, Washakie, Laramie, Hanna, Sand Wash, Green River, Big Horn, Rock Springs, Rawlings, and Hartville areas. Geologic emphasis is placed on uranium deposits occurring in extensive continental sediments, both as thick accumulations within the Basins and in thinner layers on the flanks of the bordering mountain ranges (uplifts). Predominant materials in these deposits are fine-grained sand and silt, with local occurrences of coarser sand and gravel eroded from older granitic cores of the mountain ranges. Overlying tuffaceous sediments indicate a more recent period of volcanic activity.

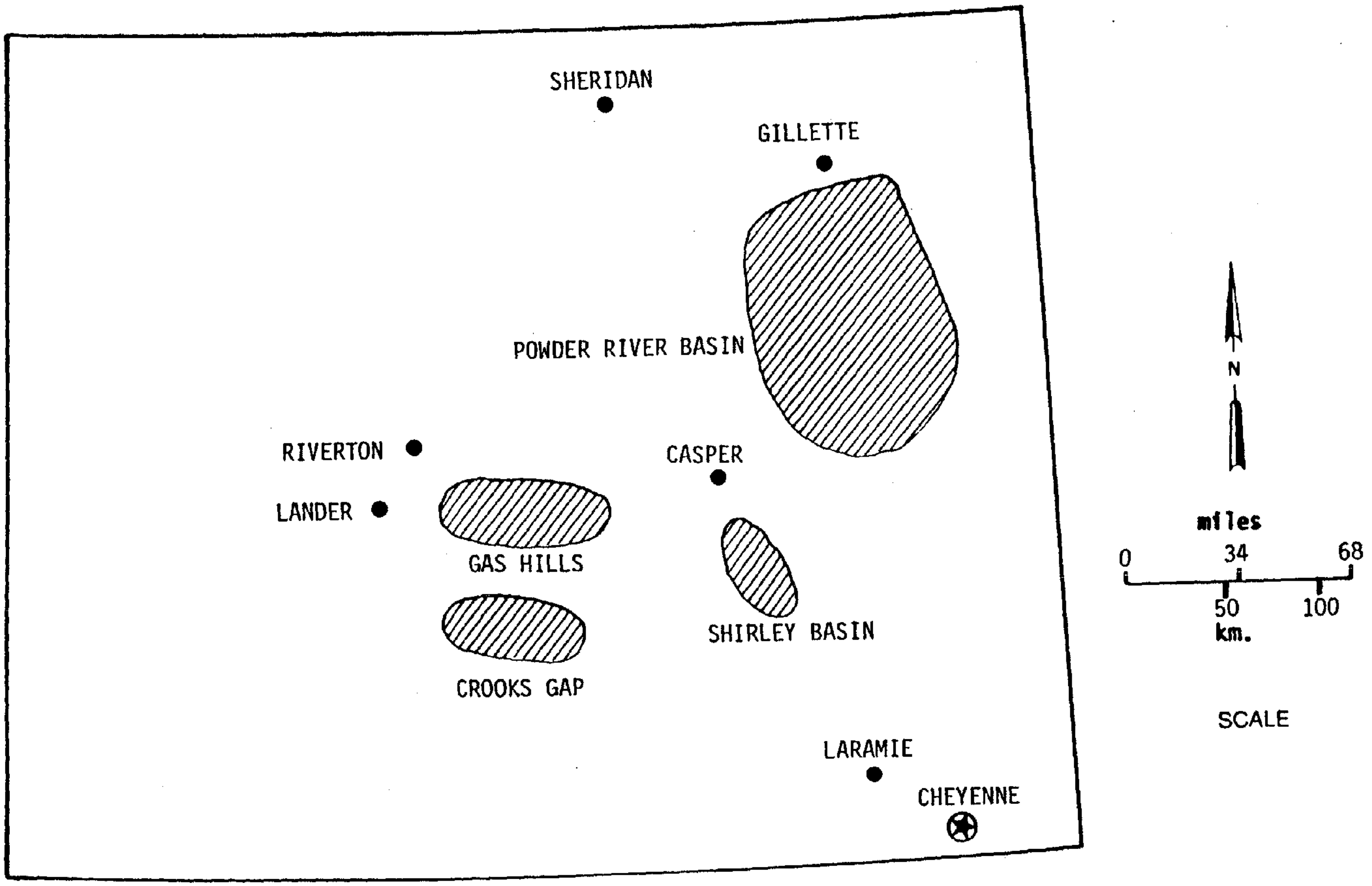


FIGURE 6-1 LOCATION OF MAJOR URANIUM AREAS
IN CENTRAL WYOMING

Important producing districts are in the regions underlain by the Wasatch, Wind River, and Battle Spring formations; of lesser importance are the uranium deposits found in the Fort Union formation (Powder River Basin). In the uplifted areas, some of the deposits occur as fan-like sedimentary accumulations (Gas Hills, Copper Mountain, and Crooks Gap localities).

Nature of Deposits

Uranium deposits of economic significance for solution leaching occur in sandstones along an interface formed by uranium-bearing solutions under the changing chemical conditions of reduction-oxidation (redox) (2). The phenomena resulting in these roll front deposits are described in Chapter 7. These deposits occur at and near the contacts of altered and unaltered rock. Color changes from oxidation (staining) are prevalent in some deposits at locations in the Powder River Basin. Less obvious effects of oxidation are found in the Gas Hills and Shirley Basin deposits. The deposits as seen today show obvious effects of past groundwater activity, indicating the possibility that some of the formations involved were aquifers. The semi-arid climate that now exists generally results in deeper water tables.

The ultimate sources of the uranium are considered to be the older granites and the younger volcanics. Drill hole logs indicate the occurrence of uraniferous material at depths of 600 m (2000 ft). Vanadium has been recovered as a by-product from the Powder River Basin ores and has been reported in uneconomically recoverable amounts in several other Wyoming deposits.

Empirically preferred exploration locations include the areas in or near major producing districts. Resources outside the known areas probably occur in older, deeper sandstones of the various basins. Possibilities also exist in the younger, more shallow formations. As a general rule, the gently inclined sediments lying along the borders of intermontane basins in Wyoming and bordering states should be considered favorable host rock for uranium deposits.

Nature of Surface Conditions

Soils

Many of the soils that overlie the central Wyoming uranium deposits have the features common to those found in other semi-arid regions, but are modified locally by the effects of a more rigorous climate, the mixing of residual soils with transported sedimentary materials, and the arenaceous remnants of sandstones or other silica-rich bedrocks. Thus, the major features that characterize these mixed materials (sand, silt, clay) place them in the loam category. Local environments and geological history usually determine whether the loams are clayey, silty, or sandy. The clayey soils are predominant over large areas, particularly those where airborne volcanic ash was deposited during the past geologic ages. Sandy and silty loams predominate in those areas directly underlain by the various sandstone formation. Local modifications include the effects of topography, drainage patterns and grades, vegetation, and organisms.

The surface topography is characteristically gently rolling hills and broad valleys. Elevations range between 900-1800 m (3000-6000 ft).

Hydrology

The region is semi-arid receiving approximately 30-35 cm (12-14 in) of annual precipitation in the Basins. The majority of rainfall generally occurs in the winter with sporadic occurrence of short-duration, high-intensity summer storms. The higher elevation areas receive average snowfalls of up to 250 cm (100 in) per year with water contents approaching 45-60 cm (18-24 in). The surface waters traversing the primary uranium basins receive runoff from the surrounding mountains with the greatest flowrates resulting from melting snowfalls. April, May and June generally experience the greatest streamflows.

Erosion has developed numerous drainage basins across the dipping sandstone units of the Wasatch and Fort Union Formations. Surface exposures of the units are points of the principal recharge to the groundwaters in the basins. The strata overlying the units have lower permeabilities and generally have low recharge capacities. A significant number of the aquifers are under artesian conditions due to the higher elevations of many of the recharge areas. Impervious strata of shale, siltstone, and mudstone adjoin many of the sandstone hosts of uranium.

Although many recharge areas are at higher elevations which receive 35-45 cm (14-18 in) of annual precipitation, the typical recharge of the basins is relatively low. The high temperatures during the summers cause extensive evapotranspiration. Significant groundwater development in a basin could result in overextracting from the basin and lowering groundwater table and piezometric heads.

One climatic factor that affects in situ leaching is frost penetration. All pipelines must be protected from freezing or year-around mining operations are not possible. The average depth of frost penetration in the area is approximately 95-115 cm (38-46 in).

The quality of many surface waters in the region is extremely poor. The compositions of surface waters from five areas, selected from numerous permit applications and baseline environmental reports, are presented in Table 6-1. Total Dissolved Solids (TDS) range from 500 to in excess of 5,000 mg/l for selected waters. Good quality surface waters are not abundant in the region and those which do exist require water quality protection, especially in terms of salinity.

The majority of the uranium basins have underlying aquifers which provide the principal water supplies to the majority of small communities and individual dwellings. The major hydrologic units include the surface alluvium, and such formations as the Wasatch Formation, and the Fort Union Formation. There are many minor aquifers located throughout the region. Groundwaters in the region occur at depths from the surface ranging between 12-45 m (40-150 ft). Many potential sites are underlain with one or more confined aquifers.

TABLE 6-1. - Typical Surface Water Qualities of Central Wyoming [a]

Constituent	A	B	C	D	E	F
Calcium	50-104	-	170-480	-	115-188	32
Magnesium	16-38	-	50-96	-	3-38	5
Potasium	9-16	-	3-9	-	2-7	15
Sodium	100-220	-	35-139	-	44-93	230
Bicarbonate	310-600	145-620	340-510	450-1410	360-420	488
Chloride	10-18	-	24-180	-	12-16	32
Carbonate	0	-	0	-	0	17
Sulfate	160-410	380-1500	370-1320	90-1790	236-370	84
TDS	510-1080	760-3210	960-2400	3070-5670	625-854	617
pH	7.1-7.7	7.4-8.4	7.0-7.8	7.5-8.4	7.6-7.9	-

[a] All concentrations are expressed in terms of mg/l except for pH.

The uranium bearing sandstones have typical permeabilities in the range of 200 to 4,000 millidarcys. Porosities have been reported to range between 20 and 34 percent. A significant characteristic of the sandstones is their anisotropic nature. Horizontal permeabilities are as much as a factor of 10 greater than vertical permeabilities. Hydraulic gradients typically range between 0.005 metric units and 0.09 feet per foot which result in velocities ranging between 1.5-183 m (5-600 ft) per year. Average groundwater velocities normally range between 0.6-6 m (2-20 ft) per year. Generalization of such parameters is of little value other than to present the reader with an overview of the region. Detailed analyses of the specific sites for in situ leaching operations are required by regulatory agencies.

Many of the sandstones bearing uranium have overlying and underlying shales with permeabilities of less than 0.2 millidarcy. Such low permeabilities mean that the shale strata is essentially impermeable unless fractured or faulted. Such paths for communication would be detected by the normal baseline geohydrology studies or the required monitoring programs.

Groundwater qualities in Wyoming range from excellent to poor, depending on specific locations. Many of the groundwaters, adjacent to or above proposed in situ sites, do not meet potable water standards and are only suitable for agricultural purposes. Table 6-2 presents the qualities of some typical groundwaters in the region. The waters are characteristically high in sulfate and many are low in calcium. These constituents are important because of their roles in scale formation and plugging of the ore zone.

Flora and Fauna

The Wyoming uranium deposits are located in a region characterized by variations in precipitation and temperature regimes, soil types, and elevations. These factors are important in determining the different types of vegetational communities present therein.

The Great Plains can be separated into two different shortgrass communities. The wheatgrass-needlegrass community, located along the eastern edge of the subject area, is a moderately dense shortgrass land. This area is dominated by western wheatgrass, blue grama, needle-and-thread grass, and green needlegrass. Farther west, this community is replaced by a grama-needlegrass-wheatgrass community. This community is rather short, open to fairly dense grassland. Dominant plant species include western wheatgrass, blue grama, and needle-and-thread grass.

Within the grassland are areas of wet lowlands that are dominated by grasses and sedges, forbs, and shrubs or rooted aquatic plants, depending upon the amount of available moisture. The grass/sedge wetlands are dominated variously by big bluestem, timothy, nutball alkaligrass, redtops, and various sedges and rushes. Forb/shrub wetlands are generally composed of western snowberry, poison ivy, horsemint, milkweeds, sunflower, and various thistles. Cattails and arrowhead occur along or in standing water.

TABLE 6-2. - Water Quality Data for Typical Wyoming Study Area Groundwaters [a]

Constituent/Site	A	B	C	D	E	F
Calcium	17	7.8	20.5	63	230	12
Magnesium	9.6	1.5	16	40	17	2.3
Potassium	2.5	7.3	7.9	-	-	-
Sodium	66	325	700	69	530	170
Bicarbonate	188	374	643	281	0.1	67
Chloride	9.0	12	21	8	360	51
Carbonates	0	7.4	120	-	170	18
Sulfate	14	202	880	130	950	220
TDS	288	917	1860	430	2300	560
Ammonia	0.1	1.8	1.5	-	-	-
Uranium	0.006	0.002	0.85	-	0.11	0.006
Selenium	0.003	0.005	0.22	-	0.01	0.01
Barium	0.5	0.05	0.5	-	1.0	1.0
Arsenic	0.01	0.02	0.02	-	0.01	0.01
Nitrate	0.05	0.85	0.32	-	0.62	0.18
pH	7.7	9.4	8.3	7.9	8.7	8.5

[a] All concentrations are expressed in terms of mg/l except for pH.

The Rocky Mountains extend into the subject area from the north as the Bighorn Mountains and from the south as the Laramie Range. With increasing elevation, plant associations encountered include the pine-Douglas fir forest (found only along the Laramie Range), the Douglas fir forest, the western spruce fir forest, and alpine meadows. These different plant communities are the result of different temperatures and precipitation associated with different elevations.

Typical pine-Douglas fir forest plants are ponderosa pine and Douglas fir. This is an open to dense forest of tall neddleleaf evergreen trees, often with much undergrowth. The Douglas fir forest is dominated by Douglas fir. This is a medium-dense forest of medium-tall needleleaf evergreen trees. Subalpine fir and Engelmann spruce dominate the western spruce-fir forest. This is a dense to open forest of low to medium-tall evergreen trees. The Alpine meadows and barren community usually are comprised of short grasses and sedges and may be dense to very open with extensive barren areas. Common plants include bentgrass, sedges, hairgrass, fescue, woodrusk, mountain timothy, bluegrass, and spice trisetum.

The Wyoming Basin is located in the western portion of the subject area. The soils in the Wyoming Basin are alkaline and can be considered desert soils. Plants growing in this area are usually highly alkali-tolerant species. In the northern portion of the Wyoming Basin a wheatgrass-needlegrass shrub steppe community occurs. Dominant species include western wheatgrass, big sagebrush, plains bluegrass, and needle-and-thread grass. A sagebrush steppe community occurs in the southern portion of the Wyoming Basin. Bluebunch wheatgrass and big sagebrush are the dominant plants.

A considerable variety of animals are found associated with the different plant communities of the Wyoming uranium area. Rodents are the most abundant animals in the prairies. Badgers, weasels, coyotes, and red foxes are also common. Waterfowl utilize stock watering ponds and reservoirs as resting places during migration and some individuals remain through the summer to breed. Game animals found in the area include antelope, mule deer, sage grouse, mourning doves, and cottontail rabbits.

South Texas Physical Setting

Geographic Location

The Coastal Plain of the United States extends as a wide band from south-central Texas on the west to New Jersey on the east, following the coastal areas along the Gulf of Mexico, Mississippi Embayment, and Atlantic Ocean. Parts of this large plain contain various levels of uranium. Known uranium mineralization that can be broadly classified either as a reserve or a resource is confined to Texas, Louisiana, and Florida. As previously discussed, only the southwest Texas deposits will be considered here.

The Gulf Coast of Texas is underlain by a series of partially consolidated sedimentary rocks--relatively young in age, as measured in terms of the Earth's geologic history. These beds which are composed largely of terrigenous non-marine) materials, deposited as a thick wedge of gently inclined sediments, are host for uranium in many locations. The primary ore deposits being mined by in situ leaching are located in the area around Corpus Christi as illustrated in Figure 6-2. In this area, the currently exploited uranium deposits occur in a series of strata that outcrop widely on the surface and extend to depths below the surface of many hundred feet.

Nature of Surface Conditions

Soils

Derivation of the surface materials in this Gulf Coastal Plain area of South Texas follows the pattern of soils formed in other humid regions. Typical alfisols are characterized by generally higher compounds of iron and aluminum - a feature associated with warm and humid climate. In addition, materials overlying the uranium deposits of South Texas reflect the influence of both local and regional factors such as low relief (topographic) and more abundant organic sources (both animal and vegetable). A modifying influence is created by a discontinuous veneer of quartz sand, the stable remnants of earlier beach sands and marine terraces deposited during latter stages of the Ice Age. Thus, in a given part of this Gulf Coastal Plain area of Texas, the surface materials may occur as a complete soil profile shown by the normal sequence of topsoil, subsoil, and residuum. The surface materials also may exist as incomplete soil horizons, modified locally by both major and subordinate classes of weathering such as climate, relief, parent material, vegetation, leaching, and oxidation.

Hydrology

The region receives approximately 75-125 cm (30-50 in) of annual precipitation. The precipitation rapidly decreases with increasing distances from the coast. The majority of rainfall generally occurs as short-duration, high-intensity storms during the summer. The surface waters traversing the areas of the primary uranium deposits have their greatest flows during the months of April, May, and June.

The sandstone hosts of uranium are typically located several hundred feet below the surface and are confined aquifers. Most uranium deposits have one or more overlying aquifers which may or may not be confined. Porosities of the ore-bearing sandstones typically range between 27 and 38 percent. Permeabilities are relatively typical of sandstones ranging between 20 and 4,000 millidarcys. The hydraulic gradient of the piezometric surface of the ore body aquifer is less than 0.5 percent under natural conditions the water velocity through the ore bearing zone is in the range of 1.5-9 m (5-30 ft) per year.

Hydrologic aspects which affect the suitability of waste storage and evaporation ponds are the net evaporation rate and the intensity of rain storms. Total evaporation per year in the region averages approximately 135 cm (54 in) per year. The net evaporation rate, which is defined as the total evaporation rate minus the annual precipitation, ranges between 10-60 cm (4-24 in) per year, depending on distance from the coast.

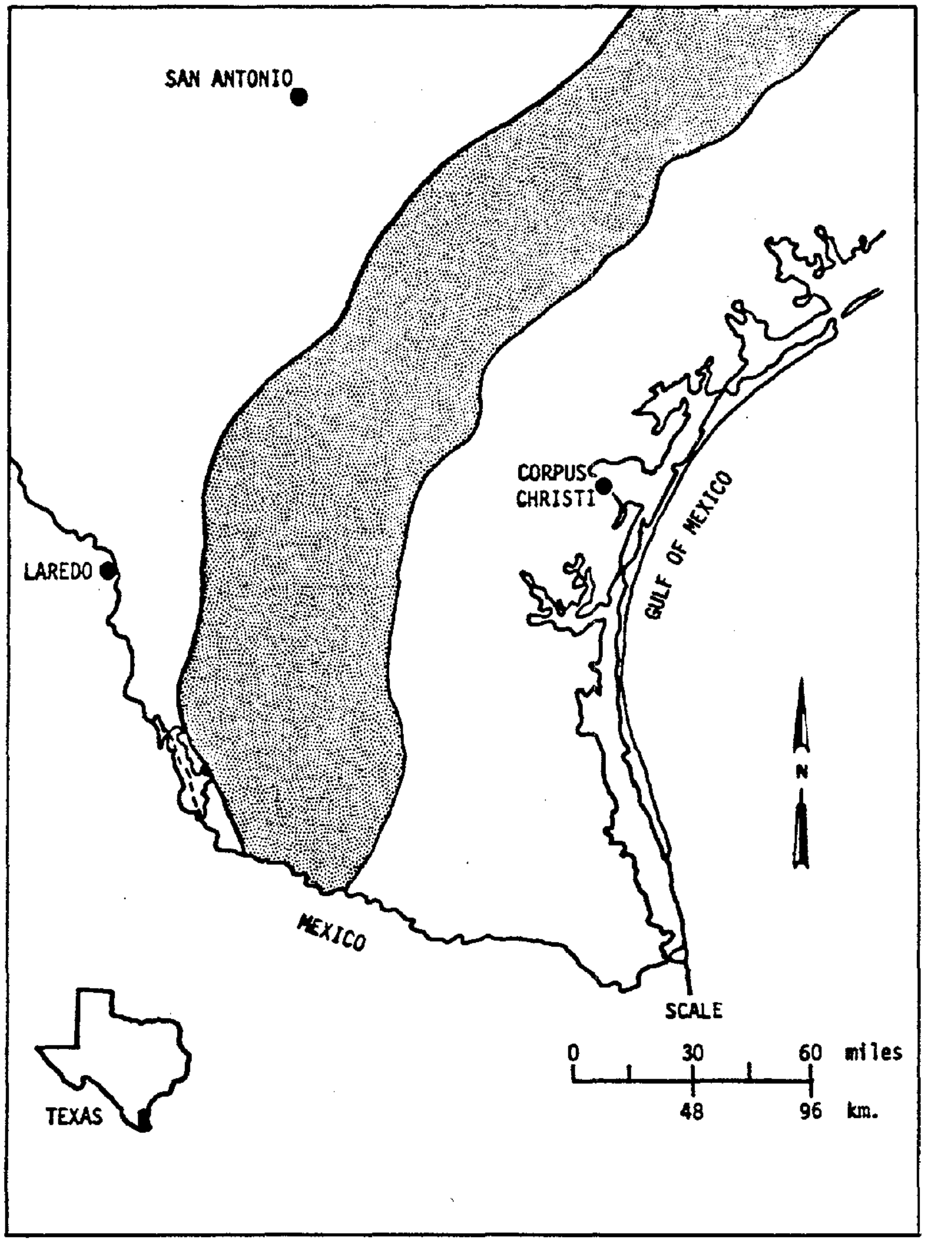


FIGURE 6-2 BELT OF URANIUM BEARING SANDSTONES

In general, the quality of water in the ore bodies and in the aquifers adjacent to the ore bodies do not meet the quality requirements for potable waters. The compositions of waters in the ore production zone and in the vicinity of ore bodies are presented in Tables 6-3 and 6-4, respectively. This data was selected from various Texas Department of Water Resources permits for five different sites in the south Texas uranium region. None of the water analyzed met the EPA recommended total dissolved solids limit of 500 mg/l. Four of the five water samples located in the ore production zones also had excessive concentrations of toxic trace metals such as arsenic, lead, mercury, and selenium. Only two of the six water samples in the vicinities around ore bodies had excessive concentrations of trace metals. The major difference in composition of waters within and in the vicinity of the ore body is the radium level.

Flora and Fauna

The Texas uranium area lies in a region known as the Gulf Coastal Plains. the subject area, the Plains increase in elevation from east to west from an average of about 75-215 m (250-700 ft). Major rivers include the Rio Grande, Nueces, San Antonio, Guadalupe, Colorado, and Brazos.

Four major vegetational associations are located within the area. These include from east to west the gulf prairies and marshes, post oak savannah, and blackland prairies. The Rio Grande plains association occurs in the southern portion of the area. The distributional pattern of these different vegetational associations is due in part to the decreasing precipitation occurring from north to south in the area.

The Gulf prairies and marshes vegetational associations characterize the eastern portion of the subject area. Typical marsh vegetation occurs along the Gulf coast, east of the study area. The climax vegetation of the Gulf prairies is largely grassland (tall grass prairie) or post oak savanna. The predominant tall bunch grasses include big bluestem, seacoast bluestem, Indian grass, eastern gamagrass, Gulf muhly, and various species of *Panicum*. Much of the area has been invaded by trees and brush such as mesquite, oaks, prickly pear, and acacia. Other invading plants include yankee weed, broomsedge, smutgrass, western ragweed, tumblegrass, and many annual plants.

The post oak savanna association is dominated by an overstory of predominately post oak and blackjack oak, with an understory of grasses such as little bluestem, Indian grass, switchgrass, purple top, silver bluestem, and Texas winterweed. Other common species include red lovegrass, broomsedge, splitbeard bluestem, yankee weed, bull nettle, green brier, smutgrass, and western ragweed. This area may have originally been a true prairie association. There is evidence that the brush and tree densities have greatly increased in the area in recent times.

The blackland prairies association has been classed as a true prairie dominated by little bluestem. Other important grasses are big bluestem, Indian grass, switchgrass, sideoats grama, hairy grama, tall dropseed, silver bluestem,

TABLE 6-3. - Water Quality in Ore Production Zone - mg/l Except pH, Conductivity, and Radon 226

Parameter	Location No. of Wells	A 15 wells	B 8 wells	C 3 wells	D 17 wells	E 5 wells
Calcium		42	52	80	267	14.5
Magnesium		9	10	11.6	68	2.9
Sodium		212	341	163	413	337
Carbonate		0	0	0	0	0
Bicarbonate		197	285	281	121	347.8
Sulfate		41	51	142	142	141
Chloride		280	436	143	1090	289.4
Fluoride		1.02	0.91	-	0.17	1.31
Nitrate (N)		0.07	-	0.05	0.05	2.78
pH		7.94	7.6	7.3	7.4	8.05
TDS		699	931	764	2312	1052
Conductivity[F]		1281	1589	1310	3835	1154
Arsenic		0.003	0.074	0.01	-	0.2
Barium		0.1	0.2	0.5	0.05	0
Boron		0.53	1.2	0.57	0.19	2.15
Cadmium		0.001	0.0001	0.0025	0.007	0.01
Copper		0.007	0.004	0.015	0.007	0.64
Chromium		0.01	0.01	0.01	-	0.024
Lead		0.009	0.004	0.02	0.052	0.25
Manganese		0.01	0.02	0.046	-	5.06
Mercury		0.0001	0.0003	0.0001	0.0007	0.36
Nickel		0.02	0.03	-	0.037	0.01
Selenium		0.012	0.002	0.005	0.005	0.61
Silver		0.01	-	0.0023	0.007	0.1
Zinc		0.37	0.03	0.02	0.04	0.18
Ammonia		0.15	0.2	0.01	0.17	2.1
Uranium		0.07	0.1	0.181	0.15	0.17
Molybdenum		0.05	0.03	0.2	0.05	0.25
Vanadium		0.1	-	0.003	0.05	0.2
Radium-226[G]		96	349	274	19.2	52.3
Iron		0.02	2.6	-	-	2.06

A - TWQB Permit No. 02025, Dalco-U.S. Steel Burns Lease
B - TWQB Permit No. 01890, ARCO Clay West Mine
C - TWQB Permit No. 02050, IEC Pawnee Plant
D - TWQB Permit No. 01942, Wyoming Mineral Corporation Bruni Site
E - TWQB Permit No. 01941, Mobil Oil Corp O'Hern Uranium Plant
F - Micromhos per centimeter.
G - Picocuries/liter.

TABLE 6-4. - Water Quality in the Vicinity of Ore Body (External to Production Zone) All Units mg/l Except pH, Conductivity, and Radium 226

Parameter	Location	A	B	C	D	E	F
	No. of Wells	13 wells	3 wells	12 wells	7 wells	15 wells	1 well
Calcium		48	61	55	118	186	12.8
Magnesium		10	11.7	9.7	14.0	43.5	4.1
Sodium		238	206	308	173	327	352
Carbonate		0	0	0	0	0	0
Bicarbonate		209	352	292	292	145	274
Sulfate		72	4	35	155	73	164
Chloride		306	235	395	217	822	309
Fluoride		0.97	0.87	0.88	-	0.2	-
Nitrate		0.41	-	-	0.05	2.18	0.08
pH		8.00	7.7	7.5	7.3	7.5	8.21
TDS		795	698	992	903	1671	1026
Conductivity[G]		1475	1087	1458	1567	2890	1704
Arsenic		0.019	0.074	0.133	0.014	0.017	0.02
Barium		0.1	0.2	0.2	0.5	0.15	0.0
Boron		0.54	0.6	0.9	0.40	0.69	1.15
Cadmium		0.002	0.0001	0.0002	0.003	0.002	0.02
Copper		0.007	0.006	0.005	0.012	0.006	0.05
Chromium		0.01	0.01	0.01	0.01	0.002	0.02
Lead		0.005	0.005	0.006	0.03	0.005	0.15
Manganese		0.01	0.01	0.100	0.059	0.039	-
Mercury		0.0002	0.0005	0.0005	0.0001	0.0007	0.0024
Nickel		0.01	0.02	0.03	-	0.337	0.1
Selenium		0.002	0.002	0.001	0.006	0.023	0.01
Silver		0.01	-	-	0.002	0.002	0.05
Zinc		0.40	0.02	0.07	0.081	0.03	0.30
Ammonia		0.07	0.2	0.2	0.01	0.24	0.5
Uranium		0.02	0.02	0.1	0.011	0.06	0.110
Molybdenum		0.02	0.1	0.02	0.41	0.026	0.4
Vanadium		0.1	-	-	0.005	0.029	-
Radium-226[H]		37	19.5	106	10.47	19.5	-
Iron		0.05	1.3	1.2	-	0.32	0.68

A - TWQB Permit No. 02025, Dalco-U.S. Steel Burns Lease - Production Vicinity
B - TWQB Permit No. 01890, ARCO Clay West Mine-Overlying Non-Production Zone
C - TWQB Permit No. 01890, ARCO Clay West Mine-Production Vicinity
D - TWQB Permit No. 02050, IEC Pawnee Plant-Production Vicinity
E - TWQB Permit No. 01942, Wyoming Mineral Corporation Bruni Site-Overlying Non-Production Zone
F - TWQB Permit No. 01941, Mobil Oil Corp. O'Hern Uranium Plant-Overlying Non-Production Zone
G - Micromhos per centimeter.
H - Pico curies/liter

and Texas wintergrass. Under heavy grazing, Texas wintergrass, buffalo grass, Texas grama, smutgrass, and many annual species increase in numbers. Mesquite, post oak, and blackjack oak have increased in localized areas. In areas along streams, tree species such as various oaks, pecan, cedar, elm, and mesquite occur.

The Rio Grande plains association, or Tamaulipan Brushland, consists mostly of range land, although there are large acreages of cultivated land. The open prairies are characterized by mesquite, granjeno, cactus, clepe, coyotillo, guayacan, white bush, brasil bisbirinda, cenizo huisache, catclaw, black bush, guajillo, and other small trees and shrubs which are found in varying degrees of abundance and composition. Grass species composition varies greatly reflecting the different soil types and moisture-holding capacities.

Since the study area includes prairies, shrub communities, and woodlands, a variety of wildlife species occur. Some of the more common include armadillo, bobcat, whitetailed deer, various species of squirrels and mice, jackrabbits, cottontail rabbits, and peccary. In addition, a large variety of birds and snakes also occurs.

Typical Uranium Deposit Amenable to Solution Leaching

At the present time there are several full-scale production in situ leaching operations. Additionally, there are several pilot scale or small production projects in operation in Texas and Wyoming. These existing operations are processing 4-8 hectares (10-20 acres) at one time. Many permits have been issued since 1976 for leaching larger total areas contingent upon successful restoration of individual subsections of the site.

For the purpose of the environmental evaluation, a "typical" mine site is defined as a 40-hectare (100-acre) deposit which will be mined in 2-10 hectare (4-25 acre) subunits. This size mine should be typical of production operations occurring in southwest Texas or central Wyoming for the next few years. The findings of the study are not limited by this definition of a typical operation since the findings are directly applicable to both smaller and larger sites.

The typical ore body will be defined to have an area of 40 hectares (100 acres), a thickness of 6 meters (20 feet) and a uranium content of 0.05 percent (U_3O_8). It is assumed that the total area will be leached over a ten-year period. A two-year leaching period and a one-year restoration period are assumed for a portion of each subunit of this "typical" ore body. Such a deposit would contain approximately 6.5 million pounds of uranium based on the assumed conditions. With a project life and an assumed recovery of 80 percent of the uranium, the annual production rate would be approximately 227,000 Kg (500,000 lbs) per year.

The roll-front deposits generally have length-to-width ratios of 2 to 6 for the size deposit defined as typical. The geometry of the deposit affects the perimeter-to-area ratio which, in turn, affects the number of perimeter monitoring wells.

In south Texas, as in Wyoming, the sandstone-bearing uranium are typically a confined aquifer at depths of 100-180 meters (350-600 feet) below the surface.

MINING TECHNIQUES

Premining Studies

Prior to construction of production facilities for an in situ leaching operation, there are many State and Federal environmental and regulatory requirements which must be met. The various regulatory requirements are described in Section 3 (Chapter 13 and following) of this report. From an operational viewpoint there are major environmentally-related studies or operations which must be completed prior to actual production. These are described in this section.

Definition of Ore Body Limits

In order to maximize uranium recovery, the limits of the ore body are always defined through an exploratory program. Obviously definition of the ore body is extremely important in determining the financial viability, the potential environmental impacts, and overall feasibility of a project. This is also an important aspect in terms of water quality and monitoring because restoration requirements are based on the mine development plan which is, in turn, based on the geometry and extent of the ore body.

Restoration refers to the actions following mineral extraction which must be performed to return the surface and subsurface environments to their original or some other acceptable state. The restoration requirements vary with both the specific site characteristics and the responsible regulatory agencies.

Hydrologic Testing of Aquifer

A prime requirement for in situ leaching is that the solutions can be controlled, once injected into the ore body. The ore zones considered to date are usually confined aquifers which are developed on the assumption that there is no communication with underlying and overlying aquifers. This must be verified. Well pump tests must be performed to define the hydrologic characteristics of the ore zone and the potential for hydraulic communication with overyling and underlying aquifers.

Other data such as ore zone porosity, permeability, hydraulic gradient, and natural groundwater velocities are determined. The data obtained by the hydrologic test program is also required for development of the injection-extraction well layout. Proper production well layout is a prerequisite for solution containment and restoration. A poorly designed injection system decreases uranium recovery by not uniformly distributing lixiviant. Likewise, such a system will not uniformly flush the aquifer during restoration.

Baseline Water Quality Survey

Documentation of the qualities of surrounding waters is a critical aspect of premining studies. Restoration requirements are generally defined in terms of baseline conditions. Improper definition of the baseline conditions can result in restoration water quality requirements which cannot be attained. The baseline survey must define natural variations as well as average values for qualities of waters in overlying and underlying aquifers. Documentation is especially important if aquifers are existing or potential potable sources.

Table 6-5 presents the range and average concentrations of five constituents of native groundwaters at two pilot leaching operations in Texas. There are significant variations in concentrations of all constituents with minimum: average and maximum:average ratios of 0.0013 and 12.7, respectively. The averages for the Clay West and Burns Lease Sites are based on eight and fifteen samples, respectively.

The effects of the number of wells on the average conductance and bicarbonate values are presented in Table 6-6. The averages presented represent the average of all wells listed in the table above the particular average. This data indicates that the average composition which might be used to define restoration requirements can be greatly affected by the number of wells in the baseline summary. One can conclude that at a minimum, average values are difficult to define and can lead to potential difficulties if single numerical values are used to define restoration levels.

Pilot Demonstration

Prior to approval of permits for operation of a production-scale in situ leaching operation, the regulatory agencies require that groundwater quality restoration be demonstrated. The current practice is to have a 4 to 5 month leaching period followed by 4 to 12 months of restoration. If unusual ore body conditions preclude or make restoration difficult, the pilot operation will define the processes and costs of achieving restoration. The pilot test should determine the volumes of water which must be pumped through the leached ore to remove residual lixiviant. Obviously, if the costs of restoration are excessive, the economics of the operation may preclude commercial mining. With regards to the impacts of the pilot scale tests, the small size of a pilot leach field (800-2,000 m^2 or 0.2-0.5 ac) preclude significant environmental effects.

Facilities Description

Injection-Extraction System

The uranium sandstone ore bodies which are suitable for in situ leaching because of permeability, depth of occurrence, favorable hydrologic conditions, and other factors are prepared for in situ recovery operations by drilling a pattern of injection and recovery wells at spacings varying from 8-30 meters (25-100 feet). This grid of production wells is surrounded by a ring of monitor wells to insure protection of other aquifers. Should the monitor wells detect

TABLE 6-5. - Variations in Native Water Compositions

	Clay West-ARCO (12)		Burns Lease (13)	
Constituent*	Average	Range	Average	Range
Bicarbonate	285	277-292	197	93-251
Sulfate	51	38-75	41	22-80
Arsenic	0.074	0.0001-0.94	0.003	0.001-0.008
Selenium	0.002	0.001-0.005	0.012	0.003-0.025
Radium-226	349	6-1938	96	19-220

*All concentrations in mg/l except for Radium 226 which is in pC/l.

TABLE 6-6. - Effect of Natural Variations in Native Water Compositions on Average Water Values of Conductance and Bicarbonate [a]

Well	Conductance (mhos/cm)		Bicarbonate (mg/l)	
ID No.	Value	Average	Value	Average
30	1798	1798	281	281
31	1772	1785	327	304
32	1742	1770	318	308
35	1622	1743	349	319
44	1699	1735	403	336
46	1690	1727	290	328
67	950	1616	352	331
68	960	1534	372	337
69	915	1465	367	340
77	965	1415	339	340

[a] The average value presented is the average of all wells having lower ID numbers than the entry.

escape of leaching solution, either the rate of recovery can be increased or the rate of injection can be decreased to pull the solutions back into the desired pattern. The recovery wells must be large enough to accommodate a submersible pump. Figure 6-3 is a typical vertical cross-section illustrating injection, extraction and monitoring wells. The wells are perforated in the ore zone and elsewhere they are cased and cemented so that solution cannot escape in undesired directions into other aquifers. Open screen or perforated sections of pipe in the ore zone permit production of leach solution with minimum of entrained particulates. The material of choice for well piping to depths of 160 m (500 ft) is polyvinyl chloride (PVC) because of its corrosion resistance, ease of handling, and moderate cost. It is frequently left in the ground at the conclusion of operations, after it is sealed properly.

A well spacing of 23 meters (75 feet) results in an average density of approximately 3 production wells per hectare (8/acre). This is equivalent to 160 wells per 8 hectares (20 acres), the area under leaching at any one time.

It is not necessary to fracture these naturally permeable sandstones (void space up to 30 percent) for uranium recovery but merely to inject and withdraw leaching solutions through the prepared wells. A large ore body might be leached in sections using various patterns of injection and recovery wells such as: five-spot (four injection wells in the periphery with a central recovery well or vice versa), or a seven or even thirteen-spot pattern. Irregular patterns may be used to accommodate local variations in ore configuration. The leach pattern selected is important for maximizing recovery of uranium but does not affect the environment as long as all injected fluid can be recovered.

The remainder of the in situ leaching equipment consists of a pressure pump for injection, a storage or surge tank, and associated piping with flow and pressure gauges.

A pipe network connecting production wells with the processing plant is required. These pipelines because of their temporary nature would normally be aboveground. In cold climates, such as Wyoming, it may be necessary to protect pipelines against freezing with either insulation or burial. Obviously, burial will result in greater surface disturbance and the need for revegetation upon termination of the operation.

Uranium Recovery Processes

Processing equipment for a uranium in situ leaching operation typically consists of an ion exchange resin column plant with several parallel trains depending on capacity followed by yellowcake precipitation, filtration, washing, and drying operations. A simplified flowsheet of such a plant is presented in Figure 6-4.

A wastewater disposal system consisting of evaporation ponds or deep injection wells are also required.

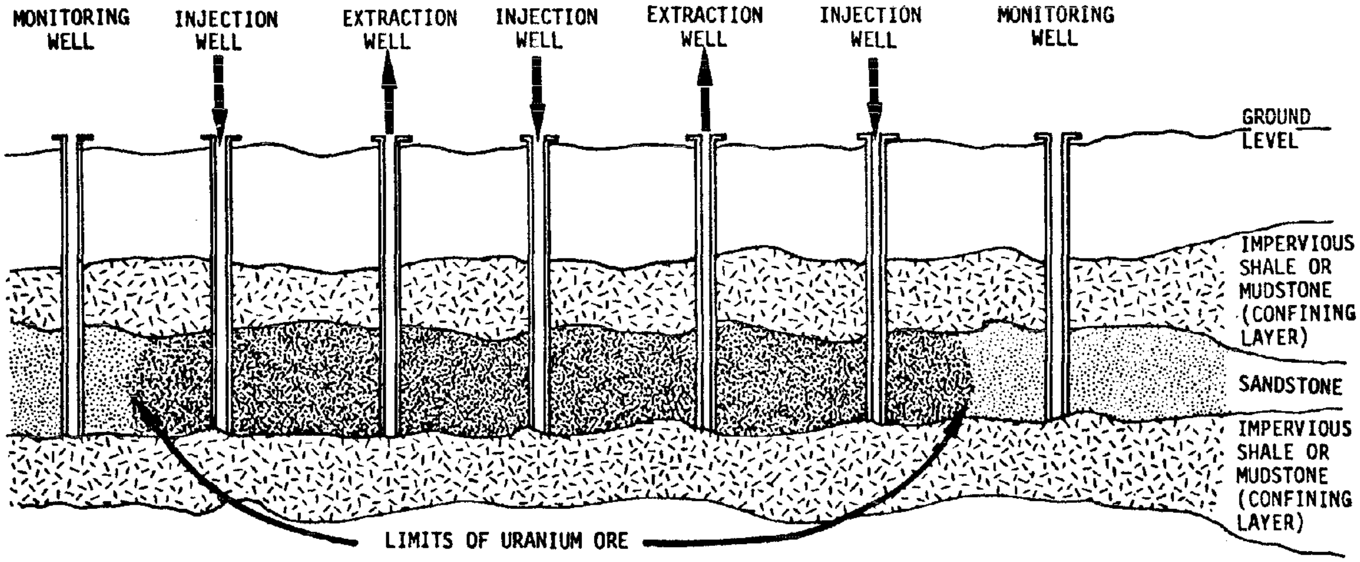


FIGURE 6-3 VERTICAL CROSS SECTION OF TYPICAL IN SITU SOLUTION LEACHING LAYOUT FOR URANIUM ROLL FRONT DEPOSIT

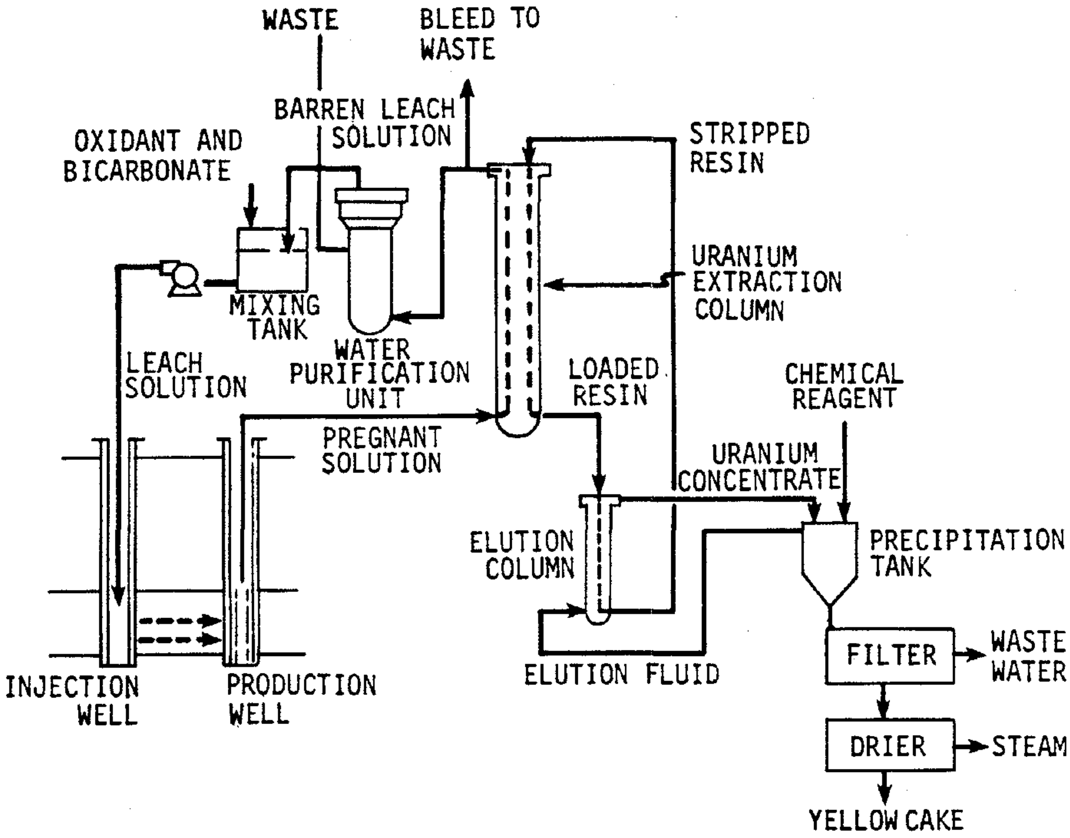


FIG 6-4 SIMPLIFIED SCHEMATIC DIAGRAM OF ION EXCHANGE URANIUM RECOVERY PLANT

Operation of the plant is routine, with only pump whirring to be heard. Control is largely by instrumentation requiring only a few operators. Plant expansion is accomplished with ease, since not much additional operator labor is needed.

In addition to the waste streams illustrated in Figure 6-4, there are process waste streams generated by the elution and concentration circuits. These wastes are described in the section on Wastewater Treatment and Disposal in this chapter.

The equipment used for production size facilities would normally be prefabricated off-site. In Texas, the units could be installed indoors or outdoors. In Wyoming, it would be necessary to protect the units from freezing during the winter. A structure with an area of approximately 1,860-2,320 m^2 (20,000-25,000 sq ft) would be required to house a 227,000 Kg (500,000 lb) /year processing plant.

The flow diagram illustrated in Figure 6-4 has three primary circuits: the leach circuit, the uranium concentration circuit, and the precipitator-dryer circuit. The uranium-rich lixiviant is pumped from the ore body through a surge tank and into the extraction column. The extraction column contains a standard ion exchange resin which retains the uranium with the release of the regenerate anion. The commonly used regenerates are listed in Table 6-7. Sodium chloride is the most widely used reagent for regeneration since chloride causes minimal interference with in situ leaching. Sulfuric acid regeneration increases the sulfate concentration of the recycled lixiviant, which can precipitate gypsum ($CaSO_4$) and clog the injection system. Ammonium nitrate has been very successfully used for regeneration in vat leaching. However, for in situ leaching, there is an increase in the nitrate concentration of the leach solution which can complicate the restoration process since the USEPA Potable Water Standards limit nitrate to 10 mg/l as N.

TABLE 6-7. - Chemicals Commonly Used in Recovery of Uranium at In Situ Leaching Facilities

Circuit	Chemicals
Ion Exchange	Sodium Chloride Sulfuric Acid Ammonium Nitrate Ammonium Chloride
Precipitation	Ammonia Magnesium Oxide Hydrogen Peroxide Ammonium Chloride Ammonium Bicarbonate

The elution-precipitation circuit typically uses ammonium salts for recovery of the uranium from the resin in elution column. The pH is decreased through the addition of an acid such as hydrochloric, and the uranium is converted to the uranyl ion (UO_2++). The uranyl ion is precipitated as ammonium diuranate (($(NH_4)_2 U_2O_7$) by the addition of ammonia. The precipitated ammonium diuranate is thickened into a slurry which is then filtered to remove excess moisture and dried in a kiln. Calcining at about 600°C converts the ammonium diuranate into U_3O_8 which is called yellowcake. Yellowcake is generally transported from the site in sealed drums in accordance with DOT/NRC regulations.

Figure 6-4 illustrates a water purification unit for the recycled lixiviant. Many lixiviants accumulate large concentrations of calcium which clog the injection wells by precipitating as calcium sulfate or calcium carbonate. The water purification system generally involves precipitation of calcium carbonate which is supersaturated due to the ammonium bicarbonate addition.

Leaching Processes

The chemistry of uranium enables recovery by either acid or alkaline leaching solutions provided that the uranium either is or can be oxidized to the hexavalent form. If the uranium does not naturally occur in the hexavalent form, an oxidizing agent is added to the acid or alkaline lixiviant. Roll front uranium deposits usually require the use of an oxidant.

The selection of a particular leaching solution is generally controlled by: 1) reactions with the gangue materials present in the formation; (calcite, pyrites, feldspars, zeolites and clays); 2) variations in uranium recoveries with lixiviant composition; 3) groundwater quality restoration requirements.

The uranium industry has extensive experience in optimizing lixiviant selection based on the first two factors. The restoration requirement is unique to uranium in situ operations and has only recently been appreciated as a result of difficulties in achieving restoration at pilot sites. There are two phenomena which cause the lixiviant composition to affect restoration. First, lixiviant constituents can adsorb to gangue materials and then be gradually released. An example of this process is the adsorption of ammonium ions on clays and their gradual desorption during the restoration process. Secondly, toxic trace constituents of the ore can be solubilized by the lixiviant. These toxic trace constituents can complicate wastewater disposal or necessitate extensive flushing to restore the groundwaters.

Acidic Lixiviants

The primary constituent of acidic lixiviants is sulfuric acid. Other strong mineral acids such as hydrochloric or nitric are technically viable but costs are economically prohibitive. Nitric acid has the added disadvantage of increasing the nitrate levels. Various oxidizing agents can be used in the acid leach including sodium chlorate, manganese dioxide and ferric sulfate. In acidic solutions, the soluble uranium specie is hexavalent UO_2++.

The composition of typical acid lixiviants is presented in Table 6-8. Typically the pH must be maintained below 2 or leaching slows, above pH 4 the uranium will not solubilize, thereby preventing recovery.

Acid typically reacts with gangue constituents such as calcite, magnesite, iron carbonates and oxides, phosphates, sulfides and montmorillonite clays (3). As the acids are recirculated certain dissolved constituents will accumulate and require that a portion of the flow be wasted to control resulting concentrations. Typically the total dissolved solids, sulfate and calcium ion concentrations dictate bleed-off requirements.

There is a potential problem with accumulation of toxic trace materials in the recirculated solution. The loss of lixiviant containing toxic trace elements to the environment can have negative environmental impacts. Concentrations of various substances occurring in recirculated acid leaching solutions are presented in Table 6-9. It is emphasized that these concentrations are not typical and should not be projected to other leaching systems. The factors contributing to accumulation of substances in leaching solutions are discussed in Chapter 7.

Alkaline Lixiviants

The two types of alkaline leach used are: sodium carbonate-sodium bicarbonate and ammonium carbonate-ammonium bicarbonate. The carbonate ion is needed for solubilizing the uranium. Chemically the sodium and ammonium systems are similar, but consideration of swelling of clays caused by the sodium cation generally leads to the choice of an ammonium cation system as practiced in the Texas Coastal Plain uranium belt. Beyond this, economics should dictate which reagent to use. The concentrations of chemicals used to prepare alkaline lixiviants generally suitable for in situ solution leaching are presented in Table 6-10. The pH range of commonly employed lixiviants is 7.8 to 8.8. The sodium carbonate/bicarbonate-based lixiviant has potential for ore deposits with low clay contents.

The soluble uranium specie in alkaline carbonate solutions is the very stable uranyl tricarbonate anion, $UO_{2(CO_3)_3}^{-4}$. Formation of this specie requires that the uranium be in a highly oxidized state, for example, hexavalent. The alkaline dissolution reactions are quite specific for uranium and vanadium materials. This causes the recirculated leach solutions to contain less impurities as compared to acid systems. The composition of a recirculated alkaline lixiviant is presented in Table 6-11. The alkaline systems are especially suitable for ores containing large concentrations of carbonate materials which have high acid consumptions. The pH range of alkaline lixiviants (6 to 10) includes the range of most natural formation waters.

Comparisons of Lixiviants

Generally the alkaline reactions are slower and it has been reported that they do not achieve as great uranium recoveries as the acidic lixiviants (3). The primary environmental considerations in selecting the optimum lixiviant for

TABLE 6-8. - Concentrations of Typical Components of Acid Lixiviants

Constituent		Concentration Range (g/l)
Acid - Sulfuric Acid		3 to 20
Oxidant [a] -	Sodium Chlorate	0.1 to 0.6
	Manganese Dioxide	0.2 to 1.3
	Ferric Sulfate	1.5 to 5

[a] Only one oxidizing agent is used in a given lixiviant.

TABLE 6-9. - Partial Composition of Recirculated Acid Lixiviant (4)

Constituent	Concentration mg/l
Arsenic	$\leq$0.05
Copper	1.00
Zinc	4.30
Lead	0.70
Manganese	1.20
Iron	25.40
Nickel	0.60
Chromium	0.15
Strontium	3.70
Zirconium	3.30
Vanadium	1.00
Cobalt	0.20
Ra-226	390 pCi/l

TABLE 6-10. - Concentrations of Typical Components of Alkaline Lixiviants

Component	Concentration g/1
BASE	
Carbon Dioxide	0.5 - 15.0
Ammonia	0.2 - 5.5
OXIDANT	
Hydrogen Peroxide (50%)	0.5 - 2.0
Oxygen	0.5 - 4.0

TABLE 6-11. - Partial Composition of Recirculated Alkaline Lixiviant (4)

Constituent	Concentration mg/1
Arsenic	$\leq$0.05
Copper	0.04
Zinc	0.10
Lead	0.20
Selenium	1.60
Iron	0.60
Nickel	0.06
Chromium	0.07
Molybdenum	0.90
Strontium	1.50
Zirconium	0.90
Radium	1750 pCi/1

a given ore body are: 1) constituent adsorption and resistance to restoration; 2) solubilization of toxic trace metals. Obviously, there are technical and economic factors which also must be considered.

Alkaline leaching has several environmental advantages over acid leaching, including:

1. More selectivity for uranium minerals so that leaching solutions contain less impurities. Some of these impurities are toxic and pose potential health problems. The mechanism of solubilization is discussed in Chapter 7.

2. Relatively noncorrosive solutions which have a lower probability for mechanical failure and subsequent spills.

3. Solutions that may be regenerated and recycled with less problems due to impurity buildup, resulting in smaller waste stream flowrates. Calcium precipitates on the ion exchange resins thereby reducing their exchange capacities.

4. Suitability with high lime ores. The use of acid lixiviants for lime ores would use excessive amounts of acid and result in high sulfate levels in the leaching solutions.

5. Ease of handling and a smaller potential for accidents and injury to personnel.

The environmental advantages of the acid lixiviants over the alkaline lixiviants are:

1. Leaching rates which are more rapid, reducing the mining period and the period of surface disturbances.

2. Uranium recoveries which are greater so that less area must be developed to produce a given amount of uranium. Area refers to the total area being mined throughout the county and not the area of a single operation.

3. Lower potential for solubilizing radium 226.

4. No adsorption problems with clays (when compared with ammonia and sodium).

Extensive research is currently being conducted to identify environmentally suited lixiviants. The major lixiviant problem in Texas is restoration difficulty due to ammonium ion adsorption on clays.

A recently proposed alkaline lixiviant utilizes potassium carbonate. It has recently been reported that a potassium carbonate-bicarbonate solution with hydrogen peroxide as the oxidant is as effective as the ammonia carbonate system.

Initial results indicate that the leaching rate of the potassium system is slightly less than that for the ammonia system. The potential advantages of potassium in high clay ores could favor its use. The entire aspect of lixiviant optimization in terms of environmental factors requires future study.

Waste Generation

The wastes generated at an in situ uranium mine and precipitation plant are functions of the specific ore and processing circuits employed. In this section the wastes generated are described. Waste production rates will be presented for the typical production size facility described in a previous section (capacity 227,000 Kg or 500,000 lb uranium per year; area - 40 hectares or 100 acres).

It is emphasized that the wastes produced are site specific and that the following descriptions are for a single situation. Factors affecting the composition and rates of the waste streams are described to aid site specific evaluations. The waste streams are discussed in the following: water, air and solids.

Wastewaters

The wastewater streams generated by the typical in situ mining and processing facilities described previously in this chapter are described in Table 6-12. The largest stream is generated during groundwater quality restoration. Since large projects are operated on a phased basis, there will normally be restoration fluids generated during the major portion of a plant's life. All the waste streams listed in Table 6-12 with the exception of sanitary wastes may contain trace amounts of radioactive materials and thus cannot be released into the environment. The sanitary wastes can be treated and disposed of in standard septic tank systems.

The annual mass emission rates of the constituents in major liquid waste streams are presented in Table 6-13.

In view of the high cost of radioactive wastewater disposal, most systems are designed for maximum in-plant water reuse and conservation. The lixiviant blend waste stream can be fed into other processing circuits to reduce discharge volumes. The spent resin wash and the eluant bleed waste streams can be included in the 20 gpm flowrate of waste stream one if reuse is practiced. The total volume of radioactive processing wastes, excluding restoration waters, can be as low as 1.47 l/sec (23.3 gpm), if maximum reuse is practiced. The 1.47 l/sec flowrate is the sum of waste streams one, four and five of Table 6-12. In general, the compositions of these wastes are characterized as brines (1,500-5,000 mg/l TDS) with possible small concentrations of trace metals (0-10 mg/l).

The volume of restoration wastewaters can be greatly reduced by reuse of waters and optimization of the restoration process. The 6.4 l/sec (102 gpm) flowrate presented in Table 6-12 is based on a flushing requirement of 10 pore volumes and a nine-year restoration project. The nine-year period is for the

TABLE 6-12. - Wastewaters Generated by Ion Exchange, 500,000 pounds uranium per year
In Situ Solution Leaching Operation Main Lixiviant Circuit
Flowrate = 63 l/sec (1,000 gpm), 24-hour operation

Waste Stream	Description	Flowrate	Annual Volume
1. Lixiviant Bleed	Barren Lixiviant Bleed produce net inflow into mine area.	1.25 l/sec (20 gpm)	2780 m^3 metric/English (32 AF)
2. Spent Resin Wash [a]	Water used to wash NH_4 Cl from spent resin.	0.63 l/sec (10 gpm)	1390 m^3 (16 AF)
3. Eluant Bleed [a]	Barren eluant bleed prevents salt accumulation in closed circuit.	0.63 l/sec (10 gpm)	1390 m^3 (16 AF)
4. Well Cleaning	Injection wells must be flushed to prevent clogging (2500 gal/well/month)	0.2 l/sec (3 gpm)	420 m^3 (5 AF)
5. Monitoring Wells	Flushing well prior to sampling produces representative sample 50 monitoring wells @ 250 gallons twice per month	0.02 l/sec (0.3 gpm)	42 m^3 (0.5 AF)
6. Sanitary Wastes [b]	1.25 l/sec (20 gpd) /employee x 60 employees	0.05 l/sec (0.8 gpm)	110 m^3 (1.3 AF)
7. Restoration	Water flushed through leached areas to remove all traces of lixiviants.	6.4 l/sec (102 gpm)	14,170 m^3 (164 AF)

[a] Lixiviant bleed can be used - flowrate is then contained in Item 1.

[b] Low water use fixtures, assumes showers for 80 percent of employees.

