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16. Abstract (Limit: 200 words)

This report details work performed and results obtained in a study of the water management aspects of oil shale mining and retorting in the Piceance Creek Basin. Three specific sites were investigated, and optimal water management systems for both conventional and in situ extraction processes were generated. Water-related legal and environmental constraints on development were identified and the water management schemes were developed in compliance with these regulations. Limitations on shale oil production implied by limited water supplies were evaluated. Potential basin-wide effects of development were evaluated using a computer model, and mitigation strategies were developed. Recommendations for additional investigation and analyses were presented.

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APPENDICES

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APPENDIX B

LEGAL AND REGULATORY ASPECTS OF WATER MANAGEMENT IN A COLORADO OIL SHALE INDUSTRY

by
A. Brown and B. C. Brooking

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CHAPTER ONE
INTRODUCTION

1.0 BACKGROUND

This report sets out the regulatory and legal aspects relating to water management in oil shale development in the Piceance Creek Basin, Colorado.

The work is part of a broader study of water management in oil shale mining, and has been produced separately in order to be available for critical review by interested parties prior to final incorporation in our project report.

Water availability for oil shale mining has long been an item of debate. There are two aspects to availability, legal and physical. To be useful, water must exist, and must also be legally capable of being made available. This report looks at the laws and regulations which bear on water availability in the Piceance Creek Basin.

While there are some water requirements which are forced on the developer because of the mining, processing, and waste handling approaches he chooses, there are also some regulations which directly or indirectly force him to use water (for example in dust control or revegetation of waste piles). This report excludes this aspect of the regulations. However, these regulations deserve scrutiny before mining takes place, because it may be that a significant environmental impact on the Colorado i Basin might be forced by them in order to avert a minor i on an oil shale mine site.

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1.1 FORMAT AND SOURCES OF INFORMATION

This report is, as it must be, a pastiche of legislative acts, regulations, and interpretations. The material has been gathered from a multitude of sources, and many primary and secondary sources are directly quoted. Where possible we have indicated the origin of the quotations, but in the interests of readability we have omitted some credits. The principal reference documents used are:

1. Radosevich, G.E., K.C. Nobe, D. Allardice, and C. Kirkwood, Evolution and Administration of Colorado Water Law: 1876-1976, Water Resources Publications, Fort Collins, Colorado, 1976.
2. Radosevich, G.E., D.H. Hamburg, and L.L. Swick (Eds.), Colorado Water Laws, Department of Economics, Colorado State University, Fort Collins, Colorado, 1975.
3. Radosevich, G.E. and P. Allen (Eds.), Colorado Water Quality Control and Administration Laws and Regulations, Department of Economics, Colorado State University, Fort Collins, Colorado, 1975.
4. Dewsnup, R.L., D.W. Jensen (Eds.), and R.W. Swenson (Assoc. Ed.), A Summary-Digest of State Water Laws, National Water Commission, Arlington, Virginia, 1973.
5. DeWeerdt, J.L., and P.M. Glick (Eds.), A Summary-Digest of the Federal Water Laws and Programs, National Water Commission, Arlington, Virginia, 1973.

A fuller bibliography of relevant documents is included at the end of this text. It is strongly recommended that those wishing to familiarize themselves with the water management aspects of oil shale should purchase the above and use them as detailed reference material. This report attempts to provide a layman's introduction to the material presented in these and other documents.

1.2 A BRIEF OUTLINE OF WATER ACQUISITION, USAGE, AND DISPOSAL IN OIL SHALE MINING

In general it can be said that shale oil production requires between 1 and 5 barrels of water for every barrel of oil produced. As plans include production from the Piceance Creek Basin of up to 1 million barrels per day, there is a required water input of up to 5 million barrels per day (approx. 150,000 gpm, 200 cfs, or 250,000 acre-ft./year). It is clear that a potential demand problem exists, and it is also clear that a serious water pollution potential exists from discharges and leachates.

There are three phases of water management: acquisition, use, and disposal. A further related matter, subject to regulation, is the alteration in water quality and geohydrology due to shale mining.

1.2.1 Acquisition

Acquisition of water in oil shale mining will occur in two ways. First, there will be an involuntary acquisition of groundwater flowing into the mine, precipitation water to the mine site, and sour water produced as part of the retorting process. Rational planning dictates that these sources will be used to satisfy as much of the water demand as possible. From a regulatory standpoint, the inflow of groundwater raises the question of water ownership, and of regional groundwater depletion. These are discussed in Section 2.1.6. The rights to precipitated water are the same as the rights to surface water once it runs off, and these are discussed in Section 2.1. The rights to sour water which has been developed by the process are probably vested in the producing company, but an adjudication on this would be prudent (Section 2.1.1).

The second method of acquisition involves importing water to the project site, probably from outside the Piceance Creek Basin. This will clearly be expensive, both in acquiring water rights (Sections 2.1.1 & 2.1.3) and in transporting the water (Section 2.1.2). However, mechanisms exist for this, and Colorado water law clearly allows for the transport of water to remote usage locations. There is a suggestion that wells in the Piceance Creek Basin will be needed to supplement water supplies, and if this is chosen as a supply plan, then Section 2.1.6 and Section 3.2.1 set out the regulations and the regulatory agencies involved. All water rights matters are under the control of the State Engineer and the Water Courts, as set out in Section 3.2.1.

1.2.2 Use

There are very few regulatory restrictions on water use. Some regulations relating to the quality of drinking water (Section 2.2.4) exist, but are barely within the scope of this study.

However several regulations relating to dust control, waste disposal, and reclamation demand conditions which require the use of water. As such they are in a sense water regulations. Although the regulations are not presented in this report, the agencies involved are discussed in Section 3.2.4.

1.2.3 Disposal

Methods of direct disposal of excess water or wastewater which have been considered for oil shale mining and processing include direct discharge and subsurface injection.

The regulations which relate to direct discharge are primarily concerned with quality. Water quality standards (Section 2.2)

have been set up by the State and approved by the Federal Government (Section 3.1.3), and are enforced primarily by Colorado State agencies (Section 3.2.2). It should be noted in this connection that it is a stated Federal policy that zero discharge of pollutants should be implemented where technically feasible (PL 92-500, see 101, A-1). Because the Piceance Creek Basin lies within the watershed of the Colorado River, salinity of discharges are also subject to regulation by the Federal Government. The relevant limitations are set out in Section 2.2.3.

Subsurface disposal, using injection wells or infiltration beds, is subject to significant regulation at a Federal level (Section 2.2.6). Water quality regulations are enforced to ensure limitation of pollution, and pressures used for injection are controlled. Well design is also controlled.

1.2.4 Indirect Impact Regulations

There are a number of potential impacts on the water regime on the project site which arise from mining, processing, and spent shale disposal.

Surface water pollution may arise from run-off of precipitation or irrigation water from spent shale areas. There are regulations to cover this aspect, which are presented in Section 2.2.2, and are policed primarily by the Colorado Department of Health (Section 3.2.2). In addition to surface pollution there is a possibility that foul leachate may be produced from spent shale piles. The regulations relating to leachates are discussed in Section 2.2.5, and the regulatory agency is once again the Colorado Department of Health (Section 3.2.2).

Finally, the groundwater regime in the Basin will be significantly disturbed by mining. Mixing of waters from different "aquifers" which are connected by mining may cause groundwater resource degradation, mine backfilling leachate can degrade aquifer water quality, and drawdown of piezometric levels can cause environmental impacts on springs and groundwater wells. These matters are also dealt with in the above sections.

CHAPTER TWO
WATER LAWS AND REGULATIONS

2.0 QUANTITY AND QUALITY OF WATER

There are two major bodies of law and regulations which are involved in water management in Colorado oil shale mining. The first is Colorado water rights law, which sets the framework for the acquisition of water for any project. The shortage of water in Colorado creates an environment where the development of industries demanding significant quantities of water will require a good understanding of the existing water law.

The second body of law and regulations relates to water disposal and escape. This concern stems from the likely environmental impact from disposal of relatively large quantities of water from an oil shale mining complex, and the impact of seepage and leachates from spent shale.

2.1 COLORADO WATER RIGHTS LAW

The principles of Colorado water law have always been and still remain strongly founded on the development of an agricultural industry in the arid and semi-arid land of the state. The water law which has evolved is known as the "Colorado Doctrine", and is based on appropriation and beneficial use of the waters of the state. The State constitution declares that the unappropriated water of every natural stream is the property of the public, subject to appropriation, and that the right to divert unappropriated waters of any natural stream to beneficial uses shall never be denied (Colorado Constitution, Art. XVI, Sec. 6).

Becasue of the limited quantity of available waters, of necessity there has also developed a priority system. This is based on a

first-in-time, first-in-right concept: between competing users the older the appropriation the higher the priority of right. Consequently, in times of shortage the supply of persons whose appropriations are junior in date of initiation is curtailed to make water available to those whose appropriations are senior in time, and therefore prior in right.

A more detailed discussion of Colorado water law is appended to this report. Because of the importance of water to the development of the state it is hardly surprising to find that a vast body of legislation, case law, books, articles, and other material is available to the interested reader. A bibliography listing references to the more significant of this material is also appended to this report for the inquiring (and presumably tireless) reader. A broad outline of the mechanics of the appropriation system is presented below to aid in understanding the role of the state agencies.

2.1.1 Method of Acquiring Rights

The method of acquiring rights has always been to take unappropriated water and apply it to beneficial use. There has never been a requirement of making an application to an administrator for a permit to appropriate surface water. However a right has no priority in time of shortage unless it is legally perfected as set out below. It should be noted that there is a requirement to appropriate groundwater; in this case a well permit must be obtained from the State Engineer before any appropriation can take place (CFR 37-90-107).

The first essential of an appropriation is the actual diversion of water and application to a beneficial use. "Beneficial" use

has been held to mean domestic, agricultural, industrial, municipal, and recreational.

The second essential of rights acquisition is the obtaining of priority. The priority of a water right is determined in an adjudication proceeding before a water judge (or a water referee). In these proceedings any objector may file statements of opposition. A priorty is determined based on the date of initiation of the appropriation and the date of adjudication.

In the case where there is an intention to appropriate, rather than an actual appropriation, a priority can be obtained, based on when the intention to appropriate was formulated by a physical act. This results in the creation of a conditional right, which is made absolute only after the actual appropriation is made. This may be many years after the priority date, as in the case of storage dams. The perfecting of such claims requires the appropriator to show reasonable progress ("diligence") in moving towards completing his project and claiming his appropriation. Until he completes the appropriation, the water may be claimed and used by junior appropriators.

2.1.2 Nature and Limits of Rights

The concept of beneficial use restricts the type of use and quantity of water which may be diverted. No one may divert more water than he needs for his intended beneficial use. Both direct flow diversions and diversions to storage are recognized. The former are rights to a certain rate of flow for specified purposes, the latter for a certain total volume of water per year (usually one reservoir filling).

The beneficial use concept also imposes requirements of efficiency and conservation on water appropriators. Water use and transport

shall be "reasonably efficient", and the means of diversion is required to be reasonable. An appropriative right may not be enlarged beyond the amount beneficially needed and used for the original purpose for which the priority was awarded.

Appropriators are entitled to be supplied in the order of their priorities. The most senior appropriator is entitled to be supplied without interference to the full extent of his original appropriation, even when there is insufficient water for more junior appropriators. Junior appropriators have a right to have stream conditions as they found them at the time of their appropriations to the extent that a senior appropriator cannot change his manner or location of diversion and use in a way which would injure junior appropriators.

Finally, for the purpose of transporting the water, an appropriator is entitled to one right-of-way through the lands which lie between the point of diversion and point of use. The most direct, practicable route must be selected.

2.1.3 Sales, Transfers, and Changes of Rights

A water right is what is known as a "usufructuary" right. A usufruct is the right of enjoying a thing, the property of which is vested in another (in this case the public) and to draw from the same all profit, utility, and advantage which it may produce, providing it be without altering the substance of the thing (Black's Law Dictionary, 1968). Accordingly this right may be sold or transferred as if it were property, providing all aspects of the right, including the point of diversion and intended use, remain the same. However, if a change is required as part of the sale or transfer this must be achieved by the established procedure.

A change of water right can be accomplished only with approval of the water judge. The judicial proceeding is intended to ensure that the rights of other appropriators are not injured by the change. Restrictive conditions may be applied to the change to protect other users. Colorado law also authorizes substitution or exchange of water in which appropriators may provide substituted supplies of water to other appropriators, particularly to achieve changes in the decreed right.

2.1.4 Loss of Rights

Colorado has no water-right forfeiture statute. Water rights may be wholly or partly lost by abandonment. Voluntary non-use of a water right for 10 years or more creates a rebuttable presumption of abandonment. Conditional water rights may be lost through failure to proceed to appropriation with "due diligence". Water rights may also be lost through adverse use, although the courts have been very reluctant to use this provision, defining the limits of adverse use very narrowly.

2.1.5 Stored Waters and Springs

Colorado law recognizes appropriation by storage of water (for future application to beneficial use) and is administered within the same priority system as direct flow rights. One reservoir filling per year is allowed per priority, however, refill decrees may be granted upon application to the courts. Impoundment plans and construction must be approved by the State Engineer, and the owners are liable for any damage from leakage, overflow, or floods caused by embankment breakage.

2.1.6 Groundwater

Because groundwater cannot be seen before it is appropriated, there has always been a less clear-cut treatment of it in Colorado water law. As a general rule, it can now be assumed that all groundwater in Colorado is subject to the law of appropriation, under rules modified from surface appropriation procedures. These rules are set out in CFR 37-90-102, The Colorado Ground Water Management Act of 1965.

In general, the conditions for appropriation and beneficial use of groundwater are similar to those for surface water. One difference is the requirement that an application to construct a well or to expand the supply of an existing well must be obtained before any appropriation occurs.

Groundwater in the Piceance Basin may be appropriated under the following rules (CFR 37-90-137):

i. There is no material injury to the vested water rights of senior appropriators.

ii. There is available unappropriated water.

iii. There is enough water in the aquifer being used to provide a minimum of 100 years life assuming no substantial artificial recharge.

This last requirement is potentially limiting in the case where natural recharge to the aquifer is very limited.

The Colorado Ground Water Management Act is administered by the Colorado Ground Water Commission, which determines the amount of appropriation which should be allowed in the Basin and issues

permits accordingly, on a first-in-time, first-in-right basis. The commission administers and manages designated groundwater through the State Engineer who serves as executive director.

2.1.7 Administration

The distribution and administration of both surface and tributary groundwater is the statutory responsibility of the State Engineer who is ex-officio Executive Director, Division of Water Resources, Department of Natural Resources.

2.2 WATER QUALITY LAW

Water pollution and water quality law is set up under the Federal Government's Environmental Protection Agency, and administered and policed by the Colorado Department of Health.

2.2.1 Federal Water Pollution Law

At the federal level, the current regulations are drawn under Public Law 92-500: Federal Water Pollution Control Act Amendments (1972). In this law, pollutant is defined in the following terms (Sec. 502, Item 6):

> The term 'pollutant' means dredged spoil, solid waste, incinerator residue, sewage, garbage, sewage sludge, munitions, chemical wastes, biological materials, radioactive materials, heat, wrecked or discarded equipment, rock, sand, cellar dirt and industrial, municipal, and agricultural waste discharged into water. This term does not mean (A) 'sewage from vessels' with the meaning of Section 312 of this Act; or (B) water, gas, or other material which is injected into a well to facilitate production of oil or gas, or water derived in association with oil or gas production and disposed of in a well, if the well used either to facilitate production or for disposal purposes is approved by authority of the State in which the well is located, and if such State determines that such injection or disposal will not result in the degradation of ground or surface water resources.

Enforcement is based upon effluent standards, with a system of permits for any industrial or other pollution source. The permits are issued by the Environmental Protection Agency (EPA), or by the states operating under EPA-approved programs within the National Pollution Discharge Elimination System (NPDES). Permitted discharges must comply with "best practicable available technology" by mid-1977, and "best available technology economically achievable" by mid-1984. Zero discharge of pollutants is the goal by 1985.

The EPA system relies upon the development of limitations for effluent discharges on an industry-by-industry basis. Oil shale mining is not presently included in these, but several similar industries are, and these give some indication as to the likely content of the regulations which will be adopted. We have chosen to present the regulations relating to:

i. Coal mining, because this is a sedimentary hydrocarbon as is oil shale,

ii. Bauxite mining, because it is an aluminum mineral process, like dawsonite extraction, and

iii. Petroleum refining, as it is similar to shale oil retorting.

Table 1 presents, for each case, the best practical control technology currently available. Maximum one day averages are quoted. In general 30-day average limitations are half of one day averages.

2.2.2 State Water Quality Law

The presently operative water quality control law in Colorado is the Water Quality Control Act of 1973. The act created the Water

TABLE 1

NPDES EFFLUENT LIMITATIONS PROMULGATED BY

THE FEDERAL ENVIRONMENTAL PROTECTION AGENCY

NOTES:
- I Selected industries
- II Best practical control technology currently available
- III Maximum average concentrations allowable for one day

I. INDUSTRY	II. EFFLUENT CHARACTERISTIC	III. EFFLUENT LIMITATION
Coal Mining	Iron (Total)	7.0 mg/l
	Manganese (Total)	4.0 mg/l
	Total Suspended Solids	70.0 mg/l
	pH	6-9
Bauxite Mining	Total Suspended Solids	30 mg/l
	Iron	1.0 mg/l
	Zinc	0.2 mg/l
	Aluminum	1.2 mg/l
	pH	6-9
Petroleum Refining	Biochemical Oxygen Demand	54.4 kg/1000 m^3 of feedstock
	Total Suspended Solids	32.8 kg/1000 m^3 of feedstock
	Chemical Oxygen Demand	388.0 kg/1000 m^3 of feedstock
	Oil and Grease	17.1 kg/1000 m^3 of feedstock
	Phenolic Compounds	.40 kg/1000 m^3 of feedstock
	Ammonia (as N)	23.4 kg/1000 m^3 of feedstock
	Sulphide	.35 kg/1000 m^3 of feedstock
	Total Chromium	.82 kg/1000 m^3 of feedstock
	Hexavalent Chromium	.017 kg/1000 m^3 of feedstock
	pH	6-9

Quality Control Commission, which is a part of the Colorado Department of Health. The commission administers the water quality control system, and the Department of Health monitors and polices it. The legislation has "teeth" - fines of $10,000 per day for violators, or jail sentences of up to a year, or both, can be imposed.

Water quality control is achieved through a pollution discharge permit system. A permit will be issued unless the discharge conflicts with a federal or state requirement. Toxic wastes must be shown beyond a reasonable doubt to be non-polluting or non-migrating. The Colorado State Department of Health's system has been approved (in all except two details) by the EPA, and so becomes part of the NPDES permit system. For the purposes of this study its primary application is in discharges to rivers and streams. The standards are contained in a publication entitled "Water Quality Standards and Stream Classification" published by the Water Quality Control Commission in 1974. The text of this volume is attached as Appendix 3. We understand that these standards are currently being revised.

Streams in Colorado are classified into two groups, depending on approved use. Class A waters are to be "suitable for all purposes for whcih raw water is customarily used, including primary contact recreation, such as swimming and water skiing." The Class B definition is identical, but excepts primary contact recreations. Table 2 sets out the major aspects of the classification.

Interestingly, Piceance Creek and its major tributaries, and Yellow Creek and its major tributaries, are not specifically mentioned in the stream classification, with the exception of Fawn Creek, classified B1. To cover the omission, the

TABLE 2

STANDARD	CLASS			
	A_1	A_2	B_1	B_2
Settleable Solids	Free From	Free From	Free From	Free From
Floating Solids	Free From	Free From	Free From	Free From
Taste, Odor, Color	Free From	Free From	Free From	Free From
Toxic Materials	Free From	Free From	Free From	Free From
Oil and Grease	Cause a film or other discoloration	Cause a film or other discoloration	Cause a film or other discoloration	Cause a film or other discoloration
Radioactive Material	Drinking Water Standards	Drinking Water Standards	Drinking Water Standards	Drinking Water Standards
Fecal Coliform Bacteria	Geometric Mean of <200/100ml from five samples in 30-day per.	Geometric Mean of <200/100ml from five samples in 30-day per.	Geometric Mean of <1000/100ml from five samples in 30-day per.	Geometric Mean of <1000/100ml from five samples in 30-day per.
Turbidity	No increase of more than 10 J.T.U.	No increase of more than 10 J.T.U.	No increase of more than 10 J.T.U.	No increase of more than 10 J.T.U.
Dissolved Oxygen	6 mg/l minimum	5 mg/l minimum	6 mg/l minimum	5 mg/l minimum
pH	6.5 - 8.5	6.5 - 8.5	6.0 - 9.0	6.0 - 9.0
Temperature	Maximum 68°F. Maximum Change 2°F.	Maximum 90°F. Maximum Change: Streams - 5°F. Lakes - 3°F.	Maximum 68°F. Maximum Change 2°F.	Maximum 90°F. Maximum Change: Streams - 5°F. Lakes - 3°F.
Fecal Streptococcus	Monthly average of <20/100ml from five samples in 30-day per.	Monthly average of <20/100ml from five samples in 30-day per.	----	----

SOURCE: Water Quality Control Commission. Water Quality Standards and Stream Classification, 1974, p. 11

following clause appears (p. 10): "Basic standards will apply to all waters of the state, whether classified or not." The basic standards appear on pages 3 and 4 of the Water Quality Standards (see Appendix 3).

2.2.3 Salinity Regulation

Regarding salinity (which is not defined, but is assumed here to mean total dissolved solids) the state has not yet decided upon appropriate guidelines, but reserves this right.

The major limitation on salinity comes from the international treaties regarding quality of the water in the Colorado River. Specifically, the salinity below Hoover Dam is recommended to be kept below 723 mg/l. Major federal programs are currently underway to help achieve this and other goals.

Colorado salinity regulations, when they are promulgated will probably use three criteria in guiding discharge permit limits:

i. Colorado River salinity. This may limit TDS (total dissolved solids) to somewhere around 700 mg/l.

ii. Irrigation water standards. For sensitive crops, a limit of between 500 mg/l to 1,000 mg/l is considered (by the EPA) to be advisable (Proposed Criteria for Water Quality, EPA, October 1973).

iii. Existing stream quality. Particularly where water is taken from a stream, used, and returned to the stream, it seems unrealistic to expect a user to have to return the water in better condition than he received it. Accordingly permits may be based on incremental TDS loads above water quality in adjacent streams (see Appendix 3, pages 3 and 4).

For planning purposes in the Piceance Creek Basin, typical salinity of the existing waters average 500-1,000 mg/l near C-b Tract, 600-3,000 mg/l near C-a Tract, and 2,000-3,000 mg/l at the mouths of Yellow and Piceance Creeks. Accordingly, it would seem reasonable to expect that oil shale industry users will have to meet a standard of about 700 mg/l TDS for discharges, based on all three criteria.

2.2.4 Drinking Water Standards

For metallic, toxic, deleterious non-metallic ion, and radioactive discharges, the regulations generally require that drinking water standards be met. Primary drinking water standards have been promulgated in interim form (Environmental Protection Agency National Interim Primary Drinking Water Regulations; 40 CFR 141; 40 FR 59565, December 24, 1975; Amended by 41 FR 28402, July 9, 1976. An Advance Notice of Proposed Rulemaking for Organic Chemical Contaminants appeared in 41 FR 28991, July 14, 1976.) and the requirements germane to this discussion are summarized in Table 3. All oil shale industry discharges will probably have to meet these standards unless specifically excluded in the discharge permits, although it may be that the discharge maximum will be defined by the quality of the water delivered to the industry. Of particular interest is the fluoride requirement, which is very much lower than typical ambient concentrations in deep groundwater in the Piceance Creek Basin (which ranges from 4 mg/l to 18 mg/l).

2.2.5 Leachates

The laws relating to leachates which are expelled from waste dump material are not particularly clear. Two categories of leachates can be distinguished: those that appear at the surface without significant intermixing with subsurface waters,

TABLE 3

PRIMARY DRINKING WATER STANDARDS

Contaminant	Maximum Level Allowable (mg/l)
Arsenic	.05
Barium	1.0
Cadmium	.010
Chromium	.05
Lead	.05
Mercury	.002
Nitrate (as N)	10.0
Selenium	.01
Silver	.05
Fluoride	1.4 (or up to 2.4 mg/l based on air temperature)
Turbidity	1 unit (5 units max.)
Coliforms	1 per 100 ml (max. monthly ave.)

SOURCE: National Interim Primary Drinking Water Regulations, 40 CFR 141; 40 FR 59565, December 24, 1975; Amended by 41 FR 28402, July 9, 1976.

and those which are injected into the general groundwater regime.

Surface-appearing leachates are clearly subject to normal point source discharge regulations (Section 2.2.2), unless they are collected and recycled. Leachates which escape into the subsurface regime are also likely to be regarded as point source discharges, although a distinction will likely be made between receiving groundwater resources which are potentially "underground drinking water sources" and those which are not. Seepage into the alluvial or Uinta formation aquifers would probably be regarded as providing pollutants into potential drinking water, and would thus be subject to drinking water standards. As the leachates from spent shale would unquestionably fail to meet these standards, a zero discharge of leachates will probably be enforced.

2.2.6 Injection Wells

Subsurface injection of wastewater from oil shale mining and processing is an economically attractive alternative to treatment and surface discharge. However the environmental problems associated with some injection schemes have led the EPA to oppose this method of disposal. The EPA's position is contained in "Decision Statement No. 5 on Subsurface Emplacement by Well Injection" (February 6, 1973). In this statement of policy, the administration warns that:

> The EPA will oppose placement of materials by subsurface injection without strict controls and a clear demonstration that such emplacement will not interfere with present or potential use of the subsurface environment, contaminate groundwater resources, or otherwise damage the environment.

A more detailed set of proposed regulations are contained in "State Underground Injection Control Program", 40 CFR Part 146, August 31, 1976. The basic thrust of these proposed regulations is that the underground injection must be such as to avoid "endangering underground water sources". Subpart 146.2(x) proposes the following definition of "endangerment":

> Underground injection "endangers underground drinking water sources" if (1) such injection may make it necessary for a public water system using an underground drinking water source to increase treatment of the water, or (2) if such injection might make it necessary for a public water system which uses the source in the future to use more extensive treatment of the water than would otherwise have been necessary, or (3) if such injection may otherwise adversely affect the health of persons such as by adding a substance that would make water from the source unfit for human consumption.

This requirement is not intended to extend to groundwater which is not considered potable, and in any case to groundwater which has in excess of 10,000 mg/l total dissolved solids.

Two injection scenarios are worthy of consideration. First, injection of toxic wastes into deep aquifers may be considered. Based on the above decision statement and proposed regulations it seems likely that these schemes would meet strong opposition from the EPA. However there is no legal prohibition at this time.

Second, re-injection of mine inflow waters which are in excess of surface needs may be proposed. The overall impact of the mine dewatering could be minimized by simply re-injecting the waters back into the same strata from which they came, at some distance from the mine. This would minimize the drawdown of the aquifers involved due to mine water drainage, and would have a neutral impact on aquifer quality. It is debatable whether the EPA's objections would apply to this case, although

no decision is known to exist. It is, however, likely that a distinction will be drawn between mine inflow and water intercepted external to the mine. In the former case, it is likely that some quality degradation will occur in the collection and transfer operation, whereas in the second case, water intercepted by wells or drains prior to entry to the mine could be maintained at a relatively unchanged quality. Mine planners would do well to explore this matter prior to dewatering system design.

CHAPTER THREE
THE REGULATORY SYSTEM

3.0 THE REGULATORY FRAMEWORK

The regulatory framework associated with water management in the Colorado oil shale industry has two basic aspects: development of laws, guidelines, and regulations, and administering and policing them.

Guiding legislation on matters relating to water rights, water pollution, environmental protection, and river basin management has been generated primarily at the federal level with some involvement of state agencies. Some restrinctions in water-related matters also stem from interstate and international pacts and treaties.

The administration and policing of these regulations in their application to the oil shale industry is largely in the hands of state government agencies, with federal activity mainly in the areas of land use and pollution control.

An important aspect of regulation in the Piceance Creek Basin stems from land ownership. Of the uncontested land in the Basin, almost three quarters is federally owned. This generates a higher federal involvement in this area than would normally exist in most other areas of the United States.

This chapter sets out the relevant activities of the Federal and State agencies involved in water-related regulations in the Colorado oil shale industry. For a fuller coverage the reader is directed to DeWeerdt and Glick (Eds.) "A Summary-Digest of the Federal Water Laws and Program" (1973), and Dewsnup and Jensen (Eds.) "A Summary-Digest of State Water Laws" (1973).

3.1 FEDERAL AGENCIES

Federal agencies in general are heavily involved with establishing standards for water management. The relevant activities of the more important agencies are briefly described below (alphabetic list).

3.1.1 Department of Agriculture

The responsibilities of the Forest Service of the Department of Agriculture include the management of reserved water flowing through national forests and wilderness areas within them. Major national forest lands exist close to areas of oil shale development, and include the headwaters of the White River. Thus the Forest Service will be involved in any development in this area.

The Soil Conservation Service of the Department of Agriculture operates under the Soil Conservation Act (1935). The service controls soil conservation on federally-owned land except for that under the jurisdiction of the Department of the Interior. As the Federal oil shale land falls within the purview of the Department of the Interior, the involvement of the Soil Conservation Service is largely limited to setting guidelines for mine spoil restoration.

3.1.2 Council of Environmental Quality

This council was set up under the National Environmental Policy Act of 1969 (NEPA) and reports on environmental matters to the President. It has a mandate to develop and review national environmental policies.

3.1.3 Environmental Protection Agency (EPA)

For purposes of water management, the Environmental Protection Agency's major function concerns the regulation of water quality. The enabling acts are the Water Pollution Control Act Amendments of 1972 (Public Law 92-500) and the Safe Drinking Water Act (Public Law 93-523). Under the first act, a permit program has been established to regulate the discharge of pollutants. Conditions and criteria for the issuance of permits are established in terms of water quality standards of the receiving waters, and in terms of the effluent limitations. These conditions will apply to all oil shale facilities.

3.1.4 Department of Interior (DoI)

The Department of Interior has jurisdiction over many aspects of oil shale development, as a result of the high percentage of federal land involved. The Bureau of Land Management of the Department of Interior manages federal oil shale lands under the 1920 Mineral Leasing Act. It exercises the Secretary of Interior's discretionary authority to determine whether or not leases, permits, or licences are issued. The Bureau is responsible for all aspects of land use on federal oil shale lands. Responsibility for minerals, water, and air on lands set aside under the Federal Prototype Oil Shale Leasing Program has been transferred within the Interior Department to the Area Oil Shale Supervisor (AOSS), which is a section of the Conservation Division of the United States Geological Survey (USGS).

The Area Oil Shale Supervisor is the sole representative of the Secretary of I[illegible]or in all matters relating to operations on the leased land[illegible]luding surface use, environmental protection,

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and reclamation. As a part of the supervision of the prototype leasing program, the Area Oil Shale Supervisor receives advice from a number of groups including the Oil Shale Environmental Advisory Panel (OSEAP).

The Bureau of Mines of the Department is involved in oil shale water management through the Mining Enforcement and Safety Administration (MESA). MESA is charged, among other things, with enforcing the Mine Safety Act of 1966 and the Occupational Health and Safety Act of 1970. In terms of water management these acts require consideration of water requirements for dust control in mines, and mining dewatering for stability.

The Bureau of Reclamation (BuRec) operates under the 1902 Reclamation Act which authorizes it (among other things) to construct works for the storage, diversion, and development of waters, including artesian wells. Following the requirements of the Act, the Bureau has since 1961 been active in its efforts to study the availability of water in the Northwestern Colorado region for a number of uses including oil shale development. The Bureau has, however, little regulatory power.

The Office of Saline Water exists to develop technology for economical conversion of saline and other chemically contaminated waters into useable water, under the Saline Water Act of 1971. It may be of assistance in water purification problems in oil shale mining.

The Bureau of Sport Fisheries & Wildlife operates under the Fish and Wildlife Act of 1956. Its activities are directed to the protection and enhancement of fish and wildlife programs. In general it is not expected that this agency will have any direct impact on water management aspects of oil shale development.

3.1.5 The Water Resources Council

The Water Resources Council was established by the Water Resources Planning Act of 1965, to coordinate the "...conservation, development, and utilization of water and related land resources..." (42 U.S.C.A. 1962). Among other things this work involves setting up River Commissions performing river basin studies and performing water planning programs. As such it is expected that this council will continue to exert some influence over water management matters in the Colorado River Basin.

3.2 COLORADO STATE AGENCIES

The major functions of the Colorado State Agencies are administration of the State's water resources and laws, and protection of its environment.

The major Colorado State agencies involved in water management matters fall within the Department of Natural Resources and the Department of Health. A third agency with some involvement is the Colorado Land Use Commission. These are discussed briefly below, together with mention of other water management groups within the Colorado State Government structure of which oil shale developers should be aware.

3.2.1 Colorado Department of Natural Resources

The Colorado Department of Natural Resources is divided into several subgroups. The activities of those relevant to water management are summarized below.

The primary water management function of the state is performed by the Office of the State Engineer of the Division of Water

Resources. The State Engineer has general supervision of measurement, record keeping, and distribution of the public waters of the state. For the purposes of the actual administration and distribution of water the state is subdivided into seven water divisions, with each division being administered by a divisional engineer. These seven divisions are shown on Figure 1. For water management in the Piceance Creek Basin, Division 6 and (to a lesser extent) Division 5 are of importance.

The State Engineer and division engineers administer and distribute water rights to holders in accordance with the priority of each right. As part of this function, since 1969, a centralized file of all conditional and absolute rights in Colorado has been maintained by the State Engineer's office in Denver.

With respect to groundwater the State Engineer is also responsible for carrying out the requirements and procedures established by the Ground Water Commission.

The Ground Water Commission is an administrative unit of the Division of Water Resources. The purpose of this commission is to define designated groundwater basins, administer the water resources found in the basins, and create new groundwater management districts. This purpose is carried out by periodic review of the state's groundwater resources and establishment of appropriate withdrawal rates and locations for wells in designated areas. The Piceance Creek Basin is not at present a designated basin.

The State Board of Examiners of Water Well and Pump Installation Contractors is a statutory body within the Division of Natural Resources. The board's purpose is to ensure the proper locations, construction, and abandonment of wells, and to licence

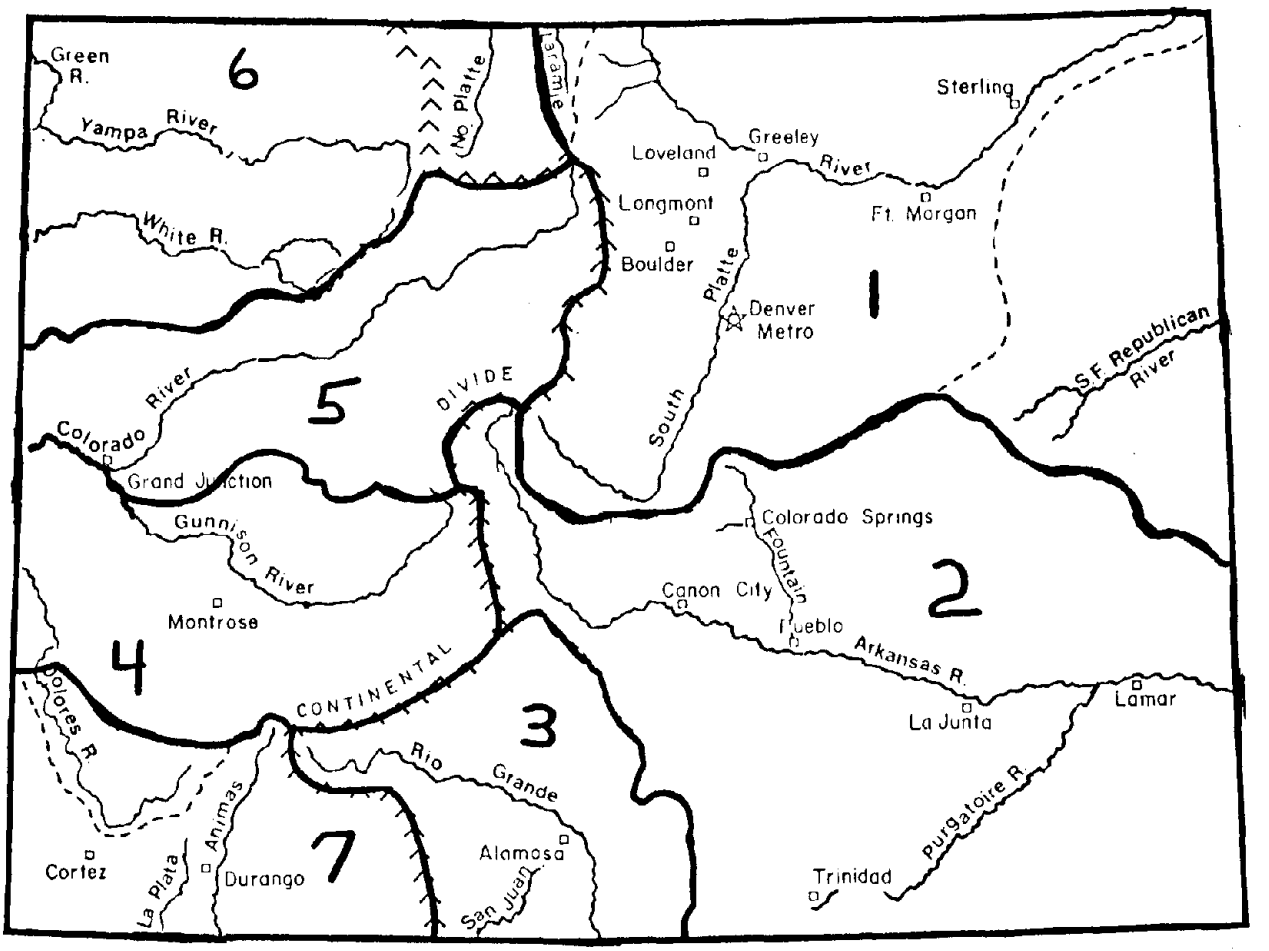

Figure 1.

COLORADO WATER DIVISION BOUNDARIES

SOURCES: Colorado Water, League of Women Voters of Colorado, 1975.

Evolution and Administration of Colorado Water Law: 1876-1976, Radosevich, Nobe, Allardice, and Kirkwood, 1976.

those engaged in well construction. It may be expected that the board will be involved in dewatering and water-supply well installation in oil shale mining.

3.2.2 The Colorado Department of Health

The Colorado Department of Health has regulatory authority over sewage disposal, water discharge, and any other potential or real health hazards. This authority is based on Federal and State statutes which give the Department of Health responsibility for promulgation and enforcement of State standards, after approval by the Federal Environmental Protection Agency.

The Water Quality Control Commission regulates the state discharge permits system and injection of water into underground disposal wells. The Water Pollution Control Commission administers and enforces water pollution prevention, abatement, and control under the Colorado Water Pollution Control Act of 1966.

3.2.3 The Colorado Land Use Commission

The Colorado Land Use Commission was set up under the Colorado Land Use Act to (among other things) encourage planned and orderly land use development, to conserve resources (including water), and to promote the efficient and economical use of public resources.

With respect to oil shale development, the Commission is specifically empowered to regulate matters relating to mineral resource areas, solid waste disposal sites, new communities, and municipal and industrial water projects. In the Piceance Creek Basin area the Colorado West Area Council of Governments is the legal grouping. This corresponds to Planning and

Management Region No. 11, established to coordinate local, state, and federal planning activities. It is certain that this body will be heavily involved in land use decisions in oil shale mine development, including those relating to water.

3.2.4 Other Colorado Agencies Involved in Water Management

There are a number of Colorado agencies more peripherally involved in water management in Colorado oil shale mining. A brief list and description is given below for information.

The Water Conservation Board was set up in 1937 to promote flood control and water conservation within the state. It may be involved with external water supply to Piceance Creek Basin oil shale mines.

The Division of Mines of the Department of Natural Resources monitors mine safety practices under the Mining Employees Safety Act (MESA). It also will have authority over spent shale disposal stabilization, and both these aspects will require some water for satisfaction of the required standards.

The Mined Land Reclamation Board of the Department of Natural Resources develops and promulgates standards for land reclamation planning. As the revegetation and compaction of spent shale requires considerable water, this agency will also have some impact on water management.

The Colorado River Water Conservation District is a quasi-municipal corporation of Colorado established by legislative act in 1937 to conserve, develop, and safeguard for Colorado all the water to which the State is entitled under the Colorado River Compact of 1922. As the Piceance Creek Basin falls within the Colorado River Basin, and all surface water available

for development of Colorado oil shale is tributary to the Colorado River, it is clear that this corporation will have a significant impact on water management. The corporation owns substantial conditional water rights, and is an umbrella organization for various conservancy districts which exist within it.

Conservancy Districts have been set up in Colorado under the Water Conservancy Act, to undertake large projects, generally for agricultural or municipal purposes. They can acquire, sell, lease, or otherwise dispose of water and water rights. One of the more significant districts in terms of water supply for oil shale development is the Yellow Jacket Conservancy District, which holds major conditional rights on the White River. It is likely that this district will supply any water required for Piceance Basin oil shale development.

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EXHIBIT 2

Colorado Water Rights
Law Summary

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NATIONAL
WATER
COMMISSION

A Summary-Digest
of
State Water Laws

Richard L. Dewsnup
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Associate Editor

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Chapter 6. COLORADO

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DISCUSSION

1. Development of Colorado Water Law

Colorado has always been an "appropriation" doctrine State. It has long been established that the common law or riparian rights doctrine never was the law of Colorado, even before statehood. As was said in a famous, early case:

> **Imperative necessity, unknown to the countries which gave it birth, compels** the recognition of another doctrine in conflict [with the riparian doctrine].
>
> * * * * * * *
>
> **The climate is dry, and the soil, when moistened only by the usual rainfall, is arid and unproductive; except in a few favored sections, artificial irrigation for agriculture is an absolute necessity. Water in the various streams thus acquires a value unknown in moister climates. Instead of being a mere incident to the soil, it arises, when appropriated, to dignity of a distinct usufructuary estate, or right of property.**[1]

Since Colorado was the first State to adopt a pure appropriation system, abrogating the riparian rights theory in toto, the doctrine early became known as the Colorado doctrine, as distinguished from the California doctrine which attempted to recognize both riparianism and appropriation.

The State constitution declares that the unappropriated water of every natural stream is the property of the public, subject to appropriation, and that the right to divert unappropriated waters of any natural stream to beneficial uses shall never be denied.[2] The constitution also provides that as between those using water for the same purpose, priority of appropriation shall give the better right.[3] These

[1] *Coffin v. Left Hand Ditch Co.*, 6 Colo. 443 (1882).
[2] Colo. Const., art XVII, sec. 5 and 6.
[3] Colo. Const., art. XVI, sec. 6.

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constitutional expressions of the appropriation doctrine have been supplemented by legislative declaration that all waters of the State have always been and are the property of the public, dedicated to the use of the people, subject to appropriation and use in accordance with law.[4]

2. State Organizational Structure for Water Administration and Control

Responsibility for water administration and control in Colorado is divided between the State engineer, who is the executive officer of the division of water resources of the State department of natural resources,[5] and the judiciary, specifically, one district court judge designated a water judge for each of the seven water divisions of the State established by law.[6] The State engineer has exclusive jurisdiction to administer, distribute, and regulate the waters of the State.[7] The water judges, on the other hand, have exclusive jurisdiction over "water matters" in the State district courts within their respective divisions.[8] "Water matters" are those matters which are specified by statute to be heard by the water judges. They include determinations of amounts and priorities on applications for new water rights and conditional water rights, and determinations of rights with respect to proposed changes of water rights, plans for augmentation, and biennial findings of diligence in the perfection of conditional rights.[9]

2.1 *Administration of Water Rights*

The State engineer is charged with the administration and distribution of the waters of the State.[10] As chief of the division of water resources, he is responsible to the executive director of the department of natural resources.[11] He has general supervisory control over measurement, recordkeeping, and distribution of the public waters of the State.[12]

As noted in connection with the territorial jurisdiction of water judges, the State has been divided into seven water divisions. The divisions correspond roughly with the major drainage basins of the State.[13] A division engineer is appointed by the State engineer for each division.[14] The actual administration and distribution of water is conducted through the offices of the division engineer.[15] Each division is subdivided into field offices headed by water commissioners who are members of the division engineer's staff.

Unlike State engineers in so-called "permit" States, the Colorado State engineer does not grant or deny applications to appropriate

[4] Colo. Rev. Stat. Ann., sec. 148-21-2 (Supp. 1969).
[5] Colo. Rev. Stat. Ann., sec. 148-11-3 (supp. 1969).
[6] Colo. Rev. Stat. Ann., sec. 148-21-10 (supp. 1969).
[7] Colo. Rev. Stat. Ann., sec. 148-21-34 (supp. 1969).
[8] Colo. Rev. Stat. Ann., sec. 148-21-10 (supp. 1969).
[9] Colo. Rev. Stat. Ann., sec. 148-21-18 (supp. 1969).
[10] Colo. Rev. Stat. Ann., secs. 148-21-17, 34 (supp. 1969).
[11] Colo. Rev. Stat. Ann., sec. 148-11-3(6) (supp. 1969).
[12] Colo. Rev. Stat. Ann., sec. 148-11-3(1)(l) (supp. 1969).
[13] Colo. Rev. Stat. Ann., sec. 148-21-8 (supp. 1969).
[14] Colo. Rev. Stat. Ann., sec. 148-21-9 (supp. 1969).
[15] Colo. Rev. Stat. Ann., sec. 148-21-17 (supp. 1969).

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water, although a permit is required to construct a well for the appropriation of ground water.[16] In Colorado, the rights of appropriators are determined in judicial proceedings in the district courts presided over by the water judges. The State engineer and division engineers administer and distribute water to water rights holders in accordance with court adjudicated decrees for certain amounts of water and priorities in time for each right.[17] Administration, distribution, and regulation of the use of water, both surface and underground, is accomplished through the promulgation of rules and regulations and through the issuance of orders to individual owners and users of water rights.[18] For example, division engineers must order discontinuance of any diversion of water not necessary for beneficial use[19] or of any diversion of water causing material injury to water rights having senior priorities.[20] They must also order the release from storage of water illegally or improperly stored.[21] They administer the movement of water involved in a plan of augmentation or a water use project.[22] They may order the installation and maintenance of meters, gages, and other measuring devices[23] and may issue orders so that streams may be kept clear of unnecessary dams and obstructions that may impede the flow of water to water users.[24]

The State engineer and division engineers may enforce their orders by applying through the attorney general to the division water judge for injunctions.[25] In addition, injured persons may recover triple damages suffered by reason of the violation of an order of State and division engineers.[26]

Among the more important duties of the State and division engineers is the tabulation of decreed water rights. Before 1969, no system had been devised to keep statewide or division records of all the decreed priorities drawing water from the same or common sources of supply. Until 1969, the State was divided into 70 irrigation districts. There were separate adjudications of water rights in each district. Though a water use adjudicated in one district might affect the source of supply in other districts, there was no systematic effect to integrate the ever-growing lists of decreed priorities for separate districts, even within the same river drainage system. Adjudications occurred sporadically. Decrees were usually, though not always, filed in the office of the State engineer in Denver. In the best of circumstances it was necessary to review all the adjudication and transfer decrees for a given district in order to ascertain the relative priority and rank of any given water right. Sometimes records of other districts, court records, or records of county clerks and recorders had to be consulted as well. Many decreed rights had been abandoned or had gone so long unused as to leave doubt as to their continuing validity.

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[16] Colo. Rev. Stat. Ann., sec. 148-18-36 (1963 and supp. 1965).
[17] Colo. Rev. Stat. Ann., sec. 148-21-17(3) (supp. 1969).
[18] Colo. Rev. Stat. Ann., secs. 148-21-34, 148-21-35 (supp. 1969).
[19] Colo. Rev. Stat. Ann. sec. 148-21-35(2) (supp. 1969).
[20] Colo. Rev. Stat. Ann. sec. 148-21-35(2) (supp. 1969).
[21] Colo. Rev. Stat. Ann. sec. 148-21-35(3) (supp. 1969).
[22] Colo. Rev. Stat. Ann., sec. 148-21-35(4) (supp. 1969).
[23] Colo. Rev. Stat. Ann., sec. 148-21-35(5) (supp. 1969).
[24] Colo. Rev. Stat. Ann., Secs. 148-21-35(6) and (7) (supp. 1969, 1971).
[25] Colo. Rev. Stat. Ann., sec. 148-21-36 (supp. 1969).
[26] Colo. Rev. Stat. Ann., sec. 148-21-37 (supp. 1969).