TABLE 6-13. - Annual Mass Emission Rates of Major Liquid Wastestream Constituents. Rates Expressed as Kg/yr Except for Ra-226 and Th-230 Which are Expressed as Ci/yr (NUREG-0407, 1978)

	Water Softener Brine	Resin Rinse	Elution Bleed	Yellowcake Wash Water	Restoration Wastes
As	-	-	-	-	90-270
Ca	6,000-10,000	-	-	-	-
Cl	6,000-10,000	60,000-90,000	72,000-90,000	56,000-84,000	-
CO_3	-	3,000-4,800	-	-	270,000-540,000
HCO_3	-	3,600-5,400	-	-	360,000-630,000
Mg	2,000-4,000	-	-	-	-
Na	20,000-30,000	36,000-66,000	36,000-48,000	42,000-56,000	340,000-650,000
NH_4^+	-	-	-	-	-
Se	-	-	-	-	45-135
Ra-226 Ci/yr	1x10	$6x10^{-4}$ to $1.2x10^{-3}$	$6-18x10^{-4}$	$2.8-7x10^{-4}$	0.045-0.09
Th-230 Ci/yr	$1x10^{-5}$	$3-6x10^{-4}$	$6-18x10^{-5}$	$1.4-2.8x10^{-4}$	0.022-0.067
U	2	6-18	30-60	42-70	900

entire site; any given subsection would be restored within one year following completion of leaching. In some instances it has been reported that as many as 25 pore volumes are flushed through before restoration is achieved. Under such flushing requirements the restoration wastewater flowrate would be in excess of 16 l/sec (250 gpm).

Atmospheric Emissions

A primary advantage of in situ solution leaching is its low atmospheric emission rates for both radioactive and nonradioactive substances. The primary radioactive specie emitted is radon. The nonradioactive species emitted are a function of the lixiviant and uranium recovery and concentration processes. The following are potential sources of atmospheric emissions at in situ solution leaching sites. Not all the process units described are utilized at a given production facility.

1. Pregnant Liquor Surge Tank - The pregnant lixiviant surge tanks are the primary radon source at a production facility. Radon-222 is dissolved from the ore body into the recirculating leaching solution and vented to the atmosphere at the surge tanks.

   The maximum radon emission rate can be estimated by assuming: 1) that all radon associated with the solubilized uranium also enters the pregnant solution; 2) all the radon in the pregnant solution is released. These assumptions are environmentally conservative and result in an estimation of the maximum emission rate. Obviously, the reactions of specific ores with specific lixiviants result in variations in concentrations of radon in the lixiviant which results in variations in radon atmospheric emission rates. Each leaching operation has to be evaluated individually.

   The majority of undisturbed ores are in a state of secular equilibrium, such as, daughter products forming at the same rate at which they are decaying with the concentration of any daughter product remaining constant. Selective natural leaching or controlled leaching of the ore can disrupt this equilibrium. However, since most ores are initially in secular equilibrium, it is possible to closely estimate the amounts of radon in leaching solutions from their uranium concentrations.

   It has been reported that pregnant lixiviants contain from 10 to 350 mg/l of uranium with an average value of about 150 mg/l assuming that radon is leached in direct proportion to the uranium the maximum and average radon-222 concentrations in the lixiviant are 110,000 pCi/liter and 45,000 pCi/liter. The release of all dissolved radon from the lixiviant results in maximum and average daily emission rates of 0.61 Ci/day and 0.25 Ci/day. The average rate would be applicable for estimation of annual emission rate. (0.25 Ci/day is equivalant to 91 Ci/year.)

2. Uranium Recovery Process Facilities - Small emissions of both radioactive and nonradioactive fines will occur in the processing areas. "Fines" refer to dust-size particulates which readily become airborne. The yellowcake drying and packing unit will liberate U_3O_8 fines, volatilized solution salts and the combusted oil, natural gas, propane or butane used to fire the kiln. The drying and packing unit is typical of that used at conventional uranium mills and mines. A scrubber system is used to trap U_3O_8 fines and greatly reduce their release to the atmosphere. Based on information obtained from dryers at conventional mills [NRC 1976] [Humeca ES], the uranium emissions passing through a scrubber is approximately 337μCi/day for 800,000 lb/yr of U_3O_8. This is equivalent to 210μCi/day for the hypothetical in situ system under consideration. The daily rate produces an annual emission of 77 mCi/yr. This corresponds to approximately 500,000 lbs/yr of uranium.

   The dryer will also volatilize the ammonium salts used to precipitate the yellowcake. The release of these constituents depends on the efficiency of the filter and their solution concentrations. Typically, both ammonia and ammonium chloride are emitted.

   Products of combustion will also be released. SO_2 could be a significant emission if oil is used to fuel the dryer. Natural gas (or propane, butane) are much cleaner fuels and will produce significantly fewer emissions. The dryer will annually release approximately 700 to 1600 tons of carbon dioxide.

3. Waste Storage-Disposal Ponds - The wastewater storage and disposal ponds are a source of both radioactive and nonradioactive emissions. The primary radioactive material released is radon-222, while the composition of the nonradioactive materials depend on the chemicals used in the process circuits. The emission rates are determined by the composition of the waste solutions, the evaporation rates, the prevailing winds, and the water temperature.

   Liquid wastes entering the storage-disposal ponds are bleed solutions from the ion exchange, yellowcake precipitation, and leaching circuits. The estimated flow rates and the generation rates of substances entering these ponds are presented in Tables 6-12 and 6-13 for a sodium carbonate-bicarbonate leach, a sodium chloride eluent, and an ammonia yellowcake precipitate. A storage pond for such wastewater would have atmospheric emission of ammonia, carbon dioxide, ammonium chloride, and radon. The suitability of atmospheric radon emissions depends on the magnitude of the emission rate in comparison to natural background levels. Conventional uranium mills license procedures of the U.S. Nuclear Regulatory Commission consider such emissions.

   Airborne particulate emissions from the storage-disposal ponds are minimized by maintenance of a liquid layer over the pond area.

4. Water Purification Unit - The water purification unit, if it is required, is a potential source of atmospheric emissions for ammonium carbonate-bicarbonate lixiviants. The water purification units are generally open at the top and permit the release of ammonia, ammonium chloride, carbon dioxide, and small concentrations of Radon-222.

5. Solid Wastes - Radioactive solid wastes would generally be hauled to acceptable disposal sites. Such wastes would not normally be stored or disposed of at an in situ leaching site.

ENVIRONMENTAL MONITORING AND RESTORATION REQUIREMENTS

The primary potential adverse impact of in situ solution mining of uranium is groundwater contamination. The environmental impacts which are discussed in the next chapter are predicated on the assumption that environmental monitoring and restoration will be conducted. In this section the required monitoring and restoration programs applicable to Texas and Wyoming are described and discussed. The State of Wyoming has not finalized their in situ regulations at this time (August 1978), and the reader is cautioned in that the following requirements can be modified in the future. Modifications to requirements of the State of Texas can also be anticipated as new techniques are developed and additional operation experience is accumulated.

Monitoring Wells

Monitoring wells are required for all in situ uranium operations to detect any flow of lixiviant from the leaching zone. The toxic composition of the lixiviant due to the presence of acid, excessive dissolved solids, uranium, and low concentrations of heavy metals such as arsenic, selenium, and vanadium, necessitates its containment within the mining area. The high value of the uranium laden lixiviant provides additional incentive for control and recovery of pregnant lixiviant.

The primary means of currently detecting excursions is sampling and analyzing the groundwater surrounding the leaching area. Sampling is achieved through a series of wells tapping the perimeter of the uranium strata and any overlying and underlying aquifers.

Location of Wells

Regulatory agencies generally specify guidelines for the number and location of monitoring wells. Figure 6-5 illustrates a 20-acre production in situ leaching site surrounded by a network of perimeter monitoring wells. The principal requirements for locating the monitoring well sites which are graphically depicted in Figure 6-5 are:

- Maximum well spacing: 122 meters (400 feet) - Texas
- Maximum well spacing in direction of natural groundwater flow: 61 meters (200 feet) - Texas

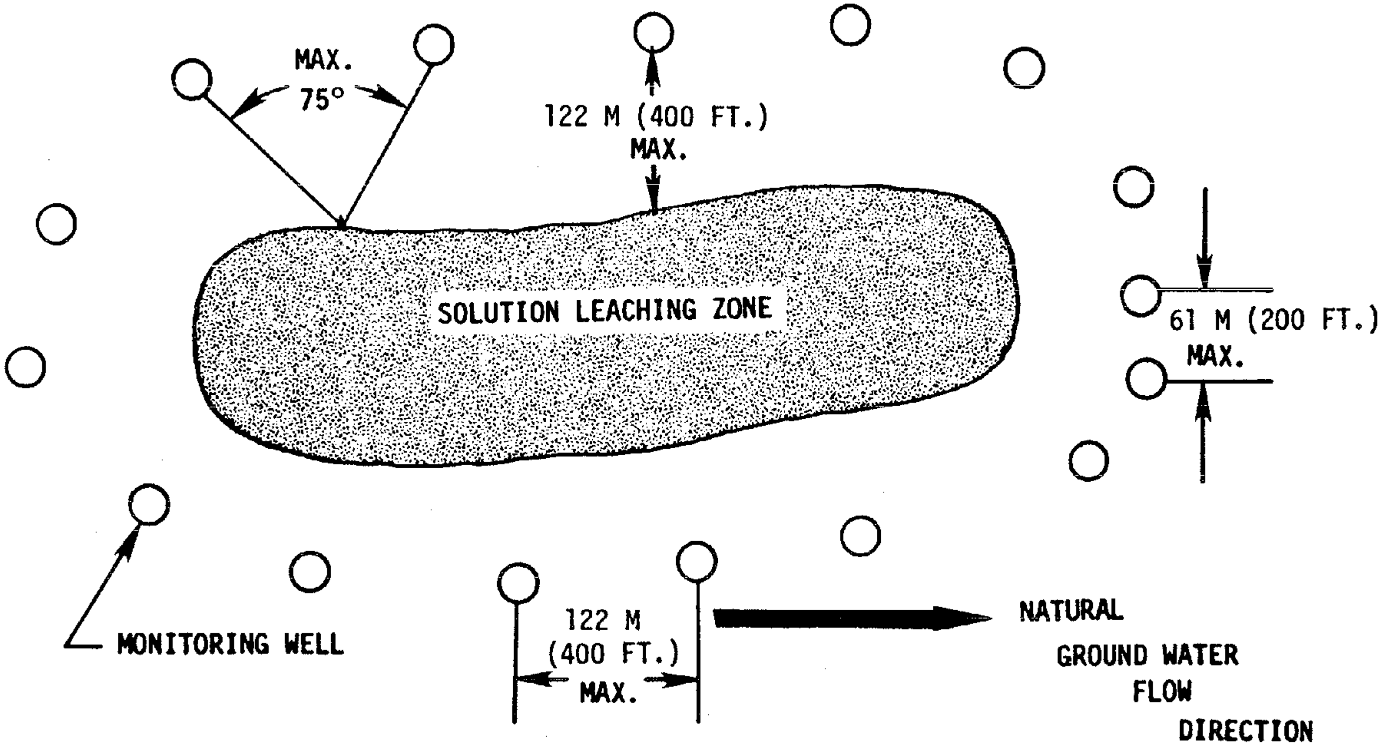


FIGURE 6-5. LOCATION REQUIREMENTS FOR MONITORING WELLS

- Maximum angle between two adjacent wells at any point on production perimeter: 75 degrees - Texas

- Maximum distance from perimeter to monitor well: 122 meters (400 feet) - Texas; 61 meters (200 feet) - Wyoming

In addition, there is a requirement for shallow and deep monitor wells. Shallow and deep refer to the aquifers or strata above and below the uranium-bearing stratum, respectively. Wyoming typically recommends a minimum of one shallow and one deep monitor well for each five acres of production area. As a comparison, the uranium stratum monitoring wells are located at a density of approximately one per acre for the typical roll front deposits. Obviously, since these are perimeter wells, their density is a function of the deposit geometry.

Solution leaching pilot operations are generally of such limited size that the above-listed requirements are not directly applicable. Employment of one monitoring well on each side of the pilot operation generally satisfies the requirements. Most pilot tests are fully monitored for both environmental and technical parameters in view of the importance of the pilot demonstration in defining the economic viability of expensive production operations. Existing regulations are such that any environmental degradation caused by new uranium mining/processing operations requires mitigation. In the past, mining activities have not been required to restore the environment. Generally, companies have pilot test monitoring programs more extensive than regulatory agency requirements since improper evaluation or the lack of identification of potential problems can result in mitigation actions which could be expensive on a production scale.

Both production and monitoring wells must be drilled and cased in a manner preventing leakage between adjacent aquifers. The cement basket technique for sealing the casing is typically employed. In many locations the piezometric heads of the uranium bearing strata are greater than that of the overlying aquifers and improperly sealed well casings are the primary paths of hydraulic continuity.

Monitoring Requirements

Source material licenses specify certain requirements for monitoring which are becoming standard for NRC and Texas production and pilot operations. An insufficient number of production licenses have been granted by the NRC to enable generalization about production monitoring requirements at this time.

The NRC currently requires recording of water levels and chemical analysis of water samples obtained from the monitoring wells on a biweekly basis. Changes in water levels may be indicative of changes in aquifer hydraulics which generally accompany lixiviant excursions. The biweekly water samples are analyzed for a variety of constituents which are indicative of lixiviant excursion. The constituents which must be analyzed on a routine basis are specified by the regulatory agency based on evaluation of the native groundwater and lixiviant compositions. The constituents monitored on a biweekly basis by most Texas operations and by two recent NRC applicants are presented in Table 6-14. Texas currently requires that only three constituents (ammonia, uranium, and TDS) be analyzed on a routine biweekly basis. If a deviation from the background conditions as documented in the permit application occurs for any one of these three constituents, then the concentrations of the more complete set of constituents (Column D, Table 6-14) must be determined.

It is highly possible that the analytical requirements for Wyoming will be reduced as site and regional specific information on excursions is obtained.

Changes in hydrostatic water level elevations may be a leading indicator of excursions. As such, Texas requires the installation of continuous water level recorders (generally two or three) in selected monitoring wells. Each water level recorder will be checked daily for variations in piezometric water elevations relative to the background elevations.

Texas also specifies that conductivity be measured at specific locations and that the meters be read and values recorded at a maximum interval of twice per week.

Regulatory agencies specify minimum sampling and analytical procedures which must be utilized in the monitoring program. In Texas and Wyoming, the monitoring wells are pumped until the produced water is free of mud and foreign material. A minimum volume equal to the water contained in the casing between the water surface and the aquifer being sampled must be pumped prior to sampling. Excess water pumped from the ore body is considered a wastewater and must be treated as such.

Sample preservation, analysis, and analytical quality control procedures are those defined in Methods for Chemical Analysis of Water and Wastewaters and Analytical Quality Control in Water and Wastewater Laboratories (EPA).

Excursions

An excursion refers to the flow of leaching solution out of the well field area. Under normal conditions, excursions are prevented by the operation and control of injection/production rates and the bleeding of a small fraction of the recycled lixiviant. This bleed is a purposely initiated imbalance of the injection-extraction volumes. This imbalance imposes a cone of depression on the groundwater table (potentiometric water surface for confined aquifers) causing a flow of native water into the production area. This action should prevent a lateral excursion of lixiviant into the surrounding stratum of the uranium bearing ore.

Definition and Detection

The natural variations in composition of groundwaters can cause concentrations of specific constituents to substantially increase above-average baseline levels. In recognition of natural variations, regulatory agencies require that definite verification and control procedures be initiated whenever routine

TABLE 6-14. - Required Constituents in Routine Monitoring Samples for Recent Uranium Solution Mining Projects [a]

	Project			
	A	B	C [b]	D [c]
Ammonia	-	0	0	0
Arsenic	0	0	-	-
Bicarbonate	0	0	-	0
Calcium	-	-	-	0
Carbonate	0	-	-	-
Chloride	0	0	-	-
Selenium	0	0	-	-
Sulfate	-	-	-	0
Uranium	0	0	0	0
pH	0	0	-	-
TDS/Conductance	0	0	0	0
Water Level	0	0	0	0

[a] "0" - Required.
"-" - Not required.

[b] Column C constituents are analyzed biweekly.

[c] Column D constituents are determined only if excursion is indicated by excessive values of Column C constituents.

biweekly monitoring detects an increase in one or more constituents above a maximum limit specified in the permit. The upper limits indicating a possible excursion are based on the native groundwater composition, the nature of the lixiviant and water quality requirements.

The ranges or ratios of the concentrations indicating an excursion to the baseline concentrations are presented in Table 6-15 for a recent Texas permit. The ratio is calculated by dividing the concentration defined by regulatory agencies as an excursion by the baseline value. The ranges of values resulted from consideration of several different mining areas in a single permit. The NRC excursion control procedure applicable to Wyoming differentiates between high concentrations of toxic and non-toxic species. The major steps common to excursion control procedures of the NRC and Texas are verification analysis, initiation of restoration action, construction of detection well(s), and continued sampling at a frequent interval until the excursion is cleaned up.

TABLE 6-15. Ranges of Ratios Between Upper Limit Indicating an Excursion and Baseline Water Quality for a Recent Texas Permit

Constituent	Ratios between Excursion and Baseline Concentrations
Ammonia	3.8 - 10.4
Bicarbonate	1.3 - 1.7
Calcium	2.0 - 2.6
Sulfate	1.4 - 1.6
Uranium	16 - 35
Conductivity	2.0 - 2.5

If the routine biweekly monitoring program indicates that a specified increase occurs in any one of the specified constituents, the operator is required to perform a confirming analysis. The magnitude of the increase is specified in the operating permit. In Texas, an evaluation must be made of all constituents listed in Column D of Table 6-14 as part of the confirming analysis. If this confirming analysis verifies that an excursion has occurred, the operator must take the following actions:

1. Notify regulatory agency with jurisdiction in the State where leaching is performed.
2. Initiate daily sampling and analysis of the wells in the area of the excursion.
3. Initiate excursion control operations which are based on increasing the extraction rate over the injection rate.

4. In Texas, if a cleanup trend is not produced within four days, installation of a secondary monitoring well in a direction away from the production zone is required. Generally the secondary monitoring well is located 15 meters (50 feet) from the primary monitoring well. The objective of this secondary monitoring well is to refine the extent of the excursion.

   In Wyoming, whenever an excursion occurs, its extent must be defined by the installation of monitoring well(s).

5. Daily sampling of all affected monitoring wells shall continue until the formation water concentrations decrease to below the limit defining the excursion.

If a local excursion cannot be cleaned up, it will be necessary to suspend all injection operations. Injection operations can only commence when cleanup is achieved and approval for operation is obtained from the agency issuing the permit.

Excursion Control

There are a variety of techniques identified in recent in situ mining NRC environmental statements for containing and correcting the migration of leach solution. These techniques, which all result in a relative increase of extraction to injection on a local or total in situ leaching basis, are:

1. Field Overpumping - Increased extraction from total field.

2. Reordering - Adjustment in individual well extraction rates to produce large extraction/injection ratio in area of excursion.

3. Injection Reduction - Lowering the injection rate on a local and/or total well field basis.

4. Commencement of Restoration - Large scale extraction when all other efforts have failed.

Restoration

Groundwater quality restoration is a process by which an in situ leach site is returned to an environmentally acceptable state after mining is complete. Surface restoration consists of removing all structures, pipelines, etc., and the sealing or removal of evaporation ponds. Subsurface restoration, the primary area of concern, is achieved by discontinuation of lixiviant injection and continued operation of the extraction wells. In some operations, good quality water is injected through the lixiviant injection wells to better control the flow of water through the leached ore body. This causes native groundwaters to flow through the leached sandstones, flushing out the residual concentrations of acid or carbonate lixiviants. In this section the following are discussed:

restoration criteria, demonstrated restoration samples, restoration wastewaters, and potential problem areas.

Hydrologic Considerations

Several schemes have been proposed for restoration of the leached ore bodies. Common to all schemes is the discontinuance of lixiviant injections and continued extraction. Several of the pilot operations have indicated that economically recoverable levels of uranium will occur in the initial restoration waters and that it is cost-effective to pass these waters through the ion exchange system. Operators have also found that pumping stoppage in the aquifer for several weeks allows the concentration of uranium (and other constituents) to increase in the restoration fluid. This has economic advantages when recovering uranium from the restoration waters. This increase in concentrations is due to the diffusion of constituents from "dead-end" pores within the sandstone grains. This diffusion phenomena is discussed in further detail in Chapter 7 since it is not specifically limited to uranium leaching.

A primary factor in achieving restoration is flushing all areas having experienced leaching. Computer modeling is widely used for development of restoration pumping schemes. Such an approach can minimize the restoration period and the volume of wastewater produced.

Another important factor which affects the volume of total water flushed through the aquifer is the three-dimensional distribution of permeability. Restoration will be delayed if the restoring solutions finger through zones of high permeability rather than sweep evenly through the formation. This same phenomena is faced in uranium recovery phases of the operation.

Restoration Criteria

Permits or licenses generally specify the levels which must be attained by the restoration operation. In the early days of in situ uranium leaching, many restoration programs for pilot tests attempted to achieve a water composition identical with or within 10 percent of the original water quality. Regulatory agencies now realize the great difficulty or even impossibility of restoring the original groundwater quality conditions and have adopted more realistic restoration requirements based on:

- Native water composition
- Potable water quality standards
- Water quality required for probable future uses
- Treatability of waters

It has been proposed (but not adopted) that the initial water quality characteristics determine the degree of restoration required. For example, restoration requirements of a potable water may dictate that all individual ions are reduced to within 10 percent of their original concentrations. On the other hand, if the original quality did not permit the use of water for any usages, then only the TDS and leach constituents would have to be restored to within 10 percent of their original concentrations. Obviously, there are intermediate categories which would establish guidelines for defining restoration requirements for water uses such as agricultural waters and livestock waters.

The restoration requirements for several recently granted applications in Texas, along with baseline need of water compositions, are presented in Table 6-16. Wyoming is currently in the process of developing rules and regulations for specification of restoration water quality requirements. Public hearings reviewing these rules and regulations occurred in September 1979. Final regulations were not available at the time of this report's completion.

Restoration Process

At the present time, no substantial size larger than 2 hectares (5 acres) in situ site has been completely restored to baseline conditions. There is, however, information indicating that restoration by flushing is possible [Wyoming Mineral Corporation] (4). The unanswered questions concern the number of sweeps or pore volumes which must be flushed at specific sites.

Figures 6-6 and 6-7 illustrate the response of residual conductance and ammonium concentrations to restoration for two sites in Texas. Figure 6-6 is for Wyoming Mineral Corporation's Bruni Site (4), and Figure 6-7 is for Union Carbide's Palangana Project (9). The data in these figures indicates that flushing does reduce the concentrations of ammonium ion and conductance.

A principal additional source of information on restoration feasibility is the documentation required for cleanup of excursion. Excursion cleanup is similar to restoration if native waters are used as the flushing solution. There is much current interest in the use of additives to facilitate restoration. This is discussed in the following sections on potential problems.

Figure 6-8 illustrates the response of molybdenum, sulfate, and conductivity levels to cleanup actions at well MD-118 of Arco's Clay West site (10). These data are summarized in Table 6-17 in terms of percent of restoration. The data indicate that these three species can be "cleaned up" to background levels within 35 days. The cleanup period is primarily a function of flushing rate. The period can be shortened or lengthened depending on requirements. requirements. There appears to be no environmental disadvantage in using 35 to 50 days for achieving baseline conditions.

Ammonia Sorption

Texas in situ mining operations have experienced difficulty in removing ammonia from the leached ore bodies. Ammonium ion in the alkaline lixiviant will be adsorbed by an ion exchange mechanism to the clays in the uranium-bearing sandstone. In the exchange reaction, ammonium ions typically replace calcium or magnesium ions on montmorillonite clays. Montmorillonite has a large surface

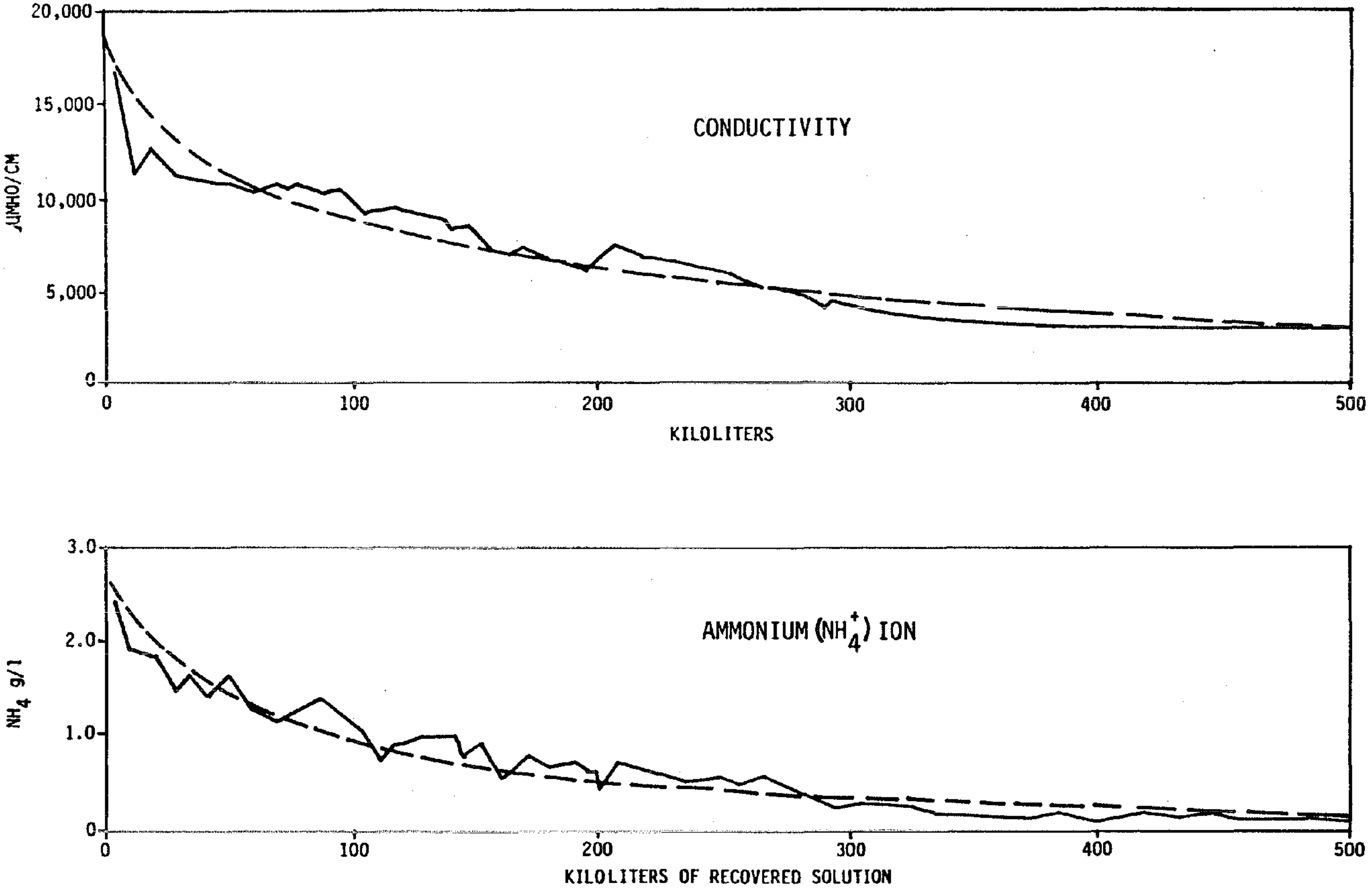


FIGURE 6-6 BRUNI RESTORATION DEMONSTRATION

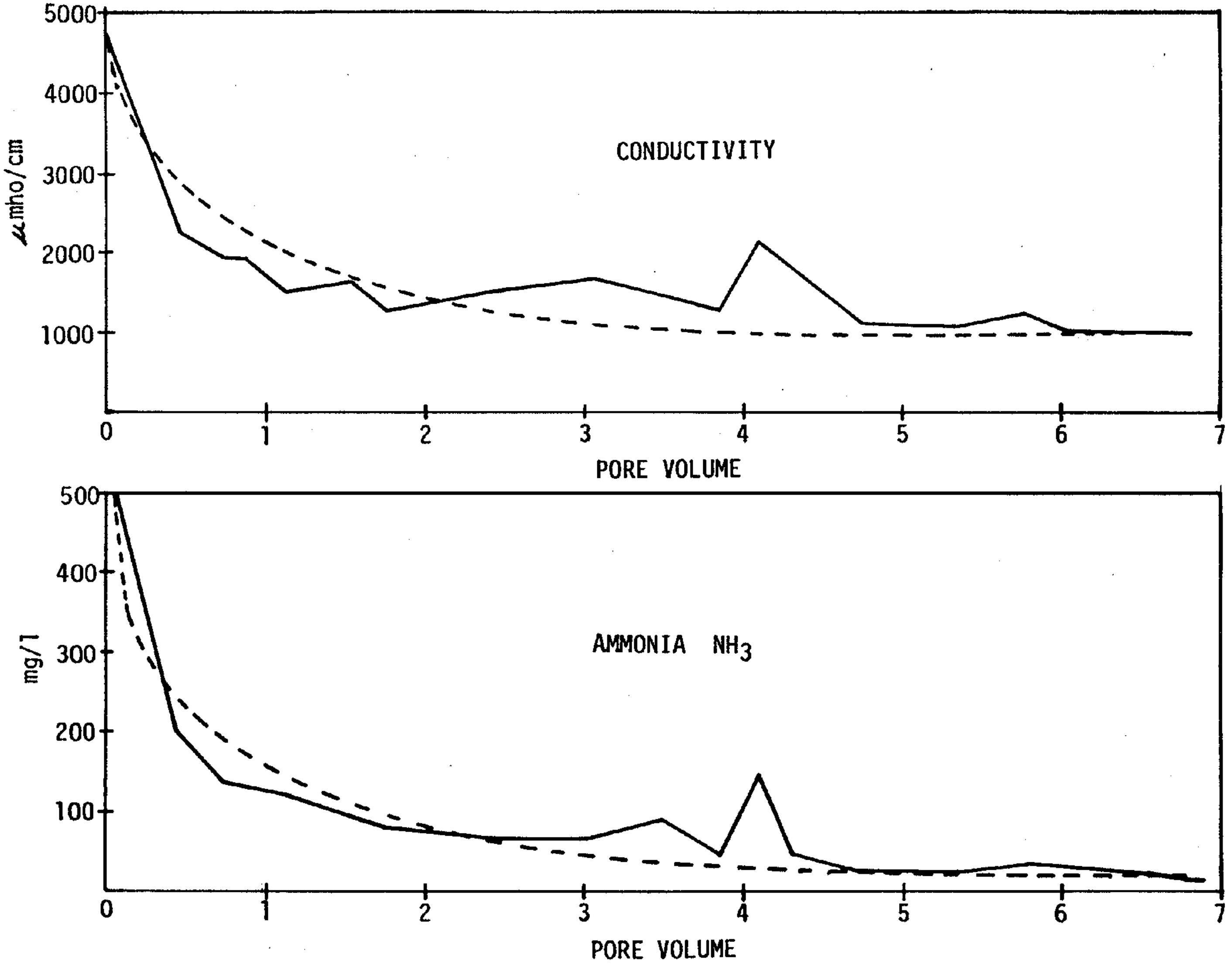


FIGURE 6-7 PALANGANA PROJECT RESTORATION DEMONSTRATION

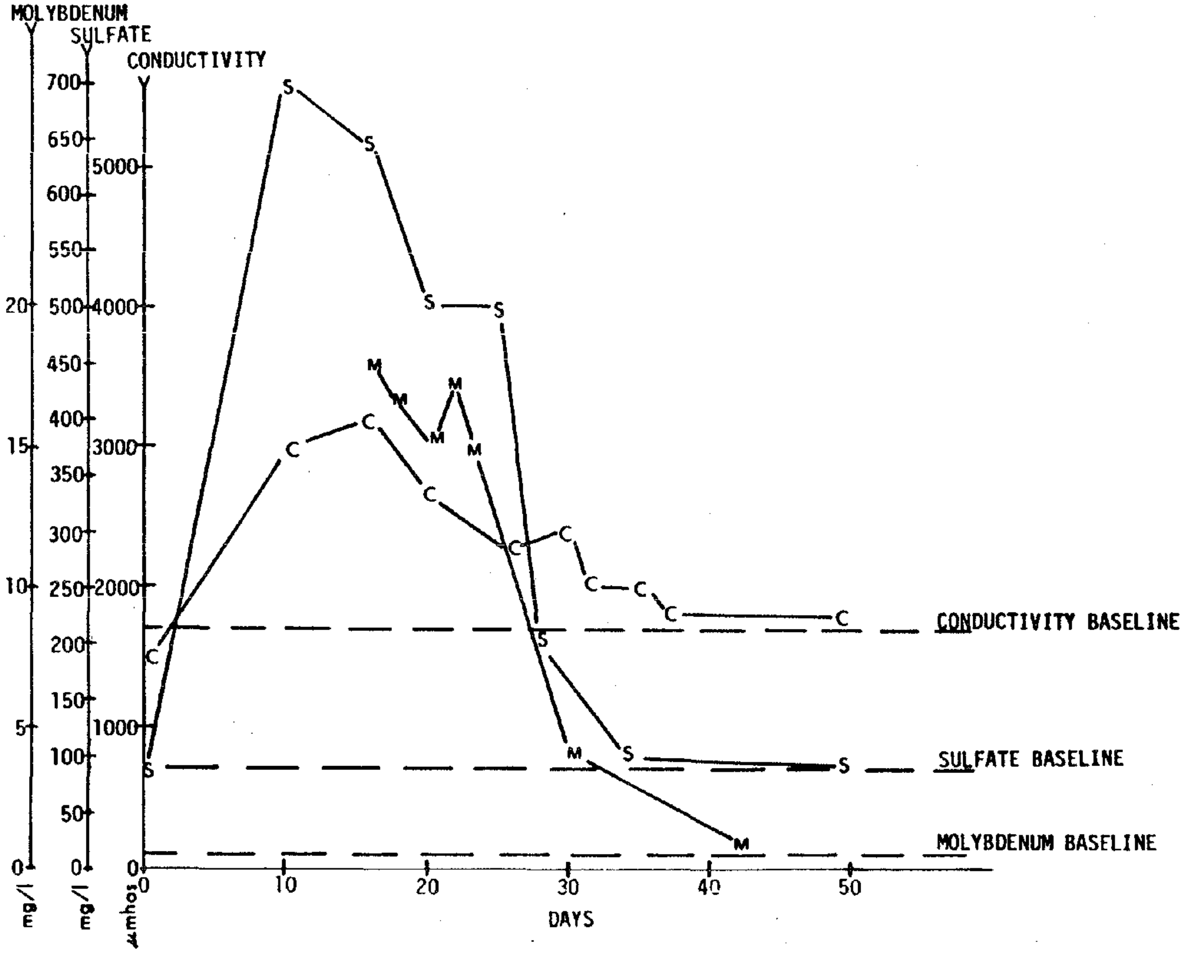


FIGURE 6-8. RESPONSE OF MOLYBDENUM, SULFATE AND CONDUCTANCE LEVELS TO CLEAN-UP ACTIONS AT MD-119.

TABLE 6-16. - Water Quality Requirements of Restoration and Native Water Composition at Four Texas Solution Mining Sites

	A		B		C		D	
Constituent	Base Line mg/l	Restoration Value mg/l	Base Line mg/l	Restoration Value mg/l	Base Line mg/l	Restoration Value mg/l	Base Line mg/l	Restoration Value mg/l
Ammonia	0.76	0.8	-	0.01	1.0	1.4	2.1	2.1
Bicarbonate	175	500	281	500	230	500	348	500
Calcium	192	270	80	200	31	200	14	200
Sodium	307	410	163	200	235	245	-	-
Sulfate	76	300	142	250	116	250	141	300
Chloride	754	1100	143	250	209	250	-	-
Uranium	0.21	5.0	0.2	2.0	0.05	2.0	0.17	2.0
TDS	1615	2310	764	903	751	878	924	1000
Nitrate (N)	2.04	10	0.05	10	0.1	10	0.86	10.0

TABLE 6-17. - Summary of Excursion Cleanup Data Presented in Figure 6-8 [a]

Days after Peak Concentration	Percent Reduction of Excursion		
	Conductance	Molybdenum	Sulfate
7	13%	6%	13%
10	33%	17%	33%
15	60%	34%	37%
20	53%	80%	87%
25	80%	87%	93%
30	93%	95%	95%
35	98%	95%	96%

[a] After (10)

area, which results in a substantial cation exchange capacity and its presence in even small concentrations can markedly increase the retention ammonia ions in the ore body. During the restoration process, as native water sweeps through the ore body, the ammonia is desorbed from the clays. This desorption process occurs at a relatively low rate and will continue to "bleed" ammonia into the aquifer for a relatively long period of time. It has been reported that sweeping an ore body with ten pore volumes will only reduce the ammonia concentration to 15 to 25 mg/l.

The ammonium ion is not particularly toxic to man (5). It has been reported that injection of water with 40 mg/l of ammonia over a long period of time resulted in no detrimental effects on cattle. A major concern with ammonia is its potential for conversion to the nitrate ion, which has a maximum permitted concentration for potable waters of 10 mg/l. Water with nitrate at this level can cause methemoglobinemia in infants. Infant methemoglobinemia is a disease characterized by specific blood changes and cyanosis. The disease has been attributed to high nitrate concentrations in the water used for preparing formula. The human body can also reduce nitrate to nitrite which may combine with metabolic amines to form nitrosamines, regarded by many as carcinogenic.

The amount of ammonium ion adsorbed by a particular ore body is primarily a function of its clay content. In South Texas, the principal clay mineral is montmorillonite which exhibits a very high exchange capacity per unit of pure clay. However, it is impossible to generalize about the degree of ammonia retention within the ore body since the clay content in and around in situ leach areas varies between 0.5 and 20 weight percent. Ammonium ion has been the preferred cation for the alkaline lixiviant to leach the south Texas uranium deposits. Sodium ion causes swelling of the clays and subsequent plugging of the formation. Calcium ion reacts with the sulfate to precipitate gypsum, which also decreases the permeability of the formation. Research is currently being conducted to see if potassium can be used as the cation without adsorption or swelling problems.

The clay content of ores leached with ammonium-based lixiviants will determine the difficulty in restoring the groundwater to low ammonium ion levels. Generally, when the clay content is high, ammonium ion removal is more difficult. There is another aspect to the clay adsorption problem. While clay does hinder restoration, it also impedes the transport of ammonium ion from the zone of the ore body. As native water flows through the leached area, ammonium ions would be leached and transported short distances beyond the leached ore body where they would be then adsorbed by additional clays. This would impede its transport for any significant distances in the aquifer.

While ammonium ion is relatively immobile, the nitrate ion is extremely mobile and would not precipitate or be retained by sorption. In surface waters, ammonium ion is typically converted to nitrate by aerobic bacteria. If this conversion can occur in the groundwaters, then in situ leaching operations can generate a significant quantity of a mobile species considered toxic at 10 mg/l. This conversion which is referred to as nitrification only occurs under specific biological and chemical environments. Under the conditions of pH and Eh typical of natural water in the confined aquifers in south Texas, there is little likelihood that ammonium ions can be converted to nitrate ions. However, if aerobic conditions can be maintained as a result of mining operations, it may be possible to form significant amounts of nitrates (6). At this time there is inadequate data for quantification of the potential nitrification.

As previously mentioned, research is currently being conducted on alternative cations for the alkaline lixiviants. This would eliminate the ammonium ion adsorption problem. Research is also being conducted on the effectiveness of the use of additives to restoration fluids. The removal of the ammonium ions from clays occurs by an ion exchange process. This means that calcium, potassium, sodium or some other cation is adsorbed onto the clay as ammonium ion is released. Distilled water would act as a very poor restoration fluid because it has few cations. Current research involves the use of calcium and potassium-enriched solutions for "sweep flushing."

ENVIRONMENTAL IMPACTS

In a site-specific environmental analysis of a particular project, all real and potential impacts would be described, discussed, and evaluated. The following discussions are not directed to all environmental impacts of in situ uranium solution mining. The impacts common to all uranium recovery processes such as dust generation by vehicular traffic are listed in the Environmental Matrices presented in Appendices A-3 and A-4. Radiological aspects of in situ uranium leaching are discussed to enable the reader to contrast their impact with those of conventional uranium mining and milling methods.

Radiological Aspects of In Situ Leaching

Background

The radioisotopes associated with uranium and thorium can be grouped into three major series: uranium, thorium and actinium. Each of these series is headed by a long-lived nuclide, contains a single gaseous member, and terminates as a stable isotope of lead. The thorium series begins with thorium 232 (half life = 1.41 x 10^{10} years) and the actinium series with uranium 235 (half life = 7.1 x 10^{8} years). The decay change of uranium 238 known as the uranium-radium family is of primary importance since natural uranium contains approximately 99.28 percent of uranium 238, 0.71 percent uranium 235, 0.01 percent uranium 234, and small amounts of thorium. Figure 6-9 is a graphical representation of the sequence of decay from uranium 238 to radiogenic lead 206.

The majority of ores contain this radioactive family of elements in secular equilibrium; for example, the daughter products are being formed at the same rate at which they are decaying with the amount of any member actually present remaining constant. Some ores have had this equilibrium disrupted by selective natural leaching, however, most are in equilibrium. When ores are in equilibrium, it is possible to estimate rather closely the amount of daughter products in the ore from knowledge of its uranium content so the daughter product

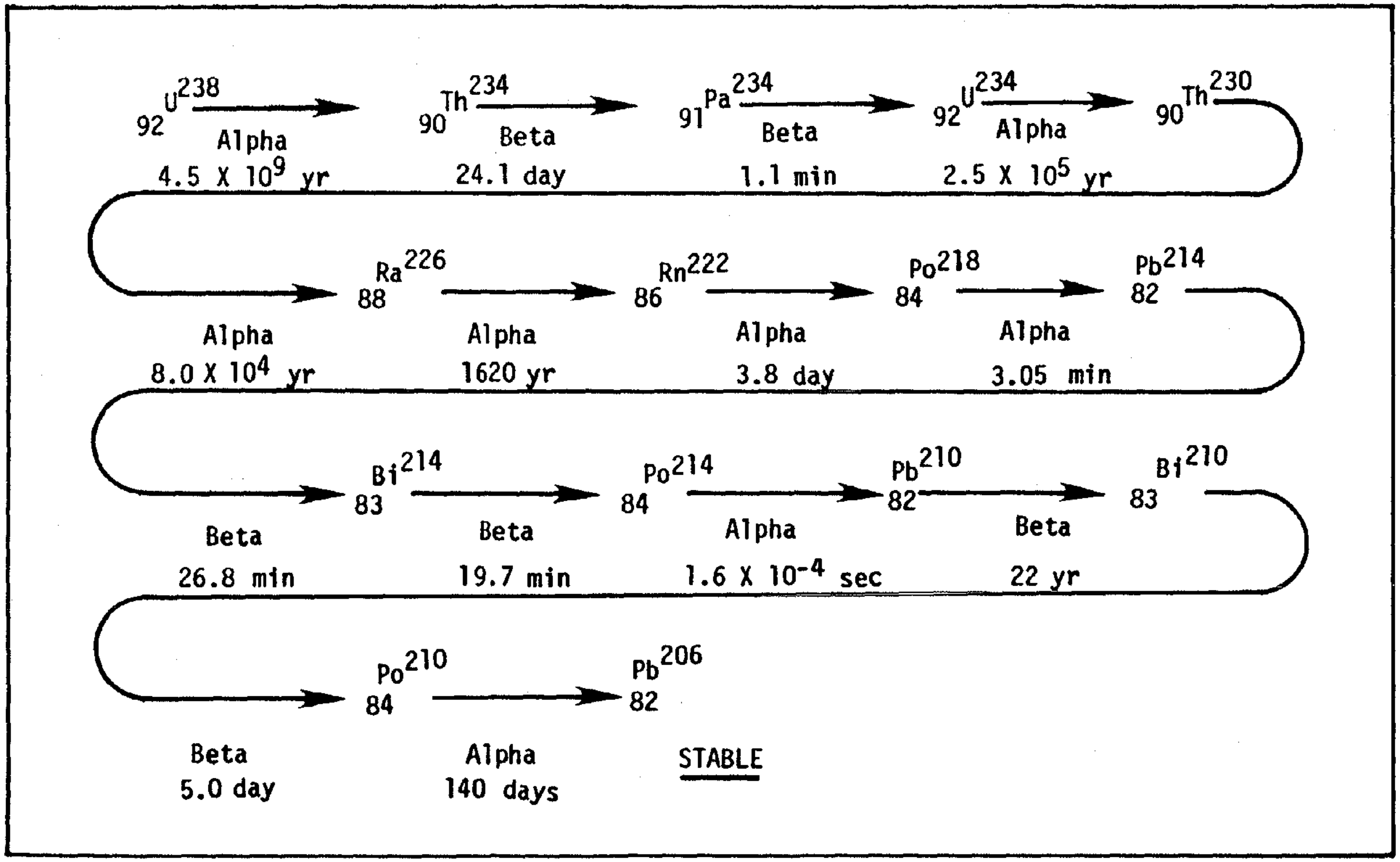


FIGURE 6-9 URANIUM-RADIUM FAMILY

concentrations in the ore can be used to estimate maximum concentrations in leaching solutions.

The above discussion is important because: 1) natural uranium deposits contain most elements of the uranium-radium family; 2) leaching solutions and wastewaters at in situ operations have the potential for containing the majority of daughter products; 3) a knowledge of the composition of the ore makes it possible to estimate maximum emission rates of individual species.

Toxicity

While uranium itself is hazardous in large quantity by virtue of its chemical toxicity, its radiological hazard is by far much greater due to its decay products. From the standpoint of water pollution, the radioisotope radium 226 is the most hazardous. It has a maximum permissible concentration (MPC) an order of magnitude less than the MPC's of any other decay isotopes. The lower MPC level is because of the potential radiation effects of its daughter products. The maximum permissible concentrations of the uranium family, along with their half lives and the nature of their decay products, are presented in Table 6-18.

Of special importance to in situ operations is the potential for radon gas emissions. Radium 226 decays into its immediate daughter radon 222 which is released into the atmosphere and is transported from the immediate vicinity of the site.

Sources of Radioactive Gaseous Emissions

In general, the emission rates of radioactive gases are quite low for in situ processing plants operating under normal conditions. The emission rates have been described in previous sections. The primary source of particulate uranium 238 is from the yellowcake drying operation. The primary source of radon gas emissions is the pregnant liquor surge tank which releases approximately 2 orders of magnitude more radon than all other sources at the site. Minor radon gas emissions are produced by the water purification unit and by the liquid waste evaporation disposal ponds.

The excursion of radioactive materials into the strata surrounding the ore body is considered a normal potential emission. This is not regarded as an accident since its probability of occurrence for in situ operations is relatively large. The preceding discussions describing excursion and the success of excursion clean up indicate that there is no long term effect or environmental contamination of the subsurface strata by an excursion. The data upon which this conclusion is based is extremely small and it is recommended that additional information be accumulated and analyzed to better define the success of clean up.

Since the in situ uranium leaching industry only began in 1966, its infancy does not permit a discussion of documented accidents. Operating experience is limited, and it is necessary to postulate the effects of accidents based upon similar operations in conventional mining and milling uranium operations.

TABLE 6-18. - Characteristics of the Uranium-Radium Family

Nuclide	MPC_W[a] pCi/liter	Half-life	Emission
Ra^{266}	3.3	1,602 yr	Alpha
Pb^{210}	33	20.4 yr	Beta
Po^{210}	233	138.4 days	Alpha
Th^{230}	667	8×10^4 yr	Alpha
Th^{234}	6,667	2.41 days	Beta
U^{234}	10,000	2.47×10^5 yr	Alpha
U^{238}	13,000	4.51×10^9 yr	Alpha
Bi^{210}	13,300	5 days	Beta
Pa^{234}	b	1.1 min	Beta
Po^{218}	b	3.05 sec	Alpha
Po^{214}	b	1.64×10^{-4} sec	Alpha
Bi^{214}	b	19.7 min	Beta
Pb^{214}	b	26.8 min	Beta
Rn^{222}	N/A (gas)	3.82 min	Alpha
U^{nat} [c]	6,667	4.51×10^9 yr	Alpha
Th^{nat} [d]	333	1.41×10^{10} yr	Alpha

[a] MPC_W value is the Maximum Permissible Concentration in water for an average member of the general population (1/30th HB 69 value for continuous occupational exposure), NCRP, 1959.

[b] No value given for these short-lived materials.

[c] Since the specific activity of U^{nat} ($U^{238} + U^{234} + U^{235}$; 99% U^{238} by weight) is 3.34×10^{-7} curies per gram, the MPC_W may also be expressed as 2×10^4 µg/l or 20 mg/l.

[d] Comprised of Th^{232} and Th^{228}.

Excluding transportation accidents which are a potential at all uranium recovery operations, potential accidents are categorized into three groups: interior accidents, outdoor surface accidents, and subsurface accidents.

Interior accidents refer to accidents resulting in failure of processing equipment contained within the processing building. Other than leakage or rupture of tanks, it is highly improbable that any significant fires or explosions will occur. The chemicals normally used in uranium recovery operations have an insignificant potential for explosion except for hydrogen peroxide solutions. The normal occupational hazards associated with using chemicals, such as acids, are present. Rupture of conduits or tanks containing uranium-laden solutions cause little hazard to human life because of the low level of radioactivity. The largest health hazard would be the failure of the air filtration system concurrent with the release of the airstream into the processing building. This could result in the inhalation of significant amounts of uranium oxide dust. The probability for this is almost non-existent because of the construction of the air ventilation system. If the air filter system should fail, there would be hazardous atmospheric emissions for only a very short period.

Surface accident could be caused by failure of pipelines, tanks or evaporation ponds. Environmental consequence of such an accident is dependent upon the volume and nature of the material leak and the potential for transmitting this material beyond the site boundaries. Obviously, the detrimental environmental effects would be much greater if a spillage was carried into an adjacent waterway and affected its ecosystem. The failure of pipelines or the leakage of chemical and leaching solution from storage tanks will release relatively small volumes (less than 1,000 liters) of liquid onto the surface. The utilization of monitoring equipment such as low pressure switches in the pipeline could automatically shut down all pumps immediately upon failure. Larger tanks could be surrounded by leakage detection equipment which would inform an operator of any substantial leakage. Any such spills could be cleaned up by removal of the contaminated soil and disposal by acceptable techniques. It would probably be possible to use the evaporation ponds for storage but not burial of this material. The potential environmental effects of such spillage accidents is not great, as long as the radioactive materials are not transmitted from the site. However, the ultimate aim is to leave the site for unrestricted use, a truly environmentally-acceptable situation.

The catastrophic failure of a waste storage or evaporation pond would have significant environmental affects because of the large volumes of water contained within the pond systems. However, the probability for failure of properly designed and constructed ponds is extremely low. All evaporation ponds would require a flexible membrane lining system. Earthquakes generally cause little damage to such liners. The probability for damage to the pond systems by flood waters is extremely low if the surface hydrology is properly evaluated.

The subsurface environment can be contaminated by radiological materials through various types of accidental failures. The accidents include: 1) undetected communication between production and underlying or overlying stratum; 2) well casing failures; 3) production well failures. The environmental consequences of such failures is a function of the volume and nature of the solution which escapes into the environment. Of those solutions which are used in the wells, the pregnant liquor has the most environmentally detrimental composition, such as toxicity. The possible volumes which could be released by failures of such systems are relatively small if proper monitoring of the injection/extraction and monitoring well systems is performed. Significant damage to the environment prior to restoration activities will be minimal if the escaped solutions remain in the vicinity of the injection/extraction operations. The ability of escaped materials to travel in subsurface strata surrounding the ore body is site specific. For example, if an overlying aquifer is a potable source and has a relatively high velocity (9-15 m/day or 30-50 ft/day), the environmental consequences of leakage might be considered unacceptable. However, this hypothetical example cannot occur near the great majority of in situ leached ore bodies since such high velocities in overlying aquifers does not occur. The purpose of this hypothetical example is only to illustrate an effect of site specific factors on the environmental consequence. The operator's required detailed hydrologic study would identify the potential for such excursions and an operating permit would probably not be granted.

Environmental Pathways

The primary pathways associated with the transport of radionuclides from the recovery and yellowcake preparation operations into the environment are illustrated in Figure 6-10. In an evaluation of the radiological aspects of an in situ operation, it is necessary to consider all illustrated pathways. This is normally done by using maximum emission and dose levels which are based upon biological concentration factors.

Of the pathways illustrated in Figure 6-10, only those which introduce radioactive nuclides into the atmospheric environment occur under normal operations. No emissions, except under accidental conditions, are released into the hydrological environment.

Radiological Impacts

The radiological impacts of a properly designed and operated in situ leaching plant for uranium are minimal. Emission rates are much less that those of conventional uranium mining and milling operations. Disturbances to the environment and exposure of radium laden tailings are minimized by the in situ technique. This is a significant advantage of in situ uranium leaching when compared to conventional uranium mining and milling practices. With acidic in situ leaching, only a small portion of the radium in the ore body is leached and transported to the surface. Alkaline lixiviants solubilize more radium than acid lixiviants because radium hydroxide is more soluble than radium sulfate. Radium is the primary source of radon gas, which is a major concern with conventional operations, as it is for in situ operations.

The magnitude of radium transport to the surface environment can be estimated by analysis of standard mill operations. In a typical acid leach

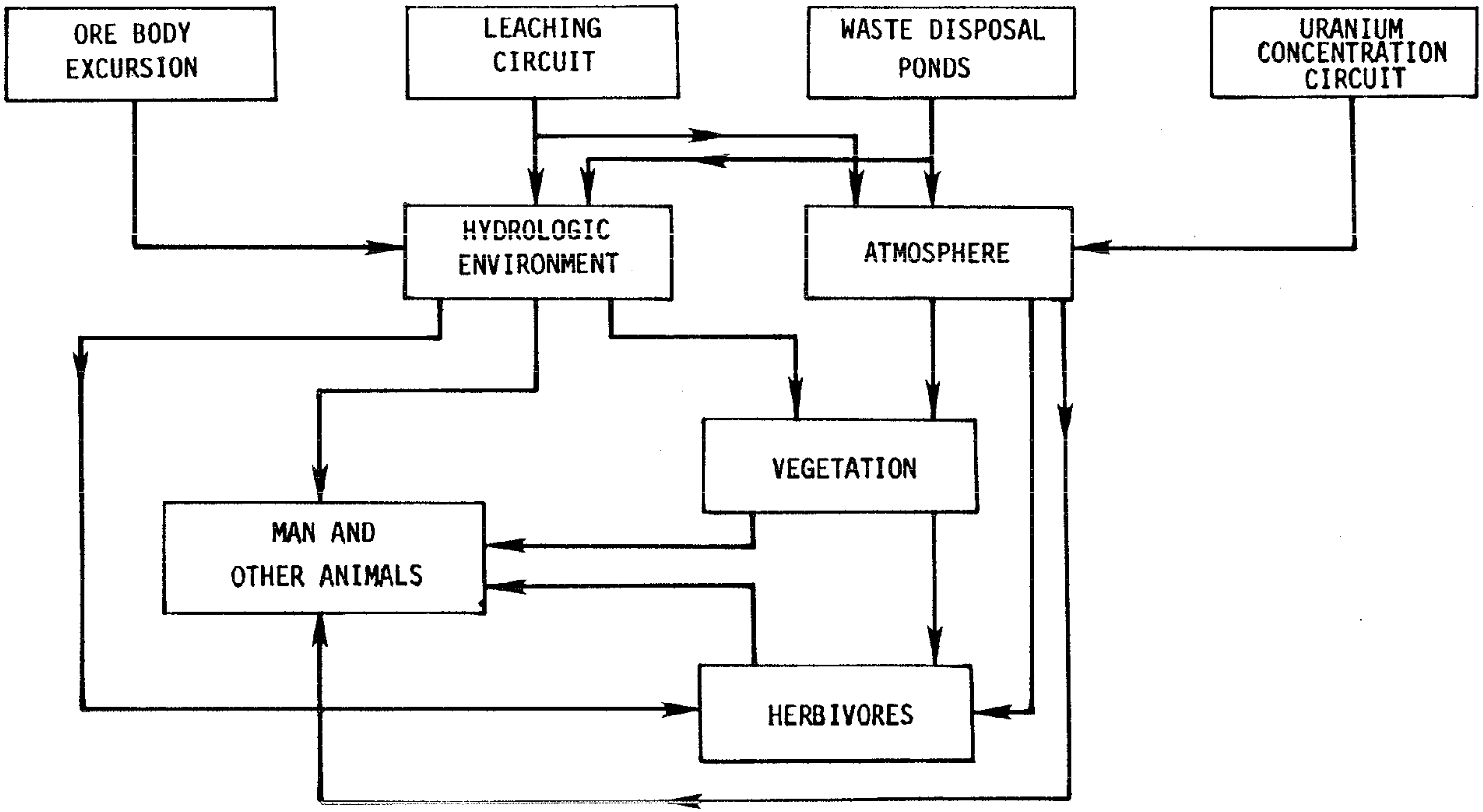


FIGURE 6-10 POTENTIAL ENVIRONMENTAL PATHWAYS FOR TRANSPORT OF RADIONUCLIDES FROM IN SITU SOLUTION LEACHING

resin-in-pulp uranium mill, only 0.38 percent of the total radium 226 in the ore was dissolved in the leaching circuit and of this, only 0.02 percent was precipitated into the yellowcake. In a typical alkaline leach uranium mill, it was found that about 2 percent of the radium in the ore dissolved into the leach solution and essentially all of the precipitated dissolved into the yellowcake (7).

The primary emissions from an in situ operation and its recovery plant are the radon gas emitted from the pregnant liquor surge tank and the uranium 238 oxide dust passing through the scrubber system of the yellowcake dryer. The estimated emission rates for radionuclides emanating from these two locations at the Irigaray project of Wyoming Mineral Corporation are presented in Table 6-19. This information is based on data presented in the Draft Environmental Statement prepared by the U.S. Nuclear Regulatory Commission (NUREG-0399). Along with the annual emission rates are the estimated maximum annual doses for humans living approximately 7 km (4 miles) from the plant site. These doses are broken down into total body, bone, lung, and kidney categories in Table 6-19. At the bottom of the table the maximum NRC Standards for annual doses and the proposed EPA standard for maximum doses are presented. Under the current NRC Standards, the proposed Irigaray project produces exposures to humans less than 0.1 percent of the maximum allowable dose. In terms of the more conservative proposed EPA standards, the proposed Irigaray project results in a total body doses of 5 percent of the maximum.

The above annual doses at 7 km (4 miles) from the plant site have been calculated using an atmospheric dispersion model and meteorological data for the area (8). The NRC (8) has also estimated the annual dose commitments from atmospheric emissions to the population living within 80 km (50 miles) of the operating facilities. The dose commitments due to a 230,000 Kg (500,000 lb) per year uranium in situ leaching recovery plant are approximately 5.3 x 10^{-3} man-rem per year. This must be compared with the natural background which is approximately 1,080 man-rem per year.

Obviously, a solution uranium mining facility produces a small impact on the radionuclide dose to surrounding populations when the dose increment due to mining is only 5 x 10^{-4} percent of the natural background level.

Based upon the above discussions and information, it is the authors' opinion that a properly operated in situ leaching and processing plant will have little, if any, adverse radiological affects for environmental impacts. This is especially true if one compares the in situ techniques to the conventional mining and milling practices.

Impacts on the Terrestrial Environment

The land surface will be disturbed by the construction of roads, production facilities, offices, evaporation ponds and the production well facilities. The site will require fencing and access will be limited. The major disturbances to the land surface for the greater portion of the site is due to well drilling and construction of tailings or evaporation ponds. After production operations

TABLE 6-19. - Estimated Emission Rates for Radionuclides Emanating from Two Locations (8) at the Irigaray Project of Wyoming Mineral Corporation

		Maximum Annual Dose at 7 km From Mine-Plant Site			
Radionuclide	Plant Site Emission Rate Ci/yr	Total Body (millirem)	Bone (millirem)	Lung (millirem)	Kidney (millirem)
Recovery Plant					
U - 238	1.5×10^{-1}	3.8×10^{-3}	4.1×10^{-2}	0.46	1.0×10^{-2}
U - 234	1.5×10^{-1}	2.9×10^{-3}	4.2×10^{-2}	0.52	1.0×10^{-2}
U - 235	7.0×10^{-3}	1.0×10^{-3}	3.2×10^{-2}	2.4×10^{-2}	1.1×10^{-3}
Th - 230	2.6×10^{-3}	5.5×10^{-4}	1.7×10^{-2}	8.8×10^{-3}	5.3×10^{-3}
Ra - 226	1.0×10^{-4}	2.9×10^{-4}	2.9×10^{-3}	1×10^{-3}	3.0×10^{-4}
Pb - 210	1.0×10^{-4}	2×10^{-5}	4.4×10^{-4}	1×10^{-3}	4.0×10^{-4}
Po - 210	1.0×10^{-4}	1×10^{-5}	1.1×10^{-4}	1×10^{-3}	2.6×10^{-4}
Well Field Surge Tank					
Rn - 222	76×10^{-3}	4.9×10^{-4}	2.5×10^{-2}	8.6×10^{-2}	$5.5\ X\ 10^{-3}$
Total Dose	--	9.1×10^{-3}	1.1×10^{-1}	1.1	3.3×10^{-2}
Maximum NRC Standard (millirem)		500	3,000	1,500	--
Percent of NRC Standard (percent)		0.002%	0.004%	0.07%	--
Proposed EPA Standard for Maximum Dose (millirem)		25	25	25	--

commence, there will be relatively little need to drive heavy equipment over the site which will be covered by a net work of pipelines. Each production well and monitoring well will be inspected on a daily or weekly basis. It is probable that a pickup truck or automobile will be used to reach the individual wells. Access for a drilling rig would have to be provided since new production and/or monitoring wells might have to be drilled.

Flora and Fauna

The environmental impact on the flora and fauna is site specific. The construction activities will definitely disturb the vegetation. However, relatively little top soil will be disturbed and complete reclamation of the surface of the site should also be possible after closure.

The extent of environmental impacts of the minimal in situ construction activities depends upon the fragility of the natural environment. In many areas, the disturbance of several hundred hectares (acres) of land has negligible effect on the regional ecology. However, if this area is adjacent to an ephemeral stream which provides the major riparian habitat of a region, obviously the impact would be much greater. This is an example of a site specific situation for consideration, but is beyond the scope of this report. Similarly, the presence of an endangered specie on the site is also a site specific aspect.

A properly operated in situ leaching and recovery plant should have no effect on the aquatic environment since no liquid discharges occur. If liquid discharges do occur, they must be treated to meet specific NPDES regulations.

Land Use

The impacts on land use result primarily from the fencing and limiting of access to the plant site. If a typical site occupies approximately 40 hectares (100 acres), this land would be unavailable or restricted for recreational and grazing activities. This would not be expected to be a significant detrimental environmental impact for the study areas in Texas or Wyoming.

There will be other unavoidable and long-term impacts on land use of the area, such as the construction of homes and roads for the employees of the site. Again, this is a site specific impact and beyond the scope of this study.

A primary impact on land use results from the siting of the evaporation ponds. After closure of a leaching site, the only areas which will have any lasting radioactivity are the evaporation and other waste disposal sites. These sites will be removed or closed by environmentally-acceptable procedures, such as that illustrated in Figure 13-1, which is applicable to uranium mill operations. Future construction directly over such burial sites should be prohibited.

Impacts on Water Environment

Surface Water

In general, there will be minimal, if any, detrimental impacts on the surface waters in the region surrounding an in situ mine if proper operation procedures are maintained. The subsurface water which can be affected by the in situ operations does not generally have direct communication with surface waters. It is possible that inclined strata outcrop kilometers (miles) from the in situ leaching operations and, under these conditions, it would be possible for contaminated groundwaters to eventually reach surface waters. In view of the groundwater monitoring programs which are required, the probability for such contamination is very low. It is possible that there will be minimal degradation of the surface waters by increased sediment loads resulting from construction of roads, wells, and the processing plant. The increase in the sediment loads to the surface waters would be relatively insignificant for any drainage basin having an area of more than several square miles. Mine operators would have to comply with the NPDES point discharge standards regulating sediment discharges.

Groundwater

In situ solution leaching inherently has potential for contamination of groundwaters. During the active leaching operations, the water in the ore zone is toxic and highly saline. The reader is referred to Chapter 7 for a discussion of leaching solution toxicity. The groundwater quality of the area would be degraded if this water were to remain in the ore body or escape to surrounding aquifers. All existing and proposed in situ leaching operations have provisions for restoration of the groundwater. Documented restoration and excursion clean-up operations show that the great majority of substances injected into the groundwaters can be removed.

A primary factor in achieving restoration is the definition of restoration. At the present time, regulatory agencies have not agreed upon or adopted firm definitions for restoration. It is highly improbable that all major and minor constituents in leached areas can be returned to their baseline conditions. Variations in concentrations from initial levels do not necessarily mean that degradation has occurred. There are relatively large natural variations in the qualities of waters within a given area and for a given well over a period of time. The very nature of the roll front uranium deposit causes areas of varying chemical environments (including variations in Eh). The variation of water quality within the ore body is evidenced by the relatively large standard deviations for the average baseline water quality.

If restoration requirements for a particular site were defined so that each and every constituent must be returned to baseline condition, restoration could be very difficult, if not impossible. The concentrations of many constituents in water can be increased to particular levels without degrading the general quality of the water for particular uses. If restoration requirements are defined with recognition of variations without degradation, then restoration should generally be technically feasible.

The number of pore volumes of water which must be pumped from the ore zone to effect water quality restoration is dependent upon the compositions of the ore, the lixiviant and on the layout and pumping schedule of the extraction well system. Since ores such as those in Texas which contain high clay concentrations experience difficulty in removal of ammonium ions, pumping of additional water through the ore body for attainment of restoration is required. In addition to the costs involved with long-term pumping for restoration, there are two environmental impacts: 1) consumptive use of groundwater and; 2) the disposal of wastewaters. Both the consumptive use and the wastewater volume can be decreased by application of such wastewater concentration techniques as reverse osmosis or electrodialysis. Reverse osmosis and electrodialysis are technically viable processes with each producing two water streams: a concentrated brine and a relatively pure water which is suitable for surface or subsurface disposal. The greatest obstacle to the application of reverse osmosis for wastewater treatment is its high cost.

Excursions of contaminated water from the mine site are possible due to undetected geological faults, variations in permeabilities of the sandstones, improper well field operation or accidental failures of subsurface equipment. If such excursions do occur, there is a very high probability that they will be detected by the monitoring well system. If the excursion is undetected and lasts for a relatively long period, an escape of many liters (gallons) is possible since escape flow rates of several liters/second (gpm) are reasonable, undetected by mass balance calculations of injected and extracted flows. The leaching solution could contain appreciable amounts of toxic trace metals in addition to sizable levels of the lixiviant constituents. As an excursion flows through porous media, natural dispersion gradually dilutes the concentrations of its constituents. Physical chemical processes such as ion exchange, adsorption, and precipitation can further reduce concentrations of specific constituents. It is highly improbable that such an excursion could reach a nearby water supply well in view of the monitoring well system and the low flow velocities in the aquifer; for instance, 3-6 meters/year (10-20 ft/year).

The potential impact can be evaluated in terms of the hypothetical, standard sized leaching operation. A 227,000 Kg/yr (500,000 lb/yr) uranium plant will produce a minimum of 1-2 l/sec (15-30 gal/min) of process water. The major use of water is the restoration operation. Based on a porosity of 30 percent, an area of 40 hectares (100 acres) and an ore body thickness of 6 m (20 ft), each pore volume flushed for restoration produces approximately 75 hectare-meter (600 acre-ft) of water. If this water is not recycled and restoration requires from 8 to 15 sweeps, the total volume of water for restoration is between 590-1100 hectare-meter (4800-9000 acre-feet) of water over the 10-year life of the project. This flushing volume could be reduced greatly by the utilization of a reverse osmosis system. The process water bleed streams are equivalent to 5.9 hectare-meter/year (48 acre-feet/year). The environmental impact of this consumptive use is site specific since it depends upon the availability of water in the region.

Contamination of the overlying aquifers can occur by leakage from surface waste disposal ponds. A proper pond monitoring system detects any leakage which occurs.

Air Quality

The non-radiological emissions to the atmosphere are minimal. The sources for emissions are the construction activity and chemical dusts or gases emitted from the processing plant. During construction, dust will be generated and vehicular emissions will occur. Dust from the roads can be minimized by conventional dust control procedures. Dust from evaporation ponds is minimized by always keeping liquid in the pond. The atmospheric emissions from the processing plant include the combustion products of the fuel or the yellowcake dryer. The rate and composition of emissions depends upon the type fuel used for the dryer.

It is possible that the withdrawal of water from the aquifer will lower the pieziometric head at distances relatively far from the mining site. The magnitude of any decrease in the pieziometric surface is a function of the aquifer characteristics.

Emissions of ammonia vapors and ammonium chloride particulates from the processing facilities and waste ponds have been described in a previous section. These emissions are relatively low and do not adversely impact the air quality of most regions.

CHAPTER 6 REFERENCES

1. Meehan, R.J. Statistics of the Uranium Industry. Pres. at Uranium Mining Technology Conference, University of Nevada, Reno, Nevada, April 25-29, 1977.

2. Shock, D.A., and F.R. Conley. Solution Mining - Its Promise and Its Problems. Pres. at Proc. Solution Min. Symp., AIME Annual Meeting, Dallas, Texas, Feb. 25-27, 1974, pp. 79-97.

3. Merritt, R.C. The Metallurgy of Uranium Extraction. Pres. at Uranium Mining Technology Conference, University of Nevada, Reno, Nevada, April 25-29, 1977.

4. ______. Environmental Report - Irigaray Project, Johnson County, Wyoming. Wyoming Mineral Corporation, 1977.

5. McKee, J.E., and H.W. Wolf. Water Quality Criteria. State Water Quality Control Board Pub. No. 3-A, Sacramento, Calif., 1963.

6. Colorado State University, Dept. of Agricultural Engineering. Rate of Ammonia Nitrification and Nitrate Leaching in Soil Columns. Fort Collins, Colorado, 1976.

7. ______. Waste Guide for the Uranium Milling Industry. U.S. Dept. of Health, Education and Welfare, Public Health Service Pub. TW-W62-12.

8. U.S. Nuclear Regulatory Commission, Office of Nuclear Material Safety and Standards. Environmental Statement Related to Operation of Wyoming Mineral Corporation Irigaray Solution Mining Project. Docket No. 40-8502, 1978.

9. Woolery, R.G. Letter to Mr. William Taylor, Texas Water Quality Board, regarding Palangana Project Restoration Demonstration, May 10, 1976.

10. Taylor, W.R. Memorandum to T.L. Morris, Assistant Director Field Operations, Texas Water Quality Board, Austin, Texas, October 14, 1976.

11. Texas Water Quality Board Permit No. 01890, ARCO Clay West Mine, 1975.

12. Texas Water Quality Board Permit No. 02025, Dalco-U.S. Steel Burns Lease, 1976.

CHAPTER 7

GENERAL ENVIRONMENTAL CONSIDERATIONS

This chapter contains a description of factors which affect the technical viability and environmental suitability of in situ leaching. This information is presented in general terms and is applicable to both copper and uranium leaching. The implication of these factors on the restoration of in situ leached areas are discussed.

ENVIRONMENTAL GEOCHEMISTRY

Chemical Aspects of Leaching

The action of a lixiviant on the minerals in an ore body is not totally specific to the mineral being leached in that many substances can undergo dissolution and appear in the pregnant liquor. The leached minerals are continually removed from the recycled solution by the recovery process, while many of the other dissolved substances continue to accumulate until their concentrations reach saturation values. These secondary or unintentional products of dissolution can pose a greater threat to the environment than the recovered minerals since the recovered mineral is constantly removed from the recycled solutions. This would be particularly true for toxic trace metals, such as arsenic or selenium.

The composition of a leaching solution is directly related to the composition of both the lixiviant and the ore body being mined. This dependency prevents generalizations concerning the trace metal composition of the leaching fluids since each ore has a particular composition. It can be stated, however, that the leaching solution can only contain elements present in the ore or added to the lixiviant.

Substances such as copper or uranium have been accumulated in an ore body due to the occurrence of a particular geochemical environment. Figures 7-1 and 7-2 adapted from Shock and Conley (1) illustrate the roles of aquifer hydrology and the chemical environment in the formation of a roll front uranium ore body and the distribution of U_3O_8 within the ore body. A simplified model is that uranium, which is mobile in the oxidized zone, accumulates by precipitation in the reduced chemical environment. A shift in the pH or the oxidation-reduction potential of the groundwater within the ore body would shift the chemical equilibrium of the system and possibly result in dissolution of the uranium over a period of time.

As discussed in Chapter 4, the leaching operation consists of dissolving the metal of interest in the lixiviant by shifting the pH and/or the Eh (a measure of the oxidation-reduction potential). Operationally, these changes or shifts are accomplished through the addition of acids or bases and oxidants.

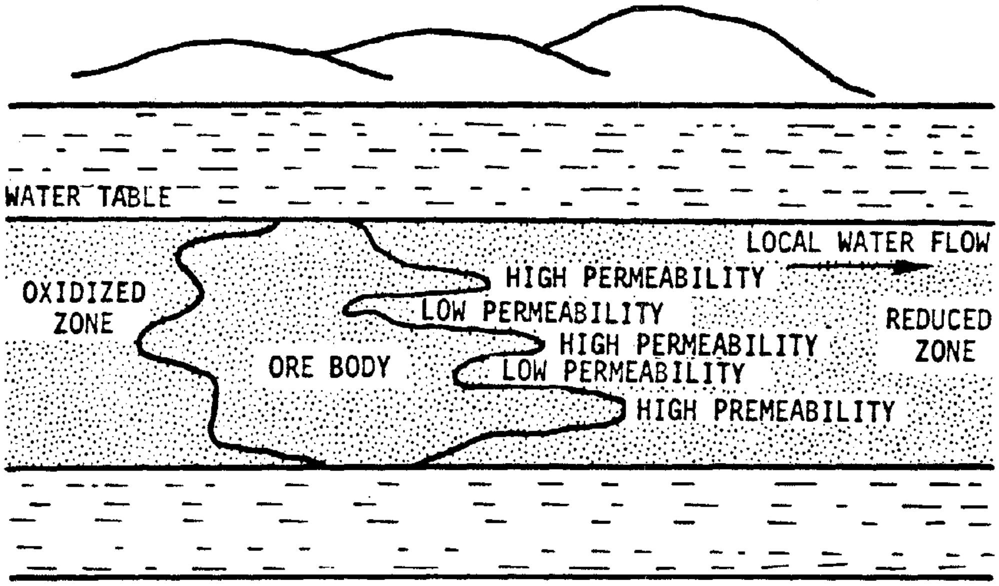


FIGURE 7-1 VERTICAL SECTION OF ROLL FRONT URANIUM ORE BODY

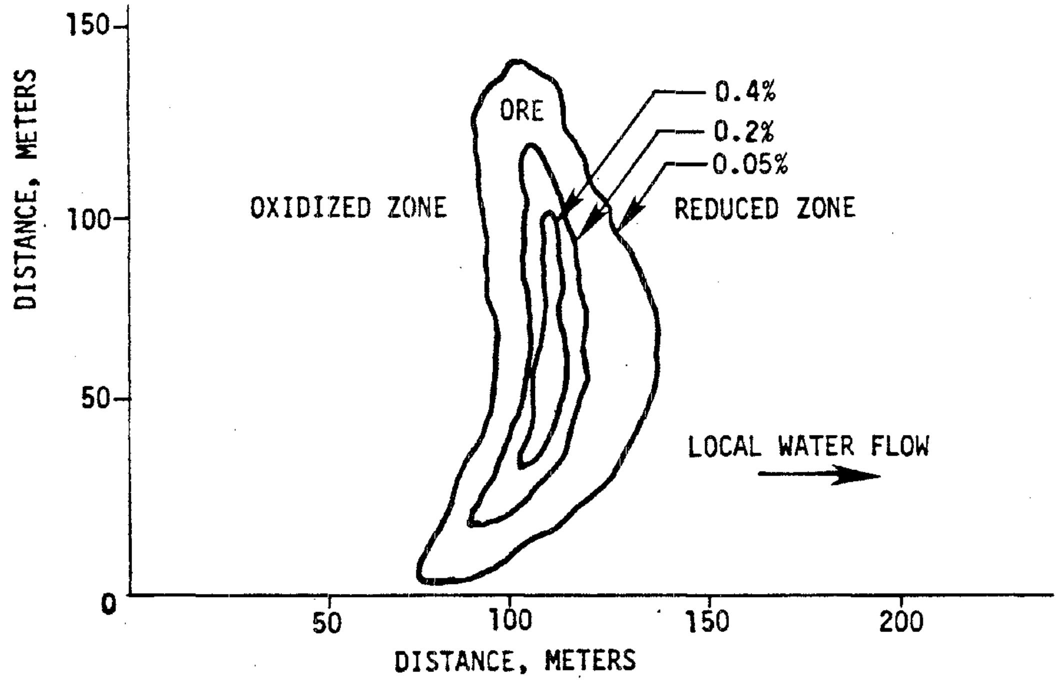


FIGURE 7-2 PLAN VIEW OF A ROLL FRONT URANIUM ORE BODY SHOWING ISO-CONCENTRATION LINES OF U_3O_8 IN PERCENT

Although the effects of pH and Eh on the chemistry of minerals have been described in great detail by Garrels and Christ (2), much speculation continues to exist concerning the geochemistry occuring in in situ leaching systems (3). Many strong and complex chemical interactions occur which greatly complicate the leaching chemical reactions.

The conditions necessary for leaching copper ores are illustrated in Figure 7-3 which has been adapted from Rickard (3). This diagram indicates that copper will dissolve if the pH is maintained below 4 while the Eh exceeds 0.5 volts. The addition of ferric iron and sulfuric acid can modify the chemical environment to produce the conditions necessary for solubilization of the copper. The sulfuric acid lowers the pH while the ferric iron acts as an oxidizing agent. In groundwaters, under natural conditions, the pH is generally much greater than five and the Eh is less than zero. This natural water zone, illustrated as a cross-hatched area on Figure 7-3, indicates that copper generally is insoluble in natural waters.

Similar diagrams describing required leaching conditions for the recovery of uranium by the use of alkaline leaching systems can also be prepared.

Pourbaix diagrams, such as Figure 7-3, have certain limitations in that they are based on an assumed set of chemical reactions and do not address the chemical kinetics of the system. If unknown species or different chemical form other than those assumed are present, the diagram does not correctly describe the chemical system. The Eh-pH region of most natural waters is illustrated in Figure 7-3. Figure 7-3 explains why it is necessary to add acid or acid + oxidant for leaching of different copper ores. The oxidized copper ores (CuO and Cu_2O) only require lowering of the pH in order to enter the soluble region in Figure 7-3. The sulfide ores (Cu_2S and CuS) require that the Eh be raised through oxidant addition and that the pH be lower through acid addition. Operationally, oxidized ores are leached with acid lixiviants while reduced ores are leached wth an oxidizing-acid lixiviant.

The effects of Eh and pH on the solubility of arsenic and lead are shown in Figures 7-4 and 7-5, respectively. The chemical conditions for each of these diagrams are described in the figure captions. Note that both the arsenic and lead solubilities increase at higher Eh values and at both high and low pH values. This indicates that both of these metals would be solubilized by the lixiviants used for copper and uranium leaching.

Many metals occurring in reduced environments experience this increased solubility at higher Eh levels. Likewise, many metals occurring in both oxidized and reduced environment can form soluble species at both high and low pH values. In general, however, metal solubility decreases in basic solutions due to the formation of relatively insoluble metal hydroxides, sulfides, and carbonates. For this reason, the alkaline leach solutions - carbonate - bicarbonate and the ammonium salts are considered to have a low potential for solubilizing trace metal contaminants present in the ore.

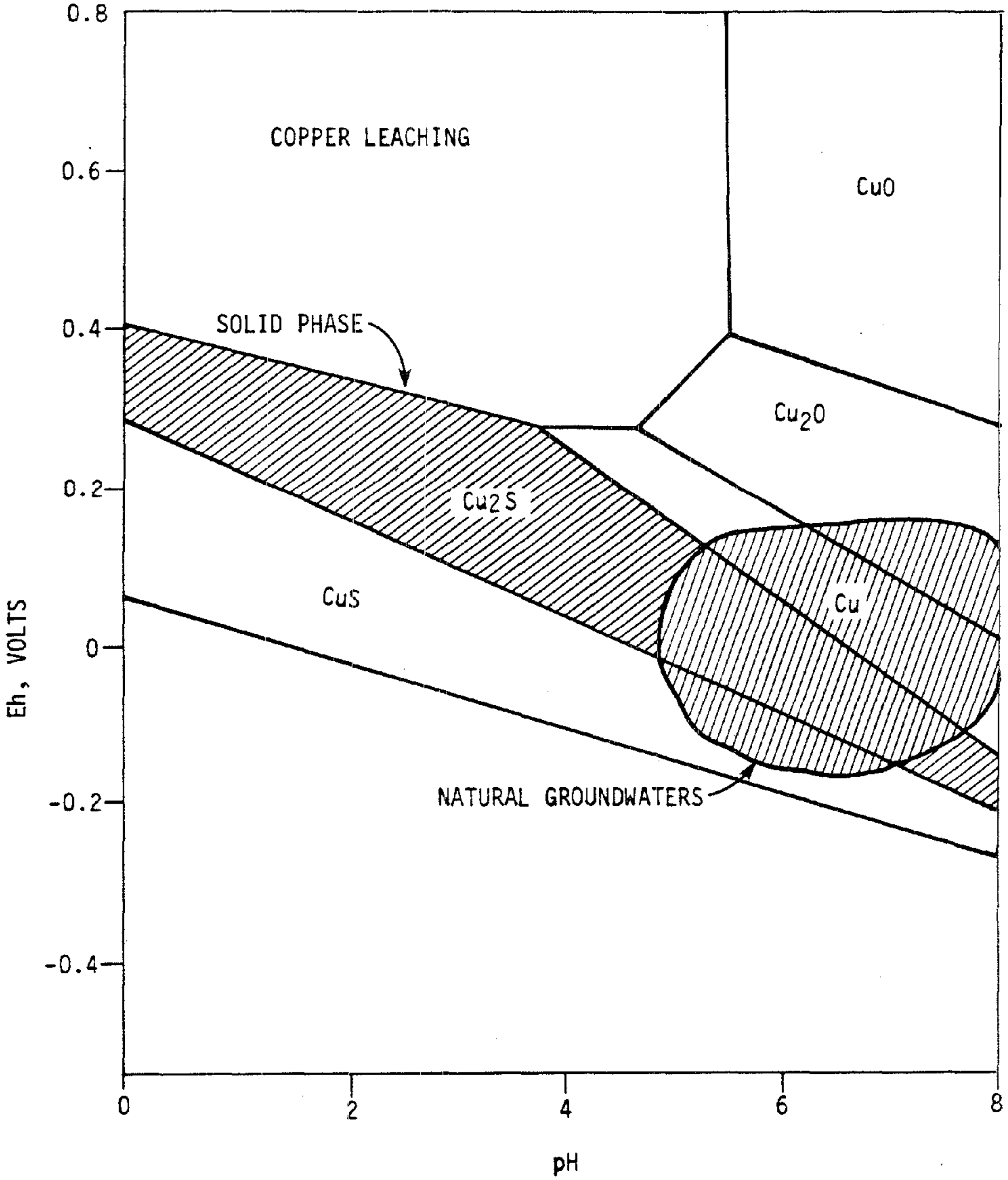


FIGURE 7-3 Eh-pH DIAGRAM FOR COPPER

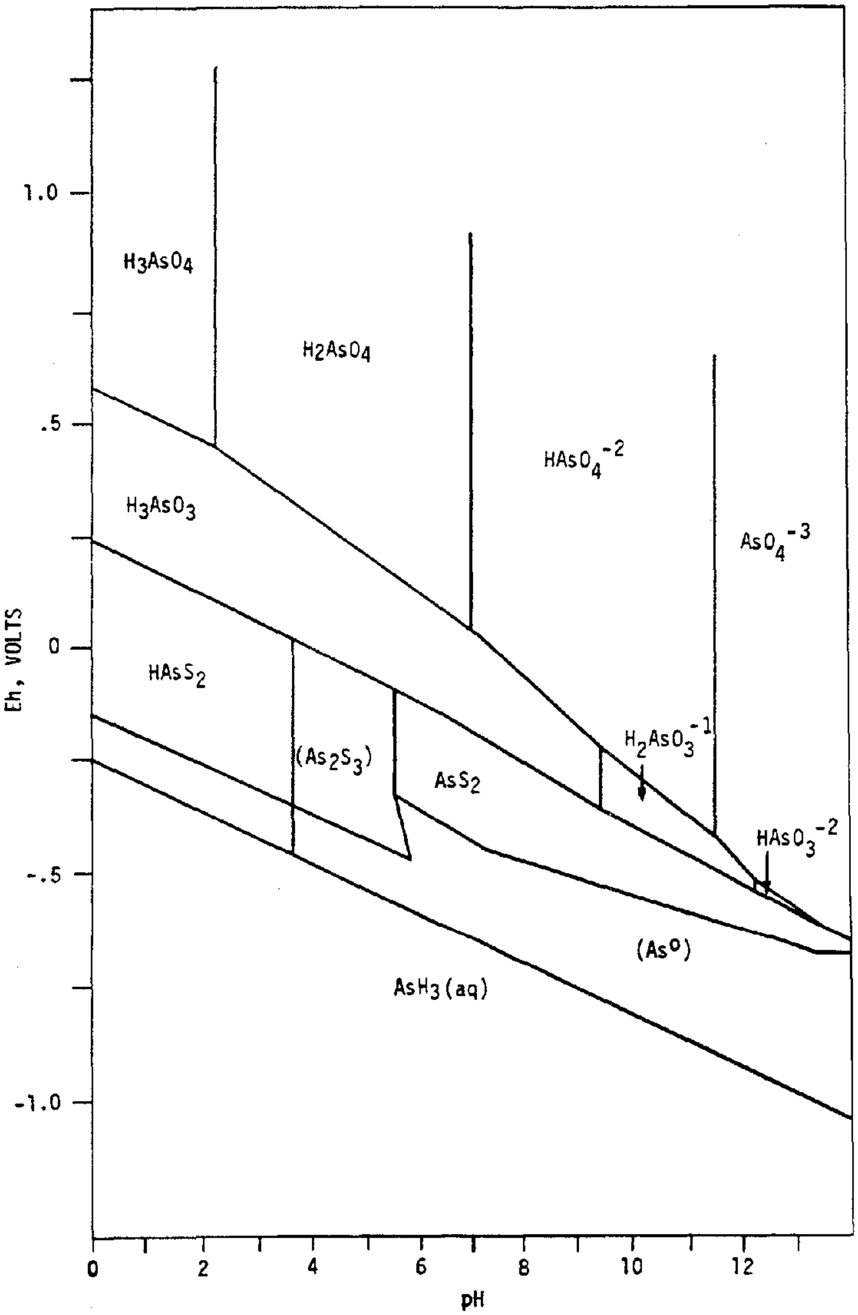


FIGURE 7-4 THE Eh-pH DIAGRAM FOR As AT 25°C AND ONE ATMOSPHERE WITH TOTAL ARSENIC 10^{-5} M AND TOTAL SULFUR 10^{-3} M.

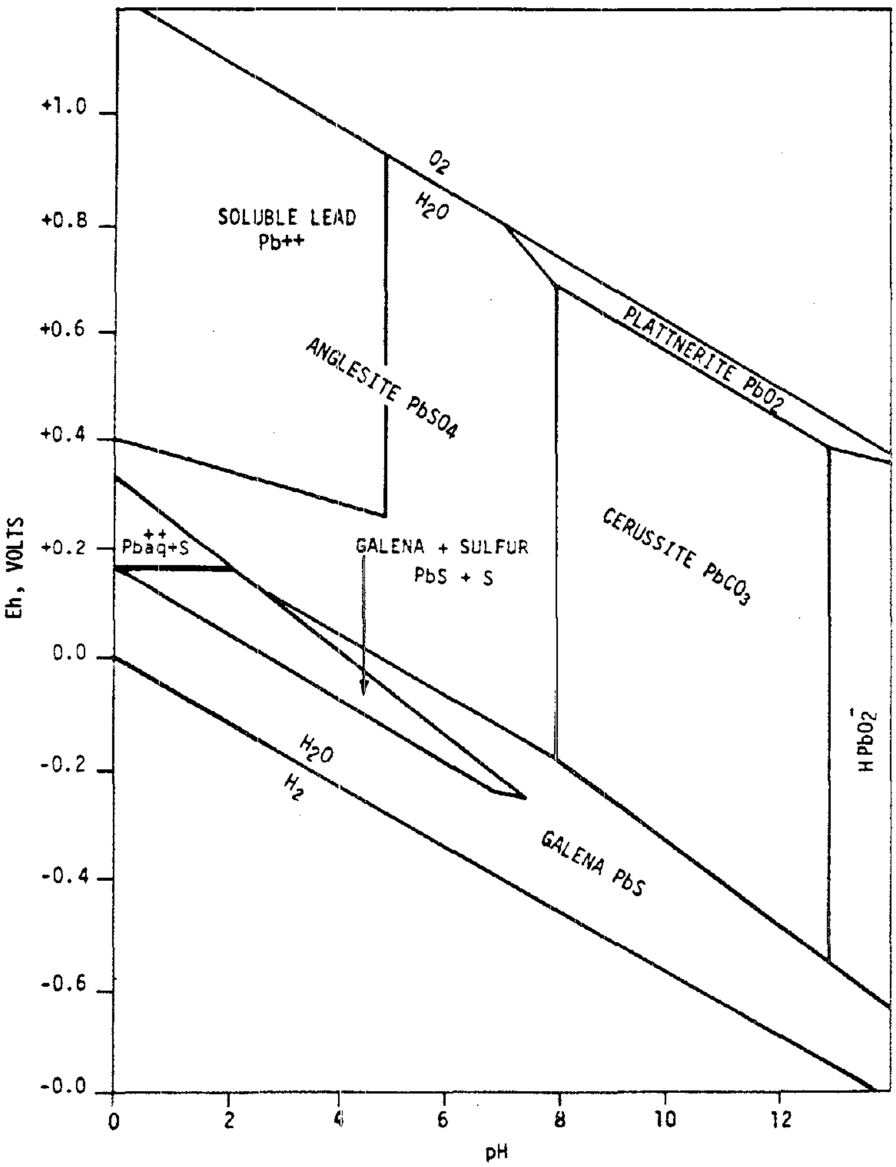


FIGURE 7-5 Eh-pH DIAGRAM FOR LEAD AT 25°C AND 1 ATMOSPHERE TOTAL PRESSURE. TOTAL DISSOLVED SULFUR = 10^{-1}, $P_{CO_2} = 10^{-4}$.

Mobility of Selected Species

It is possible to generalize about the mobilities of chemical species in the subsurface environment for assumed sets of specific chemical conditions such as acidic, alkaline, oxidizing or reducing.

The relative mobilities of elements in the subsurface environment are presented in Table 7-1. This table illustrates the effects of both pH and the redox potential on the ability of the different elements to remain in the soluble form and travel throughout porous media.

An important limitation of the mobility data presented in Table 7-1 is that the information was developed for a set of specific chemical conditions which does not account for such phenomena as chemical complexation, ion pairing or chelation. Such phenomena can increase the solubility of particular species and enhance their mobilities through the subsurface environment.

The complexing agent can be either organic or inorganic and can affect the solubility of a specie by direct association or by indirect association with a second specie which controls the solubility of the specie of interest. Direct association refers to the formation of a complex which reduces the concentration of the free species remaining in solution. An example of direct complexation is the reaction between humic substances and calcium in which an organic calcium complex is formed. The concentration of free calcium ion is lower, thereby increasing its total solubility in a system where calcium sulfate limits calcium ion solubility. Indirect association refers to the phenomena whereby the complexing agent reduces the concentration of the specie which limits the concentration of the specie of interest. For example, if complexing reduces the concentration of the free sulfate in the system described above, then more free calcium can be present before calcium sulfate precipitation occurs.

There are various sources of complexing agents. It is possible that the organic compounds used as lixiviant additives or those used in conjunction with operation and maintenance of the ion exchange systems could have complexing characteristics. This is only a possibility and is suggested at this time simply as one postulation for explaining the occurrences of unexpectably high concentrations of particular species. In contrast with the postulated system is the ammonia leaching solution in which it has been well documented that ammine complexes can form with such metals as palladium, zinc, cadmium and silver (4).

Fates of Constituents in Escaped Leaching Solutions

The primary problem with an excursion of pregnant or barren lixiviant from the mining area is the contamination of the surrounding subsurface environment with toxic or otherwise non-potable waters. The following discussion is primarily concerned with the fates of trace metals and other chemical species present at relatively low concentrations in the leaching solutions, e.g., concentrations less than 10^{-4} molar.

TABLE 7-1. - Relative Mobilities of the Elements of the Subsurface Environment

Relative Mobilities	Chemical Environment			
	Oxidizing	Acid	Neutral to Alkaline	Reducing
Very High	Cl, I, Br S, B	Cl, I, Br S, B	Cl, I, Br S, B Mo, V, U, Sc, Re	Cl, I, Br S, B
High	Mo, V, U, Sc, Re Ca, Na, Mg, F, Sr, Ra Zn	Mo, V, U, Sc, Re Ca, Na, Mg, F, Sr, Ra Zn Cu, Co, Ni, Hg, Ag, Au	Ca, Na, Mg, F, Sr, Ra	Ca, Na, Mg, F, Sr, Ra
Medium	Cu, Co, Ni, Hg, Ag, Au As, Cd	As, Cd	As, Cd	
Low	Si, P, K Pb, Li, Rb, Ba, Be Bi, Sb, Ge, Cs, Ti	Si, P, K Pb, Li, Rb, Ba, Be Bi, Sb, Ge, Cs, Ti Fe, Mn	Si, P, K Pb, Li, Rb, Ba, Be Bi, Sb, Ge, Cs, Ti Fe, Mn	Si, P, K Fe, Mn
Very Low to Immobile	Fe, Mn Al, Ti, Sn, Te, W Nb, Ta, Pt, Cr, Zr Th, Rare Earths	Al, Ti, Sn, Te, W Nb, Ta, Pt, Cr, Zr Th, Rare Earths	Al, Ti, Sn, Te, W Nb, Ta, Pt, Cr, Zr Th, Rare Earths	Al, Ti, Sn, Te, W Nb, Ta, Pt, Cr, Zr Th, Rare Earths S, B Mo, V, U, Sc, Re

TABLE 7-1. - Relative Mobilities of the Elements of the Subsurface Environment - Continued

Relative Mobilities	Chemical Environment			
	Oxidizing	Acid	Neutral to Alkaline	Reducing
Very Low To Immobile	Al, Ti, Sn, Te, W Nb, Ta, Pt, Cr, Zr Th, Rare Earths	Al, Ti, Sn, Te, W Nb, Ta, Pt, Cr, Zr Th, Rare Earths	Al, Ti, Sn, Te, W Nb, Ta, Pt, Cr, Zr Th, Rare Earths	Al, Ti, Sn, Te, W Nb, Ta, Pt, Cr, Zr Th, Rare Earths
				S, B
				Mo, V, U, Sc, Re
			Zn	Zn
			Cu, Co, Ni, Hg, Ag, Au	Co, Cu, Ni, Hg, Ag, Au
				As, Cd
				Pb, Li, Rb, Ba, Be Bi, Sb, Ge, Cs, Ti

Transport of materials from the leaching area to the surrounding subsurface environment requires that the chemicals be in a soluble form. Materials in the solid phase are generally removed completely from the solution by the filtering action of the porous media. The trace metals and other chemical constituents which are solubilized by the leaching operation, can undergo several chemical reactions, phenomena, or fates which could result in their immobilization. These chemical phenomena which are illustrated in Figure 7-6 are adsorption, ion exchange, and precipitation. Adsorption is a physico-chemical process by which dissolved constituents attach to the surfaces of granular material or other solid phases. The adsorption process does not involve a change in the phase of the constituent being immobilized. Ion exchange is similar to adsorption in that dissolved constituents attach to the exchange surface, but differs in that another constituent is released from the exchange surface and enters into the solution. The most common ion exchange reactions remove multivalent ions and replace them with monovalent ions. Clays, and other fine-grained minerals having large surface area, have been observed to be excellent ion exchange media. It is possible that the exchange reaction could release less desirable constituents which then enter the solution. Precipitation, the third phenomenon affecting the fates of dissolved constituents, is the change of soluble phase material into the solid phase. Since the solid phase is not mobile in porous media, the precipitated material is effectively removed from the solution and cannot be transported into the environment. Precipitation is the reverse of the solubilization process whereby the copper or uranium in the area enters solution. Precipitation of cations can result from the presence of large concentrations of anions such as sulfide, sulfate, hydroxides, and carbonates. It can also lead to complex formation.

The occurrences of the above physico-chemical phenomena are dependent on the physical and chemical properties of both the leaching solutions and the surfaces of the porous media. Chemical factors include the pH, oxidation potential, and chemical activities of the constituent undergoing solubilization and all other constituents present. Physical factors include temperature, the flow velocity of the solution in the porous media and the presence of suitable surfaces which provide sites for heterogeneous nucleation.

It is possible to develop a model using computer techniques to describe the fates of various constituents in both leaching solutions and native groundwaters. The application of such a model to in situ leaching operations, requires that the model be based on chemical equilibria of multiple anion/cation systems. A viable model for the leaching systems under consideration would require consideration of the effects of the surfaces of the minerals present in the orebody and surrounding areas. Another model prerequisite is consideration of the kinetics of the immobilization processes. This is the most difficult aspect of developing a suitable model since relatively little data on chemical kinetics of the precipitation process in porous media is currently available.

Escaped leaching solutions flowing through the aquifer will gradually be diluted by the natural dispersion process. This dilution can result in changes of constituent concentrations, oxidation potentials and/or pH values. Figure 7-7 illustrates a hypothetical excursion and the resulting dilution which

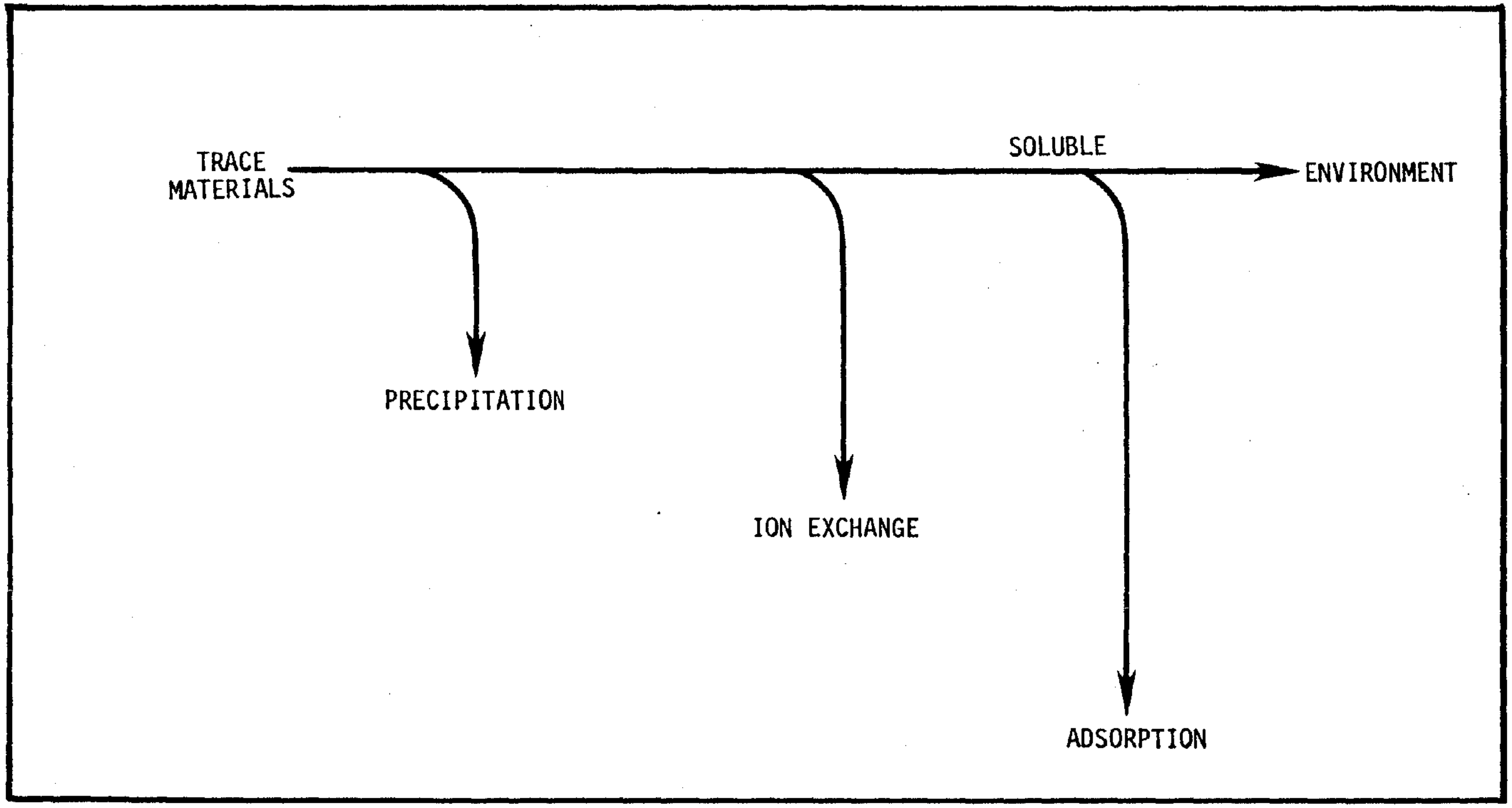
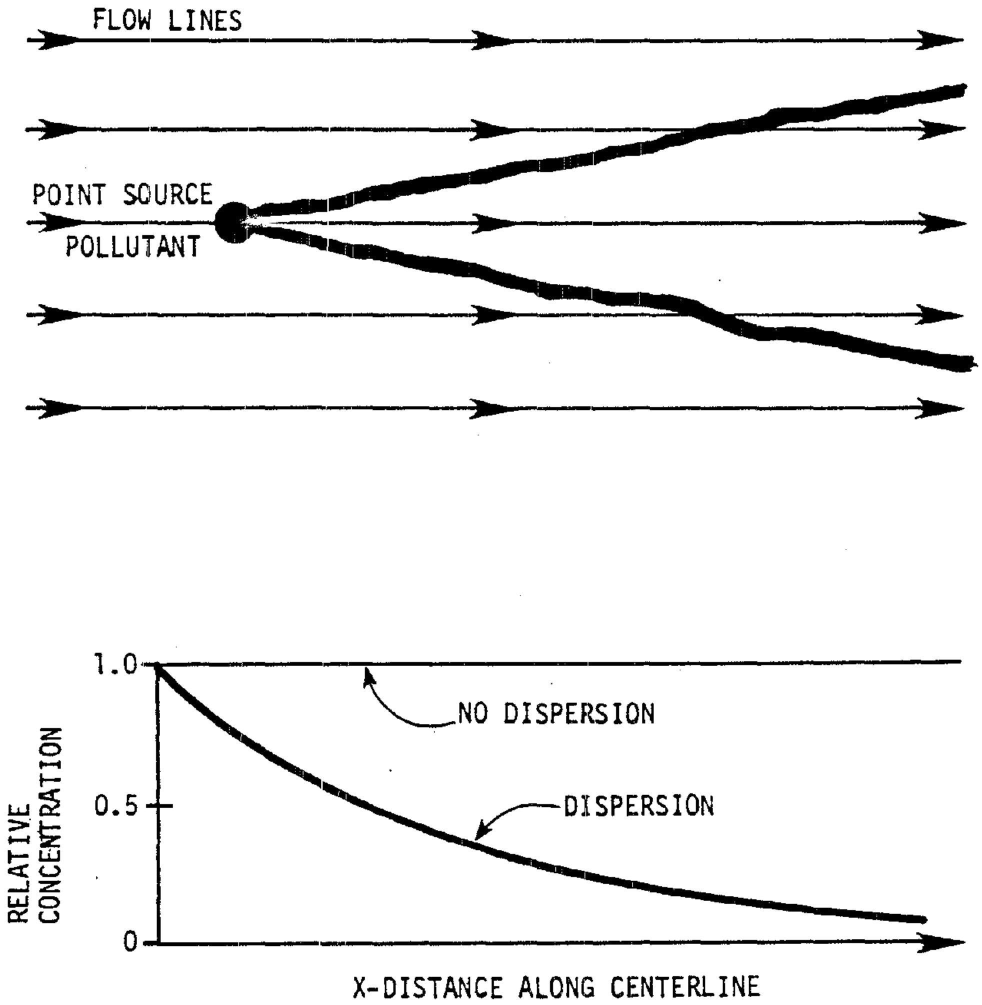


FIGURE 7-6 FATES OF TRACE MATERIALS



7-7 FIGURE 7-7 DISPERSION ACTS TO REDUCE CONCENTRATION OF POINT SOURCE POLLUTANTS occurs as a result of dispersion. Immobilization by precipitation, ion exchange or adsorption will occur only after specific chemical conditions are attained. It is possible that these phenomena will occur in specific areas at some distance from the ore body. It is possible that those areas where trace metals have accumulated will not be affected by an excursion restoration operation and that, after closure of the mine, trace metal dissolution into the virgin groundwaters will gradually occur. This illustrates the need for long-term, low-frequency monitoring.

TOXICITIES OF LEACHING SOLUTIONS

An analysis of the toxicity of substances originating from any source requires definition of the species being affected or the application for which the water is used. The beneficial applications or uses include domestic or potable supplies, industrial water supplies, fish and other aquatic wildlife, agriculture (irrigation) water supplies, and various levels of recreational uses. While potable or domestic uses would seem to have the highest or greatest quality requirements, many industrial processes and species of fish actually require water with a better quality than potable.

Water Quality Standards

The toxicity analysis presented in this section will be based on two water uses: potable and fish and aquatic wildlife. Potable or domestic uses are being considered for the obvious reason of protecting human life and well-being. Fish and aquatic wildlife have been included since their requirements for specific constituents are in many cases more stringent than human requirements. This is illustrated by the recent utilization of particular fish species as toxicity indicators for effluents from domestic and industrial wastewater treatment plants. Industrial water quality requirements will not be considered in view of the large quality variations for different industries and the fact that industry practice has been to provide for required quality upgrading.

Drinking Water (Potable) Standards

The criteria for human toxicity of substances possibly leached from mineral bodies cannot be based solely on the EPA's Drinking Water Standards. These potable water standards are predicated on utilization of the best raw water source available and are based on a historical record of substances commonly found in supplies of raw potable waters. If a substance is not detected in waters commonly used for potable supplies, it is not included in the U.S. Drinking Water Standards.

The historical record basis is illustrated by the 1974 Drinking Water Standards, which became effective in mid-1977. The maximum contaminant level (MCL) for cyanide, which was 0.2 mg/l in the 1962 U.S. Drinking Water Standards, was deleted. The deletion of cyanide from the 1974 Standards is due to lack of occurrence and not non-toxicity. According to the National Interim Primary Drinking Water Regulations: (5)

> This substance (cyanide) is rarely a problem in drinking water, and there appears to be no justification for including cyanide in the list of inorganic chemicals for which MCL's are established in these Regulations. Cyanide has not been identified during routine sampling of drinking water in concentrations greater than the 1/10 of the proposed MCL, which itself is 1/100 of the level at which cyanide has adverse health effects on humans. It does not appear that there is justification for requiring tens of thousands of communities to monitor for this substance.

The nonapplicability of the U.S. Drinking Water Standards to waters from all sources is also illustrated by the fact that compliance with the standards does not ensure potability for reclaimed wastewaters.

The current U.S. Drinking Water Standards are presented in Table 7-2 for substances contained in both the lixiviants and the ore bodies. The basis for the standard, whether toxicity, aesthetics, or use is also indicated. The 1974 Standards are categorized into primary and secondary standards which are toxicity or health-related and aesthestics or use-related, respectively.

A different approach to establishing maximum permissible concentrations of harmful substances in potable waters has been adopted by Russia (6). The Ministry of Health of the U.S.S.R. has specified limits for 294 different substances that could possibly occur in waters used for hygenic and domestic purposes. The list includes substances originating from both natural and man-made sources. Several of the substances occurring in ore bodies capable of being leached by in-site processes are included in the Russian Standards and are not considered in the U.S. Potable Water Standards. The Russian Standards and the World Health Organization (WHO) Standards are also included in Table 7-2.

The basis for the Russian Potable Water Standards presented in Table 7-2 are "sanitary toxicological" (health) and "general sanitary" which is a combination of aesthetics, taste, scaling, and gastrointestinal irritation effects. WHO Standards are based on toxicity, taste, and aesthetics.

Freshwater Aquatic Life

In many instances, compliance with potable water standards is not sufficient for the protection of many forms of aquatic life. Certain aquatic species are orders of magnitude more sensitive than man to particular chemicals. For instance, 0.011 to 0.018 mg/l of copper in a soft water is toxic to fathead minnows while the standard for human consumption is 1.0 mg/l, based on taste problems. The effects of water quality will vary according to specie, age and environmental conditions. This is obviously a site-specific consideration.

One of the causes for the increased sensitivity of certain aquatic species to materials in their environment is the ecological food chain. Lower lifeforms, such as plankton and algae, which are used as food by fish and higher aquatic life forms, can concentrate particular chemicals to levels several hundred or thousand times greater than solution concentrations. The higher life forms also

TABLE 7-2. - Drinking Water Standards

	US EPA (1975-77)		Russian (1970)		World Health Organization (WHO)	
	Limit mg/l	Basis [a]	Limit mg/l	Basis [a]	Limit mg/l	Basis [a]
Aluminum						
Antimony			0.05	H		
Arsenic	0.05	H	0.05	H		
Barium	1.0	H				
Beryllium			0.002	H		
Boron						
Cadmium	0.01	H	0.01	S	0.05/1.5	T&A
Calcium					200	A
Chloride	250	T			600	T
Chromium	0.05	H				
Cobalt			1.0	H		
Copper	1.0	T	0.1	S	0.05/1.5	T&A
Cyanide	--	-	0.1	H	0.05	H
Fluoride	1.4-2.4[d]	H				
Iron	0.3	A			0.01/1.0	T&A
Lead	0.05	H	0.1	H	0.1	H
Lithium						
Magnesium					150	T&G
Manganese	0.05	A			0.05/0.5	T&A
Mercury	0.002	H	0.005	H	0.001	H
Molybdenum			0.5	H		
Nickel			0.1	S		
Potassium						
Phosphate						
Nitrate (as N)	10	H			10	H
Selenium	0.01	H	0.001	H	0.01	H
Silica						
Silver	0.05	H				
Sodium						
Strontium			2.0	H		
Sulfate	250	T			200/400	G
Tellurium			0.01	H		
Thorium						
Tin						
Titanium						
Uranium						
Vanadium						
Zinc	5	T				
Zirconium						
TDS	500	T			500/1500	

TABLE 7-2. - Drinking Water Standards - Continued

[a] H=Health (Primary Drinking Water Regulations, Federal Register V. 40, No. 148, December 24, 1975, pp. 59566-59579;

T=Taste;

A=Aesthetics (Secondary Drinking Water Regulations, Federal Register V. 42, No. 02, March 31, 1977, pp. 17143-17146;

S=General Sanitary;

G=Gastrointestinal irritation

[b] Maximum permissible level related to temperature

[c] Related to sulfate not more than 30 mg/l if there is more than 250 mg/l sulfate.

can concentrate materials further until a toxic level is achieved. In recent years several situations have been identified where concentration through the food chain has resulted in overall concentration factors of several million between the aquatic level and the levels of particular species of fish.

It is impossible for a toxicity study to define a single level which affects all members of a given species equally since individual members exhibit different levels of resistance to a given toxic substance. Aquatic wildlife standards are generally based on the environmental concentration that causes death to 50 percent of a population within a specified time period (LD 50). A commonly used toxicity level is the concentration lethal to 50 percent of the members of a species within 96 hours (96-hour LC 50). The standard for protection of all members of a species is set at concentration ranging from 1/100 to 1/10 of the 96-hour LC 50.

Different species exhibit different levels of sensitivity to a given toxic substance. For example, Ball (7) found that lethal concentrations for coarse fish were three to four times greater than those for trout. Toxicity levels or concentrations are related to particular species. While it would be possible to set maximum permissible values of aquatic wildlife standards at levels protecting the most sensitive species, these levels would be unnecessarily restrictive if the sensitive species did not naturally occur in the water body being protected. The general philosophy in the United States for protection of wildlife is identification of the most sensitive species present in a given water body and then selection of water quality standards protecting the most sensitive specie. Universal aquatic wildlife standards have not been adopted.

In this study no attempt has been made to present a single set of water quality standards for protection of aquatic wildlife. In Table 7-3, two toxicity levels are present for materials commonly found in lixivants and in copper and uranium ore bodies, typical of those processed by in situ leaching. The data in Table 7-3 was obtained primarily from Water Quality Criteria-1972 prepared by the National Academy of Sciences for the EPA and Water Quality Criteria by McKee and Wolf (8). These publications are two of the most complete sources of water quality data currently available.

Column 2 of Table 7-3 present the range of freshwater concentrations that have been observed to cause some effect on a variety of aquatic species. These concentration ranges are sublethal doses for the organisms studied. The effects used as a criteria for a response include interference with reproduction, changes in heart rate, respiration and physical movements, hinderance of food intake, immobilization, diarrhea, hemorrhaging, distress syndromes, loss of equilibrium, retardation of growth rates, and pigmentation.

The ranges presented in Table 7-3 are not complete in that species may exist which are less tolerable to a specific substance than those used in the toxicity studies. The lack of a value for a chemical is due to a lack of data resulting from insufficient toxicity studies or to the fact that the chemical is not toxic. For example, while chloride is not toxic at concentrations less than several thousand mg/l, detrimental effects resulting from upset of the osmotic

TABLE 7-3. - Fish and Aquatic Wildlife Toxicity

Chemical	Range Causing An Effect mg/1	Range of 96m LC 50 Values mg/1	Recommended Maximum Aqueous Concentration mg/1	Effects of hardness, alkalinity dissolved oxygen, pH
Aluminum	0.1	5	-	moderate
Antimony	1.0	9-80	-	-
Arsenic	1.8	5-160	-	-
Barium	10	11-4,000	-	-
Beryllium	-	0.15-31	-	-
Boron	10	3,600-19,000	-	-
Cadmium	0.0004-0.003	0.06-70	0.004-0.03	significant
Calcium	920	2,980-10,000	-	-
Chloride	-	-	-	-
Chromium	-	0.03-340	0.05	minor
Cobalt	0.5	-	-	-
Copper	0.006	0.04-75	-	extreme
Fluoride	-	2.7-260	-	-
Iron	2-130	15-300	-	-
Lead	0.03	4-480	0.03	extreme
Lithium	5	7-850	-	-
Magnesium	7.2-740	3,400-17,000	-	-
Manganese	50-1,000	3,400-17,000	-	-
Mercury	0.006-0.6	0.02-40	-	-
Molybdenum	54	70-370	-	-
Nickel	0.095	1-43	-	significant
Phosphate	-	700-1,380	-	-
Potassium	300-1,000	680-1,330	-	-
Selenium	2.5-180	2.5 data lacking	-	-
Silica	-	-	-	-
Silver	0.00015	0.004-1.0	-	-
Sodium	-	1,100-13,000	-	-

TABLE 7-3. - Fish and Aquatic Wildlife Toxicity - Continued

Chemical	Range Causing An Effect mg/l	Range of 96m LC 50 Values mg/l	Recommended Maximum Aqueous Concentration mg/l	Effects of hardness, alkalinity dissolved oxygen, pH
Strontium	-	114-14,000	-	-
Sulfate	-	-	-	-
Sulfide	0.9-6.0	16-750	-	-
Tellurium	-	-	-	-
Thorium	-	0.4-1,000	-	-
Tin	-	1.2-1,000	-	-
Titanium	2-5	8.2-120	-	significant
Uranium	0.5-28	2.8-135	-	significant
Vanadium	-	4.8-55	-	significant
Zinc	0.04-160	0.87	-	significant
Zirconium	-	14-270	-	significant

≠ 96 m LC 50 = 96 minute exposure - lethal concentration for 50 percent of test population.

Lack of an entry indicates that data is unknown.

Reference: 1972 and 1962 <u>Water Quality Criteria</u> by National Academy of Science and McKee, respectively.

equilibrium will occur at levels of 1,000 to 3,000 mg/l. No attempt has been made to categorize substances according to critical toxicity modes of action or mechanisms.

In reviewing the available data, the data was adjusted so that toxicity was attributed to the proper ion of a salt. Many of the investigations utilized sodium salts of such chemicals as fluorides and copper. Some of these investigation reviews have reported toxicity in terms of both cations and anions. This was not done in the present study, although there actually were synergistic effects which would cause the sodium salt of a particular toxic anion to be more toxic than the potassium salt of the same anion.

No range of concentrations causing detrimental effects in aquatic wildlife has been presented for phosphate. The major problem with low level phosphate discharges is eutrophication, which eventually disrupts the entire ecological balance of a water body. Excessively heavy growths of algae can cause the death of fish by depletion of the dissolved oxygen at lower levels. Also, at lower depths, oxygen is depleted by both dead algae which have settled and undergone decomposition, and by viable algae which have been hydraulically transported downward below the photosynthetic zone and undergo a nonphotosynthetic biochemical reaction which consumes oxygen.

Data for the ranges of the 96-hour lethal concentration for 50 percent of a given specie are presented in Column 2 of Table 7-3. It should be reemphasized that the presented values are not necessarily the minimum toxicity values, since they have been based on or derived for specific biological species. It is possible that more sensitive species will be identified, thereby reducing the lower toxicity limit.