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In 1969, the general assembly authorized the very substantial undertaking of tabulating lists of priority in numbered sequence for all decreed rights taking water from the same or a common source of supply.[27] The existing 70 irrigation district subdivisions were abolished and the present seven water divisions were created. A "common source" was defined as including "all of those waters in a water division, either surface or underground, which if left in their natural state would join together to form a single natural watercourse prior to exit from the water division."[28]

The division engineer of each division was directed not later than October 10, 1973, to prepare for administrative purposes a tabulation of all decreed water rights and conditional rights in his division in order of seniority, setting forth the priority and amount for each right as established by court decrees.[29] Provision was made for publication and mailing of the tabulations for each division, as well as for filing objections to the manner in which a water right is listed in a tabulation, and for necessary or advisable revisions of the tabulations. These tabulations, prepared for administrative purposes,[30] were to serve as the basis for preparation of another set of tabulations to be completed by July 1, 1974, and for successive revisions of the tabulations in each even-numbered year after 1974.[31] The 1974 and succeeding tabulations are to be filed in court for adjudication by the water judge for each division.[32] After adjudication, during which opportunities are to be afforded "any person who wishes" to protest either omissions from the tabulation or the manner of inclusion of water rights therein,[33] the water judge for each division is directed to enter a judgment and decree either incorporating the tabulation of the division engineer as filed, or incorporating the tabulation with such modifications as the water judge may determine proper.[34] Appellate review of the judgment and decree may be had as in other civil actions.[35]

In preparing the 1974 and successive tabulations, division engineers are directed to include priorities awarded subsequent to those listed in the preceding tabulations, to incorporate any changes of water rights that have been approved, to note any changes from conditional water right to water right, to modify any water rights which the division engineer determines to have been abandoned in part, and to omit any water rights which the division engineer determines to have been totally abandoned.[36] Nonuse of a water right for 10 years or more, "when needed by the person entitled to use same," creates a rebuttable presumption of abandonment.[37] Division engineers are to prepare separate priority lists as necessary so that only those water rights taking water from the same source and which are in a position to affect one another will be on the same priority list.[38] Adjudication

[27] Colo. Rev. Stat. Ann., sec. 148-21-27 (supp. 1969).
[28] Colo. Rev. Stat. Ann., sec. 148-21-27(1)(b)(I) (supp. 1969).
[29] Colo. Rev. Stat. Ann., sec. 148-21-27(1)(a) (supp. 1969).
[30] Colo. Rev. Stat. Ann., sec. 148-21-27(5) (supp. 1969).
[31] Colo. Rev. Stat. Ann., secs. 148-21-28(1), (2) (supp. 1969).
[32] Colo. Rev. Stat. Ann., sec. 148-21-28(2) (supp. 1969).
[33] Colo. Rev. Stat. Ann., sec. 148-21-28(2)(d) (supp. 1969).
[34] Colo. Rev. Stat. Ann., sec. 148-21-28(2)(e), (f) (supp. 1969).
[35] Colo. Rev. Stat. Ann., sec. 148-21-28(2)(h) (supp. 1969).
[36] Colo. Rev. Stat. Ann., sec. 148-21-28(1) (supp. 1969).
[37] Colo. Rev. Stat. Ann., sec. 148-21-28(2)(j) (supp. 1969).
[38] Colo. Rev. Stat. Ann., sec. 148-21-28(1) (supp. 1969).

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of a tabulation is to be considered a general adjudication proceeding, although it is in addition to and not in lieu of the procedures established for adjudication of individual, new appropriations described below in section 3.1, "Method of Acquiring Rights." [39]

2.2 *Resolution of Water Use Conflicts*

a. Rule of Priority

The basic rule set forth in the constitution is that between competing users of water priority of appropriation gives the better right.[40] Consequently, in time of shortage of supply the uses of persons whose appropriations are junior in date of initiation are curtailed to make water available to those whose appropriations are senior in time, and therefore, prior to right.

The State officials who are charged with administration and distribution of water—the State engineer, the division engineers, and the water commissioners of their staffs—are governed by the priorities for water rights established by judicial decrees entered in court adjudication proceedings for the determination of water rights.[41] Until 1969, separate adjudication proceedings were conducted for each of the 70 irrigation districts of the State. Proceedings called supplemental adjudications were held in a district whenever a water user desiring an adjudication of a new appropriation petitioned the district court for the county within his irrigation district having jurisdiction. After a petition was filed, the proceedings were open to other users in the district to adjudicate any claims for new rights that had arisen since the completion of the last, previous adjudication in the district. Supplemental adjudications of this nature continued until all such claims were heard and adjudicated. Thereupon the proceedings were closed until such future time as a new petition for supplemental adjudication might be filed. In this manner, adjudications occurred in each district intermittently, usually at intervals of one or more decades and lasting, once begun, for several years.[42] Claims for water rights were identified by and adjudicated according to their actual historical dates of initiation, but no priority could be awarded in any supplemental adjudication senior to any priority awarded in any previous adjudication for the same district.[43]

In the 1969 Water Right Determination and Administration Act [44] the Colorado General Assembly changed the procedures for adjudicating water rights. A water clerk and a water judge were named for each of the seven water divisions.[45] Water referees were appointed by the water judges to make investigations and initial rulings.[46] Any person who wishes a determination of a water right, conditioned water right, change of water right, plan of augmentation, or biennial finding of reasonable diligence in perfecting a condi-

[39] Colo. Rev. Stat. Ann., sec. 148-21-28-(2)(k) (supp. 1969).
[40] Colo. Const., art. XVI, sec. 6.
[41] Colo. Rev. Stat. Ann., sec. 148-21-17(3) (supp. 1969).
[42] Colo. Rev. Stat. Ann., secs. 148-9-1 et seq. (1963).
[43] *Hardesty Res. & Canal Co. v. Arkansas Valley Sugar Beet Co.*, 85 Colo. 555, 277 Pac. 763 (1929); see also, *Luis Coppa & Son v. Kuiper*, 467 P. 2d 273 (Colo. 1970).
[44] Colo. Rev. Stat. Ann., secs. 148-21 1 to 148-21-45 (supp. 1969).
[45] Colo. Rev. Stat. Ann., secs. 148 21 10, 148 21 11 (supp. 1969).
[46] Colo. Rev. Stat. Ann., sec. 148-21-10(4) (supp. 1969).

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tional water right, may at any time file an application with the water clerk.[47] Others may file statements of opposition.[48] The application is referred to the referee who, after publication and investigation, may either rule on it or refer it back to the water judge.[49] If the referee rules on the matter, the water judge thereafter may hear protests of the ruling and may confirm, modify, reverse, or reverse and remand the ruling. If the referee does not rule on the matter, but instead refers it back to the water judge, the water judge decides it.[50] Appellate review of judgments and decrees of the water judge is provided for.[51]

Priorities awarded under procedures established in the 1969 act are junior to all priorities awarded in decrees entered prior to June 7, 1969, the effective date of the Act.[52] Priority dates awarded for applications filed in each division during each calendar year are junior to all rights awarded in the division in any previous calendar year.[53] An exception to the foregoing two rules was made for wells for which priorities had not been established or sought but for which an application was filed with the water clerk on or before July 1, 1972.[54]

The 1969 adjudication procedure is applicable to new appropriations of all waters of the State except water in certain designated ground water basins.[55] In addition, stock watering, domestic, and certain other wells not exceeding 15 gallons per minute may, but are not required to be adjudicated.[56]

The 1969 act places jurisdiction of all "water matters" exclusively in the water judges. "Water matters," in addition to adjudication of claims, include all matters involving beneficial application of water or priorities of appropriation,[57] enforcement of orders of the State engineer or division engineers,[58] and validity of rules and regulations of the State engineer.[59] Other matters, such as one affecting the manner in which irrigation water is allowed to run off the land [60] or a suit to enjoin use of water of a designated ground water basin—which is outside the purview of the 1969 act and is administered by the Colorado Ground Water Commission—may be brought in a State district court having ordinary civil jurisdiction.[61]

b. Preferences

The Colorado constitution provides that whenever the waters of any natural stream are not sufficient, "those using the waters for domestic purposes shall have the preference over those claiming for any other purpose, and those using the water for agricultural purposes shall have preference over those using the same for manu-

[47] Colo. Rev. Stat. Ann., sec. 148-21-18(1), as amended (supp. 1971).
[48] Colo. Rev. Stat. Ann., sec. 148-21-18(1), as amended (supp. 1971).
[49] Colo. Rev. Stat. Ann., sec. 148-21-19, as amended (supp. 1971).
[50] Colo. Rev. Stat. Ann., sec. 148-21-20(3), as amended (supp. 1971).
[51] Colo. Rev. Stat. Ann., sec. 148-21-20(9) (supp. 1969).
[52] Colo. Rev. Stat. Ann., sec. 148-21-22(1), as amended (supp. 1971).
[53] *Id.*
[54] *Id.* See note 179 and accompanying text.
[55] Colo. Rev. Stat. Ann., sec. 148-21-45, as amended (supp. 1972).
[56] Id. *Davis* v. *Conour*, 497 P. 2d 1015 (Colo. 1972).
[57] *Baumgartner* v. *Stremel*, 496 P. 2d 705 (Colo. 1972).
[58] Colo. Rev. Stat. Ann., sec. 148-21-36 (supp. 1969).
[59] *Kuiper* v. *Owners Conservation Ass'n*, 490 P. 2d (Colo. 1971).
[60] *Baumgartner* v. *Stremel*, 496 P. 2d 705 (Colo. 1972).
[61] *Larrick* v. *District Ct.*, 493 P. 2d 647 (Colo. 1972).

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facturing purposes."[62] The courts have held that the preference is not self-executing, but must be exercized by condemnation and the payment of compensation by the preferred user-condemnor to the condemnee whose right, though not preferred, may nevertheless be senior in priority.[63]

2.3 *Other Agencies Having Water Resource Responsibilities*

a. Colorado Water Pollution Control Commission

The Water Pollution Control Commission has authority to adopt and promulgate water quality standards under the Colorado Water Pollution Control Act of 1966.[64] The commission administers water pollution prevention, abatement, and control and through the attorney general enforces the Pollution Control Act in the courts.[65]

b. Colorado Water Conservation Board

The Colorado Water Conservation Board was created in 1937 with the powers to: (1) Foster, encourage, and assist in the financing of various types of districts, mutual companies, and other agencies created under Federal and State laws; (2) to cooperate with the Federal Government and others in the formulation of plans and the gathering of information regarding plans and projects; (3) to submit drafts of proposed Federal and State legislation; (4) to investigate plans and activities of the Federal Government and other States which might affect interstate waters of Colorado; (5) to confer and appear before appropriate agencies, courts, et cetera, to protect Colorado's interests in interstate waters in Colorado; (6) to acquire real property for flood prevention of flood control with respect to federally authorized projects, et cetera; (7) to promote conservation of water in the State in order to secure the greatest utilization of such water; and (8) to contract for the construction of conservation projects both within and outside the State and perfect water rights in the name of the Department of Natural Resources.[66] The board makes continuing studies of the water resources of the State, including present and potential uses, and has authority to conduct State water planning under the Federal Water Resources Planning Act.[67]

c. Colorado Ground Water Commission

The Ground Water Commission was created in 1965 by the Ground Water Management Act.[68] The commission consists of 12 members, nine of whom are appointed by the Governor and confirmed by the State senate. In addition to the appointed members, the Executive Director of the Department of Natural Resources, the State engineer, and the director of the Colorado Water Conservation Board are voting members.[69] The commission adjudicates water rights and

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[62] Colo. const., art. XVI, sec. 6.
[63] *Montrose Canal Co. v. Loutsenhizer Ditch Co.*, 23 Colo. 233, 48 Pac. 532 (1896); *Town of Sterling v. Pawnee Ditch Ext. Co.*, 42 Colo. 421, 94 Pac. 339 (1908).
[64] Colo. Rev. Stat. Ann., sec. 66 28-8 et seq. (supp. 1967).
[65] Colo. Rev. Stat. Ann., secs. 66 28 8, 66-28-10 (supp. 1967).
[66] Colo. Rev. Stat. Ann., secs. 149-1-11, 149-1 14, 149-1-15 (1963 and supp. 1971).
[67] Public Law 89 80, July 22, 1965, 79 Stat. 244, 42 U.S.C. 1962.
[68] Colo. Rev. Stat. Ann., secs. 148-18-1 to 38 (supp. 1965), as amended (supp. 1967, 1969, 1971).
[69] Colo. Rev. Stat. Ann., sec. 148-18-3(1), (1) (supp. 1971).

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regulates the use of designated ground water under special statutory rules within certain geographic areas defined by it on the basis of statutory criteria as designated ground water basins.[70]

d. Ground Water Management Districts

Districts may be formed in designated ground water basins with the approval of the ground water commission upon the petition of at least 15 percent of the taxpaying electors within the proposed district[71] and after an election within the district. Elected directors of the districts are empowered in cooperation with the ground water commission to regulate the use, control, and conservation of the ground water of the district by a number of methods, including well-spacing, pumping limitations, ground water recharge, planning, research, and regulation of use.[72] Districts have taxing powers and powers to make special assessments.[73]

e. Irrigation Districts

State law authorizes the formation of irrigation districts as public corporations having powers to exercise eminent domain, make special tax assessments on lands suitable for irrigation and cultivation, and issue bonds to finance construction and maintenance of irrigation systems.[74] They are formed after a petition of landowners within the district[75] and after an election of a board of directors.[76] The board conducts the affairs of the district which may include cooperation with the Federal Government in the construction of irrigation and drainage works.[77] Powers of the district and the board are specified by statute.[78]

f. Conservancy Districts

Authorized to be formed under the Water Conservancy Act,[79] water conservancy districts have broader taxing authority extending not just to lands suitable for irrigation and cultivation, but to all land within the district[80] and they usually cover a larger geographic area than irrigation districts. They are organized to undertake larger, more extensive, and costlier projects. Ordinarily, they are formed for the purpose of contracting with the U.S. Bureau of Reclamation for delivery of water from reclamation projects to water users within the districts.

g. Carrier and Mutual Water and Ditch Companies

Carrier ditch companies are for-profit private water distributors. They are public utilities whose rates are regulated by county com-

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[70] Colo. Rev. Stat. Ann., sec. 148-18-5 (supp. 1971); see note 6, p. 25, and accompanying text.
[71] Colo. Rev. Stat. Ann., secs. 148-18-17, -19 (supp. 1967).
[72] Colo. Rev. Stat. Ann., sec. 148-18-29 (supp. 1965).
[73] Colo. Rev. Stat. Ann., sec. 148-18-31 (supp. 1967).
[74] Colo. Rev. Stat. Ann., secs. 150-1-1, et seq. (1963), 150-2-1, et seq. (1963).
[75] Colo. Rev. Rev. Stat. Ann., sec. 150-2-1 (1963).
[76] Colo. Rev. Stat. Ann., sec. 150-2-8 (1963).
[77] Colo. Rev. Stat. Ann., sec. 150-2-10(2)(a) (1963).
[78] Colo. Rev. Stat. Ann., secs. 150-2-10, 150-2-10-13 (1963).
[79] Colo. Rev. Stat. Ann., secs. 150-5-1 et seq. (1963).
[80] Colo. Rev. Stat. Ann., sec. 150-5-16 (1963).

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missioners.[81] They divert and transport water through their facilities for hire to their customers. The carrier's diversion unites with the consumer's use to make an appropriation.[82] The consumer is regarded as an appropriator from the stream supplying the ditch, though his rights are limited by the terms of his contract with the carrier company.[83] Consumers are entitled by law to purchase the amounts of water they contracted for in each previous year at rates set by the county commissioners.[84]

Mutual ditch and water companies are not-for-profit private water distributors who furnish water solely to their shareholders, who, in effect, are the appropriators, having equitable ownership in the water rights of the mutual company represented in their stock certificates.[85] Subject to reasonable rules and bylaws of the company, a shareholder may sell his shares and his proportionate ownership of the water right and may change his point of diversion and place of use.[86]

h. Nonprofit Corporations

Basinwide nonprofit corporations have recently been organized in Colorado by and for the owners of wells drawing ground water tributary to the Arkansas and South Platte Rivers. Both the Ground Water Appropriators of the South Platte River Basin, Inc. (GASP), and the Colorado Water Protective and Development Association (Arkansas basin) represent cooperative efforts of junior well appropriators to develop plans to augment the flows of their respective rivers through release of purchased storage water and water from large capacity wells to the rivers to replace water being consumed by junior appropriators where demanded by senior surface appropriators of the rivers under their senior decreed priorities.

3. Surface Waters

Surface waters of the State are all waters in or tributary to natural streams. The term includes continuous and intermitent flows.[87] All waters, both surface and underground, originating in or flowing into the State are subject to appropriations and use under the law.[88]

3.1 *Method of Acquiring Rights*

The Constitution declares that the right to divert and put unappropriated water to beneficial use "shall never be denied."[89] As a consequence, the method of appropriation historically has been to take unappropriated water and apply it to beneficial use.[90] There

[81] Colo. Rev. Stat. Ann., sec. 148-8-5(2) (1963).
[82] *Farmers High Line Canal Co.* v. *Southworth*, 13 Colo. 111, 21 Pac. 1028 (1889).
[83] *Denver* v. *Brown*, 56 Colo. 216, 138 Pac. 44 (1914).
[84] Colo. Rev. Stat. Ann., sec. 148-8-1 (1963).
[85] *United States* v. *Akin*, 248 F. 2d 742 (10 Cir. 1957).
[86] *Wadsworth Ditch Co.* v. *Brown*, 39 Colo. 57, 88 Pac. 1060 (1907).
[87] Colo. Const., art. XVI, secs. 5 and 6; Colo. Rev. Stat. Ann., sec. 148-21-3 (supp. 1969); see *In re German Ditch & Res. Co.*, 56 Colo. 252, 139 Pac. 2 (1913).
[88] Colo. Rev. Stat. Ann., sec. 148-21-2(1) (supp. 1969).
[89] Colo. Const., art. XVI, sec. 6.
[90] *Board of County Commissioners* v. *Rocky Mtn. Water Co.*, 102 Colo. 351, 79 P. 2d 373 (1938). Until 1969, there was a statutory provision for filing a map and statement with the State engineer but it was held that the water right was not based on filing maps or statements and the provision merely supplied a method of evidencing the appropriation. See *DeHaas* v. *Benesch*, 116 Colo. 544, 181 P. 2d 453 (1947).

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has never been a requirement of making an application to an administrator for a permit to appropriate water, although permits are required to drill wells [91] and no priority will be awarded in court for a well unless either a well permit or evidence either of denial thereof by the State engineer or of his failure to act on an application therefor within 6 months of filing is presented to the water judge.[92]

a. Acts of Appropriation

The first essential of an appropriation is the actual diversion of water with intent to apply it to beneficial use.[93] What constitutes an actual diversion may depend on the facts of the case, but ordinarily a physical diversion by a structure is implied.[94] Uses recognized as "beneficial" are domestic,[95] agricultural,[96] industrial,[97] municipal,[98] and recreational.[99]

b. Obtaining Priority

The priority of a water right is determined in an adjudication proceeding before the water judge. An application for a determination is made, as explained above, to the diversion water clerk and may be referred to a referee or decided by the water judge. At a minimum, applications must set forth a legal description of the diversion, a description of the source of the water, the date of initiation of the appropriation, the amount of water claimed, and the use of the water.[100] (The steps in the proceeding are outlined in section 2.2, supra.) A priority date based on the date of initiation of appropriation is determined, but the legal priority of the right—that is, the seniority by date as of which the right is entitled to divert—must be determined in relation to all other rights deriving water from a common source [101] subject to the rule that no award of priority made in any calendar year can be senior to any award made for rights for which applications were filed in a previous calendar year.[102]

Priorities may be obtained for conditional water rights in the same manner though, owing to a necessary lengthy period of development, no water under an application can be expected to be applied to beneficial use, even for many years, until after the initial application.[103] In such cases, subject to the rule requiring due diligence in prosecuting a project to completion, the appropriation date is said to relate back from the date of completion to the earliest date on which a substantial act providing an open, physical demonstra-

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[91] Colo. Rev. Stat. Ann., sec. 148-18-36 (1963 and supp. 1965). The State engineer must issue the permit if he finds that there is unappropriated water available for withdrawal by the proposed well and that the vested water rights of others will not be materially injured.
[92] Colo. Rev. Stat. Ann., sec. 148-21-18(2) (supp. 1971).
[93] *Safranck* v. *Limon*, 123 Colo. 330, 228 P. 2d 975 (1951).
[94] *Lamont* v. *Riverside Irr. Dist.*, 498 P. 2d 1150 (Colo. 1972); see *Thomas* v. *Guiraud*, 6 Colo. 530 (1883); *Town of Genoa* v. *Westfall*, 141 Colo. 533, 349 P. 2d 370 (1960).
[95] Colo. Const., art. XVI, sec. 6.
[96] Id.
[97] Id.
[98] *Denver* v. *Sheriff*, 105 Colo. 193, 96 P. 2d 836 (1939).
[99] Colo. Rev. Stat. Ann., sec. 148-21-3(7) (supp. 1969).
[100] Colo. Rev. Stat. Ann., sec. 148-21-18(2) (supp. 1971).
[101] Colo. Rev. Stat. Ann., sec. 148-21-3(10) (supp. 1969).
[102] Colo. Rev. Stat. Ann., sec. 148-21-22 (supp. 1971).
[103] Colo. Rev. Stat. Ann., sec. 148-21-18(1) (supp. 1971).

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tion thereof is joined with an intention to initiate an appropriation.[104] An appropriator of a conditional right must show reasonable progress in completion of his project and in seeking to have his claim allowed. Showings of reasonable diligence are made by filing applications for findings thereof with the water clerk not later than June 1 of each even-numbered year.[105] When perfected, a conditional right obtains the same priority it would have received had the original proceedings in which the conditional decree was entered remained open until the final determination of the right.[106]

c. Rights-of-Way

In Colorado, any person owning a water right is entitled to a right-of-way through the lands which lie between the point of diversion and the point of use for the purpose of transporting water for beneficial use. [107] The power of eminent domain is conferred on water rights owners for the purpose of acquiring such a right-of-way [108] but no occupied land can be subjected to the burden of more than one ditch or other structure without the landowner's consent and the shortest and most direct route practicable must be selected.[109]

3.2 *Nature and Limit of Rights*

Ownership of unappropriated water in natural streams is in the public, subject to appropriation.[110] The appropriative right is a right of possession and use of water, rather than of ownership of the corpus. It is usually characterized as an interest in real property—a usufruct.[111] As such, it is a vested property right, protected by the Constitution,[112] until lost by abandonment.[113] It is alienable and transferable, either as an appurtenance to land, or if severed from the land, separately and independently therefrom.[114]

a. Measure of the Appropriative Right

The concept of beneficial use not only prescribes the types of uses for which water may be diverted,[115] but also is the basis for determining or measuring the water right. No one may divert more water than he reasonably needs for his intended beneficial use.[116] This amount may vary, of course, depending on the nature, place, and time of use,[117] and different duties of water may be established for different water rights depending on the circumstances of each case.[118]

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[104] *Elk-Rifle Water Co. v. Templeton*, 484 P. 2d 1211 (Colo. 1971); *Four Counties Water Users Association v. Colorado River Water Cons'n Dist.*, 161 Colo. 416, 425 P. 2d 259 (1967).
[105] Colo. Rev. Stat. Ann., sec. 148-21 14 (supp. 1971).
[106] Id.
[107] Colo. Const., art. II, seec. 14, Colo. Rev. Stat. Ann., sec. 148-3-1 (supp. 1969).
[108] Colo. Rev. Stat. Ann., sec. 148-3-3 (supp. 1969).
[109] Colo. Rev. Stat. Ann., sec. 148-3-5 (supp. 1969).
[110] Colo. Const., art. XVI, sec. 5.
[111] *West End Irr. Co. v. Garvey*, 117 Colo. 109, 184 P. 2d 476 (1947); *Coffin v. Left Hand Ditch Co.*, 6 Colo. 443 (1882).
[112] *Town of Sterling v. Pawnee Ditch Ext. Co.*, 42 Colo. 421, 94 Pac. 339 (1908).
[113] Colo. Rev. Stat. Ann., sec. 148-21-3(13) (Supp. 1969).
[114] *James v. Barker*, 99 Colo. 551, 64 P. 2d 598 (1937).
[115] See notes 5-9, p. 14.
[116] Colo. Rev. Stat. Ann., sec. 148-21-3(7) (supp. 1969); see, e.g., *Denver v. Sheriff*, 105 Colo. 193, 96 P. 2d 836 (1939).
[117] See Colo. Rev. Stat. Ann., sec. 148-21-17(2) (supp. 1969).
[118] *Farmers Highline Canal & Res. Co. v. Golden*, 129 Colo. 575, 272 P. 2d 629 (1954).

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Both direct flow rights to divert for immediate use and storage rights to divert and store for future use are recognized.[119] Direct flow rights are measured in terms of rate of flow in cubic feet per second. A direct flow water right is a right to a certain rate of flow, usually determined by the capacity of the ditch or canal, for such periods of time as may reasonably be necessary to fulfill the appropriator's announced purpose at the time he makes his appropriation.[120] In contrast, storage rights are quantified and measured by the capacity of the storage reservoir in acre-feet of water. A water right to store water entitles its owner to fill his reservoir to its adjudicated capacity once each year.[121]

b. Limits of the Appropriative Right

In addition to prescribing the types of use and amounts of water that may reasonably be diverted for each type, the beneficial use concept also imposes requirements of efficiency and conservation on water appropriators. Statute law defines beneficial use as use of "that amount of water that is reasonable and appropriate under reasonably efficient practices to accomplish without waste the purpose for which the diversion is lawfully made." [122] An appropriator may not direct, transport, and use more water than he actually needs.[123] He must convey diverted water in a ditch or canal or store water in a reservoir without an unreasonable loss through seepage or evaporation.[124] Supervision of diversion and conveyance practices is vested in the State engineer and division engineers.[125]

Appropriators are required to have a reasonable means of diversion. An appropriator may not "command the whole flow of the stream merely to facilitate his taking the fraction of the whole flow to which he is entitled." [126]

An appropriative right may not be enlarged or extended beyond the amount beneficially needed and used for the original undertaking for which priority was awarded.[127] That is, a priority for a water right will be enforced as against junior appropriators only to supply that amount of water to the senior priority holder which he has historically needed and used.[128]

c. Rights of Senior and Junior Appropriators

Appropriators are entitled to be supplied in the order of their priorities. The most senior appropriator is entitled to be supplied without interference to the full extent of his original appropriation,[129] whether his right is for direct use or for storage for future

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[119] *Handy Ditch Co.* v. *Greeley & Loveland Irr. Co.*, 86 Colo. 197, 280 Pac. 481 (1929); Colo. Rev. Stat. Ann., sec. 148-5-1 (1963).
[120] *Westminister* v. *Church*, 167, 1, 445 P. 2d 52 (1968).
[121] *Orchard City Irr. Dist.* v. *Whitten*, 146 Colo. 127, 361 P. 2d 130 (1961).
[122] Colo. Rev. Stat. Ann., sec. 148-21-3(7) (supp. 1969).
[123] Colo. Rev. Stat. Ann., sec. 148-7-8 (1963).
[124] *Comstock* v. *Larimer & Weld Res. Co.*, 58 Colo. 186, 145 Pac. 700 (1914).
[125] Colo. Rev. Stat. Ann., secs. 148-5-1 et seq and 148-7-1 et seq. (1963).
[126] Colo. Rev. Stat. Ann., sec. 148-2-2(2)(b) (supp. 1969); *Colorado Springs* v. *Bender*, 148 Colo. 458, 366 P. 2d 552 (1961).
[127] *Fort Lyon Canal Co.* v. *Chew*, 33 Colo. 392, 81 Pacfl 37 (1905).
[128] *Enlarged Southside Irr. Ditch Co.* v. *John's Flood Ditch Co.*, 116 Colo. 580, 183 P. 2d 552 (1947).
[129] *Comstock* v. *Ramsay*, 55 Colo. 244, 133 Pac. 1107 (1913).

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use,[130] even when there is insufficient water in the source of common supply to meet the demands of all other junior appropriators.[131] The uses of junior appropriators, whether they divert from the main stream, a tributary stream,[132] or from a ground water source,[133] may be curtailed, if necessary, at his request, by the responsible State water officials to satisfy his lawful demand for water,[134] subject to the so-called "futile call" rule that "no reduction of any lawful diversion because of the operation of the priority system shall be permitted unless such reduction would increase the amount of water available to and required by water rights having senior priorities." [135]

Junior appropriators have a right to have stream conditions continued as they existed at the time of their appropriations.[136] Thus, no appropriator may change his manner of diversion and use of water in any way that would alter stream conditions to the injury of appropriators who are junior to him and who are entitled to rely on the continuance of such conditions.[137]

3.3 *Changes, Sales, and Transfers*

In Colorado, water rights may be sold or transferred freely, subject to certain rules and principles. A change in ownership by sale of a water right, whether or not the right is appurtenant to land, creates no serious problems peculiar to water rights law and is merely the subject of sales, conveyancing, and recording laws. Many changes in ownership, however, are also the occasions of a "change of water right," [138] which is broadly defined to include changes in the type, place or time of use, and changes in point of diversion or storage.

A change of water right may be accomplished only with approval of the water judge. An application must be filed with the water clerk.[139] The application must set forth a description of the water right for which a change is sought, its amount and priority, and a description of the proposed change.[140] The proposed change must be approved if it will not injuriously affect other vested rights.[141] If the proposed change would injure other rights, it may be approved subject to terms and conditions proposed either by the applicant or by any person opposed to the application. The terms and conditions may include limitations on use of the water subject to the change, relinquishment of part of the decree for which change is sought or of other decrees used by the applicant, time limitations on diversion of water, and such other conditions as are necessary to protect vested rights.[142] Approval may be conditioned on subsequent reconsideration by the water judge on the question of injury to vested rights, or on

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[130] *People* v. *Hinderlider*, 98 Colo. 505, 57 P. 2d 894 (1936).
[131] *Strickler* v. *Colorado Springs*, 16 Colo. 61, 26 Pac. 313 (1891).
[132] Id.
[133] *Kuiper* v. *Well Owners Conservation Association*, 490 P. 2d 268 (1971).
[134] Colo. Rev. Stat. Ann., sec. 148-21-17(3) (supp. 1969).
[135] Colo. Rev. Stat. Ann., sec. 148-21-2(2)(d) (supp. 1969).
[136] *Farmers Highline Canal & Res. Co.* v. *Golden*, 129 Colo. 575, 272 P. 2d 629 (1954).
[137] *Enlarged Southside Irr. Ditch Co.* v. *John's Flood Ditch Co.*, 116 Colo. 580, 183 P. 2d 552 (1947).
[138] Colo. Rev. Stat. Ann., sec. 148-21-3(11) (supp. 1969).
[139] Colo. Rev. Stat. Ann., sec. 148-21-18 (supp. 1969).
[140] Colo. Rev. Stat. Ann., sec. 148-21-18(2) (supp. 1971).
[141] Colo. Rev. Stat. Ann., sec. 148-21-21(3) (supp. 1969).
[142] Colo. Rev. Stat. Ann., sec. 148-21-21(4) (supp. 1969).

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any other provision which the water judge deems proper in determining the rights and interests of persons involved.[143]

In a recent case, the Colorado Supreme Court distinguished a change of point of return of irrigation or municipal effluent from other changes of water rights, holding that other appropriators had no vested rights to the maintenance by Denver of its original point of return of sewage effluent in the South Platte River.[144]

Colorado law also authorizes practices of substitution or exchange of water in which individuals or private or public entities may provide substituted supplies of water to appropriators senior to them to satisfy the rights of the senior. In return, the suppliers may then take and use amounts of water equivalent to the amounts supplied to the senior appropriator. A practice of substitution or exchange may constitute an appropriative right and may be adjudicated as any other right.[145]

3.4 *Loss of Rights*

Colorado has no forfeiture statute. Water rights may be lost in whole or in part by abandonment. Abandonment has been defined by statute as "the termination of a water right in whole or in part as a result of the intent of the owner thereof to discontinue permanently the use of all or part of the water available thereunder." [146] Abandonment of a conditional water right occurs as a result of failure to develop the proposed appropriation with reasonable diligence.[147]

A recently enacted law provides for an administrative determination of abandonment by the division engineer when he prepares biennial water rights tabulations.[148] These tabulations are routinely subjected to judicial scrutiny by the water judge at the times when they are presented pursuant to law for adjudication.[149] For purposes of this procedure, nonuse of a water right for 10 years or more creates a rebuttable presumption of abandonment.[150]

Water rights may also be lost through adverse use.[151] Adverse use for the statutory period of 18 years [152] or use under claim and color of title coupled with payment of assessed taxes for a statutory period of 7 years [153] may ripen into a water right. Application of the doctrine of adverse use to appropriate rights is sharply limited by the rule that water not needed by an appropriator for beneficial use by him belongs to other appropriators on the stream and is thus not available to be subjected to adverse use.[154] Similarly, reservoir seepage that is allowed to return to the stream is public water available for appropriation and is not subject to use adverse to the owner of the reservoir.[155]

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[143] Colo. Rev. Stat. Ann., sec. 148-21-20(6) (supp. 1971).
[144] *Metropolitan Denver Sewage Disposal District* v. *Farmers Res. & Irr. Co.*, 499 P. 2d 1190 (1972).
[145] Colo. Rev. Stat. Ann., sec. 148-11-25(2) (supp. 1969).
[146] Colo. Rev. Stat. Ann., sec. 148-21-3(13) (supp. 1969).
[147] Colo. Rev. Stat. Ann., sec. 148-21-3(14) (supp. 1969).
[148] Colo. Rev. Stat. Ann., sec. 148-21-28(1) (supp. 1969).
[149] Colo. Rev. Stat. Ann., sec. 148-21-28(2)(e) (supp. 1969).
[150] Colo. Rev. Stat. Ann., sec. 148-21-28(2)(j) (supp. 1969).
[151] *Lomas* v. *Webster*, 109 Colo. 107, 122 P. 2d 248 (1942).
[152] Colo. Rev. Stat. Ann., sec. 118-7-1 (supp. 1967).
[153] Colo. Rev. Stat. Ann., sec. 118-7-8 (1963).
[154] *Granby Ditch & Res. Co.* v. *Hallenbeck*, 127 Colo. 236, 255 P. 2d 965 (1953).
[155] *Lamont* v. *Riverside Irr. Dist.*, 498 P. 2d 1150 (Colo. 1972).

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3.5 *Storage Waters, Artificial Lakes, and Ponds.*

As noted above, Colorado law recognizes and makes provision for appropriation by storage of water for future application to beneficial use under the same system of priorities as that by which direct flow rights are administered.[156] Reservoirs to store water may be constructed either in the channel or bed of a natural stream or elsewhere.[157] Storage decrees authorize one annual reservoir filling, although more than one priority may be obtained so as to permit more than one annual filling.[158] The State engineer's approval of plans for construction and completion of reservoirs is required by law.[159] Reservoir owners are held strictly liable for damages arising from leakage, overflow, or floods caused by the breaking of embankments of their reservoirs.[160]

3.6 *Springs*

Spring water, like other water, is subject to appropriation and use.[161] The Colorado Supreme Court has thus upheld an injunction against a landowner preventing his interference with the appropriative use of spring water tributary to a natural stream even though the water arose on the landowner's land and a statute specifically gives landowners the right to use spring water arising on their lands.[162] Landowners, too, must acquire an appropriative right to use tributary spring water.[163] Spring water that is not tributary to a natural stream may also be appropriated, in which case the priorities are determined just among the users of the spring water rather than among all water users in the drainage basin.[164]

3.7 *Diffused Surface Waters*

Rainwater and other water following no defined course or channel is appropriable in Colorado as part of the waters of natural streams of the State "whether found on the surface or underground." [165]

4. Ground Water

The Colorado Constitution dedicates to the people and applies the appropriation doctrine to the unappropriated "waters of any natural stream." [166] The treatment of ground water in the State has historically involved the characterization of the ground water involved as

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[156] See notes 119, 120, and 121, and accompanying text.
[157] See Colo. Rev. Stat. Ann., sec. 148-7-17 (supp. 1969).
[158] *Windsor Res. & Canal Co.* v. *Lake Supply Ditch Co.*, 44 Colo. 214, 98 Pac. 729 (1908); *Orchard City Irr. Dist.* v. *Whitten*, 146 Colo. 127, 361 P. 2d 130 (1961).
[159] Colo. Rev. Stat. Ann., Sec. 148-5-5 (1963).
[160] Colo. Rev. Stat. Ann., sec. 148-5-4 (1963); *Barr* v. *Game, Fish & Parks Comm'n*, 497 P. 2d 340 (Colo. app. 1972).
[161] Colo. Rev. Stat. Ann., sec. 148-2-1 (supp. 1969); *Hehl* v. *Hubbell*, 132 Colo. 96, 285 P. 2d 593 (1955).
[162] *Nevius* v. *Smith*, 86 Colo. 178, 279 Pack. 44 (1928). See Colo. Rev. Stat. Ann., sec. 148-2-2 (1963).
[163] *Cline* v. *Whitten*, 150 Colo. 179, 372 P. 2d 145 (1962).
[164] Colo. Rev. Stat. Ann., sec. 148-2-3 (supp. 1969).
[165] Colo. Rev. Stat. Ann., sec. 148-2-1 (supp. 1969); *In re German Ditch &Res. Co.*, 56 Colo. 252, 139 P. 2d 2 (1914). See note, *A Survey of Colorado Water Law*, 47 Denver L.J. 226, 296 (1970).
[166] Colo. Const., art. XVI, secs. 5 and 6.

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water of, i.e., tributary to, a natural stream or as water not of, or tributary to, a natural stream. In general, water tributary to a natural stream has been treated as water subject to appropriation.[167] The status of water not tributary to a natural stream has been in doubt until recent times[168] when the enactment of the 1965 Ground Water Management Act[169] authorized the creation of "designated ground water" basins, within which designated ground water, by definition, would appear to include all water not tributary to any natural stream or at least not in practice a part of the source of supply of appropriators from any natural stream.[170] Designated ground water, too, is now administered according to a modified version of the appropriation doctrine under the 1965 act, and so it may be said generally that ground water in Colorado, like surface water, is subject to the law of appropriation.

4.1 *Tributary Ground Water*

Tributary ground water includes what is sometimes called seepage, underflow, or percolating water, if that water would eventually become a part of a natural stream.[171] A natural stream's waters include water "in the unconsolidated alluvial aquifer of sand, gravel, and other sedimentary materials, and all other waters hydraulically connected thereto which can influence the rate or direction of movement of the water in that alluvial aquifer or natural stream."[172] There is a presumption that water is tributary to a natural stream, although the presumption may be overcome.[173]

Tribuary ground water is subject to the 1969 Water Right Determination and Administration Act.[174] The 1969 act specifically recognized that previous and then existing laws had given inadequate attention to the development and use of underground waters of the State.[175] In particular, surface water diversions and wells had usually been administered separately in the State. Few wells had been adjudicated. Though most wells were relatively junior to surface appropriations, little effort had been made to devise any plan to regulate their use even when their proliferation and use appeared to threaten interference with the flow of surface streams. The situation encouraged investment in the development of agricultural economies based on wells of uncertain legal status even as conflicts between surface diverters and those well owners whose wells were nearest the surface point of diversion grew in intensity.[176] The 1969 act declared it the policy of the State to integrate the appropriation, use, and administration of underground water with the use of surface water in such a way as to maximize the beneficial use of all the waters of the State.[177]

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[167] *Colorado Springs* v. *Bender*, 148 Colo. 458, 366 P. 2d 552 (1962); see generally, note, *A Survey of Colorado Water Law*, 47 Denver L. J. 226, 307–339 (1970).
[168] See *Whitten* v. *Coit*, 153 Colo. 157, 385 P. 2d 131 (1963); *Safranek* v. *Limon*, 123 Colo. 330, 228 P. 2d 975 (1951).
[169] Colo. Rev. Stat. Ann., secs. 148-18-1 to 38 (supp. 1965).
[170] Colo. Rev. Stat. Ann., sec. 148-18-2(3) (supp. 1971).
[171] *Safranek* v. *Limon*, 123 Colo. 330, 228 P. 2d 975 (1951); *Nevius* v. *Smith*, 86 Colo. 178, 279 Pac. 44 (1929).
[172] Colo. Rev. Stat. Ann., sec. 148-21-3(4) (supp. 1969).
[173] *Safranek* v. *Limon*, 123 Colo. 123 Colo. 330, 228 P. 2d 975 (1951).
[174] Colo. Rev. Stat. Ann., secs. 148-21-1 to 45, as amended (supp. 1971).
[175] Colo. Rev. Stat. Ann., sec. 148-21-2(2) (supp. 1969).
[176] See generally, *Fellhauer* v. *People*, 447 P. 2d 986 (Colo. 1968).
[177] Colo. Rev. Stat. Ann., sec. 148-21-2(1) (supp. 1969).

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The 1969 act implemented its policy in several different ways. It made clear that, with certain exemptions,[178] water rights for wells would have to be adjudicated in order to be given priority as of their actual dates of initiation and provided a grace period within which unadjudicated wells might be given such a priority date.[179] The act also enabled a surface appropriator to secure the right to have a well so situated as to draw water from the same stream system made an alternate point of diversion to the surface right,[180] and required the use of such an approved alternate point of diversion, where it exists, before diversions under junior rights might be ordered discontinued to make water available to its owner.[181] A 1971 amendment to the act authorized the State engineer to promulgate separate rules and regulations of wells in different water divisions, stream basins, and different aquifers having separate and different hydraulic characteristics.[182] The State engineer has promulgated rules and regulations for the use of wells diverting water tributary to both the Arkansas and South Platte Rivers. The Colorado Supreme Court has upheld the rules and regulations for the South Platte Basin in the case of *Kuiper* v. *Well Owners Conservation Association*.[183]

4.2 *Nontributary Ground Water*

The Colorado Ground Water Management Act[184] makes all "designated ground waters" in the State subject to appropriation as modified by the act and in the manner defined in the act.[185] Designated ground water generally is nontributary ground water[186] within the geographic boundaries of a ground water basin "designated" by the State ground water commission after certain procedures and upon the basis of certain criteria listed in the act. From time to time, as adequate factual data become available and after publication of notice and hearings, the Commission determines designated ground water basins after making findings on the names and boundaries of aquifers within a basin, the estimated quantity of water stored in each aquifer, the estimated annual rate of recharge, the estimated use of ground water in the area, and the number of users withdrawing water during the 5 year period preceding the determination.[187] After designation of a ground water basin, any person desiring to appropriate ground water therein must apply to the Commission for a permit to do so.[188] If the Commission finds that there are no unappropriated waters in the designated source, or that the proposed

[178] Colo. Rev. Stat. Ann., sec. 148-21-15 (supp. 1969), as amended.
[179] Colo. Rev. Stat. Ann., sec. 148-21-22, as amended (supp. 1971). See note 54.
[180] Colo. Rev. Stat. Ann., sec. 148-21-17(3)(b) (supp. 1969).
[181] Colo. Rev. Stat. Ann., sec. 148-21-35(2) (supp. 1969).
[182] Colo. Rev. Stat. Ann., sec. 148-21-31 (supp. 1969), as amended (supp. 1971).
[183] 490 P. 2d 268 (Colo. 1971).
[184] Colo. Rev. Stat. Ann., secs. 148-18-1 to 148-18-41 (supp. 1965), as amended (supp. 1971).
[185] The doctrine of appropriation has been modified with respect to waters governed by it to permit the full economic development of water resources. Colo. Rev. Stat. Ann., sec. 148-18-1 (supp. 1965).
[186] The act defines designated ground water as "that ground water which in its natural course would not be available to and required for the fulfillment of decreed surface rights, or ground water in areas not adjacent to a continuously flowing natural stream wherein ground water withdrawals have constituted the principal water usage for at least 15 years preceding the date of the first hearing on the proposed designation of the basin; and which in both cases is within the geographic boundaries of a designated ground water basin." Colo. Rev. Stat. Ann., sec. 148-18-2(3).
[187] Colo. Rev. Stat. Ann., sec. 148-18-5 (supp. 1965), as amended (supp. 1971).
[188] Colo. Rev. Stat. Ann., sec. 148-18-6 (supp. 1971).

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appropriation would unreasonably impair existing water rights from the source or would create unreasonable waste, it must deny the application.[189] If the proposed appropriation will not unreasonably impair existing rights or create unreasonable waste, the Commission grants the permit subject to such reasonable conditions and limitations as the Commission may specify.[190] In determining the effect of a proposed appropriation on existing rights, the Commission must consider the area and geologic conditions, the average annual yield and recharge rate of the supply, the priority and quantity of existing claims, the proposed method of use, and other matters appropriate to such questions.[191] The Commission may formulate appropriate tests for determining what may constitute unreasonable lowering of the water level beyond reasonable economic limits of withdrawal or use. In one designated basin a 3-mile radius test by which the Commission denied new applications was upheld by the courts.[192] There, pumping of wells within a 3-mile radius of a proposed well was already sufficient to deplete available water by 40 percent over 25 years' time. The court held that the Commission was justified in using the test in concluding there was no longer any unappropriated water available.

Although priority of claims within designated basins is determined by priority of appropriation,[193] the procedures for determining priorities are different from those for determining the priority of claims for surface water appropriations and of appropriations of ground water tributary to a natural stream. Priorities of appropriation in designated basins are determined, after hearing, by the ground water commission.[194] Appropriations based on actual taking and use of ground water before the effective date of the 1965 Ground Water Management Act are related back to the date of original use. Claims initiated after the effective date of the act are dated from the filing of an application with the commission.[195]

As explained above,[196] the administration and enforcement of the Ground Water Management Act is placed in the ground water commission, locally formed management districts, and the State engineer, in each of whom are vested certain regulatory or administrative powers and functions.[197]

PUBLICATIONS AVAILABLE

Institution for Water Resource Research:
Natural Resources Center
Colorado State University
Fort Collins, Colo. 80521
303-491-6952

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[189] Colo. Rev. Stat. Ann., sec. 148-18-6(4) (supp. 1971).
[190] Colo. Rev. Stat. Ann., sec. 148-18-6(3) (supp. 1965).
[191] Colo. Rev. Stat. Ann., sec. 148-18-6(5) (supp. 1965).
[192] *Fundingsland v. Colorado Ground Water Commission*, 468 P. 2d 835 (Colo. 1970).
[193] Colo. Rev. Stat. Ann., sec. 148-18-8(1) (supp. 1965).
[194] Colo. Rev. Stat. Ann., sec. 148-18-8(3), (5) (supp. 1965); Colo. Rev. Stat. Ann., sec. 148-18-8(4) (supp. 1971).
[195] Colo. Rev. Stat. Ann., sec. 148-18-8(1) (supp. 1965).
[196] See note 68.
[197] Powers of the State engineer are enumerated in Colo. Rev. Stat. Ann., sec. 148-18-9 (supp. 1965). Powers of the ground water commission are enumerated in Colo. Rev. Stat. Ann., sec. 148-18-10 (supp. 1965). Functions of management districts are detailed in Colo. Stat. Ann., sec. 148-18-17 to 148-18-31 (supp. 1965), as amended (supp. 1967, 1971).

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Publications:

Harrison, Sandstrum, Groundwater—*Surface Water Conflict and Recent Colorado Legislation*, 43 U. Colo. L. Rev. 1 (1971).

Comment, *Appropriation and Colorado's Ground Water: A Continuing Dilemma?*, 40 Colo. L. Rev. 133 (1967).

Comment, *Phreatophyte Eradication as a Source of Water Rights in Colorado*, 43 U. Colo. L. Rev. 473 (1972).

Ross, *Acquisition of Existing Water Rights*, 13 Rocky Mt. M.L. 477 (1967).

Moses and Vranesh, *Colorado's New Ground Water Laws*, 38 U. Colo. L. Rev. 281 (1966).

Note, *Foreign Water in Colorado—The City's Right to Recapture and Re-use its Transmountain Diversion*, 42 Denver L.C.J. 116 (1965).

Note, *Developments in Colorado Water Law of Appropriation in the Last Ten Years*, 35 U. Colo. L. Rev. 493 (1963).

Note, *Water—Granting of Conditional Decree of Water Priority Under the Doctrine of Relation Back*, 34 Rocky Mt. L. Rev. 423 (1962).

Note, *Water Pollution Control in Colorado*, 36 U. Colo. L. Rev. 413 (1964).

Note, *Actual Physical Diversion not Necessary to Effect an Appropriation*, 33 Rocky Mt. L. Rev. 249 (1961).

Kelly, *Colorado Ground Water Act of 1957—is Ground Water Property of the Public*, 31 Rocky Mountain L. Rev. 165 (1959).

Note, *Presumption that all Waters are Tributary Applied to Ground Water; Right to Lift Recognized*, 28 Rocky Mountain L. Rev. 145 (1955).

Note, *Recurring problem of Colorado's Underground Water*, 28 Rocky Mountain L. Rev. 371 (1956).

Danielson, *Water Administration in Colorado—Hierarority or Priority?* 30 Rocky Mountain L. Rev. 293 (1958).

Note, *Constitutionality of Colorado Statutes Providing for Transmountain Water Diversions*, 25 Rocky Mountain L. Rev. 363-9 (1953).

Martz, Who has the Better Right to Non-tributory Ground Waters in Colorado—Landowner or Appropriator?, 31.

Note, *Change of point of Diversion—Time Limitation on Use of Water by Municipality*, 24 Rocky Mountain L. Rev. 121-3 (1951).