Maximum concentrations recommended by the Environmental Studies Board of the National Academies of Science and Engineering for the protection of aquatic wildlife are listed in Column 3 of Table 7-3. The recommended limits are based on lethal toxicity. The Environmental Studies Board has made recommendations for relatively few of the substances listed in Table 7-3 since toxicity data is incomplete for all species at this time.

In several instances the Environmental Studies Board recommended application factors based on the 96-hour LC 50 value. Utilization of application factors requires that the 96-hour LC 50 value be determined for the most sensitive species before the water quality standard is set as the product of the application factor and the 96 hour LC 50. Application factors have been recommended where existing toxicity data is sufficient to establish application factors but not maximum limits for all species or where the sensitivity varies so greatly from species to species that selection of a single limit would be excessively restrictive in many cases.

Large variations between the lower and upper concentrations of the toxicity range are due to differences in specie sensitivities and to the physical, biological, and chemical conditions under which the toxicity studies were performed.

Physical factors include flow velocities, volume of water, bottom contour, rate of water exchange between surface and lower levels, currents, light penetration depth, and temperature. Much of the data in Table 7-3 is based on laboratory studies which are conducted under static conditions. Application of static data to natural water systems is valid if conservative safety factors or application factors are employed.

The chemical factors with the greatest effect on toxicity of inorganic substance are concentrations of hardness, alkalinity, chelating agents and dissolved oxygen and the pH. The mechanisms by which these substances affect toxicities are not known in all cases. It is believed that pH affects the acid-base chemistry of both the toxic chemical specie and the organism.

The aqueous chemistry of metals is especially pH dependent in that different chemical species exhibiting different degrees of toxicity exist in different pH ranges.

In the neutral pH range, several metals exist primarily in the solid phase which is generally less toxic than soluble species. At higher or lower pH values, solubilities increase and toxicity problems occur. The relative toxicities of solid and dissolved phases is related to the species. There have been examples where dissolved zinc has been more, equally or less toxic than suspended zinc particles for different organisms.

The increased solubility at higher, or lower, pH values is the cause for the presence of most of the metals in the pregnant leach solutions. The use of acid leach solutions for recovering copper is dependent on increased solubility at low pH.

Dissolved oxygen concentrations affect toxicity levels by a different mechanism. Low dissolved oxygen values stress many organisms thereby reducing their resistances to other toxic substances.

The effects of hardness on the lethal toxicity is well documented for some metals such as lead, zinc, cadmium and nickel. It has generally been observed that the toxicity of these metals are reduced at higher hardness levels. The 48-hour LC 50 of zinc increases from 0.5 mg/l at 10 mg/l total hardness as $CaCO_3$ to over 4 mg/l at 500 mg/l total hardness as $CaCO_3$. Column 5 of Table 7-3 indicates the relative effects of such factors as hardness, alkalinity, dissolved oxygen (D.O.) and pH on the toxicities of some of the substances listed. For copper, the difference in toxicity may not be related to the difference in hardness per se, but to the difference in alkalinity of the water that accompanies change in hardness (9).

Chelating agents of both natural and synthetic sources including domestic wastewater effluents have been shown to reduce the toxicity of copper (10). Apparently the organic metal complexes do not contribute to the lethal toxicity. Chelating agents have been found to reduce the toxicity of zinc (11), and it is probably safe to assume that the toxicities of other metals will also be affected.

Although it is known that different species or complexes of a given chemical exhibit different degrees of toxicity, water quality standards are generally written in terms of total soluble concentration since the chemistry of most natural water systems is not sufficiently understood to predict future transformations between species.

In evaluating surface water quality, a question arises as to the definition of soluble versus solid phases which must be operationally defined by a laboratory separation technique. In the present study, which is primarily concerned with groundwaters, all solid species are effectively filtered by flowing through the porous media and only soluble forms can be present.

It is possible that exfiltration of groundwater to a surface stream or river will result in the formation of solid phases of particular metals due to a shift in the redox state which could occur when the former groundwater undergoes aeration. Surface water qualities should be evaluated in terms of the concentrations of soluble species.

Metals which have precipitated or have adsorbed to the sediments can reenter the soluble phase at a later time through dissolution or desorption processes resulting from shifts in chemical equilibrium brought about by changes in concentrations of soluble methods, or chelating agents, pH or oxidation state.

Leaching Solutions

There are two sources of potentially toxic lixiviant constituents: 1) chemical added to the lixiviant to enhance its leachability; 2) species in the ore which solubilize. It is possible to generalize about the first source since there are a limited number of chemicals which are used in the preparation of lixiviants. The second source is site specific and depends upon the composition of the ore being recovered.

Lixiviant Additives

The identity and approximate concentration range of the chemicals most commonly used in uranium and copper lixiviants are presented in Table 7-4. The concentrations of oxidants such as oxygen or hydrogen peroxide are not included in Table 7-4 since the oxidant decomposes and only appears at low concentrations in recovered solutions. Hydrogen peroxide is rapidly reduced after injection into an ore and has not appeared in detected excursions. Also included in Table 7-4 are the problems or potential problems associated with each of the specific additives.

The lixiviants do not meet the drinking water standards because of excessive total salinity (total dissolved solids) and excessive concentrations of specific toxic species. The ammonia used in native copper and uranium lixiviants is normally oxidized to nitrates if it is not adsorbed to the clay fraction of the ores. There has been speculation as to the occurrence of ammonia nitrification but review of groundwater quality data indicates that ammonia in groundwaters is only detected in relatively low concentrations, for instance, less than 1-2 mg/1.

TABLE 7-4. - Composition of Conventional Lixiviants and Potential Drinking Water Problems

	Leachate				
Leachant Components (Partial)	Porphyry Copper g/l	Native Copper g/l	Uranium g/l	U.S. Secondary Drinking Water Standards g/l	Problem or Potential Problem
Ammonia (as N)	-	25-50	0.5-1.5	(0.01)*	Taste and potential conversion to nitrates which can be toxic
Bicarbonate/carbonate	-	10-25	0.5-2	-	Excessive Salinity
Copper	-	0-3	-	0.001	Taste and aesthetics
Iron	0-1	-	-	0.0003	Taste and aesthetics
Sodium	-	-	0-0.1	-	
Sulfate	5-10	-	2-5	0.25	Gastrointestinal Irritation
Total Dissolved Solids	10-30	25-50	1-3	0.5	Gastrointestinal Irritation
pH**	1-2	9-11	1-2 & 9-11	6.5-8.5	Toxicity

* U.S. Primary Drinking Water Standard for nitrate as N.

**pH in conventional units, not g/liter.

No attempt has been made to estimate the concentration of each specie presented in Table 7-4 which will remain in solution in the event of an excursion. Certain species can precipitate (sulfate, iron) or be adsorbed to mineral surfaces in the ore (ammonium, hydrogen ions).

Ore Solubilized Species

A great variety of highly toxic species can be solubilized by the action of certain lixiviants on particular ores. Very little published information on the concentrations of trace metals in pregnant solutions currently exists. Without such information, it is difficult to generalize about the overall toxicity of leaching solutions.

In Table 7-5 the concentrations of constituents identified in pregnant solutions are presented, as well as the ratio of that concentration to the potable water standard. The ratio is important in evaluating the dilution which is necessary before the constituent reaches the potable limits. For example, the total dissolved solids in a porphyry copper leaching solution exceed the potable water standard by a factor of 40. Therefore, at a minimum, natural dispersion would have to mix each volume of porphyry copper lixiviant with 40 volumes of good quality groundwater before the total dissolved solids would be diluted to a range acceptable for potable waters. Beryllium in the same lixiviant exceeds the potable standard by a factor of 25,000. While simple dilution by natural dispersion would not be adequate to reduce the beryllium concentration to required potable limits, it is highly probable that specific chemical phenomena such as precipitation or absorption could significantly reduce the concentration of this specie.

It should be emphasized that the data in Table 7-5 is limited by the availability of accurate data on the complete chemical compositions of pregnant liquors. The information is based on partial analyses of samples obtained at a single location with a specific ore.

HYDROLOGICAL ASPECTS OF MONITORING PROGRAMS

The obvious objective of the groundwater monitoring program is detection of subsurface excursions of leaching solutions. A subsurface excursion is defined as the escape or loss of containment of any injected leaching solutions (barren or pregnant) from within the boundaries of the area being mined. Monitoring requirements for Texas and Wyoming uranium in situ solution leaching operations are presented in Chapter 6. In the present chapter the general hydrologic aspects of monitoring are presented.

Causes of Excursions

Excursions can be due to improper balances between injection/extraction rates, undetected high permeability strata or geological faults, uncontrollable changes in piezometric pressures of confined aquifers or establishment of density induced flows.

TABLE 7-5. - Constituents in Leaching Solutions Relative to U.S., WHO and Russian Potable Water Standards [1]

Constituent	Standard For Potable Water mg/l	Porphyry Copper		Native Copper		Uranium	
		Concentration mg/l	Conc./STD	Concentration mg/l	Conc./STD	Concentration mg/l	Conc./STD
NH_3	0.5	--	--	4,000	8,000	3,000	6,000
As	0.05	--	--	0.5	10	--	--
Be	0.0002	5	25,000	--	--	--	--
Cl	250	--	--	870	3.5	200	0.8
Co	1.0	--	--	2.0	2	--	--
Cr	0.05	4	80	--	--	--	--
Cu	1.0	1,000	1,000	650	650	--	--
Fe	0.3	3,000	10,000	--	--	--	--
Pb	0.05	2	40	--	--	--	--
Mn	0.05	100	2,000	--	--	--	--
Mo	0.5	10	20	--	--	125	250
Ag	0.05	--	--	0.10	2	--	--
Na	--	200	--	--	--	250	--
Sr-90	2.0	15	7.5	--	--	--	--
SO_4	200	15,000	75	--	--	1,500	7.5
TDS	500	20,000	40	12,000	24	12,000	24

[1] Source of many constituents is the ore being leached.

Imbalances between injection and extraction rates can occur in either a localized area or over the entire area being leached. Localized imbalances can occur as a result of mechanical equipment failure or clogged injection/extraction wells connected to common manifolds where only total flowrates are measured. A single well or several wells which become clogged and cease to function could go undetected since the other wells on the common manifold would compensate for the loss of flow. The total flow through the mainfold could remain unchanged.

Clogging of an extraction well on the perimeter of the leaching area would permit a localized groundwater "mound" to develop and cause solutions to flow out of the area. Injection well clogging would cause an increase in the flowrates of the other injection wells on a common manifold. This could cause a localized excursion where injection rates exceed the extraction rates. No excursion problems would occur in those other areas where extraction rates exceed injection rates.

The severeness of localized excursions resulting from clogging on an injection/extraction well is a function of the position of the clogged well within the total injection/extraction system. It is highly improbable that imbalances occurring in the interior of the injection/extraction system could result in escape of solutions from the leaching area.

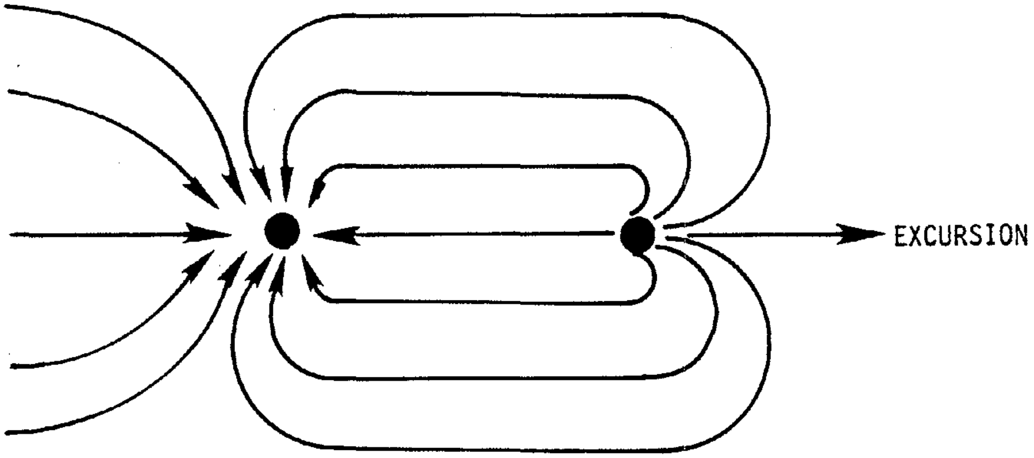
Figure 7-8 illustrates a potential excursion of leaching solutions resulting from the presence of strata with relatively high permeabilities. Generally, any such zones are detected during the logging of the test, production or monitoring borings. Recovery of solutions from high permeability zones is possible by proper location of extraction wells and optimum spacing of the casing perforations.

The existence of either a vertical or horizontal geological fault can result in the escape of fluids from the mining area. Such faulting would typically be identified from geophysical testing or analysis of boring logs. Faults or fissures are the primary escape paths for leaching solutions in porphyry copper deposits.

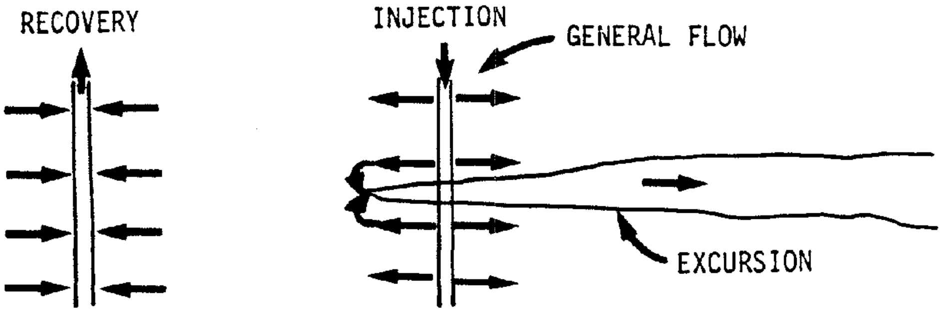
Leaching Zone Hydrodynamic Characteristics

The objective of a monitoring well is to intersect solutions which are flowing out of the leaching zone. Figure 7-9 illustrates a conventional layout for a system of perimeter monitoring wells in porous media. Also illustrated in Figure 7-9 are two hypothetical excursions, one of which passes undetected through the monitoring well perimeter. Under the conditions of the hypothetical example the success of detection is simply dependent on the location of the excursion relative to the monitoring well and the width of the excursion plume which is controlled by the hydrodynamic characteristics of the porous media.

Uranium bearing sandstones typically have porosities ranging from 36 percent to 43 percent and permeabilities between 200 and 4,000 millidarcys. Typical native water velocities range between about 1-30 meters (3-100 ft) per year.



(a) PLAN VIEW OF GENERAL FLOW AND EXCURSION



(b) ELEVATION VIEW ILLUSTRATING GENERAL FLOW AND EXCURSION

FIGURE 7-8 EXCURSION RESULTING FROM THE PRESENCE OF HIGH PERMEABILITY STRATUM OR FAULT

Figure 7-9 is not representative of the groundwater hydrology of porphyry copper deposits which occur in rock or fractured rock. Great variations occur in the water transmission characteristics of rock aquifers and it is impossible to present generalized or universally applicable values. Additional hydrologic details for specific ore bodies are presented in Chapters 3-6.

Monitoring Well Systems

Location of Monitoring Wells

The location, spacing and number of monitoring wells is a function of many parameters including the area of the in situ operation, the hydrodynamic characteristics of the leaching zone, the operating procedures of the monitoring wells, the nature of the strata overlying and underlying the ore zone, and the potential damage resulting from leaching solution excursions.

Operational Procedures for Monitoring Wells

The rates of pumping from a monitoring well can effectively increase its zone of influence and increase the probability of excursion detection. Theoretically, an unpumped monitoring well can only detect leaching solutions when the solutions come in direct contact with the well casing. Practically, however, removal of the sample causes replacement groundwater to flow into the casing and results in a small detection zone. The actual size of the zone could be less than one or two feet depending on the volume of the sample and the length of the perforated zone in the casing.

The situation has occurred in which excessive pumping of a remote monitoring well has caused the processing solutions to flow from the mining area. This is now a recovery well for the duration of the leaching operation.

Electrical Resistivity Detection of Excursions

Electrical resistivity is a technique which can determine subsurface characteristics from a series of ground surface tests. The relative resistances between electrodes are indications of the subsurface formation characteristics and the salinity of the groundwater. While the resistivity techniques have generally been used to define geological characteristics and to locate groundwater, they have been successfully used to define the presence and extent of groundwater contamination or pollution (12) [Berk and Yare, 1977; Hackbarth 1971; Warner 1969; Yare 1975].

The conventional technique involves measurement of the resistance between four equally-spaced vertical electrodes. The potential drop, applied current and electrode spacing are used to calculate the apparent resistivity which is a measure of the resistance of all materials down to a depth which is proportional to the spacing of the electrodes.

A more sensitive system for excursion of detection from in situ solution leaching operations would result by installation of the electrodes within the ore body.

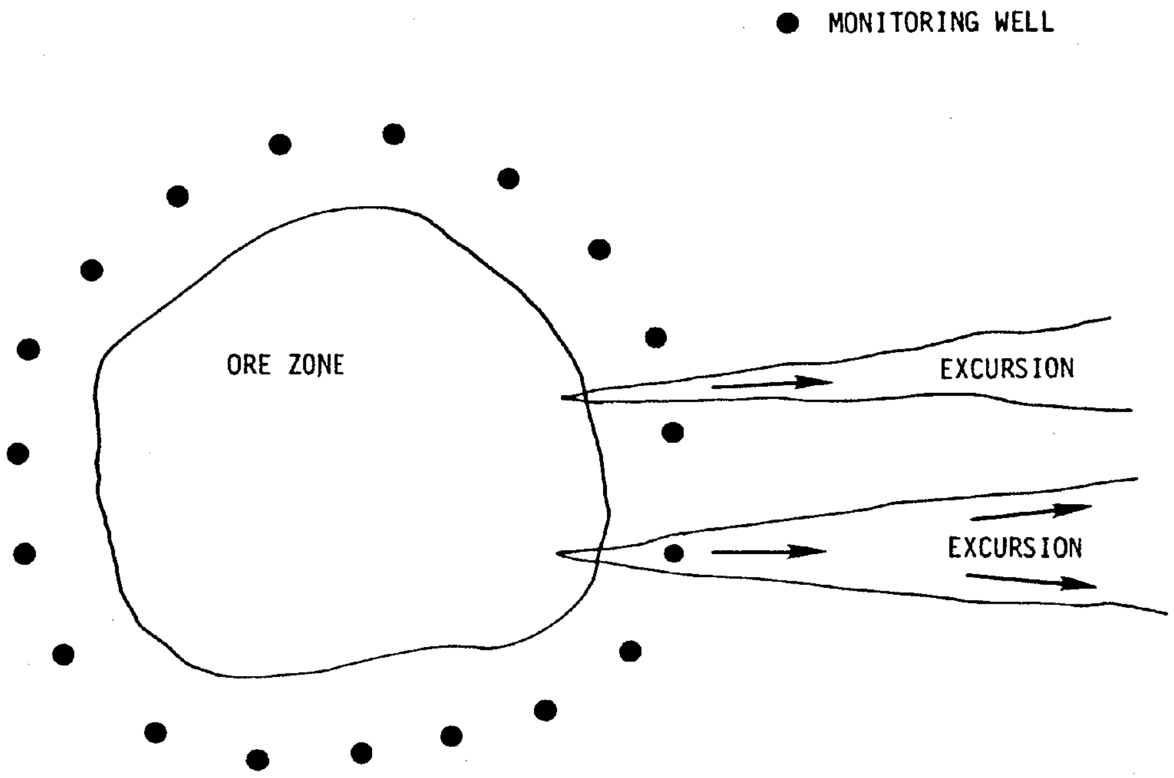


FIGURE 7-9 PLAN ILLUSTRATION OF PERIMETER MONITORING SYSTEM

Electrical resistivity measurements can be used to define the presence and extent of groundwater contamination if the resistance of the pollutant markedly differs from that of the native groundwater. The sensitivity of the technique is improved by the presence of relatively homogeneous subsoils, uniform shallow water tables and flat topography. Monitoring of pollutant excursions can be performed by comparison of resistivity surveys obtained prior to and after commencement of the mining operation or by comparison of surveys in mining areas with those in virgin areas. Typically, a routine monitoring program would consist of measuring potential drops and applied currents between various pairs of electrodes in an electrode grid system. A difference in measured values would indicate an excursion.

The geological, groundwater and lixiviant characteristics of in situ uranium mining are favorable for electrical resistivity detection of excursions. The technique has potential for early detection of excursions since escaped lixiviant would decrease the apparent resistivity prior to its arrival at a monitoring well. Resistivity measurements could be used to control the operation of the pumping/injection system to optimize uranium recovery.

Potential problems which might interfere with the method include the electrical short-circuiting of the pipeline grids in the mining area. The inhomogenity of the porphyry ore deposits prevents the use of electrical resistivity to detect leaching solution excursions. Likewise, the characteristics of native copper ore deposits will not permit successful application of this method. A possible excursion that would allow the use of this method would be in low-grade copper ores (relatively low conductivity).

If demonstration studies indicate that electrical resistivity techniques are adequate for groundwater monitoring around uranium in situ operations, the techniques would be environmentally favored when compared with a system of monitoring wells. Monitoring wells require that holes be drilled through various horizontal strata which isolate separate aquifers.

Although the wells are cased and sealed the possibility remains that contaminants can escape from the zone of uranium ore and enter overlying aquifers.

CHAPTER 7 REFERENCES

1. Shock, D.A., and F.R. Conley. Solution Mining - Its Promise and Its Problems. Pres. at Proc. Solution Min. Symp. AIME Annual Meeting, Dallas, Texas, Feb. 25-27, 1974.

2. Garrels, R.M., and C.L. Christ. Solutions, Minerals and Equilibria. Harper and Row, New York, 1965.

3. Rickard, R.S. Chemical Constraints on In-Situ Leaching and Metal Recovery. Pres. at Proc. Solution Min. Symp., AIME Annual Meeting, Dallas, Texas, Feb. 25-27, 1974, pp. 185-192.

4. Kunda, W., H. Veltman, and D.H.I. Evans. Production of Copper from Amine Carbonate Systems. Pres. at EMD Copper Metallurgy Symposium, 99th Annual AIME Meeting, Feb. 16-19, 1970.

5. ______. Primary Drinking Water Regulations. Federal Register, Volume 40, No. 148, December 24, 175, pp. 59566-59579.

6. Tardiff, R.G., and M. Deinzer. Toxicity of Organic Compounds in Drinking Water. Proc. 15th Annual Water Quality Conference, Univ. of Illinois, Bulletins No. 70, 122, June 4, 1973.

7. Ball, I.R. The Relative Susceptibilities of Some Species of Freshwater Fish to Poisons I. Ammonia. Water Research I, N. 11-12, 1968, pp. 767-775.

8. McKee, J.E., and H.W. Wolf. Water Quality Criteria. State Water Quality Contol Board Pub. No. 3-A, Sacramento, Calif., 1963.

9. Stiff, M.J. Copper/Bicarbonate Equilibria in Solutions of Bicarbonate Ion at Concentrations Similar to Those Found in Natural Water. Water Resources, N. 5, 1971, pp. 171-176.

10. Bender, M.E., W.R. Matson, and R.A. Jordan. On the Significance of Metal Complexing Agents in Secondary Sewage Effluents. Environmental Science and Technology, N. 4, 1970, pp. 520-521.

11. Sprague, J.B. Promising Anti-Pollutant: Chelating Agent NTA Protects Fish From Copper and Zinc. Nature, 1968, pp. 1345-1346.

12. Berk, J.W., and B.S. Yare. An Integrated Approach to Delineating Contaminated Groundwater. Ground Water, N. 15, No. 2, 1977, pp. 138-145.

12. Hackbarth, D.A. Field Study of Subsurface Spent Sulfite Liquor Movement Using Earth Sensitivity Measurements. Ground Water, N. 9, No. 3, 1971, pp. 11-16.

12. Warner, D.L. Preliminary Field Studies Using Earth Resistivity Measurements for Delineating Zones of Contaminated Groundwater. Ground Water, N. 7, No. 1, 1969, pp. 9-16.

12. Yare, B.S. The Use of a Specialized Drilling and Groundwater Sampling Technique for Delineation of Hexavalent Chromium Contamination in an Unconfined Aquifer, Southern New Jersey Coastal Plain. Ground Water, N. 13, No. 2, 1975, pp. 151-154.

CHAPTER 8

CONCLUSIONS AND RECOMMENDATIONS - IN SITU LEACHING

INTRODUCTION

In situ leaching processes for recovery of uranium in sandstone hosts and porphyry copper are currently technically viable. In situ mining of native copper from deposits such as those in Houghton County, Michigan remains to be demonstrated. In general, the environmental impacts of mineral recovery by the in situ leaching techniques are significantly less adverse than those of conventional mining and milling practices. This is especially true for uranium mining where disposal of tailings produced by the conventional mining methods is a major environmental problem, as seen by recent legislation.

As of 1978, the environmental impacts of in situ leaching were not completely defined due to the techniques' state of development. A much better understanding of the direct and indirect impacts will occur over the next two-to-five-year period when production scale and additional pilot scale operations will be conducted.

NON-RADIOLOGICAL ENVIRONMENTAL IMPACTS

Terrestrial Environment

In situ techniques require significantly less disturbance of the overburden than conventional techniques. This enables more rapid and less costly reclamation of the terrestrial environment after closure of the mine than is possible with conventional techniques. The blasting required to fracture the porphyry copper deposits has only short term detrimental effects on the surface ecology and will not limit the applicability of the techniques. Of greater importance is the lixiviant application technique. Surface spraying of acid solutions can be environmentally unacceptable depending on site specific conditions. Acid mists can travel relatively long distances (0.1 to 1 km) and can damage flora and fauna. This problem can be eliminated by modification of the lixiviant application system.

Construction activities associated with mine establishment and operation will produce dust, exhaust emissions, surface disturbance, and noise disturbance characteristic of any construction operation. Such disruption is of relatively short duration but may have comparatively greater adverse aesthetic and biological impacts than most construction activities due to the frequent pristinity of the areas being mined.

The surface subsidence resulting from block caving can be substantial 6-30 meters (20-100 feet) depending on the volumes of ore extracted. In terms of in situ leaching, block caving is a fragmentation technique for increasing permeability of the ore body.

Air Quality (Non-Radiological)

The in situ techniques evaluated will only have minimal impacts on the geographical areas investigated in this study. Minimal dust and exhaust emissions will occur during construction and operation. The only measurable potential atmospheric emissions are sulfuric acid mists from spray lixiviant applicators at porphyry copper mines and ammonia gas and ammonium chloride particulates at the evaporation ponds and yellowcake dryer at uranium recovery plants. In terms of atmospheric emissions, in situ techniques are superior to open pit mining methods which produce large amounts of dust and exhaust emissions.

Water Environment

In situ leaching, by its nature, has certain potential for groundwater pollution. The adverse impacts to the water environment can be minimized and even eliminated by proper monitoring and restoration actions. In this section the conclusions regarding the environmental impacts for each of the three ores investigated in this study are summarized.

Porphyry Copper

There have been relatively few in situ leaching operations for extracting porphyry copper. The majority of existing and past applications of the technique have used sites previously mined by conventional techniques. Very little effort has been given to documenting the baseline conditions or the effects of such operations. The following conclusions are based on the limited data available on in situ leaching of copper and the wealth of information on heap and dump leaching.

The proposed lixiviants for porphyry coppers are toxic in view of their low pH and high trace metal contents. While the exact compositions of pregnant lixiviants are unknown, the chemical nature of the lixiviant and the ore compositions indicate that many toxic metals will be present in the enriched solutions.

Although the porphyry copper deposits do not occur in aquifers, faults and fissures common to most deposits provide potential paths for lixiviant escape from the mining area. Detailed geologic studies will be required to define the presence and characteristics of any such communication paths. Typically such fissures or paths will surface or end in alluvium aquifers. The lack of containment of leaching solution within the ore body could cause contamination of surrounding potable water aquifers. While the potential for such degradation exists for all in situ operations, its actuality is determined by site specific conditions.

The limited application of in situ leaching of porphyry copper has not resulted in definition of restoration requirements. It is highly probable that the groundwater protection aspects of the Safe Drinking Water Act will require the development of guidelines for the protection of groundwater from in situ leaching operations.

Excursions of lixiviants from the mine area are possible. While hydrologic principles indicate that extraction of leaching solutions from faults and fissures is theoretically possible, such clean-up operations have not been sucessfully demonstrated.

Restoration demonstration is obviously in the same category as clean-up operations. One significant factor is that porphyry copper deposits do not occur in aquifers. It might be environmentally acceptable to leave leaching solutions in the mine area if it can be demonstrated there is no possibility of communication with potable aquifers.

In a properly designed and operated in situ leaching operation, there will be no surface discharges. Flows to permitted evaporation ponds are not surface discharges since the ponds are within the mine site boundaries. This eliminates adverse impacts to surface waters other than those caused by excursions via faults and fissures.

Evaporation ponds will probably be used for disposal of process wastewaters. Seepage from unlined ponds will permit transport of toxic solutions to the surrounding environment. Such seepage will generally cause unacceptable levels of environmental degradation and it is highly probable that evaporation ponds will require impervious liners. Any outflows will likely require treatment. Proper closure procedures for the ponds are needed at completion of operations.

Tailings ponds are currently used for disposal of process wastes from conventional porphyry copper mining and milling operations. The presence of large amounts of tailings in conventional tailings ponds results in a natural sealing of the pond. This will not be the situation with in situ evaporation ponds since no tailings are produced. Beneficiation of the enriched lixiviant is a solution processing operation which produces or involves no solids. Evaporation ponds are very well suited to the desert southwest, where precipitation is low and evaporation rates are high.

Any mining operation in the desert southwest impacts the available water supplies. In situ opertions have relatively low consumptive water usages. This is a significant advantage over conventional mining and milling methods which use large quantities of water for dust control and processing of tailings.

Native Copper

The technical feasibility of in situ leaching of native copper has only been demonstrated on a laboratory/pilot scale. There have been no attempts at in situ leaching any natural ore or low grade ore backfilled in stopes. Laboratory studies indicate that initial lixiviants are toxic. Recycled lixiviants solubilize gangue constituents and become more toxic.

The primary hydrologic consideration of any in situ mining operation is the protection of surrounding aquifers. The native copper formations do not have natural subsurface communication paths with aquifers in adjacent formations and the potential for escape of lixiviants is low. There is, however, a potential problem with contamination of the waters within the native copper formation which are presently filling the abandoned mines in the area proposed for leaching. As discussed in Chapter 5, these waters are currently being used as potable supplies by several small communities in the region. While water supplies did not exist naturally in these formations, their degradation could be considered an adverse environmental impact. The previously mined ore zone contains hundreds of miles of interconnected tunnels. At one time it was possible to travel approximately 32 km (20 mi) horizontally through adjoining mining operations. Attempts had been made at sealing sections of the ore body with concrete bulkheads. The integrity of these bulkheads is unknown and will be difficult to evaluate. The saline water formations at depths greater than 3,000 meters (10,000 feet) provide a disposal site for process wastewaters containing large concentrations of inorganic salts. The consumptive use of water by in situ mining in the native copper region would have insignificant impacts on regional or local water supplies.

Uranium

The concern over potential contamination of groundwater by uranium in situ leaching operations is greater than for porphyry and native copper in situ mining. This is because of the radionuclides associated with uranium and because of the immediate potential for significant growth of the uranium solution mining industry.

Both the acid and alkaline lixiviants are toxic due to their high salinities. The recirculated solutions are highly toxic due to the solubilization of radium and other toxic trace metals. The escape of barren or pregnant lixiviants from the immediate mine area will result in degradation of groundwater quality.

The quality of native water in most ore deposits generally do not meet the potable water standards. In many instances, the waters are also unfit for consumption by livestock. The waters in the vicinity of the roll front deposits generally have total dissolved solids (TDS) concentrations in excess of 500 mg/l which exceeds recommended drinking water standards. This excessive TDS concentration (500 to 1,000 mg/l) is not a basis for rejection of the water for potable uses.

Leaching solutions have the potential for solubilization of many trace metal constituents of the gangue. The composition of each recycled leaching solution will be unique. This may not affect the environmental considerations since the solutions must be contained and isolated from the environment due to their uranium content.

During normal operations, there is a moderate probability that excursions could occur. Excursions will not significantly affect the groundwaters detrimentally if clean-up operations are initiated immediately. Clean-up has been demonstrated to be technically viable, but expensive, when loss of production is considered. The escaped solution can be returned to the main ore body by increasing the extraction rates relative to injection (1).

The use of monitoring wells appears to have a high probability for detection of excursions. The current guidelines for the number and location of monitoring wells as required by the State of Texas appear sufficient to prevent any significant release of solutions from the general mining area. Review of the literature has not revealed any in-depth analysis of the probability of excursion detection by monitoring well systems under the aquifer conditions characteristic of roll front uranium deposits. Such a study is recommended to verify the suitability of the adopted monitoring guidelines.

The possibility of undetected, long-term excursions is extremely small if: 1) adequate premining hydrologic studies are performed to define the characteristics of the ore deposit; 2) mass balances on the leaching solutions are performed on a routine and monthly basis. If such excursions do occur, dispersion will dilute the levels of all constituents as the solutions flow from the mine site. Insufficient data exists for prediction of the maximum contaminant concentration as a function of distance from the plant site.

Pilot scale operations have demonstrated that is is possible to reduce concentrations of solutions in leached areas by sweeping with native groundwaters. To date, complete return off all constituent levels to baseline concentrations has not been fully demonstrated. Specifically, the south Texas operations have experienced difficulties in removal of ammonium ion sorbed to the clay fraction of the ores. It has been reported that sweeping with 10 to 15 pore volumes only reduces ammonium concentrations to approximately 20 mg/l (as N) (1).

Techniques are currently under evaluation for accelerating the restoration process by the use of chemical additives in sweep solutions. These additives are based on the facts that adsorbed ammonium ion is removed by an ion exchange reaction and that the exchange ion can be systematically added to the flushing water. Chemical additives would be advantageous when surrounding native groundwaters have low potential for successful flushing.

The gradual desorption of ammonium ions into the groundwater does not necessarily mean that the ammonium ions will be transported any significant distance. The clays in the deposits surrounding the mine will adsorb and retain the ammonium ion. The waters would have to be used in the immediate vicinity of the mining area or it is improbable that they would contain significant quantities of ammonium ion.

Investigations are currently being conducted to identify alternatives for the ammonium ion in alkaline lixiviants. It appears that potassium may have similar uranium leaching characteristics without the restoration difficulties. Additional research must be performed to verify this.

In situ leaching and the uranium recovery processes produce liquid wastes which must be segregated from the environment. Properly designed and operated lined evaporation ponds and deep injection wells appear to be suitable disposal techniques.

Restoration by sweeping produces the greatest volume of wastewaters. The composition of the restoration waters dictate that they be isolated from the environment.

Membrane desalination processes such as reverse osmosis and electrodialysis can be used to reduce the volumes of wastewater which must be disposed. These systems which have been used since 1972 for treatment of various industrial wastes produce two liquid streams: a concentrated wastewater brine and potable water. Reverse osmosis is capable of reducing waste stream flowrates by a factor of 2 to 6 at considerable costs.

The treatment-disposal requirements for waters used in uranium in situ leaching preclude the use of large quantities of water. This limits the amounts of water which will be used in such operations. The consumptive water use of in situ solution leaching should not adversely affect the regional water supplies in either Texas or Wyoming.

RADIOLOGICAL IMPACTS OF URANIUM SOLUTION MINING

Properly designed and operated solution mining and uranium recovery operations do not produce appreciable radiological emissions. The water and terrestrial environments do not receive direct emissions of process waters or waste solids. The only radiological emissions are radon gas from the pregnant liquids surge tank and the water purification system and uranium 238 dust from the yellowcake dryers. These emissions from a typical 227,000 Kg/yr (500,000 lb/yr) mine and recovery plant produce a radiation dose to humans located 6.4 km (4 miles) away of only 0.009 millirem/year. This is only 0.002 percent of the annual maximum whole body dose recommended by the NRC.

Uranium recovery using the in situ leaching technique has significant environmental advantages over the conventional mining and milling methods. The most important advantages are the release of only small amounts of radium from the ore body, the lack of significant volumes of tailings which can generate significant qualities of radon gas, and the lack of major disruption of the surface environment.

CHAPTER 8 REFERENCES

1. William F. Guzton & Associates. M8-13 Excursion Bruni Mine Site. June 1977.

CHAPTER 9

HYDRAULIC BOREHOLE (SLURRY) MINING

INTRODUCTION

Hydraulic borehole (slurry) mining (hereinafter referred to as hydraulic borehole slurry mining) has been proposed and demonstrated as a technique for ore extraction and transport. The technique eliminates the massive surface disturbances occurring with open pit mining and the occupational hazards of tunnel mining.

In the following descriptions of the technology and the discussion of environmental aspects, it is emphasized that hydraulic borehole slurry mining has been demonstrated only recently as a technically viable process and has not undergone extensive commercial pilot testing. The existing equipment is commercially used for other applications, and it is expected that commercial hydraulic borehole mining operations will be developed in the near future.

The process of hydraulic borehole slurry mining is depicted in Figure 9-1. Initially, a borehole is drilled into the ore zone. Next, the ore is slurried by a cutting jet-pump device and then it is pumped to the surface. The slurry is processed by conventional beneficiation operations. The tailings are used to backfill the borehole cavities and minimize subsidence.

The use of water jets to fragment rock which occurs in the borehole is not a new technique. It was used effectively by the placer miner and has been commercially used in the recovery of gilsonite in Utah. The primary difference between placer mining and hydraulic borehole mining is that the borehole technique takes place below the surface while placer mining occurs on the surface. The nature of the technique makes it applicable to shallow ores (30 to 300 meters below the surface) which can be slurried by hydraulic jetting. Major commercially-developed candidate ores are pebble phosphates and uranium sandstones. Borehole mining appears to have potential application in the recovery of certain mineral ore deposits which cannot be mined by conventional techniques due to economic and environmental considerations. This mining approach eliminates all hazards to the miner posed by underground tunneling. Since all subsurface activity is accomplished with machinery, the process could have significant economic advantages in view of the high cost and dangers associated with men working underground. The technique also affords the opportunity to reduce environmental degradation associated with conventional mining by surface disruption and providing for the return of the majority of the tailings into the borehole. The technique does result in a potential wastewater problem, since the liquid phase of the slurry must be properly disposed if adverse environmental impacts are to be prevented.

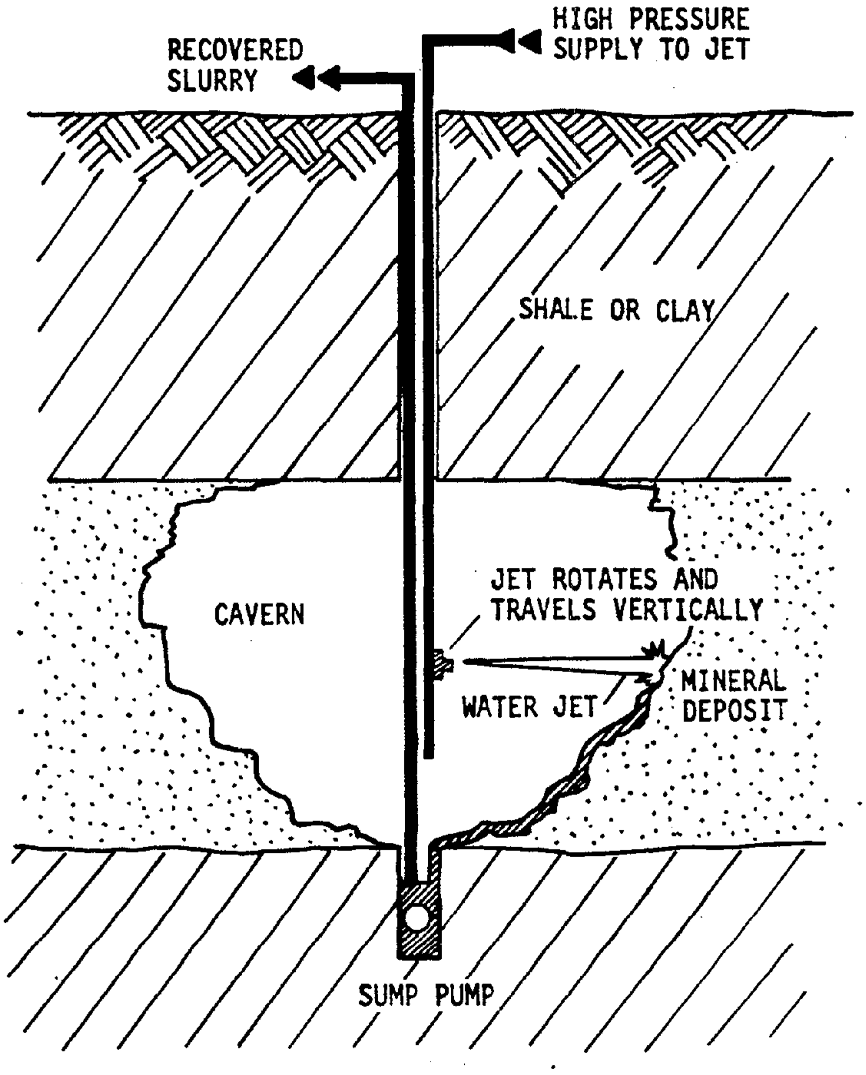


FIGURE 9-1 SCHEMATIC DIAGRAM OF THE HYDRAULIC BOREHOLE SLURRY MINING TECHNIQUE

DESCRIPTION OF TYPICAL OPERATION

The following description of a hydraulic borehole slurry mining operation is based on a recently developed hydraulic cutting jet. In terms of environmental aspects, this particular jet is typical of other demonstrated and proposed mining units.

Access to the ore is provided by drilling a hole of sufficient diameter to accommodate the hydraulic jetting tool. Typically, a 45-centimeter (18-inch) diameter hole would be drilled to approximately 2 meters (6 feet) below the mineral bearing strata. A casing would be installed above the ore body to prevent cave-ins of the overburden. The cutting jet assembly is positioned in the hole at the end of a rigid service column containing the necessary conduits for pressurized water and transport of the slurry to the surface. The lower section of the cutting jet assembly contains the slurry pump which is positioned in the hole below the ore body. After the mining unit is positioned in the borehole and the above ground equipment (pumps, tanks, separators, etc.) are installed, the high pressure water, bearing and seal water, slurry and hydraulic connections are made.

Normally, the underground mining operation is started with the jet set at the lowest position. The jet rotates and cuts material through an arc of 200 to 300 degrees leaving a segment of unmined material to support the overlying strata. The material is removed to a radius of up to 25 meters (76 feet) depending on the properties of the ore and the design of the jet system, such as, pressure, nozzle, shape, and diameter. After this material is removed, the jet is raised to reach the next level of ore. The slurry is pumped to the surface where it is decanted for processing. The decanted water is recycled and used for slurrying new ore. Treatment requirements for this water are minimal since low concentrations of suspended solids do not interfere with the jetting operation. Various other provisions can be incorporated into the borehole slurry pump to control problems specific to particular ores. For example, in the event the slurry pump intake becomes clogged with oversize material, a flush jet could be employed to clear the slurry pump intake area using high pressure water.

The duration of mining at a borehole is simply a function of the ore characteristics and the capacity of the jetting apparatus. It has been projected that a 15 to 25-meter (46 to 77-foot) diameter borehole could be completely mined in 8 to 24 hours (1 to 3 working days), assuming an ore zone of 10 meters (30 feet) thickness.

It has been proposed that large ore bodies be mined with a systematic drilling, mining, processing and backfilling operation such as that illustrated in Figure 9-2. The initial mining pattern would leave substantial ore between boreholes for support of the surface. These areas would be mined in a second phase after the original boreholes are backfilled. Figure 9-2 illustrates one secondary recovery bore located adjacent to the completed, backfilled borehole. The secondary recovery boreholes will have to be located in a pattern preventing previously backfilled tailings from flowing into the secondary borehole. It is possible that future development studies will identify additives for

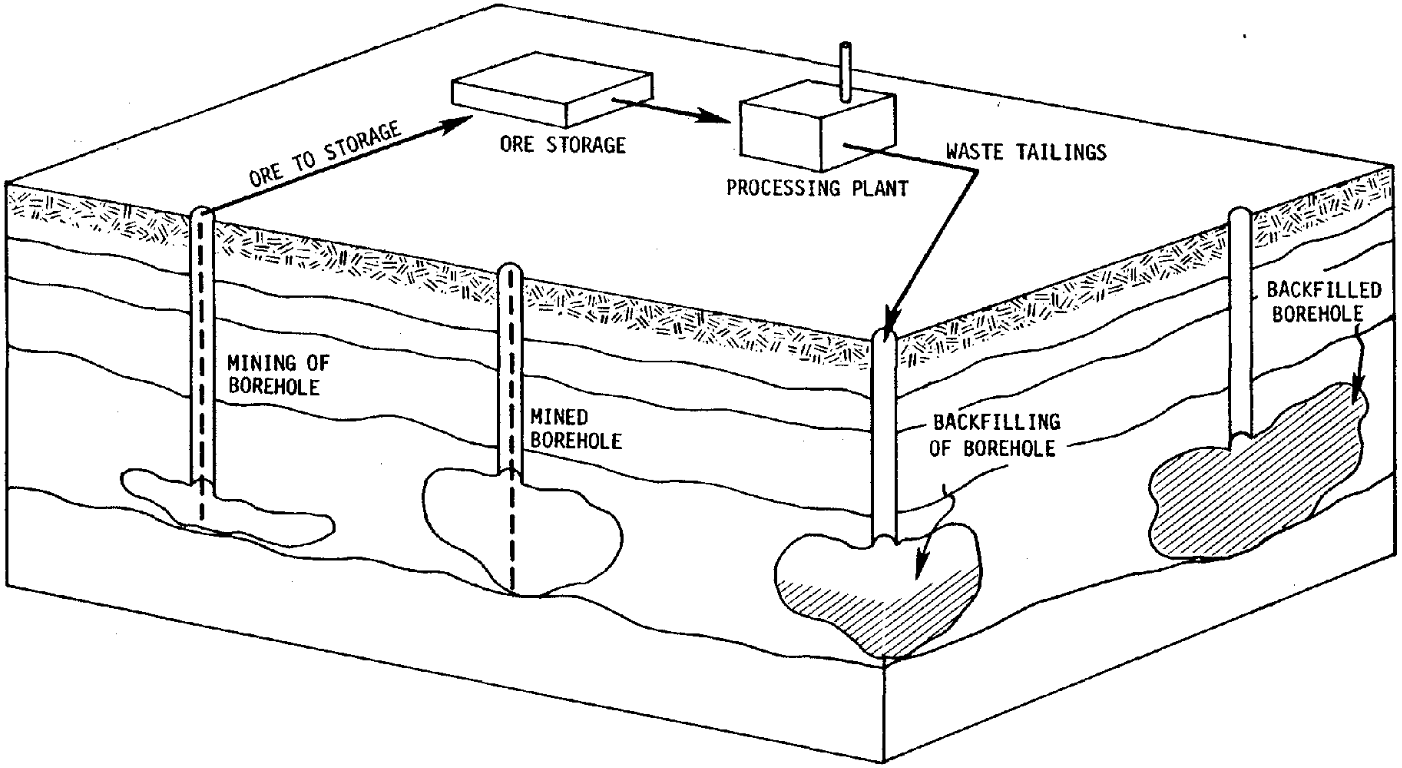


FIGURE 9-2 CENTRALIZED PROCESSING, MINING AND BACKFILLING OF MULTIPLE BOREHOLE OPERATION

stabilization of backfilled tails to prevent their repeated extraction. Based on geometric considerations, 75 to 80 percent of the ore in a given deposit should be minable. Chemical stabilization additives could increase the maximum recovery.

APPLICABILITY

The primary prerequisite for borehole slurry mining is that the ore be amenable to fracture by a hydraulic jet. Demonstration tests have indicated that certain pebble phosphates and uranium-bearing sandstone ores can be mined by hydraulic jets and transported as a slurry (1). Excessive jetting requirements increase the costs of the hydraulic borehole techniques to the point of economic nonviability.

In the following two chapters, the applicability and potential environmental effects of hydraulic borehole slurry mining techniques for the recovery of uranium from sandstone ores and phosphate from pebble phosphate ore are described. It is again emphasized that as of 1978, no commercial projects were in operation and that the environmental analyses are based on limited demonstration projects and descriptions of the techniques published in the literature.

ENVIRONMENTAL ASPECTS

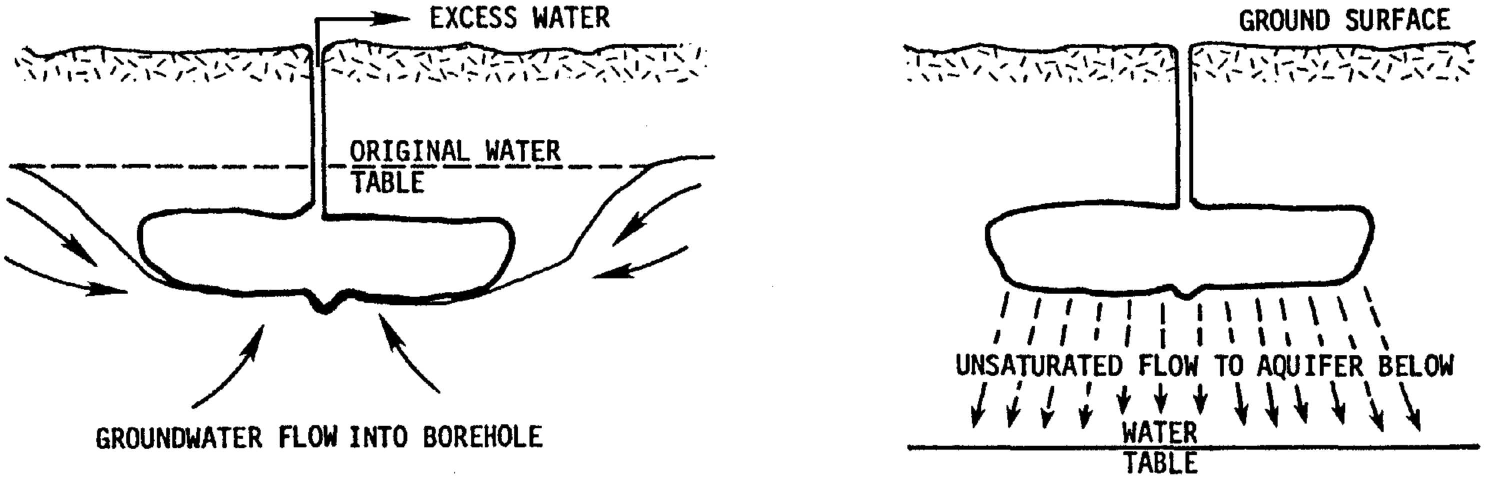
Modification of Adjacent Aquifers

Hydraulic borehole slurry mining has the potential to impact many aquifer characteristics. These impacts range from very slight to extremely significant and can vary from short- to long-term in duration, with some being irreversible. In general, most physical, chemical, and biological processes within aquifers are relatively slow. Thus, although an aquifer can be impacted significantly within a short period of time, returning the aquifer to its approximate original state may require a very long period of time. Because of this slow recovery process, any adverse impact acquires greater importance.

Borehole operations may be located above or below the natural groundwater table whether or not the aquifer is confined (Figure 9-3 illustrates these situations). Location of the groundwater table below a hydraulic borehole provides an opportunity for transport of soluble chemical constituents into the aquifer. The potential sources of soluble constituents are the water used for the hydraulic jetting and leachable constituents in the ore or the underlying strata.

Rates and Composition

The rate at which constituents are transported into adjacent strata is a function of several factors, including: 1) the original permeabilities of the surrounding strata; 2) the tendency of the slurried ore to clog the flow channels and thus reduce permeabilities; 3) the magnitude of the hydraulic gradients



A. GROUNDWATER TABLE LOCATED ABOVE BOREHOLE

B. GROUNDWATER TABLE LOCATED BELOW BOREHOLE

FIGURE 9-3 POSSIBLE HYDROLOGIC CONDITIONS established during and after mining operations; 4) the duration of the borehole operation.

The constituents leached from the ore or underlying strata will depend upon the geochemical reactions occurring between the aqueous and solid phases. The degree of leaching or solubilization is affected by various physical and geochemical parameters including oxidation potential, pH, temperature and composition of the water and the underlying strata. These factors are all site specific, and it is impossible to project specific constituents without extensive data.

Mitigative Procedures

If significant contamination of an underlying aquifer does occur, there are various control techniques which can be employed to restore the aquifer. Figure 9-4 illustrates the utilization of extraction wells to recover leachant once it enters the zone of saturated flow. Proper adjustment of the extraction well flow rates can enable the extraction rate to balance the seepage into the aquifer. Such a balance results in a condition where there is no net flow to the surface or into the aquifer.

Other possible techniques for reduction or elimination of contaminant leaching include chemical modification of the hydraulic fluid to prevent solubilization of toxic substances, and hydraulic fracturing and grouting of a strata directly below the borehole. Interception of the seepage in the unsaturated zone would require installation of collection galleries over 100 percent of the area under the borehole since unsaturated flow cannot be controlled by conventional pumping techniques.

Consumptive Water Use

A major environmental problem with a hydraulic borehole located below the groundwater table is the disposal of the excess water produced by the mining operation. A hydraulic jet will only be effective if the borehole is completely dewatered and the cutting jet comes in direct contact with the ore. The dewatered borehole acts as a large diameter well and can produce large quantities of water depending upon the hydraulic characteristics of the water bearing strata. The flow of water into the borehole is affected by the size of the borehole, its depth below the groundwater table and the duration of the dewatering operation. Excess water can be minimized by completion of the mineral extraction operation as rapidly as possible.

In water short areas, there may be adverse environmental effects resulting from evaporation or consumptive use of the excess water. The mine operator may be required to obtain legal ownership of the water before being permitted to develop the borehole.

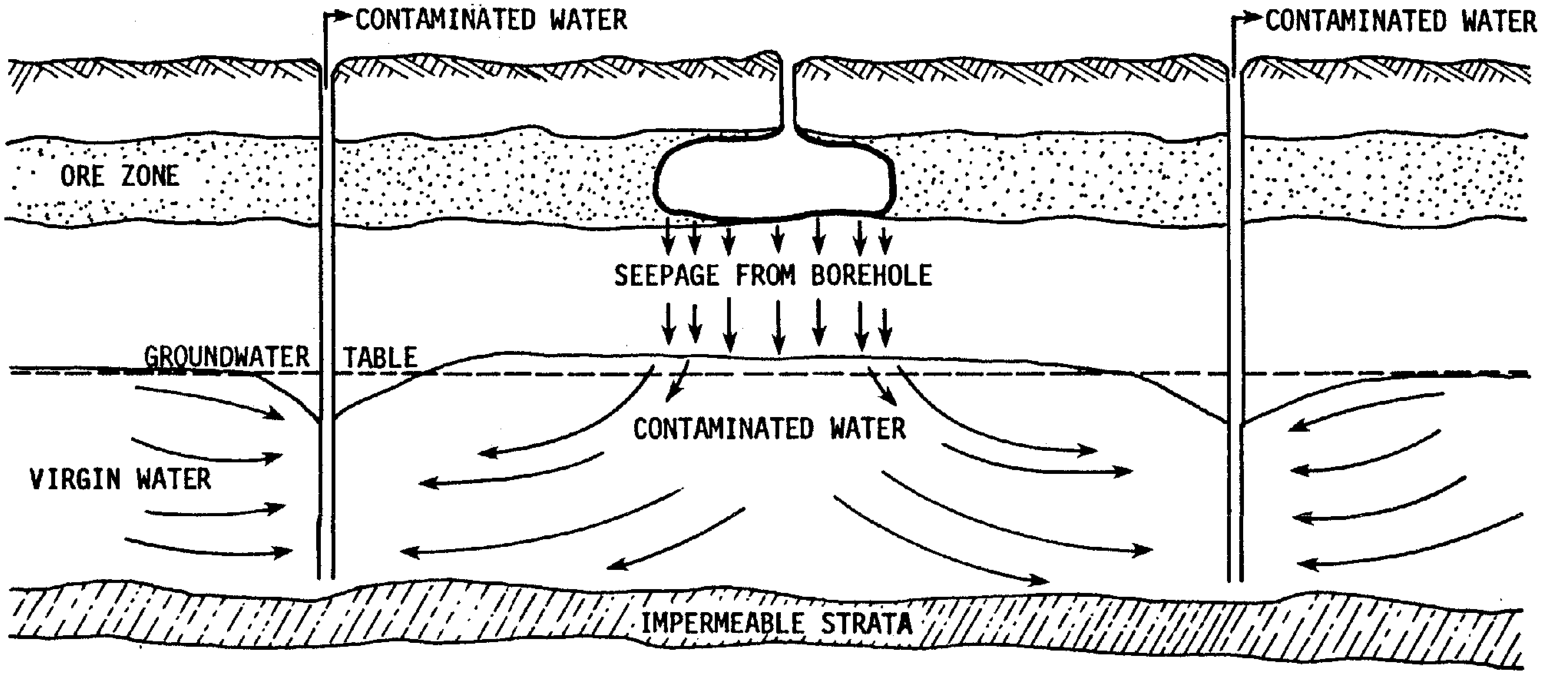


FIGURE 9-4 PUMPING OF UNDERLYING AQUIFER TO RESTORE GROUNDWATER QUALITY

Improperly Sealed Casings

A variation of the hydrologic scenarios described above is the occurrence of perched or isolated aquifers above the borehole. Any penetration of a strata isolating two aquifers provides the opportunity for the transmission of water from one aquifer into the other. Potential problems which can result from an improperly sealed casings include: 1) flooding of borehole; 2) loss of valuable water resources if potable water flows into nonpotable aquifers; 3) contamination of the potable aquifer by saline, brackish, or contaminated waters; 4) reduction in piezometric pressure of wells in surrounding areas.

It should be noted that the potential subsurface environmental problems described above are not unique to in situ slurry techniques. Extraction of the ore by any other available techniques would result in equal or greater disturbance of the existing conditions.

Subsidence

Subsidence is defined as sinking of the ground surface. The sinking causes damage to surface structures such as buildings, roads and utilities.

Causes

Subsidence occurs in many areas and is not unique to areas mined by borehole slurry techniques. Collapse of any subterranean void, whether it is a mine or a natural occurrence, will cause surface subsidence if all strata between the void and the surface collapse. It has been proposed that boreholes be backfilled to prevent subsidence. However, subsidence can occur even though the borehole is backfilled with the tailings produced by the mineral beneficiation process. Figure 9-5 illustrates the compaction of backfill, the collapse of the roof of the borehole, and the resulting subsidence of the overlying strata. The original borehole was not filled properly, or was incompletely filled or not fully compacted.

Factors Affecting Degree of Subsidence

The degree of subsidence is affected by various parameters or factors which can be broken down into three categories: backfill techniques, nature of overburden, the geometry of borehole. The techniques used during the mining operations should not significantly affect the resulting degrees of subsidence.

The various parameters of the backfill operation which affect the degree of subsidence include the degree of moisture of the backfill material, the grain size distribution of the backfill material, chemicals which are added to modify the strength or dewatering properties, and the actual dewatering period.

Probably the most important factor controlling the degree of surface subsidence is the nature of the strata between the surface and the borehole. If adequate strength of the strata persists, no surface subsidence will occur even though the borehole is not backfilled. This would be similar to an open mine.

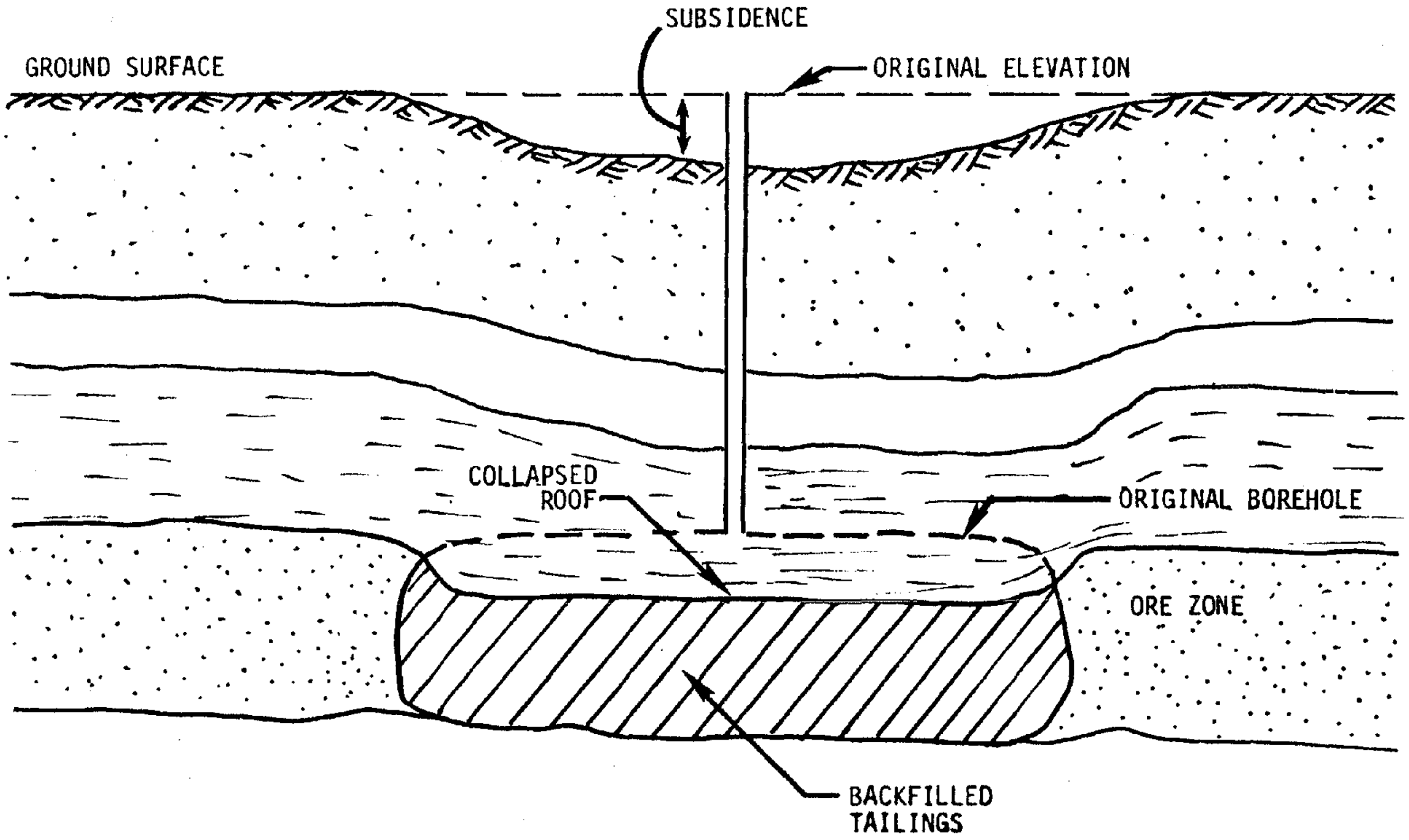


FIGURE 9-5 CROSS-SECTION ILLUSTRATING COMPACTION OF BACKFILLED TAILINGS, COLLAPSE OF BOREHOLE ROOF AND UPPER STRATA, AND SURFACE SUBSIDENCE

The strength of the overburden can be affected by the degree of saturation of the materials. If the mining operation modifies the subsurface hydrologic conditions, it is possible that surface subsidence could occur as a result of dewatering the overlying strata. Such subsidence depends on the nature of the strata and the degree of dewatering.

Various borehole characteristics determined by the mining operation can also affect the degree of subsidence. Specifically, the depth of the borehole can affect the actual volume of void produced by compaction of the backfill. For example, when subsidence is due to compaction of the backfilled tailings, a 12-meter (37-foot) thick borehole would produce twice the subsidence as would a 6-meter (18-foot) thick borehole. Secondly, the depth of the borehole below the surface has a significant effect on surface subsidence. In general, the greater the depth of the roof of the borehole below the surface, the smaller the amount of subsidence. This is because of the natural ability of the overlying areas to dissipate subsidence. Other factors which effect the extent of subsidence include the diameter or the standoff of the borehole, the degree or cut of the borehole (that is, whether a full 360° is used or only a 270°), and finally, the spacing of the support pillars between the boreholes.

Mitigative Actions

At the present time, borehole backfilling has not been attempted. Review of similar backfilling applications indicates that techniques will be developed to minimize surface subsidence and the resulting detrimental effects.

It would be possible to reduce subsidence by maximizing the backfilling of the borehole. This could be accomplished by periodically adding more tailings after natural compaction occurs. Obviously, if the borehole collapses, backfilling operations would be impossible.

Chemical additives, including cements, could be mixed with the backfilled tailings to increase their strength and reduce their compaction. Chemical additives are generally expensive and some have the potential for contamination of the groundwater. It is also possible that other special techniques such as pressure grouting above the backfill material could be employed at various periods after backfilling has ceased to reduce subsidence. Figure 9-6 illustrates one technique utilizing pressure grouting above the backfilled tailings.

A technique which has potential for dewatering slimes or other fine-grained materials is electrokinetic dewatering. An electrical field is established between two electrodes buried in the slurry. The negatively-charged collodial particles move toward the positive electrode effecting a separation of the solid and liquid phases. Power is the major cost of the electrokinetic separation process. Sprute and Kelsh (2) have estimated power consumption of 33-39 kwh/m^3 of densified fill. This corresponds to a cost of \$0.65-\$0.78 per cubic meter backfilled. This cost should be compared with the value of the mined uranium and phosphate. For example, one cubic meter of 0.04 percent U_3O_8 ore contains approximately 0.78 kg of uranium. Recovery of 65 percent of the uranium in the

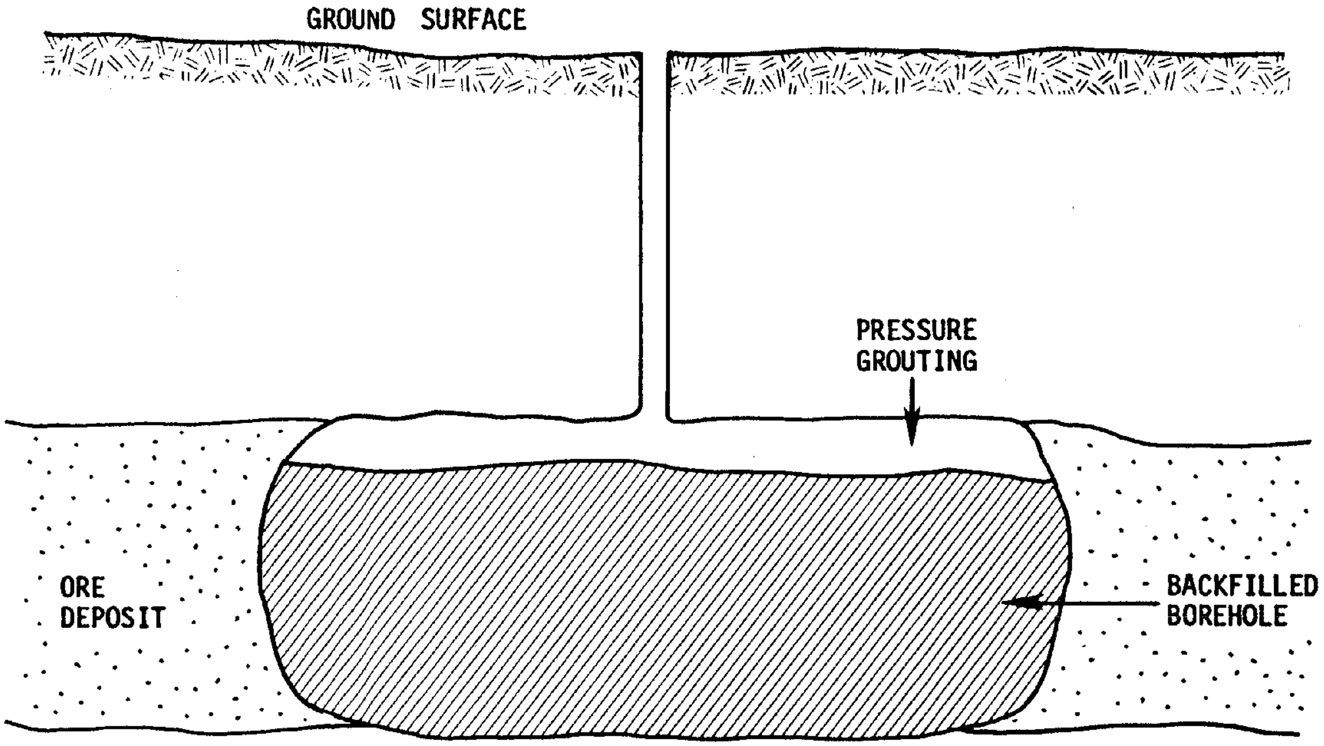


FIGURE 9-6 PRESSURE GROUTING FOR REDUCING SUBSIDENCE

ore results in about 520 grams of uranium which has a current value of about $48.00. One potential difficulty in the use of electrokinetics for densification of the backfill in the borehole is the installation of the electrodes. The borehole only provides limited access and the electrodes require separation.

Environmental Effects

The environmental effects of subsidence are directly related to the degree of subsidence and the use being made of the land. Generally, boreholes would be located under land not being used for structures. It is probable that surface subsidence will not occur for the majority of properly operated borehole mines, hence, detrimental effects due to subsidence should be minimal or non-existent. Proper operations would result in backfilled boreholes which would be capable of supporting the overlying strata.

If surface subsidence does occur, there is an obvious damage to any structures overlying the boreholes. Structural damage due to subsidence generally first appears as cracks in concrete or plaster walls and does not cause disasterous structural failures. If the borehole slurry technique is extensively utilized in an area susceptible to subsidence, it may be necessary to prohibit building of any structures directly above the boreholes.

Several environmental effects could occur if significant subsidence occurs in undeveloped areas. Modification of the surface topography could result if subsidence occurs over each borehole. It is possible that the surface water hydrology would be modified by the ponding of water in the subsided areas. This could result in changes in the flora and fauna on a local basis. It is conceivable that natural groundwater recharge or surface runoff could be modified. Whether these modifications would be adverse depends on specific site conditions.

Surface Disturbances

Surface disturbances can be classified into two main categories; short- and long-term. Short-term surface disturbances are relatively minor and can probably be mitigated, without difficulty, using existing technology. Long-term surface disturbances will require significantly larger efforts to properly mitigate and may not completely restore a site to its original state.

Prior to initiation of the mining operation, there will be minor short-term disturbances of the land surface and topography due to site preparation, grading, construction of access roads, construction of the processing plant and associated units, and water storage reservoirs. Land surfaces during this period will be subject to increased erosion potential, alteration of natural drainage patterns, and disturbance and displacement of natural soils and vegetation, as well as permanent modification. Operational failures such as spills, leaks and pipeline failures will also impact the land surface by flooding, ponding or chemical alteration of the surface strata. Obviously, if toxic fluids are involved in the failures, the magnitudes of the environmental impacts will be greater.

Long-term impacts on land surfaces include tailings disposal areas. The topography of any project site will be permanently modified by tailings piles and evaporation ponds. Mitigation measures would include revegetation of all surfaces as well as sealing ponds to prevent migration of leachates to underlying aquifers. If it is possible to locate the tailings piles directly over subsidence areas, this action would require extensive monitoring to assure containment of leachates from waste tailings, a primary consideration of this type of project. On-site or near-site nonconventional disposal of tailings will undoubtedly require extensive and exhaustive study into the long-term impacts on land surfaces, as well as subsurface impacts.

Normal Environmental Effects

Borehole mining will have the typical environmental impacts due to road construction, processing plant construction, surface disturbance during mining, and socioeconomic development. These impacts are normal for most mining operations. It should be emphasized that open pit mining, an alternative to borehole slurry mining would cause significantly greater surface disturbances. Extraction of ore generally causes a 10 to 20 percent increase in the volume of removed ore. This prevents backfilling of all waste tailings into the borehole and necessitates alternate tailings disposal techniques. The particular disposal technique employed would be determined primarily by the type of mineral being mined.

The wastes generated by the mineral processing plant will not be affected by the utilization of the borehole slurry technique for mining. These processing wastes require disposal by conventional environmentally acceptable techniques.

The actual volume of water used consumptively by the borehole mining technique is small since relatively little evaporation occurs from the slurry and water recycling is employed. Large consumptive uses could occur if significant volumes of slurry fluid flow into surrounding or underlying aquifers. Under such circumstances, the groundwater contamination potential is much greater than the negative impacts of increased consumptive use. Minor additional amounts of water would be required for dust control, human consumptive and sanitary functions at the site.

Summary

Hydraulic borehole slurry mining is an in situ ore extraction technique which has great potential for mining certain ores such as pebble phosphates or uraniferous sandstones. The potential for adverse environmental impacts appears less than with conventional mining techniques such as underground or strip mining. The environmental suitability and economics of the technique must be evaluated for specific minerals and at specific locations.

CHAPTER 9 REFERENCES

1. Savanick, G.A. Water Jet Perforator for Uranium Leaching Wells. Presented at Uranium Mining Technology Conference, the Mackay School of Mines, University of Nevada, Reno, Nevada, April 25-29, 1977, 24 pages.

2. Sprute, R.H., and D.J. Kelsh. Using Slimes for Backfill in Deep Mines. Mining Congress Journal, April 1976, pp. 22-26.

CHAPTER 10

HYDRAULIC BOREHOLE SLURRY MINING OF PHOSPHATES

The mining of phosphate by the hydraulic borehole slurry method has potential for extraction of pebble phosphate deposits. In this chapter the environmental settings and potential environmental impacts are developed for major phosphate mining areas in Florida and North Carolina.

FLORIDA PHOSPHATE PHYSICAL SETTING

Geographic Location

Phosphate deposits in Florida include those located in three regions, designated in relative order of current importance as:

1. Central Florida - containing an enormous measured reserve of land pebble phosphate in its west central area.
2. South Central Florida - with an unpublished reserve and apparent large resource of land pebble phosphate - similar to the deposits of central Florida.
3. North Florida - with a large resource of land pebble phosphate in the northern peninsula area and a smaller reserve of "hardrock" phosphate located in the area between the central and far north Florida regions.

Phosphate resources in Florida are abundant. Only the central Florida deposits with current or near future in situ potential, which are located in Figure 10-1, are considered here. Although local exceptions exist, a preponderance of similar features in this region dictates their practical description in this report under the general category of pebble phosphate deposits. Modifying influences which create significant local differences will be noted.

Natural features of Florida subtly reflect the influence of those forces that have "shaped" the scenery of many geographic locations throughout geologic time such as: structural and geochemical instability, massive marine transgressions, intense weathering. Figures 10-2 and 10-3 present the geological cross-section of central Florida and the Land Pebble Phosphate District. Once a relatively flat, essentially featureless shelf or platform (similar in many respects to present-day continental shelf areas) peninsular Florida now consists of several gently contrasting regions. Thus the higher ground (low hills and ridges) of north central Florida grade successively through the karst topography that dominates the landscape in the south central portion, through savanna-like plains, marshes, and swamps typical of south Florida. Karst topography refers to irregular limestone topography formed by surface and groundwater solution cavities.

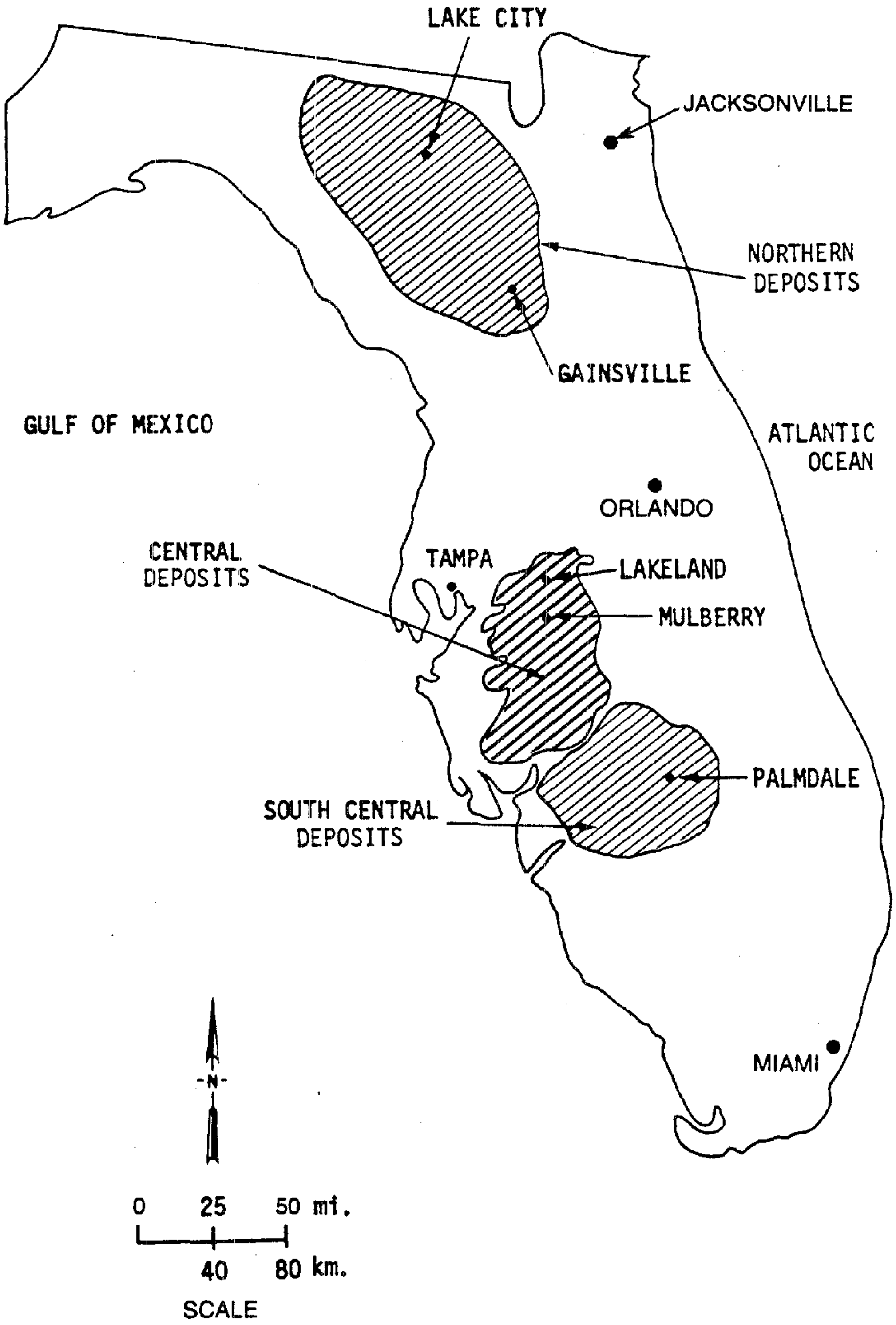


FIGURE 10-1 PHOSPHATE RESOURCES IN FLORIDA

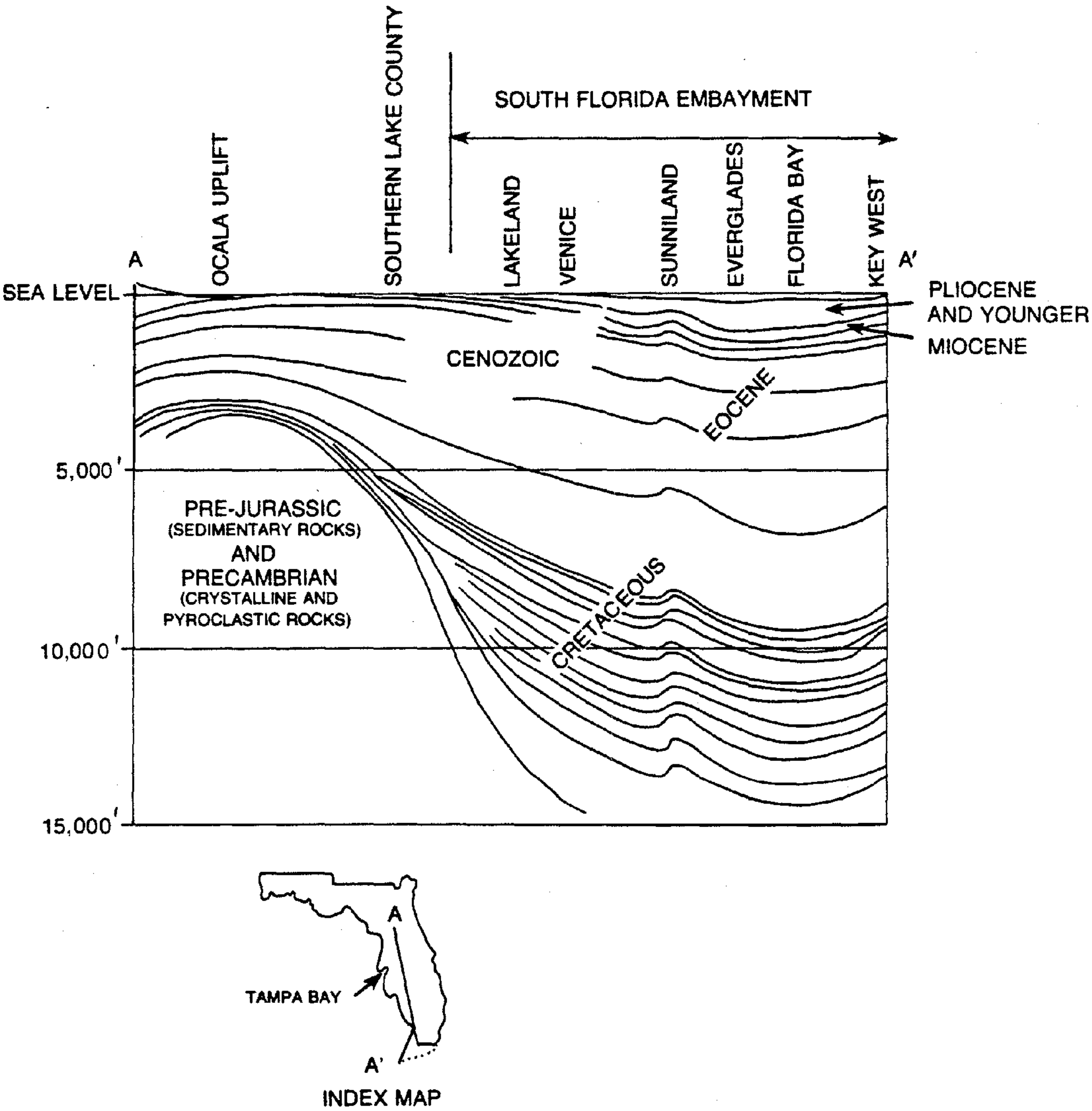


FIGURE 10-2 CROSS-SECTION THROUGH CENTRAL PENINSULAR FLORIDA, PEBBLE PHOSPHATE DISTRICT. ADAPTED FROM (1)

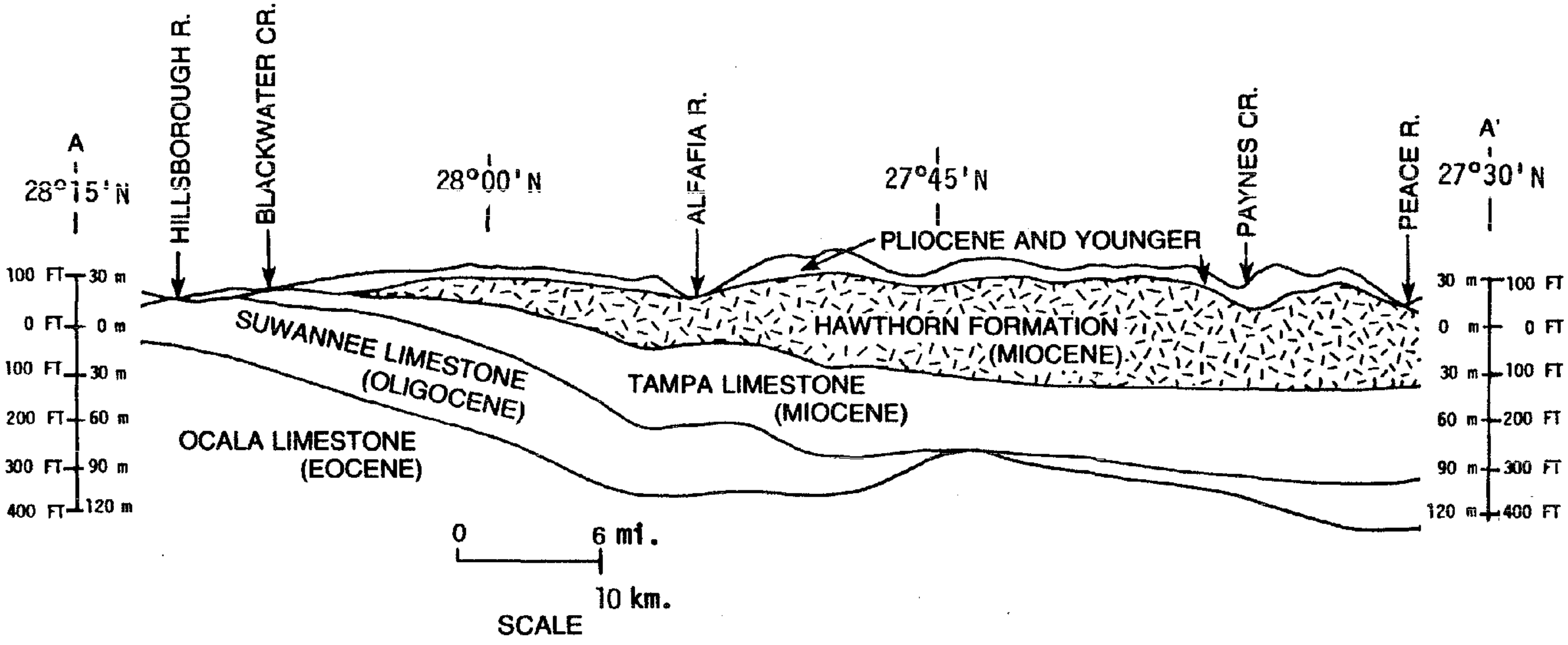


FIGURE 10-3 CROSS-SECTION THROUGH PEBBLE PHOSPHATE STUDY AREA (CENTRAL FLORIDA). ADAPTED FROM (1)

Nature of Deposits

Underlying the Florida Peninsula is a thick section of tertiary sedimentary strata, consisting primarily of carbonate rocks, but with some phosphatic beds as shown in Figures 10-2 and 10-3. These formations represent both the substance and source of one of the world's major mineral deposits, the Florida pebble phosphates, a cross-section of which is shown in Figure 10-3. Although now produced from near surface deposits by conventional stripping and open pit mining methods, long term exploitation of deeper deposits might employ in situ techniques of borehole slurry mining.

More than 80 percent of United States phosphate production comes from secondary deposits of marine phosphorites, such as those of the Bone Valley Formation. Table 10-1 presents the Bone Valley lithology and stratigraphy and Figure 10-4 shows the lithology and stratigraphic relations in the Land Pebble Phosphate District.

The phosphorite deposits of central Florida are found in a zone approximately 100 kilometers (60 miles) long and 65 kilometers (40 miles) wide. This zone is the product of reworking a submarine phosphate-rich residual deposit resulting from original deposition from solution in ocean waters. These deposits were further increased in grade by natural leaching and weathering processes. The Formation has acquired the name of Bone Valley for the fossilized remains of prehistoric marine animals which occur in the layer. The phosphate bed varies in thickness from 0.3-10 meters (1-35 feet) and is usually overlain by a layer of sand and clay up to 15 meters (50 feet) in depth.

Phosphate pebbles may be from 20-mesh size up to 1/2-inch, are quite hard, and normally have a bone phosphate of lime (BPL) content of 50 to 70 percent. Matrix grades are generally much lower, in the 30 percent BPL region. Processing losses from slime contained in phosphate ore are usually substantial, and the slime is not generally amenable to benefication processes.

In 1973, the U.S. Bureau of Mines reported the recoverable reserves in the central Florida district at 1.2 billion short tons. Projected mining life for this particular deposit, at current projected rates of processing, is about 30 years. The 1.2 billion tons may contain up to 150,000 tons of uranium oxide and a content of 3 percent fluorine. These are considerable resources and the technology for recovery of both these materials from phosphoric acid production has already been demonstrated.

SURFACE CONDITIONS

Soils

Soils overlying most of the important Florida phosphate deposits consist of sandy loams, some with little or no clay, but containing large amounts of decayed organic matter (humus) in their upper portions. Surficial materials here present unique differences, many of which defy the usual factors applied to describe and classify soils. Thus, large areas have very loose covers of quartz sand which

TABLE 10-1. - Summary of Stratigraphy and Lithology, Land-Pebble Phosphate District, Florida
Adapted from (7)

Age	Formation or Deposit	Lithology: "Normal" Section	Lithology: Intensely Weathered Section
Pleistocene	Pleistocene (?) sand or Residual sand mantle	Unconsolidated quartz sand, massive. Some organic material at surface. May have groundwater podsol.	Unconsolidated quartz sand, massive. Some organic material at surface. May have groundwater podsol.
		Overburden	Overburden
		WEATHERING BOUNDARY	
	Upper Unit	Green clayey sand, minor apatite particles that are more abundant at base. Finely bedded, graded bedded, and crossbedded. Clay mineral, montmorillonite, weathered to kaolinite at top of unit.	White clayey sand, leached and indurated. Secondary aluminum phosphate minerals replacing clay and apatite. Clay is kaolinite. Basal layers may be vesicular, where the lower unit is altered. Aluminum phosphate alteration extends only partly into lower unit, but may replace parts of Hawthorn and Tampa Formations where they are close to the surface.
		Overburden	
		CONTACT GRADATIONAL	Leached or Aluminum Phosphate Zone
			WEATHERING BOUNDARY
	Lower Unit	Phosphorite. Sand, clay, and gravel containing very abundant phosphate particles. Bedded, and crossbedded. Green, brown, and black.	Phosphorite, as in unweathered section.
		Matrix	Matrix

TABLE 10-1. - Summary of Stratigraphy and Lithology, Land-Pebble Phosphate District, Florida - Continued

Age	Formation or Deposit	Lithology: "Normal" Section	Lithology: Intensely Weathered Section
		CONTACT UNCONFORMABLE	WEATHERING BOUNDARY
	Middle Lower	Sandy, clayey, phosphate-bearing limestone. Dolomitic near surface. Buff, white, or cream. Contains interbedded sand, clay, or sandy clay. Bedrock	Residual calcareous, sandy clay, containing abundant phosphate particles; lower part grades into carbonate rock. Possible development of aluminum phosphate minerals, particularly in the northern part of the district, where the overlying formations are thin or absent. Bedclay
		CONTRACT RELATIONS UNCERTAIN (CONFORMABLE TO SOUTH, DISCONFORMABLE TO NORTH)	
	Lower	Sandy and Clayey limestone, contains chert nodules and trace amounts of phosphate. May form the bedrock in northern part of district. Tampa fossils reported from the Tenoree mine.	Calcareous clay and sandy clay containing chert and phosphate. Aluminum phosphate minerals present when the formation is very close to the surface.
		CONTACT UNCONFORMABLE	
Oligocene	Suwannee Limestone	Limestone, contains minor sand and clay, but no phosphate. Chert present.	Secondary chert replacing limestone near the surface.
		CONTACT UNCONFORMABLE	
Eocene	Ocala Limestone	Very pure limestone.	Known only in subsurface.

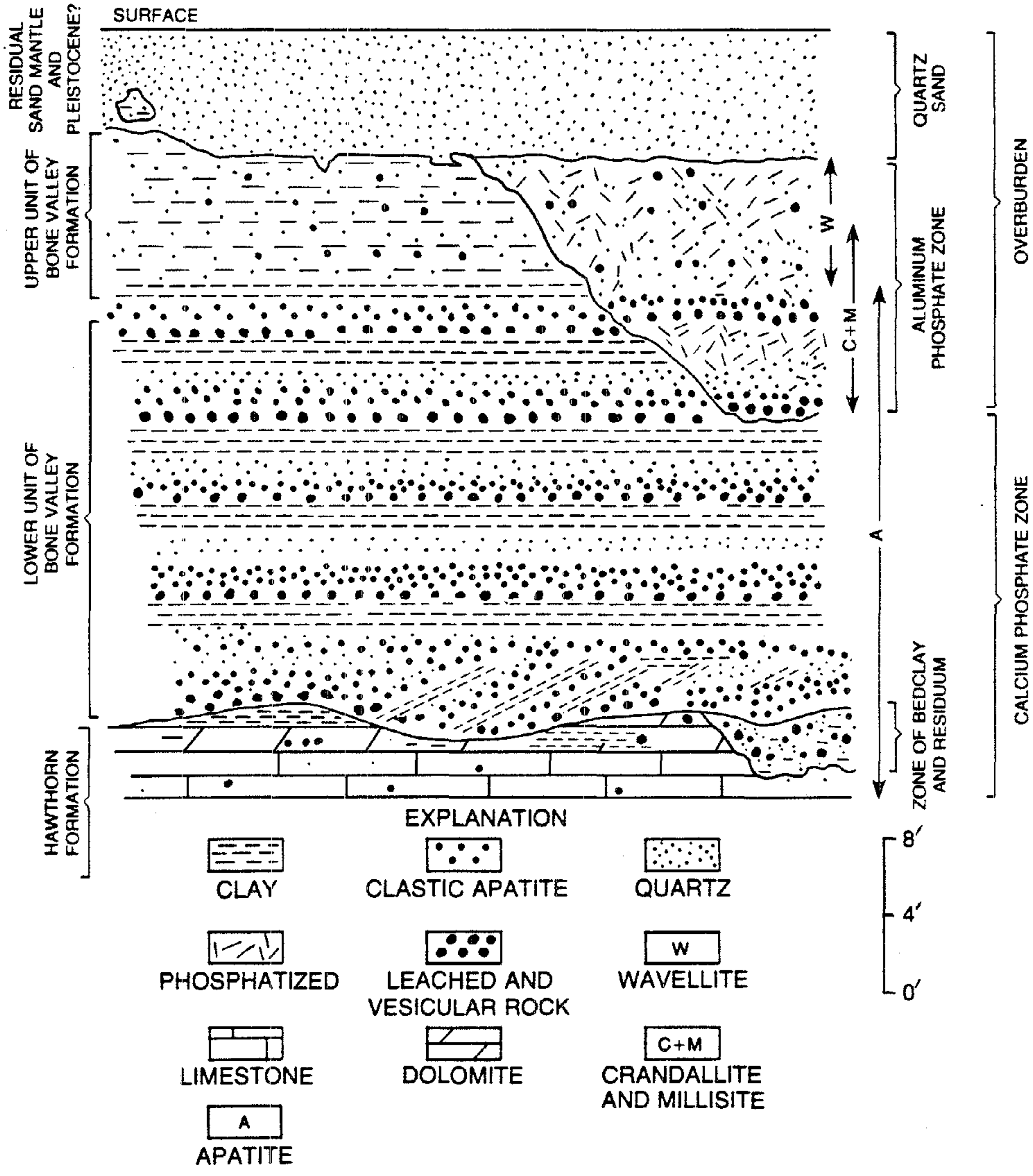


FIGURE 10-4 LITHOLOGY AND STRATIGRAPHIC RELATIONS IN THE PEBBLE PHOSPHATE STUDY AREA.

can contain significant amounts of organic matter. Also at given locations, organic mats, underlain by a thin organic mineral layer, occur at the level of previous, stable groundwater surfaces. These layers are well indurated, and may be thick enough in places to present penetration and/or removal problems. Other factors in this warm, humid climate act to form soils typical of areas having subtropical weathering as a dominant force. Topographic relief and parent material are subordinate factors.

Hydrology

Water enters the central phosphate-rich area of Florida as rainfall and groundwater inflow and is temporarily stored in streams, lakes or aquifers, while enroute to points of discharge from the area. The annual precipitation rate exceeds the annual potential evaporation rate so that there is a net recharge to the aquifers occurring during the summer season when the precipitation greatly exceeds the rate of evapotranspiration. During the drier winter months, water levels in the aquifers decline due to continued use of the water.

Since the area has a humid subtropical climate, there are only two pronounced seasons, winter and summer. The average annual rainfall ranges between 122-135 centimeters (48-53 inches), with 60 percent occurring from June through September. The maximum and minimum annual precipitation rates for the period 1915 to 1959 are approximately 180 and 90 centimeters (70 and 35 inches), respectively (1).

The corrected average annual evaporation rate as determined from pans, with a pan coefficient of 0.7, is approximately 1 meter (40 inches). Both cultivated and native vegetation areas have transpiration rates which approach the evaporation rates.

The surface drainage in much of the phosphate-rich area is poorly developed and is almost entirely of two types: basins with subsurface drainage; streams with very low hydraulic profiles which, for the most part, do not occupy well-defined valleys. Not all subbasin drainage areas are hydraulically isolated; some are physically separated with surficial sands of high permeabilities. Most surface streams flow continually due to groundwater exfiltration.

The area has a great number of lakes. Polk County, the center of the pebble phosphate industry, has nearly 500 lakes ranging in size from about 0.2 hectare (0.5 acre) to more than 14,000 hectares (35,000 acres). The largest lakes are located in the lowlands and are connected to drainage systems by means of natural or artificial channels. It is unlikely that lakes located in the lowlands infiltrate through bottoms because of significant artesian activity in these areas (2).

The lakes of the area are of significant value to the hydrology and the economy. They serve to moderate the temperatures and climates, function as reservoirs for water which might otherwise leave the area more rapidly as surface flow, and provide large supplies of water for recreation and irrigation.

Most lakes fluctuate in response to precipitation, subsurface inflow, evaporation, downward losses to underlying aquifers, surface inflow and outflow, and pumping. The quantities of water involved in these transfers are controlled by site specific factors such as climate, topography, geology and hydrologic characteristics.

In much of the pebble phosphate area there are four different aquifers. The uppermost aquifer is unconsolidated sand and clayey sand at, and just below, the land surface. These sands cover the entire area and together with the underlying coarse elastics where present, form this nonartesian aquifer. The thickness of this aquifer varies with location and generally ranges from 10 centimeters to 76 meters (4 inches to 250 feet). The clay content and hence porosity and permeability differ widely over Polk County (3). This uppermost aquifer overlies the pebble phosphate deposits. This constitutes the overburden which must be removed before the phosphate ore can be recovered by surface mining techniques.

The second uppermost aquifer is made up of the pebble phosphate deposits which underlie the surficial sands. This second aquifer is in the coarse, sandy, phosphatic gravel zones of the phosphate deposits and is confined above and below by dense clays. The piezometric surface of this confined aquifer is the second uppermost aquifer, and is composed of the pebble phosphate deposits which underlie the surficial sands. This second aquifer is in the coarse, sandy, phosphatic gravel zones of the phosphate deposits and is confined above and below by dense clays. The piezometric surface of this confined aquifer is generally 1-2 meters (3-6 feet) below the water table of the uppermost aquifer. In some areas, the pebble phosphate aquifer has high permeabilities and a great thickness. These characteristics cause the aquifer to be highly productive and to interfere with surface phosphate mining. In these areas of high productivity, the piezometric surface may be related to the nonartesian aquifer because of the high porosity of the upper confining layer.

Dewatering operations for conventional surface or for borehole slurry mining techniques will cause a localized depression in the piezometric surface. This is true for both the pebble phosphate aquifer, which is the uppermost artesian aquifer, and the overlying nonartesian aquifer. Wells in the immediate vicinity of the dewatering operation will be affected by a decline in water levels. It is not expected that this will be a significant problem since few wells currently obtain water from either pebble phosphate or the overlying nonartesian aquifers. Seawater intrusion is not expected to result from the drawdown of the groundwater table or the piezometric surface due to the distance of the mining operations from the oceans.

There is a second artesian aquifer immediately below most of the pebble phosphate deposits. This second artesian aquifer is primarily composed of the Hawthorn Formation lower sections (principally limestone) of the Bone Valley Formations. In several areas, the limestone aquifers are 3 meters (10 feet) or less in thickness, and are soft and deeply weathered. Permeabilities of such limestones are very low and significant amounts of groundwater do not occur. In those areas where the aquifer is thicker, high capacity wells have been constructed which penetrate solution cavities. Such wells typically have total depths of 9-23 meters (30-75 feet). The piezometric surface of this limestone aquifer is near or above the top of the pebble phosphate aquifer. Strip mining excavations below the pebble phosphate deposits could have significant inflow if they tap into this limestone aquifer.

The principal aquifer in the area is the Floridan Aquifer which underlies the three above-mentioned aquifers. The Floridan Aquifer is artesian, and is the source of all major public, industrial and irrigation water supplies in the region. The aquifer consists of a series of limestones ranging in age from middle Eocene to Miocene. The upper surface of the aquifer is located 9-30 meters (30-100 feet) below the ground surface depending on location. The bottom of the Floridan Aquifer, and hence its thickness, has not been completely defined. Several wells extend over 425 meters (1400 feet) below the ground surface. The existence of low permeability zones in the aquifer which restrict vertical movement of water have been reported. Recharge to the Floridan Aquifer is not restricted to areas of high water levels but occurs over the entire region through permeable overlying materials, through sinkholes and from streams and lakes. Samples of the Floridan Aquifer obtained at various locations and depths have the following properties: coefficient of transmissivity 2,000,000-6,800,000 liters/day/meter (165,000-550,000 gallons/day/foot) and coefficient of storage 0.002 to 0.007 (4). In general, low porosity and permeability values indicate that the limestones contribute relatively little water to a well and that the high capacity wells are supplied by penetration through solutional features such as tubules or small cavities.

Quality of Groundwaters

The slightly mineralized rainwater gradually dissolves some of the minerals it contacts as it percolates through the soil and the rock. The four aquifers, ranked in increasing degree of solubility are: nonartesian (uppermost), pebble phosphate (uppermost artesian); the secondary and artesian Floridan Aquifers. The range of chemical compositions of samples obtained from each of these aquifers is presented in Table 10-2. In general, all the waters are potable with intermediate levels of dissolved solids and relatively high hardnesses.

Biology

Broadly speaking, the central Florida phosphate area comprises two major natural vegetation types: southern mixed forest, which occupies a major portion of the area, and palmetto prairie, which occurs in a few localities in the southern portion of the region. Palmetto prairie, characterized by wire grass and saw palmetto, occurs only in Florida. The southern mixed forest, which is the major forest type of southeastern United States, contains as dominant species beech (not in central Florida), sweet gum, southern magnolia, slash pine (especially characteristic in Florida), loblolly pine, white oak (not in central Florida), and laurel oak.

The major vegetation types may be subdivided into nine plant communities which characterize the area under consideration. These are described briefly below:

TABLE 10-2. - Range of Concentration of Chemical Constituents in Waters from Aquifers in Florida Pebble Phosphate Region (3)

Constituent	Nonartesian Aquifer[a]		Pebble Phosphate Aquifer[a]		Secondary Artesian Aquifer[a]		Floridan Aquifer[a]	
	From	To	From	To	From	To	From	To
Temperature (°F)	72	79	73	74	72	82	71	82
pH	4.9	7.6	6.8	7.3	5.8	8.4	6.7	9.1
Hardness as $CaCO_3$	5	430	215	232	67	306	40	284
Dissolved solids	20	710	214	534	119	343	62	348
Specific conductance	16.2	924	395	737	174	724	113	599
Silica (SiO_2)		8	-		13	37	1.1	31
Total Iron (Fe)	0.4	.51	-		0.02	0.25	0.01	2.1
Calcium (Ca)	1	57	-	45	18	65	15	107
Magnesium (Mg)	.6	15	-	25	5.4	31	0.6	28
Sodium (Na)	1.5	5.4	-	5.6	5.2	11	3.0	20
Potassium (K)	0	.2	-		0.0	0.8	0.0	4.0
Bicarbonate (HCO_3)	1	205	-	252	9	337	32	353
Sulfate (SO_4)	0	22	-	1.0	0.0	31	0.0	122
Chloride (Cl)	2.5	20	-	8.0	6	26	3	32
Fluoride (F)	-	-	-		0.3	0.8	0.0	1.0
Nitrate (NO_3)	0.2	0.5	-		0.0	0.9	0.0	4.8
Phosphate (PO_4)	0.0	0.89	-	0.14	0.00	2.1	0.00	0.3
Number of Samples	9	-	2		29		109 (From 71 Wells)	

[a] Concentrations in parts per million unless otherwise noted.

1. Coastal Strand. This category includes the vegetation of beaches, dunes, sand flats, and similar situations on barrier islands and the coast of the mainland. The vegetation of the coastal strand typically exhibits distinct zonation, with sparse grasses, shrubs, and herbs in the areas close to water and denser shrubby and low forest growth farther inland.

2. Pine Flatwoods. These are open woodlands on level sites, with one or more species of pine as the dominant tree, and an understory of grasses, palmettos, shrubs, or small trees. Small hardwood stands, various kinds of cypress swamps, prairies, marshes, bay tree swamps, and ponds are often found within general areas of flatwoods. This is the most extensive vegetative association in Florida.

3. Sand Pine Scrub Forest. This association occurs mostly on excessively well-drained, deep sandy soils, usually on old coastal dunes, residual dunes, or other very sandy areas in the interior. Sand pine is the dominant tree, and the understory consists of various shrubs.

4. Forests of Longleaf Pine and Xerophytic Oaks. This association occurs primarily on well-drained uplands. Longleaf pine, turkey oak, and wiregrass, are characteristic species, although in many examples of this association the pine has been logged off or is very scarce. This vegetation has been replaced by citrus groves on thousands of hectares in central Florida.

5. Cypress Swamp Forest. This periodically flooded forest association is dominated by cypress, although hardwoods may be intermixed. Cypress swamp forests may occur as circular stands of dome-like form or long strands.

6. Swamp Forests. These are periodically flooded forest associations dominated by hardwood species which border rivers or occur in basins. They may contain bay trees, gum, and cypress zones.

7. Mangrove Swamp Forest and Coastal Marsh. These are wooded and open, herbaceous associations, respectively, associated with low-energy coastlines, usually occurring where tidal conditions vary from saline to brackish.

8. Hardwood Forests. These associations consist of mixed evergreen and deciduous hardwoods, mainly occurring on rich upland soils. Many of these associations now found in Florida are second growth and contain pines.

9. Grasslands of Prairie Type. These are open, low herbaceous associations on level ground. In some areas they form extensive treeless plains or savannas with widely scattered trees. Wet prairies occur on seasonally flooded lowlands, whereas dry prairies are found on drier sites and are seldom flooded. Many areas of this vegetative type have been converted to improved pastures.

The considerable diversity in habitat comprising the central Florida phosphate region gives rise to a great variety of wildlife. The spectrum of habitat types occurring in this area range from forested inland to the marshes and estuaries of the coast. Particularly important are the various swamp habitats, which are unique to this part of the United States.

NORTH CAROLINA PHOSPHATE PHYSICAL SETTING

Geographic Location

Coastal plain regions of the southeastern United States contain massive phosphate deposits, in outcroppings or in shallow, near-surface horizons, all part of a relatively young (Miocene to Recent) series of sedimentary beds that occur from Florida northward along the Atlantic Seaboard. Part of the North Carolina deposits in the Kidd Creek area has potential for in situ mining, such as the hydraulic borehole slurry technique. The general location of these deposits is illustrated in Figure 10-5. A more detailed location map is presented in Figure 10-6.

Nature of Deposits

Coastal plain regions of the southeastern United States contain massive phosphate deposits in outcropping or shallow, near-surface beds, all part of a relatively young (Tertiary to Recent) series of sedimentary rocks that underlie portions of the Atlantic Seaboard. Data concerning Florida phosphates are abundant. Details of the North Carolina deposits and others within the general area of the Atlantic Coastal Plain province are much less prevalent.

The Carolina deposits occur in typical Tertiary environments of this region being directly associated and/or related to the Miocene Hawthorne Formation or its time equivalents. The beds are loose to semi-consolidated accumulations of quartz sand, montmorillonite clays, and nodules of phosphate (calcium-apatite), ranging from microcystalline to gravel in size. The phosphatic strata may be essentially horizontal or gently inclined, depending upon conditions at the time of deposition.

The Carolina phosphate deposits occur in Tertiary environments being associated and/or related to sedimentation, phosphorite deposition, and other major geological features typical of this region. As a group, the sediments comprise the upper part of a monocline that trends northeast-southwest and is inclined at low angles (6-12 meters/kilometer or 15-30 feet/mile) toward the southeast. A stratigraphic cross-section is illustrated in Figure 10-7.

Phosphorites (phosphate rock deposits) range from 1-27 meters (3-90 feet) thick and are overlain by strata that range between 14-76 meters (45-250 feet) in thickness. In descending sequence, the "overburden" consists of undifferentiated surficial sand and clay deposits with lenticular shell beds, marl, sand,

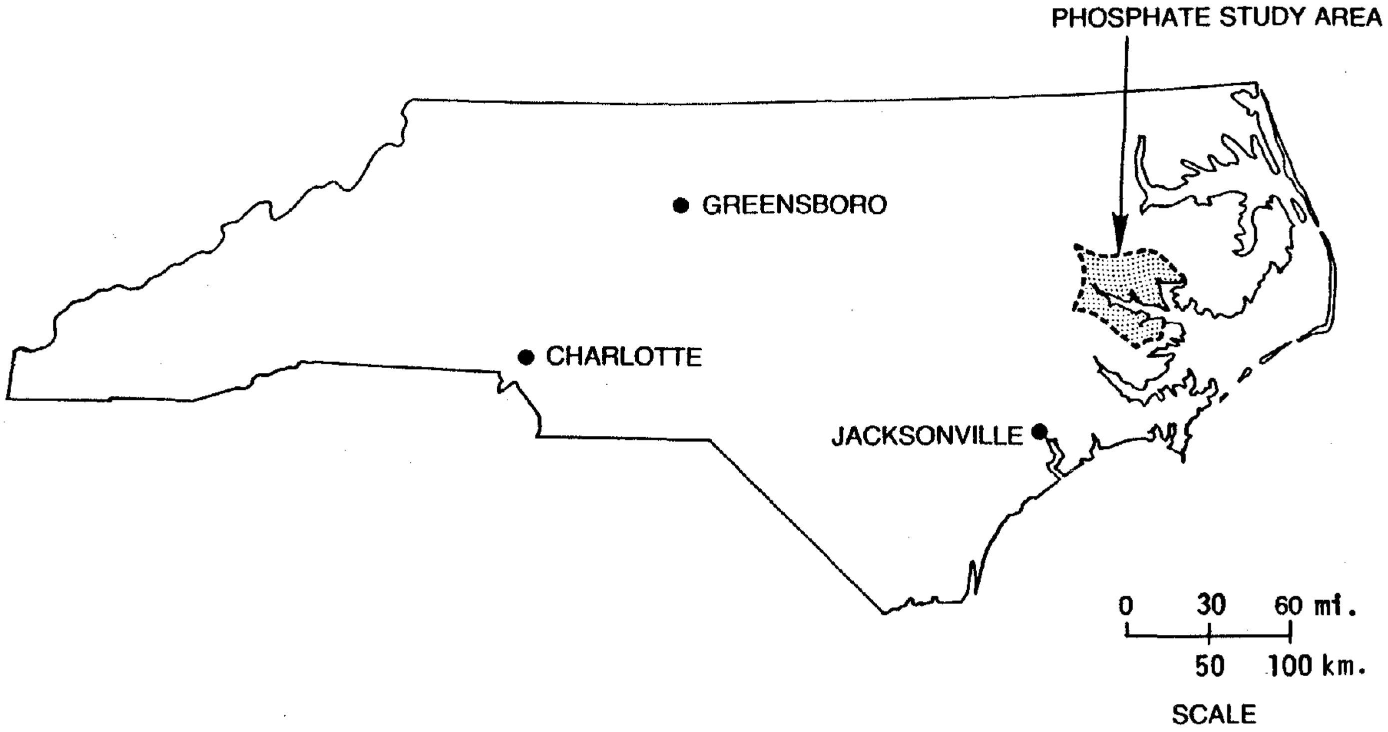


FIGURE 10-5 GENERAL LOCATION OF NORTH CAROLINA KIDD CREEK PHOSPHATE DEPOSITS.

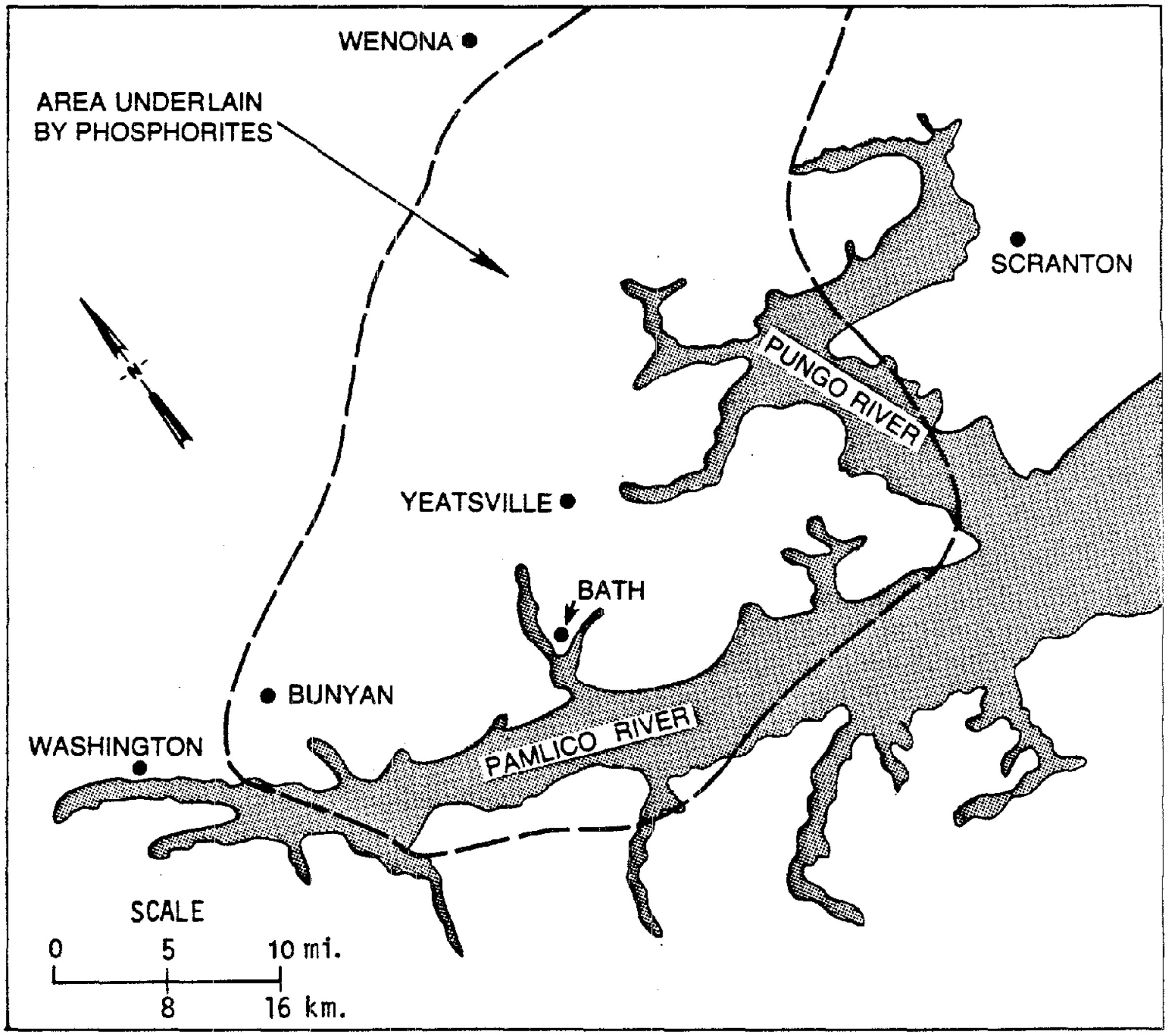


FIGURE 10-6 DETAILED MAP LOCATING COASTAL PLAIN PHOSPHATE DEPOSITS.