EXHIBIT 3

Colorado Water Quality Standards

COLORADO DEPARTMENT OF HEALTH
Water Quality Control Commission
4210 East 11th Avenue
Denver, Colorado 80220
Adopted: January 15, 1974
Effective: June 19, 1974

WATER QUALITY STANDARDS FOR COLORADO

AUTHORITY

These standards are promulgated pursuant to section 66-28-202(b) and section 66-28-204 C.R.S. 1963, as amended.

PURPOSE

These standards are the foundation for the classification of the waters of the State of Colorado, as defined in the Water Quality Control Act of 1973, intended to implement the act, to maintain and to enhance the quality of the state's waters for public water supplies, for protection and propagation of wildlife and aquatic life, and for domestic, agricultural, industrial, recreational and other beneficial uses. They are further intended to be consistent with the goals and policies of the Federal Water Pollution Control Act Amendments of 1972, which are stated in section 101 thereof. These standards shall be construed in a manner consistent with these purposes.

The division shall review stream standards not less than once every three years and report its findings to the commission.

Sampling for the purpose of determining quality of state waters shall not be done in areas immediately adjacent to outfalls.

MIXING ZONE

The area or volume of a stream designated by the division within which effluent shall become thoroughly mixed with the waters of the stream.

The total area or volume of a stream designated as a mixing zone shall be limited to that area or volume which will not interfere with biological communities or populations of important species to a degree which is damaging to the ecosystem and which will not cause substantial damage to other beneficial uses.

ZONE OF PASSAGE

A continuous water route which joins segments of a stream, reservoir or lake above and below a mixing zone without going through the mixing zone.

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Water Quality Standards for Colorado
Adopted: January 15, 1974
Effective: June 19, 1974

ZONE OF PASSAGE (continued)

The zone of passage shall have volume and area sufficient to allow passage of freeswimming and drifting organisms in a manner producing no significant effects on their populations except during periods when there is no water in the stream, lake or reservoir, or except when flow or level is less than the minimum seven day low flow or level which is expected to occur once in ten years.

FLOW CRITERIA AND EXCEPTIONS

The water quality standards for a particular class of water shall apply at all times, except during periods of time when lake or reservoir water levels or streamflows are less than the minimum seven day low flow or level which is expected to occur once in ten years. During such periods of time, the basic water quality standards shall apply. Exceptions on specific parameters may be allowed through discharge permits.

ANALYTICAL TESTING

Tests or analytical procedures to determine compliance with standards shall, insofar as practicable and applicable, be made in accordance with the methods given in the latest edition of "Standard Methods for the Examination of Water and Waste Water" published by the American Public Health Association, or in accordance with tests or analytical procedures which the commission finds to be at least equally satisfactory.

ANTIDEGRADATION STATEMENT

Waters of the state, whose quality exceeds the limits set in these standards, shall be maintained at existing quality unless and until it can be demonstrated to the state that a change in quality is justified to provide necessary economic or social development. In that case, treatment to the extent necessary to protect the current classification of such waters shall be required. The appropriate federal authority shall be provided with information, from time to time, required to discharge his responsibilities under the Federal Water Pollution Control Act, as amended.

DEGREE OF TREATMENT

All wastes prior to discharge into state waters shall receive the degree of treatment necessary to comply with the Standards for the Discharge of Wastes, Water Quality Standards (Stream Standards) and the Antidegradation Statement.

Water Quality Standards for Colorado
Adopted: January 15, 1974
Effective: June 19, 1974

1 BASIC STANDARDS APPLICABLE TO ALL STATE WATERS:

(1) All state waters shall be:

a. free from substances attributable to municipal, industrial, or other discharges or agricultural practices, which will settle to form objectionable sludge deposits;

b. free from floating debris, scum, and other floating materials attributable to municipal, industrial, or other discharges or agricultural practices, which are present in amounts sufficient to be unsightly or deleterious;

c. free from materials attributable to municipal, industrial, or other discharges or agricultural practices, which produce color, odor, or other conditions in such a degree as to create a nuisance or impart any undesirable taste to fish flesh or in any way make fish inedible;

d. free from substances attributable to municipal, industrial, or other discharges or agricultural practices in concentrations or combinations which are toxic or harmful to human, animal, plant, or aquatic life;

e. free from substances and conditions or combinations thereof attributable to municipal, industrial, or other discharges or agricultural practices in concentrations which produce undesirable aquatic life;

f. free from residues attributable to wastewater or visible film oils or globules of grease, which are present in concentrations which cause a film, other discoloration of the surface, or which cause an emulsion to be deposited beneath the surface of the water or upon adjoining shorelines or which prevent classified uses of such waters.

(2) The radioactivity of surface waters shall be maintained at the lowest practical level and shall in no case, except when due to natural causes, exceed the latest Federal Drinking Water Standard as established by the United States Public Health Service, the Environmental Protection Agency or their successor.

(3) The Commission presently has not adopted a standard regarding salinity, but has reserved this section for such criteria. Since Colorado has been collecting and analyzing stream samples for a relatively short period of time, it is felt that insufficient data is available to set numerical standards at this time. In addition, technological know-how has not advanced to the point where all sources of salinity (irrigation return flows, for example) can be resolved. Therefore, Colorado proposes, where possible, to maintain salinity concentrations at or below present levels while gathering additional data so that meaningful numerical salinity standards can be established at some future date. In the meantime, Colorado will continue to take action against known discharges contributing to the salinity problem where present technology allows for such

control; continue with demonstration projects, such as the Grand Valley Project; and, through whatever means available, strive to educate the irrigator in proper water management and irrigation practices.

With regard to the Colorado River system and its tributaries, the State of Colorado will cooperate with other Colorado River Basin states and the Federal Government to support and implement the conclusions and recommendations adopted April 27, 1972, by the reconvened 7th Session of the Conference in the Matter of Pollution of the Interstate Waters of the Colorado River and its tributaries.

WATER QUALITY STANDARDS FOR CLASS A_1 OR A_2 WATERS

(1) State waters designated class A_1 or A_2 are waters suitable or to become suitable for all purposes for which raw water is customarily used, including primary contact recreation, such as swimming and water skiing.

(2) Water in class A_1 exhibits or is to exhibit the following characteristics:

a. Bacteriological concentrations which do not exceed a geometric mean of 200 fecal coliform groups per 100 milliliters nor 1000 total coliform groups per 100 milliliters based on a minimum of not less than five samples obtained during separate 24-hour periods for any 30-day period, nor do 10 percent of the fecal coliform groups exceed 400 groups per 100 milliliters, nor do 20 percent of the total coliform groups exceed 2000 groups per 100 milliliters during any 30-day period. In addition, the fecal streptococcus count does not exceed an average of 20 per 100 milliliters based upon an average of five consecutive samples within a 30-day period.

b. The dissolved oxygen concentration is not less than 6 milligrams per liter.

c. A pH rating of not more than 8.5 nor less than 6.5 units.

d. Temperature maintains a normal pattern of diurnal and seasonal fluctuations and does not change abruptly. No warming discharge is permitted in the hypolimnion of lakes. Temperature is not increased above 68° F. by any means other than natural means, or is temperature increased in streams and in the epilimnion of lakes or reservoirs more than 2°F., by any discharge.

e. Wastes of other than natural origin do not cause the turbidity of the water to be increased by more than ten Jackson Turbidity Units or its equivalent.

(3) Water in class A_2 exhibits or is to exhibit the following characteristics:

Water Quality Standards for Colorado
Adopted: January 15, 1974
Effective: June 19, 1974

a. Bacteriological concentrations which do not exceed a geometric mean of 200 fecal coliform groups per 100 milliliters nor 1000 total coliform groups per 100 milliliters based on a minimum of not less than five samples obtained during separate 24-hour periods for any 30-day period, nor do 10 percent of the fecal coliform groups exceed 400 groups per 100 milliliters, nor do 20 percent of the total coliform groups exceed 2000 groups per 100 milliliters during any 30-day period. In addition, the fecal streptococcus count does not exceed an average of 20 per 100 milliliters based upon an average of five consecutive samples within a 30-day period.

b. The dissolved oxygen concentration is not less than 5 milligrams per liter.

c. A pH rating of not more than 8.5 nor less than 6.5 units.

d. Temperature maintains a normal pattern of diurnal and seasonal fluctuations and does not change abruptly. No warming discharge is permitted in the hypolimnion of lakes or reservoirs. Temperature is not increased above 90° F. by any means other than natural means, or is temperature increased by discharges in streams more than 5° F., and in the epilimnion of lakes or reservoirs more than 3° F.

e. Wastes of other than natural origin do not cause the turbidity of the water to be increased by more than ten Jackson Units or its equivalent.

WATER QUALITY STANDARDS FOR CLASS B_1 OR B_2

(1) State waters designated class B_1 or B_2 are waters suitable or to become suitable for all purposes for which raw water is customarily used, except primary contact recreation, such as swimming and water skiing.

(2) Water in class B_1 exhibits or is to exhibit the following characteristics:

a. Bacteriological concentrations do not exceed a geometric mean of 10,000 total coliform groups or 1000 fecal coliform groups per 100 milliliters based on a minimum of not less than five samples obtained during separate 24-hour periods for any 30-day period, nor do 10 percent of the fecal coliform samples exceed 2000 groups per 100 milliliters during any 30-day period.

b. The dissolved oxygen concentration is not less than 6 milligrams per liter.

c. A pH rating of not more than 9.0 nor less than 6.0 units.

d. Temperature maintains a normal pattern of diurnal and seasonal fluctuations and does not change abruptly. No warming discharge is permitted in the hypolimnion of lakes. Temperature is not increased above 68° F. by any means other than natural means, nor is temperature increased in streams and in the epilimnion of lakes or reservoirs more than 2° F. by any discharge.

e. Wastes of other than natural origin does not cause the turbidity of the water to be increased by more than ten Jackson Units or its equivalent.

(3) Water in class B_2 exhibits or is to exhibit the following characteristics:

a. Bacteriological concentrations do not exceed a geometric mean of 10,000 total coliform groups or 1000 fecal coliform groups per 100 milliliters based on a minimum of not less than five samples obtained during separate 24-hour periods for any 30-day period, nor do 10 percent of the fecal coliform samples exceed 2000 per 100 milliliters during any 30-day period.

b. The dissolved oxygen concentration is not less than 5 milligrams per liter.

c. A pH rating of not less than 6.0 nor more than 9.0.

d. Temperature maintains a normal pattern of diurnal and seasonal fluctuations and does not change abruptly. No warming discharge is permitted in the hypolimnion of lakes or reservoirs. Temperature is not increased above 90° F. by any means other than natural means, or is temperature increased by discharges more than 5° F. in streams and more than 3° F. in the epilimnion of lakes or reservoirs.

e. Wastes of other than natural origin does not cause the turbidity of the water to be increased by more than ten Jackson Units or its equivalent.

TERMS AND DEFINITIONS AS PRESENTED BY THE WATER QUALITY CONTROL COMMISSION

BIOCHEMICAL OXYGEN DEMAND - A measure of the amount of oxygen necessary to satisfy the biochemical oxidation requirements of pollution in a sample that is maintained at a temperature of 20° Centigrade for a period of five days.

BIOCIDE - A toxic, chemical substance or mixture intended to abate or destroy noxious forms of life, such as vermin, insects, viruses and fungi harmful in agriculture, fisheries and forestry.

CLASSIFICATION - The application of a standard or standards to a segment or segments of the waters of the state.

COLIFORM GROUP ORGANISMS (TOTAL COLIFORM GROUPS) - The coliform group includes all of the aerobic and facultative anaerobic, Gram-negative, non-spore forming, rod shaped bacteria that ferment lactose broth with gas formation within 48 hours at 35° Centigrade.

CONDUCTIVITY - A measure of the ability of water to conduct an electric current, which may be used for approximating the salinity in water.

CONTROLLABLE SOURCES - A source of waste discharge that can be controlled by physical means.

DISINFECTION - A method of reducing the organisms pathogenic to man.

DISSOLVED OXYGEN - A measure of the amount of free oxygen (oxygen which is not chemically combined with other substances) available in water to oxidize oxygen demanding materials.

EPILIMNION - In a thermally stratified lake, the layer of water that extends from the surface to the thermocline.

EUTROPHICATION - The process of a lake becoming rich in dissolved nutrients thereby enhancing the growth of aquatic plants leading to possible seasonal oxygen deficiencies and accelerating the rate of lake aging.

FECAL COLIFORM ORGANISMS - That portion of the coliform group which is present in the intestinal tract of warm-blooded animals. It generally includes organisms which are capable of producing gas from lactose broth in a suitable culture medium within 24 hours at 44.5° ± 0.5° Centigrade.

HYPOLIMNION - The region below thermal stratification in a lake or reservoir.

MF - Refers to the membrane filter technique of water analysis. This technique involves the passing of a certain volume of water through a cellulose ester filter which is then impregnated with a food product for the bacteria that are retained on the surface of the filter.

STANDARD METHODS FOR THE EXAMINATION OF WATER AND WASTE WATER, LATEST EDITION - A publication prepared jointly by the American Public Health Association, American Water Works Association, and the Water Pollution Control Federation, accepted by Federal, State, and local authorities in the field of water pollution control as the authority for analytical procedures to be utilized in the examination or analysis of waters and waste waters.

STANDARDS - An official limiting value used to determine the quality of water for a classified use as established by the Water Quality Control Commission.

THERMOCLINE - In thermally stratified lakes, the layer below the epilimnion. It is the stratum in which there is a rapid rate of decrease in temperature with depth; a minimum of one degree Centigrade per meter in de.*h.

TOXIC MATERIAL - Materials which are harmful to human, plant, animal, and aquatic life.

TURBIDITY - A measure of the clarify and the light penetration of water as affected by suspended and colloidal matter.

MPN - An abbreviation of "Most Probable Number" - a test of bacterial density derived from multiple tube fermentation techniques. It is expressed as a number of organisms per hundred milliliters. It is a number most likely to occur, in statistical theory, under the given circumstances or conditions of the test.

MILLIEQUIVALENT PER LITER - A unit for expressing the concentration of chemical constituents in terms of interreacting values of electrically charged particles or ions in solution. One milliequivalent per liter of a positively charged ion will react with one milliequivalent per liter of a negatively charged ion.

MILLIGRAMS PER LITER - Also referred to as "parts per million." This is a unit for expressing the concentration of any substance by weight, usually as grams of substance per million grams of solution. Since a liter of water weighs one kilogram, one milligram per liter is equivalent to one part per million.

MILLILITER - One-thousandth of a liter. One liter is equal to 1.06 quarts.

NATIONAL BUREAU OF STANDARDS HANDBOOK 69, LATEST EDITION - A reference book published by the U. S. Department of Commerce, National Bureau of Standards. It contains recommendations as to the maximum permissible concentrations of radio nuclides in the human body, air, and water.

NATURAL CAUSES - (As applied to temperature fluctuation standards) - Temperature fluctuations due to effluents from domestic sewage treatment plants and identifiable irrigation return flows shall be considered as originating from natural causes.

pH - The pH value indicates the relative intensity of acidity or alkalinity of water, with the neutral point at pH 7.0. Values lower than 7.0 indicate the presence of acids; above 7.0, the presence of alkalies.

PRIMARY CONTACT RECREATION - Raw surface waters in which the human body may be completely submerged and there is prolonged and intimate contact involving considerable risk of ingesting waters in sufficient quantities to pose a significant health hazard. Although the water may be ingested accidentally, it is not intended for use as a potable water supply unless acceptable treatment is applied. These waters may be used for swimming, water skiing, skin diving and other similar activities.

SECONDARY CONTACT RECREATION - Raw surface water where the human body may come in direct contact with the water but normally not to the point of complete submergence and there is little likelihood that the water will be ingested. This water may be used for fishing, boating and other similar activities.

SODIUM ADSORPTION RATIO - An index of hazard to physical condition of soil due to sodium in irrigation water.

Adopted: March 19, 1974
Effective: June 19, 1974

CLASSIFICATION OF INTERSTATE AND INTRASTATE STREAMS IN COLORADO BY RIVER BASINS

AUTHORITY: Section 66-28-202(a) and Section 66-28-203 C.R.S. 1963, as amended.

GENERAL PROVISIONS:

1. Basic Standards will apply to all waters of the state, as defined in the Water Quality Control Act, whether classified or not.

2. The classification of waters shall not be construed as an action to supplant or interfere with decreed uses of the water. Nothing herein shall be construed to require the delivery of water from one basin to another or from one state to another or to affect the provisions of any interstate compact or U. S. Supreme Court Decision.

3. Owners (municipalities, irrigation companies and industries) of specific bodies of water may utilize the waters as desired provided that the water quality standards set for that body of water are maintained.

Adopted: March 19, 1974
Effective: June 19, 1974

WATER QUALITY STANDARDS SUMMARY

STANDARD	CLASS			
	A_1	A_2	B_1	B_2
Settleable Solids	Free From	Free From	Free From	Free From
Floating Solids	Free From	Free From	Free From	Free From
Taste, Odor, Color	Free From	Free From	Free From	Free From
Toxic Materials	Free From	Free From	Free From	Free From
Oil and Grease	Cause a film or other discoloration	Cause a film or other discoloration	Cause a film or other discoloration	Cause a film or other discoloration
Radioactive Material	Drinking Water Standards	Drinking Water Standards	Drinking Water Standards	Drinking Water Standards
Fecal Coliform Bacteria	Geometric Mean of <200/100ml from five samples in 30-day per.	Geometric Mean of <200/100ml from five samples in 30-day per.	Geometric Mean of <1000/100ml from five samples in 30-day per.	Geometric Mean of <1000/100ml from five samples in 30-day per.
Turbidity	No increase of more than 10 J.T.U.	No increase of more than 10 J.T.U.	No increase of more than 10 J.T.U.	No increase of more than 10 J.T.U.
Dissolved Oxygen	6 mg/l minimum	5 mg/l minimum	6 mg/l minimum	5 mg/l minimum
pH	6.5 - 8.5	6.5 - 8.5	6.0 - 9.0	6.0 - 9.0
Temperature	Maximum 68°F. Maximum Change 2°F.	Maximum 90°F. Maximum Change: Streams - 5°F. Lakes - 3°F.	Maximum 68°F. Maximum Change 2°F.	Maximum 90°F. Maximum Change: Streams - 5°F. Lakes - 3°F.
Fecal Streptococcus	Monthly average of <20/100ml from five samples in 30-day per.	Monthly average of <20/100ml from five samples in 30-day per.	----	----

Adopted: March 19, 1974
Effective: June 19, 1974

COLORADO RIVER BASIN

CLASSIFICATION

AREA NO.	AREA	FROM	TO	QUALITY CLASS
1	Main Stem of Colorado River and tributaries and standing bodies of water on main stem and tributaries in this area (refer to Appendix A) except for specific listing.	Sources	Confluence with Parachute Creek near Town of Grand Valley	B_1
2	Grand Lake, Shadow Mountain Reservoir and Granby Reservoir	Inlet	Outlet	A_1
3	Main Stem of Colorado River	Confluence with Parachute Creek near Town of Grand Valley	Colorado-Utah State Line	B_2
4	Plateau Creek and tributaries and standing bodies of water on main stem and tributaries (refer to Appendix A)	Sources	Confluence with Colorado River	B_1
5	Fraser River and Williams Forks of River (including Williams Fork Reservoir)	Sources	Confluence with Colorado River	B_1
6	Blue River including Dillon Reservoir	Source	Confluence with Colorado River	B_1

Adopted: March 19, 1974
Effective: June 19, 1974

COLORADO RIVER BASIN

CLASSIFICATION

AREA NO.	AREA	FROM	TO	QUALITY CLASS
7	Eagle River including Homestake Creek	Source	Confluence with Colorado River	B_1
8	Gore Creek	Source	Confluence with Eagle River	B_1
9	Roaring Fork River and tributaries and standing bodies of water on main stem and tributaries (refer to Appendix A)	Sources	Confluence with Colorado River	B_1
10	Gunnison River and North Fork of Gunnison River, including tributaries and standing bodies of water on main stem and tributaries (refer to Appendix A)	Sources	Confluence of Uncompahgre River and main stem of Gunnison River	B_1
11	Gunnison River and tributaries and standing bodies of water on main stem and tributaries except for specific listings (refer to Appendix A)	Confluence of Uncompahgre River and main stem of Gunnison River	Confluence with Colorado River	B_2
12	Uncompahgre River	Confluence with Canyon Creek	Confluence with Gunnison River	B_1

APPENDIX C

MANUAL ANALYSIS OF INFLOW TO UNDERGROUND MINES IN TABULAR SEDIMENTARY DEPOSITS

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1.0 INTRODUCTION

The purpose of this appendix is to present the methods used in analyzing the inflows to mines in the Piceance Basin. The simple analytical methods developed in this appendix have been used to compute all the inflow values presented in this study.

The basic inflow cases have been presented:

i. Uncaved roof case.
ii. Caved roof case.

These two cases represent the minimum and maximum total flow cases respectively; however, it is possible to develop situations where the uncaved roof case can produce higher instantaneous flow rates than the caved case.

2.0 METHOD OF ANALYSIS

The basic method of analysis is to break the problem up into three zones, to analogue the real mine layout. A schematic of the arrangement is shown in Figure 1. Three main zones of flow are defined:

i. Zone 1. Flow in Zone 1 is radial beyond the periphery of the mine, changing to near vertical above the mine.

ii. Zone 2. Flow in this zone is radial. The size of the zone is determined by the mine height, plus the zone of disturbance above and below the mine.

iii. Zone 3. Flow in this zone is radial outside the mine periphery, turning to vertically upwards as it approaches the mine floor.

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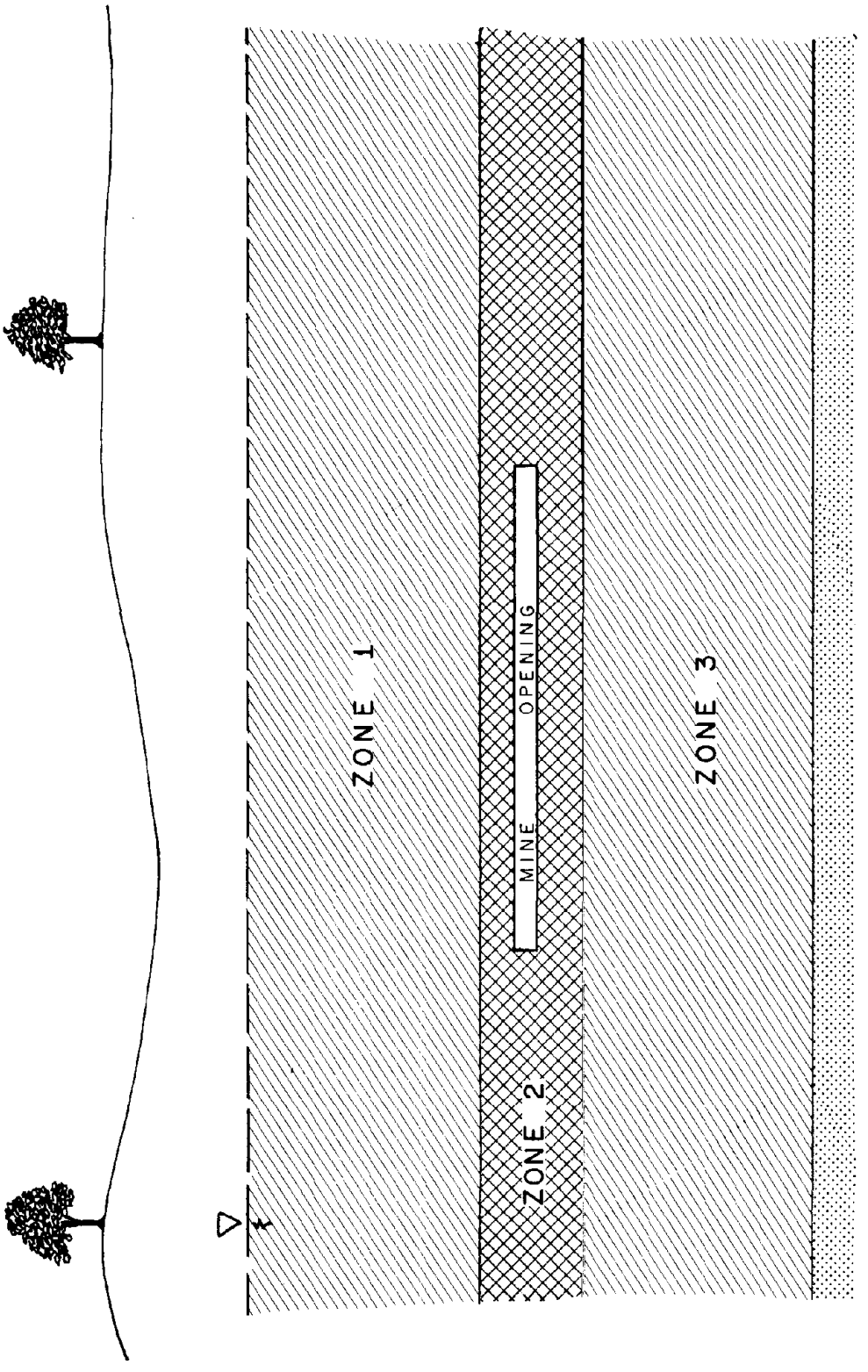


Figure 1 SCHEMATIC OF SITUATION ANALYZED

Because of their basic simplicity, the flows in Zones 2 and 3 are amenable to hand calculation using analytical solutions. The flow in Zone 1 is more complex, and so a general computer analysis of this flow regime was performed, and charts of flow as a function of geometric and hydrologic parameters were developed.

3.0 ASSUMPTIONS

A number of basic assumptions have been made for the analysis.

i. Flow is governed by Darcy's law.

ii. The material in each zone is homogeneous and anisotropic, with the principal permeabilities horizontal and vertical.

iii. The horizontal permeability is the same in all directions.

iv. The horizontal permeability is equal to or less than the vertical permeability.

v. The mine is circular, and expands at a constant areal rate.

vi. The mine is held at atmospheric pressure.

vii. Flow to the mine is sufficiently small so that the boundaries of the flow field are unaffected by the mine inflow.

viii. When the pressure in the rock medium drops to zero, the rock de-saturates.

ix. Flows in the three zones are independent.

Where these assumptions appear to be violated, they have been tested - the results are presented in this appendix.

4.0 FLOW ANALYSES IN ZONE 1 - UNCAVED CASE

In the uncaved case, the flow to the mine from Zone 1 is as shown in Figure 2. The flow originates from the compression of the rock, the movement of the phreatic surface (when this is allowed), and from the remote boundary. The system is assumed to be axially symmetrical, for analytical simplicity.

4.1 UPPER BOUND INFLOW ANALYSIS - UNCAVED CASE

4.1.1 Approach

In order to evaluate the upper bound to mine inflow in the uncaved case, the situation presented in Figure 3 was analyzed using the Finite Element Method (see Appendix E). The boundary conditions were very simple, with the water table being held fixed at its original position. This condition will be realistic in two circumstances:

i. When the mine is small compared with the thickness of the zone ($R_o << D$).

ii. When the rate of movement of the phreatic surface is slow compared to the rate of expansion of the mine.

The rate of movement of the phreatic surface is a strong function of the porosity and the vertical permeability of the rock, and a weak function of the horizontal permeability and the mine size. Surface infiltration will also retard phreatic surface movement.

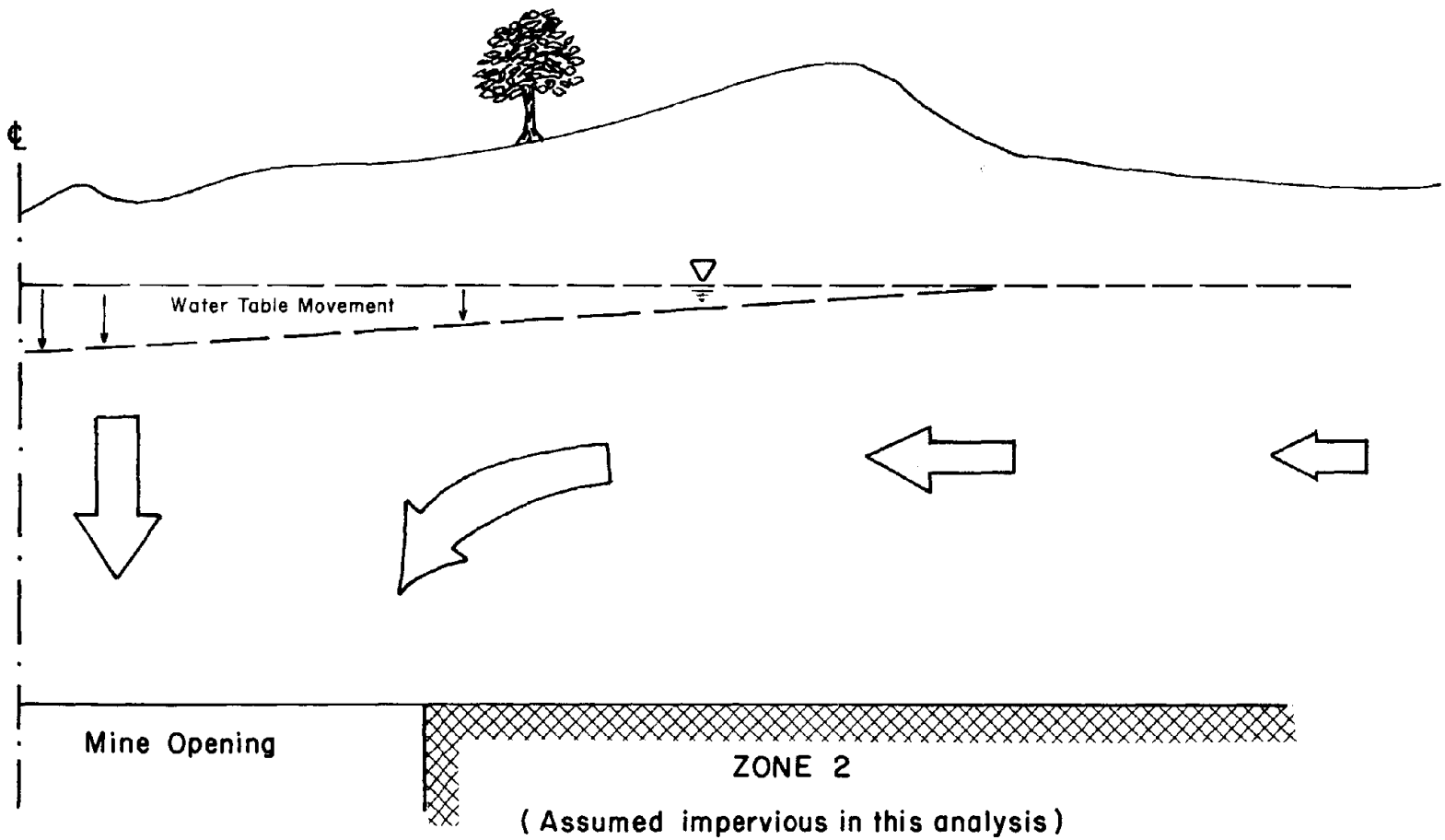


Figure 2 SCHEMATIC OF FLOW IN ZONE 1

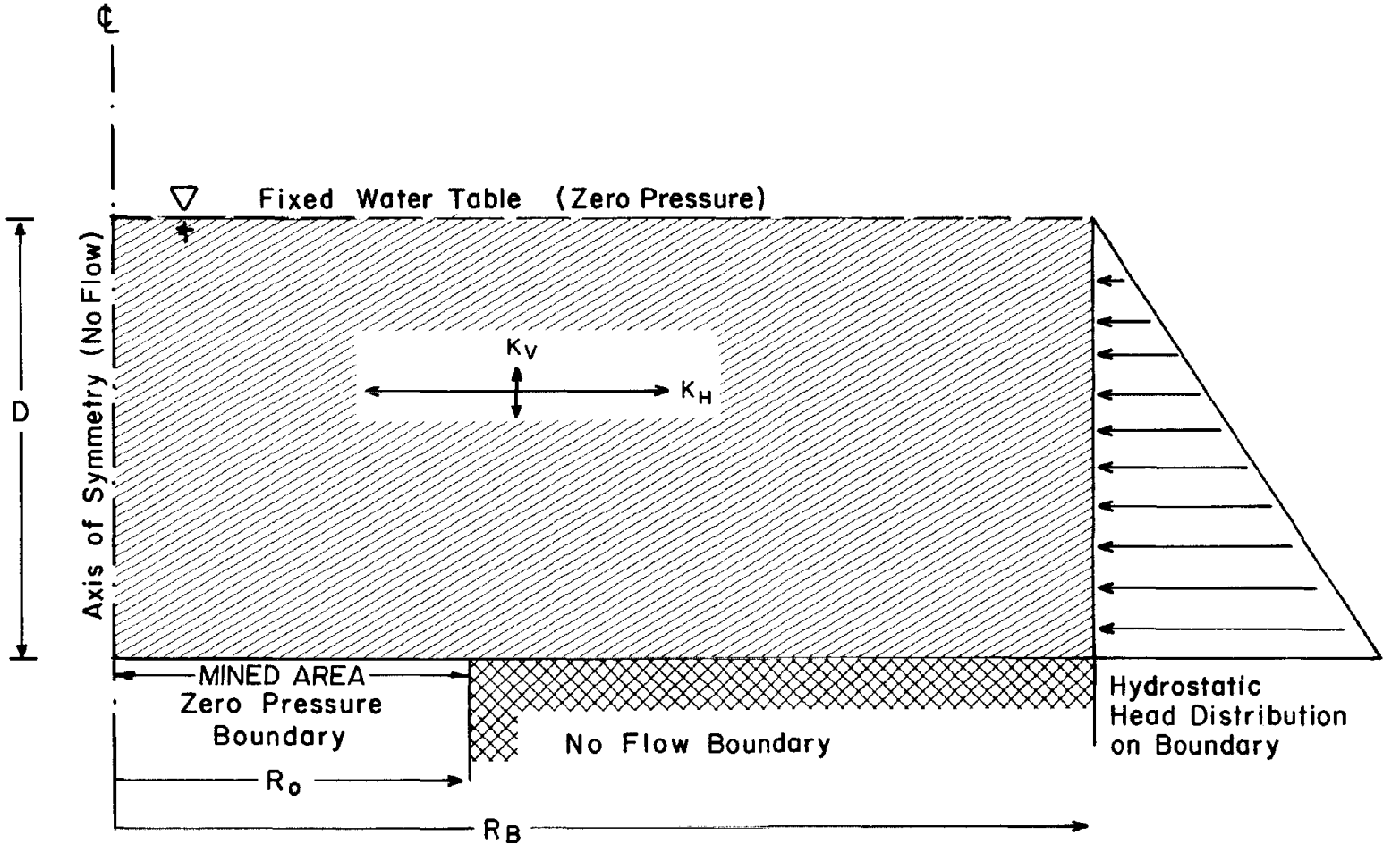


Figure 3 DIAGRAM SHOWING UNCAVED ZONE 1 ANALYSIS BOUNDARY CONDITIONS AND MATERIAL PROPERTIES

All analyses run for this section were for the flow to the mine at steady state. The very stringent boundary conditions ensure that this is a reasonable approach, as the time scale of interest is of the order of years. The only material property producing transient behavior in this analysis is the rock compressibility, and this is only weakly related to inflow in any case.

4.1.2 Results Presentation

In order to generalize the results of the study, a dimensionless presentation was developed. Dimensional analysis shows that

$$\left[\frac{Q_1}{K_V R_o^2} \quad , \frac{K_V}{K_H} \quad , \frac{R_o 2}{D^2} \right] = 0$$

where Q_1 = flow to the mine from Zone 1 at steady state
K_V = vertical permeability of Zone 1
K_H = horizontal permeability of Zone 1
R_o = mine radius
D = depth of mine roof below water table.

It turns out that, for the boundary conditions used, the latter two terms can be combined to produce a dimensionless "geometry ratio", γ where

$$\gamma = \frac{K_V R_o^2}{K_H D^2}$$

Physically this is proportional to the vertical flow in the plug of material above the mine, divided by the horizontal flow in Zone 1 to the periphery of the mine.

A dimensionless flow parameter with less variation was obtained by converting the first term:

$$\alpha = \frac{Q_1}{K_V R_o^2} \quad \text{to} \quad \beta = \frac{Q_1}{R_o D \sqrt{K_V K_H}}$$

Thus results are plotted in the form

$$\frac{Q_1}{R_o D \sqrt{K_V\ K_H}} \quad \text{versus} \quad \frac{K_V R_o^{\ 2}}{K_H D^2}$$

4.1.3 Results of a Typical Analysis

In order to illustrate the full analysis results in one case, the most typical results are presented in full here. The case chosen is characterized by (see Figure 3 for symbols)

$$R_o/D = 2$$
$$K_H/K_V = 100$$
$$R_B/D = 100.$$

Chosen values of parameters were:

$$K_V = 1 \text{ ft./day}$$
$$D = 1{,}000 \text{ ft.},$$

Note that the results are scalable to any value of these two parameters.

Figure 4 shows the flow net for the near-mine region of the problem. Note the concentration of flow in the upper outside corner of the mine, and the almost vertical flow above most of the mine.

Figure 5 shows the pressure distribution for the near-mine region. The pressure in the material above the mine has

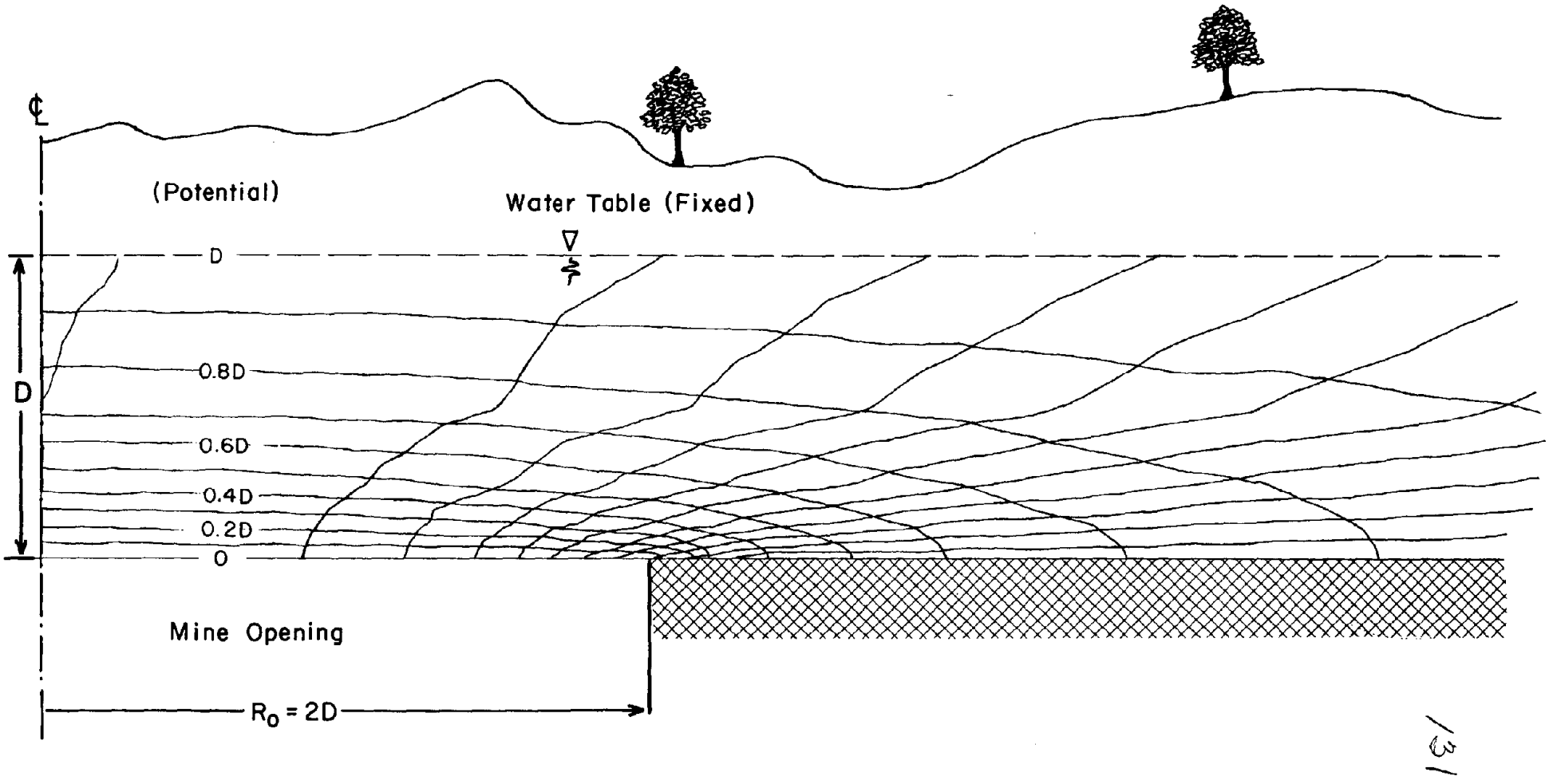


Figure 4 FLOWNET FOR TYPICAL ZONE 1 ANALYSIS

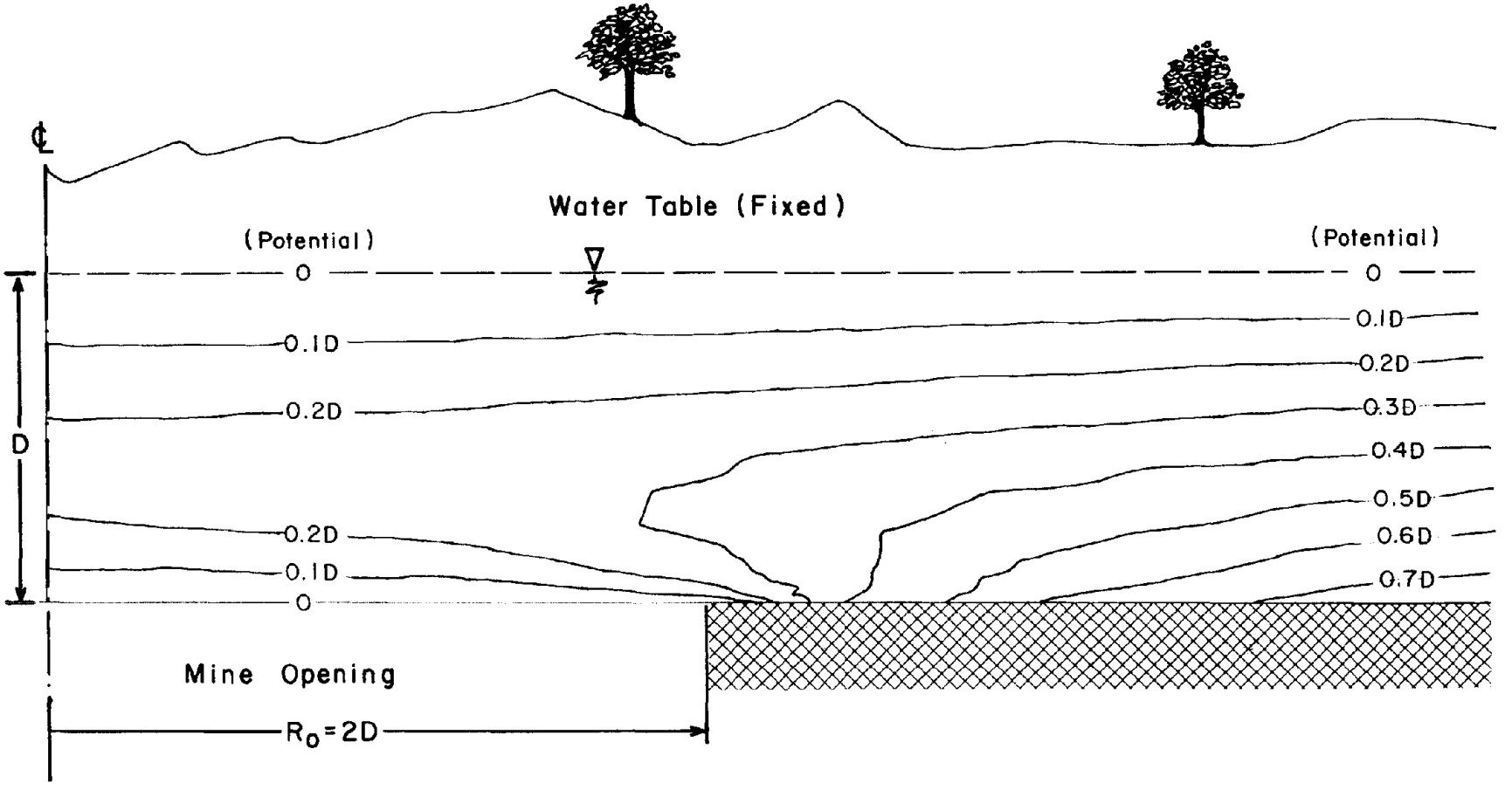


Figure 5 PRESSURE DISTRIBUTION FOR TYPICAL ZONE 1 ANALYSIS

been substantially reduced, but conditions rapidly revert to hydrostatic as the distance from the mine increases.

In this case, flow to the mine was computed to be 9.4×10^7 cu.ft./day, which is equivalent to 500,000 gpm. However, scaling the vertical permeability from 1 ft./day to a more realistic 0.003 ft./day produces a flow of 1,500 gpm in this particular case.

4.1.4 Results of All Analyses

As the interest in this evaluation is in mine inflow for Zone 1, this section will present only flows to the mine. In all, 17 analyses were performed, which covered the expected values of the parameters used in the study. The results are presented in Table 1. The resulting values of dimensionless flow, β, are plotted against the dimensionless geometry ratio, γ, in Figure 6. As can be seen, the plot is very well behaved, with all values forming a very smooth curve.

The area of main interest is for the geometry ratio, γ, in the range 0.01 to 1.0. The low values represent conditions where the mine is effectively in a semi-infinite homogeneous continuum, whereas the high values approach conditions where the mine is very large compared with the effective thickness of the zone, and thus almost all the flow is from the water table vertically downward into the mine.

Figure 6 PLOT OF DIMENSIONLESS FLOW TO MINE FROM ZONE I - UPPER BOUND ANALYSIS

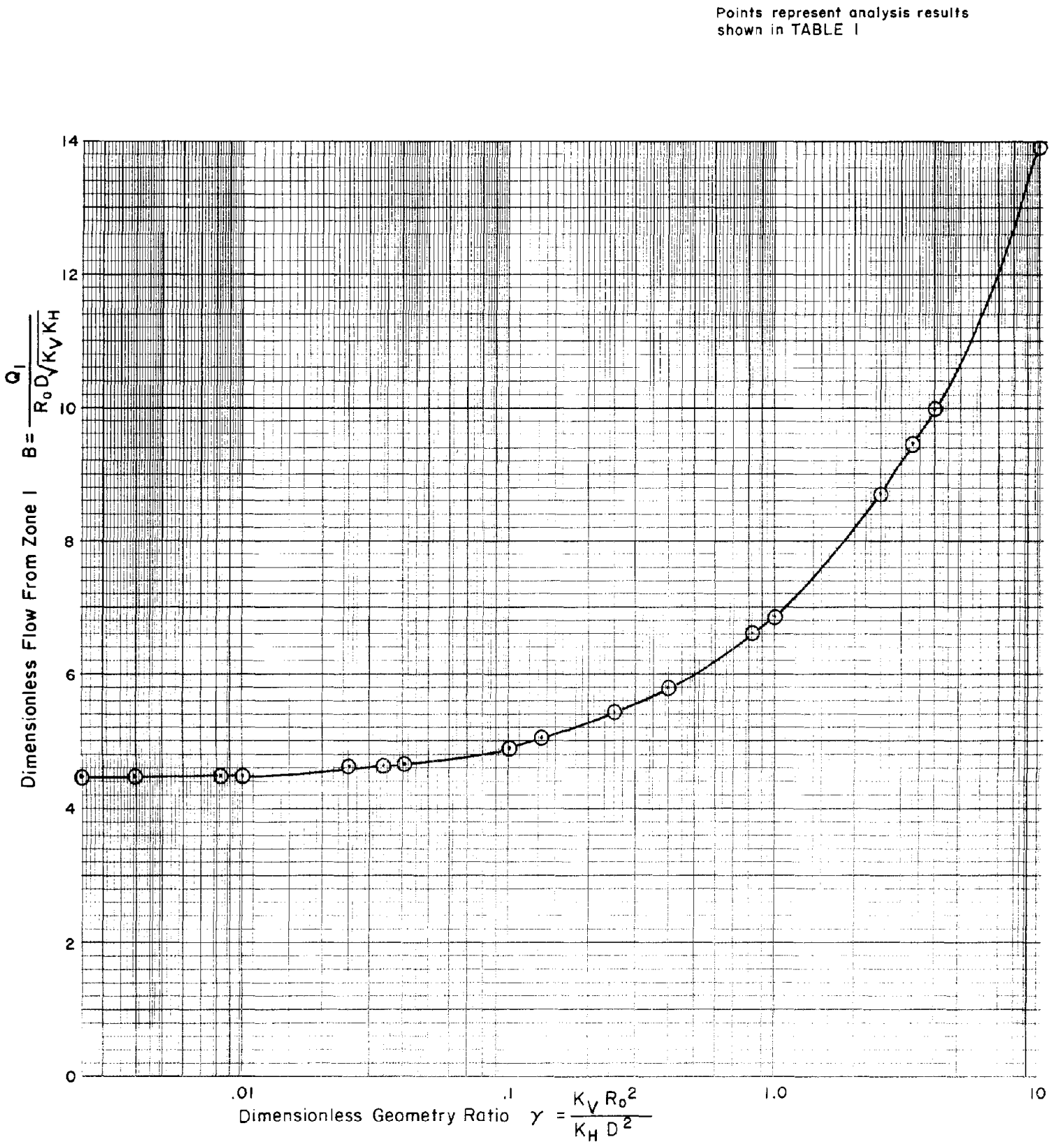


TABLE 1

VALUES OF $\beta = Q_1/(R_O D\sqrt{K_V K_H})$ FOR ZONE 1

COMPUTER INFLOW ANALYSES - UPPER BOUND

$\frac{K_H}{K_V}$	R_O/D = 0.5	1	2	5	10
1	-	-	10.10	-	-
10	4.62	4.90	5.79	8.73	13.95
30	4.49	4.66	5.08	6.61	9.49
100	4.50	4.51	4.70	5.42	6.88
1,000	-	-	4.49	-	-

4.2 TRANSIENT EFFECTS

4.2.1 Approach

The above analysis is an upper bound to the inflow from Zone 1 because it fails to take into account the transient effects of movement of the groundwater table. The rate of movement of the groundwater table is dependent primarily upon the rock porosity and vertical permeability. In order to evaluate this effect, some analyses of fixed size mines were carried out, allowing the phreatic surface to move.