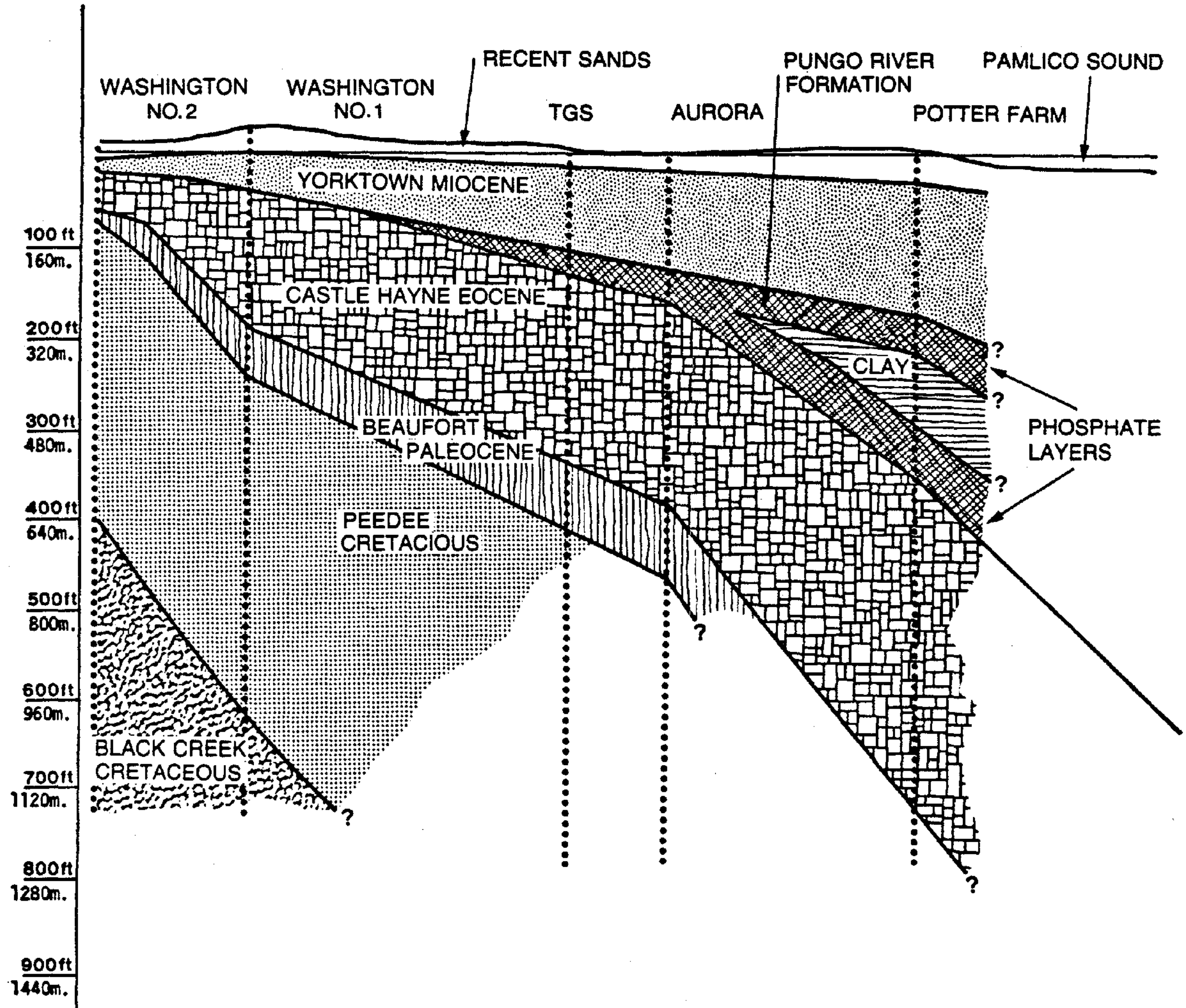


FIGURE 10-7 STRATIGRAPHIC CROSS SECTION. AFTER (6)

and clay of the Yorktown Formation (late Miocene), directly overlying the phosphate deposits. This phosphorite section commonly contains phosphatic sands and alternate layers of calcitic and dolomitic limestones composed principally of shells.

Makeup of the phosphatic sands is predominantly spherical pellets of brown collophane (phosphate) and angular quartz sand with minor amounts of phosphatic silt, and clay. Black pellets of collophane are rare. Phosphorus content (as P_2O_5) relegate the deposits to the low grade category (less than 10 percent), especially when compared with the pebble phosphates of Florida. The presence of uranium and thirteen other metals have been determined by chemical and spectrographic analyses.

Surface Conditions

Soils

North Carolina phosphate deposits occur in an area where surface environments are similar to those in Florida and other occurrences within the Atlantic Coastal Plain, with some modifications expressed by a more rigorous climate, temperate zone vegetation, and hydrological differences. Podsolization is a factor in North Carolina, but less so than in Florida and more southerly climates. The effects of topographic relief, erosion, bedrock chemistry, and related factors are minor.

Physical Setting

The landscapes of eastern North Carolina are subdued, reflecting a physical environment typical of this coastal plain area. Enormous quantities of water, occurring as both marine and fresh water varieties, have a profound effect on present conditions and activities here. Beaufort County, principal site of the North Carolina phosphate deposits, partially encircles a major reentrant of the Pamlico Sound and has marine shorelines measured in many tens of kilometers, accentuated locally by small inlets and bays.

Terrains are similar to other coastal plain areas in the southeastern United States, being part of a series of sedimentary beds that occur from Florida northward along the Atlantic Seaboard. Numerous shallow water wells, a developed but sluggish drainage system, marshlands, and the results of hydrologic studies all attest to the abundance of fresh water.

Hydrology

The coastal plain phosphate region of North Carolina has a temperate climate. Precipitation ranges between 115-127 centimeters (45-50 inches) per year depending upon topographical features and distance from the ocean. There are approximately 5-10 centimeters (2-4 inches) of snowfall per year. The annual evaporation from open water surfaces and the annual potential evapotranspiration range between 100-104 centimeters (40-42 inches) and 63-75 centimeters (25-30 inches), respectively.

It has been estimated that the average annual runoff accounts for 25-30 centimeters (10-12 inches) and the average annual groundwater recharge is approximately 25 centimeters (10 inches). The remaining 63-76 centimeters (25-30 inches) of water is returned to the atmosphere by evaporation or transpiration. The surface waters in the area flow continually throughout the year being replenished from the uppermost, nonartesian aquifer.

Figure 10-7 illustrates the location of the phosphate deposits, relative to the other deposits occurring in the phosphate-rich area.

The uppermost aquifer, which is nonartesian, consists primarily of surficial sands ranging in thickness from 15-60 meters (50-200 feet) in the area of phosphate deposits. The sands are interdispersed with layers of fine silts and clays of low permeabilities which restrict vertical movement of water through the aquifer. This nonartesian aquifer has received significant use as a water supply for municipal and industrial interests in spite of the presence of the underlying Castle Hayne Formation, which is a major artesian aquifer.

Immediately underlying the nonartesian aquifer are the pebble phosphate deposits which consist of quartz sand, silt, clay and limestone. The permeability of this unit is relatively low in those areas where substantial amounts of clay and silt are present. The low permeability sections provide the upper confining layer for the artesian Castle Hayne Aquifer. In some localities, the pebble phosphate deposits have large enough permeabilities to be considered viable aquifers for water supplies.

The Castle Hayne Aquifer is the principal artesian system in the area and the most productive in the state. It extends along the coastal area for approximately 288 kilometers (180 miles) and has a width ranging between 16-96 kilometers (10-60 miles). The natural movement of water in the Aquifer is generally west to east. This flow direction transports water from the higher elevation land areas to the Atlantic Ocean. The Aquifer gradually becomes saline as it extends out under the ocean.

It has been reported that the upper elevation of the Aquifer ranges from about sea level in the western part of the area, to about 180 kilometers (600 feet) below sea level in the eastern part. The thickness increases from 45 meters (150 feet) in the western part of the area to about 210 meters (700 feet) in the eastern part. Transmissivities have been reported to range between 620,000-3,100,000 liters/day/meter (50,000-250,000 gallons/day/foot).

Dry open pit mining of the phosphate ore in the deposits immediately overlying the artesian Castle Hayne Aquifer requires that the piezometric pressure of the artesian aquifer be reduced. This can be accomplished by massive withdrawal from the Castle Hayne Formation, which potentially affects local wells and locations of seawater/freshwater interfaces. A 1965 mining activity, pumping 246 x 106 liters/day (65 mgd) from the aquifer created immediate well and pump problems in an area of several hundred square kilometers (square miles). It was necessary for the mining company to bear pump replacement and/or well construction costs for about 800 wells in the affected area (6).

A potentially greater problem, in terms of effects on use of water, is that resulting from seawater intrusion. Lowering the piezometric surface can cause seawater encroachment from three sources: 1) horizontal movement of saline water, presently located in the eastern region of the aquifer; 2) upward movement of saline water which occurs naturally at the lower levels of the aquifer; 3) downward leakage of saline water from overlying surface salt water bodies. Borehole slurry mining could cause similar effects if extensive dewatering operations are required.

The water in the Castle Hayne Aquifer is of generally good quality, except where residual or "fossil" seawater has not been completely flushed from the aquifer over recent geological periods (6). The water generally has TDS values less than 300 to 500 mg/l and is considered moderately hard. Hydrogen sulfide has occurred in objectionable amounts throughout the eastern sections of the phosphate-bearing area. The chloride concentration is typically low in the western part of the aquifer, and gradually increases to high values in the eastern part of the aquifer where incomplete flushing of "fossil" seawater has occurred.

Flora and Fauna

The North Carolina phosphate area is located within two Coastal Plain physiographic regions in the eastern portion of the state. The Outer Coastal Plain, or Tidewater Region, lies next to the ocean. It is extremely flat, averages less than 6 meters (20 feet) above sea level, and contains large swamps and lakes, indicative of poor drainage. The Inner Coastal Plain lies farther inland, is higher in elevation, and is more dessicated and better drained. Major streams in the study area include the Cape Fear, New, Neuse, and Tar Pamlico.

North Carolina embraces a great variety of plant species and community types. Inland from the beach and dune areas, forests are the climax vegetation in virtually all of North Carolina. Coastal plant community types include beaches and dunes, saltwater marshes and freshwater marshes. The beach and dune communities close to the ocean occur under harsh environmental conditions of windblown sands, storms, infertile soils, and occasional inundations of salt water. The dunes are dominated by perennial grasses such as sea oats and American beach grass. Other common species include beach pea, crotin, dune elder, broomsedge, spurge, and primrose.

Progressing inland, maritime shrub thickets and maritime forests are encountered. Common shrub species include yaupon, wax myrtle, and red cedar. In areas where the maritime forest is near the ocean, the trees may be small and gnarled. Further inland a well-developed forest occurs. Common species include live oak, beech, pines, hickory, and hophornbeam.

In protected areas where flooding waters are saline or brackish, salt marshes occur. Common constituents include smooth cordgrass, black needlerush, and saltgrass. In areas where peaty soils are continually waterlogged with fresh to slightly brackish water, freshwater marshes occur. Typical member species include bulrush, cattail, sawgrass, and big cordgrass.

The plant communities of the Coastal Plain inland from the beaches and dune communities are characterized by a wide variety of plant species. The occurrence and distribution of these communities is determined largely by depth of the water table, soil texture, and fire.

Swamp forests occur along the rivers of the Coastal Plain. Gum-cypress swamps are best developed on the floodplains of backwater rivers and on flats associated with upland drainage channels. Cypress occurs in the wettest portions of such swamps where the soil rarely, if ever, dries out. Tupelo gum and swamp gum dominate the slightly drier sites. Floodplains that are flooded only by periodic freshwater floods during the heavy rains of winter and early spring support a hardwood swamp forest. Common species include willow oak, water oak, cherryback oak, sweet gum, oak, sycamore, river birch, and elm.

Another wetland vegetation type is the pocosin, or shrub bog, a community consisting of dense groupings of evergreen shrubs with scattered pond pine growing on highly organic peat soils. Pocosins are very susceptible to fire and often burn extensively during dry periods. It is thought that some pocosins may have originated as a result of natural burning of gum-cypress swamps. Pond pine is the only tree of any importance and is usually scattered in rather open stands. Sweet bay, red bay, and loblolly bay often occur as large shrubs or small trees. Other common shrubs are ti-ti, gallberry, fetter bush, honey cup, cane, and sweet pepperbush.

Pine flatwoods, or savanna, communities occur on gently sloping sand ridges and on extensive poorly-drained flatlands. The major trees are longleaf pine and pond pine. Their occurrence is determined by soil texture and drainage. Shrubs vary considerably in their abundance, appearing commonly in some places and rarely, or not at all, in others. Gallberry, wax myrtle, and sweet bay are the most common. On well-drained soils, wire grass is the common savanna grass. In wetter areas, wire grass occurs with asters, sunflowers, goldencock, lillies, pitcher plants, and orchids. The unique Venus's-flytrap occurs in grassy, poorly-drained areas, that have been recently burned. Repeated fires perpetuate grasses at the expense of shrubs, and permit the savanna to persist.

The longleaf pine-turkey oak-wire grass community occurs on deep, well-drained coarse-sand soils. This community has a distinct appearance, usually consisting of an open layer of scattered, large longleaf pines and a lower layer of scrub oaks, primarily turkey oak, bluejack oak, blackjack oak, and scrubby post oak. Virtually all herbs show adaptation to the extreme dryness of the habitat, as do many of the woody species.

Oak-hickory forests are the final vegetational community found in the Coastal Plains. Since most of the sites where this community originally existed are desirable for farming, much of the forested lands have been cleared. On moist, but well-drained sites, white oak, southern red oak, water oak, willow oak, post oak, swamp chestnut oak, hickories, sweet gum, tulip poplar, beech, black gum, red maple, and pines are the most common tree constituents. On drier sites which grade into the longleaf pine community, blackjack, post, and turkey oaks are the dominants along with hickory and pine.

Due to the great diversity of habitats the Coastal Plain supports an extremely rich wildlife population. A wide number of game birds and animals are found throughout the area. Deer and wild turkey populations vary in density throughout the area. Populations of bobwhite, quail, mourning dove, various squirrels and rabbits, raccoon, opposum, skunk, mink, and fox also occur.

Description of a Typical Minable Ore Body in North Carolina

To be suitable for in situ borehole slurry mining, a phosphate deposit must meet the following criteria: 1) the phosphate-bearing bed should be thick, preferably 8 meters (25 feet) or greater; 2) the grade of ore should average approximately 18 percent P_2O_5 or greater; 3) the ore should be overlain by a competent layer of rock which would be self-supporting over short distances (borehole diameters) and for a long enough period to allow backfilling after excavation of the phosphate. The pebble phosphate deposits which are currently being worked are a loosely cemented sandy member and are thus suitable for jet slurrying. In fact, current production technology uses hydraulic monitors to slurry the ore for transportation from the pit to the benefication plant.

The North Carolina phosphate deposits are buried relatively deep. This will tend to limit open pit development and provides a unique opportunity for borehole slurry mining. This is particularly true since the phosphate beds are overlain by the relatively competent rock of the Yorktown Formation as shown in Figure 10-7.

Reserves of 18 percent P_2O_5 ore are listed as high as 10 billion tons and a processing rate for an economically viable complex might be 25,000 tons of ore a day, yielding over 8,000 tons of concentrate per day at a tail:P_2O_5 ratio of 3 to 1. Such a plant might require a sulfuric acid facility capable of 3,000 tons of acid production per day. This is as large as any sulfuric acid plant currently in existence.

Considering the nature of the deposits, the North Carolina phosphate area appears to be more suitable than the Florida phosphate area for borehole slurry mining.

GENERAL BOREHOLE (SLURRY) MINING OPERATIONS:
FLORIDA AND NORTH CAROLINA

The recovery of phosphate products from phosphate ores requires a complex processing facility which is not mobile. It is necessary for phosphate ore to be transported to the processing plant and for waste material to be disposed of in the vicinity of the processing plant or transported back to the boreholes. The relative locations of the mining areas and the processing facility are depicted in Figure 10-8. Ore would be transported to the processing plant as a slurry through portable pipelines. One section of the mining area could be in the mining phase while the boreholes in a previously mined section are undergoing backfilling. Portable pipelines would not be moved until backfilling is completed.

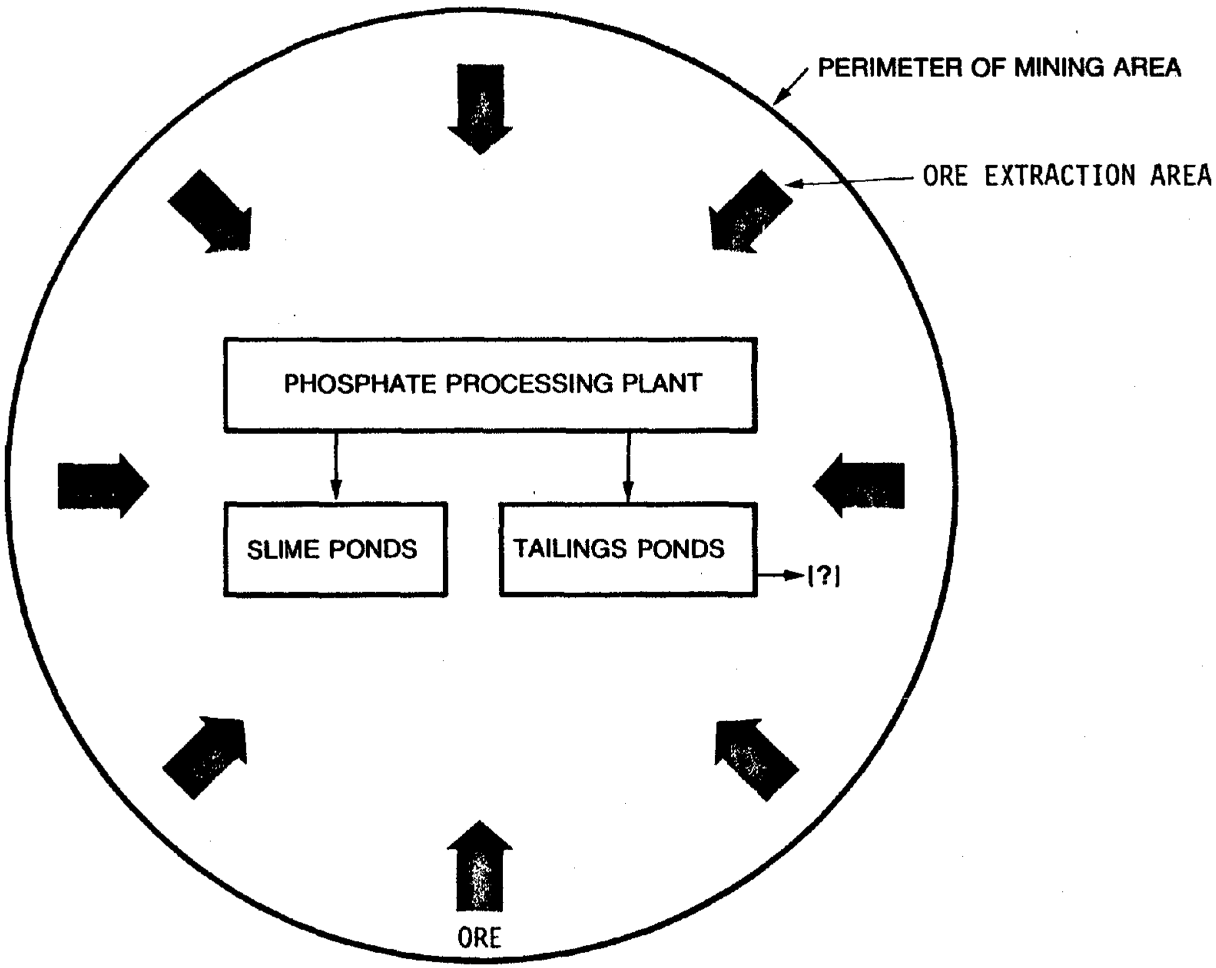


FIGURE 10-8 RELATIVE LOCATIONS OF PHOSPHATE ORE MINES AND PROCESSING FACILITIES

Site Preparation

Prior to drilling boreholes, the primary site preparation activity involves providing access. Roads through densely wooded areas must be provided to enable drilling equipment to reach the sites. The relatively small borehole diameter achievable by existing equipment necessitates drilling at 23 or 46-meter (75 or 150-foot) centers throughout the ore area. The size of the equipment and the need for maneuverability will require clearing between 35 and 100 percent of the mined areas.

In cold climates it will be necessary to bury slurry pipeline to prevent freezing. Frost penetration in the coastal regions of North Carolina are approximately 30-60 centimeters (1-2 feet); snowfall typically ranges between 5-10 centimeters (2-4 inches) per year, depending on specific location. Even if a site-specific pre-mining study indicates that pipelines can be placed on the surface (a certainty in Florida), access over the pipes will have to be provided. This necessitates construction of earth berms or underground piping.

BOREHOLE MINING TECHNIQUES: FLORIDA AND NORTH CAROLINA

A typical operation could require drilling of a series of holes to and through the phosphate horizon. The holes might be 45-60 centimeters (18-24 inches) in diameter, cased to the ore horizon. The hole would extend to 1.8 meters (6 feet) below the bottom of the ore to accommodate the equipment, including the slurry pump. The part of the hole in ore would be uncased. Typical borehole slurry mining equipment is illustrated in Figure 9-1.

Ore Extraction

The general technique ore extraction and the currently available equipment have been described in Chapter 9.

Processing Plant

The phosphate processing plant is usually a complex operation of very high capital cost and a multiplicity of steps depending upon the final product or products produced. Ore recovered by the hydraulic borehole method could be concentrated by a conventional phosphate ore process plant such as that illustrated in Figure 10-9. Essentially, the ore passes through a washer section to eliminate slimes, a feed preparation section to prepare a coarse product, a flotation section to reduce impurities, a phosphoric acid manufacturing facility, a granular triple superphosphate section, and a granular ammoniated phosphate manufacturing facility. As part of the phosphoric acid manufacture, sulfuric acid either has to be produced on site (preferable) or shipped to the plant in large quantities. One existing phosphate plant in North Carolina produces 3,000 TPD of sulfuric acid for its own use in making phosphoric acid.

The typical plant will occupy approximately 40-80 hectares (100-200 acres), depending on land availability and the capacity of the processing plant.

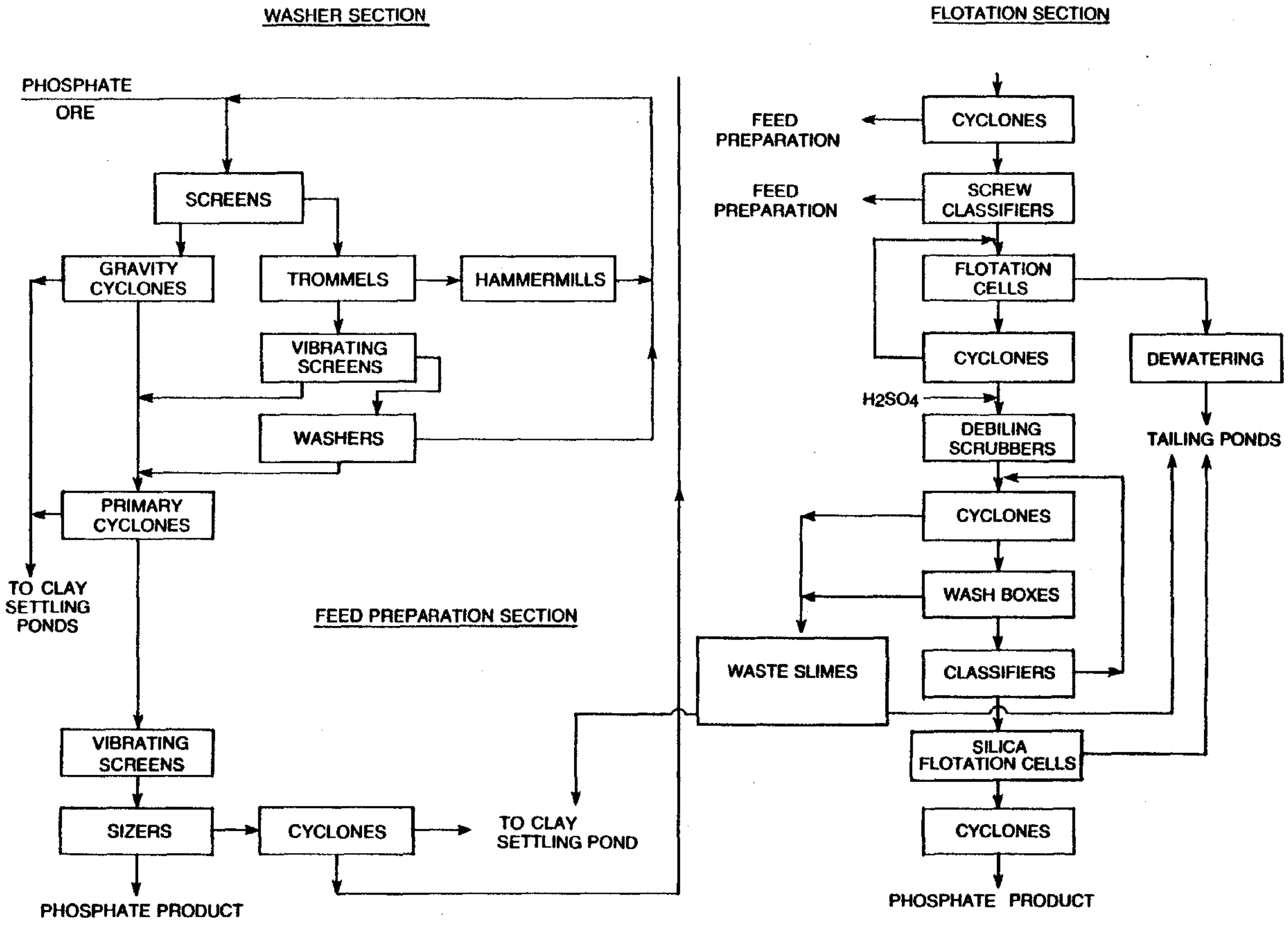


FIGURE 10-9 CONVENTIONAL PHOSPHATE ORE PROCESSING PLANT.

CHAPTER 10 REFERENCES

1. Cherry, R.N., J.W. Stewart, and J.A. Mann. General Hydrology of the Middle Gulf Area, Florida. Florida Bureau of Geology Report of Investigations No. 56, 1970.

2. Heath, R.C. Surface-Water Resources of Polk County, Florida. Florida Geological Survey Information Circular 25, 1961.

3. Stewart, H.G. Ground Water Resources of Polk County. Florida Geological Survey Report of Investigations No. 44, 1966.

4. Peek, H.M. Ground Water Resources of Manatee County, Florida. Florida Geological Survey Report of Investigations No. 18, 1958.

5. Engineering and Mining Journal. Richard Hoppe. From Matrix to Fertilizer: Florida's Phosphate Industry Girds to Produce over 50 Million TPY, September 1976, p. 81-87.

6. North Carolina Department of Natural and Economic Resources. "Status Report on Groundwater Conditions in Capacity Use Area No. 1 Central Coastal Plain, North Carolina." Groundwater Bulletin No. 21, 1974.

7. Sellards, E.H. The Pebble Phosphate Districts of Florida, Florida State Geological Survey, Seventh Annual Report, Tallahassee, Florida, 1915.

CHAPTER 11

HYDRAULIC BOREHOLE SLURRY MINING OF URANIUM

Any ore which can be eroded hydraulically is amenable to extraction by the borehole slurry technique. The principal uranium ores which can be mined by this method are the uraniferous sandstones.

Both the central Wyoming and south Texas physical settings for sandstone uranium ores amenable to in situ solution leaching were discussed in Chapter 6 and reference is made to that section, which applies equally well to areas mined by hydraulic borehole slurry techniques.

Both the Wyoming and Texas areas will be discussed simultaneously since the uranium occurrences are very similar and no differences in borehole slurry techniques applicable to each area have been identified. It is possible that large-scale pilot or commercial operations will modify the basic borehole slurry techniques for optimum ore extraction at each site. The techniques discussed also could be applied under suitable conditions in Colorado Plateau sandstone uranium deposits in such states as Colorado, Utah, Arizona, and New Mexico.

DESCRIPTION OF A TYPICAL MINABLE ORE BODY

The typical uranium ore bodies amenable to recovery by hydraulic borehole techniques are the "roll front" deposits described in detail in Chapter 6 of this report. Application of hydraulic slurry techniques requires that the ore deposit have certain characteristics. In general, while most uranium bearing sandstones are minable by hydraulic slurry technique, those which are most easily slurried by hydraulic jetting will be the most profitable to develop. There is a technical and economic limit to the maximum depth of a borehole below the surface.

Maximum Ore Depth

At present time the maximum depth of a borehole appears to be limited only by the technical viability of the slurry pumping equipment. Assuming that the technical problems related to slurry pumping can be solved in the future, the maximum minable depth of a borehole will only be limited by the value of the product, the uranium content of the ore, the cost of uranium extraction from the recovered ore and the resistance of the ore to hydraulic jet slurification. A deep deposit which is easily slurried might be more amenable to borehole slurry techniques than a shallow deposit which is resistant to hydraulic jetting. Figure 11-1 illustrates the effects of ore strength and borehole depth on mining costs per unit of ore brought to the surface. No attempt has been made to evaluate numerical values of depths or costs in Figure 11-1 because of the lack of substantiated data on the variation of operational costs with borehole depth. The entire technology of hydraulic borehole slurry mining is in such an infancy that costs will change substantially as new equipment is developed. Any cost or maximum depth values presented would be immediately outdated due to the infancy of the technique.

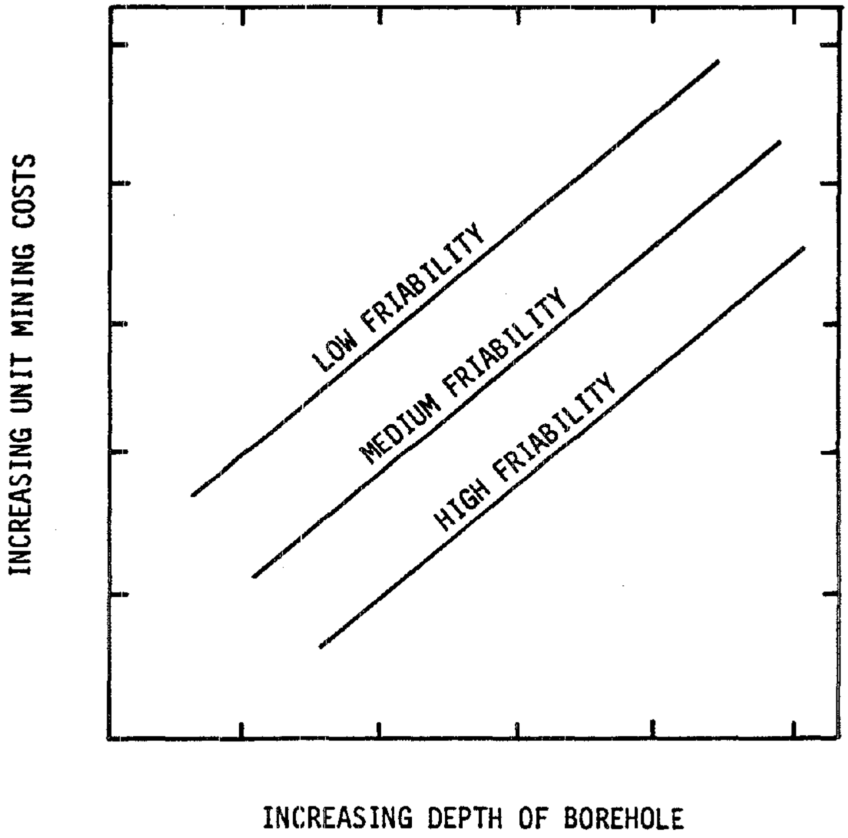


FIGURE 11-1 THE GENERAL EFFECTS OF DEPTH TO THE BOREHOLE AND THE RESISTANCE OF THE ORE TO HYDRAULIC SLURRIFICATION ON THE UNIT MINING COSTS

The minimum depth of a borehole is technically limited by the structural strength of the overburden to prevent collapse of the surface. There is also an economic minimum depth at which point it is more cost effective to recover the ore by open pit techniques.

It has been estimated that sandstone ores with uranium contents of 0.06 percent could be economically mined by the borehole slurry method at depths up to 61 meters (200 feet) based on a uranium market price of $92/Kg ($42/lb).

Ore Body Shapes/Sizes

The borehole slurry mining process is technically capable of recovering ores from any shape or size deposit amenable to hydraulic erosion (1). Not all sizes and shapes may be economical, however. The limited data currently available appears to indicate that borehole slurry mining will be more expensive than in situ solution leaching. This economic factor will probably limit the borehole slurry technique to those deposits where other factors change the economics. For example, it is possible that future demonstration studies will confirm that the borehole technique has little potential for groundwater pollution and thus an extensive environmental monitoring program is not required. Environmental monitoring and establishment of baseline qualities are required for solution leaching of any size ore body.

Groundwater

The majority of uranium-bearing sandstones occur below the groundwater table. This is consistent with the roll-front formation theory. The borehole slurry technique requires that the borehole be drained during the extraction operation. The technique can be applied to suitable deposits located above or below the groundwater table providing that boreholes below the groundwater table can be temporarily dewatered.

From a technical viewpoint, the potential for groundwater contamination by hydraulic borehole slurry mining is less than by in situ solution leaching. The fluids for the borehole operation are not selected for solubilization of uranium. Assuming that future environmental monitoring requirements are less extensive (and costly) for the borehole slurry technique, it would be more cost effective to mine small or long, narrow deposits by the borehole technique than by in situ leaching.

Potential groundwater problems which could limit site selection have been discussed in Chapter 9. These potential problems are site specific and will require evaluation on a case-by-case basis.

MINING TECHNIQUES

Ore Body Preparation and Mining

This section only contains a description of those mining aspects which are unique to borehole slurry mining of uranium. A description of equipment currently available or proposed for borehole slurry mining is presented in Chapter 9 and is not repeated in this section.

The preparation of uranium ore bodies for borehole slurry mining is in many respects similar to that required for ore body preparation for in situ leaching. At any rate, a pattern of holes large enough to accommodate the jet cutting equipment and slurry pump is required.

A possible development in borehole slurry mining is the use of lixiviant rather than native water to jet and slurry uranium ore, thus obtaining a "head start" on leaching and reducing the required plant capacity of the surface facility. Carbonate leach solutions would be compatible with most equipment materials while acidic lixiviants would require use of corrosion resistant materials for borehole mining equipment.

A major disadvantage of using lixiviants for hydraulic slurrification is that groundwater monitoring requirements would be greatly increased. The possibility of the escape of present lixiviants would require the establishment of a rather extensive groundwater monitoring program and its associated high costs. Another consideration, which must be addressed, is that the addition of foreign material to the hydraulic slurry water could result in the entire operation coming under UIC regulations of the Safe Drinking Water Act.

At the present time it would appear that the use of a lixiviant with borehole slurry mining would reduce the claimed regulatory advantages of the mining technique. Figure 9-1 presents a schematic diagram of the borehole slurry operation applicable for the mining of uranium bearing sandstones. Figure 11-2 presents a simplified flowsheet illustrating the initial slurry processing required. Slurry from the boreholes is classified into two and possibly three streams depending upon the nature of the ore. The classifier will segregate the liquid stage, which is returned to the borehole for further hydraulic slurrying, and a concentrated ore which is then processed for the recovery of uranium. It is possible that the classifier can differentiate between the uranium-bearing material and an inert material which may be lime or quartz. The waste material from the conventional beneficiation process is then sent to a classifier or directly to storage/disposal ponds. A classifier may have the advantage of reducing the volume of fine materials which must be consolidated before their disposal. The coarse solids are stored in a pond and then used to backfill previously mined boreholes.

It has been estimated that borehole slurry mining could remove as much as 75 to 90 percent of ore in a given area depending on characteristics of the ore and the mining operations. This uranium recovery is in the same range as that obtained by in situ leaching.

Uranium Recovery From Borehole Mining Slurries

Conventional uranium mills use crushing and grinding operations. In borehole slurry mining these operations are accomplished largely hydraulically by the underground jet, and it may be sufficient to recover the uranium directly

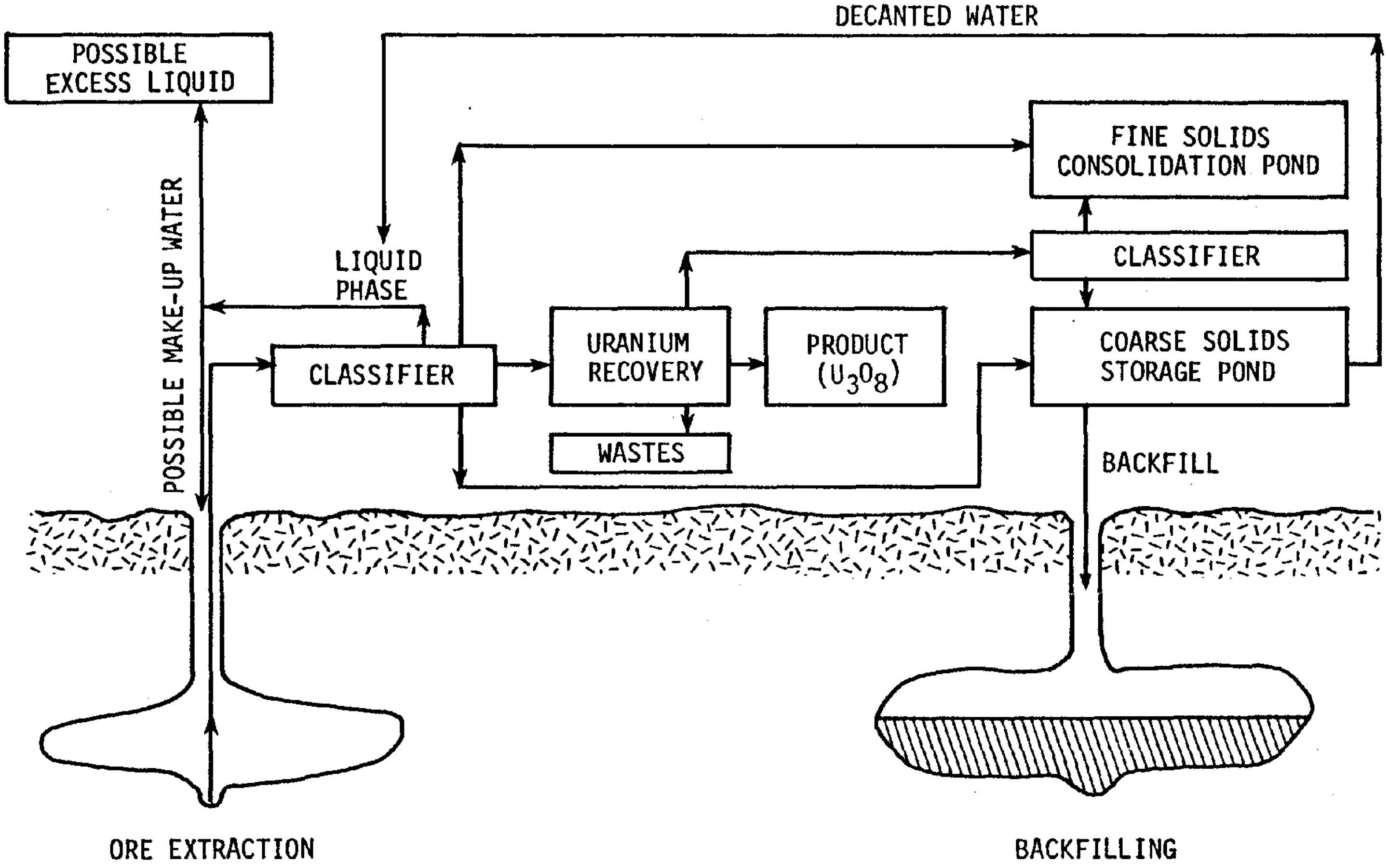


FIGURE 11-2 SOLIDS HANDLING FOR HYDRAULIC BOREHOLE (SLURRY) MINING OF URANIUM SANDSTONES

from a concentrated slurry. A simplified flowsheet of conventional uranium processing is presented in Figure 11-3. Note that not all of the operations illustrated in Figure 11-3 are required for processing of ores from borehole slurry mines.

An in-depth analysis of the liquid streams generated by the beneficiation processes is beyond the scope of this study. These waste streams are typical of those from any conventional mill operation and could be disposed of by proven techniques. Some modifications in the disposal operations may be required due to the fact that the majority of the tailings are returned to the borehole for backfilling.

It is neither technically nor environmentally feasible to inject the liquid processing wastes into the backfilled boreholes in view of the lack of containment and possible communication with surrounding aquifers. Adverse environmental effects due to the disposal of these liquid wastes can, however, be minimized or eliminated by employment of conventional techniques such as deepwell injection, evaporation in lined ponds or concentration followed by evaporation in lined ponds.

The selection of either acid or alkaline as the leaching reagent can directly affect the environment depending on the composition of the ore and the technique used for disposal of waste liquids. From the processing viewpoint, the circuits are quite similar except that the alkaline circuit incorporates regeneration of the reagent with maximum recycle of solutions. Many more impurities are solubilized by acid lixiviants and it is necessary to provide a greater bleed off for prevention of lixiviant contamination. If excess water is pumped from a borehole and the classification operation, preceding the uranium recovery process, is unable to separate the uranium-bearing fines from the water stream, it will be necessary to process large quantities of water.

Sand-Slime Separation

An integral part of most uranium mill circuits, particularly in acid leach mills, is a sand-slime separation. This separation is accomplished by the classifiers shown in Figure 11-2. This separation produces a clean-washed sand that is stripped of uranium values and should be low in radioactive constituents. Potential toxic materials are usually found in the slime fraction. The clean-washed sands are very suitable for borehole backfill. The slimes, after separation from the pregnant liquor, are hygroscopic, exceedingly difficult to settle, and contain a large proportion of the total radioactivity. A major environmental problem associated with borehole slurry mining is disposal of or contamination by these radioactive slimes, which tend to blow away with the wind when dry and which are probably unsuitable for mine backfill due to extremely low dewatering rates and their potential for contamination of adjacent aquifers.

Disposal of the slime fines could be more difficult than regular uranium tailings disposal because of the differences in particle size distributions. The slime fines will require much longer periods to dewater than the conventional tailings.

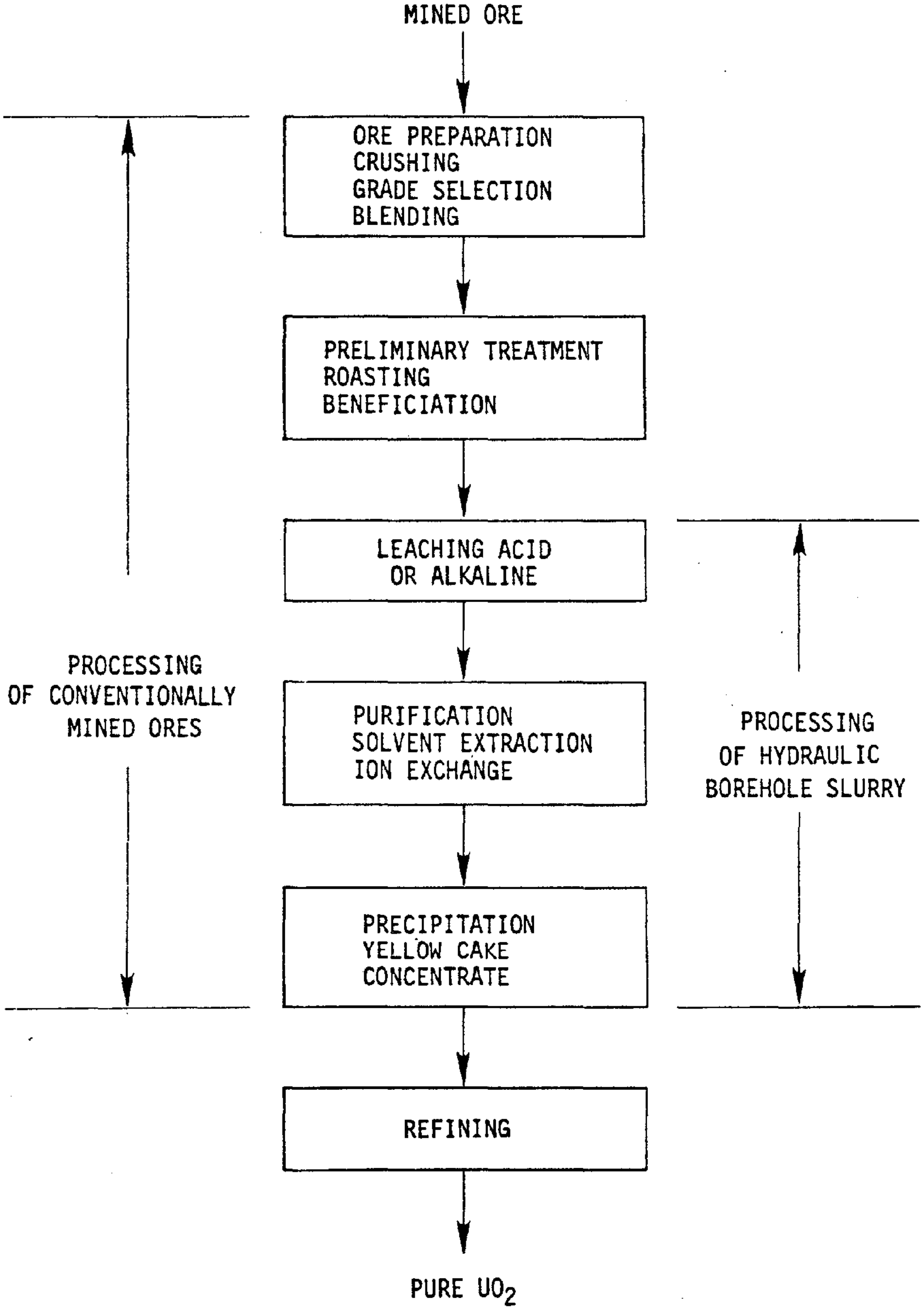


FIGURE 11-3 COMPARISON OF MILL PROCESSING FOR CONVENTIONALLY MINED AND HYDRAULIC BOREHOLE (SLURRY) MINED URANIUM ORES.

It might be possible that a fraction of the fines could be combined with the coarse sand and the mixture backfilled in the boreholes. The entire area of slime disposal requires study for identification of the environmentally acceptable disposal methods.

Waste Disposal

Waste disposal of tailings produced by borehole slurry mining of uranium could present significant problems operationally as well as environmentally. It might be economically and technically unfeasible to return all of the processed material back into the borehole because: 1) the fine solids in the processed material which may cause significant subsidence, if reinjected, cannot be economically processed (dewatered) prior to injection; 2) it is likely that the tailings will contain the major portion of the radioactive waste materials, which require special disposal techniques, such as those currently utilized with conventional uranium milling processes; 3) the beneficiation process may have adversely altered or added to the physical, chemical, or radiological character of the tailings in such a manner so as to impair or prevent the economic backfilling of a significant portion of the tailings. Because the tailings are not amenable to total disposal by backfilling, there will be secondary or indirect impacts associated with tailings disposal due to the additional handling and processing required by the "expanded" waste. Environmental factors such as air, noise, energy, and land form will be adversely impacted.

The volume of wastewaters generated by slurry mining will be greatly influenced by the hydraulic characteristics of the underlying aquifers and by the nature of the beneficiation process utilized at the project site. There are two categories of wastewaters in slurry mining, those generated by the slurrification of the ore and those generated by the mineral beneficiation process. The disposal of these wastewaters will depend upon the volume and degree of pollution. Environmental considerations include an analysis and evaluation of the quantitative impact of these wastewaters on the disposal sites. Physical impacts include clogging of the geologic strata by fine solids present in the wastewater. Chemical quality and contamination of receiving bodies by the process wastewaters is possible and radioactive pollutants may be introduced to receiving waters by waste process waters.

SITE CLOSURES

Upon completion of mining operations, it will be necessary to restore the mine site to an environmentally acceptable condition. The nature of the borehole slurry mining technique causes it to be significantly less difficult to restore that conventional open pit technique. The primary aspects of closure are: 1) backfilling of tailings in boreholes; 2) sealing of the surface tailing ponds which contain radioactive wastes; 3) sealing of the boreholes to prevent communication between any potable water aquifers and zones of poor quality water; 4) surface restoration.

The use of the borehole for tailings disposal has been described in the preceding section. The surface tailings ponds will contain small concentrations of radium which generates radon gas. Tailings ponds containing radium are typical of uranium mill sites and closure procedures have been developed. Suitable tailings pond closure techniques are described in Chapter 13. Boreholes should be sealed with concrete or other suitable material to prevent any contamination of aquifers overlying the ore deposit. Sealing techniques have been described in Chapter 9 for boreholes and in Chapter 6 for in situ leaching wells. Surface restoration consists of removal of pipelines, revegetation of access roads and drilling sites, removal of processing facilities and removal of fences used to control access during mining operations, followed by minor landscaping and reseeding for vegetative cover.

ENVIRONMENTAL ASSESSMENT

Hydraulic borehole uranium mining could have significant impacts upon the environment, depending upon site-specific characteristics. A site-specific assessment of the possible impacts is an essential step in the evaluation process and must include consideration of the potential impact on larger physical, human-social, and economic environmental systems as well as the impacts in the vicinity of the project sites.

Such a detailed analysis is beyond the scope of this study, which addresses those potential impacts which are unique or characteristic of the borehole slurry mining techniques. Environmental evaluations of "typical" borehole mining sites in Texas and Wyoming are discussed in this section and summarized in a matrix format in Appendix A.

Direct actions resulting from implementation of hydraulic borehole mining, which may cause environmental impact upon the existing regime, are alteration of groundcover, groundwater and surface water hydrology, levels of noise, light and odor, general disturbance of the natural wildlife setting, loss of land to tailings ponds, and subsidence.

Water Environment

Borehole slurry mining of uranium can affect both the surface and subsurface water environments. The mining process does not necessarily utilize any chemicals, toxic or otherwise, which come in contact with ore body. There is however the possibility of solubilizing toxic substances in the ore which could be transmitted into adjacent formations. Solubilization would result from changes in solution pH and/or oxidation potential values. The aeration due to the jetting action could change a water from a reducing state to an oxidizing state. This solubilization process is described in detail in Chapter 6.

The magnitude of potential adverse impacts resulting from solubilization of toxic substances (if it does occur) depends on additional factors such as the proximity of potable water aquifers, the velocity of the groundwater movement, the quality of original groundwaters and the total quantity of water available in the region. While the groundwater hydrological scenarios described in Chapter 9 could result in the transport of some objectionable substances into surrounding aquifers, the potential for this transport is small. Recovery of the uranium ore by surface, underground or in situ leaching would have equal or greater potential for contamination of surrounding groundwaters.

The borehole slurry technique would have minimal effects on the groundwater quality in semi-acid regions such as Wyoming and southwest Texas. A primary impact would be an increase in the consumptive use of water in water-short areas such as Wyoming. Borehole slurry mining does not inherently consume more water than other techniques, however the potential is there, depending upon conditions. Obviously, an increase in mining activity by any extraction technique will increase consumptive water use in the developed region.

In general, the surface waters of a region would not be affected significantly by borehole mining. It is possible that negative impacts could result from accidental spills of processing solutions and from regional increased water consumptive use.

Land Transformation and Construction

Land transformation and construction activities associated with borehole mining pertain to construction of pipelines and boreholes, processing facilities, roads, cut and fill, spoil deposition and generation of noise and dust.

The majority of adverse environmental impacts would only be temporary in that they would be eliminated by proper restoration. The only long term effects would be: 1) the potential for subsidence which might restrict future construction of structures on the mined area; 2) the presence of buried uranium tailings which generate radon gas. Subsidence is not unique to uranium mining by the borehole method and has been discussed in Chapter 9. The radon gas emission rate to the environment can be controlled by proper sealing of the waste tailing ponds. The radium, which is backfilled in the borehole, does not present environmental problems if the access shaft is properly sealed. All danger associated with radioactive waste materials can be eliminated though employment of proper closure techniques.

Accidents

Mining operation activities are subject to the occurrence of accidents. The probability, extent and severity of damage suffered in such events are directly related to the complexity of the operation and maintenance of facilities. Possible accidents include explosions, spills and leaks, and operational failures. Subject to risk are public and private property, and the health, safety and life of persons inside and outside the premises of the project site.

The potential for accidents and their detrimental consequences are significantly less for borehole slurry mining than for the conventional methods of surface and underground mining. These factors are significant since underground mining is the most dangerous occupation in the United States.

CONCLUSIONS

Borehole slurry mining of uranium does not have any inherent adverse effects on the environment which preclude its use. Proper measures such as tailings control and borehole closure can be employed which minimize environmental impacts. Borehole slurry mining may enable recovery of uranium from deposits which are economically undevelopable by conventional methods at the present time.

CHAPTER 11 REFERENCES

1. Savanick, G.A. Borehole Mining of Shallow Uranium Deposits. Presented at the In Situ Leaching and Borehole Mining of Uranium Seminar, Sponsored by U.S. Dept. of Interior, Bureau of Mines. July 26, 1978.

CHAPTER 12

CONCLUSIONS - HYDRAULIC BOREHOLE (SLURRY) MINING

The borehole slurry technique has recently been demonstrated as a technically viable alternative to surface or strip mining for ores which can be slurried hydraulically (1). The technique has not yet been applied at a full production scale and the following conclusions are based on the general characteristics of the process and the data from short-term demonstration tests. In the previous three chapters the general characteristics of the technique and its applicability to Florida and North Carolina pebble phosphate deposits and Texas and Wyoming uraniferous sandstone deposits were presented.

The in situ borehole slurry method, which is a specialized mining or ore extraction technique, is contrasted with the in situ leaching process. Conventional mills or processing plants must be used for beneficiation of the ore extracted by the borehole method. The waste streams, either solid-, liquid-, or airborne-produced by the mill, are typical of mills processing conventionally mined ores. It has been proposed that the waste tailings be backfilled into the boreholes for disposal (1). Such backfilling requires the prior dewatering of the tailings, which occurs at a relatively slow rate, unless the coarse materials are separated from the fines or slimes.

The long period for dewatering of the slimes could prevent their usefulness for backfilling into the borehole. The slimes or the fines will probably be stored on the surface in conventional evaporation-tailings ponds. For uranium ores, the major quantities of radium are associated with the slime fraction. This necessitates the use of the standard radioactive waste tailings ponds. The large clay content of the pebble phosphate ores results in the generation of large volumes of slimes. These slimes, while less voluminous than those generated by conventional techniques, will have a significant impact on the surface environment. Accordingly, the slime ponds present the most significant environmental impacts in the existing phosphate mining industry in Florida.

The potential for solubilization of trace metals in the gangue material does exist with borehole slurry mining. The use of plain water which has been proposed for the hydraulic solution will minimize the solubilization of toxic materials. The jetting action in the borehole results in aeration of the water. Development of this oxidizing chemical environment could solubilize metals if the native groundwater was reducing. The short period required for mining a borehole minimizes the potential for transport of any solubilized materials in the surrounding aquifers. If the borehole is located below the groundwater table, then dewatering must occur and water will flow into the borehole from the aquifer. There is very little potential for pollutant transport out of the borehole under these conditions.

If the borehole is located above the groundwater table, the bore should be in a relatively oxidized state, and the use of an oxidized jetting water might not solubilize large quantities of metals. Depending upon the distance of the

borehole above the groundwater table and the permeability of the deposit between the borehole and the groundwater table, all water seeping from the borehole could be retained in the unsaturated soil zone by capillary action.

If the borehole is located in a confined aquifer underneath potable water aquifers, it will be necessary to case the access hole to prevent contamination of overlying waters. The dewatering of the borehole for the duration of the mining operation could result in lowering the piezometric surface several kilometers (miles) away. This could necessitate the deepening of surrounding water-supply wells and the installation of larger pumps.

Ordinarily, the process does consumptively use small quantities of water. A major component of the consumptive water use is the evaporation ponds. A very large consumptive use of water could occur for boreholes located below the groundwater table or in areas of high permeability. These boreholes would have to be dewatered, and the excess water would be pumped to and disposed of on the surface. This large consumptive use would not pose any significant impacts in Florida or North Carolina but could use sizeable quantities of water relative to availability in Texas and Wyoming.

Compaction of backfilled boreholes could result in surface subsidence. In most of the areas under consideration, mining subsidence is not a significant problem except for roads, construction, and utilities. The magnitude of subsidence in some areas would require that no buildings be constructed over the backfilled boreholes. The degree of subsidence is determined by the nature of the strata between the borehole and surface, by the degree of filling and the nature of the fill material.

In an area which experiences significant subsidence, a series of small depressions would develop. These depressions could retain water and cause changes in the flora and fauna. The impacts of such a change depend on the nature of the local environment.

CHAPTER 12 REFERENCES

1. Lang, E.A., and W.R. Archibald. Innovative Systems for Recovery of Uranium. Pres. at National Western Mining Conference, Denver, Colorado, February 1975.

CHAPTER 13

APPLICABLE FEDERAL ENVIRONMENTAL LAWS AND REGULATIONS

Recent years have seen the institution of numerous laws designed to improve our environmental quality. Mining operations are regulated currently by a broad spectrum of Federal laws and regulations. The principal controls affecting these operations include regulations for mine safety, air and water quality, land use and mine reclamation, and environmental impact analysis. The purpose of the present and the following chapter is to review the significant environmental laws and regulations affecting in situ leaching operations.

In the past decade the field of environmental law and the associated regulations has been in a constant state of flux with existing laws continuously being revised and new laws being added. It is therefore the intent of this part of the report to present an overview of the current laws and regulations which may affect an in situ leaching operation.

This overview was finalized in late 1978 and the reader is cautioned that many changes are expected to occur in the next few years.

Because in situ leaching is not a mature mining method, regulatory agencies may exert control over a mine operation through interpretation of laws not specifically addressed to in situ leaching. Thus, as in situ leaching becomes more commonplace, regulations may be expected which are directed towards controlling in situ leaching.

The Federal environmental laws which appear to have the most significant impact on in situ leaching and borehole slurry mining are the following acts:

- Atomic Energy Act of 1954
- National Environmental Policy Act of 1969 (NEPA)
- Federal Water Pollution Control Act Amendments of 1972 (FWPCA)
- Safe Drinking Water Act of 1974 (SDWA)
- Energy Reorganization Act of 1974
- Resource Conservation and Recovery Act of 1976 (RCRA)

The following sections will review these acts, the regulatory agencies in control of the implementation of the acts, and will discuss pertinent regulations affecting in situ leaching.

NATIONAL ENVIRONMENTAL POLICY ACT OF 1969 (PL 91-190)

Regulatory Agency -- Council on Environmental Quality (CEQ)

Regulations -- National Environmental Policy Act - Regulations
November 29, 1978 40 CFR 1500 July 30, 1979
(Effective Date)

Discussion

The purpose of NEPA is:

> "To declare a national policy which will encourage productive and enjoyable harmony between man and his environment; to promote efforts which will prevent or eliminate damage to the environment and biosphere and stimulate the health and welfare of man; to enrich the understanding of the ecological systems and natural resources important to the Nation; and to establish a Council on Environmental Quality."

The result of NEPA is that all agencies of the Federal government are required to prepare a detailed Environmental Impact Statement (EIS) ". . . on all proposals for legislation and major Federal actions significantly affecting the quality of the human environment." In drafting NEPA, Congress did not attempt to pull within the Act's EIS requirement all state, local and private actions which may cause environmental degradation. Thus, an important issue in NEPA's implementation is whether a particular action is sufficiently "Federal" for NEPA to apply (1). The types of Federal action which fall within NEPA's jurisdication are projects, permits, licenses, certificates, regulatory actions, and proposals on legislation. The definition of major Federal action and "significant" has been, and undoubtedly in the future will be, the cause of much conjecture and court review.

The procedure followed in determining if an EIS is required will be discussed briefly. A mine operator submits an environmental report to the lead or permitting agency for review. The agency then reviews the proposed action to determine if there is a significant environmental impact. If so delineated, the lead agency is responsible for preparing a draft EIS. Publication of the draft EIS and the public hearing follows. The lead agency then grants or denies the permit, taking into account the public review comments. This process has greatly extended the lead time necessary in premine planning. If an EIS is required, it must be prepared in accordance with Sec. 1021(2)C of NEPA quoted below and 40 CFR 1500:

> "Sec. 102. The Congress authorizes and directs that, to the fullest extent possible: (1) the policies, regulations, and public laws of the United States shall be interpreted and administered in accordance with the policies set forth in this Act, and (2) all agencies of the Federal Government shall--
>
> (C) include in every recommendation or report on proposals for legislation and other major Federal actions significantly affecting the quality of the human environment, a detailed statement by the responsible official on--

(i) the environmental impact of the proposed action,

(ii) any adverse environmental effects which cannot be avoided should the proposal be implemented,

(iii) alternatives to the proposed action,

(iv) the relationship between local short-term uses of man's environment and the maintenance and enhancement of long-term productivity and

(v) any irreversible and irretrievable commitments of resources which would be involved in the proposed action should it be implemented.

Prior to making any detailed statement, the responsible Federal official shall consult with and obtain the comments of any Federal agency which has jurisdiction by law or special expertise with respect to any environmental impact involved. Copies of such statement and the comments and views of the appropriate Federal, State, and local agencies, which are authorized to develop and enforce environmental standards, shall be made available to the President, the Council on Environmental Quality and to the public as provided by Section 552 of the Title 5. United States Code, and shall accompany the proposal through the existing agency review processes;"

FEDERAL WATER POLLUTION CONTROL ACT AMENDMENTS OF 1972 (PL 92-500)

Regulations --	Effluent Guidelines and Standards Issued for various Industry
Regulatory Agency --	U.S. Environmental Protection Agency and states granted primacy in permit issuance

Discussion

The passage of the 1972 amendments to the Federal Water Pollution Control Act represented the culmination of a long evolutionary trend in enforcement of water pollution control in the United States. The original Federal legislation on this subject was passed in 1948 and authorized a modest program of construction grants for municipal sewage treatment facilities. The Water Pollution Control Act Amendments of 1956 strengthened the enforcement provisions by providing for an abatement suit at the request of a State Pollution Control Agency; where health was endangered. The Federal Government no longer had to receive the consent of all states involved. The Water Quality Act of 1965 required that the separate states establish receiving water standards related to the highest demonstrated and/or desirable uses for particular water bodies (e.g., recreation, fishing, industry, etc.). Allowable effluents from dischargers were predicated based upon attainment of these water quality standards.

The primary enforcement responsibility belonged to the individual states, while the Federal government was empowered to conduct enforcement actions in matters pertaining to interstate pollution. The practical difficulties associated with the designation of acceptable water uses, the establishment of appropriate water quality standards, and the subsequent translation of the effects of such standards to effluent limitations led to major delays in construction of abatement facilities. Furthermore, theoretically at least, sources discharging to large bodies of water could have had somewhat of an economic advantage since a lesser investment in abatement facilities would insure the attainment of water quality standards.

The Clean Water Restoration Act of 1966 imposed a $100/day fine on pollutors who failed to submit a required report. The Water Quality Improvement Act of 1970 established a State certified procedure.

The 1972 amendments to the Federal Water Pollution Control Act mandated the achievement by July 1, 1977, of the "best practicable control technology currently available" for all sources of water pollution regardless of existing water quality standards. The amendments further mandated that the "best available treatment economically achievable" (BATEA) be installed by July 1, 1983, and established as a national goal that the discharge of pollutants to the navigable waters of the United States be eliminated by 1985. The Act required that the United States EPA provide guidelines for effluent limitations that would meet the "best practicable control technology currently available" (BPCTCA) criterion. In addition, the Act required the establishment of standards of performance for twenty-seven industrial source categories which reflected the greatest degree of effluent reduction determined to be achievable by application of demonstrated technology.

The United States EPA has determined that the effluent limitations and standards of performance should be incorporated into waste discharge permits for all sources of water pollution in the United States (2). Should water quality standards dictate more stringent effluent limitations than those required by the best practicable technology, EPA feels that these more stringent limitations must be incorporated in the waste discharge permit. The development of the effluent guidelines, standards of performance, and waste discharge permits, in coordination with establishment of applicable water quality standards, constitute the National Pollutant Discharge Elimination System (NPDES), Section 402 of the 1972 Act.

Section 404 of the Water Pollution Control Act Amendments of 1972 (PL 92-500) authorizes the Secretary of the Army, through the Corps of Engineers, to issue permits for the discharge of dredged or fill material into navigable water of the United States at approved discharge sites.

Implementation of Section 404 has generated significant controversy, as a result of the broad definition of navigable waters adopted by the Corps of Engineers. The term "navigable waters" is defined to include not only coastal waters, rivers, lakes, streams, and artificial water bodies that have been used in the past or are now used (or are susceptible to use) as a means to transport interstate commerce, but also all interstate waters and tributaries of navigable waters up to their headwaters and landward of their ordinary high water marks. This is taken to mean the point on the stream above which the flow is normally less than 5 cubic feet per second.

Dredged material is defined as material that is excavated or dredged from navigable waters, but excluding material resulting from normal farming and ranching activities. A discharge permit is required for the addition of dredged material into navigable waters in excess of 1 cubic yard when used in a single operation. Fill material is any pollutant used to create fill in the traditional sense of replacing an aquatic area with dry land or changing the bottom elevation of a water body for any purpose. Thus, any dredging of waterways within the project site area, or filling of potential waterways, including the construction of road crossings of streams, will require dredge and fill permits to be issued by the Army Corps of Engineers under Section 404. Any alteration of a natural stream channel, construction of diversion dams, construction of bulkheads, and discharge of tailings likewise will require a Section 404 permit.

Because the activities enumerated above are so vast, the Corps of Engineers has chosen to implement the permit procedure in three phases. Discharges into coastal waters or into inland navigable waters, navigable in the traditional sense, and discharges into fresh wetlands require permits as of July 25, 1975. Discharges into primary tributaries and lakes are covered as of October 1, 1976. Discharges into all other "navigable waters" including the headwaters of tributaries are governed as of July 1, 1977.

A crucial requirement of the permit review process under Section 404 is the requirement that certification be given by the State or appropriate interstate water pollution control agency prior to the issuance of a permit to the effect that any discharge will comply with the applicable effluent limitations and water quality standards.

The permit application is reviewed also by the Environmental Protection Agency. The EPA has the authority to prohibit the discharge into a specific site if it determines that the proposed discharge will have an unacceptable adverse effect upon municipal water supplies, fishing areas, wildlife, or recreational areas. Time involved in obtaining such a permit is usually approximately 180 days.

Effluent Guidelines and Standards

The following is a review of the current status of effluent guidelines published for in situ leaching for copper, phosphate and uranium.

Copper and Uranium

Copper and uranium ore mining and milling are categorized under the Ore Mining and Dressing Point Source Category for which effluent limitation guidelines were published on July 11, 1978 (40 CFR 440). These guidelines established a zero discharge standard for in situ copper and uranium leaching but do allow, in areas where precipitation exceeds evaporation, that a volume of water equal to the difference between the annual precipitation falling on the treatment system (and drainage area) and the evaporation over the same area may be subject to the limitations set forth in Tables 13-1 and 13-2.

SAFE DRINKING WATER ACT OF 1974 (PL 93-523)

Regulatory Agency -- U.S. Environmental Protection Agency, Office of Water Supply

Regulations -- State Underground Injection Control Program Update

-- National Interim Primary Drinking Water Regulations 40 CFR 141 December 24, 1975

-- Drinking Water Regulations -- Radionuclide 10 CFR 141 July 9, 1976

-- Drinking Water Regulations -- Organic Chemicals to CFR 141 February 9, 1978

-- National Secondary Drinking Water Regulations (Proposed regulations) 10 CFR 143 March 31, 1977

Discussion

Possibly the most significant legislation affecting the in situ leaching industry is the Safe Drinking Water Act with its State Underground Injection Control Program regulations. The initial draft regulations were published in the Federal Register on August 31, 1976 and appeared to have been drafted from limited data on in situ leaching. On December 27, 1977, the Federal Water Pollution Control Act was further amended by passage of PL 95-217, titled the Clean Water Act of 1977.

The act requires that a list of states be published in the Federal Register which, in the opinion of the administrator, require an underground injection control program to assure that underground injections do not endanger underground drinking water sources. In situ mining wells are regulated under Subpart D Section 146.32 Requirements for Special Process Recovery Wells.

The proposed regulations are designed to protect the quality of existing aquifers or potential sources of drinking water for public systems. Public water systems include any system serving the public having at least 15 service connections. Underground drinking water sources are defined to include aquifers currently supplying a public water system or ones which contain a TDS of less than 10,000 mg/l.

TABLE 13-1. Effluent Limitations for Copper Mining and Milling

Effluent characteristic	Maximum for any one day	Average of daily values for 30 consecutive days shall not exceed
	Milligrams per liter	
TSS	30	20
Cu	0.1	0.05
Zn	0.4	0.2
Pb	0.4	0.2
Hg	0.002	0.001
Cd	0.10	0.05
CN	0.02	0.01
pH	Within the range 6.0 to 9.0	--

TABLE 13-2. Effluent Limitations for Uranium Mining and Milling [a]

Effluent characteristic	Maximum for any one day	Average of daily values for 30 consecutive days shall not exceed
	Milligrams per liter	
TSS	30	20
Cd	0.10	0.05
Zn	1.0	.5
As	1.0	0.5
Ra226 [b]	10	3
U	4	2
COD	200	100
pH	Within the range 6.0 to 9.0	

[a] Federal Register, V 43, No. 133. July 11, 1978. pp 29763-29930.
[b] Values in picocuries per liter.

The proposed regulations allow the 10,000 mg/l limit to be lowered provided that adequate water supplies are available for all people in the state now and in the foreseeable future, and if adequate geological conditions exist which separate the waters to be protected from those not protected. State programs may also designate specific aquifers not to be protected if the aquifer is mineral producing, if the aquifer is at a depth which would be uneconomical to pump for domestic production, or if the water in the aquifer is so contaminated that it would be economically infeasible to treat the water to the applicable drinking water standards. It appears as though there is sufficient latitude in the regulations to allow a state administrator to designate a mineral bearing aquifer which may often contain high levels of contaminants to be exempt from the regulations.

The act allows for the issuance of area permits for large well fields. Subpart D Section 146.32 delineates the specific requirements for special process recovery wells in which mining wells are covered. The proposed regulations summarize Subpart D as follows:

> Since in some cases Class III well activities (regulated under subpart D) may take place in aquifers where hydraulically corrected portions serve as drinking water source, additional requirements would be imposed. For example, "The execution of harmful fluids from the mining area would be prohibited." Similarly, more stringent monitoring and frequent reporting requirements would be applied.

Of greatest significance to the in situ leaching operation are the proposed requirements for daily monitoring, constant maintenance of a negative hydraulic gradient, and the aquifer restoration clause. Daily monitoring of observation wells can be costly and will produce voluminous amounts of paperwork if several constituents are to be measured. Requiring a constant negative hydraulic gradient causing a continuous inflow of native groundwater into a well field could cause an operator problems; for instance, it would eliminate the "huff and puff" pumping method. The requirement of restoring an aquifer to within an acceptable level of baseline is important, as it allows a director to use flexible restoration limits, since each site is unique.

Again, it is emphasized that final regulations are not available at the time of this writing and the reader should consult the final regulations.

Although the Drinking Water Regulations do not specifically regulate in situ leaching, they establish water quality criteria which may be used as target objectives by regulatory agencies when establishing aquifer restoration programs. Presented in Tables 13-3, 13-4 and 13-5 are the Drinking Water Regulations in their present status.

Tables 13-3 and 13-4 present maximum contaminant levels which are enforceable but the secondary standards are recommended levels only and are nonenforceable. It is interesting to note that water supplies in many areas of the arid southwestern United States exceed the maximum levels for TDS.

TABLE 13-3. National Interim Primary Drinking Water Maximum Inorganic Contaminant Levels [a]

Contaminant	Level [b] (mg/l)
Arsenic	0.05
Barium	1.
Cadmium	0.010
Chromium	0.05
Fluoride	1.4-2.4 [c]
Lead	0.05
Mercury	0.002
Nitrate (as N)	10.
Selenium	0.01
Silver	0.05

[a] Federal Register. V 40, No. 248. Wed., December 24, 1975. pp 59566-59574.

[b] The maximum contaminant level for nitrate is applicable to both community water systems and noncommunity water systems.

[c] Varies as a function of the average annual air temperature.

TABLE 13-4. Drinking Water Regulations - Radionuclides Maximum Contaminant Levels [a]

Contaminant	Level PCi/1
Combined Ra 226 + 228	5
Gross alpha particle activity [b]	15

[a] Federal Register. V 41, No. 133. Fri., July 9, 1976. pp 28402-28409. Also 40 CFR part 141.

[b] Including Ra 226 but excluding radon and uranium.

TABLE 13-5. National Secondary Drinking Water Standards Maximum Contaminant Levels [a]

Contaminant	Level
Chloride	250 mg/1
Color	15 Color Units
Copper	1 mg/1
Corrosivity	Non-corrosive
Foaming Agents	0.5 mg/1
Hydrogen Sulfide	0.05 mg/1
Iron	0.3 mg/1
Manganese	0.05 mg/1
Odor	3 Threshold Odor Number
pH	6.58.5
Sulfate	250 mg/1
TDS	500 mg/1
Zinc	5 mg/1

[a] Federal Register. V 42, No. 62. Thurs., March 31, 1977. pp. 17143-17147. Also 40 CFR part 143.

ENERGY REORGANIZATION ACT OF 1974 (PL-93-438)

Regulatory Agency -- U.S. Nuclear Regulatory Commission

Regulations -- Standards for Protection Against Radiation (10 CFR 20)

-- Licensing of Source Material (10 CFR 40)

-- Licensing and Regulatory Policy and Procedures for Environmental Protection (10 CFR 51)

Regulatory Guides -- Guide 3.5 Standard Format and Content of License Applications for Uranium Mills

-- Guide 3.8 Preparation of Environmental Reports for Uranium Mills

-- Guide 3.11 Design, Construction, and Inspection of Embankment Retention Systems for Uranium Mills

-- Guide 4.14 Measuring, Evaluating, and Reporting Radioactivity in Releases of Radioactive Materials in Liquid and Airborne Effluents From Uranium Mills

-- Guide 8.22 Bioassay at Uranium Mills

-- Guide 8.15 Acceptable Programs for Respiratory Protection

Discussion

The NRC has license issuing authority over uranium mills and they have determined that in situ mine is within its jurisdiction (3). The NRC's control over a hydraulic borehole slurry mining operation is unknown, but if the mine is associated with a mill, the question is a moot point, as the mine supplies the mill and the effect of the mine's activity on the environment would need to be addressed in an EIS. Thus, the NRC has, in fact, authority over borehole mining operations, when uranium is being mined.

The NRC has established 8 performance objectives regarding tailings management which will be applicable for a borehole slurry mining operation. These new objectives are a result of past pollution problems associated with poor tailings management. The objectives are listed below.

Siting and Design

1. Locate the tailings isolation area remote from people such that population exposures would be reduced to the maximum extent reasonably achievable.

2. Locate the tailings isolation area such that disruption and dispersion by natural forces is eliminated or reduced to the maximum extent reasonably achievable.

3. Design the isolation area such that seepage of toxic materials into the groundwater system would be eliminated or reduced to the maximum extent reasonably achievable.

During Operations

4. Eliminate the blowing of tailings to unrestricted areas during normal operating conditions.

Post Reclamation

5. Reduce direct gamma radiation from the impoundment area to essentially background levels.

6. Reduce the radon emanation rate from the impoundment area to about twice the emanation rate in the surrounding environs.

7. Eliminate the need for an on-going monitoring and maintenance program following successful reclamation.

8. Provide surety arrangements to assure that sufficient funds are available to complete the full reclamation plan (3).

One method recently presented was a draft EIS for Bear Creek (Wyoming) mine and mill. A cross section of the proposed reclaimed tailings pond is presented on Figure 13-1. Like the NPDES system the NRC has granted license issuing authority to many states via the Agreement States Program with NRC. A list of these Agreement States is presented in Table 13-6. If an EIS is required in the Agreement States it is because of the requirements of the individual state.

As stated, the source material license from NRC may require the preparation of an EIS. In determining the necessity of an EIS, a mining applicant would submit an environmental report to NRC in conjunction with the source material license application. The NRC then performs an environmental review to determine if the proposed action would "significantly affect the quality of the human environment." If so, NRC then prepares a draft EIS. The areas currently receiving increased attention by NRC, on conventional minimum applications are:

1. Environmental monitoring, both premining and during operations.

2. Effect of mining and milling operations on the groundwater table.

3. Socioeconomic impacts on the local level.

4. Tailings management (3).

TABLE 13-6. NRC Agreement States

1. Alabama
2. Arizona
3. Arkansas
4. California
5. N. Carolina
6. S. Carolina
7. Colorado
8. N. Dakota
9. Florida
10. Georgia
11. Idaho
12. Kansas
13. Kentucky
14. Louisiana
15. Maryland
16. Mississippi
17. Nebraska
18. New Hampshire
19. New Mexico
20. New York
21. Nevada
22. Oregon
23. Rhode Island
24. Tennessee
25. Texas
26. Washington

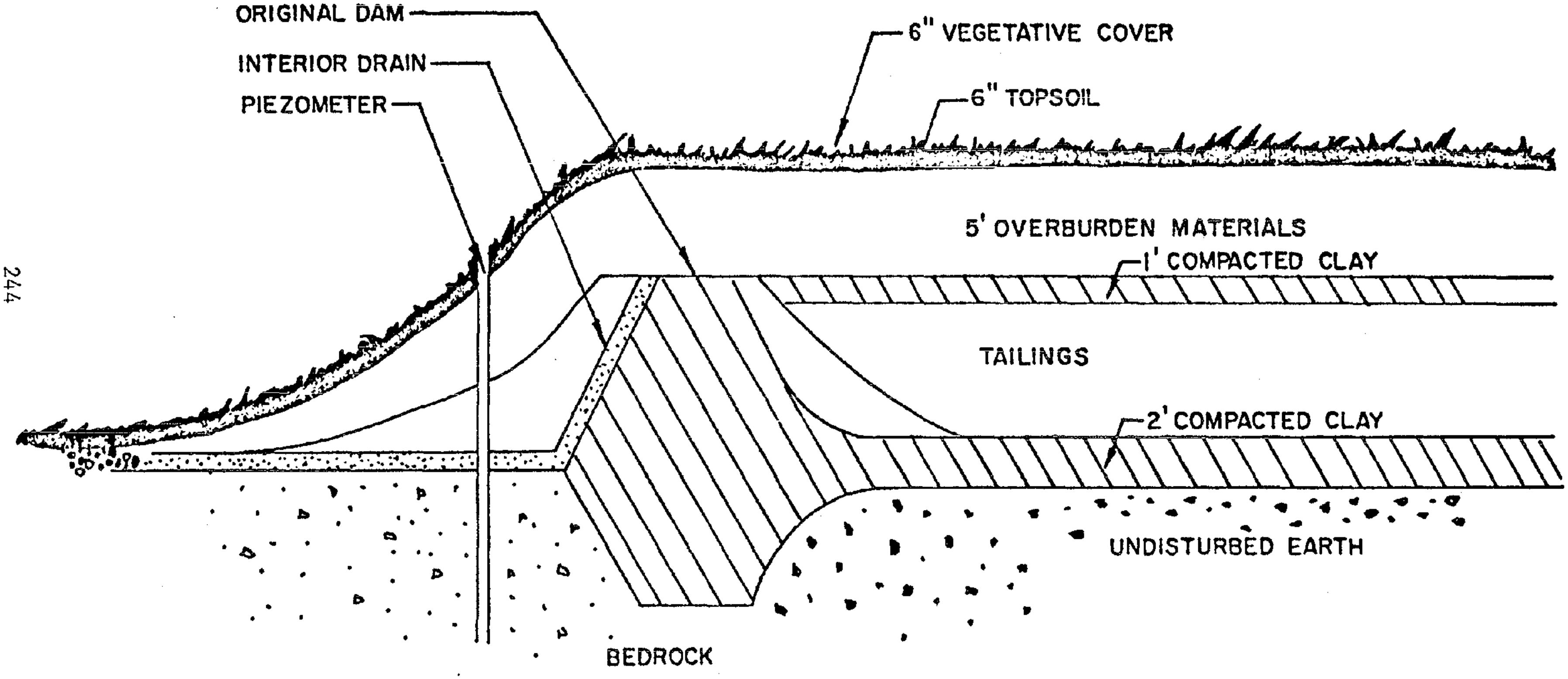


FIG 13-1 CROSS SECTION TYPICAL RECLAIMED MILL TAILINGS POND MEETING NRC STANDARDS (SCARANO 1977)

The first three areas would be applicable to some degree for an in situ leaching operation and all four would be applicable to a borehole slurry mine since the mill will undoubtedly produce tailings. An area which apparently will receive critical review for in situ leaching is aquifer restoration. It is possible that there may be an overlap in regulatory authority of aquifer restoration between NRC through the EIS process and EPA through the UIC program.

RESOURCE CONSERVATION AND RECOVERY ACT OF 1976 (RCRA)

In October 1976, Congress passed the Resource Conservation and Recovery Act (RCRA). Regulations have not yet been promulgated under this legislation. The regulations will govern the disposal of solid waste, which is very broadly defined to include "solid, semi-solid, liquid, or contained gaseous" emissions from a number of industries including the mining industry. Hazardous waste is to be defined on the basis of criteria to be developed by the Environmental Protection Agency. The RCRA provides for interested states to develop a permitting program, somewhat similar to the NPDES program, to govern the generation, transportation, and disposal of hazardous wastes. In view of the radium which would be contained in uranium ores, the waste products from mining and milling operations will probably fall under the provisions of RCRA. If so, a permit will be needed for mining, transportation, and waste disposal, with a manifest system and a complicated system of record keeping for the hazardous components contained within the solid waste.

CHAPTER 13 REFERENCES

1. Anderson, Frederic R. NEPA in the Courts. John Hopkins University Press, 1973.

2. Gallagher, T.P. and J.V. Rouse. EPA Enforcement Activity in the Uranium Mining and Milling Industry. Conference on Uranium Mining Technology. Reno, Nevada, April 1977.

3. Scarano, R.A., *et al*. Current Uranium Mill Licensing Issues. USNRC, Uranium Mining Tech Conference. Reno, Nevada, April 1977.

CHAPTER 14

APPLICABLE STATE ENVIRONMENTAL LAWS AND REGULATIONS

As previously stated, the scope of this study is limited to in situ mining of copper, phosphate, and uranium. This chapter will discuss the environmental laws and regulations affecting these commodities in those states having significant resources and reserves. A summary of the states and the type of mining is presented in Table 14-1.

This review was conducted during 1978 and will be rapidly outdated as states adopt regulations for protection of their groundwaters. As in the previous chapter on Federal laws, this chapter will dicuss those State environmental laws and regulations which may have the greatest impact on in situ mining. These subject areas include water pollution control, waste discharge standards, mine reclamation, environmental assessment and radiological material control. Although local land use laws and/or zoning ordinances may have a significant impact on the feasibility of an operation at a specific site, it is beyond the scope of this report to review and summarize such local laws.

Although in situ mining has been conducted in only a few states, it may be feasible in ore or mineral deposits in many of the states listed in Figure 14-1. Thus, the summary of laws and regulations in this chapter is an interpretation of the existing State laws which could have control over in situ mining. The data was gathered by contacting department heads in appropriate State agencies and by summarizing the appropriate laws, regulations and guidelines.

ARIZONA

Water Quality Requirements

There appear to be no State statutes to protect the quality of groundwaters. Although there are standards for domestic well construction, the objective is to ensure the production of potable water and not for the protection of water quality in the aquifers. Waste discharge to surface waters is regulated by NPDES permits which are issued by EPA.

The Bureau of Water Quality Control, Department of Health Services, appreciates the opportunity of a courtesy review of a proposed mining plan. However, they have no statuatory authority to require one. As a result of a courtesy review, a monitoring program may be recommended but an operator is under no obligation to comply with such recommendations.

Mine Reclamation Requirements

No legislation has been passed regarding mine reclamation requirements which may be imposed on a mine operator. Local land use ordinances may, however, dictate mine reclamation requirements as a condition of zoning variances or other similar local controls.

TABLE 14-1. State Summary of Minerals and Type of Mining

	Minerals		
State	Copper	Phosphate	Uranium
Arizona	X		X
California		X	
Colorado			X
Florida		X	X
Michigan	X		
Montana	X	X	
Nevada	X		X
New Mexico	X		X
North Carolina		X	X
South Dakota			X
Texas			X
Utah	X	X	X
Wyoming		X	X

Environmental Impact Statement

There are currently no State EIS requirements which may be imposed upon a mine operator.

CALIFORNIA

Limited phosphate reserves in the State may be amenable to hydraulic borehole slurry mining. The following summary reviews those laws which may have regulatory control over the process. It should be noted, however, that none of the laws address in situ mining, therefore it is not possible to determine with a great degree of certainty what requirements would be placed upon a hydraulic borehole mining operation.

The laws which appear to have the greatest potential affect on hydraulic borehole mining are:

- Porter-Cologne Water Quality Control Act of 1969;
- Surface Mining and Reclamation Act of 1975;
- California Environmental Quality Act of 1970 (CEQA).

Water Quality Requirements

Law -- Porter-Cologne Water Quality Control Act of 1969

Regulatory Agency -- The Resources Agency -- California Water Resources Control Board (SWRCB)

Discussion

The SWRCB sets broad policy and general requirements. The State is divided into nine regional areas, each governed by a Regional Water Quality Control Board (RWQCB). These local boards are in charge of setting local policy and establishing water quality control requirements. Permits for the discharge of all liquid wastes must be obtained for the RWQCB. If there is a discharge to surface streams, the permit issued is an "NPDES Permit," all others are referred to as Waste Discharge Permits.

In general, waste discharge permits for mining operations may contain the provisions which would disallow: discharge to surface waters; excursion of wastes beyond the designated area; increase in turbidity in surface waters; aquifer contamination; or modification to the hydrologic regime which would allow inter-aquifer exchanges of water with good and poor quality.

Mining Laws

Law -- Surface Mining and Reclamation Act of 1975

Regulatory Agency -- State Mining and Geology Board

Discussion

The intent of the Act is to prevent or minimize adverse environmental effects, reclaim mined lands, encourage conservation and development of mineral resources while considering other land uses, and eliminate residual hazards to public health and safety. The Act is administered by the Board, but the Act requires that each city and county adopt ordinances for the review and approval of permits for mining operations and plans for the reclamation of mined lands. The Board has drafted model reclamation plans and ordinances as a guide for cities and counties for use in meeting minimum standards in compliance with the Act.

Mined lands were defined by the Act to include the surface, subsurface and groundwater of an area in which surface mining operations are being conducted. Surface mining is defined to include: the inplace distillation, or retorting or leaching; the production and disposal of mining waste; and the prospecting and exploratory activities.

Although hydraulic borehole slurry mining is not specifically delineated, it could possibly fall under the jurisdiction of this Act.

Environmental Impact Statement

Law -- California Environmental Quality Act of 1970 (CEQA)

Regulatory Agency -- The Resources Agency

The Resources Agency of California acts as a state clearinghouse for all environmental impact reports. However, a lead agency may be any public agency with regulatory authority over a particular project.

Discussion

The CEQA requires the preparation of an Environmental Impact Report (EIR) when it is determined that a proposed project may have a significant impact on the environment. The content of an EIR is similar to that contained in a Federal EIS.

COLORADO

New uranium reserves have been discovered which may be amenable to in situ leaching. Due to the limited experience in the State with in situ mining, many State statutes which may regulate a proposed operation do not address in situ mining directly. The laws which appear to have significant impact on in situ mining include:

- Water Quality Control Act of 1973;
- State license (NRC equivalent);

- Mined Land Reclamation Act of 1973;
- State Water Law(s).

Water Quality Requirements

Law -- Water Quality Control Act

Regulatory Agency -- Water Quality Control Division (WQCD)
of the Colorado Department of Health

Discussion

The Water Quality Control Act requires a permit application for waste disposal wells. Apparently the State has decided that in situ uranium leaching wells fall within the jurisdiction of the Act. However, there are no rules, regulations, or guidelines that are addressed to in situ mining. It is, therefore, up to the mine operator to provide sufficient data, as may be requested, to convince the State that the proposed operation will not cause pollution.

Additional permits may be required from the WQCD, if a proposed mine operation is expected to produce and discharge a liquid waste stream. The WQCD is authorized by EPA to issue NPDES Permits for waste discharge to surface streams. If there is no direct surface discharge but the waste stream is expected to have a potential impact on groundwater quality, the Act requires the issuance of a permit from the WQCD.

Radiological Protection

Law -- Licensing authority given to State by agreement with the U.S. Nuclear Regulatory Commission (NRC).

Regulatory Agency -- Division of Occupational and Radiological Health,
Colorado Department of Health

Discussion

The current regulations satisfy NRC's requirements, but in situ leaching and associated milling are not addressed in depth. As previously discussed, Colorado has issued one in situ license which was for a development operation in Weld County by Wyoming Mineral Corporation. An initial concern of the Health Department was the concentration of radium in the ion exchange unit and possible escape of the associated radon gas. This concern was satisfied by the design of the facilities and proposed operation plan. The State has required Wyoming Mineral Corporation to restore the water quality in the aquifer as follows: TDS to within 10 percent of baseline, and to average concentrations of the premining baseline water quality of the ionic species identified in the Interim Primary Drinking Water Standards [EPA 1976]. The only exception is for ammonia which can exceed the original levels since the native water does not meet potable standards.

Environmental Impact Statements

An environmental report is required for a source material license in sufficient depth to "preclude overlooking any serious environmental concerns." There are no specific guidelines but, the report generally should follow the NRC guidelines for Preparation of an Environmental Report for Uranium Mills [NRC Regulatory Guide 3.8 1978].

Mine Reclamation Requirements

Law -- Colorado Mined Land Reclamation Act of 1973

Regulatory Agency -- Colorado Department of Natural Resources

Discussion

In the Colorado Mined Land Reclamation Act the State legislature declared that the extraction of minerals and reclamation of land affected were both necessary and proper activities. Operations at an in situ leaching site, which may fall within the jurisdiction of the Act, include: construction of roads; prospecting and drill sites; evaporation and settling ponds; waste discharge areas; physical facilities.

The Act requires a permit for all mining operations. If a mine affects less than 4 hectares (10 acres) and extracts less than 70,000 tons of mineral per year, it is classified as a limited impact operation and subject to limited requirements in permit application. Other mines are subjected to more extensive requirements.

There are no regulations regarding aquifer restoration after mine closure but the Act states that "Disturbances to the prevailing hydrologic balance of the affected land and surrounding area and to the quality and quantity of the water in the surface and groundwater systems both during and after mining operation and during reclamation, shall be minimized." Thus it appears that there is sufficient latitude to allow the Board to require extensive aquifer restoration.

Water Supply Permits

Law -- Colorado Water Law

Regulatory Agency -- Colorado State Engineer

Discussion

The State Engineer reviews all mining permit applications made in accordance with the Mined Land Reclamation Act for compliance with the State Water Law. A water use permit may be required from the Engineer if a mine operator plans a diversion of either surface or groundwater. Since groundwater appropriators usually have junior water rights (rights subservient to prior or senior rights) to surface appropriators, it may be necessary for an operator to join a groundwater management district, if an augmentation of supply is required to satisfy the prior rights of the senior appropriator.

FLORIDA

Florida is the country's major producer of phosphate rock. To date, there have been no known commercial applications of the hydraulic borehole slurry mining system for the extraction of phosphate. There has been some experimental work done with the MARCONAFLO system, but the results are not published. The Florida laws and regulations which appear to have control over borehole slurry mining of phosphate are the Florida Environmental Land and Water Management Act of 1972, the Industrial Waste Discharge Permit System, the Rules on Dams surrounding slime permits, consumptive use permits, and system and mine regulation rules.

Water Quality Requirements

Regulatory Agency -- Florida Department of Environmental Regulation (DER)

Regulations -- Rules of the DER, Chapter 17-3 "Pollution of Water."

Discussion

The rules were adopted to protect the waters of the state and to prevent discharge of harmful substances. Minimum conditions were established for all waters for settleable, floating, deleterious and toxic substances. The rules adopted as a minium effluent guideline established by EPA (See Federal Register 42 No. 133 July 12, 1977 pp. 35843-35852 or 40 CFR part 436) for 30 industries include the phosphate manufacturing industry. Stricter discharge standards may be required to meet applicable water quality standards.

State waters are classified by use into 5 categories:

Class I	Public water supplies
Class II	Shellfish harvesting
Class III	Recreation, propogation and management of fish and wildlife
Class IV	Agricultural and industrial water supply
Class V	Navigation, utility and industrial use.

Separate water quality standards have been established for each of the above classes.

Environmental Assessments

Law -- Florida Environmental Land and Water Management Act of 1972.

Regulatory Authority -- Florida Department of Administration,
Division of Planning

Rules -- Developments Presumed to be of Regional Impact
(Chapter 22F-2)

Discussion

The law was promulgated to protect the natural resources and the environment of the state. The Act intended that state land and water management policies should be implemented by local government. The Act allowed the formation of areas of critical concern in which land use plans must be adopted. Any Development of Regional Impact (DRI) is required to obtain a permit from one of 11 Regional Planning Councils. Mining operations are defined to be a DRI if more than 40 hectares 1/d (100 acres) are disturbed, or if the operation would consume more than 11.3×10^6 (3 mgd) of water.

Mine Reclamation

Regulatory Authority -- Florida Department of Natural Resources (DNR)
Division of Resource Management

Rules -- Mine Reclamation Rules (Chapter 16C-16)

Discussion

The severance tax program offers monetary incentives for the mine operators to reclaim their lands and recapture a portion of the severance tax paid during mining. On new mined areas, reclamation and restoration of disturbed lands is mandatory with an exception, if the product is sold:

1. To a government agency;
2. In the state and sales tax paid;
3. For the company's own use.

Prior to restoration to recover severance tax, the operator must submit an application to the DNR. Usually reclamation consists of allowing the slime pond to dry and cake over. The area may then be covered over with top soil, providing a site suitable for light farming. No building is allowed on a reclaimed site. For each $1.00 paid toward severance tax, the operator is allowed to recover 40 cents by reclaiming the mine site.

Water Resources

Law -- Florida Water Resources Act of 1972

Regulatory Agency -- Florida Department of Environmental Regulations

Discussion

Florida is divided into six water management districts. The main purpose of the district is to provide for the management of water and related land resources and to promote the conservation, development and proper use of state waters. A permit is required from the district for any project which involves the artificial recharge or introduction of water into an aquifer as may be the case in borehole slurry mining. The DER also requires water use permits.

MICHIGAN

As discussed in Chapter 5 the native copper deposits in the Keweenaw Peninsula might be amenable to in situ leaching; however, to date there have been no known in situ operations. The State could regulate in situ mining by the Water Resources Commission Act, the Mineral Wells Acts, by Guidelines for Preparing EISs under Executive Order 1974-4, or under a prospector's or mining lease, if the mine is on state lands (as is much of the land in the Keweenaw Peninsula).

Water Quality Requirements

Law -- Michigan Water Resources Commission Act 245, Public Acts of 1929 as amended.

Regulatory Agency -- Michigan Department of Natural Resources
Environmental Protection Bureau, Water Quality Division

Discussion

The Division is responsible for issuing NPDES permits for all wastewater discharges to surface waters of the state. It also issues State Wastewater Discharge Permits for all wastewater discharges to groundwaters of the state and all waters not specifically governed by NPDES permits. As discussed in Chapter 5, many of the inactive copper mines have been filling with water which may have a high TDS. The discharge of this water would require a permit by the Division and may pose a significant obstacle in obtaining approval to mine in an inactive mine.

Mining Wells

Law -- The Mineral Wells Act. Act No. 315 of Public Acts of 1969

Regulatory Agency -- Michigan Department of Natural Resources
Geological Survey Division
Supervisor of Mineral Wells

Regulations -- Rules Governing Mineral Wells, June 1972

Discussion

The act was passed for the control of drilling, operating and abandoning mineral wells to prevent waste discharge to surface or groundwaters. The regulations define mineral wells to include brine, storage, disposal and test wells. Thus, it is unclear if in situ leaching wells fall under the jurisdiction of the act; however, it is possible that a permit would be required under the requirements of the Act.

Environmental Assessments

Authority -- Governor's Executive Order 1974-4

Regulatory Agency -- Environmental Review Board

Discussion

The Order requires that all major activities of each State agency, which have a possible significant impact on the environment, be the subject of an environmental assessment by the agency involved. The Order includes administrative actions, such as issuance of permits for the discharge of materials that would result in a significant degradation of environmental quality and the authorization of changes in land use through the issuance of use permits.

Major activities may require an EIS for several reasons such as a request by the Governor, if the activity raises general public concern or controversy, if the activity is expected to cause a significant environmental impact, or if required by the Board.

If a proposed in situ mine were required to obtain permits, as discussed in previous sections, or if the mine were on State lands, it is possible that an EIS would be required. If there were no state action required, it appears that an EIS would not be required.

Mining Lease

If a proposed mine is on state-owned lands the operator would be required to obtain a State lease for either Prospecting, Exploration, or Development. The requirements for the three types of leases may vary. The Prospecting Lease terms are relatively simple while the Development Lease terms are more complex. If the action proposed in any lease is determined environmentally significant, an EIS may be required. To obtain a Development Lease an operator must submit a mining plan for approval. The plan must include provisions for mine reclamation of open pits, stockpiles, tailing basins and auxiliary lands.

MONTANA

There are three areas of environmental law in Montana which may be expected to exert control over in situ copper leaching. These areas are:

- Mine Reclamation Laws
- Montana Environmental Policy Act of 1971 (MEPA)
- Montana laws regarding water pollution

Mining and Reclamation Laws

Montana has three mine reclamation laws each governing specific minerals. The Strip and Underground Mine Reclamation Act of 1973 governs coal and uranium mining. The Open Cut Mining Act of 1973 governs bentonite, clay, scoria, phosphate rock, sand and gravel mining. The New Hard Rock Law of 1971 governs those not covered above; thus, copper mining is included under this law.

Law -- New Hard Rock Law of 1971

Regulatory Agency -- The Department of State Lands

Discussion

The purposes of the act are fourfold and are to provide: 1) the usefulness, productivity and scenic values of all lands and surface waters; 2) cooperation between administering agencies; 3) for recognition of recreational and aesthetic benefits of the land; 4) priorities and values to the aesthetics of the landscape, water and ground cover. The Act may be exempted on certain Federal lands, if the responsible Federal agency's requirements are equal to, or better than, those imposed by the Act.

The Act does not specifically address in situ leaching, nor does it appear to recognize the value of groundwater. However, underground mining is defined as "all methods of mining other than surface mining."

The Act defines three types of permits that may be required, which are: small mining, exploration, development and operating. With the exception of the small mining permit, an operator must file a mining and reclamation plan and post performance bonds with a value of between \$500-\$6250/hectare (\$200 and \$2500/acre) of affected land. The reclamation plan is addressed to reclaiming surface lands, consistent with an identified beneficial use, to a condition not better than that which existed prior to mining activities. The plan does not address groundwater restoration, therefore its present effect on in situ leaching is expected to be minor.

Environmental Impact Statement

Law -- Montana Environmental Policy Act of 1971 (MEPA)

Regulatory Agency -- Environmental Quality Council

Regulations -- Rules Implementing the Montana Environmental
Policy Act of 1971

Discussion

The purpose of the Act, much like the earlier Federal Act (NEPA), is to "declare a state policy which will encourage productive and enjoyable harmony between man and his environment; to promote efforts which will prevent or eliminate damage to the environment and biosphere and stimulate the health and welfare of man; to enrich the understanding of the ecological systems and natural resources important to the state; and to establish an environmental quality council." (MEPA)

An application for a permit, such as a mining permit may require that an EIS be prepared. The lead state agency issuing a permit would first perform a Preliminary Environmental Review (PER) to determine if a proposed action would have a significant effect on the human environment.

The permittee must supply the lead agency with sufficient data to perform the PER. If the agency determines that there is a significant impact, it will prepare a draft EIS and possibly a final EIS.

When an application for a permit is expected to result in a lead agency incurring expenses in excess of $2500 in compiling an EIS, the applicant must pay for the costs incurred. (MEPA)

Water Quality Regulations

Law -- Montana Laws regarding water pollution

Regulatory Agency -- Montana State Department of Health and Environmental Sciences

Regulations -- Water Quality Standards -- Montana Pollution Discharge Elimination System (MPDES)

Discussion

The laws make it unlawful to cause the pollution of any State water or to place waste where they are likely to cause pollution to State waters. Pollution is defined as the modification of physical, chemical, or biological properties, in excess of water quality standard, or discharge into State waters, which may render the waters harmful. The definition of state waters includes bodies of water, surface or underground. Montana has established surface water quality standards but has not yet adopted groundwater quality standards. It appears there may be sufficient latitude in the law to allow the regulation of an in situ leaching operation if an aquifer were to be affected.

The MPDES system was formed to allow the State to issue waste discharge permits under the NPDES system. The State has been granted this authority by EPA. Although this system was implemented for point source discharges to surface water, there may be sufficient latitude to require permits from in situ leach mining operators.

NEVADA

In 1973, Nevada was the fifth largest producer of copper, but it produced no uranium or phosphate. Since in situ leaching for copper occurs in hard rock, there are few, if any, water quality laws affecting copper in situ leaching. There are no state mined-land reclamation laws affecting in situ operations, but local land use and zoning laws may impose requirements on a mine operator. No EIS's are required of a mine operator, only utility companies are required to file EIS's.

Water Quality Requirements

Law -- Nevada Water Pollution Control Law of 1973

Regulatory Agency -- Nevada Department of Human Resources

Regulations -- Nevada Water Pollution Control Regulations
January 1975

Discussion

The regulations were promulgated to administer NPDES permits. The regulations govern discharges to all waters of the state which include "all bodies . . . of water, surface and underground . . ." Thus, if an in situ operation were conducted in nonwater-bearing strata and the waste were discharged into an evaporation pond, no permit would be required.

Environmental Impact Statements

There are no state EIS requirements for construction by privately-owned firms.

NEW MEXICO

The State has long been the center of a significant amount of conventional uranium mining. In January of 1977, the New Mexico Water Quality Control Commission became the first agency in the country to establish, on a state-wide basis, regulations for discharge to groundwater. The regulations were adopted under the New Mexico Water Quality Act of 1967. These regulations and the New Mexico Radiation Protection Act of 1971 appear to have the majority of control over in situ leaching. There is no State statute for mined land reclamation affecting an in situ operation.

Water Quality Requirements

Law -- New Mexico Water Quality Act of 1967
-- Environmental Quality Control Act of 1971

Regulatory Agency -- Water Quality Division, New Mexico
Environmental Improvement Agency

Regulations -- Water Quality Control Commission Regulations
(amended January 1977)

Radiological Protection

Law -- New Mexico Radiation Protection Act of 1971

Regulatory Agency -- Radiological Protection Section --
New Mexico Health Department

Discussion

The amended regulations established standards for groundwaters of 10,000 mg/l TDS, or less. The pH and constituent concentrations shown in Table 14-1 are the maximum concentrations allowable in groundwater unless the existing conditions exceed the standards, or unless otherwise specified in a discharge permit. When the existing pH or constituent concentration of any of the contaminants exceed the standards specified, the existing conditions shall be the maximum allowable limit, provided that the discharge will not result in higher concentrations at any place of withdrawal for present or reasonably foreseeable future use.

Where the Director has determined that a hazard to public health will not result, the Director may approve the following discharge plans that propose to use a limited volume of water from an aquifer:

1. To allow purification, including dilution, to take place, provided the experimental and theoretical basis for the predicted purification, including dilution, are submitted to the Director and the effectiveness of the predicted purification, including dilution, will restore the contaminated volume of groundwater to the standards of Section 2-403 unless otherwise approved, pursuant to Sections 2-410 and 2-411.

2. In an ore leaching process or any disposal process, provided the plan includes a means by which groundwater contamination will be contained in a defined limited volume of groundwater and a program for restoration of the contaminated volume of groundwater to the standards of Section 2-403 after cessation of the operation unless otherwise approved pursuant to Sections 410 and 411.

3. In an ore leaching process or any disposal process where the discharge is into a volume of aquifer which, at the date of application for discharge plan approval, has concentrations of certain contaminants above the standards of Section 2-403 due to any previous discharge, provided the plan includes a program which provides reasonable assurance that the discharge after the date of application for plan approval will not contribute to the violation of standards, to be accomplished by one of the following:

    a. After cessation of operations, return the aquifer to substantially the same condition as existed at the date of application for plan approval; or

b. After cessation of operations, return the aquifer to substantially the same conditions that would have existed if additional discharge had not taken place after the date of application; or

c. After cessation of operations, remove from the aquifer the weight of contaminants discharged after the date of plan application, with wells to remove contaminants placed to minimize potential for standards violation; or

d. Any other method or technology which will provide reasonable assurance that discharge after the date of application for plan approval will not contribute to the violation of standards (amended Regulation, January 1977).

Any person intending to discharge any of the constituents listed in Table 14-2 which may move directly or indirectly into groundwaters must notify the Director of the Water Quality Division within 60 days. The Director must notify the applicant if a discharge plan is required. The amended regulations do not address in situ leaching directly; however, the draft regulations do. The decision was made by the Commission, when it deleted the section referring to in situ mining, to use the deleted section as a guide for the Director when reviewing in situ mining applications.

The State reviews NPDES permit applications for waste discharge to surface waters and works with EPA, on a contract basis, to determine the conditions of the permit. The permit, however, is issued by EPA.

The Department issues source material licenses in accordance with the requirements established by NRC. The Department requires that an aquifer be restored after leaching to ambient standards, MPC or background radiological levels, whichever is greater.

NORTH CAROLINA

The relationship between the coastal phosphate deposits and fresh and estuarine water resources has necessitated the formulation of a multitude of regulatory controls to protect the environment during phosphate mining. The predominant laws, which may exert the major influences in controlling phosphate mining, are the Mining Act of 1971, Water Use Act of 1971, Well Construction Act, and the Dredge and Fill Law of 1970.

Mining Regulations

Law -- North Carolina Mining Act of 1971

Regulatory Agency -- Office of Earth Resources, Mining Division. North Carolina Department of Natural and Economic Resources

TABLE 14-2. New Mexico Groundwater Standards [a]

Constituent	Concentration [b]
A. Human Health Standards -- Groundwater shall meet the standards of Sections A and B unless otherwise provided.	
Arsenic (As)	0.1
Barium (BA)	1.0
Cadmium (Cd)	0.01
Chromium (Cr)	0.05
Cyanide (CN)	0.2
Fluoride (F)	1.6
Lead (Pb)	0.05
Total Mercury (Hg)	0.002
Nitrate (NO3 as N)	10.0
Selenium (Se)	0.05
Silver (Ag)	0.05
Uranium (U)	5.0
Radioactivity: Combined Radium-226 and Radium-228	30.0 [c]
B. Other Standards for Domestic Water Supply.	
Chloride (Cl)	250.
Copper (Cu)	1.0
Iron (Fe)	1.0
Manganese (Mn)	0.2
Phenols	0.005
Sulfate (SO4)	600.
Total Dissolved Solids (TDS)	1000.
Zinc (Zn)	10.0
pH	between 6 and 9 [d]
C. Standards for Irrigation Use -- Groundwater shall meet the standards of subsections A, B and C unless otherwise provided.	
Aluminum (Al)	5.0
Boron (B)	0.75
Cobalt (Co)	0.05
Molybdenum (Mo)	1.0
Nickel (Ni)	0.2

[a] New Mexico Environmental Improvement Agency, Water Quality Division

[b] mg/l unless otherwise specified.

[c] pCi/l.

[d] pH units.

Regulations -- Various regulations and guidelines have been established pursuant to many sections of the Act.

Discussion

The purpose of the Mining Act of 1971 is to ensure that the usefulness, productivity, and scenic values of the land and waters affected by mining receive the greatest degree of protection and restoration. The Act requires the issuance of a permit for a mine and requires reclamation plans as a condition of the permit. A performance bond between $2,500 and $25,000 depending on the size of the mine must be posted as part of the reclamation plan. The liability of the mine operator may not exceed the value of the posted bond.

A mining permit may be denied if it is determined that the proposed operation would: 1) have an adverse effect on wildlife or fisheries; 2) violate air, surface water, or groundwater quality standards; 3) constitute a hazard to physical improvements; 4) have an adverse effect on recreational facilities; 5) cause sedimentation or water pollution to streams or lakes; 6) the operator has not corrected previous permit violations.

Water Resources Management

Law -- North Carolina Water Use Act of 1971.

Regulatory Agency -- Division of Environmental Management Groundwater Section. North Carolina Department of Natural and Economic Resources

Discussion

In the early 1960's, along the Eastern Seaboard, extensive mine dewatering operations necessary for dry-pit phosphate mining caused a lowering of the piezometric surface of the groundwater over an extensive area. This drawdown caused many artesian wells to run dry and created fears of seawater intrusion into the freshwater aquifer. The Water Use Act of 1971 was created to control this condition.

The Act declared that the Board of Water Resources may define capacity-use areas in the State. These are areas in which the aggregate uses of groundwater and/or surface water: 1) have developed or will develop to a degree requiring coordination; or 2) exceed or threaten to exceed the replenishment of the hydrologic system. If a proposed mine is in such an area, a water use permit might be required. Generally, if an operation is expected to require the withdrawal or use of more than 378,000 l/day (100,000 gpd).

Law -- Well Construction Act of 1967

Regulatory Agency -- Division of Resource Planning and
Evaluation, Groundwater Section.
North Carolina Department of Natural
and Economic Resources.

Discussion

The Well Construction Act recognizes that in the State, groundwater reservoirs are the only source of freshwater which has not been polluted to some degree. Improper location, construction, use, and abandonment of wells is stated to be contributing to the impairment of groundwater resources. The Act gives the Environmental Management Commission of North Carolina the power to promulgate rules and regulations to control the location, construction, repair, and abandonment of wells and the installation and repair of pumps and pumping equipment.

Mining wells are included in the Act which states that "The design and construction specifications for all wells intended for the purpose of recovering minerals and ores shall be approved in writing by the Department of Natural and Economic Resources."

Law -- Wastewater Discharge Permit Regulations

Regulatory Agency -- Division of Environmental Management
North Carolina Department of Natural
and Economic Resources.

Discussion

If a waste discharge to surface waters is expected, a Water Quality Certificate is required. The certificate is issued in accordance with discharge requirements established by stream standards. Waste injection into groundwaters is prohibited.

Alteration of Aquatic Environment

Law -- North Carolina Dredge and Fill Law (of 1970)

Regulatory Agency -- Division of Marine Fisheries.
North Carolina Department of Natural
and Economic Resources.

Guidelines -- "Applying for a permit to alter Marshland,
estuarine waters, tidelands, and State-owned
lakes."

Discussion

Since many of the phosphate deposits are located under rivers and estuarine waters, it is possible that a mining operation might be proposed which would alter the water course to recover phosphate. If such is the case, it will be necessary for an operator to obtain a dredge and fill permit. The granting of the state permit does not relieve an operator from the responsibilities of obtaining the appropriate Federal Dredge & Fill Permit from the Corps of Engineers under Section 404 of the Federal Water Pollution Control Act.

A State permit is reviewed by as many as fourteen other State agencies. An objection of any of these agencies is sufficient to cause the application to be brought before the Marine Fisheries Commission of North Carolina for hearings and decision. The Commission's decision may be appealed in the courts by either party.

Environmental Impact Statements

Environmental Impact Statements are required only for projects constructed by State agencies. However, there may be a possibility that these requirements will expand into the private sector in the future. If a Dredge and Fill Permit is required, an EIS may be required by the U.S. Army Corps of Engineers under NEPA Regulations.

TEXAS

There are an abundance of developments of various production level in situ uranium leaching operations currently being conducted in the State of Texas. This abundance of mines, combined with the fact that Texas is an Agreement State with NRC, and issues source material licenses, has placed Texas in the forefront of of experience with State regulation regarding in situ uranium mining. Unlike surface mining, which is regulated by the Texas Railroad Commission, in situ leaching is regulated by the Texas Department of Water Resources (TDWR) and the Department of Health.

Water Quality Requirements

<u>Law</u> -- Texas Water Quality Act of 1967

<u>Regulatory Agency</u> -- Texas Department of Water Resources

Discussion

The purpose, in part, of the Texas Water Quality Act is to maintain the quality of the waters in the State. The definition of waters in the state includes "groundwater percolating or otherwise." Each application is treated separately and as the technology of mining is developed, the operational requirements may be modified. The basic concern of the TDWR, under the authority of this Act, is the protection of groundwater by regulating injection wells and holding or evaporation ponds.

As an example of the TDWR's requirements, the following will discuss briefly the highlights of a recent permit issued for the operation of a 2.6 hectare (6.4-acre) leach field containing a total of 72 production and injection wells.

Storage ponds were required to be lined and constructed with a 91 em (3-foot) freeboard during normal operations and a 60 em (2-foot) freeboard during emergency operations. The production area was surrounded by a total of 17 monitoring wells in the producing aquifer and two monitoring wells were required in the aquifer above the production zone. These wells are monitored semi-monthly for sulfates, ammonia, uranium, and electrical conductivity. To prevent leaching fluid migration, the TDWR required that a sufficient volume of water is to be bled from the process flow to insure a net inflow of water into the production area. The permit requires that the water quality in the aquifer be restored to conditions "consistent with" baseline conditions that existed prior to mining operations.

Law -- Texas Disposal Well Act of 1961

Regulatory Agency -- Texas Railroad Commission

Discussion

Waste disposal by injection into deep saline aquifers is regulated by the Disposal Well Act. Prior to drilling such a well, a permit is required from the TDWR. The permit application must be accompanied by a letter from the Texas Railroad Commission stating that the proposed injection well will not endanger oil or gas fields. The permit must also be approved by the Water Development Board, Health Department and the Water Well Drillers Board.

Radiological Protection Regulations

Law -- Texas Radiation Control Act of 1961

Regulatory Agency -- Department of Health Resources, Division of Occupational Health and Radiation Control.

Regulations -- "Regulations for the Control of Radiation" and Supplemental Sheet for in situ uranium mining license applications.

Discussion

The radiological health requirements of the Department of Health are similar to those promulgated by NRC. However, unlike NRC requirements no environmental statement is required. The two major requirements imposed upon an in situ leaching operation are: 1) a domestic water well sampling program whereby 1/8 of the wells within a 4.8-8 Kilometer (3 to 5-mile) radius are required to be sampled quarterly; 2) an aquifer must be restored whereby the amount of radioactive material in solution is no greater than that which existed prior to mining.

Environmental Impact Statement

There are presently no state EIS requirements. The Texas Environmental Policy Act of 1973 (TEPA) differs from other states in that this is not a statute requiring an EIS. The language of the Act only recommends an optional environmental study.

UTAH

Water Quality

Law -- Water Pollution Control Act of 1953

Regulatory Agency -- Utah State Division of Health

Discussion

The purpose of the Water Pollution Control Act is to ensure, among other things, that no waste is discharged into any waters of the state without receiving the degree of treatment required to protect the beneficial uses of the waters. The waters of the state are defined to include wells, springs, and underground sources. This definition specifically excludes bodies of water confined to and retained within the limits of private property.

The Division of Health has promulgated a "Code of Waste Disposal Regulations." The regulations establish standards of quality for waters of the state and also sets forth an anti-degradation policy for those waters. The classification system ranges from Class "A" waters which shall be protected against controllable pollution to be suitable, without treatment, for domestic, agricultural, and wildlife purposes to Class "E" waters which shall be protected against such controllable pollution as may result in a health hazard or nuisance. The Act does not address problems caused by mining. However, since wells, springs, and underground sources are included in the Act it is probable that any applicant for in situ leaching would need to insure the preservation of the water quality of any sources of nearby waters.

Mine Reclamation

Law -- Utah Mined Land Reclamation Act of 1975

Regulatory Agency -- Division of Oil, Gas and Mining, Utah
Department of Natural Resources

Discussion

Mine reclamation plans are required for all mining operations within the State. The Act limits reclamation at in situ leaching operations to only the surface effects such as milling operations, evaporation ponds, leaching dumps, waste discharge areas, and other appurtenant disturbances.

The objectives of the Mined Land Reclamation Act are: 1) to return the land, concurrently with mining or within a reasonable amount of time thereafter, to a stable ecological condition compatible with past, present and probable future local land uses; 2) to minimize or prevent present and future on-site or off-site environmental degradation caused by mining operations to the ecologic and hydrologic regimes and to meet other pertinent state and Federal regulations regarding air and water quality standards and health and safety criteria; 3) to minimize or prevent future hazards to public safety and welfare.

Although the Act does not specify groundwater restoration, the reference to hydrologic regimes in (2) above might be interpreted to give the Act authority to require restoration of groundwater quality adversely effected by mining.

The Department feels that it is important for leaching operators to prevent excursion of leach solutions to prevent contamination of springs or surface seeps used by others such as farmers. Should such a spring become contaminated by the actions of a leach mine operator, civil action could be brought against the operation by the injured party.

Environmental Impact Statement

No EIS is required by the State but an environmental assessment may be required by the Department of Natural Resources if a proposed mine is on state land and the action deemed environmentally significant. This requirement could be made by interpretation of the Governors Executive Order, August 27, 1974, Title 40-8.12.

WYOMING

Mining Permits

Law -- Wyoming Environmental Quality Act of 1973 (as amended in 1974 and 1975)

Regulatory Agency -- Land Quality Administrator, Wyoming Department of Environmental Quality

Discussion

The Act requires mine operators to obtain a mining permit for all proposed mining operations.

The Administrator requires in situ uranium leaching operators to obtain a mining permit. As part of the permit application, the operator must submit sufficient data for the Administrator to review the action for potential adverse environmental impact.

The Administrator currently requires that aquifers be restored to baseline water quality levels after in situ leaching. This approach, in contrast with Texas, where higher than baseline levels may be accepted, may severely limit the viability of in situ leaching in the State unless some increase in consituent concentration over baseline is allowed.

Water Quality Requirements

Law -- Wyoming Environmental Quality Act of 1973

Regulatory Agency -- Water Quality Administrator, Wyoming Department of Environmental Quality

Discussion

Discharges of wastewater to surface water are regulated by the Water Quality Administrator. The Water Quality Department has been granted jurisdiction for issuing NPDES permits, the act allows the Administrator to establish water quality standards and effluent standards and limitations on waters of the state (including groundwater) but the Land Quality Administrator maintains jurisdiction over in situ leaching operations.

Radiological Protection Regulations

Wyoming does not have an agreement with NRC for issuing source material licenses and is a non-agreement state, therefore NRC issues source material licenses.

Environmental Impact Statement

Wyoming has no formal EIS requirements, although a significant amount of environmental data is required with the submittal of a mining permit application. However, an EIS is required with a source material license application by the NRC, if they determine that the proposed action will have a significant effect on the environment (see NEPA Chapter 13).

Miscellaneous

If the construction cost of a proposed facility is expected to exceed $50 million it may fall within the jurisdiction of the Wyoming Industrial Siting Act and require an Industrial Siting Act of 1975 Permit. The socioeconomic and environmental impacts of a proposed action are key considerations of the permit required by the act.