In the limiting case, the material above the roof of the mine may drain, and at that time a considerable reduction in inflow would be expected to occur. This section seeks to evaluate how likely such an occurrence is, and the impact of transient effects on the results of the upper bound analysis.

4.2.2 Results Presentation

It is necessary to introduce a method of reducing time to a generalized, dimensionless form. Dimensional analysis,

coupled with a knowledge of the physical conditions of the problem, suggest a nondimensional time constant

$$\tau = \frac{K_V t}{nD}$$

where K_V = vertical permeability
t = time
n = drainable porosity
D = depth of mine roof below water table.

All transient results will be presented in this form, in order to allow generalized evaluation.

4.2.3 Results

Two analyses of a single mine geometry were performed, with the conditions at the outer boundary the only difference.

i. Outer boundary held at fixed head.
ii. Outer boundary impervious - i.e. no flow across it.

Figure 7 shows the resulting reduction in flows due to the movement of the water table in this case. Figure 8 shows the drawdown effect in the rock above the center of the mine as a function of time. Both curves are similar.

4.3 ANALYSIS METHOD FOR ZONE 1 - UNCAVED CASE

For the purposes of this study, it is somewhat difficult to know what adjustment to make for the transient effect. In general, for the mines proposed in this study, values of τ range from 0 to about 30, with normal values in the 0-10 range. This suggests a reduction of about 30% is in order for final

Figure 7 TRANSIENT ANALYSIS OF ZONE 1 INFLOWS

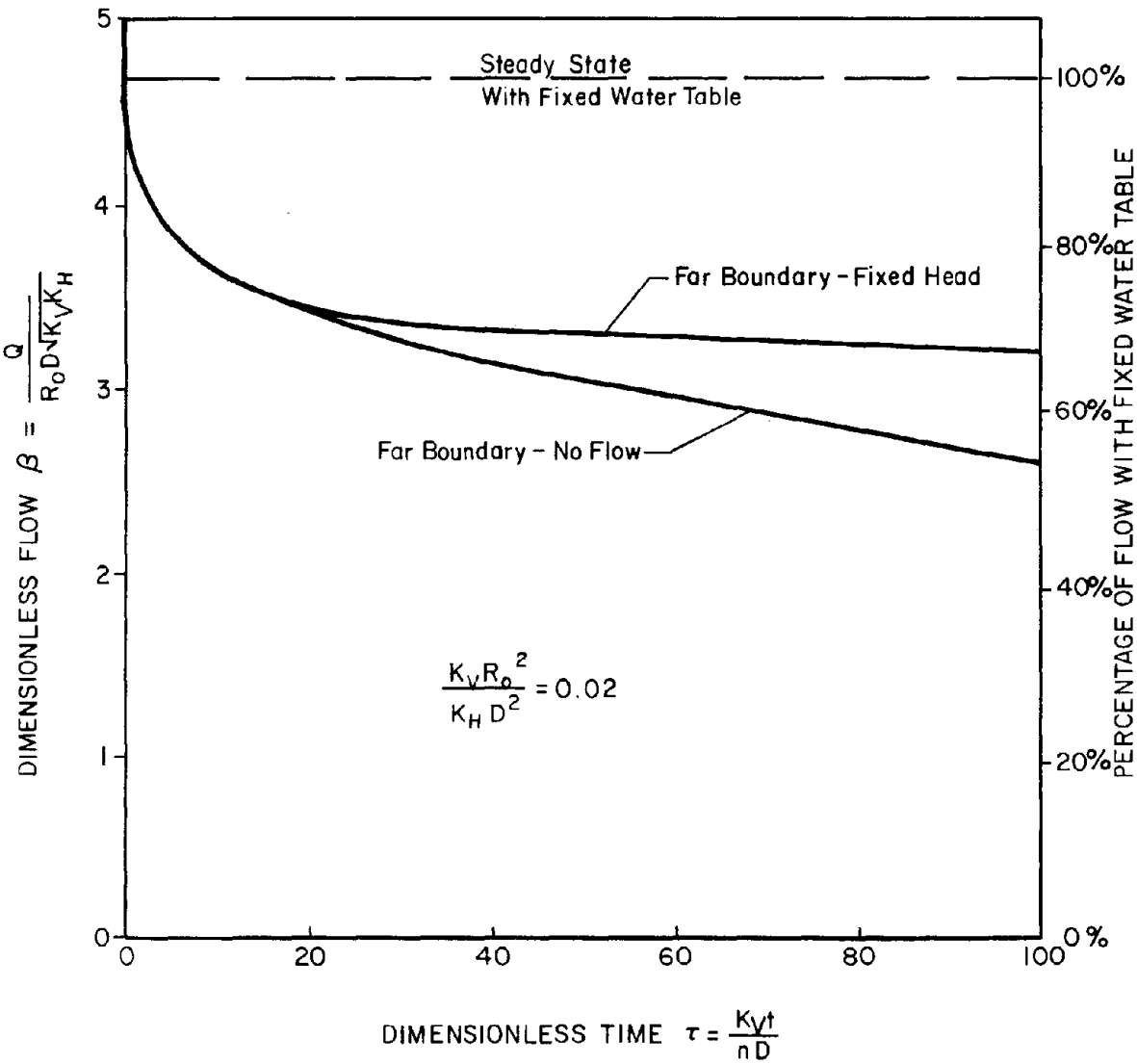
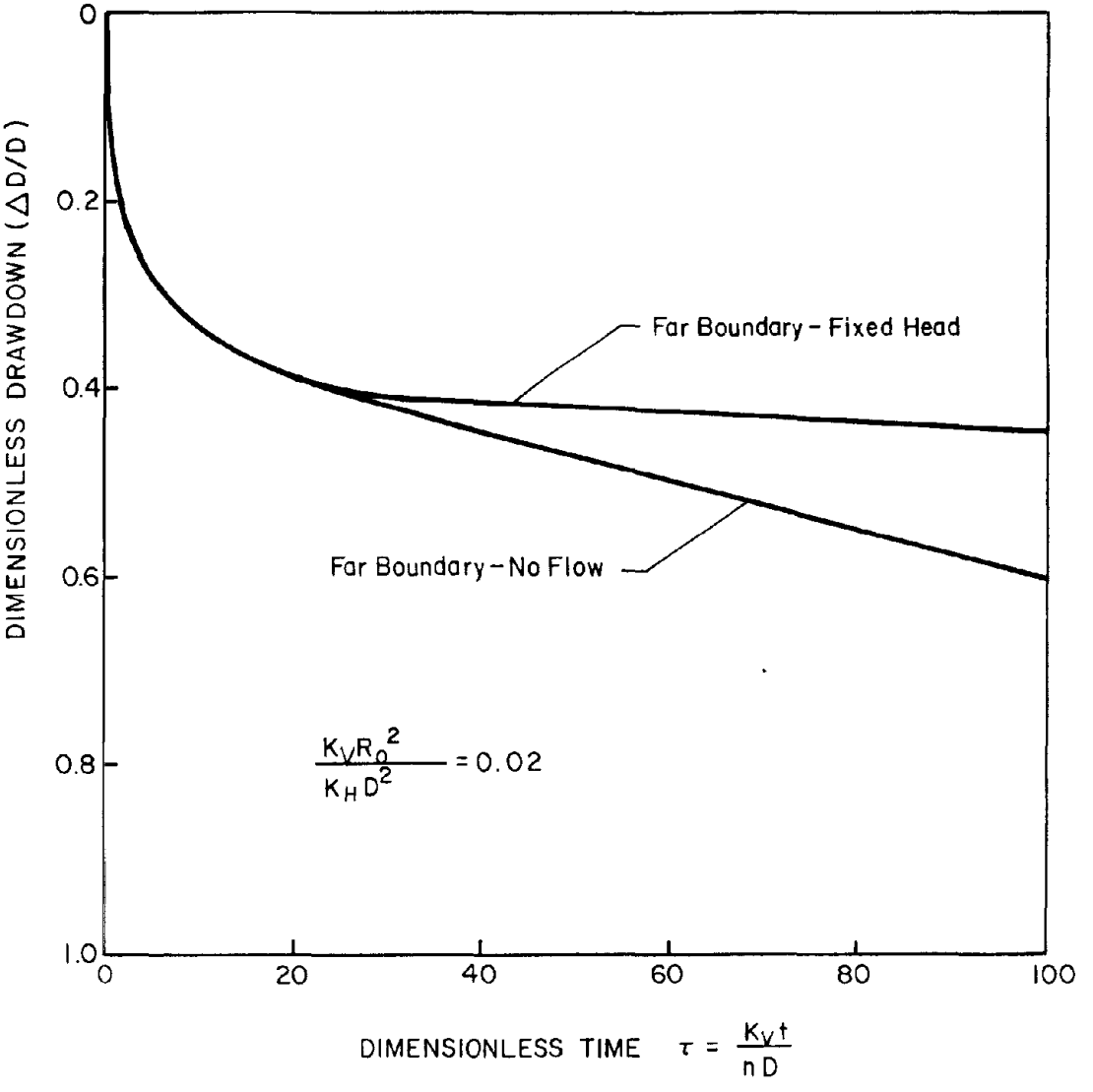


Figure 8 TRANSIENT ANALYSIS OF ZONE 1 DRAWDOWNS ABOVE THE CENTER OF THE MINE



inflows computed based on the upper bound situation. However, as this is considerably inside the accuracy of the measurement of some of the important parameters, it is questionable whether the adjustment is worth making.

A further complicating factor is the possibility of re-injection of flow to the aquifer. This would effectively slow the movement of the phreatic surface, and maintain flows close to the fixed water table case.

It was decided that analysis would be conducted as follows:

i. For very fast moving, shallow mines direct analysis of inflow to Zone 1 would be performed, using the Finite Element Method program.

ii. For all other mines, where drawdown is small over the life of the mine, flows would be computed based on the steady state, fixed phreatic surface case (Figure 6), and adjusted for drawdown using the curve obtained for the standard case (Figure 7), with the far boundary at fixed head.

Exact analysis of a number of cases indicates that errors thus introduced by computational approximations do not exceed 10% of the flow. This was considered entirely acceptable.

5.0 FLOW ANALYSES IN ZONE 1 - CAVED CASE

In the case of flow to the mine in Zone 1 when the material above the mine is fully caved, hand analysis using analytical tools is possible. This section sets out the approach used, and results obtained.

5.1 APPROACH

The analysis approach is to divide Zone 1 up into:

i. A vertical sided plug of caved material, which is assumed to de-saturate as soon as the material in the mine beneath is mined, and

ii. the uncaved portion of Zone 1, in which flow is horizontal, and behaves as flow to a fully drained well.

Each component is computed analytically below.

5.1.1 Flow from Caved Material

The act of caving the roof material creates very high vertical permeability in the caved rock, and thus any water in the rock is likely to drain directly into the mine. The resulting flow to the mine from this cause is given by:

$$Q_{1C} = nRD$$

where Q_{1C} = flow to mine from Zone 1 due to caving above mine roof

n = drainable porosity

R = mine area expansion rate

D = depth of mine roof below water table.

This equation assumes that the rock remains saturated prior to caving, and that the cave extends vertically above the mine to at least the top of the zone of saturation. Both approximations are reasonable, in that alternative assumptions do not materially alter the inflow result.

5.1.2 Flow from Material Outside Caved Area

The flow from the material outside the caved area is the same as the flow to a fully drained well, with the well radius expanding with time.

The flow to a fully drained well can be found by breaking up the aquifer penetrated by the well into thin horizontal slices, and analyzing them, as follows.

Consider a slice as shown in Figure 9, depth "d" below the water table, of thickness Δd. Infinitely far from the well, the water pressure in the slice is "d" (expressed as a head of water), while at the well the water pressure in the slice is zero. Assuming that the slice acts as a confined, horizontal, nonleaky aquifer, then the head loss in that aquifer is "d". To good approximation, the flow to the well from that incremental slice can be computed from Theis' well equation:

$$\Delta Q = 4\pi K_H . \Delta d . d / W(u_o)$$

where
- ΔQ = flow increment from slice
- K_H = horizontal permeability of material
- Δd = thickness of slice
- d = depth of slice below water table
- $W(u_o)$ = well function
- u_o = $R_o^2 V / 4K_H t$
- R_o = radius of well
- V = average yield of the rock
- t = time since well drainage started.

It is important to use the appropriate value of V, the average of the rock in Zone 1. As noted earlier, the impact

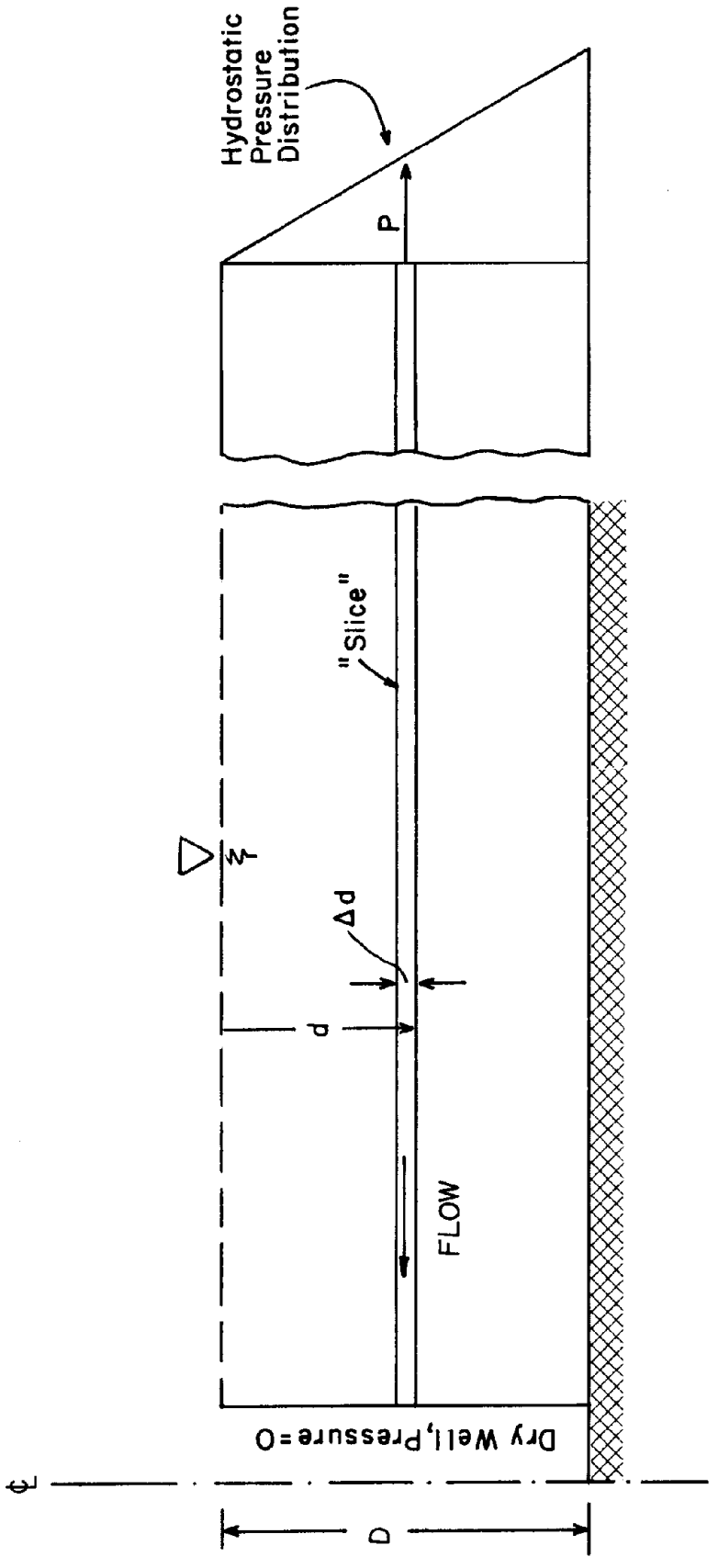


Figure 9 SCHEME FOR COMPUTING FLOW TO A DRAINED WELL

of the uneven withdrawal of water from different levels in the aquifer diminishes quickly with distance from the well. Accordingly, it is necessary to utilize the drainable porosity as well as the compressible storage to compute average yield. If we define V, the average yield, as the volume of water produced from a unit area of the aquifer when the head is lowered by one unit, then

$$V = \frac{n + DS_S}{D} = \frac{n}{D} + S_S$$

where n = drainable porosity
S_S = specific storage
D = thickness of aquifer.

For the cases considered in this study, n/D is very much greater than S_S, and so to good approximation

$$V \doteqdot n/D$$

This approximation will be used in Zone 1 for the remainder of this report.

The total flow to the well (Q_{1W}) is the sum of the flows from all slices. Hence,

$$Q = \frac{4\pi K_H}{W(u_o)} \int_0^D d'.dd'$$

$$\therefore Q_{1W} = 2\pi K_H D^2 / W(u_o)$$

Computation of the flow to the well as it expands is very much simplified by noting that

$$u_o = nR_o^2/4K_H tD$$

and that the mine expands at a uniform rate R, so that

$$R = \frac{\pi R_o^2}{t}$$

Substituting, we have

$$u_o = \pi n R / 4 K_H D$$

This is constant in time, so that $W(u_o)$ is also constant, and thus Q_{1W} is also constant.

The relationship between "u" and W(u) is well documented (see, for example, Walton, 1972) and a tabulation of useful ranges of values is included as Table 2.

It should be noted that the above analysis involves a mild tampering with the analytical theory. Particularly, the theory assumes a fixed radius well, of small dimensions when compared with the aquifer thickness. The errors in the computed inflow introduced by these approximations are small.

5.1.3 Total Flow

The total flow to Zone 1 in the caved mine case is

$$Q_1 = Q_{1C} + Q_{1W}$$

$$\therefore Q_1 = nRD + 2\pi K_H D^2 / W(u_o)$$

where Q_1 = flow to mine from Zone 1
n = drainable porosity of in-situ rock
R = mine area expansion rate

TABLE 2

VALUES OF W(u)

N u	Nx10^{-15}	Nx10^{-14}	Nx10^{-13}	Nx10^{-12}	Nx10^{-11}	Nx10^{-10}	Nx10^{-9}	Nx10^{-8}	Nx10^{-7}	Nx10^{-6}	Nx10^{-5}	Nx10^{-4}	Nx10^{-3}	Nx10^{-2}	Nx10^{-1}	N
1.0	33.9616	31.6590	29.3564	27.0538	24.7512	22.4486	20.1460	17.8435	15.5409	13.2383	10.9357	8.6332	6.3315	4.0379	1.8229	0.2194
1.5	33.5561	31.2535	28.9509	26.6483	24.3458	22.0432	19.7406	17.4380	15.1354	12.8328	10.5303	8.2278	5.9266	3.6374	1.4645	0.1000
2.0	33.2684	30.9658	28.6632	26.3607	24.0581	21.7555	19.4529	17.1503	14.8477	12.5451	10.2426	7.9402	5.6394	3.3547	1.2227	0.04890
2.5	33.0453	30.7427	28.4401	26.1375	23.8349	21.5323	19.2298	16.9272	14.6246	12.3220	10.0194	7.7172	5.4167	3.1365	1.0443	0.02491
3.0	32.8629	30.5604	28.2578	25.9552	23.6526	21.3500	19.0474	16.7449	14.4423	12.1397	9.8371	7.5348	5.2349	2.9591	0.9057	0.01305
3.5	32.7088	30.4062	28.1036	25.8010	23.4985	21.1959	18.8933	16.5907	14.2881	11.9855	9.6830	7.3807	5.0813	2.8099	0.7942	0.006970
4.0	32.5753	30.2727	27.9701	25.6675	23.3649	21.0623	18.7598	16.4572	14.1546	11.8520	9.5495	7.2472	4.9482	2.6813	0.7024	0.003779
4.5	32.4575	30.1549	27.8523	25.5497	23.2471	20.9446	18.6420	16.3394	14.0368	11.7342	9.4317	7.1295	4.8310	2.5684	0.6253	0.002073
5.0	32.3521	30.0495	27.7470	25.4444	23.1418	20.8392	18.5366	16.2340	13.9314	11.6280	9.3263	7.0242	4.7261	2.4679	0.5598	0.001148
5.5	32.2568	29.9542	27.6516	25.3491	23.0465	20.7439	18.4413	16.1387	13.8361	11.5330	9.2310	6.9289	4.6313	2.3775	0.5034	0.0006409
6.0	32.1698	29.8672	27.5646	25.2620	22.9595	20.6569	18.3543	16.0517	13.7491	11.4465	9.1440	6.8420	4.5448	2.2953	0.4544	0.0003601
6.5	32.0898	29.7872	27.4846	25.1820	22.8794	20.5768	18.2742	15.9717	13.6691	11.3665	9.0640	6.7620	4.4652	2.2201	0.4115	0.0002034
7.0	32.0156	29.7131	27.4105	25.1079	22.8053	20.5027	18.2001	15.8976	13.5950	11.2924	8.9899	6.6879	4.3916	2.1508	0.3738	0.0001155
7.5	31.9467	29.6441	27.3415	25.0389	22.7363	20.4337	18.1311	15.8280	13.5260	11.2234	8.9209	6.6190	4.3231	2.0867	0.3403	0.0000658
8.0	31.8821	29.5795	27.2769	24.9744	22.6718	20.3692	18.0666	15.7640	13.4614	11.1589	8.8563	6.5545	4.2591	2.0269	0.3106	0.0000376
8.5	31.8215	29.5189	27.2163	24.9137	22.6112	20.3086	18.0060	15.7034	13.4008	11.0982	8.7957	6.4939	4.1990	1.9711	0.2840	0.0000216
9.0	31.7643	29.4618	27.1592	24.8566	22.5540	20.2514	17.9488	15.6462	13.3437	11.0411	8.7386	6.4368	4.1423	1.9187	0.2602	0.0000124
9.5	31.7103	29.4077	27.1051	24.8025	22.4999	20.1973	17.8948	15.5922	13.2896	10.9870	8.6845	6.3828	4.0887	1.8695	0.2387	0.0000071

Golder Associates

D = depth of mine roof below water table
K_H = horizontal permeability of undisturbed rock
$W(u_o)$ = well function
u_o = $\pi nR/4K_HD$

This relationship may be readily computed for any mine geometry. Note that the flow rate is constant over the life of the mine.

6.0 FLOW ANALYSES IN ZONE 2

The flow in Zone 2 is very easily computed. It is equal to the flow to a well of radius equal to the mine height, when the well is fully drained, i.e.

$$Q_2 = 4\pi K_H HD/W(u_o)$$

where
Q_2 = flow to mine from Zone 2
K_H = horizontal permeability of Zone 2
H = height of mine zone
D = depth of center of mine zone below water table
$W(u_o)$ = well function
u_o = $\pi RS_S/4K_H$
R = mine area expansion rate
S_S = specific storage of Zone 2 rock.

Once again this inflow is constant in time, and can be readily computed.

7.0 FLOW ANALYSES IN ZONE 3

Finite Element analyses of the flow to the mine from Zone 3 indicate that it is generally an order of magnitude less than flow from Zone 1. For this reason a very simple, yet physically reasonable analytical approach has been adopted.

7.1 APPROACH

The approach used involves computing the flow to the mine through two resistive elements. The flow proceeds from the outer boundary and rock storage, horizontally along Zone 3 towards the mine. Once it nears the mine the flow must move upwards and into the mine. Both flow segments dissipate head, and both must be considered in the inflow evaluation. A schematic of the conditions analyzed are shown in Figure 10.

7.2 RESULTS

7.2.1 Horizontal Flow

The horizontal flow in Zone 3 is equivalent to well flow, with an unknown head "X" immediately beneath the mine, and a head D_3 at infinity in the aquifer. As before the flow is given by the Theis equation:

$$Q = 4\pi K_H M(D_3-X)/W(u_o)$$

where
- Q = flow to mine from Zone 3
- K_H = horizontal permeability of Zone 3
- M = thickness of Zone 3
- D_3 = static head in Zone 3 at infinity
- X = unknown head at the edge of the mining zone
- $W(u_o)$ = well function
- u_o = $\pi RS_S/4K_H$
- R = mine area expansion rate
- S_S = specific storage of Zone 3 rock.

7.2.1 Vertical Flow

In the flow model it is assumed that the entire flow to the floor of the mine from Zone 3 passes vertically through (on

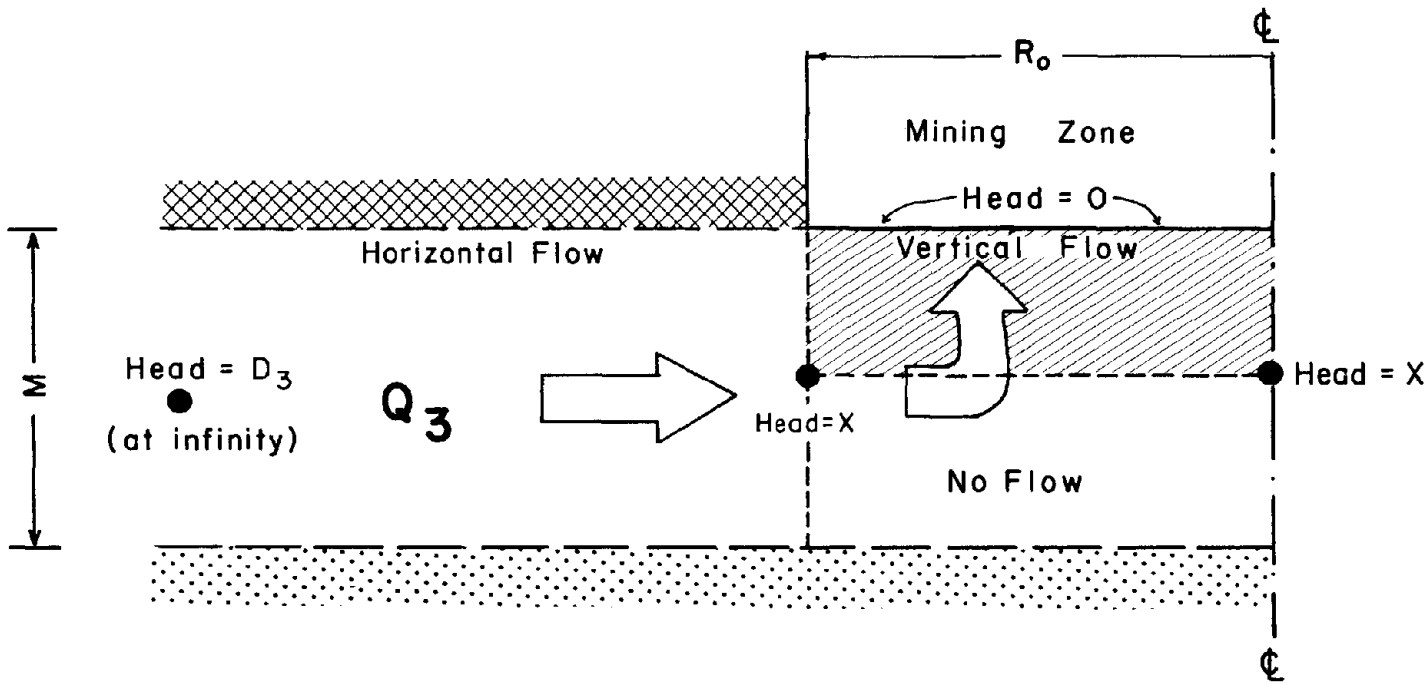


Figure 10 SCHEMATIC OF ASSUMED FLOW AND HEAD CONDITIONS FOR ZONE 3

average) half the thickness of floor rock in the aquifer (Figure 10). The driving head to achieve this flow averages "X", and the flow is given by:

$$Q = \frac{2\pi R_o^2 K_V X}{M}$$

where Q = flow to mine from Zone 3
R_o = mine radius
K_V = vertical permeability of Zone 3 rock
M = thickness of Zone 3
X = unknown head at center of Zone 3 beneath mine.

7.2.2 Total Flow

The value "X" can be eliminated by combining the two equations above to produce

$$Q_3 = \frac{4\pi K_H M D_3}{W(u_o)} \Bigg/ \left(1 + \frac{2K_H M^2}{K_V R_o^2}\right)$$

This equation is basically the horizontal flow in Zone 3 assuming that there was no resistance in the vertical flow phase, divided by a number which is always greater than unity, which reflects the additional resistance encountered in the vertical movement of water.

The result from this equation is strongly dependent upon the choice of M, the aquifer thickness. However, the flow has a maximum value when M is given by

$$M_{Qmax} = R_o \sqrt{\frac{K_V}{2K_H}}$$

The resulting maximum flow is

$$Q_{max} = \sqrt{\frac{2\ \pi D_3 R_o}{W(u_o)}}\ \sqrt{K_V K_H}$$

where
- Q_{max} = maximum flow to mine from Zone 3
- D_3 = depth to the mine floor
- R_o = mine radius
- K_V = vertical permeability of Zone 3 rock
- K_H = horizontal permeability of Zone 3 rock
- $W(u_o)$ = well function
- u_o = $\pi R S_S / 4K_H$
- R = mine area expansion rate
- S_S = specific storage of Zone 3 rock

The equation for Q_{max} is used in the analyses presented in this report, for the cases where the thickness of the aquifer exceeds the thickness necessary for maximum flow. Where this is not the case, the equation for Q_3 above is used. Note that the flow is dependent on time.

8.0 INHOMOGENEITIES IN ZONE ROCKS

The above analyses deal with homogeneous rock properties in the zones. In general, this is not the case, and allowance is made for inhomogeneities by computing effective permeabilities in the following way.

8.1 EFFECTIVE HORIZONTAL PERMEABILITIES

8.1.1 Zones 1 and 2

In the case where Zone 1 or Zone 2 consists of more than one material, the effective horizontal permeability can be found

by the normal technique for fully drained wells in horizontally layered media, by assuming independent horizontal aquifers. To good approximation

$$K_H = \frac{\Sigma K_{Hi} M_i D_i}{\Sigma M_i D_i}$$

where K_H = effective horizontal permeability
K_{Hi} = horizontal permeability of layer "i"
M_i = thickness of layer "i"
D_i = depth of the center of layer "i" below the original "water table"
Σ = indicates summation over all layers in zone.

The computation takes account of the higher driving head which exists in the lower strata, by weighting the permeabilities linearly with depth.

8.1.2 Zone 3

In this zone a simple weighting based on transmissivity is appropriate:

$$K_H = \frac{\Sigma K_{Hi} Mi}{\Sigma M_i}$$

where K_H = effective horizontal permeability
K_{Hi} = horizontal permeability of layer "i"
M_i = thickness of layer "i".
Σ = indicates summation over all layers in zone.

It should be noted, however, that only those layers down to the critical aquifer depth (see Section 7.2.2 above) should be averaged. This may require some repeated analysis.

8.2 EFFECTIVE VERTICAL PERMEABILITIES

In the case where a zone consists of layers of different materials, the effective vertical permeability for the problem is found by adding the resistance to vertical flow of each layer in series, and equating to the known vertical resistance, which produces

$$K_V = \frac{\Sigma L_i}{\Sigma L_i / K_{Vi}}$$

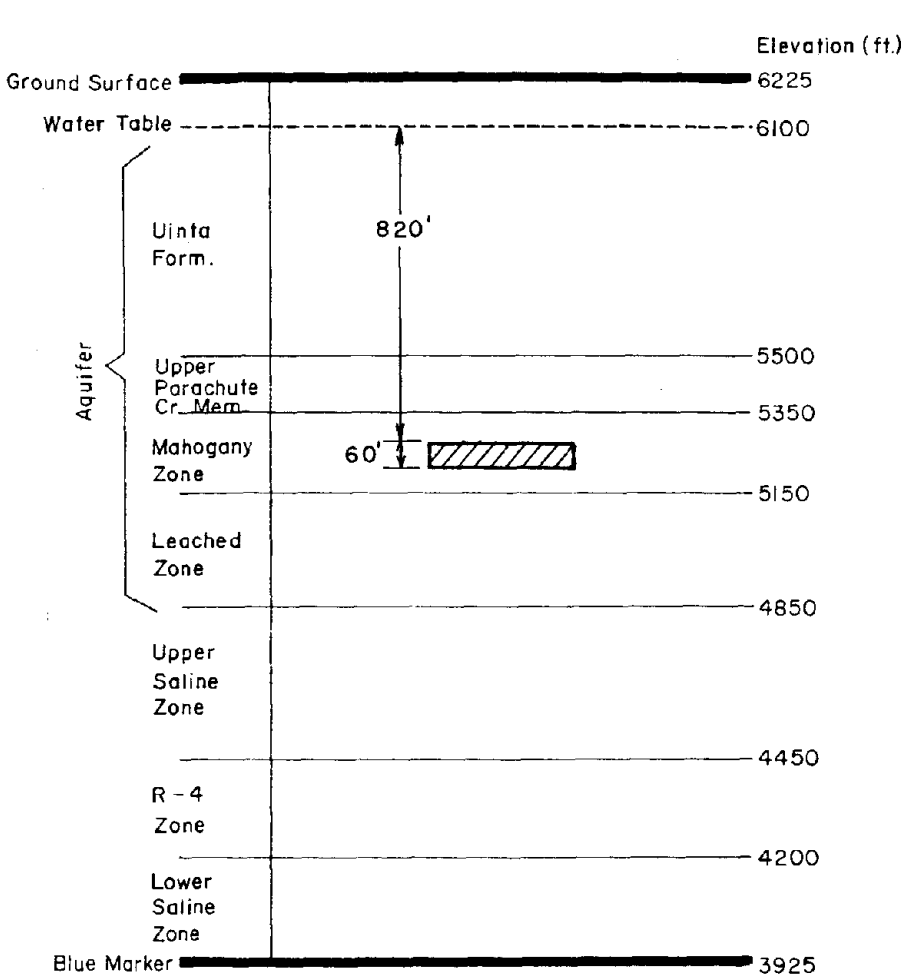
where K_V = effective vertical permeability
K_{Vi} = vertical permeability of layer "i"
L_i = thickness of layer "i"
Σ = indicates summation over all layers in zone.

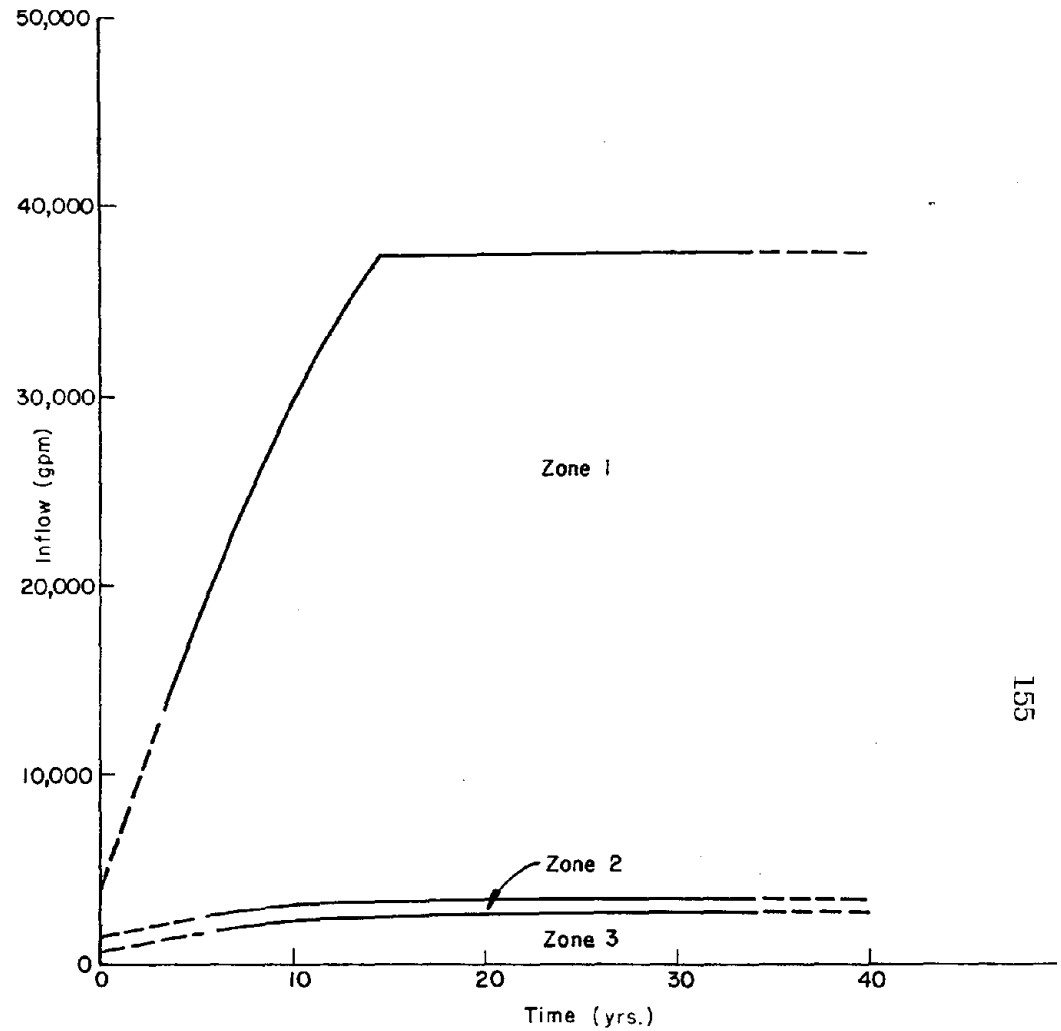
Again, in the case of Zone 3, care must be exercised to ensure that only the material actually contributing to flow is used.

APPENDIX D

MINE INFLOW ANALYSIS RESULTS

See Appendix C for computation details.





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Time - yrs.	Radius - ft.	MINE INFLOW (gpm) Zone 1	(drain) Zone 1	Zone 2	Zone 3	Total
5	3480	18,294	-	765	1681	20,740
10	4917	26,647	-	764	2125	29,540
20	6951	34,291	-	764	2450	37,510
30	8512	34,291	-	764	2582	37,640

DESCRIPTION:

Mining Method: Chamber & Pillar, No Subsidence

Number of Passes: 1

Location: Mahogany

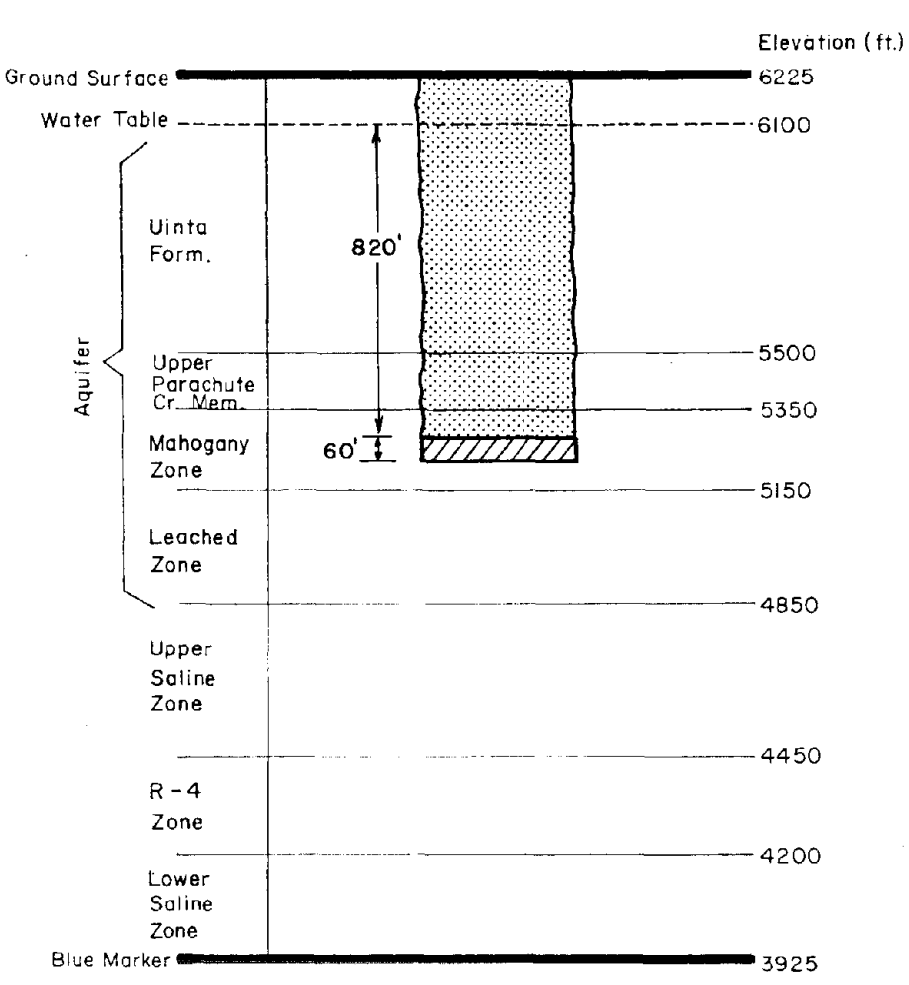
Mining Height: 60 ft

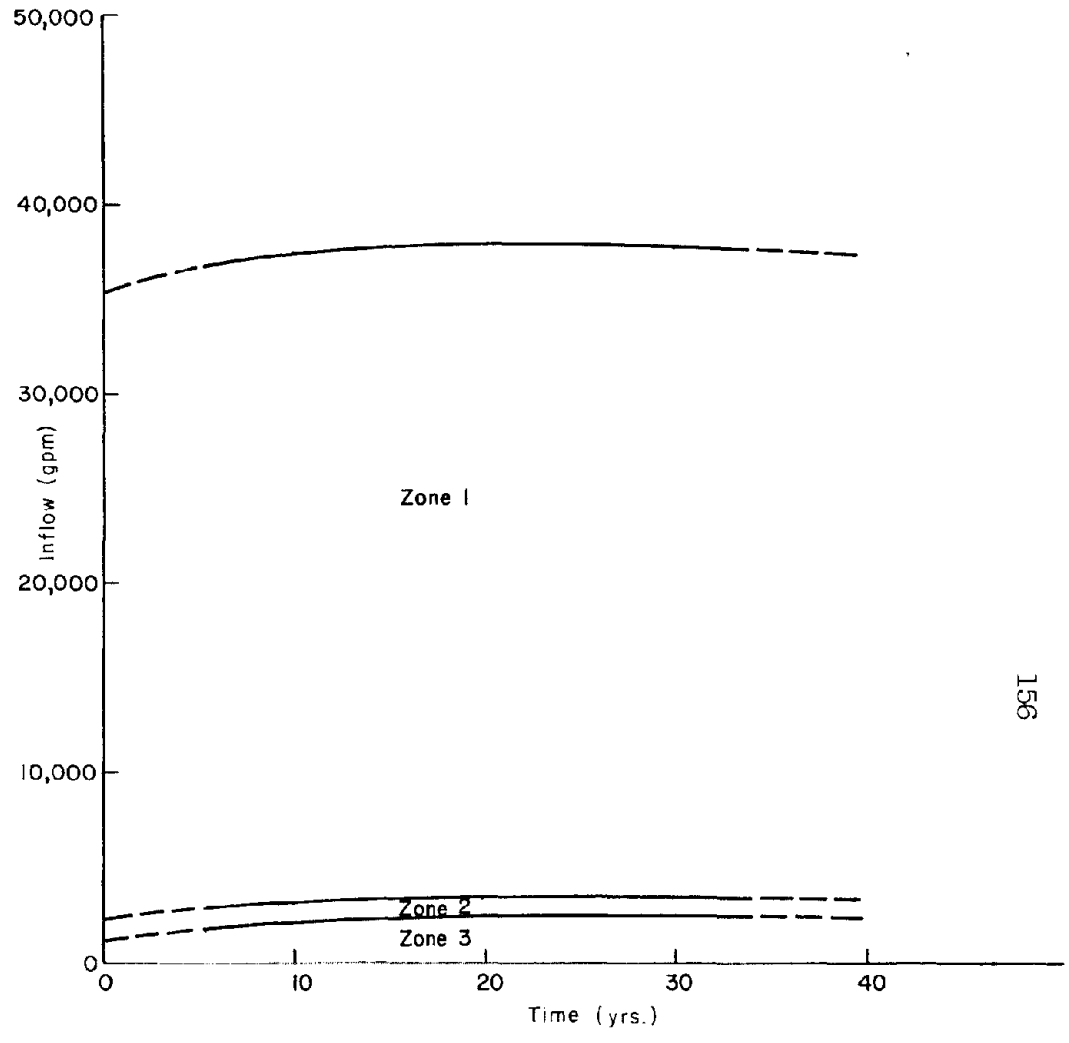
Expansion Rate: .272 mi^2/yr

Initial Radius: 200 ft

Mining Rate: 50,000 ton/day

Figure D-1 MINE INFLOW - SITE 1





Time - yrs.	Radius - ft.	MINE INFLOW (gpm) Zone 1	(drain) Zone 1	Zone 2	Zone 3	Total
5	3480	27,212	7079	765	1681	36,740
10	4917	27,212	7079	764	2125	37,180
20	6951	27,212	7079	764	2450	37,510
30	8512	27,212	7079	764	2582	37,640

DESCRIPTION:

Mining Method: Chamber & Pillar, Full Subsidence

Number of Passes: 1

Location: Mahogany

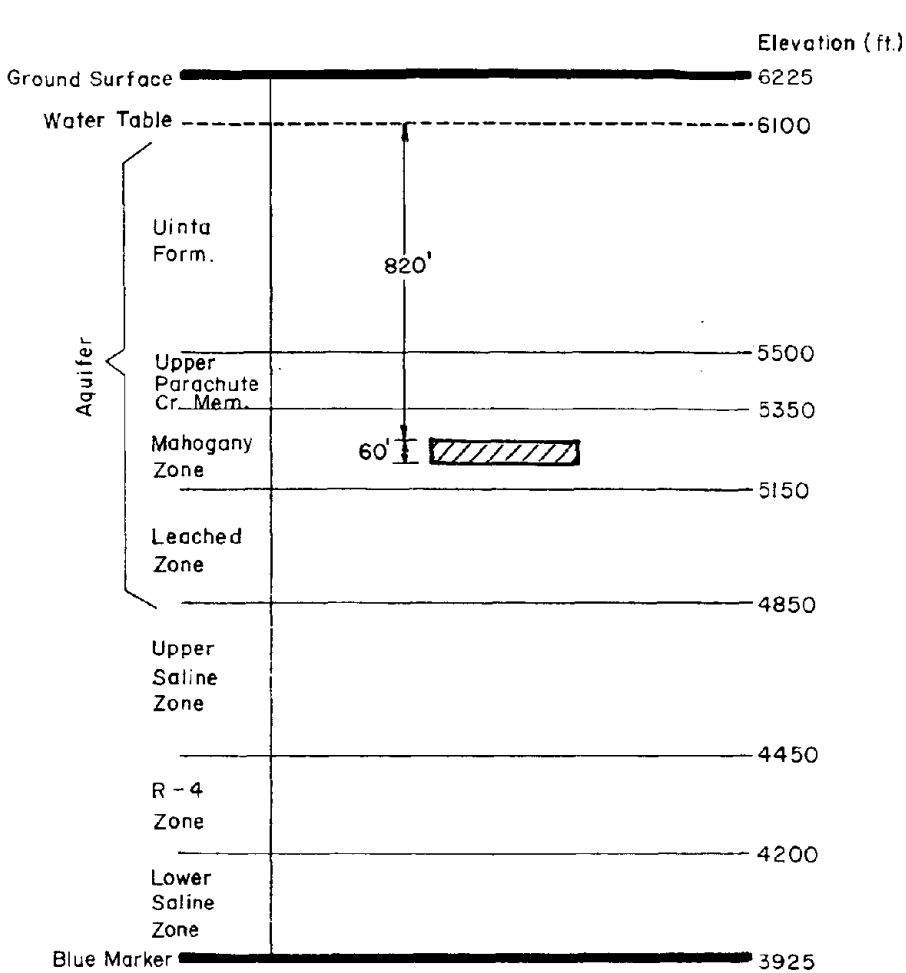
Mining Height: 60 ft

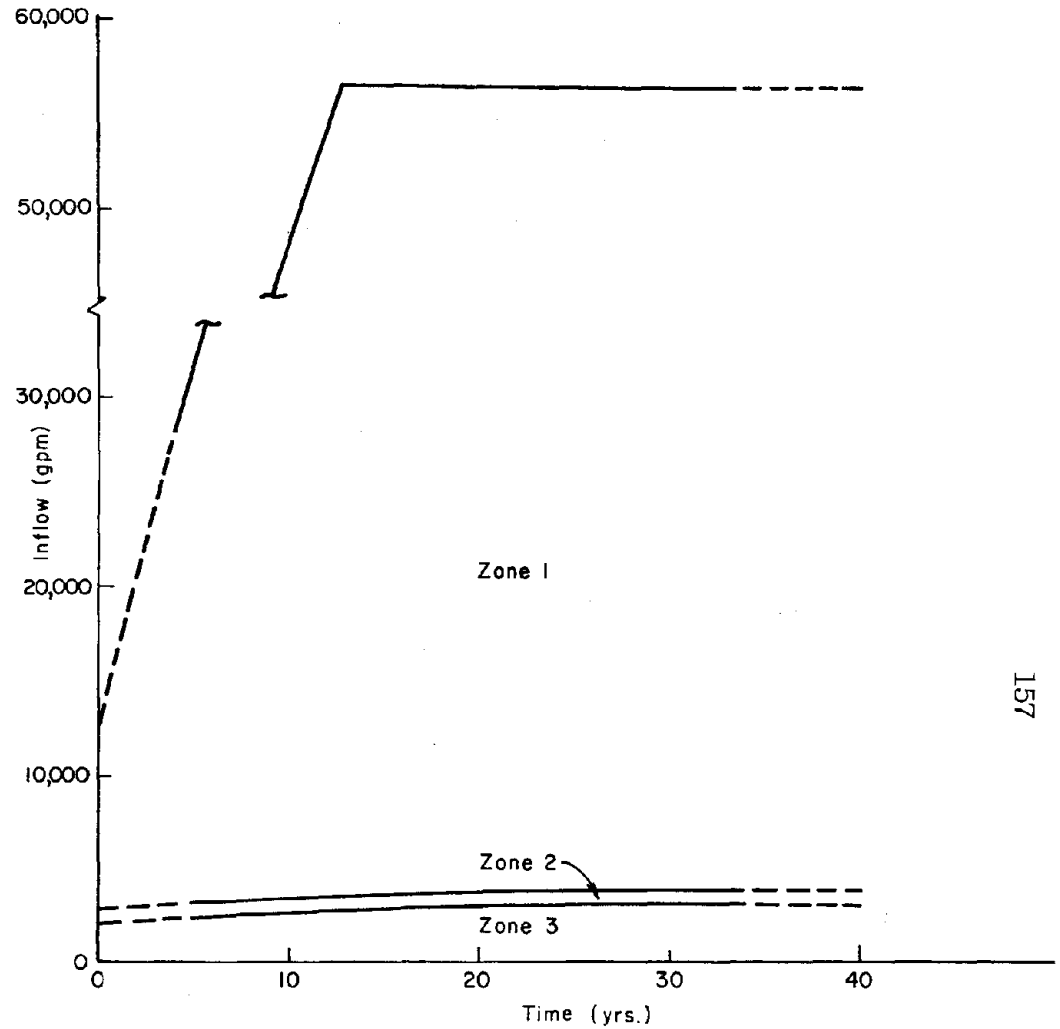
Expansion Rate: .272 mi^2/yr

Initial Radius: 200 ft

Mining Rate: 50,000 ton/day

Figure D-2 MINE INFLOW - SITE I





Time - yrs.	Radius - ft.	MINE INFLOW (gpm) Zone 1	(drain) Zone 1	Zone 2	Zone 3	Total
5	4,913	28,558	-	840	2210	31,610
10	6,944	45,246	-	840	2564	48,650
20	9,819	52,731	-	840	2788	56,360
30	12,025	52,731	-	840	2872	56,440

DESCRIPTION:

Mining Method: Chamber & Pillar, No Subsidence

Number of Passes: 1

Location: Mahogany

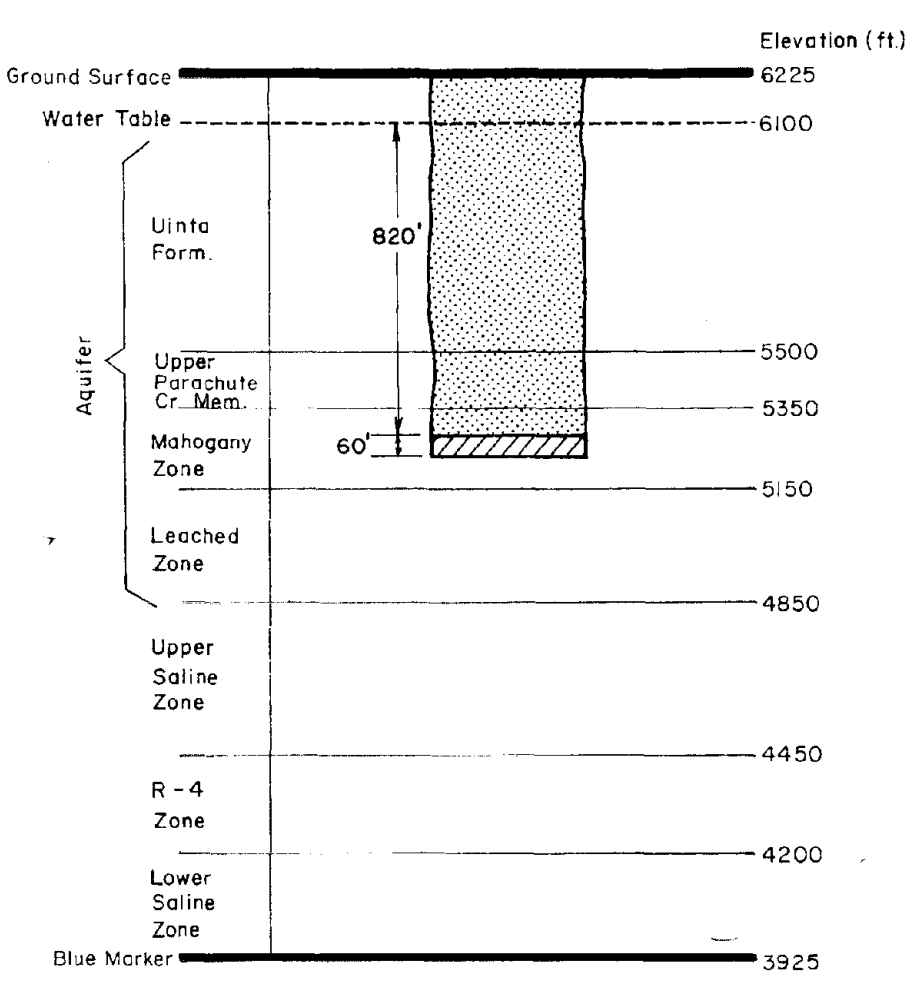
Mining Height: 60 ft

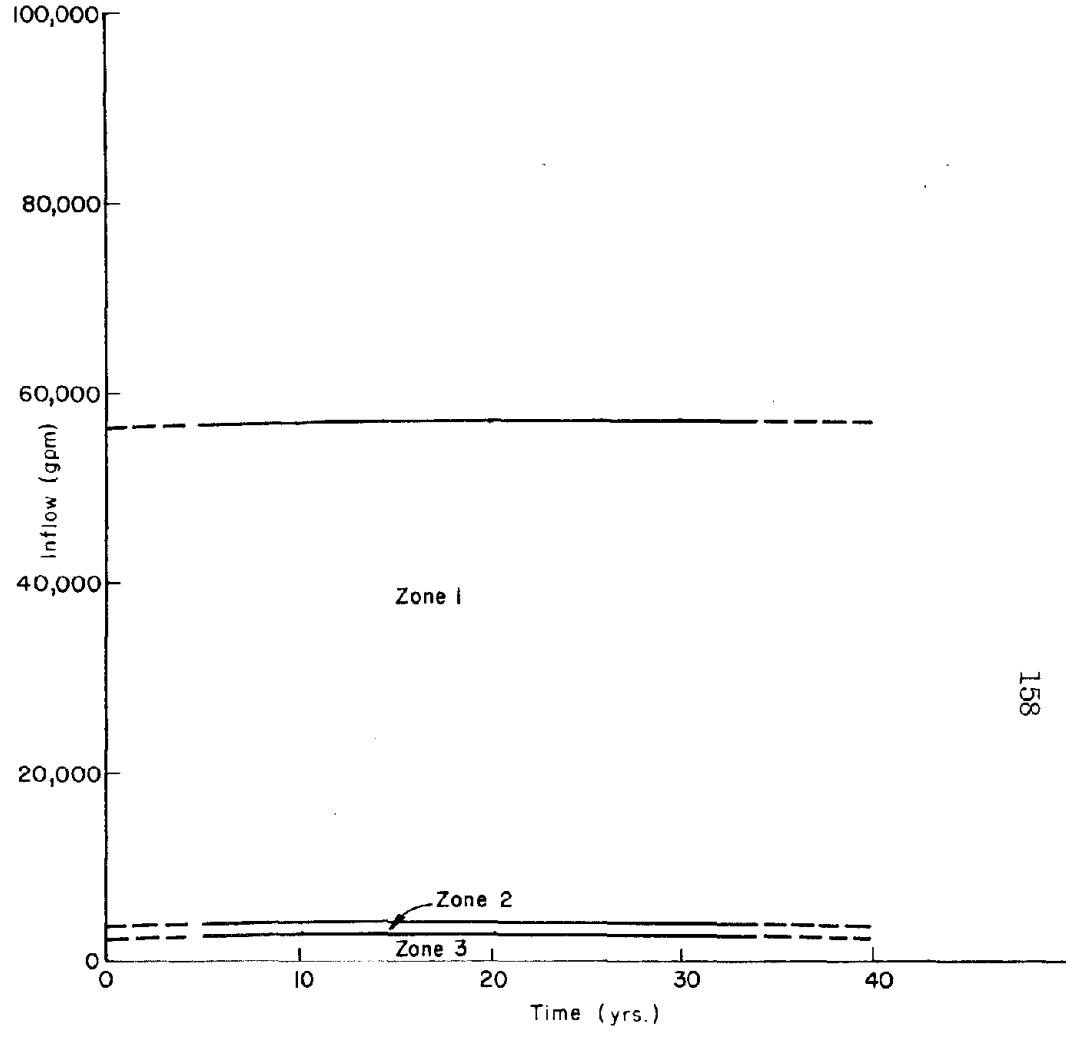
Expansion Rate: .543 mi^2/yr

Initial Radius: 200 ft

Mining Rate: 100,000 ton/day

Figure D-3 MINE INFLOW - SITE I





Time - yrs.	Radius - ft.	MINE INFLOW (gpm) Zone 1	(drain) Zone 1	Zone 2	Zone 3	Total
5	4,913	38,599	14,132	840	2210	55,780
10	6,944	38,599	14,132	840	2564	56,140
20	9,819	38,599	14,132	840	2788	56,360
30	12,025	38,599	14,132	840	2872	56,440

DESCRIPTION:

Mining Method: Chamber & Pillar, Full Subsidence

Number of Passes: 1

Location: Mahogany

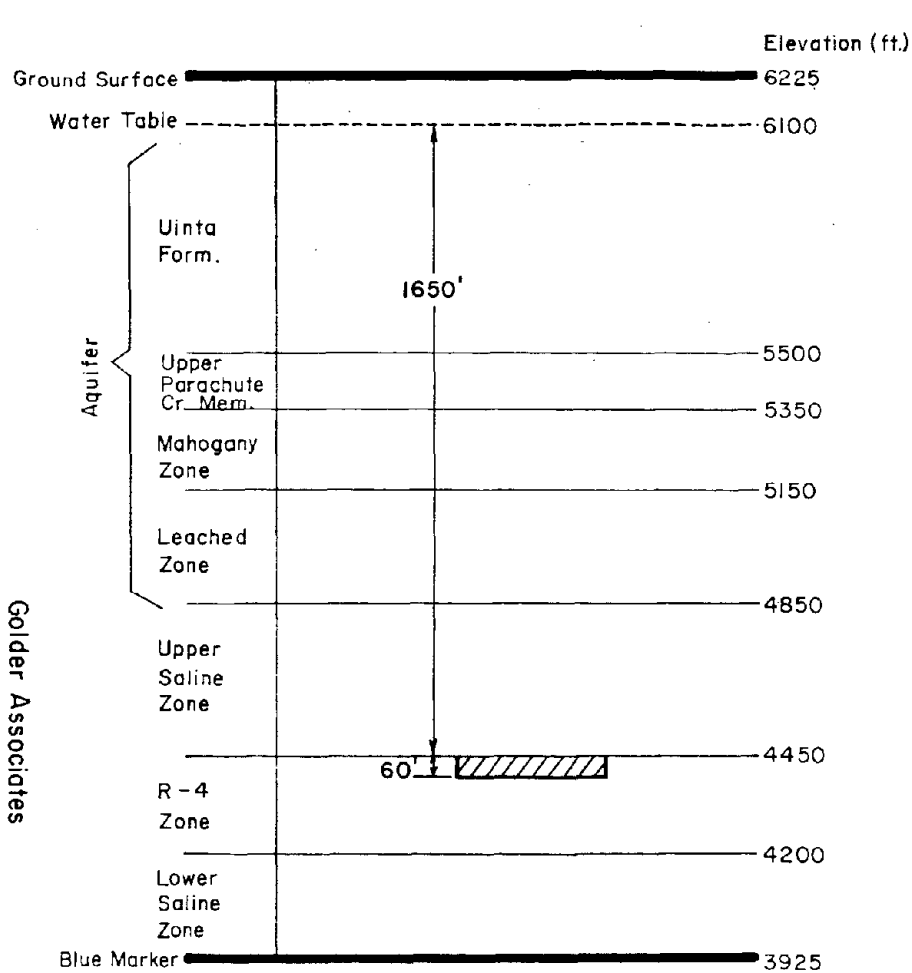
Mining Height: 60 ft

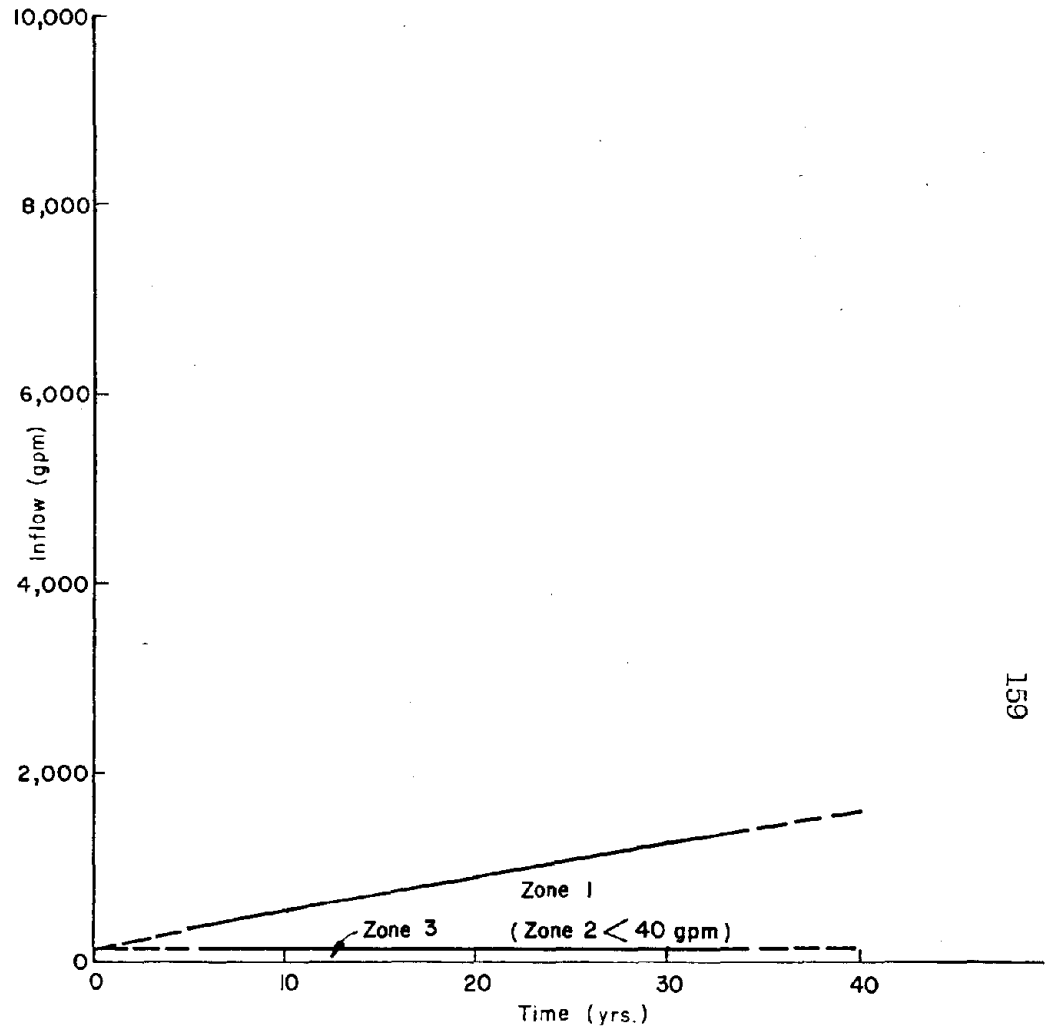
Expansion Rate: .543 mi^2/yr

Initial Radius: 200 ft

Mining Rate: 100,000 ton/day

Figure D-4 MINE INFLOW - SITE 1





MINE INFLOW (gpm)

Time - yrs.	Radius - ft.	Zone 1	(drain) Zone 1	Zone 2	Zone 3	Total
5	3480	185	-	39	90	310
10	4917	370	-	39	96	510
20	6951	739	-	39	99	880
30	8512	1108	-	39	101	1250

DESCRIPTION:

Mining Method: Chamber & Pillar, No Subsidence

Number of Passes: 1

Location: R-4

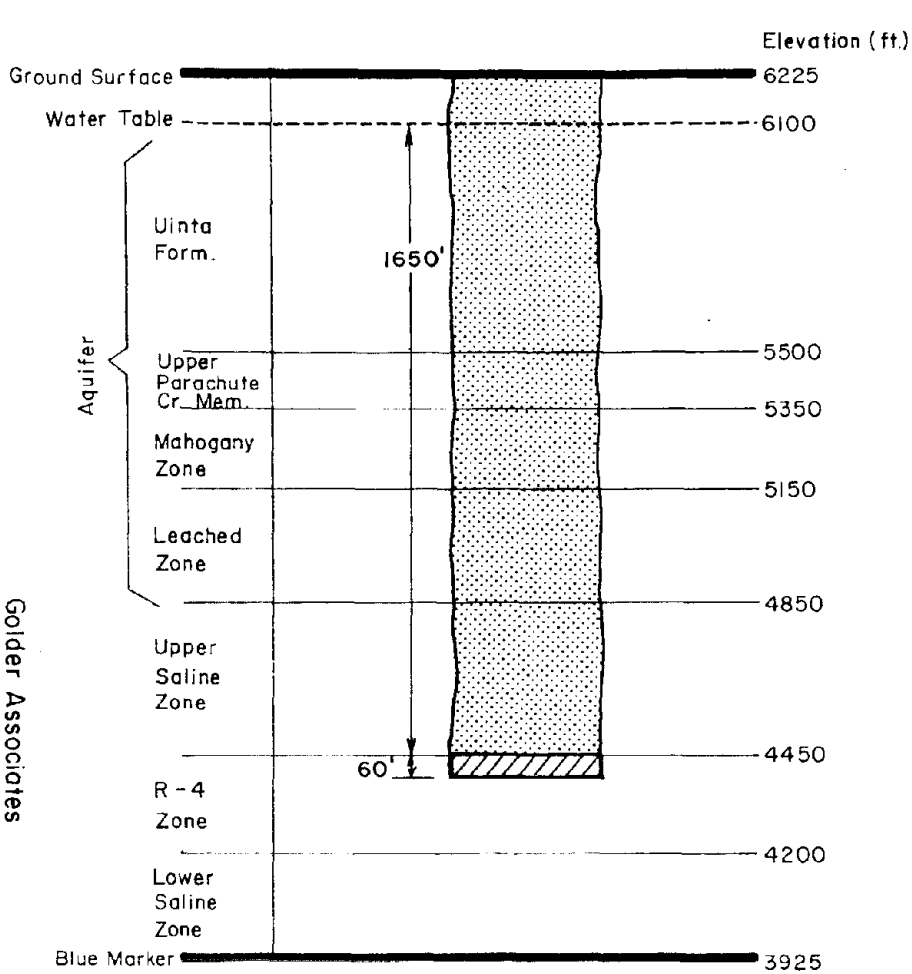
Mining Height: 60 ft

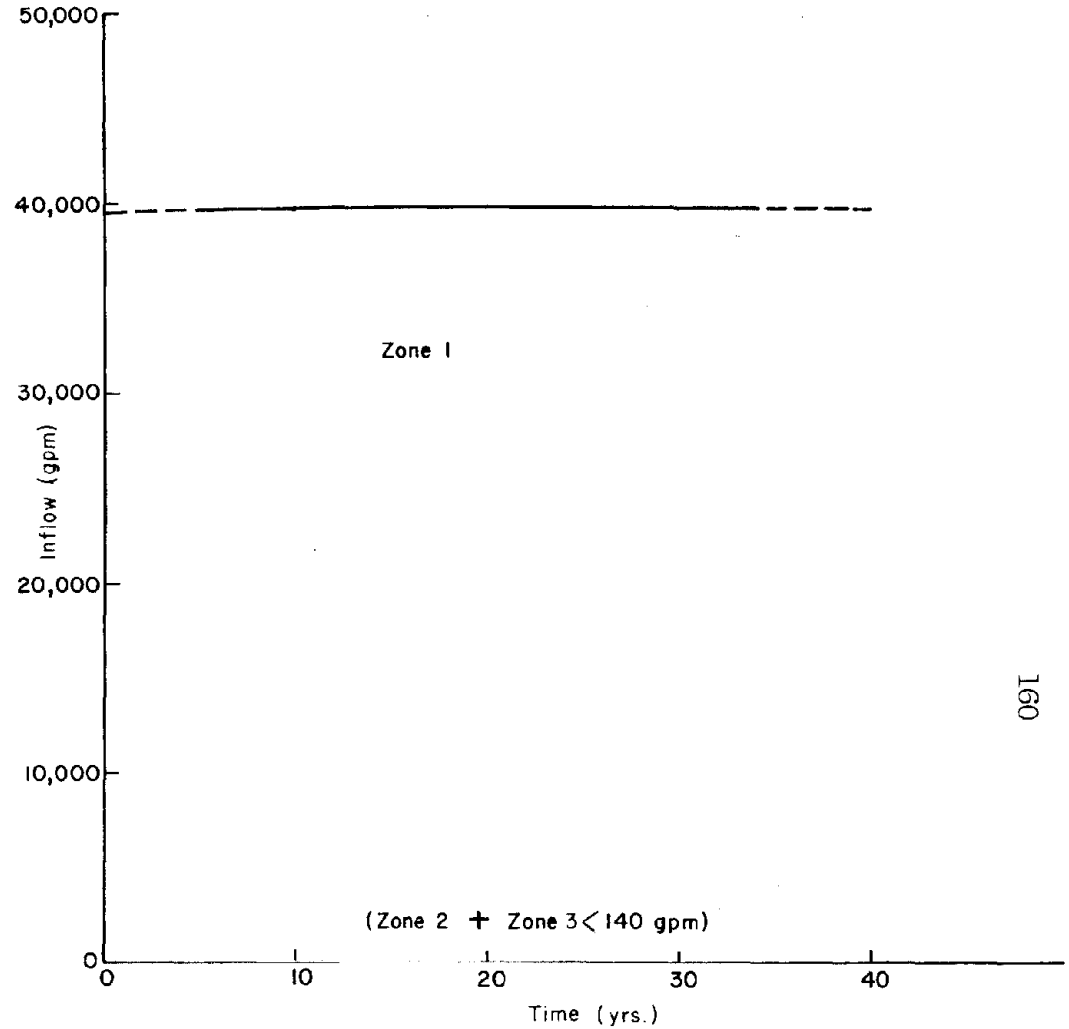
Expansion Rate: .272 mi^2/yr

Initial Radius: 200 ft

Mining Rate: 50,000 ton/day

Figure D-5 MINE INFLOW - SITE 1





Time - yrs.	Radius - ft.	MINE INFLOW (gpm) Zone 1	Zone 1 (drain)	Zone 2	Zone 3	Total
5	3480	30,812	8903	39	90	39,840
10	4917	30,812	8903	39	96	39,850
20	6951	30,812	8903	39	99	39,850
30	8512	30,812	8903	39	101	39,860

DESCRIPTION:

Mining Method: Chamber & Pillar, Full Subsidence

Number of Passes: 1

Location: R-4

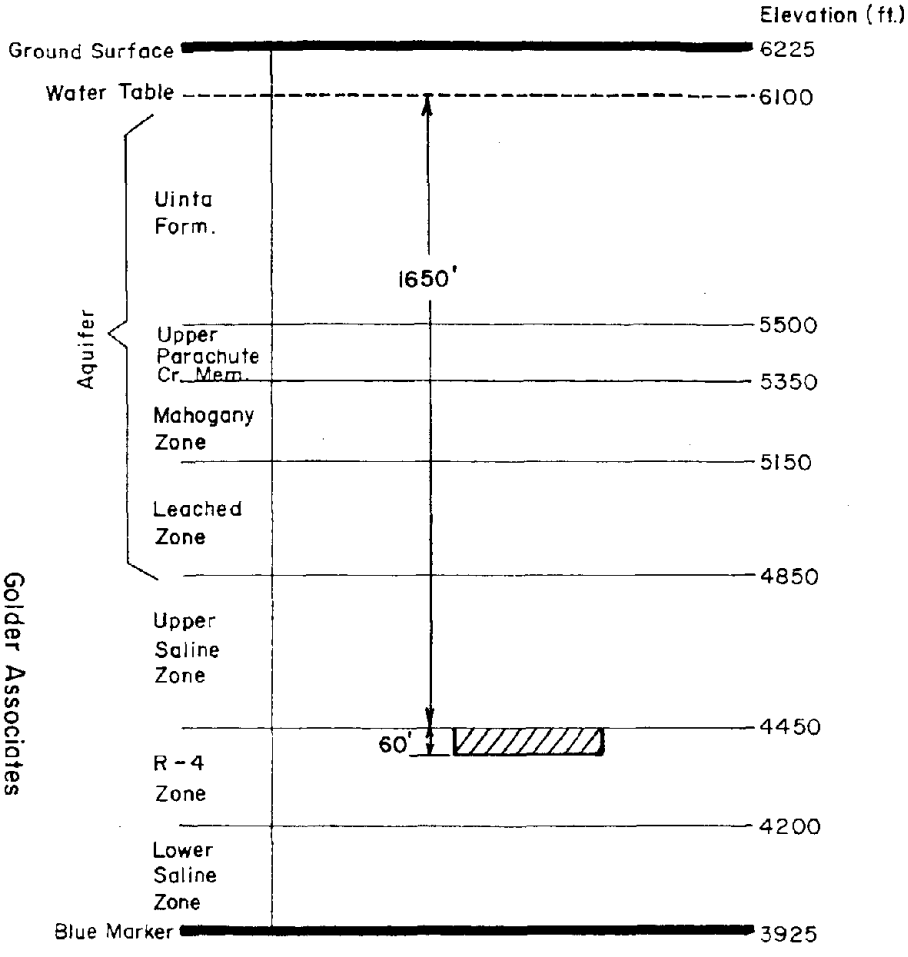
Mining Height: 60 ft

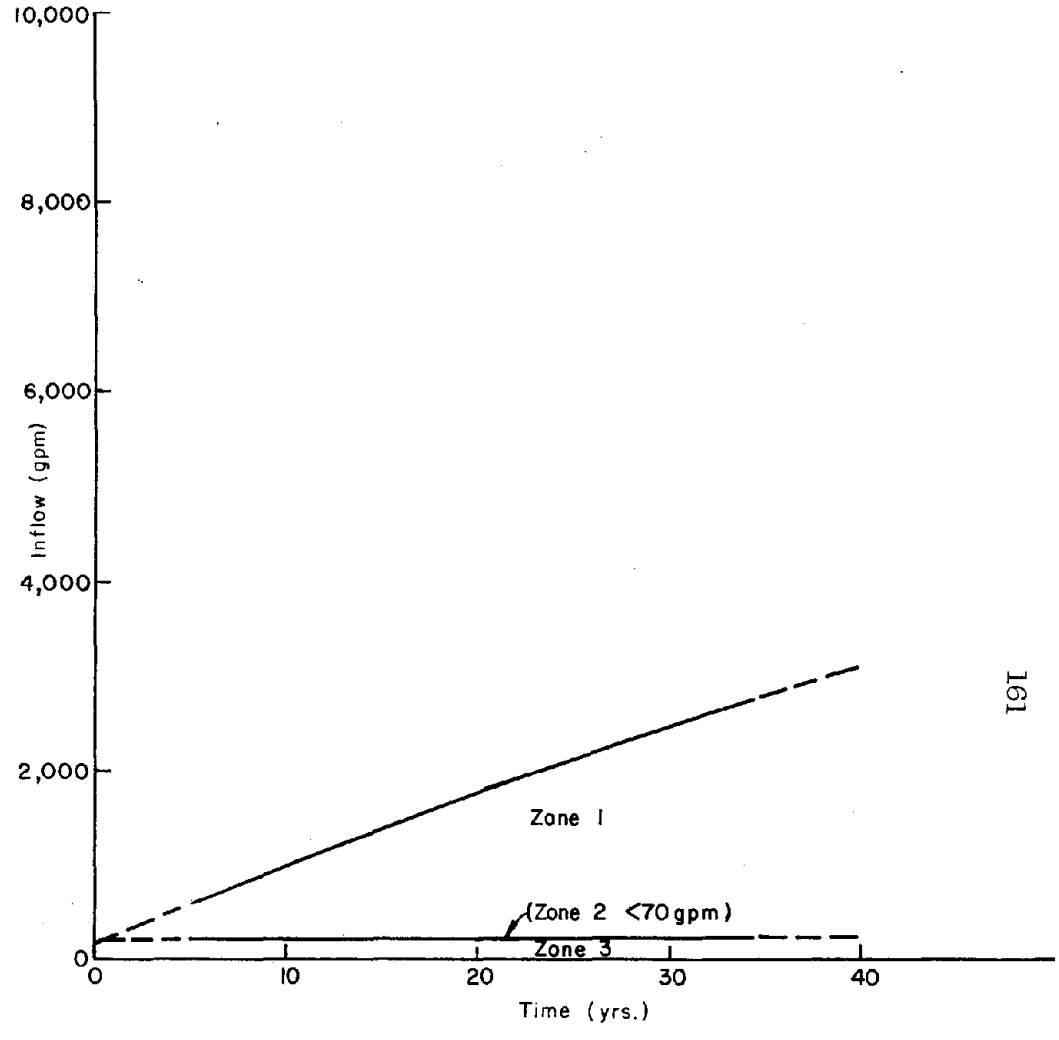
Expansion Rate: .272 mi^2/yr

Initial Radius: 200 ft

Mining Rate: 50,000 ton/day

Figure D-6 MINE INFLOW - SITE 1





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Time - yrs.	Radius - ft.	MINE INFLOW (gpm) Zone 1	(drain) Zone 1	Zone 2	Zone 3	Total
5	4,913	369	-	65	152	590
10	6,944	738	-	65	160	960
20	9,819	1475	-	65	165	1710
30	12,025	2212	-	65	167	2440

DESCRIPTION:

Mining Method: Chamber & Pillar, No Subsidence

Number of Passes: 1

Location: R-4

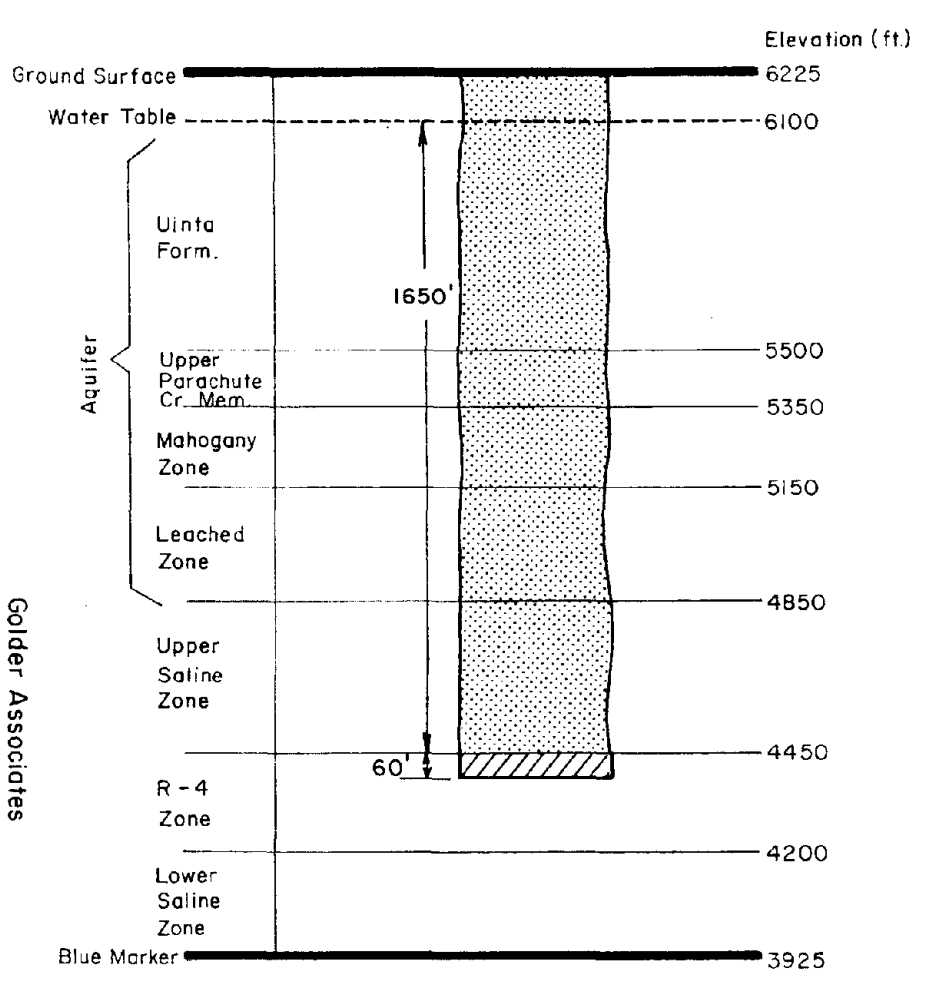
Mining Height: 60 ft

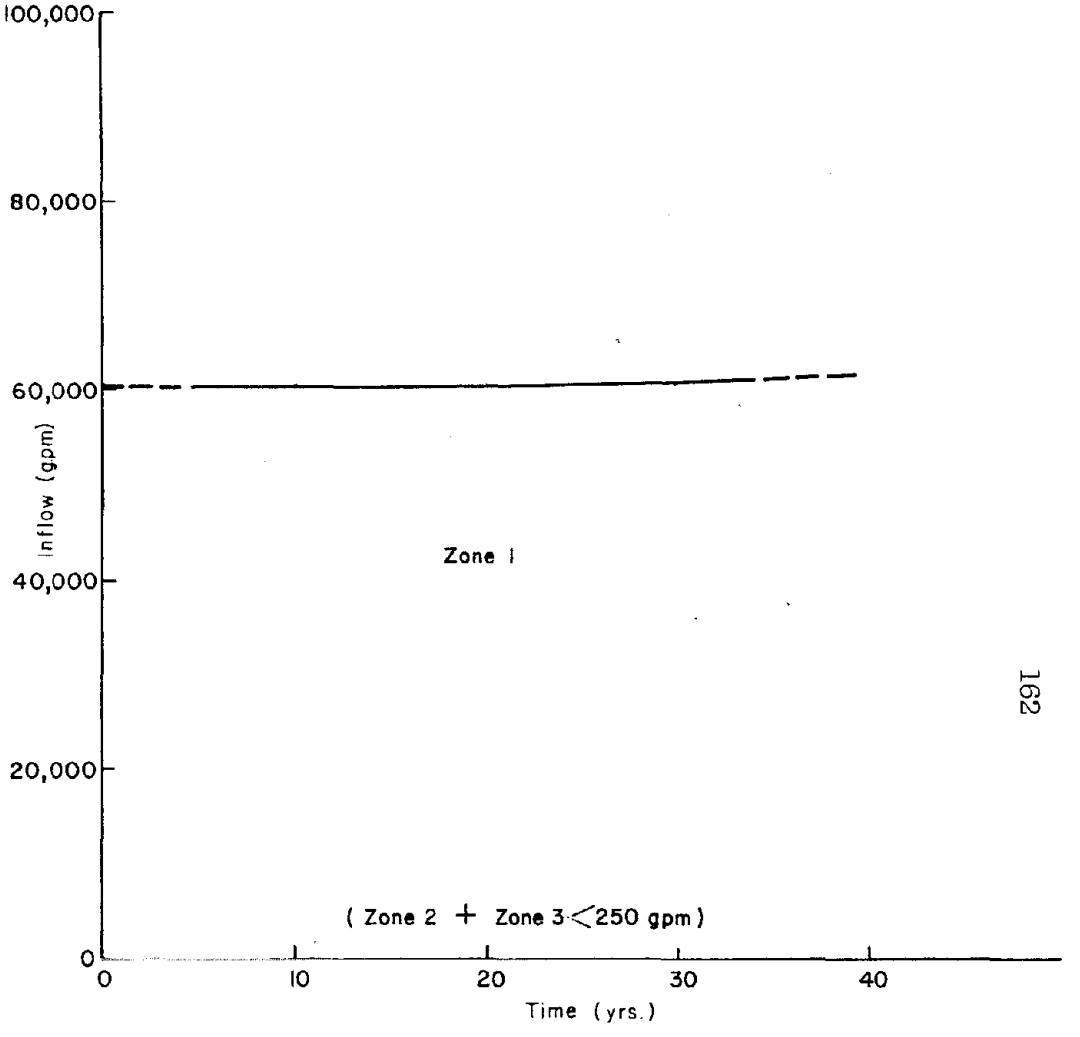
Expansion Rate: .543 mi^2/yr

Initial Radius: 200 ft

Mining Rate: 100,000 ton/day

Figure D-7 MINE INFLOW - SITE 1





Time - yrs.	Radius - ft.	MINE INFLOW (gpm) Zone 1	(drain) Zone 1	Zone 2	Zone 3	Total
5	4,913	42,707	17,773	65	152	60,700
10	6,944	42,707	17,773	65	160	60,710
20	9,819	42,707	17,773	65	165	60,710
30	12,025	42,707	17,773	65	167	60,710

DESCRIPTION:

Mining Method: Chamber & Pillar, Full Subsidence

Number of Passes: 1

Location: R-4

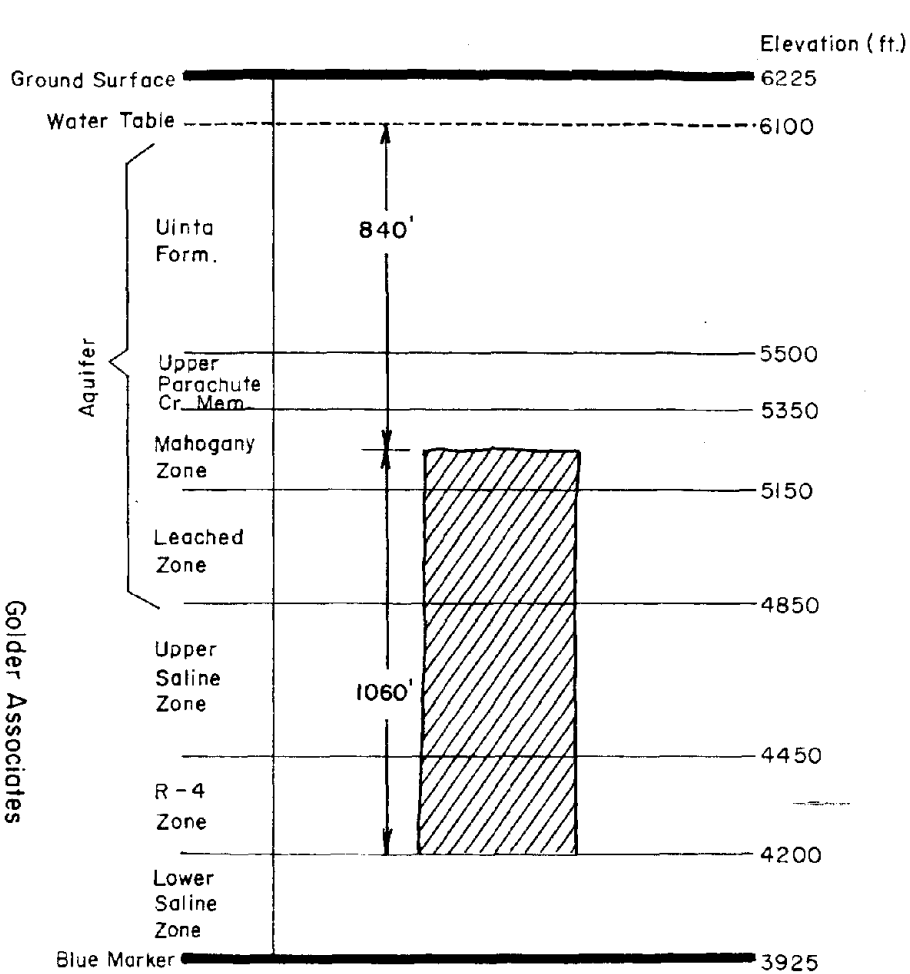
Mining Height: 60 ft

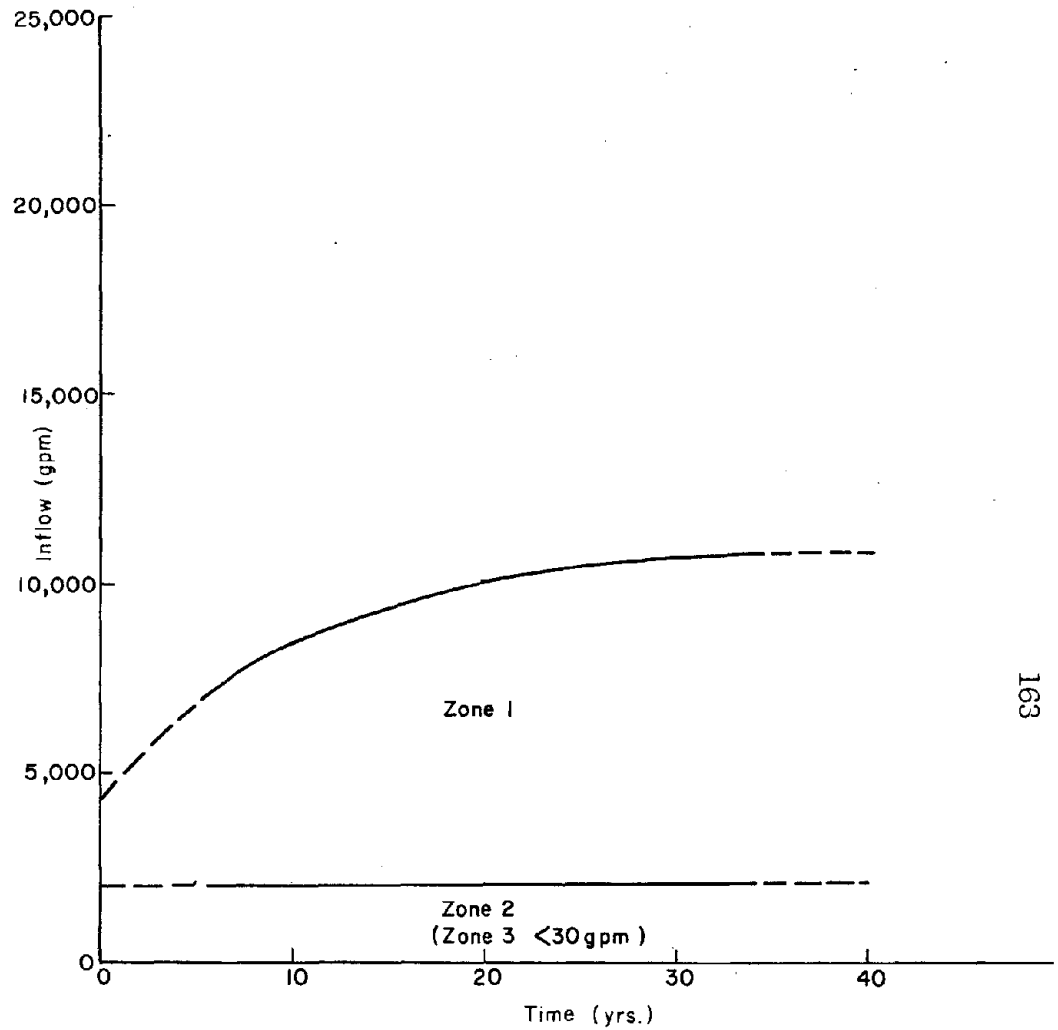
Expansion Rate: .543 mi^2/yr

Initial Radius: 200 ft

Mining Rate: 100,000 ton/day

Figure D-8 MINE INFLOW - SITE 1





Time - yrs.	Radius - ft.	MINE INFLOW (gpm) Zone 1	(drain) Zone 1	Zone 2	Zone 3	Total
5	1072	4861	-	1992	23	6,880
10	1503	6370	-	1988	26	8,380
20	2116	8067	-	1987	28	10,080
30	2588	8657	-	1985	28	10,670

DESCRIPTION:

Mining Method: Chamber & Pillar, No Subsidence

Number of Passes: 11

Location: R-4 to Mahogany

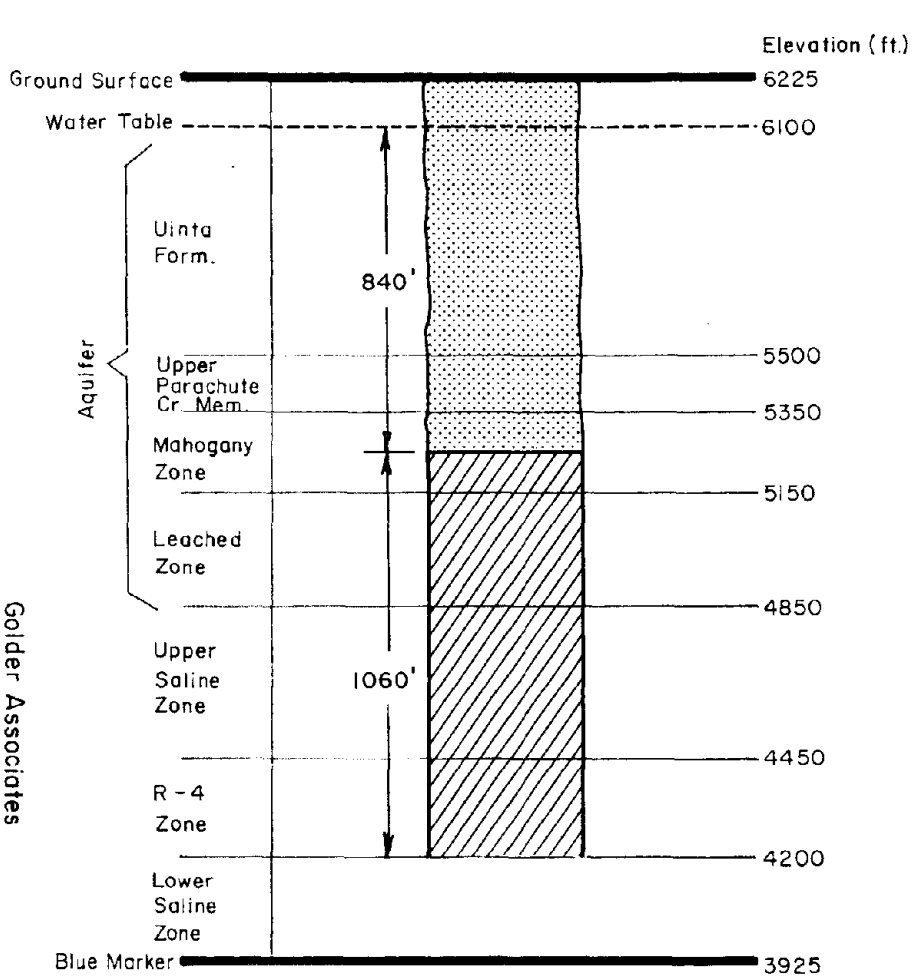
Mining Height: 60 ft, 40 ft sills, total = 1060 ft