CHAPTER 15

IMPACTS OF LEGISLATION ON INDUSTRIAL OF IN SITU MINING

In previous chapters, the impacts of the mining operations on the environment have been discribed and discussed. Reverse impacts refer to the effects of the environmental and health protection legislation on the development of the in situ mining industry. The objective of this chapter is to discuss reverse impacts and potential regulatory areas which can be optimized to reduce negative impacts on industry.

SUMMARY OF REGULATORY ASPECTS

State of Development

The previous two chapters describe a great number of regulations directly impacting the mining industry. Most of these regulations were developed during the late sixties and the seventies and continue to undergo modifications, revisions, and reinterpretations. At the present time (late 1978), few states have finalized groundwater protection regulations, Underground Injection Control regulations, or radiation exposure standards. Many states have not recognized that specific regulations are required for monitoring and control of in situ operations, whether they are for copper, phosphate or uranium.

The development and adoption of regulations concurrent with the development of mining techniques cause the miners to be constantly facing new restrictions and requirements constantly. The long lag time between exploration and mining necessitates that the future miner comply with regulations which do not exist at the time of his exploration. Costs for compliance with future regulations must be projected and considered in the economic evaluation of projects.

Regulations on the State and Federal levels can be expected to remain rather fluid for the next five to ten-year period as final environmental protection measures are adopted and additional experience is gained with in situ mining. During this period mining companies will have to utilize their "crystal balls" to anticipated future requirements. The regulations for the different types of in situ mining operations (copper, uranium, phosphate, borehole, leaching) are in different states of development. Regulations for in situ leaching of uranium should be finalized based on experience gained from the existing operations. Copper in situ leaching is in its infancy stage and several generations of regulations will probably be developed during the next two decades. The regulatory uncertainties and potential for revision of regulations are greatest for the borehole slurry in situ in view of the extremely limited application history.

Operation Permits

In non-agreement states, the primary permit required for uranium mining operations is the Source Materials License which obtained from the Nuclear Regulatory Commission (NRC). Issuance of the source materials license requires preparation and approval of an Environmental Impact Statement along with demonstration of restoration on a pilot scale. In addition to NRC requirements, there are numerous other permits which must be obtained from State, County, and possibly City agencies. Many of these additional permits are not specific to uranium. Twenty-three permits and/or approvals were required in addition to the NRC Source Materials License for a recent in situ uranium leaching operation in Wyoming. Several of these permits are issued by agencies with overlapping jurisdictions. At the present time, no state has a single agency or department for issuance of the required permits and industry must expend significant efforts to simply identify all State and local requirements.

IMPACTS OF REGULATIONS

The regulations controlling in situ uranium mining, while protecting the environment, can negatively impact development of the in situ uranium industry in that there would be more in situ leaching if there were no regulations. The absence of environmental protection regulations would be disastrous and is not being proposed or even considered. Negative impacts on industry which can be reduced include long time periods required for issuance of operation permits and high costs for preparation of permit applications due to changes in permit requirments. While environmental protection regulations are a necessity, these adverse impacts on industry could be reduced by definition and simplification of the permitting process without additional endangerment of the environment.

Mine Development Schedule

For non-uranium minerals, it typically requires between three and five years for commencement of mining after completion of mineral exploration. During this period, environmental studies, engineering design and plant construction are performed. In the case of uranium in situ leaching, this period is extended by 1-1/2 to 3 years because of the requirements to conduct pilot leaching and restoration studies and to prepare an Environmental Impact Statement. The additional time required for commencement of mining operations results in longer financing periods and greater uncertainties in the projected return on investment. It should be possible to reduce the 4.5 to 8-year period for in situ uranium mine development by ten to 15 percent by better definition of permit application requirements and elimination of overlapping agency responsibilities.

Cost of Permits

The cost of obtaining the required permits and licenses for an in situ uranium leaching operation operation in Wyoming range between $700,000 and $2,000,000 which represents a unit cost of $0.66 to $1.10/Kg ($0.30 to $0.50/lb) of uranium in a typical 23,000 Kg U_3O_8 per year operation (50,000 lbs/yr). The great majority for this cost is for the environmental studies defining the geohydrologic environment and the surface environment which include flora and fauna baseline studies along with analysis of social, economic impacts on the region. Until additional experience is gained with in situ leaching, it will be difficult if not impossible to streamline the studies by elimination of general non-site specific considerations. The largest savings which can be achieved at the present time without adverse environmental impacts would result from definition, finalization, and standardization of permitting requirements. Definition and finalization of the permitting process would enable industry to comply effectively with environmental protection regulations and measures at minimum cost.

APPENDIX A

ENVIRONMENTAL IMPACT ASSESSMENT MATRIX

The environmental impact assessment matrix presented in this appendix has been adapted from a similar matrix published by the U.S. Geological Survey. The matrix is utilized to identify and, where possible, to establish the relative magnitude of potential impacts upon the environment posed by different in situ mineral recovery scenarios. Such a matrix serves three basic functions: 1) providing an at-a-glance assessment of the significance of environmental impact of a given mining technique; 2) serving as a comprehensive checklist of all the component elements of a particular mining method which may exert effects upon the environment; 3) providing a concise vehicle for rapid comparison of different mining techniques in terms of their potential environmental impact -or a comparison of the same technique employed at different locations.

The matrix presents an arrangement of the proposed actions (components of a given mining program) as columns and the elements of the environment as rows. If a proposed action will impact an element of the environment, a designation is inserted in the appropriate block formed by the intersection of the column (action) and row (environmental element). If sufficient information is available, this designation takes the form of a number between +2 and -2 indicating relative magnitude of impact. These numbers are subjective expressions of the sum total of quantitative and qualitative information available to the evaluator(s) and are intended as tools for comparison. They have no absolute definition. Ideally, these numbers are arrived at through coordinated evaluation by several experts.

In this study it has not been possible in many cases to assign a numerical designation to a particular potential impact, due to the general nature of the investigation. In the absence of a <u>specific</u> project at a <u>specific</u> locality, it has not always been possible to determine whether a particular action was to be anticipated or whether a particular element of the environment would be present. In these instances, the matrix indicates only that an impact should be anticipated or whether a particular element of the environment would be present. In these instances, the matrix indicates only that an impact should be anticipated when the action is implemented or if the element of the environment is present. No numerical values are assigned. In certain cases, information available is not sufficient to predict with any confidence the occurrence or absence of impact. These cases are designated by a question mark.

The reader is referred to the text for a discussion of the impacts summarized by these matrices.

ENVIRONMENTAL IMPACT ASSESSMENT MATRIX

		PROPOSED ACTIONS	MODIFICATION OF REGIME				LAND TRANSFORMATION AND CONSTRUCTION					RESOURCE EXTRACTION					RESOURCE RENEWAL			WASTE GENERATION AND DISPOSAL						ACCIDENTS		
ELEMENTS OF THE EXISTING ENVIRONMENT			ALTERATION OF GROUNDWATER HYDROLOGY	ALTERATION OF GROUNDCOVER	NOISE LIGHTING ODOR LEVEL ALTERATION	EXOTIC FLORA INTRODUCTION	SURFACE FACILITIES	IMPOUNDMENTS	BLASTING	WELL AND BOREHOLE DRILLING	NOISE DUST EXHAUST EMISSIONS	FLUID INJECTION AND RECOVERY	FLUID APPLICATION & RECOVERY	LIXIVIANT SUBSURFACE ACTIVITY	MAKE-UP WATER	MINERAL PROCESSING	AQUIFER RESTORATION	SURFACE RESTORATION (REVEGETATION)	WELL AND BOREHOLE CAPPING	EVAPORATION PONDS	TAILINGS PONDS	STREAM DISPOSAL	DEEP WELL INJECTION	BURIAL	ATMOSPHERIC EMISSIONS	SPILLS AND LEAKS	EXPLOSIONS	OPERATIONAL FAILURES
PHYSICAL CHARACTERISTICS	LAND	LAND FORM						-2	-1	-1										-2				-1				
		SOIL		-1									-2					+1										
		SUBSURFACE GEOHYDROLOGY	-1						-2					-1														
	WATER	UNDERGROUND QUANTITY	0										0		-1													
		UNDERGROUND QUALITY					?						-2	-1			+1			-1						-1		
		SURFACE QUANTITY													/													
		SURFACE QUALITY							•		•			?			?									•		
	ATMOSPHERE	AIR QUALITY			-2				-1		-1		-2			-2									-2			
	PHYSICAL PROCESSES	FLOODS																										
		EROSION		-1					-1				-1					+1										
		DEPOSITION/SEDIMENTATION		•					•				•					•										
		SORPTION											-1	-1			?											
		SUBSIDENCE							-1																			
BIOLOGICAL CHARACTERISTICS	FLORA AND FAUNA	AQUATIC PLANTS							•		•		•	?			?									•		
		LAND PLANTS		-1		-2	-1	-1	-1	-1	-1		-2					?										
		RARE/ENDANGERED PLANTS		•		•	•	•	•		•		•															
		AQUATIC ANIMALS							•		•			?												•		
		LAND ANIMALS		-1	-1	-1	-1	-1	-2	-1	-1		-2					?										
		RARE/ENDANGERED ANIMALS		•	•	•	•	•	•	•	•		•					•										
	ECOLOGICAL PROCESSES	EUTROPHICATION																										
		WATER RESOURCE SALINIZATION																										
		FOOD CHAINS																										
		DISEASE VECTORS											-1							-1								
CULTURAL CHARACTERISTICS	LAND USE	OPEN SPACE		-2			-2	-2	-1	-2	-1		-2					?	+1	-2								
		WETLANDS																										
		FORESTRY																										
		GRAZING		-1		-1	-1	-1	-2		-1		-2					?										
		AGRICULTURE																										
		RESIDENTIAL																										
		COMMERCIAL																										
		INDUSTRIAL																										
	RECREATION	FISHING																										
		BOATING																										
		SWIMMING																										
		HUNTING																										
	AESTHETICS AND HUMAN INTEREST	SCENIC VIEWS		•	•		•	•	•		•		•					•	•	•	•		•	•	•			
		WILDERNESS QUALITIES		•	•		•	•	•		•		•					•	•	•	•		•	•	•			
		OPEN SPACE QUALITIES		-2			-2	-2	-1		-2		-2					?	+1	-2					-2			
		PARKS AND RESERVES																										
	CULTURAL STATUS	LIFE STYLE																										
		HEALTH AND SAFETY			-1				-1		-1		-2			-2												
		EMPLOYMENT					+1	+1	+1	+1						+1	+1	+1	+1									
		POPULATION DISTRIBUTION/DENSITY																										
		HISTORICAL/ARCHAEOLOGICAL SITES					•	•	•	•																		
		AMBIENT NOISE LEVEL			-1		-2	-2	-2	-2																		
		AMBIENT ODOR LEVEL			-2						/		-2															
	MAN-MADE FACILITIES AND ACTIVITIES	STRUCTURES																										
		TRANSPORTATION NETWORK																										
		UTILITY NETWORK																										
		ENERGY USAGE					-	-1		-1			-1				-1		-1					-1				
		WASTE DISPOSAL																										

LEGEND

THIS MATRIX ILLUSTRATES AN EVALUATION OF THE MAGNITUDE OF THE IMPACT OF PROPOSED ACTIONS UPON ELEMENTS OF THE EXISTING ENVIRONMENT.

SCALE OF ENVIRONMENTAL IMPACT

MAGNITUDE

BENEFICIAL

+2
+1
0 — NEUTRAL
—1
—2

ADVERSE

- • · IF THE ENVIRONMENTAL ELEMENT IN QUESTION IS PRESENT, AN IMPACT IS ANTICIPATED
- / · THE ACTION IN QUESTION MAY OR MAY NOT BE AN INTRINSIC COMPONENT OF THE PROGRAM. IF IT IS IMPLEMENTED AN IMPACT IS INDICATED
- ? · INSUFFICIENT INFORMATION AVAILABLE

FIGURE A-1 ENVIRONMENTAL IMPACTS OF IN SITU SPRAY LEACHING OF PORPHYRY COPPER - DESERT SOUTHWEST

ENVIRONMENTAL IMPACT ASSESSMENT MATRIX

ELEMENTS OF THE EXISTING ENVIRONMENT			MODIFICATION OF REGIME				LAND TRANSFORMATION AND CONSTRUCTION					RESOURCE EXTRACTION					RESOURCE RENEWAL			WASTE GENERATION AND DISPOSAL						ACCIDENTS		
		PROPOSED ACTIONS	ALTERATION OF GROUNDWATER HYDROLOGY	ALTERATION OF GROUNDCOVER	NOISE LIGHTING ODOR LEVEL ALTERATION	EXOTIC FLORA INTRODUCTION	SURFACE FACILITIES	IMPOUNDMENTS	BLASTING	WELL AND BOREHOLE DRILLING	NOISE DUST EXHAUST EMISSIONS	FLUID INJECTION AND [illegible]	FLUID APPLICATION & RECOVERY	LIXIVIANT SUBSURFACE ACTIVITY	MAKE-UP WATER	MINERAL PROCESSING	AQUIFER RESTORATION	SURFACE RESTORATION (REVEGETATION)	WELL AND BOREHOLE CAPPING	EVAPORATION PONDS	TAILINGS PONDS	STREAM DISPOSAL	DEEP WELL INJECTION	BURIAL	ATMOSPHERIC EMISSIONS	SPILLS AND LEAKS	EXPLOSIONS	OPERATIONAL FAILURES
PHYSICAL CHARACTERISTICS	LAND	LAND FORM						-2	/	-1																		
		SOIL		-1														+1										
		SUBSURFACE GEOHYDROLOGY	-2						/			-1		-1			?											-2
	WATER	UNDERGROUND QUANTITY	0									0			0													
		UNDERGROUND QUALITY							/					-2			?						-1			-2		-2
		SURFACE QUANTITY													/													
		SURFACE QUALITY												?			?									•		
	ATMOSPHERE	AIR QUALITY			-1						-1					-1									-1			
	PHYSICAL PROCESSES	FLOODS																										
		EROSION		-1					/									+1										
		DEPOSITION/SEDIMENTATION							•																			
		SORPTION												?			?											
		SUBSIDENCE							/																			
BIOLOGICAL CHARACTERISTICS	FLORA AND FAUNA	AQUATIC PLANTS							•		•			?			?									•		
		LAND PLANTS		-1		-2	-1	-1	/	-1	-1							+1										
		RARE/ENDANGERED PLANTS		•		•	•	•	•	•	•																	
		AQUATIC ANIMALS							•		•			?			?									•		
		LAND ANIMALS		-2	-1	-1	-1	-1	/	-1	-1							+1										
		RARE/ENDANGERED ANIMALS		•	•	•	•	•	•	•	•							•										
	ECOLOGICAL PROCESSES	EUTROPHICATION																										
		WATER RESOURCE SALINIZATION																										
		FOOD CHAINS																										
		DISEASE VECTORS																										
CULTURAL CHARACTERISTICS	LAND USE	OPEN SPACE		-1			-1	-1																				
		WETLANDS																										
		FORESTRY		?		?	?	?										?										
		GRAZING																										
		AGRICULTURE																										
		RESIDENTIAL																										
		COMMERCIAL																										
		INDUSTRIAL																										
	RECREATION	FISHING																										
		BOATING																										
		SWIMMING																										
		HUNTING																										
	AESTHETICS AND HUMAN INTEREST	SCENIC VIEWS		•	•		•	•	•		•							•	•				•					
		WILDERNESS QUALITIES		•	•		•	•	•		•							•	•				•					
		OPEN SPACE QUALITIES		-1			-1	-1	/		-1							+1	+1				+1					
		PARKS AND RESERVES																										
	CULTURAL STATUS	LIFE STYLE																										
		HEALTH AND SAFETY							/		-1			-2		-1									-1	-2	-2	-1
		EMPLOYMENT					+1	+1	/	+1		+1				+1	+1	+1	+1									
		POPULATION DISTRIBUTION/DENSITY																					+1					
		HISTORICAL/ARCHAEOLOGICAL SITES																										
		AMBIENT NOISE LEVEL			-1		-2	-2	/	-2	-2																	
		AMBIENT ODOR LEVEL			/						/																	
	MAN-MADE FACILITIES AND ACTIVITIES	STRUCTURES																										
		TRANSPORTATION NETWORK																										
		UTILITY NETWORK																										
		ENERGY USAGE																										
		WASTE DISPOSAL																										

LEGEND

THIS MATRIX ILLUSTRATES AN EVALUATION OF THE MAGNITUDE OF THE IMPACT OF PROPOSED ACTIONS UPON ELEMENTS OF THE EXISTING ENVIRONMENT.

SCALE OF ENVIRONMENTAL IMPACT

MAGNITUDE

BENEFICIAL
+2
+1
0 — NEUTRAL
−1
−2
ADVERSE

• = IF THE ENVIRONMENTAL ELEMENT IN QUESTION IS PRESENT, AN IMPACT IS ANTICIPATED

/ = THE ACTION IN QUESTION MAY OR MAY NOT BE AN INTRINSIC COMPONENT OF THE PROGRAM. IF IT IS IMPLEMENTED, AN IMPACT IS INDICATED

? = INSUFFICIENT INFORMATION AVAILABLE

FIGURE A-2 ENVIRONMENTAL IMPACTS OF IN SITU SOLUTION MINING OF NATIVE COPPER - MICHIGAN

ENVIRONMENTAL IMPACT ASSESSMENT MATRIX

ELEMENTS OF THE EXISTING ENVIRONMENT			MODIFICATION OF REGIME				LAND TRANSFORMATION AND CONSTRUCTION					RESOURCE EXTRACTION					RESOURCE RENEWAL			WASTE GENERATION AND DISPOSAL						ACCIDENTS		
		PROPOSED ACTIONS	ALTERATION OF GROUNDWATER HYDROLOGY	ALTERATION OF GROUNDCOVER	NOISE LIGHTING ODOR LEVEL ALTERATION	EXOTIC FLORA INTRODUCTION	SURFACE FACILITIES	IMPOUNDMENTS	BLASTING	WELL AND BOREHOLE DRILLING	NOISE DUST EXHAUST EMISSIONS	FLUID INJECTION AND RECOVERY	FLUID APPLICATION & RECOVERY	LIXIVIANT SUBSURFACE ACTIVITY	MAKE UP WATER	MINERAL PROCESSING	AQUIFER RESTORATION	SURFACE RESTORATION (REVEGETATION)	WELL AND BOREHOLE CAPPING	EVAPORATION PONDS	TAILINGS PONDS	STREAM DISPOSAL	DEEP WELL INJECTION	BURIAL	ATMOSPHERIC EMISSIONS	SPILLS AND LEAKS	EXPLOSIONS	OPERATIONAL FAILURES
PHYSICAL CHARACTERISTICS	LAND	LAND FORM						-2		-1										-2				-1				
		SOIL		-2														+2										
		SUBSURFACE GEOHYDROLOGY	-2									-1		-1			?							?				-2
	WATER	UNDERGROUND QUANTITY	0									0			-2													
		UNDERGROUND QUALITY												-2			+2					0						
		SURFACE QUANTITY													/													
		SURFACE QUALITY									•			?						?		0				•		
	ATMOSPHERE	AIR QUALITY			-1						-1					-1									-1			
	PHYSICAL PROCESSES	FLOODS																										
		EROSION		+1														+1										
		DEPOSITION/SEDIMENTATION		•														•										
		SORPTION												?			?											
		SUBSIDENCE																										
BIOLOGICAL CHARACTERISTICS	FLORA AND FAUNA	AQUATIC PLANTS									•			?			?					0				•		
		LAND PLANTS		-1		-2	-1	-1		-1	-1							+1										
		RARE/ENDANGERED PLANTS		•		•	•	•		•	•																	
		AQUATIC ANIMALS									•			?			?									•		
		LAND ANIMALS		-2	-1	-1	-1	-1		-1	-1							+1										
		RARE/ENDANGERED ANIMALS		•	•	•	•	•		•	•																	
	ECOLOGICAL PROCESSES	EUTROPHICATION																										
		WATER RESOURCE SALINIZATION																										
		FOOD CHAINS																										
		DISEASE VECTORS																		-2								
CULTURAL CHARACTERISTICS	LAND USE	OPEN SPACE		-2			-2	-2																				
		WETLANDS																										
		FORESTRY																										
		GRAZING		-1		-1	-1	-1						?				+1										
		AGRICULTURE																										
		RESIDENTIAL																										
		COMMERCIAL																										
		INDUSTRIAL																										
	RECREATION	FISHING																										
		BOATING																										
		SWIMMING																										
		HUNTING																										
	AESTHETICS AND HUMAN INTEREST	SCENIC VIEWS		•	•		•	•			•							•	•	/			•	•				
		WILDERNESS QUALITIES																•	•	/								
		OPEN SPACE QUALITIES		-2			-2	-2			-1							+2	+2	-2			+1					
		PARKS AND RESERVES																										
	CULTURAL STATUS	LIFE STYLE																										
		HEALTH AND SAFETY									-1			-2		-1				-1			?	?	-1	-2	-2	
		EMPLOYMENT					+1	+1		+1		+1				+1	+1	+1	+1									
		POPULATION DISTRIBUTION/DENSITY																										
		HISTORICAL/ARCHAEOLOGICAL SITES					•	•		•																		
		AMBIENT NOISE LEVEL			-1		-2	-2		-2	-2																	
		AMBIENT ODOR LEVEL			/			/																				
	MAN-MADE FACILITIES AND ACTIVITIES	STRUCTURES																										
		TRANSPORTATION NETWORK																										
		UTILITY NETWORK																										
		ENERGY USAGE					-1	-1		-1		-1					-1		-1				-1	-1				
		WASTE DISPOSAL																										

LEGEND

THIS MATRIX ILLUSTRATES AN EVALUATION OF THE MAGNITUDE OF THE IMPACT OF PROPOSED ACTIONS UPON ELEMENTS OF THE EXISTING ENVIRONMENT.

SCALE OF ENVIRONMENTAL IMPACT

MAGNITUDE

BENEFICIAL
+2
+1
0 NEUTRAL
−1
−2
ADVERSE

• = IF THE ENVIRONMENTAL ELEMENT IN QUESTION IS PRESENT, AN IMPACT IS ANTICIPATED

/ = THE ACTION IN QUESTION MAY OR MAY NOT BE AN INTRINSIC COMPONENT OF THE PROGRAM. IF IT IS IMPLEMENTED, AN IMPACT IS INDICATED

? = INSUFFICIENT INFORMATION AVAILABLE

FIGURE A-3 ENVIRONMENTAL IMPACTS OF IN SITU SOLUTION MINING OF URANIUM - WYOMING

ENVIRONMENTAL IMPACT ASSESSMENT MATRIX

ELEMENTS OF THE EXISTING ENVIRONMENT		PROPOSED ACTIONS	MODIFICATION OF REGIME				LAND TRANSFORMATION AND CONSTRUCTION					RESOURCE EXTRACTION					RESOURCE RENEWAL			WASTE GENERATION AND DISPOSAL						ACCIDENTS		
			ALTERATION OF GROUNDWATER HYDROLOGY	ALTERATION OF GROUNDCOVER	NOISE LIGHTING ODOR LEVEL ALTERATION	EXOTIC FLORA INTRODUCTION	SURFACE FACILITIES	IMPOUNDMENTS	BLASTING	WELL AND BOREHOLE DRILLING	NOISE DUST EXHAUST EMISSIONS	FLUID INJECTION AND RECOVERY	FLUID APPLICATION & RECOVERY	LIXIVIANT SUBSURFACE ACTIVITY	MAKE-UP WATER	MINERAL PROCESSING	AQUIFER RESTORATION	SURFACE RESTORATION (REVEGETATION)	WELL AND BOREHOLE CAPPING	EVAPORATION PONDS	TAILINGS PONDS	STREAM DISPOSAL	DEEP WELL INJECTION	BURIAL	ATMOSPHERIC EMISSIONS	SPILLS AND LEAKS	EXPLOSIONS	OPERATIONAL FAILURES
PHYSICAL CHARACTERISTICS	LAND	LAND FORM						-2		-1										/								
		SOIL		-2														+2										
		SUBSURFACE GEOHYDROLOGY	-2									-1					?											-2
	WATER	UNDERGROUND QUANTITY	0									0			0													
		UNDERGROUND QUALITY												-2			+2									-2		-2
		SURFACE QUANTITY													/													
		SURFACE QUALITY									•			?			?									•		
	ATMOSPHERE	AIR QUALITY			-1						-1					-1									-1			
	PHYSICAL PROCESSES	FLOODS																										
		EROSION		-1														+1										
		DEPOSITION/SEDIMENTATION		•														•										
		SORPTION												?			?											
		SUBSIDENCE																										
BIOLOGICAL CHARACTERISTICS	FLORA AND FAUNA	AQUATIC PLANTS									•			?			?									•		
		LAND PLANTS		-1		-2	-1	-1		-1	-1							+1										
		RARE/ENDANGERED PLANTS		•		•	•	•		•	•																	
		AQUATIC ANIMALS									•			?			?									•		
		LAND ANIMALS		-2	-1	-1	-1	-1		-1	-1							+1										
		RARE/ENDANGERED ANIMALS		•	•	•	•	•		•	•							•										
	ECOLOGICAL PROCESSES	EUTROPHICATION																										
		WATER RESOURCE SALINIZATION																										
		FOOD CHAINS																										
		DISEASE VECTORS																		/								
CULTURAL CHARACTERISTICS	LAND USE	OPEN SPACE		-2			-2	-2																				
		WETLANDS																										
		FORESTRY																										
		GRAZING		-1		-1	-1	-1						?				+1										
		AGRICULTURE																										
		RESIDENTIAL																										
		COMMERCIAL																										
		INDUSTRIAL																										
	RECREATION	FISHING																										
		BOATING																										
		SWIMMING																										
		HUNTING																										
	AESTHETICS AND HUMAN INTEREST	SCENIC VIEWS		•	•		•	•			•							•	•	/			•					
		WILDERNESS QUALITIES		•	•		•	•			•							•	•	/			•					
		OPEN SPACE QUALITIES		-2			-2	-2			-1							+2	+2	/			+1					
		PARKS AND RESERVES																										
	CULTURAL STATUS	LIFE STYLE																										
		HEALTH AND SAFETY									-1			-2		-1				/			?		-1	-2	-2	-1
		EMPLOYMENT					+1	+1		+1						+1	+1	+1										
		POPULATION DISTRIBUTION/DENSITY																										
		HISTORICAL/ARCHAEOLOGICAL SITES					•	•		•																		
		AMBIENT NOISE LEVEL			-1		-2	-2		-2	-2																	
		AMBIENT ODOR LEVEL			/						/																	
	MAN-MADE FACILITIES AND ACTIVITIES	STRUCTURES																										
		TRANSPORTATION NETWORK																										
		UTILITY NETWORK																										
		ENERGY USAGE					-1	-1		-1		-1					-1		-1				-1					•
		WASTE DISPOSAL																										

LEGEND

THIS MATRIX ILLUSTRATES AN EVALUATION OF THE MAGNITUDE OF THE IMPACT OF PROPOSED ACTIONS UPON ELEMENTS OF THE EXISTING ENVIRONMENT.

SCALE OF ENVIRONMENTAL IMPACT

MAGNITUDE

BENEFICIAL

+2
+1
0 NEUTRAL
−1
−2

ADVERSE

• = IF THE ENVIRONMENTAL ELEMENT IN QUESTION IS PRESENT, AN IMPACT IS ANTICIPATED

/ = THE ACTION IN QUESTION MAY OR MAY NOT BE AN INTRINSIC COMPONENT OF THE PROGRAM. IF IT IS IMPLEMENTED, AN IMPACT IS INDICATED

? = INSUFFICIENT INFORMATION AVAILABLE

FIGURE A-4 ENVIRONMENTAL IMPACTS OF IN SITU SOLUTION MINING OR URANIUM - TEXAS

ENVIRONMENTAL IMPACT ASSESSMENT MATRIX

PROPOSED ACTIONS

MODIFICATION OF REGIME · LAND TRANSFORMATION AND CONSTRUCTION · RESOURCE EXTRACTION · RESOURCE RENEWAL · WASTE GENERATION AND DISPOSAL · ACCIDENTS

ELEMENTS OF THE EXISTING ENVIRONMENT

			ALTERATION OF GROUNDWATER HYDROLOGY	ALTERATION OF GROUNDCOVER	NOISE LIGHTING ODOR LEVEL ALTERATION	EXOTIC FLORA INTRODUCTION	SURFACE FACILITIES	IMPOUNDMENTS	BLASTING	WELL AND BOREHOLE DRILLING	NOISE DUST EXHAUST EMISSIONS	FLUID INJECTION AND RECOVERY	FLUID APPLICATION & RECOVERY	LIXIVIANT SUBSURFACE ACTIVITY	MAKE UP WATER	MINERAL PROCESSING	AQUIFER RESTORATION	SURFACE RESTORATION (REVEGETATION)	WELL AND BOREHOLE CAPPING	EVAPORATION PONDS	TAILINGS PONDS	STREAM DISPOSAL	DEEP WELL INJECTION	BURIAL	ATMOSPHERIC EMISSIONS	SPILLS AND LEAKS	EXPLOSIONS	OPERATIONAL FAILURES
PHYSICAL CHARACTERISTICS	LAND	LAND FORM						-2		-1											-2							
		SOIL		-1														+1										
		SUBSURFACE GEOHYDROLOGY	-1										-1				?							?				
	WATER	UNDERGROUND QUANTITY	0										0		-1		?											
		UNDERGROUND QUALITY											0				0				?							
		SURFACE QUANTITY													/		/											
		SURFACE QUALITY									•															-2		
	ATMOSPHERE	AIR QUALITY			-1						-1																	
	PHYSICAL PROCESSES	FLOODS																										
		EROSION		-1														+1										
		DEPOSITION/SEDIMENTATION		•														•										
		SORPTION																										
		SUBSIDENCE											-2															
BIOLOGICAL CHARACTERISTICS	FLORA AND FAUNA	AQUATIC PLANTS									•															-2		
		LAND PLANTS		-1		-2	-1	-1		-1	-1							+1										
		RARE/ENDANGERED PLANTS					•	•		•	•		•													•		
		AQUATIC ANIMALS									•											/				2		
		LAND ANIMALS		-1	-1	-1	-1	-1		-1	-1							+1										
		RARE/ENDANGERED ANIMALS		•	•	•	•	•		•	•							•								•		
	ECOLOGICAL PROCESSES	EUTROPHICATION																										
		WATER RESOURCE SALINIZATION																										
		FOOD CHAINS																								-2		
		DISEASE VECTORS											-1								-1							
CULTURAL CHARACTERISTICS	LAND USE	OPEN SPACE		-2			-2	2			-1										-2							
		WETLANDS		-1			-1	-1		-1	-1															-2		
		FORESTRY																										
		GRAZING																										
		AGRICULTURE																										
		RESIDENTIAL																										
		COMMERCIAL																										
		INDUSTRIAL																										
	RECREATION	FISHING																										
		BOATING																										
		SWIMMING																								-2		
		HUNTING																										
	AESTHETICS AND HUMAN INTEREST	SCENIC VIEWS		•	•		•	•			•							•	•	•	•		•	•	•			
		WILDERNESS QUALITIES		•	•		•	•			•							•	•	•	•		•	•	•	-2		
		OPEN SPACE QUALITIES		-2			-2	-2			-1							+2	+1		-2							•
		PARKS AND RESERVES																										
	CULTURAL STATUS	LIFE STYLE																										
		HEALTH AND SAFETY									-1															-2	-2	-1
		EMPLOYMENT					+1	+1		+1						+1	+1	+1	+1									
		POPULATION DISTRIBUTION/DENSITY																										
		HISTORICAL/ARCHAEOLOGICAL SITES					•	•		•			•															
		AMBIENT NOISE LEVEL			-1		-2	-2		-2	-2		-1															
		AMBIENT ODOR LEVEL			-1						/				•													
	MAN-MADE FACILITIES AND ACTIVITIES	STRUCTURES																										
		TRANSPORTATION NETWORK																										
		UTILITY NETWORK																										
		ENERGY USAGE					-1	-1		-1			-1				-1		-1				-1	-1				
		WASTE DISPOSAL																										

LEGEND

THIS MATRIX ILLUSTRATES AN EVALUATION OF THE MAGNITUDE OF THE IMPACT OF PROPOSED ACTIONS UPON ELEMENTS OF THE EXISTING ENVIRONMENT.

SCALE OF ENVIRONMENTAL IMPACT

MAGNITUDE

BENEFICIAL

+2
+1
0 — NEUTRAL
−1
−2

ADVERSE

• = IF THE ENVIRONMENTAL ELEMENT IN QUESTION IS PRESENT, AN IMPACT IS ANTICIPATED

/ = THE ACTION IN QUESTION MAY OR MAY NOT BE AN INTRINSIC COMPONENT OF THE PROGRAM. IF IT IS IMPLEMENTED, AN IMPACT IS INDICATED

? = INSUFFICIENT INFORMATION AVAILABLE.

FIGURE A-5 ENVIRONMENTAL IMPACTS OF HYDRAULIC BOREHOLE SLURRY MINING OF PHOSPHATE - FLORIDA

ENVIRONMENTAL IMPACT ASSESSMENT MATRIX

ELEMENTS OF THE EXISTING ENVIRONMENT			MODIFICATION OF REGIME				LAND TRANSFORMATION AND CONSTRUCTION					RESOURCE EXTRACTION					RESOURCE RENEWAL			WASTE GENERATION AND DISPOSAL						ACCIDENTS		
		PROPOSED ACTIONS	ALTERATION OF GROUNDWATER HYDROLOGY	ALTERATION OF GROUNDCOVER	NOISE LIGHTING ODOR LEVEL ALTERATION	EXOTIC FLORA INTRODUCTION	SURFACE FACILITIES	IMPOUNDMENTS	BLASTING	WELL AND BOREHOLE DRILLING	NOISE DUST EXHAUST EMISSIONS	FLUID INJECTION AND RECOVERY	FLUID APPLICATION & RECOVERY	LIXIVIANT SUBSURFACE ACTIVITY	MAKE-UP WATER	MINERAL PROCESSING	AQUIFER RESTORATION	SURFACE RESTORATION (REVEGETATION)	WELL AND BOREHOLE CAPPING	EVAPORATION PONDS	TAILINGS PONDS	STREAM DISPOSAL	DEEP WELL INJECTION	BURIAL	ATMOSPHERIC EMISSIONS	SPILLS AND LEAKS	EXPLOSIONS	OPERATIONAL FAILURES
PHYSICAL CHARACTERISTICS	LAND	LAND FORM						-2		-1											-2							
		SOIL		-1														+1										
		SUBSURFACE GEOHYDROLOGY	-1										-1				?							?				
	WATER	UNDERGROUND QUANTITY	0										0		+1		?											
		UNDERGROUND QUALITY											0				0				?							
		SURFACE QUANTITY													/		/											
		SURFACE QUALITY									•															2		
	ATMOSPHERE	AIR QUALITY			-1						-1																	
	PHYSICAL PROCESSES	FLOODS																										
		EROSION		+1														+1										
		DEPOSITION/SEDIMENTATION		•														•										
		SORPTION												•														
		SUBSIDENCE											2															
BIOLOGICAL CHARACTERISTICS	FLORA AND FAUNA	AQUATIC PLANTS									•															-2		
		LAND PLANTS		-1		-2	-1	-1		-1	-1							+1										
		RARE/ENDANGERED PLANTS		•		•	•	•		•	•	•	•													•		
		AQUATIC ANIMALS									•											/				-2		
		LAND ANIMALS		-1	-1	-1	-1	-1		-1	-1							+1										
		RARE/ENDANGERED ANIMALS		•	•	•	•	•		•	•		•					•								•		
	ECOLOGICAL PROCESSES	EUTROPHICATION																										
		WATER RESOURCE SALINIZATION																										
		FOOD CHAINS																								-2		
		DISEASE VECTORS											-1								-1							
CULTURAL CHARACTERISTICS	LAND USE	OPEN SPACE		-2			-2	-2			-1										-2							
		WETLANDS		-1			-1	-1		-1	-1															-2		
		FORESTRY																										
		GRAZING																										
		AGRICULTURE																										
		RESIDENTIAL																										
		COMMERCIAL																										
		INDUSTRIAL																										
	RECREATION	FISHING																										
		BOATING																										
		SWIMMING																								-2		
		HUNTING																										
	AESTHETICS AND HUMAN INTEREST	SCENIC VIEWS		•	•		•	•			•							•	•	•	•		•	•	•			
		WILDERNESS QUALITIES		•	•		•	•			•							•	•	•	•		•	•	•	-2		
		OPEN SPACE QUALITIES		-2			-2	-2			-1																	
		PARKS AND RESERVES																										
	CULTURAL STATUS	LIFE STYLE																										
		HEALTH AND SAFETY									-1															-2	-2	-1
		EMPLOYMENT					+1	+1		+1						+1	+1	+1	+1									
		POPULATION DISTRIBUTION/DENSITY																										
		HISTORICAL/ARCHAEOLOGICAL SITES					•	•		•			•															
		AMBIENT NOISE LEVEL			-1		-2	-2		-2	-2		-1															
		AMBIENT ODOR LEVEL			-1																				/			
	MAN-MADE FACILITIES AND ACTIVITIES	STRUCTURES																										
		TRANSPORTATION NETWORK																										
		UTILITY NETWORK																										
		ENERGY USAGE					-1	-1		-1			-1				-1		-1				-1	-1				
		WASTE DISPOSAL																										

LEGEND

THIS MATRIX ILLUSTRATES AN EVALUATION OF THE MAGNITUDE OF THE IMPACT OF PROPOSED ACTIONS UPON ELEMENTS OF THE EXISTING ENVIRONMENT.

SCALE OF ENVIRONMENTAL IMPACT

MAGNITUDE

BENEFICIAL

+2
+1
0 NEUTRAL
−1
−2

ADVERSE

• = IF THE ENVIRONMENTAL ELEMENT IN QUESTION IS PRESENT, AN IMPACT IS ANTICIPATED

/ = THE ACTION IN QUESTION MAY OR MAY NOT BE AN INTRINSIC COMPONENT OF THE PROGRAM. IF IT IS IMPLEMENTED, AN IMPACT IS INDICATED

? = INSUFFICIENT INFORMATION AVAILABLE

FIGURE A-6 ENVIRONMENTAL IMPACTS OF HYDRAULIC BOREHOLE SLURRY MINING OF PHOSPHATE - NORTH CAROLINA

APPENDIX B

GLOSSARY OF TERMS RELATED TO SOLUTION MINING

Adsorptive capacity. Physical limit of adhesion of ions in solution to the surfaces of solids with which they are in contact.

ADU. Ammonium diuranate. Approximate chemical composition is given as $[UO_2(OH)_2 \text{ x } H_2O\ NH_4^+]$ salt. ADU is not the common oxide form of uranium "yellowcake" or U_3O_8 (triuranium octaoxide).

Alkalinity. A measure of the power of a solution to neutralize hydrogen ions, expressed in terms of an equivalent amount of calcium carbonate.

Alluvium. Clay, silt, sand, gravel, or other rock materials transported by flowing water and deposited in comparatively recent geologic time as sorted or semisorted sediments.

Annular space (annulus). The space between casing or well screen and the wall of the drilled hole.

Aquiclude. Geological formation that, although porous and capable of absorbing water, does not transmit it at rates sufficient to furnish an appreciable supply for a well or spring.

Aquifer. Porous water-bearing formation (bed or stratum) of permeable rock, sand, or gravel capable of yielding significant quantities of water for drinking, processing, agriculture and other purposes.

Aquifer, leaky. Aquifer overlain and/or underlain by a thin semipervious layer through which water flow into or out of the aquifer can take place.

Aquitard. Geological formation of a nearly impervious and semiconfining nature which transmits water at a very slow rate compared with an aquifer.

Area of influence. Area around a pumping well in which the water table or the piezometric surface (in confined aquifers) is lowered by pumping.

Artesian. The occurrence of groundwater under greater than atmospheric pressure.

Artesian (confined) aquifer. An aquifer overlain by confining beds containing water under artesian conditions.

Artesian well. Well tapping a confined artesian aquifer in which the static water level rises above the surface of the ground.

Assessment actions. Those evaluative actions taken during or after an accident to obtain and process information that is necessary to make decisions to implement specific emergency measures; also, actions taken for environmental and health and safety considerations.

Barren lixiviant. Leachant solution pumped underground to an ore body before it solubilizes up uranium ions.

Baseline. The environmental condition that existed prior to mining as determined by physical and/or chemical parameters and their natural variability.

Bleed system. A production adjustment technique whereby more fluid is pumped from the production zone than is injected, creating an inflow of surrounding groundwater into the production area.

Borehole. A hole with a drill, auger, or other tools for exploring strata in search of minerals for water supply, for blasting purposes, for proving the position of old workings, faults, and for releasing accumulations of gas or water.

Boundary, geohydrologic. Lateral discontinuity in geologic material, making the transition from the permeable material of an aquifer to a material of significantly different geohydrologic properties.

Boundary, impervious. Boundary of a flow through which no flow can take place because of greatly reduced permeability at the other side of the boundary.

Brine. A highly saline solution (usually greater than 100,000 mg/liter), usually of chloride salts of sodium, calcium and magnesium.

Capacity. Volume that can be contained by a tank, pond, or other vessel. Also a rate of flow that can be carried by any conducting structure.

Capacity, specific. Ratio of discharge (output) of a well to drawdown (fall of water table around well) at equilibrium.

Capillary diffusion. Movement of water by capillarity in a porous medium.

Casing. Steel or plastic pipe or tubing that is placed in a borehole to prevent entry of loose rock, gas, or liquid or to prevent loss of drilling fluid.

Chemical water quality. The nature of water as determined by its concentration of chemical and biological constituents.

Clogging. Deposition of fine particles such as clay or silt at the surface and in the pores of a permeable porous medium, e.g., soil, resulting in the reduction of permeability.

Coefficient of permeability. The quantity of water that will flow through a unit cross-sectional area per unit of time under a unit hydraulic gradient at a temperature of 15.5°C (60°F).

Concentration. The weight of solute dissolved in a unit volume of solution commonly expressed as milligrams/liter or grams/liter.

Conductivity, hydraulic. Combined property of a porous medium and the fluid moving through it in saturated flow, which determines the relationship, called Darcy's law, between the specific discharge and the head gradient causing it.

Cone of depression. The depression, ideally conical in shape, that is formed in a water table or potentiometric surface when water is removed from a well.

Confining bed. Formation overlying or underlying a much more permeable aquifer.

Consumptive use. That part of the water withdrawn from a well or other source that is no longer available because it has been evaporated, transferred, incorporated into products or crops, or otherwise removed from the immediate water environment.

Contamination. The degradation of natural water quality as a result of man's activities to the extent that its usefulness is impaired. There is no implication of any specific limits, since the degree of permissible contamination depends upon the intended end use, or uses, of the water.

Corrective actions. Those measures taken to ameliorate or terminate a situation at or near the source of the problem in order to prevent an uncontrolled release of radioactive or toxic material or to reduce the magnitude of a release, e.g., shutting down equipment, repair and damage control, or reorganizing pumping arrangements.

Curie. The quantity of any radioactive material giving 3.7×10^{10} disintegrations per second. A picocurie is one trillionth (10^{-12}) of a Curie, or a quantity of radioactive material giving 3.7×10^{-2} disintegrations/sec or 2.22 disintegrations/minute.

Darcy. Unit of intrinsic permeability defined as the permeability of a medium in which a liquid of dynamic viscosity of 1 centipoise discharges 1 cm^3/sec through a cross section of 1 cm^2 under a gradient normal to the section of 1 atm/cm.

Darcy's law. Law expressing the proportionality of the specific discharge of a liquid flowing through a porous medium to a hydraulic gradient in laminar flow (low Reynolds numbers).

Degradable. Capable of being decomposed, deteriorated, or decayed into simpler chemical forms with characteristics different from the original; also referred to as biodegradable when readily decomposed by micro-organisms.

Degradation of water quality. The act or process of reducing the level of water quality so as to impair its original usefulness.

Depletion. Continued withdrawal of water from groundwater at a rate greater than the rate of replenishment; reduction of groundwater storage in an aquifer or of the flow of a stream or spring caused by discharge exceeding natural recharge.

Dewatering. Removing water by gravity or by pumping.

Dewatering coefficient. Amount of water removed per unit horizontal area and unit drawdown.

Dispersivity. Property of a porous matrix to cause spreading of a tracer traveling through it.

Dissolved solids. Total weight of dissolved constituents in water per unit volume or unit weight of water in the sample.

Dominant direction of groundwater movement. The principal expected direction of maximal groundwater flow. This dominant direction of movement is a result of three major variables: the transmissivity of the aquifer, the hydraulic gradient, and the differential applied hydraulic pressure.

Downstream. In the direction of the current of water flow. Applicable to surface streams or underground water movement.

Drawdown. Lowering of the water table or piezometric surface caused by the extraction of groundwater by pumping, by artesian flow from a borehole, or by a spring emerging from an aquifer.

Drawdown, equilibrium. Drawdown of the water table or of the piezometric surface near a pumping well, at constant discharge, after a stationary condition has been reached.

Effluent. A waste liquid, solid, or gas, in its natural state or partially or completely treated, that discharges into the environment.

Eh. The potential gained in the transfer of 1 mole of electrons from an oxidant to H_2, expressed in volts - also known as redox potential.

Electrical resistivity. The differences in electrical response between one pair of points and another.

Eluant. The solution that removes (elutes) a material adsorbed on ion exchange resin.

Emergency action levels. Specific contamination levels of airborne, water-borne, or surface-deposited concentrations of radioactive or toxic materials; or specific instrument indications that may be used as thresholds for initiating such specific emergency measures as designating a particular class of emergency, initiating a notification procedure, or initiating a particular protective action.

Excursion. The movement of lixiviant (leachant solution) out of a leaching zone, as evidenced by measured movement at a trend or monitor well. Measurement is by an increase of selected parameter values above their established upper control limits.

Freeboard. Vertical distance between the normal maximum level of the surface of the liquid in a conduit, reservoir, tank, canal, etc., and the top of the sides of an open conduit, the top of a dam or levee, etc.

Groundwater. Water beneath the land surface in a saturated rock, pebble or sand zone that is under atmospheric or artesian pressure; the water that enters wells and issues from springs.

Groundwater management. The development and utilization of the underground resources (water, storage capacity, and transmission capacity), frequently in conjunction with surface water resources, in a rational and optimal manner to achieve defined and accepted water resource development objectives. Quality as well as quantity must be considered. The surface water resources involved may include imported and reclaimed water as well as tributary streams.

Groundwater, mining of. Withdrawal from a groundwater reservoir in excess of the average rate of replenishment.

Groundwater recession. Natural lowering of the groundwater level in an area.

Grout. To fill, or the material filling, the space around the pipe in a well, usually between the pipe and the drilled hole. The material is ordinarily a mixture of portland cement and water.

Hardness, carbonate. Hardness of water resulting from the presence of dissolved calcium and magnesium bicarbonates (temporary hardness).

Hardness, noncarbonate. Hardness of water resulting from the presence of dissolved calcium and magnesium salts other than carbonates (permanent hardness).

Hardness of water. The property of water, due mainly to bicarbonates, chlorides, and sulfates of calcium and magnesium, which prevents the production of abundant lather with soap.

Hazardous waste. Any waste or combination of wastes (which pose a substantial present or potential hazard to human health or living organisms) whose properties include flammability, evolution of toxic or irritating vapors, contact irritation, or human or animal toxicity.

Heavy metals. Metallic elements, including the transition metal series, which also include many elements required for plant and animal nutrition in trace concentrations but which become toxic at high concentrations. Examples are mercury, chromium, cadmium, and lead.

Hydraulic gradient. The change in static head per unit of distance along a flow path.

Igneous. Formed by solidification from a molten state; the rocks of one of the two great classes (metamorphic being the other class) into which all rocks are divided and contrasted with sedimentary.

Impoundment. A body of water formed by collecting water, as by a dam.

Infiltration. The flow of a liquid into soil or rock through pores or small openings.

Injection well. A well used for injecting fluids into an underground stratum or ore body by gravity flow or under pressure.

Ion exchange. Reversible exchange of ions absorbed on a mineral or synthetic polymer surface with ions in solution in contact with the surface. In the case of clay minerals, polyvalent ions tend to exchange for monovalent ions.

In situ. In place or in (natural) position.

Leachate. The liquid that has percolated through solid ore, waste, or other man-emplaced medium and has extracted dissolved or suspended material from it.

Leakage. In groundwater, the flow of water from or into an aquifer through an underlying or overlying semipervious layer.

Lixiviant. Leachate solution pumped underground to an ore body; it may be alkaline or acid in character.

Metamorphic. Characteristic of, pertaining to, produced by, or occurring during the metamorphism of certain rocks.

Mine field. Refers to the well field area(s) and affected surface associated with in situ leach mining. The term is often used interchangeably with well field.

Mine zone. The area from which an ore is extracted, including related buildings and structures. In this instance, it would include the ore body, all associated surface areas, and related well fields, process equipment, and buildings.

Mining unit (production unit). A segment or portion of an ore body capable of economically supporting mineral extraction; the minable limits of an ore body, which would normally include several production fields.

Monitor well. A surveillance (observation) well located usually along the periphery of a well field. It is used to indicate containment and/or lixiviant migration beyond the well-field boundary. When the upper control limit (concentration value) in a monitor well is exceeded, corrective action is initiated.

Monitor well zone. The area of possible monitor well location. This zone is normally outside the limits of mineralization, but can be within the limits of demineralization.

Nonpoint source. A series of sources from which the contaminant enters the receiving water in an intermittent and/or diffuse manner, as runoff from a field into an adjacent waterway.

Nonproduction zone(s). Those stratigraphic intervals underlying and overlying the production zone that are aquifers or that are relatively permeable.

Ore body. The mineralized portion of the sandstone formation where the mineral is found in various grades and concentrations which can be extracted economically.

Osmosis. Passage of a solvent from a dilute solution to a more concentrated one through a semipermeable membrane (one that is permeable to the solvent only).

Oxidation. A chemical reaction in which there is an increase in positive valence of an element from a loss of electrons; in contrast to reduction.

Percolation. Movement under hydrostatic pressure of water through unsaturated interstices of rock or soil.

Permeability. Property of a porous medium to allow for the movement of liquids and gases through it under the combined action of gravity and pressure.

Permeable rock. Rock having a texture that permits water to move through it perceptibly, under a head or gradient ordinarily found in subsurface water (pervious rock).

pH. Minus the logarithm of the hydrogen ion concentration (activity), in moles/liters. It is used as an indicator of acidity (pH less than 7) or alkalinity (pH greater than 7).

Phreatic divide (groundwater divide). Line on a water table along the sides of which the groundwater flows in opposite directions.

Piezometric surface. The surface defined by the levels to which water under artesian conditions will rise in tightly cased wells; also called potentiometric surface.

Plume. In water quality management and control, a body of contaminated groundwater originating from a specific source (water anology to smokestock in wind) and influenced by such factors as the local groundwater flow pattern, density of contaminant, and character of the aquifer.

Point source. Any discernible confined and discrete conveyance, including but not limited to any pipe, ditch, channel, tunnel, conduit, well, discrete fissure, container, rolling stock, or concentrated animal feeding operation, from which contaminants are or may be discharged onto the land, water or air.

Pollutants (water). Substances including toxic compounds that may become dissolved, suspended, absorbed, or otherwise contained in water and impair its usefulness.

Pollution (water). The degradation of natural water quality, as a result of man's activities, to the extent that its usefulness is impared.

Ponds. Small storage reservoirs.

Pore. A very small open space or void in rock or soil.

Porosity. The relative volume of the pore spaces between mineral grains in a rock as compared with the total rock volume. Expressed as percent void space or porosity.

Porous medium. Solid body containing interconnected pores more or less evenly distributed.

Pregnant lixiviant. Leaching solution containing uranium, copper, or other materials solubilized from the ore body.

Production area. The area of injection and production activity, which can be portrayed by a plan view of the well-field area and vertically by a cross section extending typically from the surface to at least 3 meters (10 ft) below the bottom of the lowest production zone.

Production cell. The grouping of injection wells about a production or recovery well arranged in various configurations and varying in number.

Production field (zone). Mine or well field(s) actively used for production. It could consist of two or more well cells.

Production module. A process plant that is modularized for ease of installation and removal and is capable of handling a given production flow and output from an in situ leaching operation.

Production well (recovery well). A well from which lixiviant is recovered for conveyance to a recovery or processing plant.

Production zone. That stratigraphic interval into which leaching chemicals are introduced. This interval extends horizontally in all directions through and beyond the production area.

Pump test. Extraction of water from a well at one or more selected discharge rates, during which piezometric or phreatic levels are measured regularly at the pumped well and at nearby observation wells. The data are used for determining the aquifer parameters in the vicinity of the pumped well.

Purification. Treatment of water for the removal of harmful or undesirable physical properties, chemical substances, and living micro-organisms.

Radius of influence. Distance from the axis of a pumped or recharged well at which the effect of the well on the piezometric or the phreatic surface is no longer perceptible.

Raffinate. The aqueous solution remaining after uranium or material being recovered has been extracted by the solvent; tailing of the solvent extraction system.

Recharge. The addition of water to the groundwater system by natural or artificial processes.

Reclamation. The return of the surface environment to acceptable preexisting conditions. This normally includes equipment removal, well plugging, surface contouring, and reseeding.

Recovery actions. Those actions taken after an emergency to restore the plant or facility as nearly as possible to its normal operational condition.

Redox potential. The potential gained in the transfer of 1 mole of electrons from an oxidant to H_2, expressed in volts or millivolts - also known as Eh.

Reduction. A chemical reaction in which there is a decrease in positive valence as a result of gaining of electrons.

Residual drawdown. The difference between the static water level in wells and the observed water level during recovery.

Restoration. The returning of the affected groundwater quality to its premining use by employing the best practical technology, consistent with environmental considerations and economics.

Reverse Osmosis. A desalination process applicable to brackish and seawaters utilizing a semipermeable membrane. High pressures (25-50 atmospheres) are required for driving the water through the membranes.

Roll front (uranium). Uranium deposition localized as a roll or interface separating an oxidized interior from a reduced exterior. The reduced side of this interface is significantly enriched in uranium, sometimes crescent-shaped in plan view.

Runoff. Direct or overland runoff is that portion of rainfall which is not absorbed by soil, evaporated, or transpired by plants but finds its way into streams as surface flow.

Saturated zone. The soil zone in which interconnected interstices are saturated with water under pressure equal to or greater than atmospheric.

Sedimentary rock. Rocks formed from the accumulation and compaction of sediment.

Seepage. Slow movement of water in unsaturated rock material; loss of water by infiltration into the soil from a canal or other body of water.

Semi-confining bed. A horizontal stratum restricting but not eliminating water seepage or flow.

Solution channels (holes or cavities). Fractures, joints, bedding planes, or other openings in soluble rocks, through which flow can occur (especially in limestone).

Sorption. A general term used to encompass processes of adsorption, absorption, desorption, ion exchange, ion exclusion, ion retardation, chemisorption, and dialysis.

Specific conductance. The ability of a cubic centimeter of water or solution to conduct electricity; varies directly with the amount of ionized minerals in the water.

Static water level. The water level that was first observed prior to pumping and the level to which the water returns following pumping or injection.

Storage coefficient. Volume of water released from storage in each vertical column of the aquifer having a base of 1 meter square (1 foot square) when the water table or other piezometric surface declines 1 meter (1 foot).

Stratigraphy. Concerning the sequence of rock types formed on the earth's surface. Each stratum is defined by its composition, distribution, succession, and geologic era.

Subsidence. Surface caving or distortion brought about by collapse of deep mine workings or cavernous carbonate formations, or from overpumping of certain types of aquifers.

Surface water. That portion of water that appears on the land surface (oceans, lakes, rivers).

Toxicity. The ability of a material to produce injury or disease upon exposure, ingestion, inhalation, or assimilation by a living organism.

Transmissivity. The rate at which water is transmitted through a unit width of the aquifer under a unit hydraulic gradient. It is expressed as the product of the hydraulic conductivity and the thickness of the saturated portion of the aquifer.

Trend well. Surveillance well for production control and/or monitoring located between the well field and the monitor wells.

Unsaturated zone. Consists of interstices occupied partially by water and partially by air and is limited above by the land surface and below by the water table.

Upconing. The upward migration of groundwater from underlying strata into an aquifer caused by a reduced hydrostatic pressure in the aquifer as a result of pumping.

Upper control limit (UCL). A concentration value for any designated chemical species (indicator species) that must not be exceeded in a monitor well. Corrective actions are initiated when the upper control limits are exceeded and are continued until UCL values are returned to acceptable levels.

Upstream. In the direction opposite to the main current of a stream on the surface or underground.

Waste. Solids or liquids (including from solution mining or associated processes) of no further value and subject to no additional productive processing. These are normally stored for concentration and ultimate disposal. Some process streams may be waste streams.

Water, brackish. Water containing salt, but significantly less than seawater. The concentration of total dissolved solids is usually in the range of 1,000-10,000 mg/liter.

Water conservation. Measures introduced to reduce the amount of water used for any purpose and/or to protect it from pollution.

Water demand. Actual quantity of water required for various needs over a given period as conditioned by economic, social, and other factors to satisfy a known or estimated requirement.

Water, drinking. Water suitable for drinking (potable).

Water, fresh. Water neither salty or bitter to the taste and in general chemically suited for human consumption (having a low dissolved solids content).

Water quality. Pertaining to the chemical, physical, and biological constituents found in water and its suitability for a particular purpose.

Water resources. Supply of water in a given area or basin interpreted in terms of availability of surface and underground water.

Water supply system. All storage reservoirs, pumps, pipes, and treatment works required for providing water of a desired quality to the different sectors of consumption.

Water table. That surface in an unconfined groundwater body at which the pressure is atmospheric. It defines the top of the saturated zone.

Water table aquifer. An aquifer containing water under atmospheric conditions.

Water yield. See yield.

Well capacity. Maximum rate at which a well will yield under a stipulated set of conditions, such as a given drawdown.

Well completion. Techniques used to control horizontal underground movement of injected fluids from a well and to maintain the integrity of over and underlying layers.

Well, disposal. Well used for the disposal of polluted or drainage water brines, etc.

Well field (mine field). Several production cells capable of supplying a given feed to a recovery plant.

Well, fully penetrating. Well that extends through the whole saturated depth of an aquifer and is constructed in such a manner that water is permitted to enter the well throughout its length.

Well, partially penetrating. Well in which the length of water entry is less than the thickness of the saturated aquifer that it penetrates.

Well radius, effective. Horizontal distance from the axis of a well to the maximum extent out into the aquifer from which poor-water supplies the well.

Yield of aquifer (economic). Maximum rate at which water can be pumped from an aquifer in the foreseeable future without continuously lowering the water table, depleting the supply, or altering the chemical character of the water to such an extent that withdrawal at that rate is no longer economically possible.

Yield, optimal. Amount of water that can be withdrawn annually from an aquifer or from a basin, according to some predetermined criterion of optimal use.

Yield, safe. Amount of water (in general the long-term average amount) that can be withdrawn from a groundwater basin or surface water system without providing undesirable results.

Zone of saturation. That part of the lithosphere in which the pores are completely filled with water.