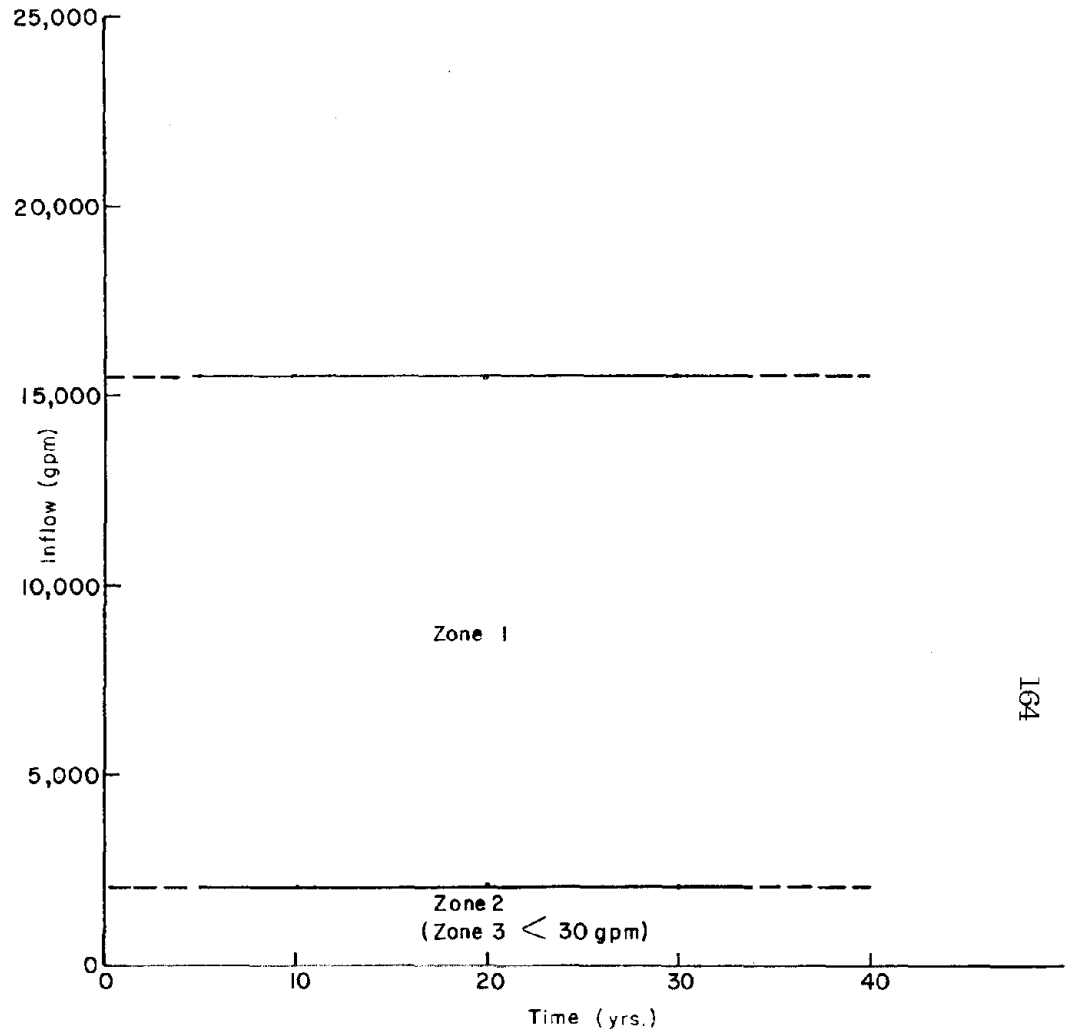
Expansion Rate: .025 mi^2/yr

Initial Radius: 200 ft

Mining Rate: 50,000 ton/day

Figure D-9 MINE INFLOW - SITE 1





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Time - yrs.	Radius - ft.	MINE INFLOW (gpm) Zone 1	Zone 1 (drain)	Zone 2	Zone 3	Total
5	1072	13,030	583	1992	23	15,630
10	1503	13,030	583	1988	26	15,630
20	2116	13,030	583	1987	28	15,630
30	2588	13,030	583	1985	28	15,630

DESCRIPTION:

Mining Method: Chamber & Pillar, Full Subsidence

Number of Passes: 11

Location: R-4 to Mahogany

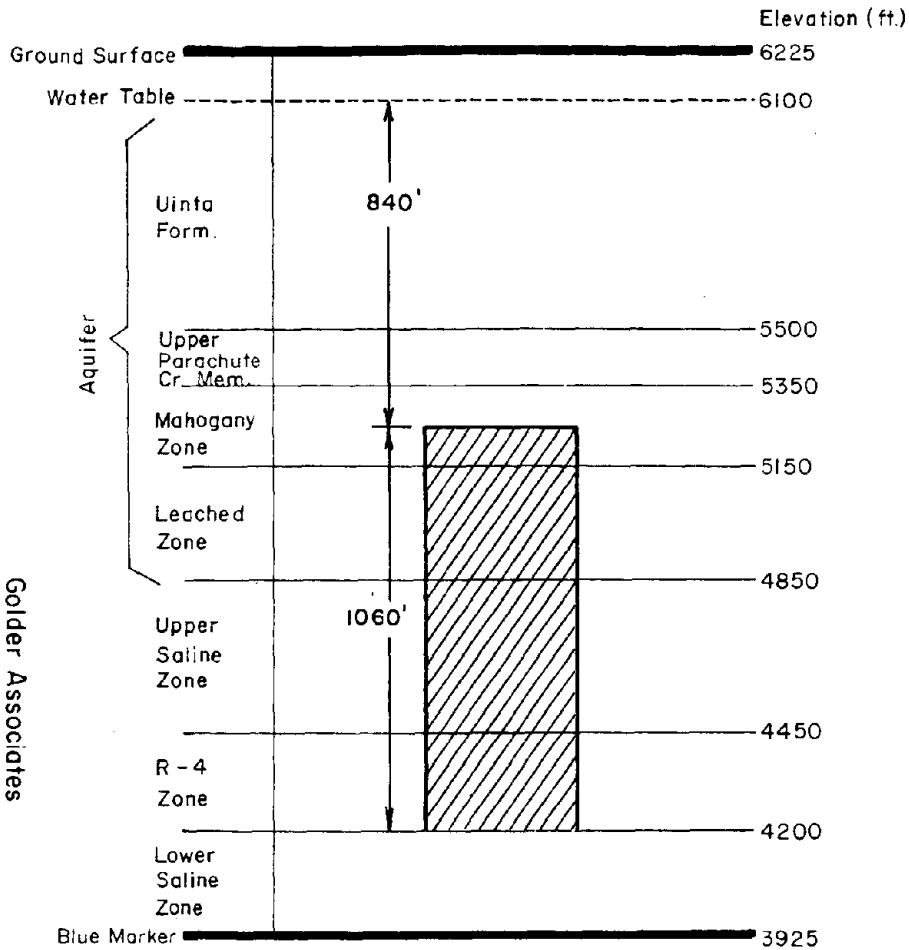
Mining Height: 60 ft, 40 ft sills, total = 1060 ft

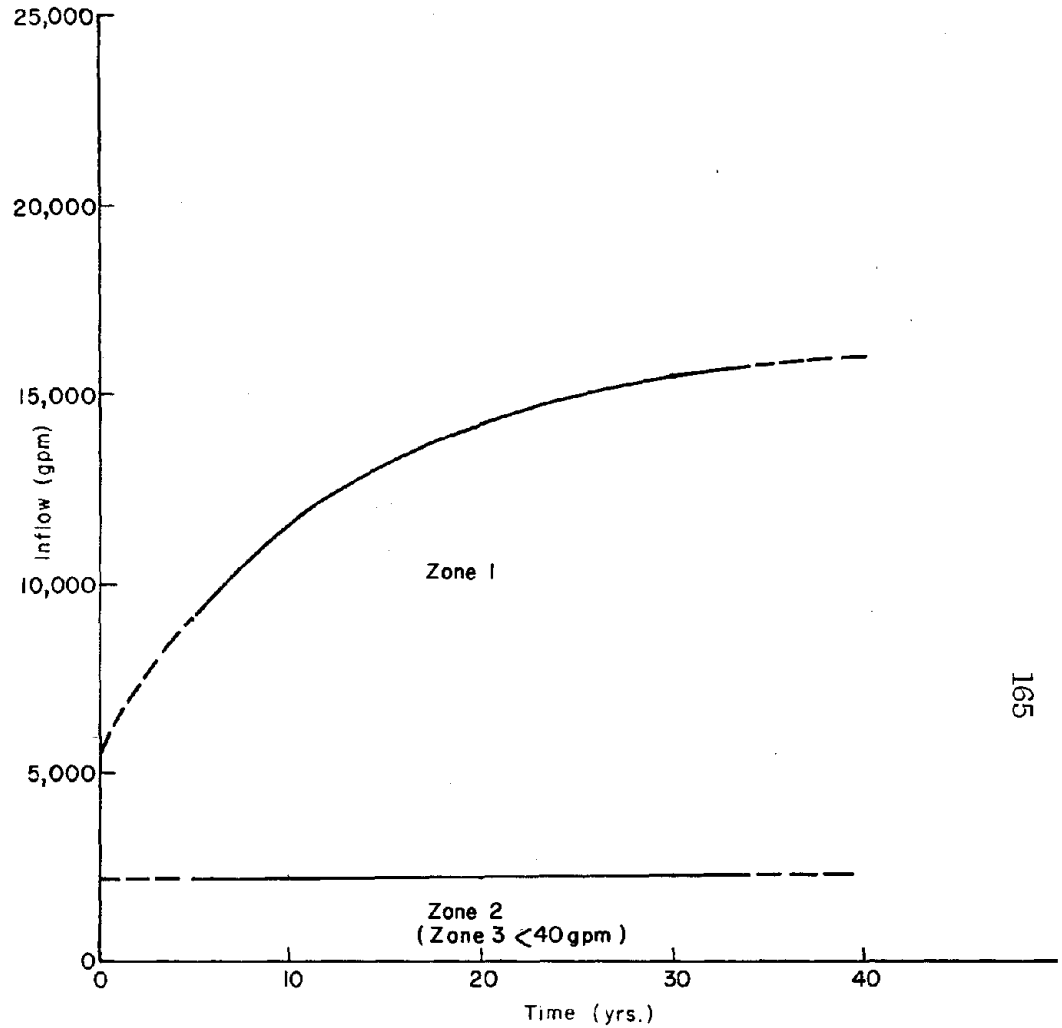
Expansion Rate: .025 mi^2/yr

Initial Radius: 200 ft

Mining Rate: 50,000 ton/day

Figure D-10 MINE INFLOW - SITE I





Time - yrs.	Radius - ft.	MINE INFLOW (gpm) Zone 1	(drain) Zone 1	Zone 2	Zone 3	Total
5	1488	6,764	-	2154	30	8,950
10	2095	9,282	-	2153	33	11,470
20	2956	11,978	-	2152	35	14,170
30	3617	13,322	-	2150	36	15,510

DESCRIPTION:

Mining Method: Chamber & Pillar, No Subsidence

Number of Passes: 11

Location: R-4 to Mahogany

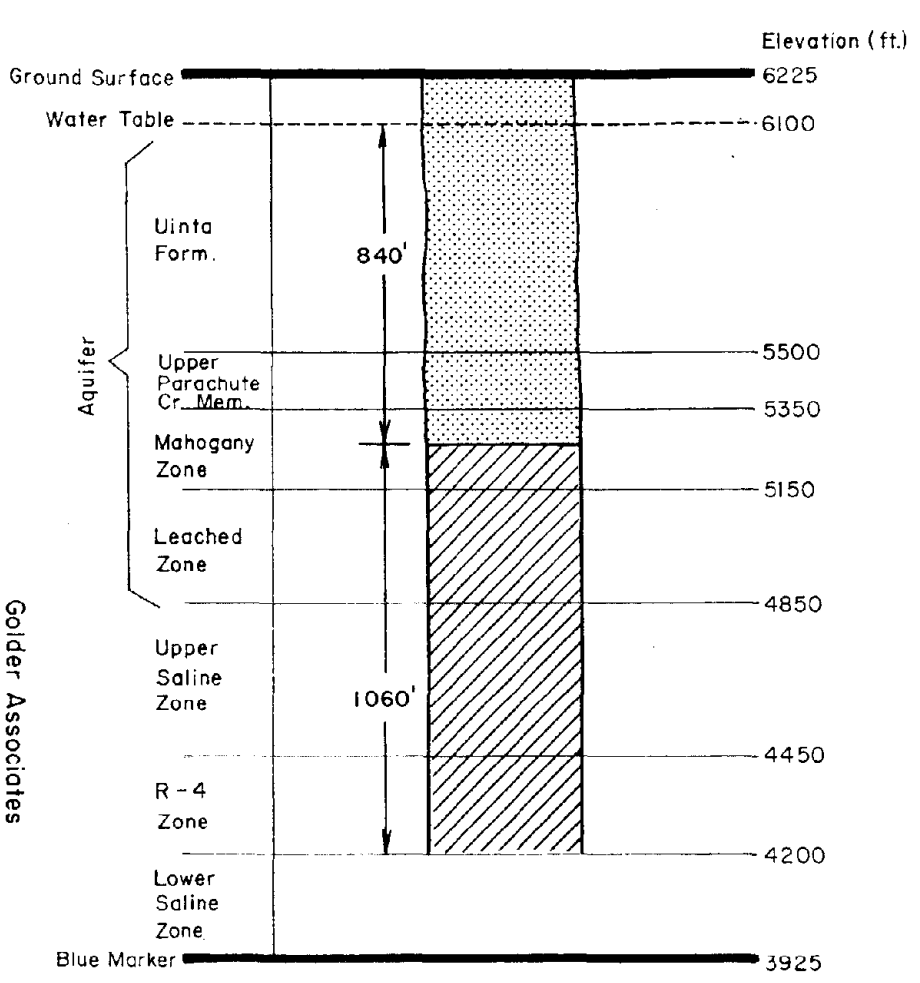
Mining Height: 60 ft, 40 ft sills, total = 1060 ft

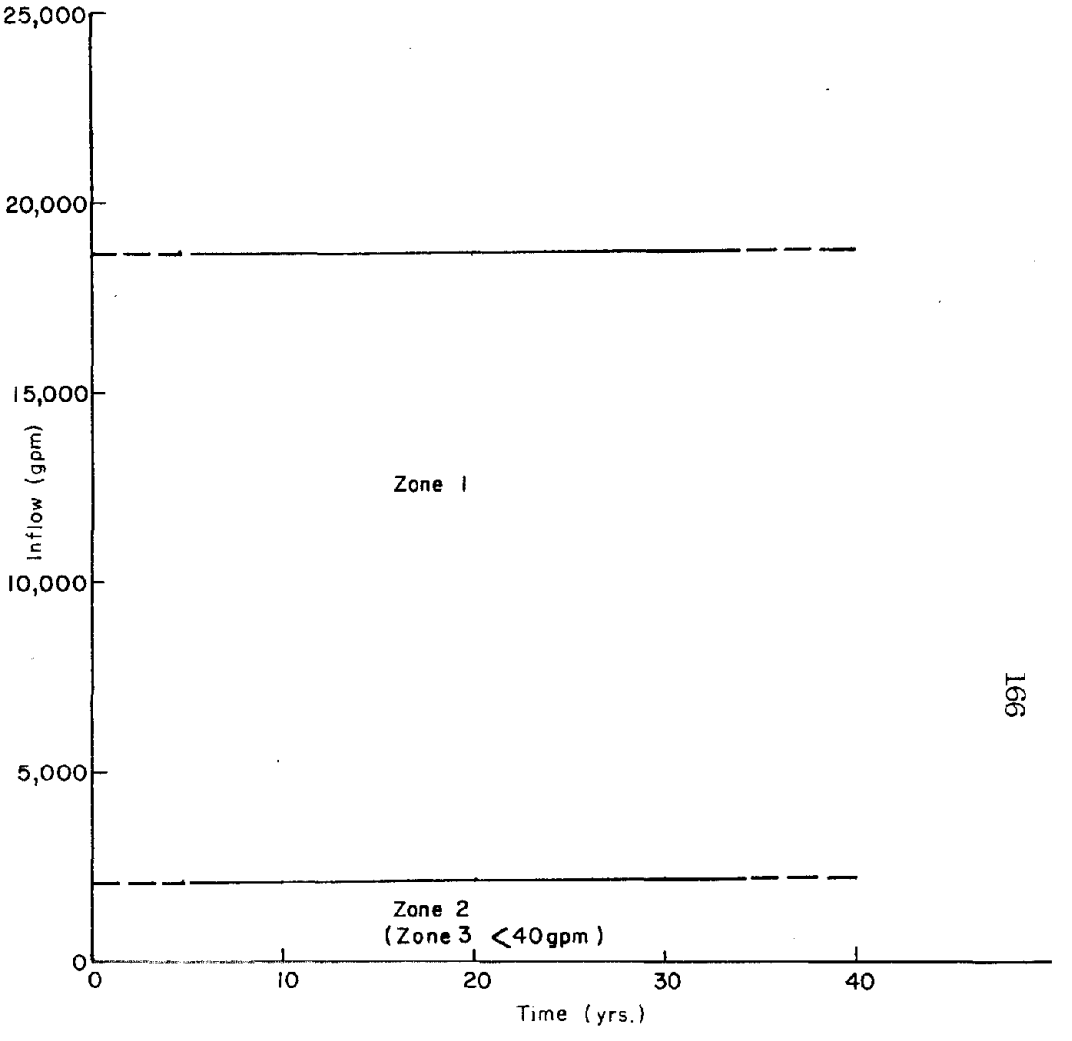
Expansion Rate: .049 mi^2/yr

Initial Radius: 200 ft

Mining Rate: 100,000 ton/day

Figure D-11 MINE INFLOW - SITE 1





Time - yrs.	Radius - ft.	MINE INFLOW (gpm) Zone 1	(drain) Zone 1	Zone 2	Zone 3	Total
5	1488	15,332	1143	2154	30	18,660
10	2095	15,332	1143	2153	33	18,660
20	2956	15,332	1143	2152	35	18,660
30	3617	15,332	1143	2150	36	18,660

DESCRIPTION:

Mining Method: Chamber & Pillar, Full Subsidence

Number of Passes: 11

Location: R-4 to Mahogany

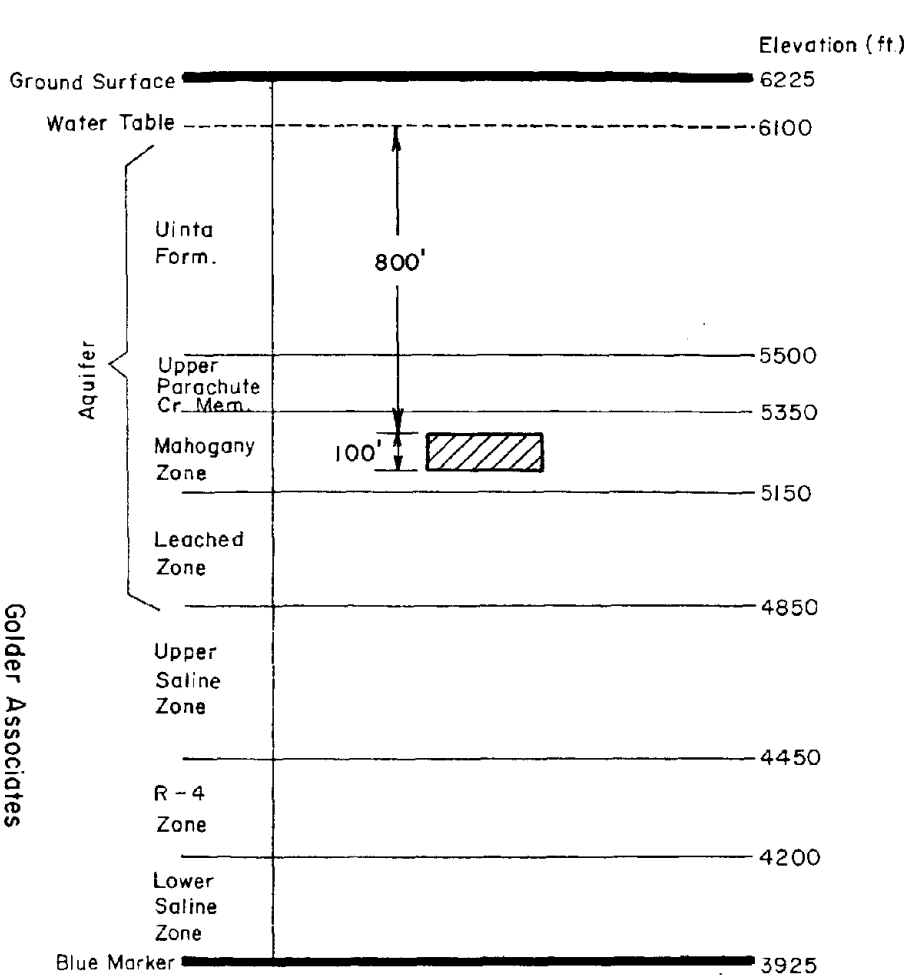
Mining Height: 60 ft, 40 ft sills, total = 1060 ft

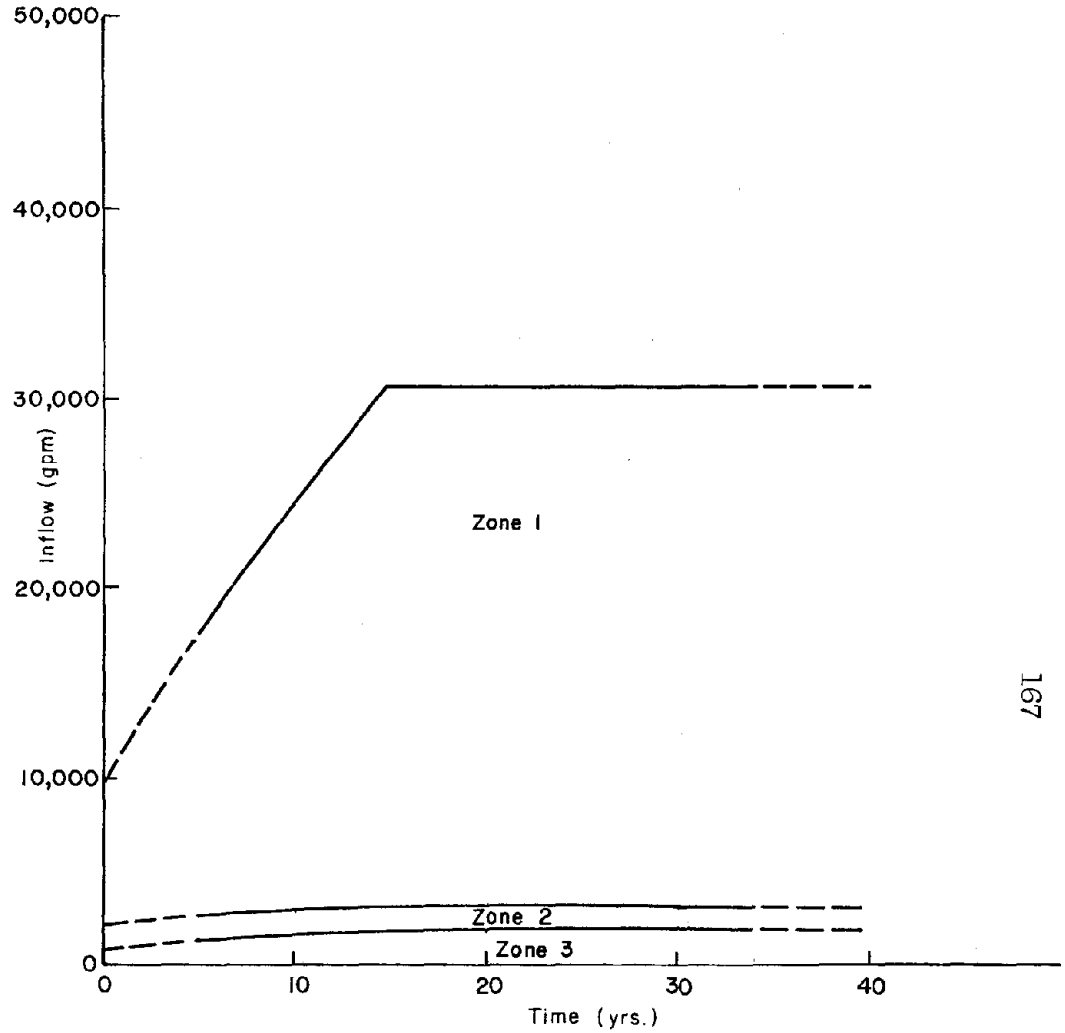
Expansion Rate: .049 mi^2/yr

Initial Radius: 200 ft

Mining Rate: 100,000 ton/day

Figure D-12 MINE INFLOW - SITE 1





Time - yrs.	Radius - ft.	MINE INFLOW (gpm) Zone 1	(drain) Zone 1	Zone 2	Zone 3	Total
5	2903	14,660	-	1216	1313	17,190
10	4100	21,397	-	1216	1687	24,300
20	5795	27,294	-	1216	1970	30,480
30	7096	27,294	-	1216	2087	30,600

DESCRIPTION:

Mining Method: Room & Pillar, No Subsidence

Number of Passes: 1

Location: Mahogany

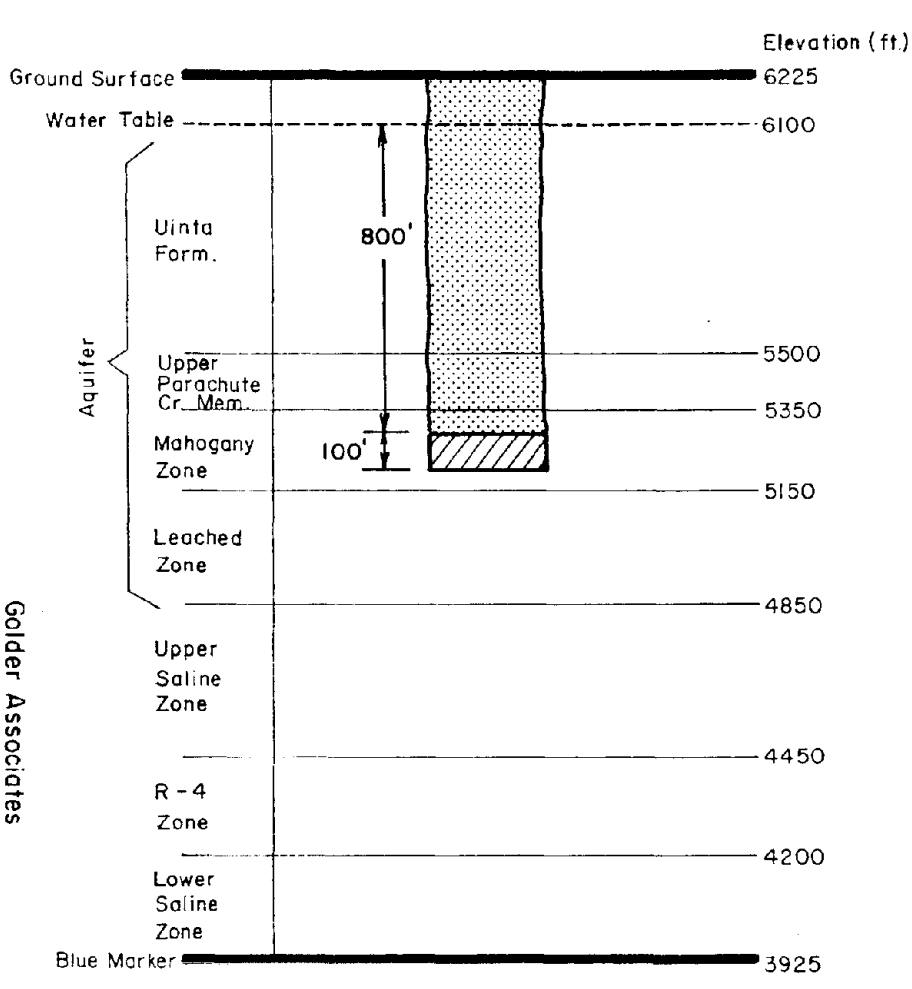
Mining Height: 100 ft

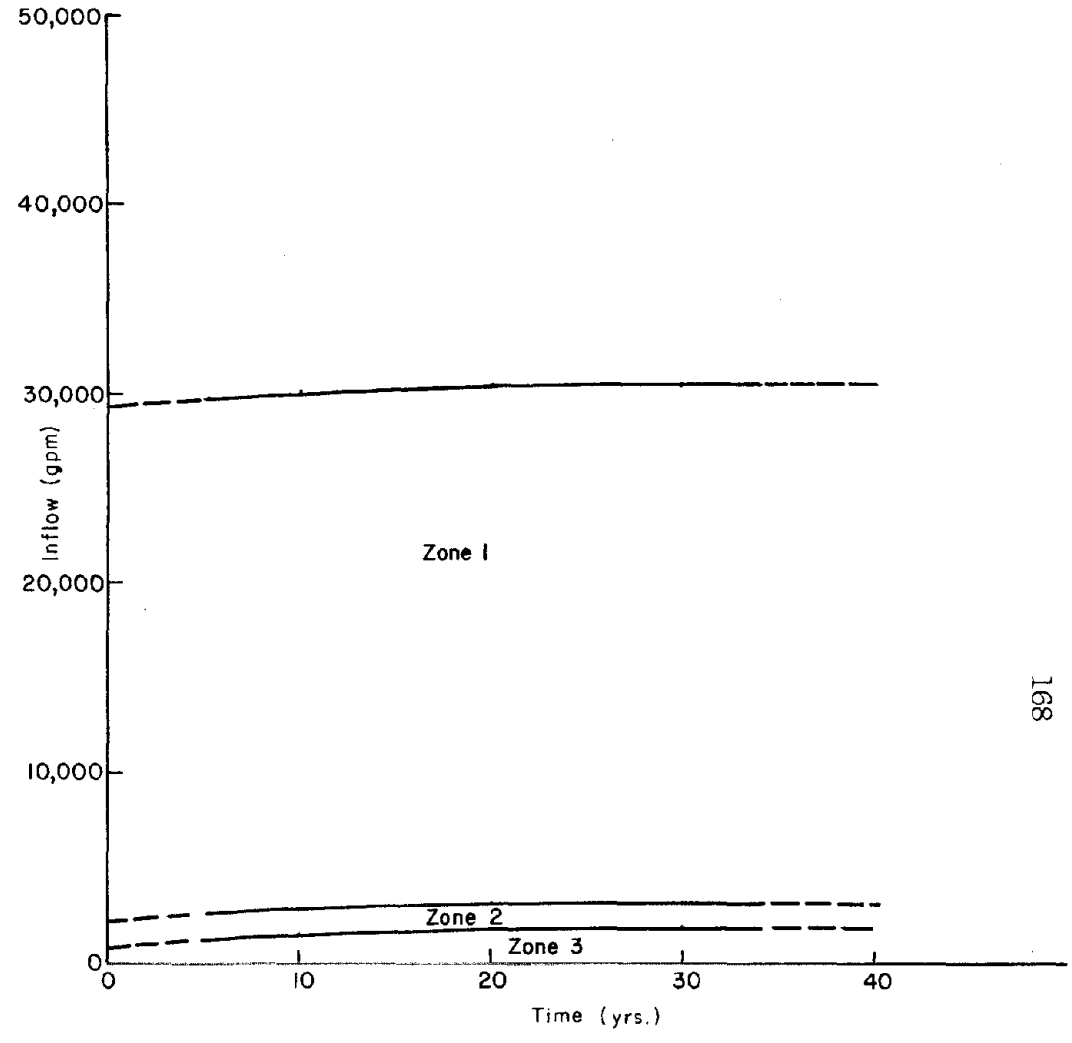
Expansion Rate: .189 mi^2/yr

Initial Radius: 200 ft

Mining Rate: 50,000 ton/day

Figure D-13 MINE INFLOW - SITE I





MINE INFLOW (gpm)

Time - yrs.	Radius - ft.	Zone 1	Zone 1 (drain)	Zone 2	Zone 3	Total
5	2903	22,495	4799	1216	1313	29,820
10	4100	22,495	4799	1216	1687	30,200
20	5795	22,495	4799	1216	1970	30,480
30	7096	22,495	4799	1216	2087	30,600

DESCRIPTION:

Mining Method: Room & Pillar, Full Subsidence

Number of Passes: 1

Location: Mahogany

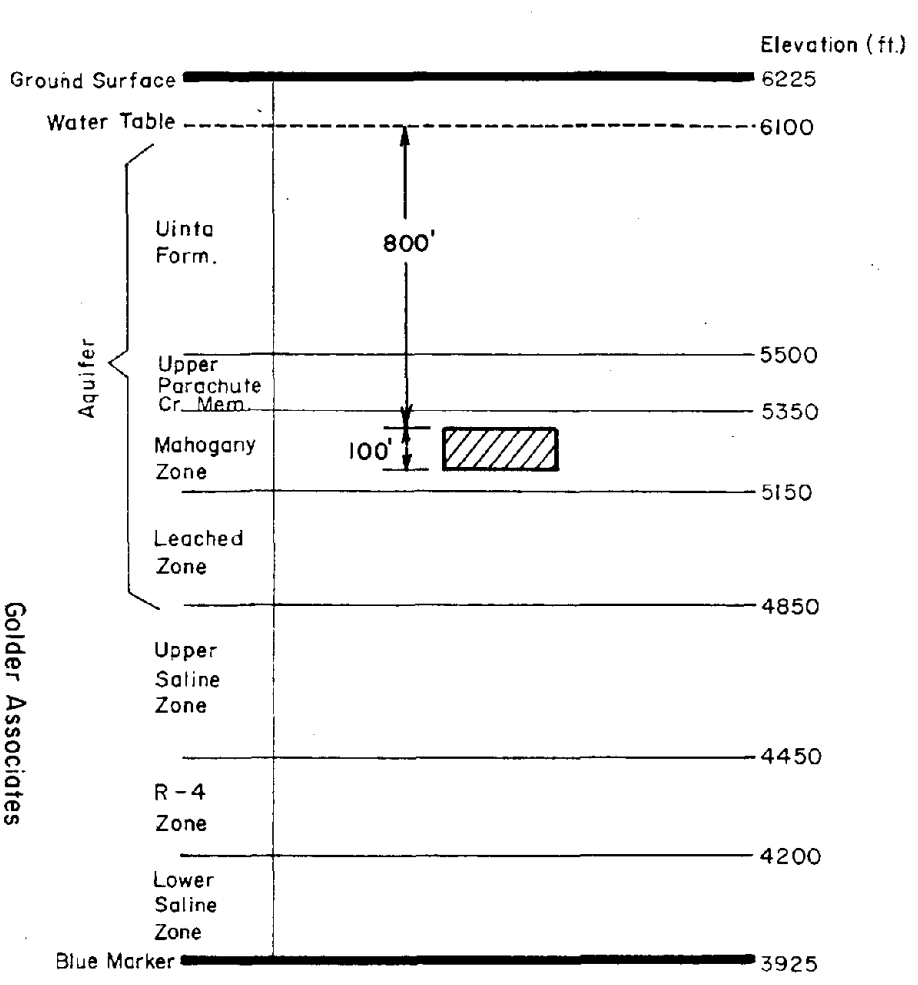
Mining Height: 100 ft

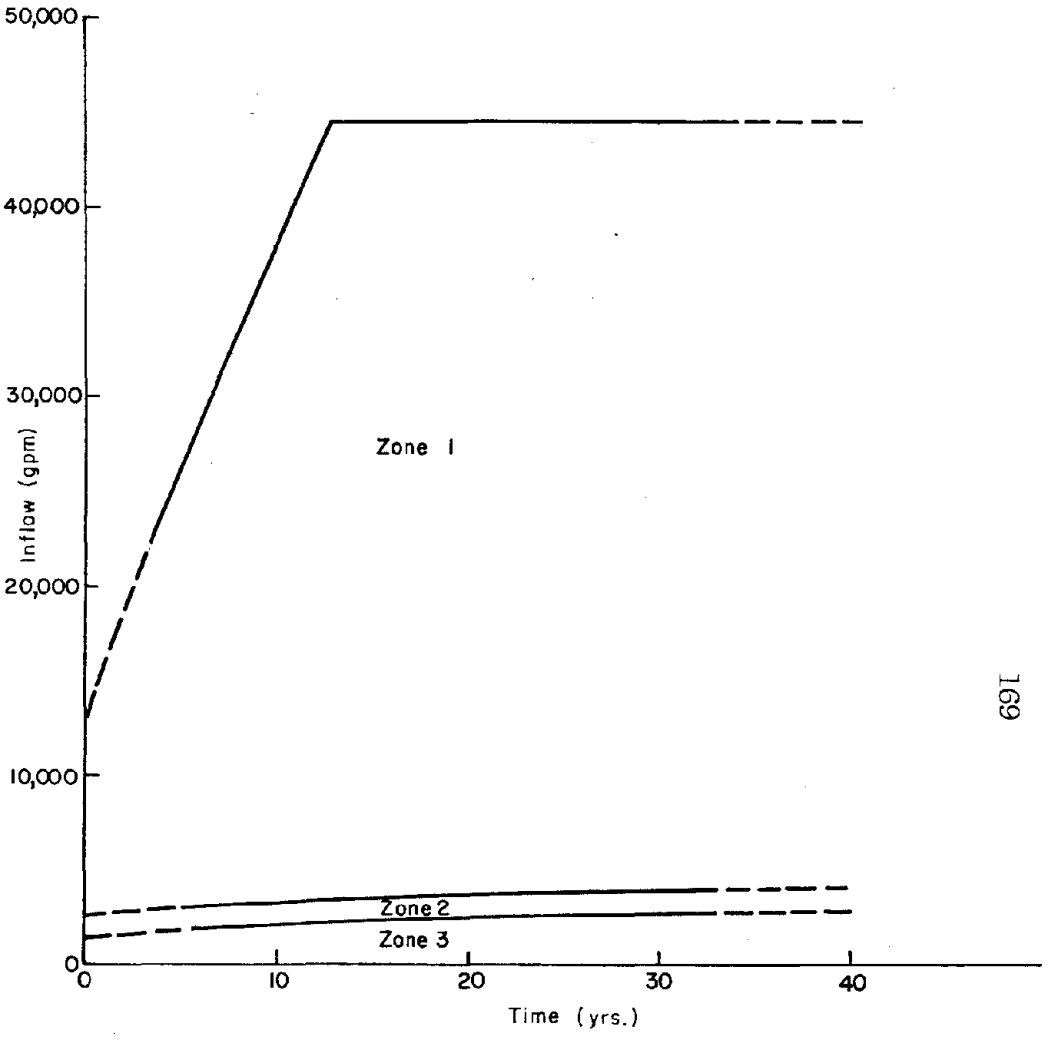
Expansion Rate: .189 mi^2/yr

Initial Radius: 200 ft

Mining Rate: 50,000 ton/day

Figure D-14 MINE INFLOW - SITE 1





Time - yrs.	Radius - ft.	MINE INFLOW (gpm) Zone 1	(drain) Zone 1	Zone 2	Zone 3	Total
5	4,100	22,823	-	1330	1805	25,960
10	5,795	34,196	-	1330	2132	37,660
20	8,193	40,562	-	1330	2345	44,240
30	10,033	50,562	-	1330	2425	44,320

DESCRIPTION:

Mining Method: Room & Pillar, No Subsidence

Number of Passes: 1

Location: Mahogany

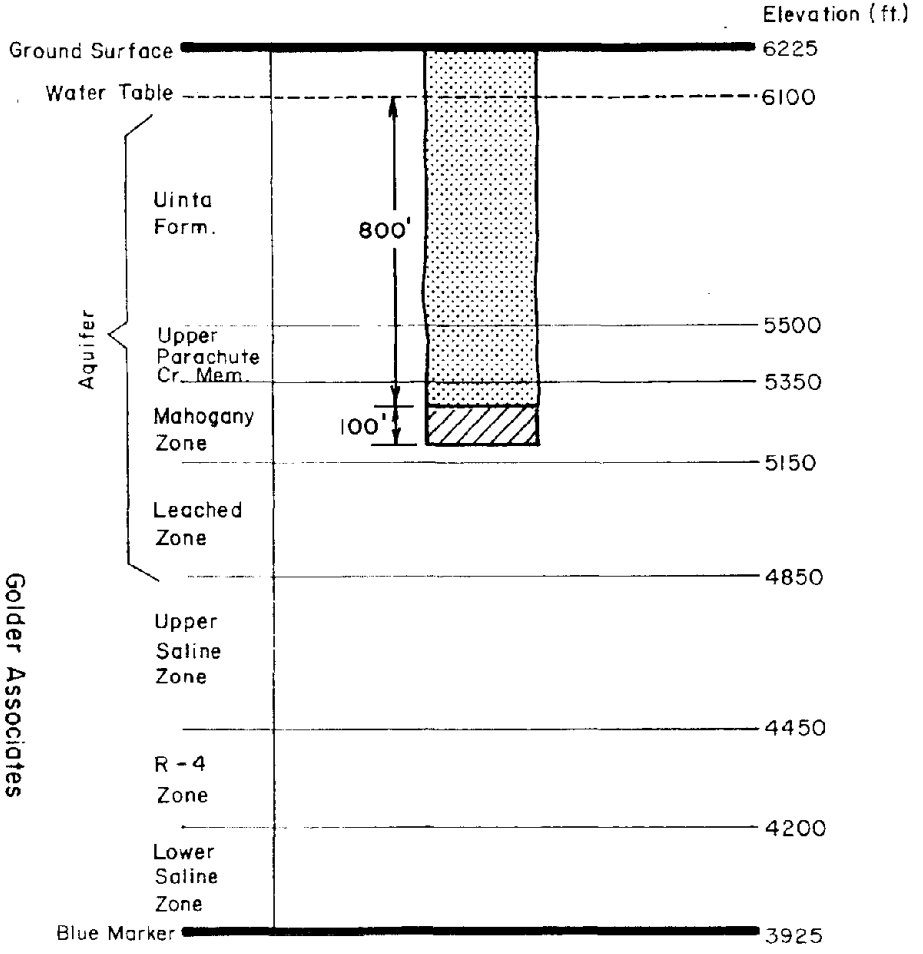
Mining Height: 100 ft

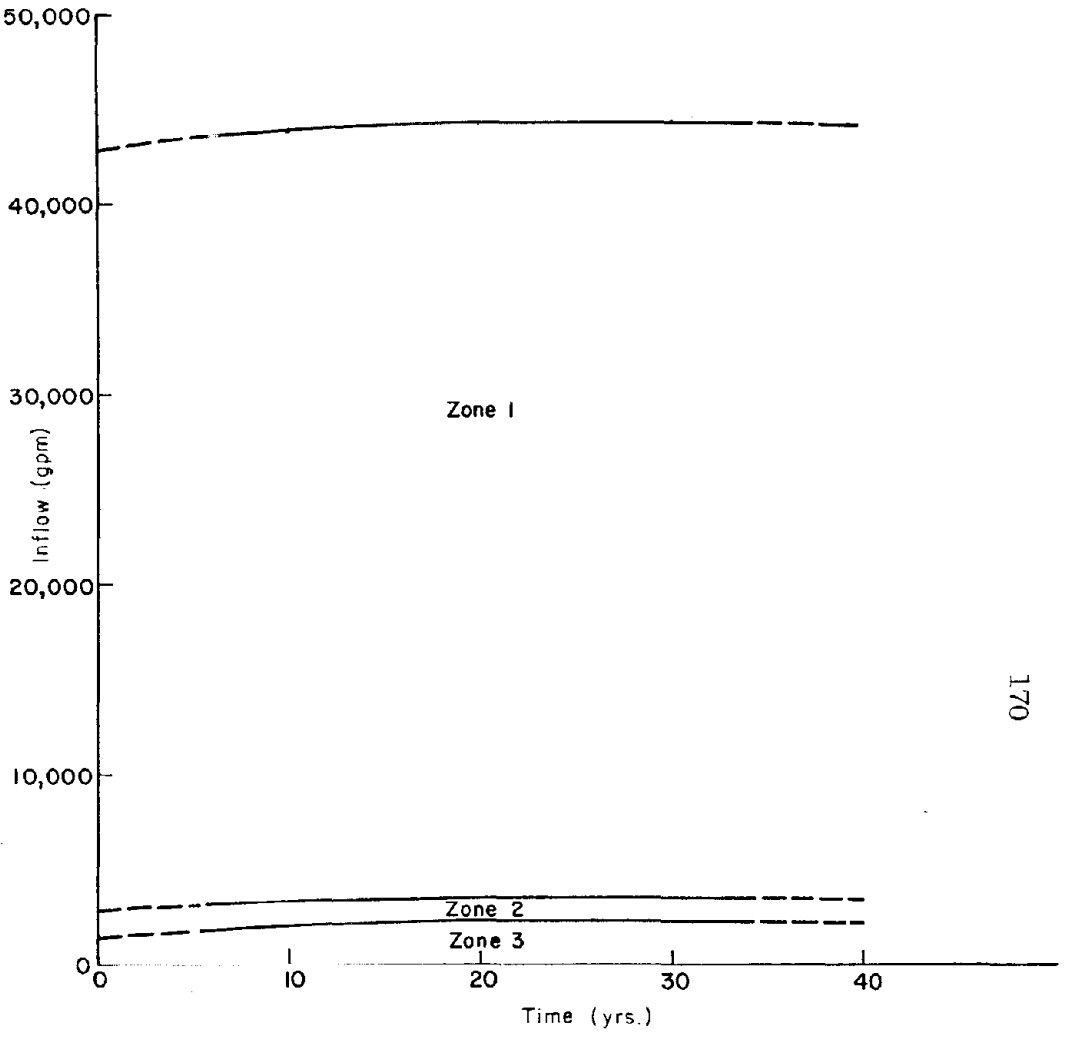
Expansion Rate: .378 mi^2/yr

Initial Radius: 200 ft

Mining Rate: 100,000 ton/day

Figure D-15 MINE INFLOW - SITE I





Time - yrs.	Radius - ft.	MINE INFLOW (gpm) Zone 1	(drain) Zone 1	Zone 2	Zone 3	Total
5	4,100	30,964	9598	1330	1805	43,700
10	5,795	30,964	9598	1330	2132	44,030
20	8,193	30,964	9598	1330	2345	44,240
30	10,033	30,964	9598	1330	2425	44,320

DESCRIPTION:

Mining Method: Room & Pillar, Full Subsidence

Number of Passes: 1

Location: Mahogany

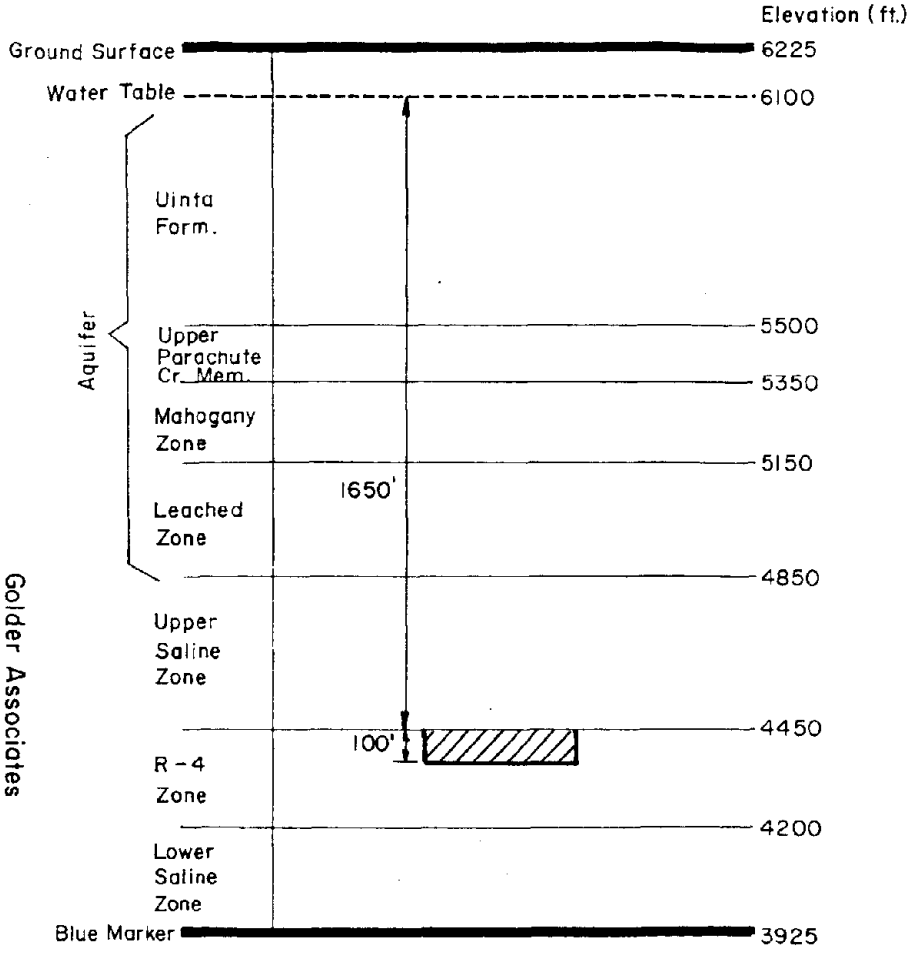
Mining Height: 100 ft

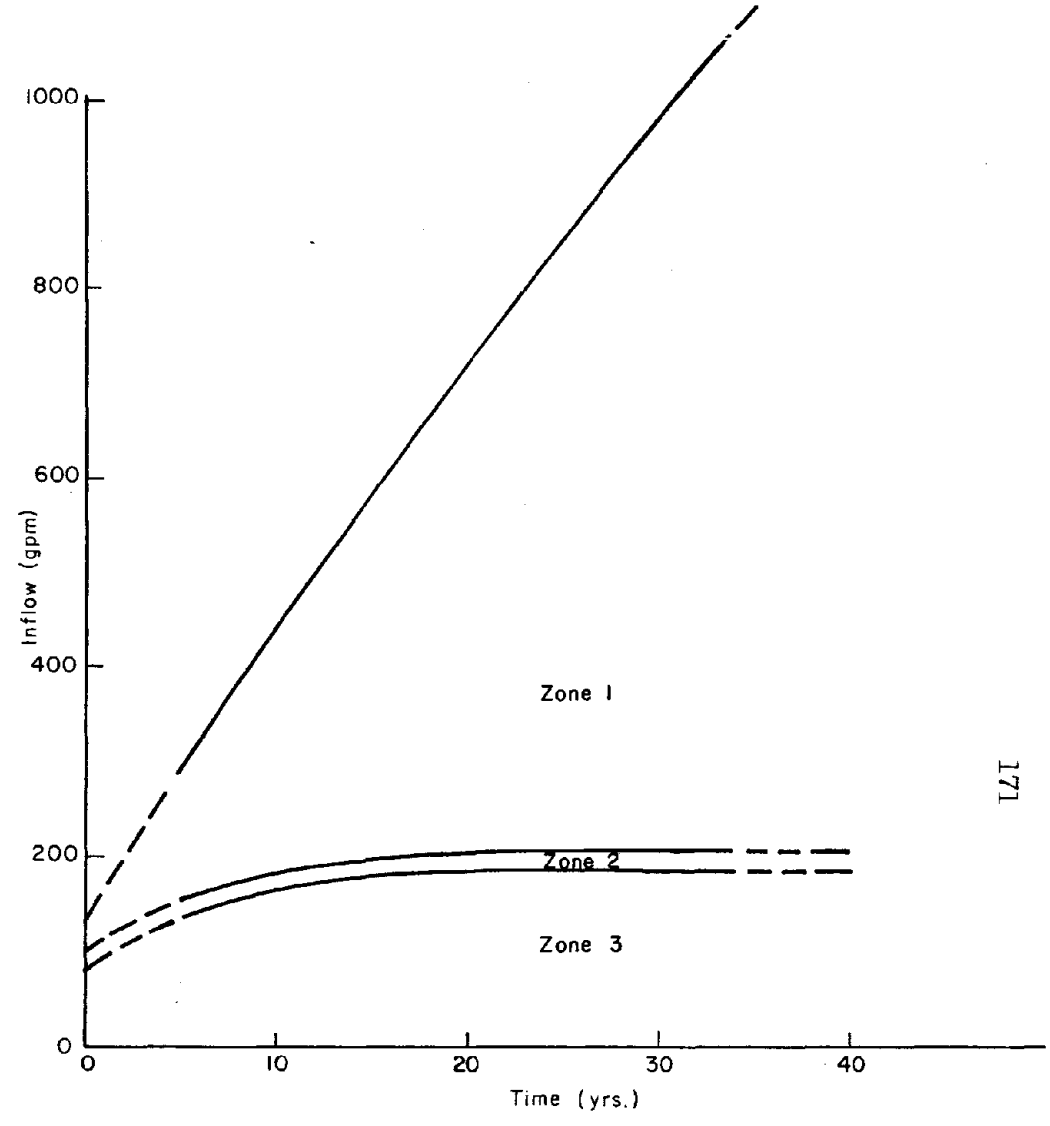
Expansion Rate: .378 mi^2/yr

Initial Radius: 200 ft

Mining Rate: 100,000 ton/day

Figure D-16 MINE INFLOW - SITE 1





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Time - yrs.	Radius - ft.	MINE INFLOW (gpm) Zone 1	(drain) Zone 1	Zone 2	Zone 3	Total
5	2903	129	-	20	137	290
10	4100	257	-	20	164	440
20	5795	514	-	20	181	720
30	7096	770	-	20	188	980

DESCRIPTION:

Mining Method: Room & Pillar, No Subsidence

Number of Passes: 1

Location: R-4

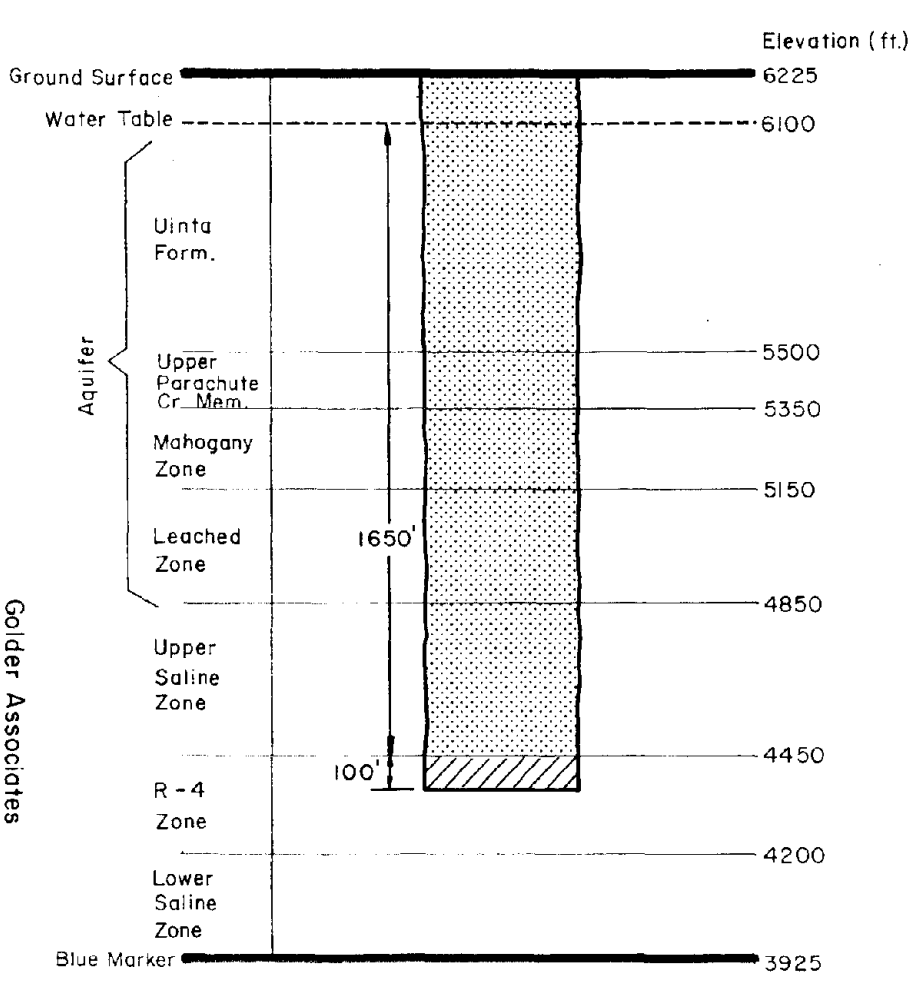
Mining Height: 100 ft

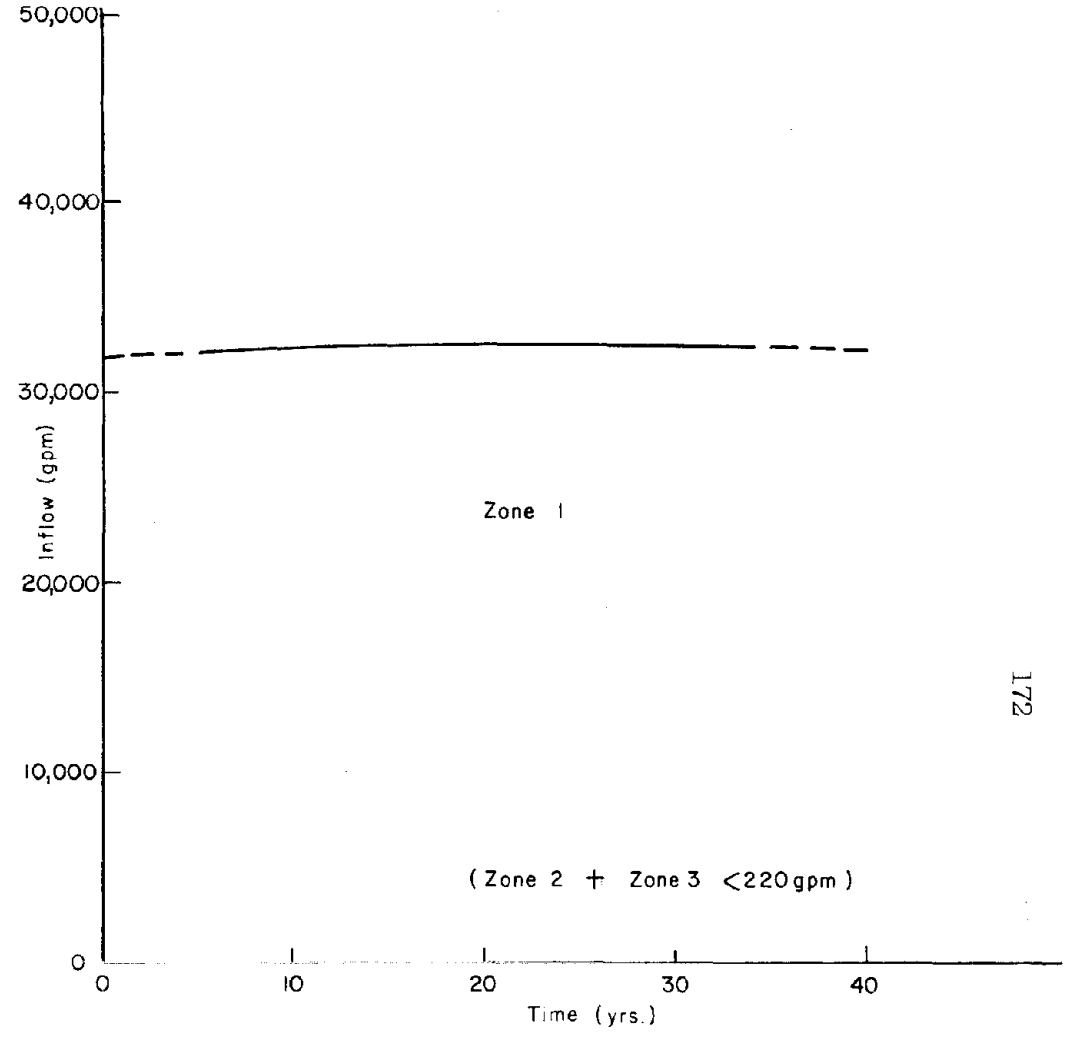
Expansion Rate: .189 mi^2/yr

Initial Radius: 200 ft

Mining Rate: 50,000 ton/day

Figure D-17 MINE INFLOW - SITE 1





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MINE INFLOW (gpm)

Time - yrs.	Radius - ft.	Zone 1	(drain) Zone 1	Zone 2	Zone 3	Total
5	2903	26,130	6186	20	137	32,470
10	4100	26,130	6186	20	164	32,500
20	5795	26,130	6186	20	181	32,520
30	7096	26,130	6186	20	188	32,520

DESCRIPTION:

Mining Method: Room & Pillar, Full Subsidence

Number of Passes: 1

Location: R-4

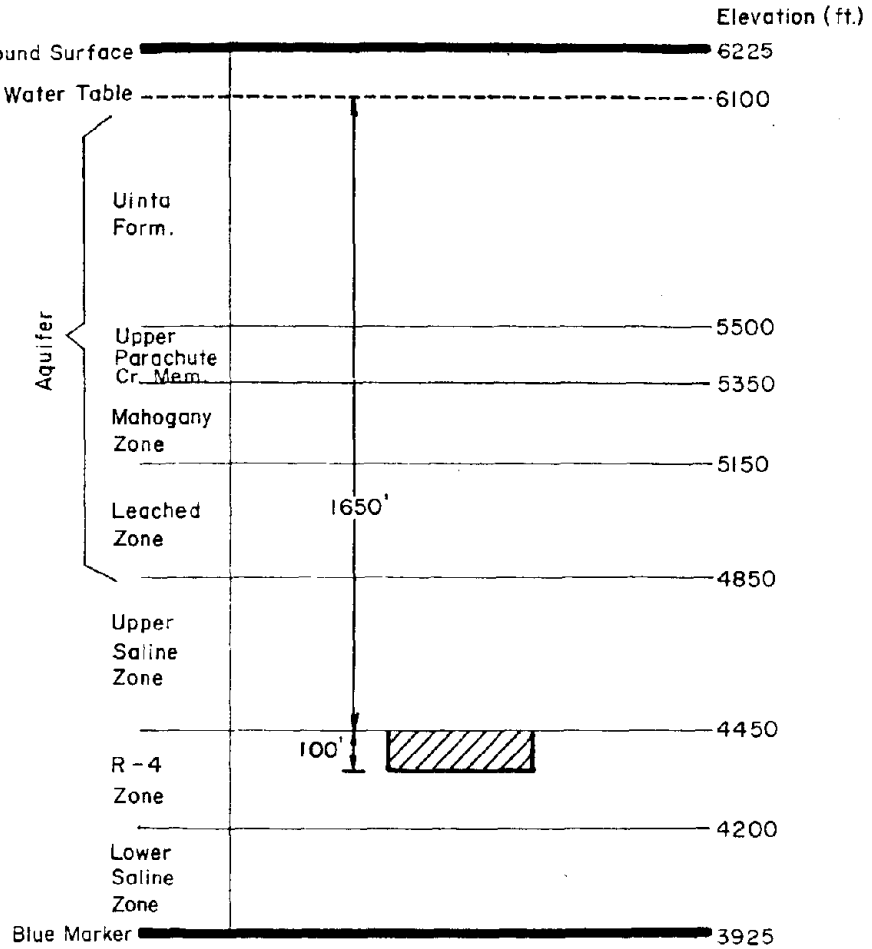
Mining Height: 100 ft

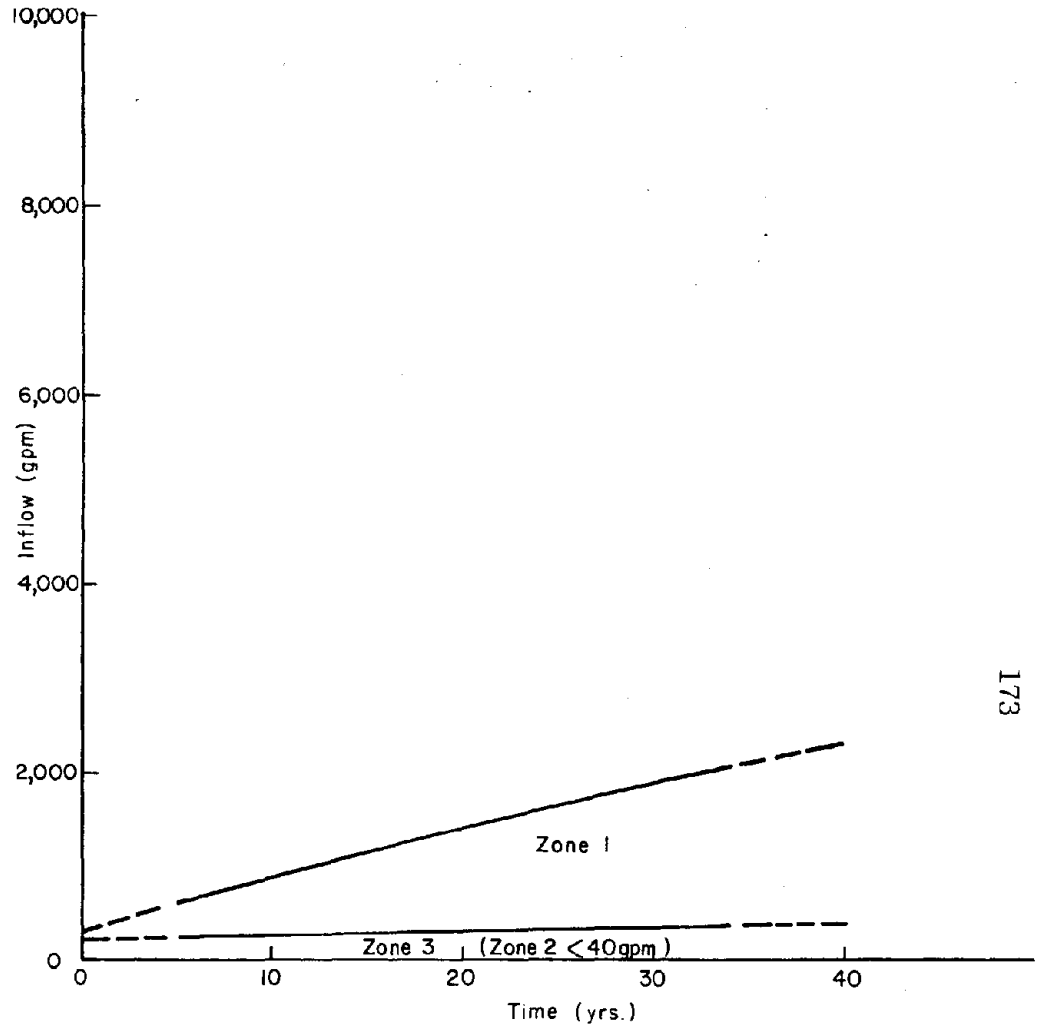
Expansion Rate: .189 mi^2/yr

Initial Radius: 200 ft

Mining Rate: 50,000 ton/day

Figure D-18 MINE INFLOW - SITE 1





Time - yrs.	Radius - ft.	MINE INFLOW (gpm) Zone 1	(drain) Zone 1	Zone 2	Zone 3	Total
5	4,100	257	-	30	227	510
10	5,795	514	-	30	262	810
20	8,193	1027	-	30	284	1340
30	10,033	1540	-	30	292	1860

DESCRIPTION:

Mining Method: Room & Pillar, No Subsidence

Number of Passes: 1

Location: R-4

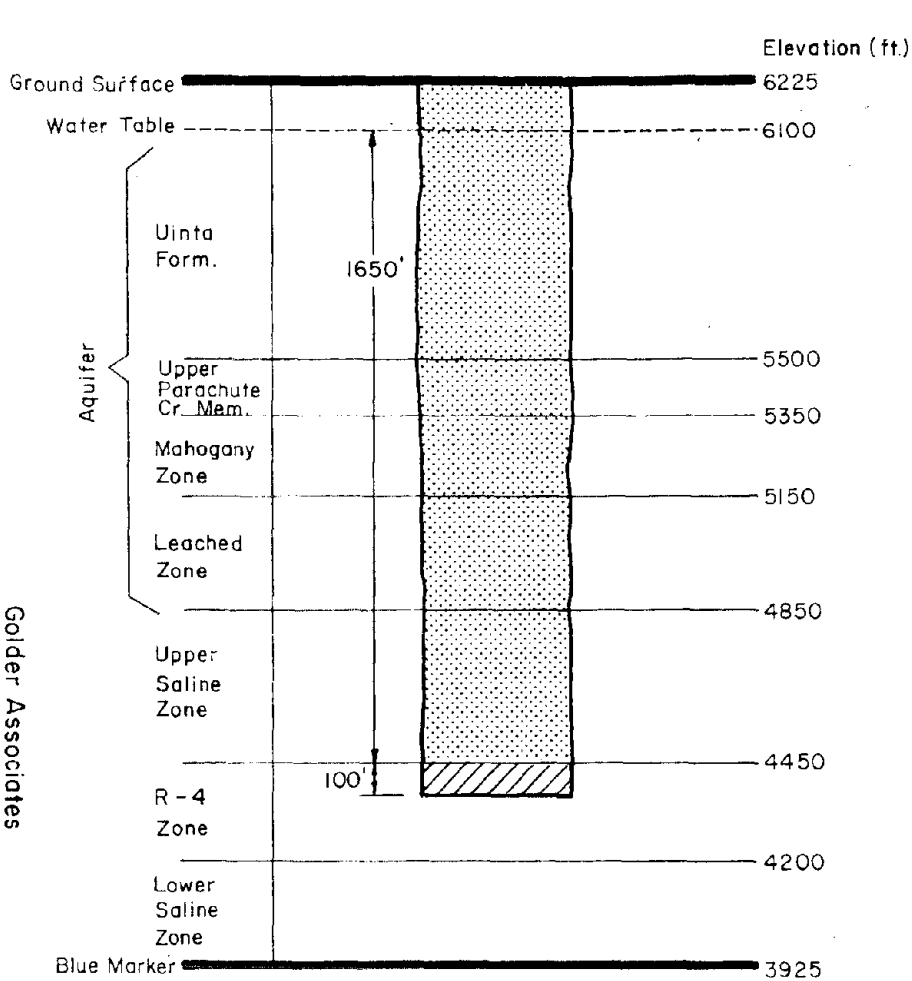
Mining Height: 100 ft

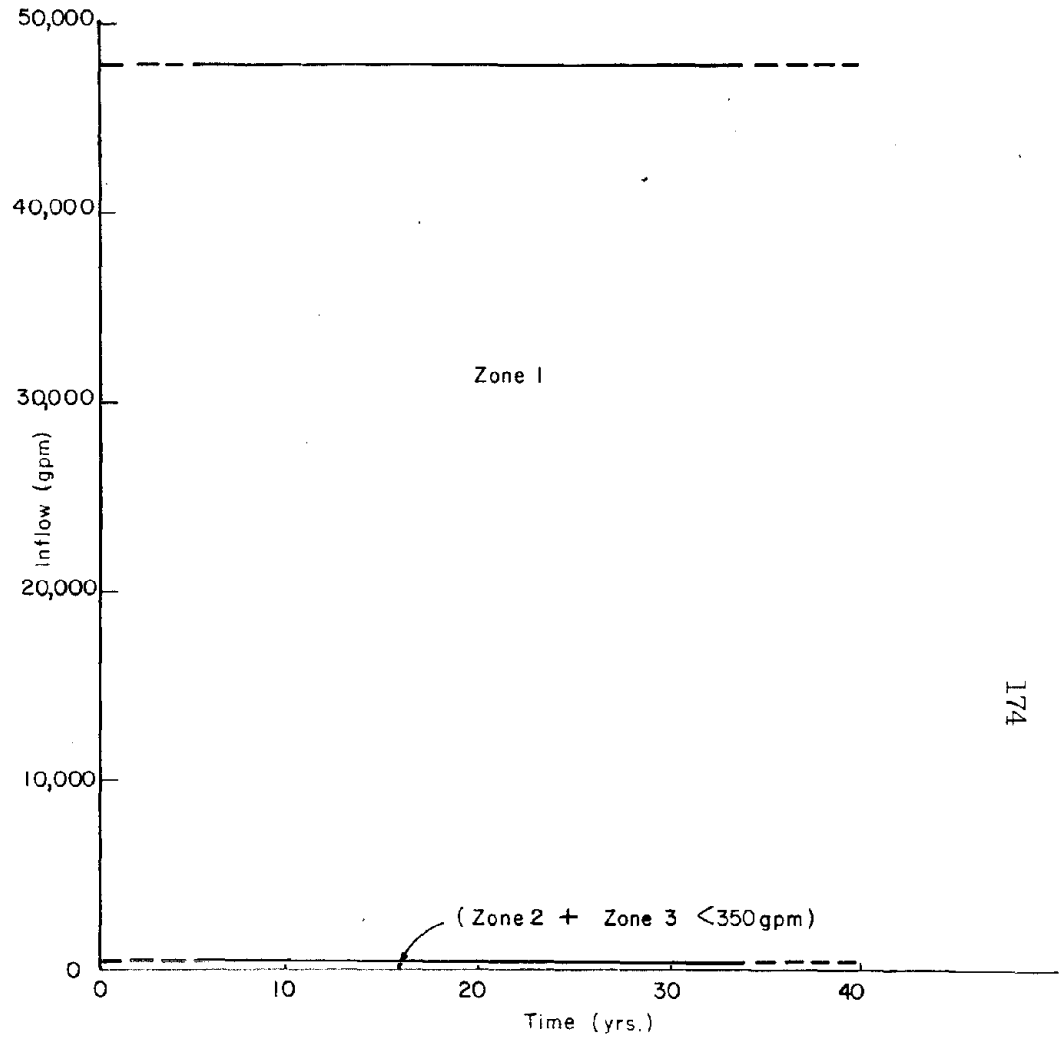
Expansion Rate: .378 mi^2/yr

Initial Radius: 200 ft

Mining Rate: 100,000 ton/day

Figure D-19 MINE INFLOW - SITE 1





Time - yrs.	Radius - ft.	MINE INFLOW (gpm) Zone 1	(drain) Zone 1	Zone 2	Zone 3	Total
5	4,100	35,026	12,373	30	227	47,660
10	5,795	35,026	12,373	30	262	47,690
20	8,193	35,026	12,373	30	284	47,710
30	10,033	35,026	12,373	30	292	47,720

DESCRIPTION:

Mining Method: Room & Pillar, Full Subsidence

Number of Passes: 1

Location: R-4

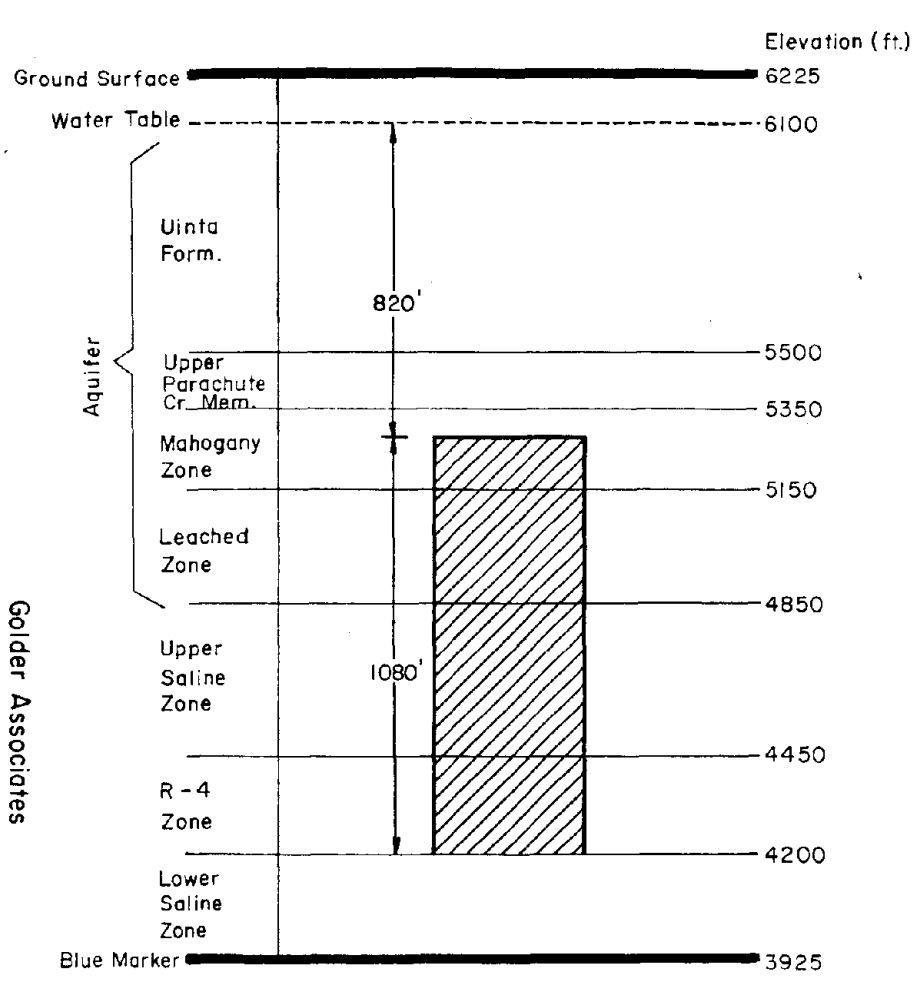
Mining Height: 100 ft

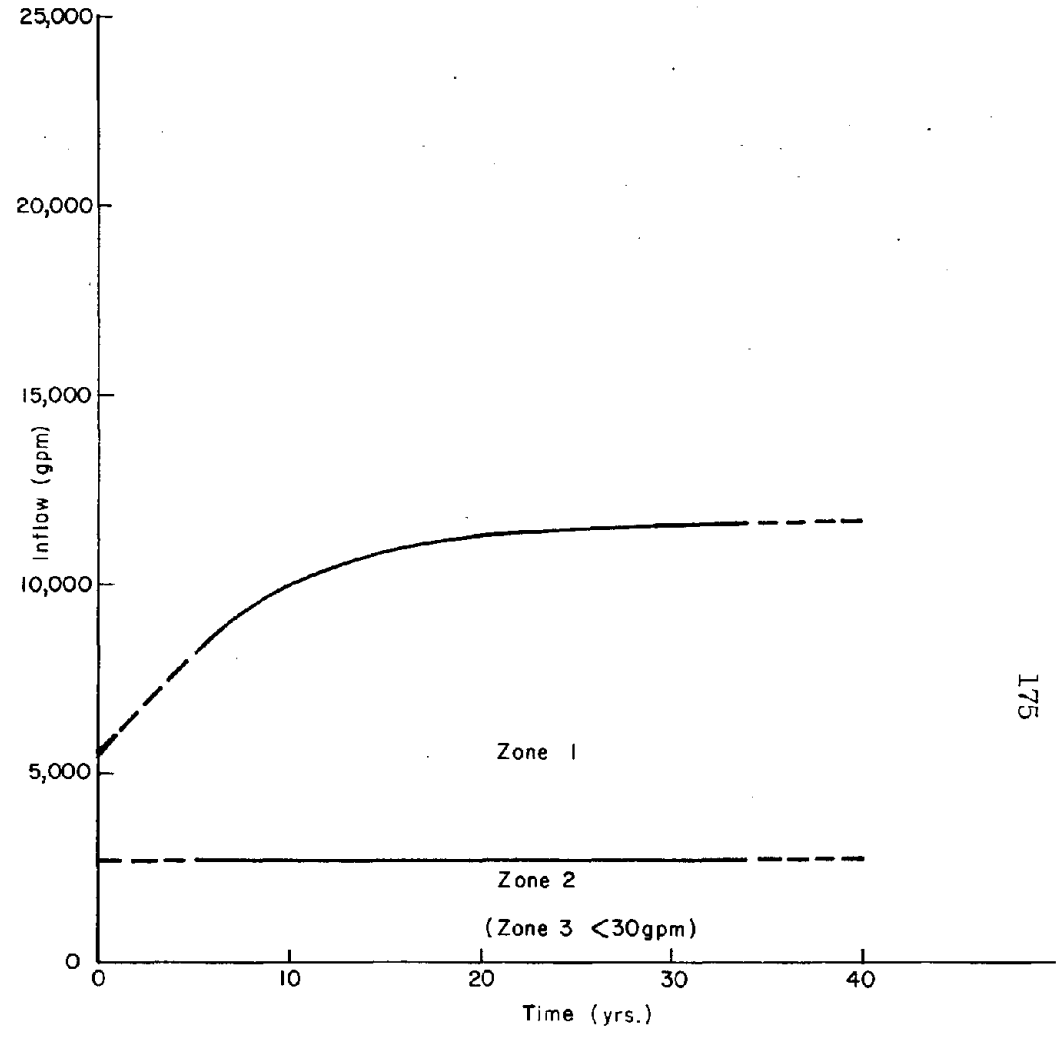
Expansion Rate: .378 mi^2/yr

Initial Radius: 200 ft

Mining Rate: 100,000 ton/day

Figure D-20 MINE INFLOW - SITE 1





Time - yrs.	Radius - ft.	MINE INFLOW (gpm) Zone 1	(drain) Zone 1	Zone 2	Zone 3	Total
5	1113	5256	-	2698	24	7,980
10	1561	7134	-	2693	27	9,850
20	2198	8609	-	2690	29	11,330
30	2688	8890	-	2689	29	11,610

DESCRIPTION:

Mining Method: Room & Pillar, No Subsidence

Number of Passes: 8

Location: R-4 to Mahogany

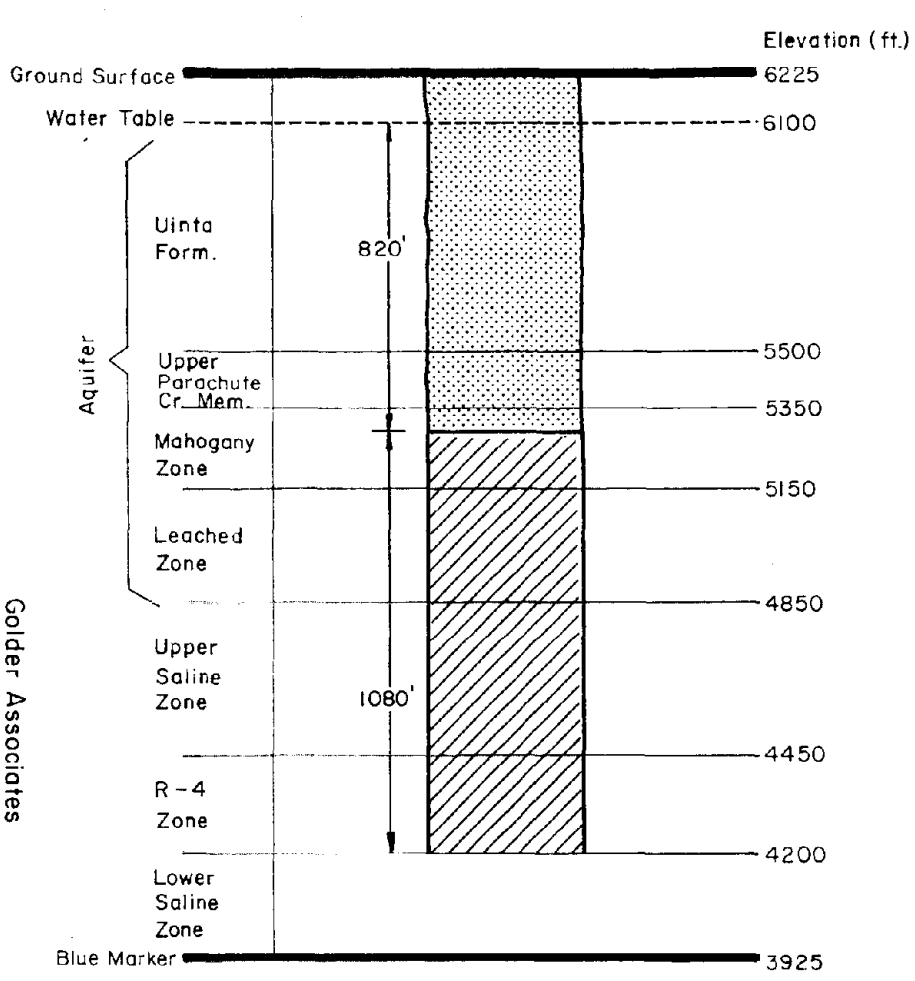
Mining Height: 100 ft, 40 ft sill, total = 1080 ft

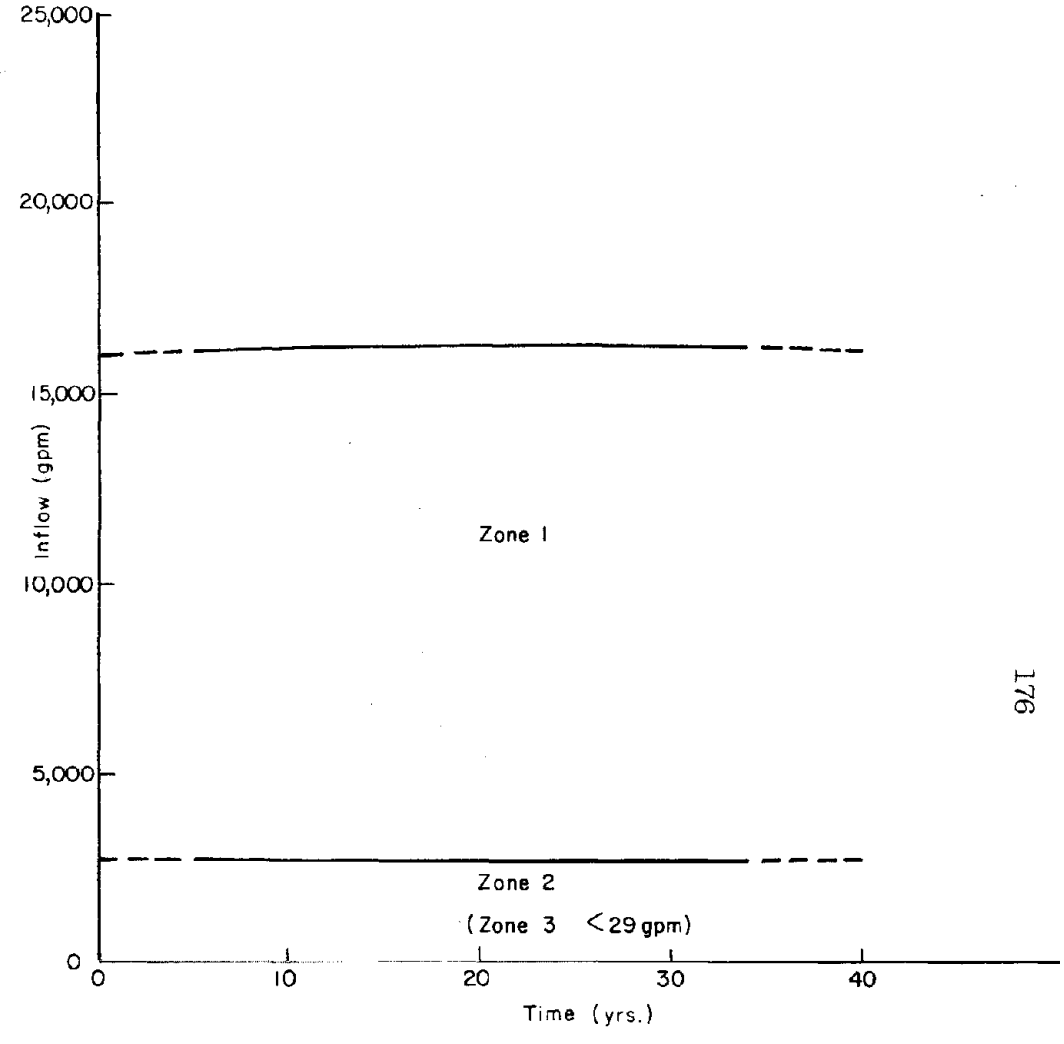
Expansion Rate: .027 mi^2/yr

Initial Radius: 200 ft

Mining Rate: 50,000 ton/day

Figure D-21 MINE INFLOW - SITE 1





MINE INFLOW (gpm)

Time - yrs.	Radius - ft.	Zone 1	(drain) Zone 1	Zone 2	Zone 3	Total
5	1113	12,806	703	2698	24	16,230
10	1561	12,806	703	2693	27	16,230
20	2198	12,806	703	2690	29	16,230
30	2688	12,806	703	2689	29	16,230

DESCRIPTION:

Mining Method: Room & Pillar, Full Subsidence

Number of Passes: 8

Location: R-4 to Mahogany

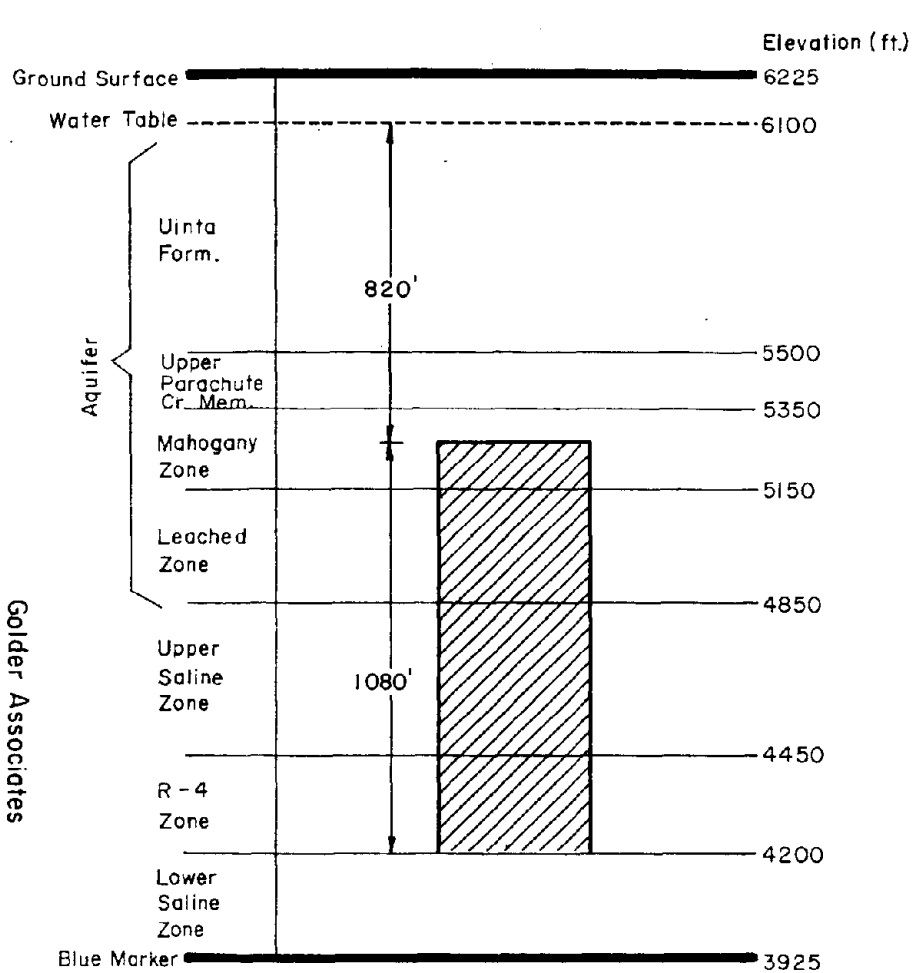
Mining Height: 100 ft, 40 ft sills, total = 1080 ft

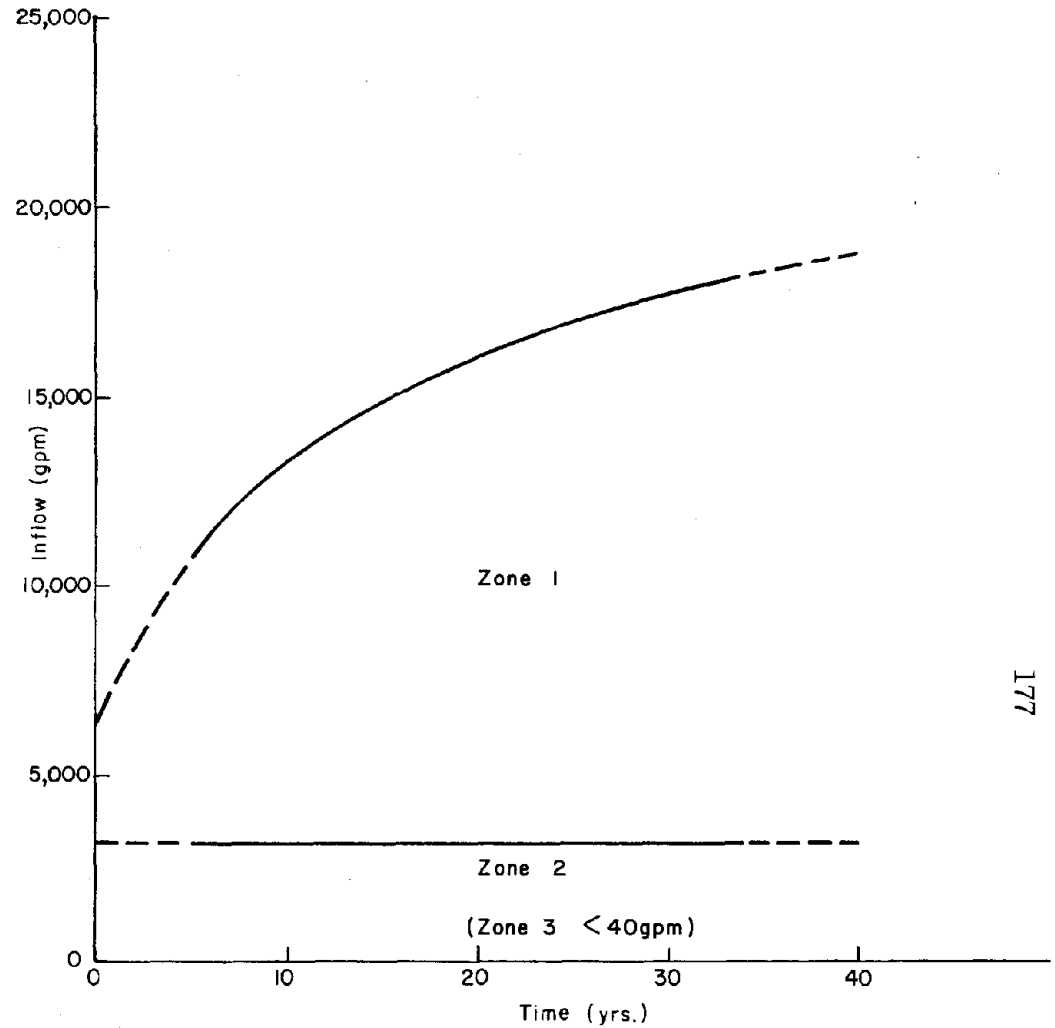
Expansion Rate: .027 mi^2/yr

Initial Radius: 200 ft

Mining Rate: 50,000 ton/day

Figure D-22 MINE INFLOW - SITE I





Time - yrs.	Radius - ft.	MINE INFLOW (gpm) Zone 1	(drain) Zone 1	Zone 2	Zone 3	Total
5	1561	7,547	-	2921	32	10,500
10	2198	10,044	-	2917	34	13,000
20	3102	13,065	-	2916	36	16,020
30	3797	14,681	-	2916	37	17,630

DESCRIPTION:

Mining Method: Room & Pillar, No Subsidence

Number of Passes: 8

Location: R-4 to Mahogany

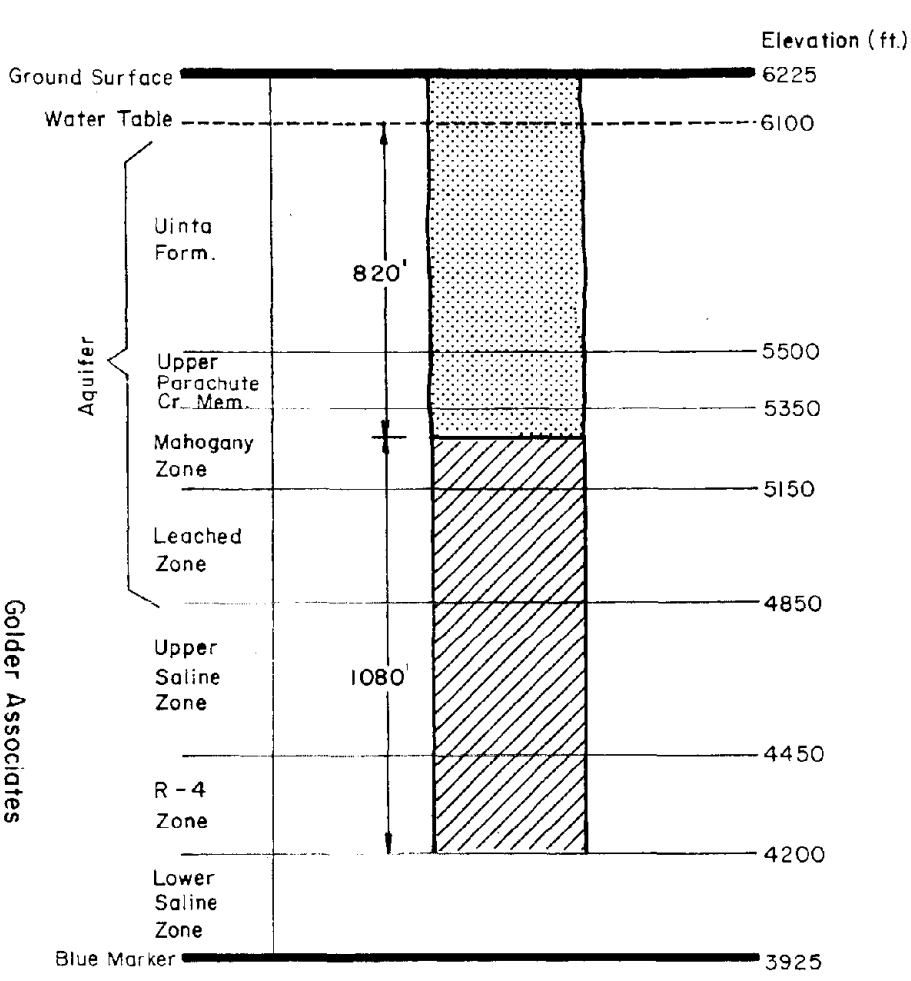
Mining Height: 100 ft, 40 ft sills, total = 1080 ft

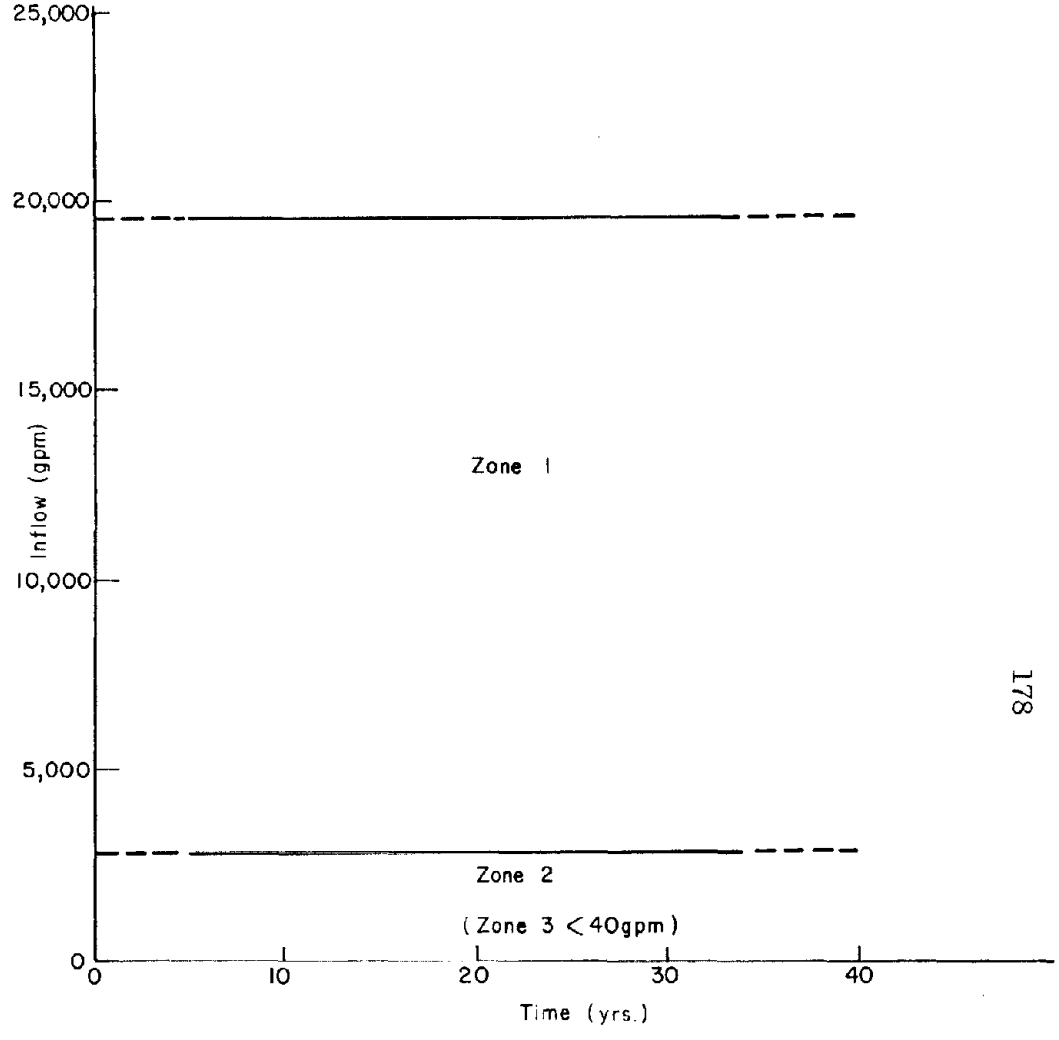
Expansion Rate: .054 mi^2/yr

Initial Radius: 200 ft

Mining Rate: 100,000 ton/day

Figure D-23 MINE INFLOW - SITE I





MINE INFLOW (gpm)

Time - yrs.	Radius - ft.	Zone 1	Zone 1 (drain)	Zone 2	Zone 3	Total
5	1561	15,245	1405	2921	32	19,600
10	2198	15,245	1405	2917	34	19,600
20	3102	15,245	1405	2916	36	19,600
30	3797	15,245	1405	2916	37	19,600

DESCRIPTION:

Mining Method: Room & Pillar, Full Subsidence

Number of Passes: 8

Location: R-4 to Mahogany

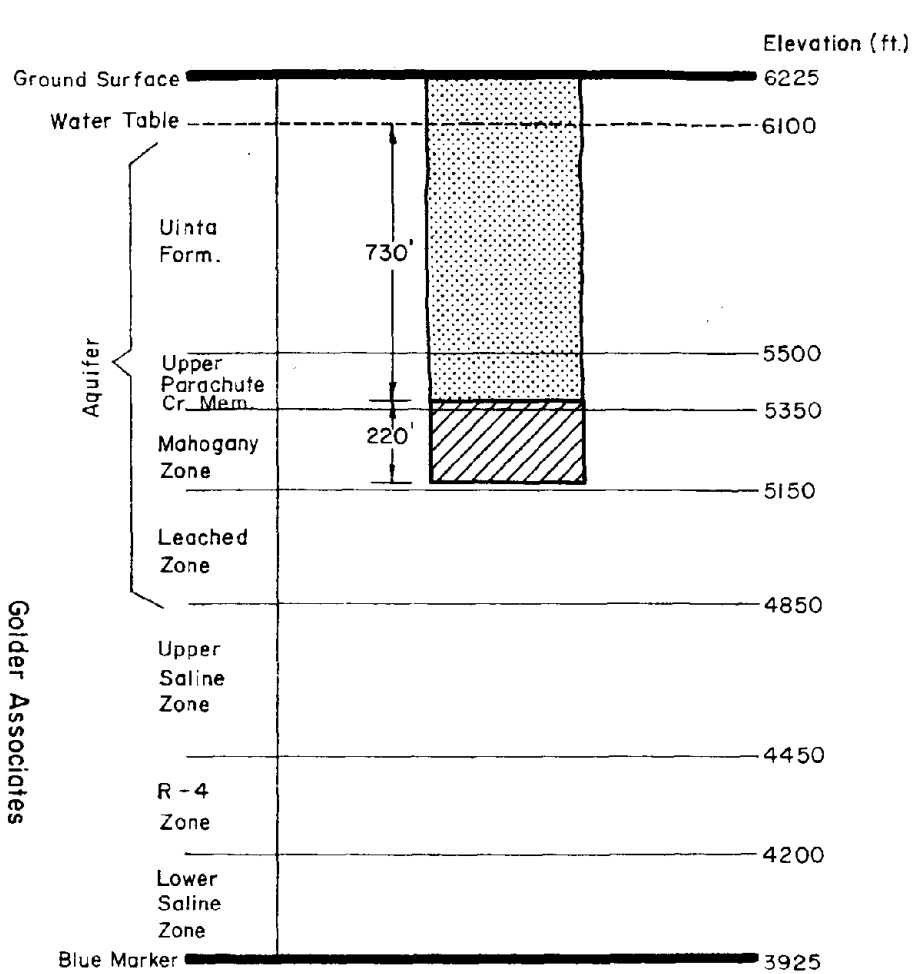
Mining Height: 100 ft, 40 ft sills, total = 1080 ft

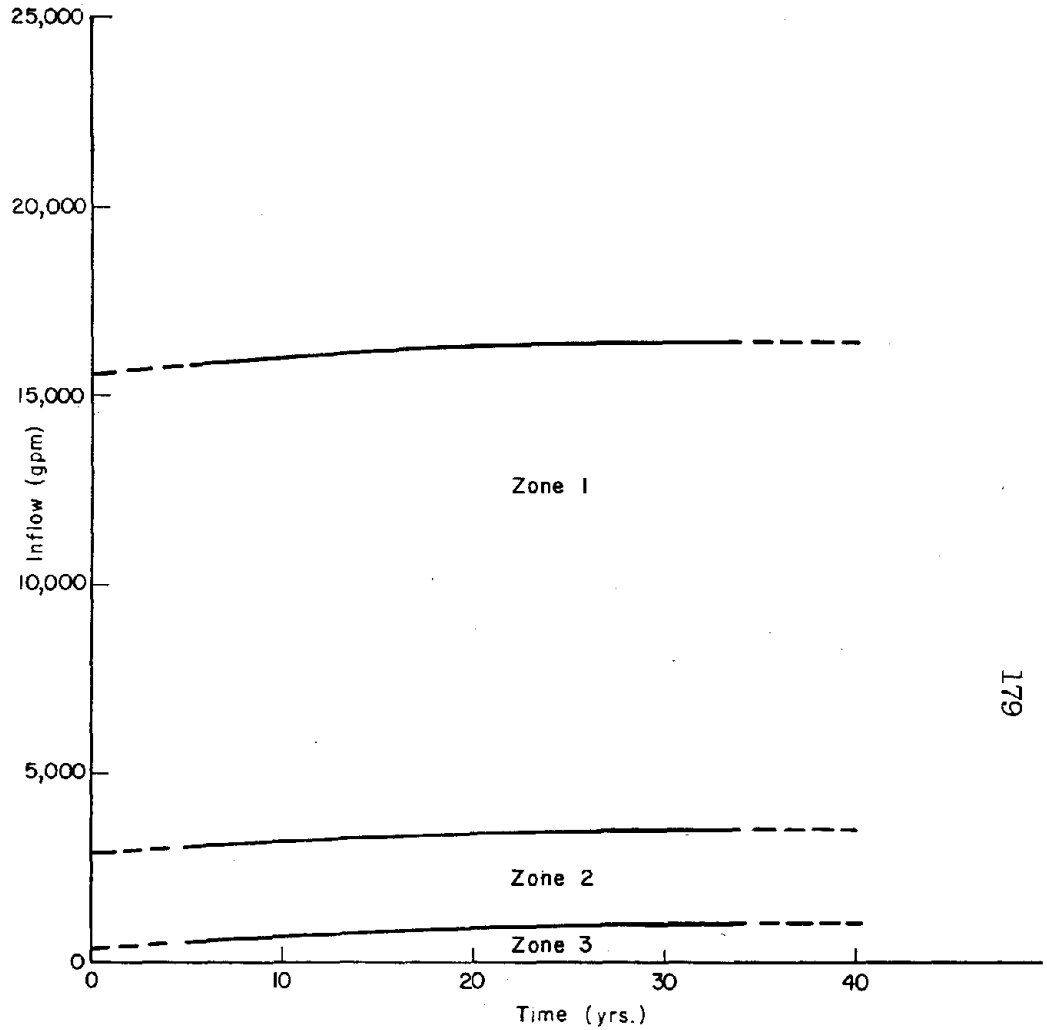
Expansion Rate: .054 mi^2/yr

Initial Radius: 200 ft

Mining Rate: 100,000 ton/day

Figure D-24 MINE INFLOW - SITE I





Time - yrs.	Radius - ft.	MINE INFLOW (gpm) Zone 1 (drain)	Zone 1	Zone 2	Zone 3	Total
5	1427	11,707	1043	2513	521	15,780
10	2008	11,707	1043	2511	755	16,020
20	2833	11,707	1043	2510	978	16,240
30	3467	11,707	1043	2509	1086	16,350

DESCRIPTION:

Mining Method: Sublevel Stoping, Full Subsidence

Number of Passes: 1

Location: Mahogany

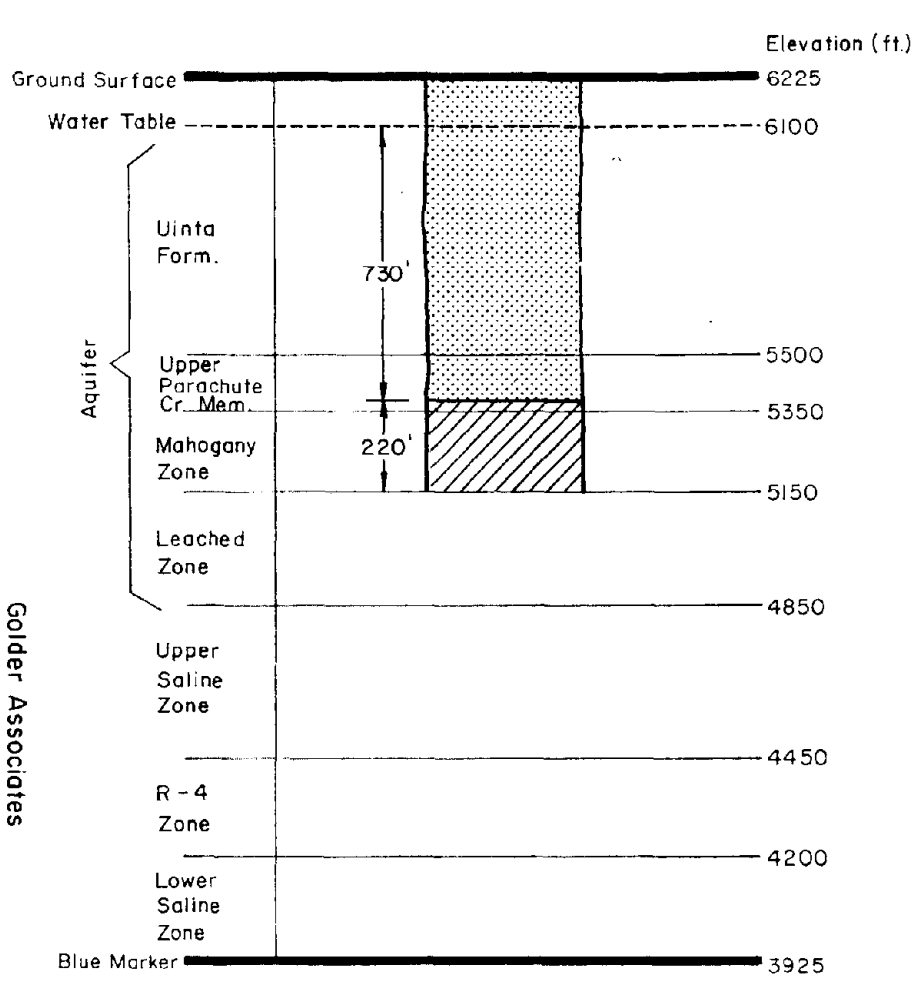
Mining Height: 220 ft

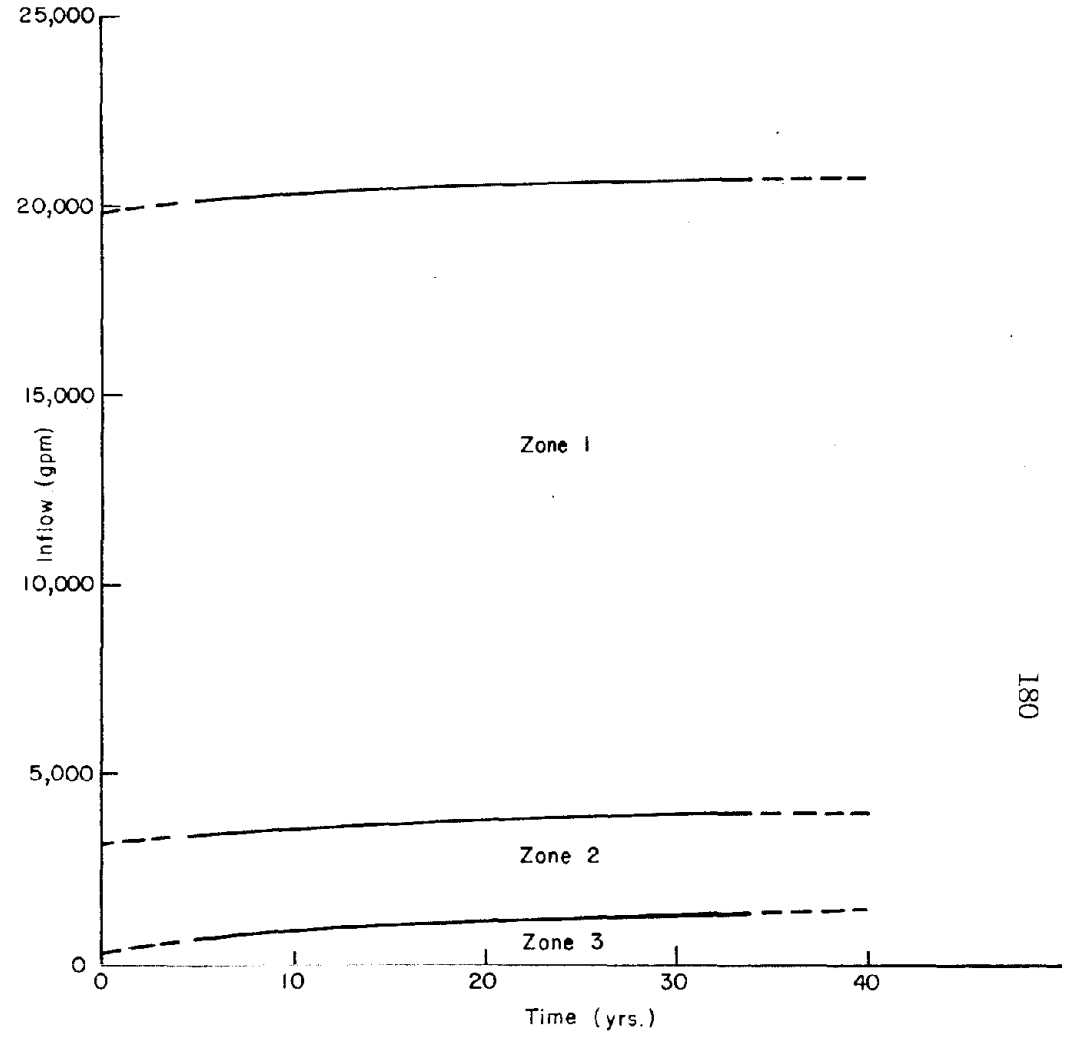
Expansion Rate: .045 mi^2/yr

Initial Radius: 200 ft

Mining Rate: 50,000 ton/day

Figure D-25 MINE INFLOW - SITE I





Time - yrs.	Radius - ft.	MINE INFLOW (gpm) Zone 1	(drain) Zone 1	Zone 2	Zone 3	Total
5	2008	14,543	2085	2707	791	20,130
10	2833	14,543	2085	2705	1039	20,370
20	4002	14,543	2085	2704	1234	20,570
30	4899	14,543	2085	2704	1317	20,650

DESCRIPTION:

Mining Method: Sublevel Stoping, Full Subsidence

Number of Passes: 1

Location: Mahogany

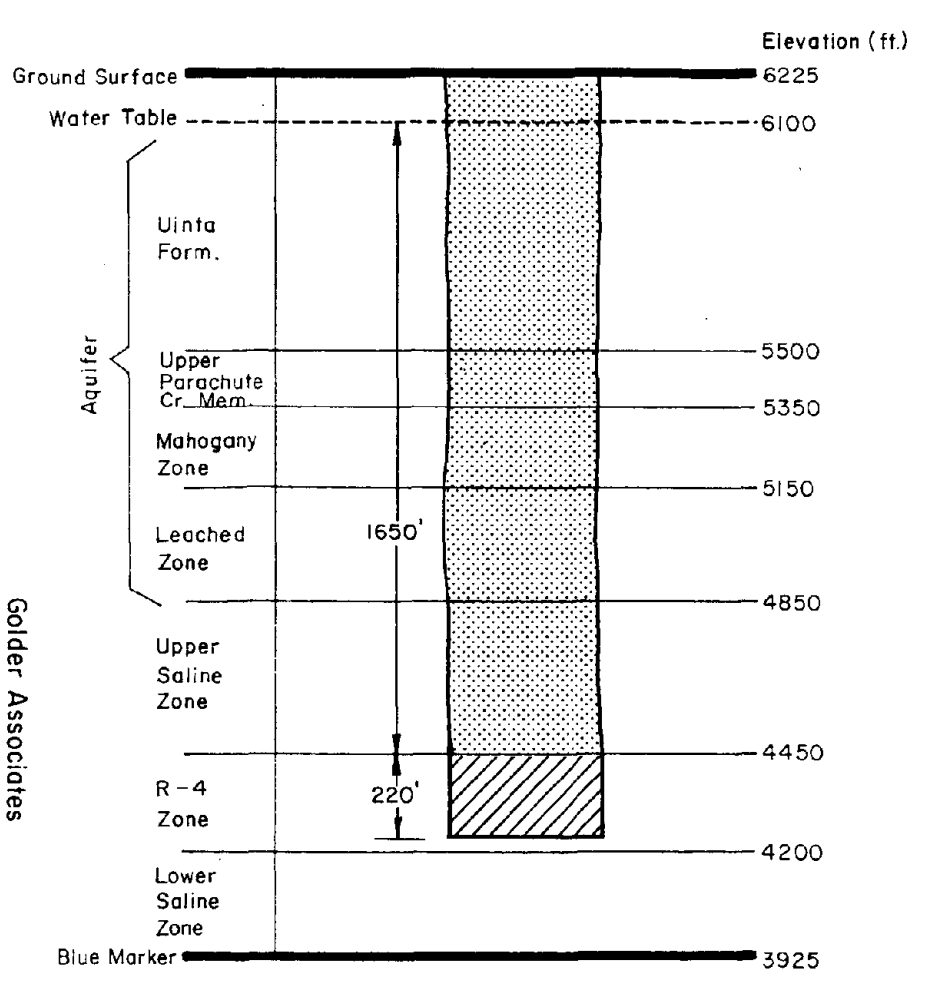
Mining Height: 220 ft

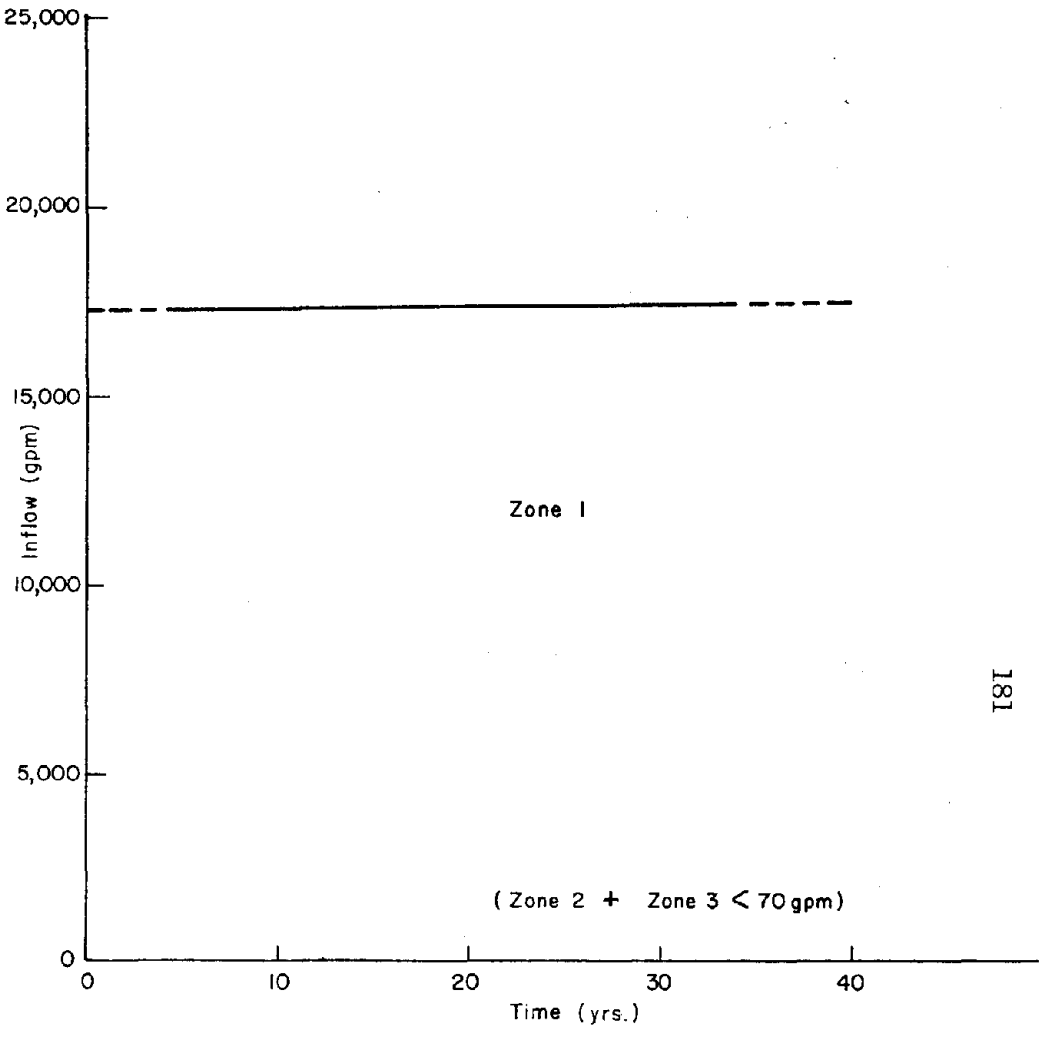
Expansion Rate: .090 mi^2/yr

Initial Radius: 200 ft

Mining Rate: 100,000 ton/day

Figure D-26 MINE INFLOW - SITE I





Time - yrs.	Radius - ft.	MINE INFLOW (gpm) Zone 1	Zone 1 (drain)	Zone 2	Zone 3	Total
5	1427	15,718	1473	25	31	17,250
10	2008	15,718	1473	25	35	17,250
20	2833	15,718	1473	25	37	17,250
30	3467	15,718	1473	25	38	17,250

DESCRIPTION:

Mining Method: Sublevel Stoping, Full Subsidence

Number of Passes: 1

Location: R-4

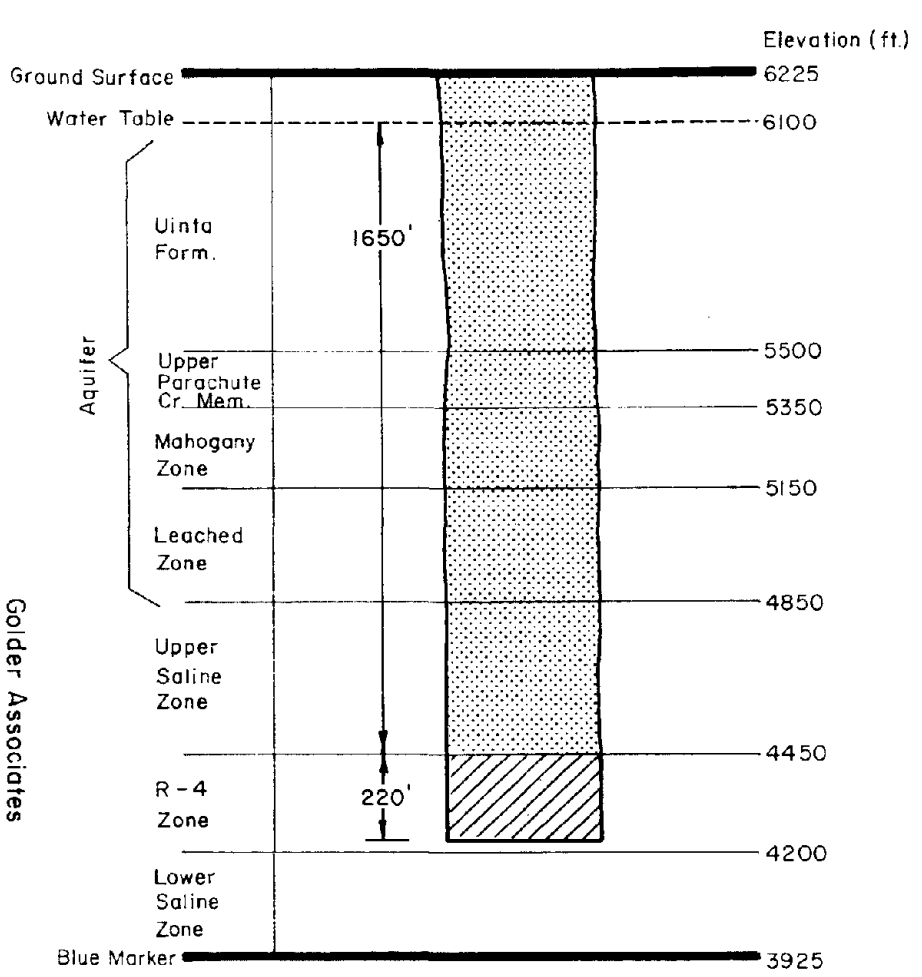
Mining Height: 220 ft

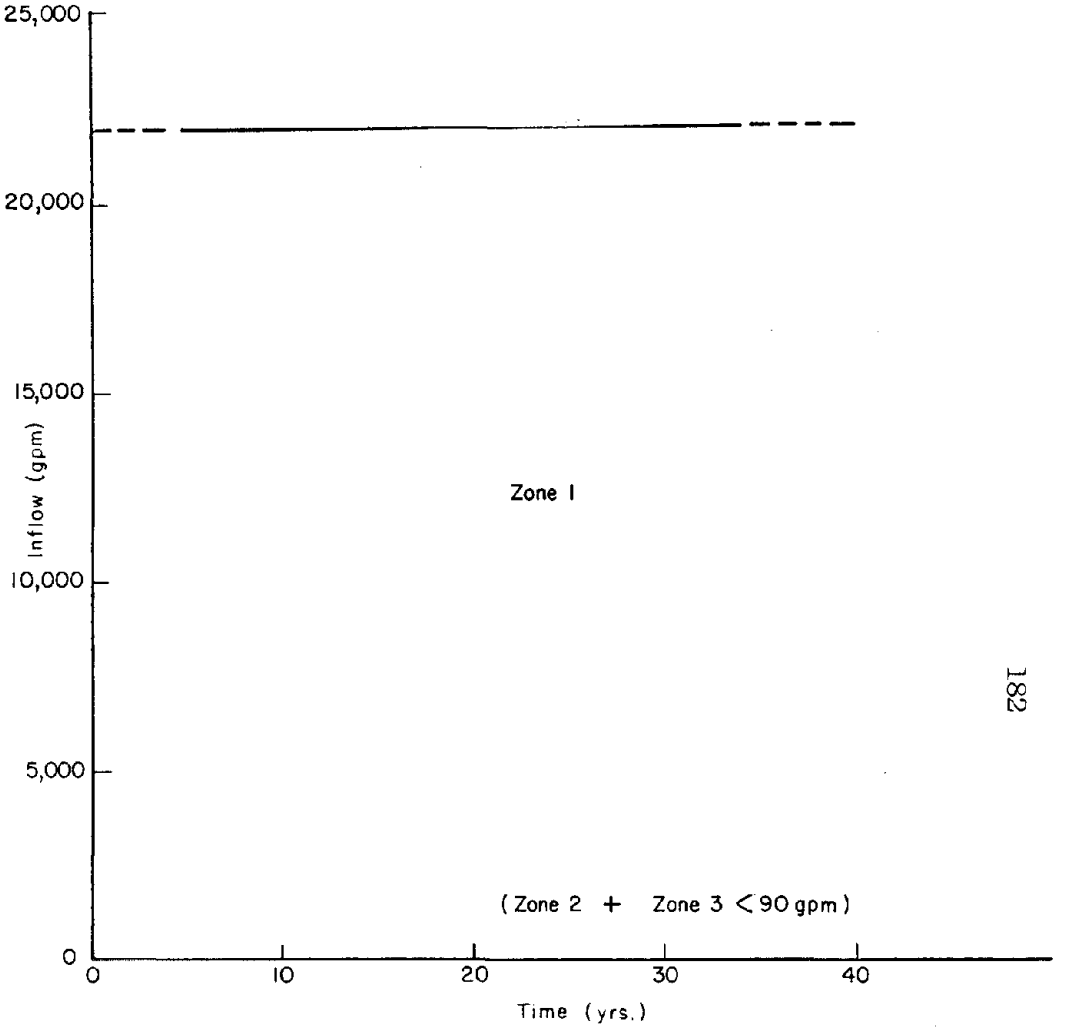
Expansion Rate: 0.045 mi^2/yr

Initial Radius: 200 ft

Mining Rate: 50,000 ton/day

Figure D-27 MINE INFLOW - SITE 1





Time - yrs.	Radius - ft.	MINE INFLOW (gpm) Zone 1	(drain) Zone 1	Zone 2	Zone 3	Total
5	2008	18,893	2946	32	43	21,910
10	2833	18,893	2946	32	47	21,920
20	4002	18,893	2946	32	49	21,920
30	4899	18,893	2946	32	49	21,920

DESCRIPTION:

Mining Method: Sublevel Stoping, Full Subsidence

Number of Passes: 1

Location: R-4

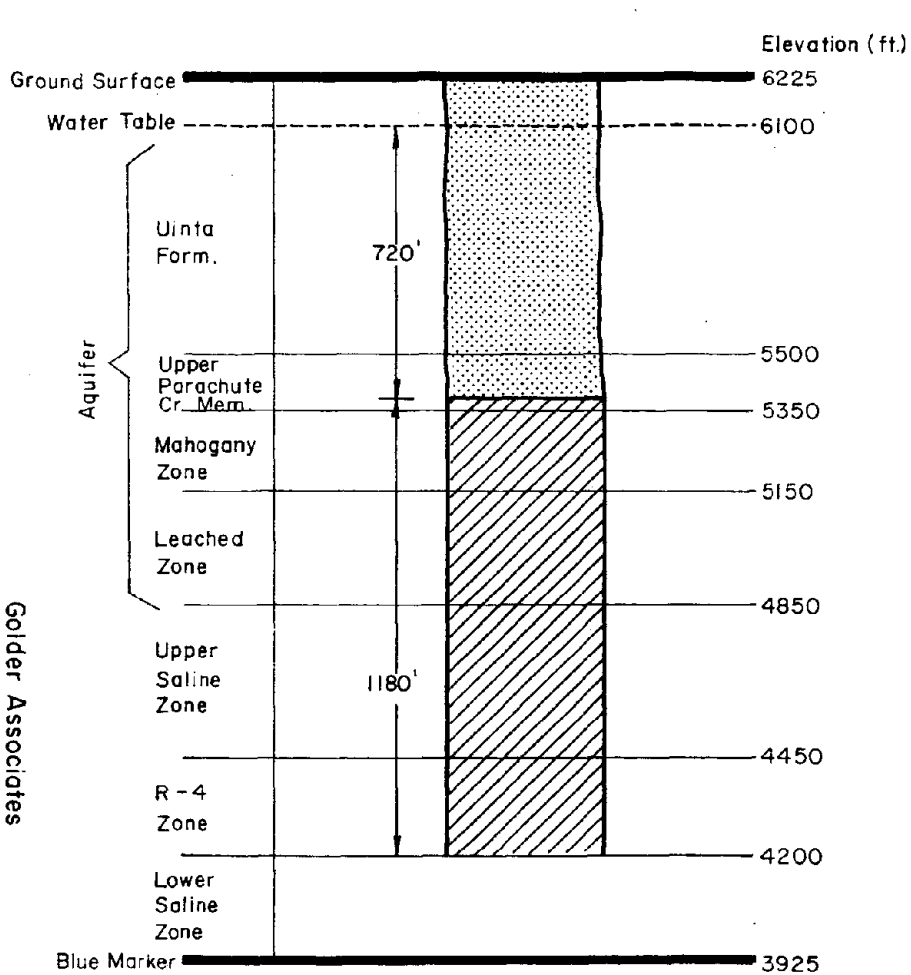
Mining Height: 220 ft

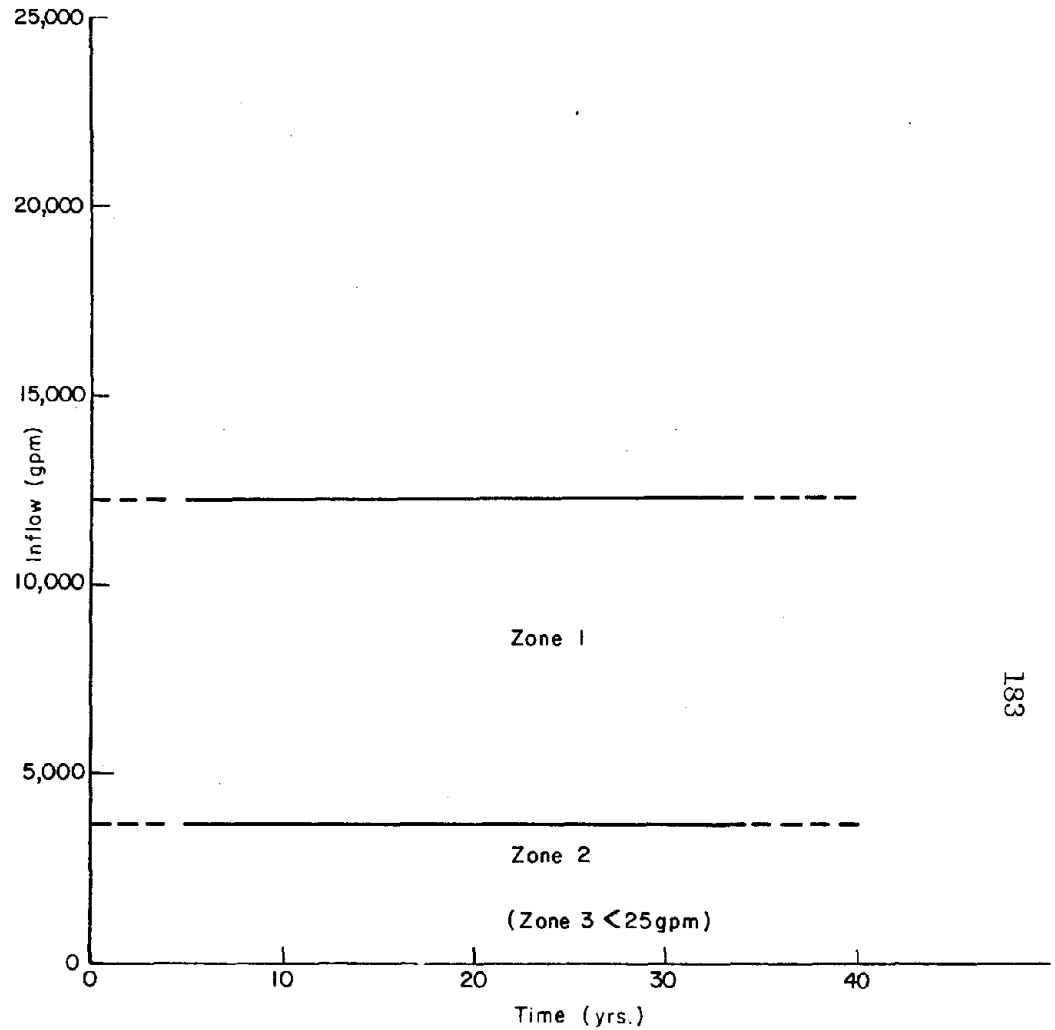
Expansion Rate: .090 mi^2/yr

Initial Radius: 200 ft

Mining Rate: 100,000 ton/day

Figure D-28 MINE INFLOW - SITE 1





Time - yrs.	Radius - ft.	MINE INFLOW (gpm) Zone 1	(drain) Zone 1	Zone 2	Zone 3	Total
5	727	8290	283	3736	15	12,320
10	1008	8290	283	3723	20	12,320
20	1411	8290	283	3715	22	12,310
30	1723	8290	283	3713	23	12,310

DESCRIPTION:

Mining Method: Sublevel Stoping, Full Subsidence

Number of Passes: 4

Location: R-4 to Mahogany

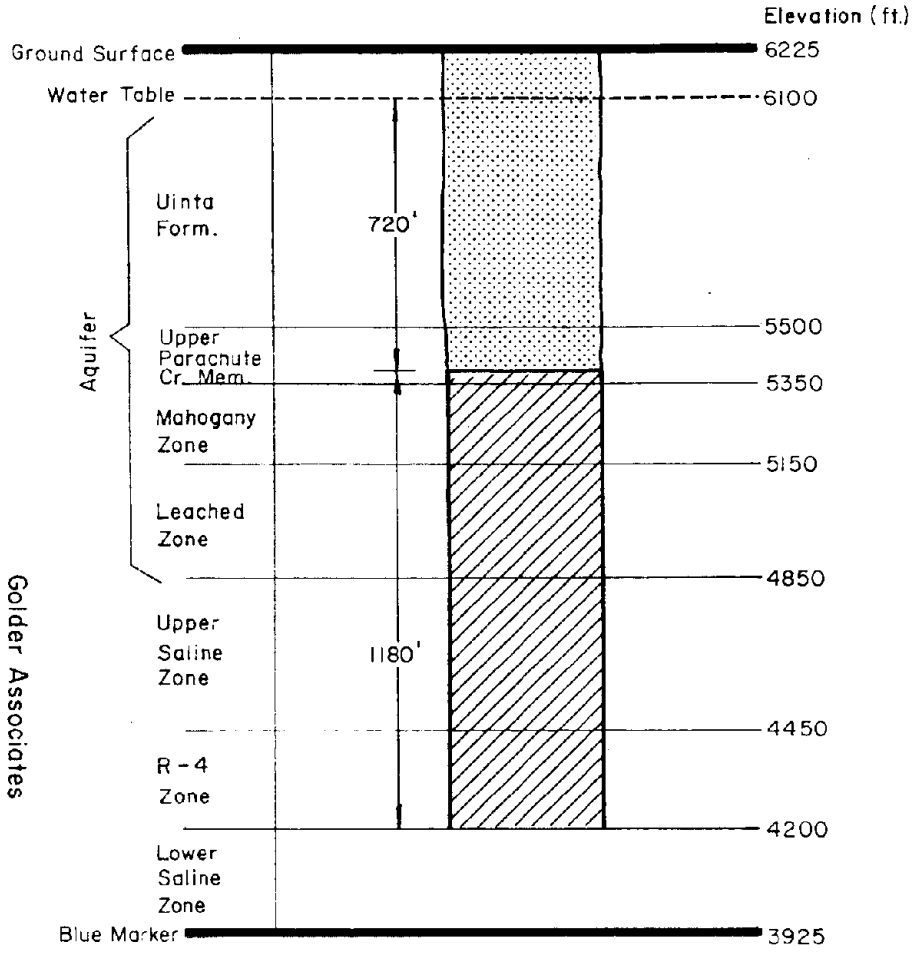
Mining Height: 220 ft, 100 ft sills, total = 1180 ft

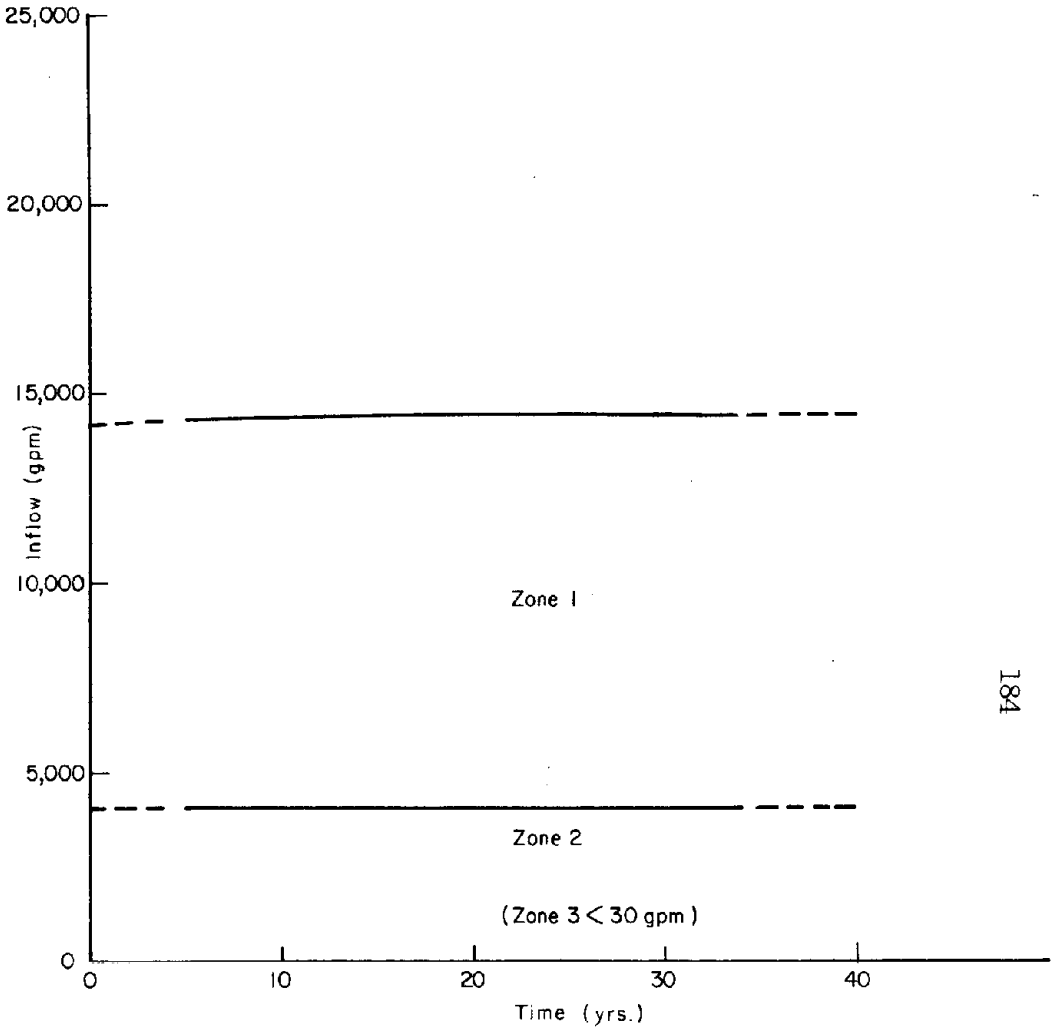
Expansion Rate: .011 mi^2/yr

Initial Radius: 200 ft

Mining Rate: 50,000 ton/day

Figure D-29 MINE INFLOW - SITE 1





MINE INFLOW (gpm)

Time - yrs.	Radius - ft.	Zone 1	(drain) Zone 1	Zone 2	Zone 3	Total
5	1030	9708	591	4008	22	14,330
10	1443	9708	591	4000	25	14,320
20	2030	9708	591	3996	27	14,320
30	2483	9708	591	3995	28	14,320

DESCRIPTION:

Mining Method: Sublevel Stoping, Full Subsidence

Number of Passes: 4

Location: R-4 to Mahogany

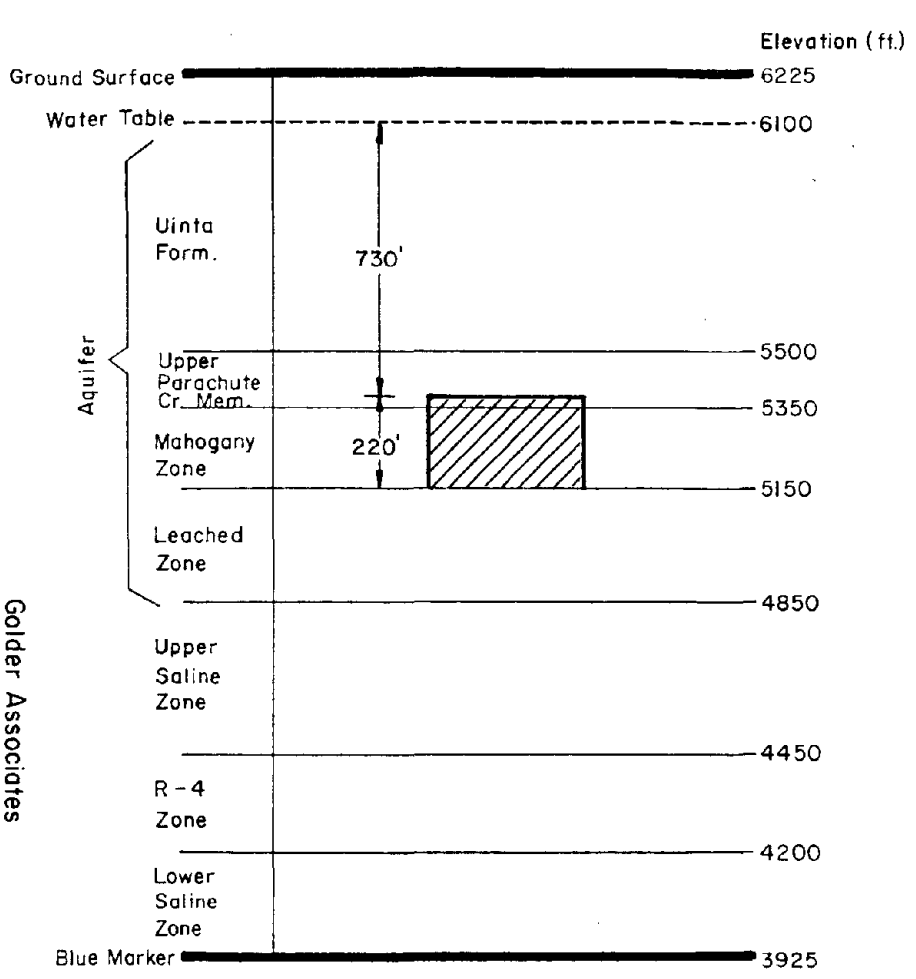
Mining Height: 220 ft, 100 ft sills, total = 1180 ft

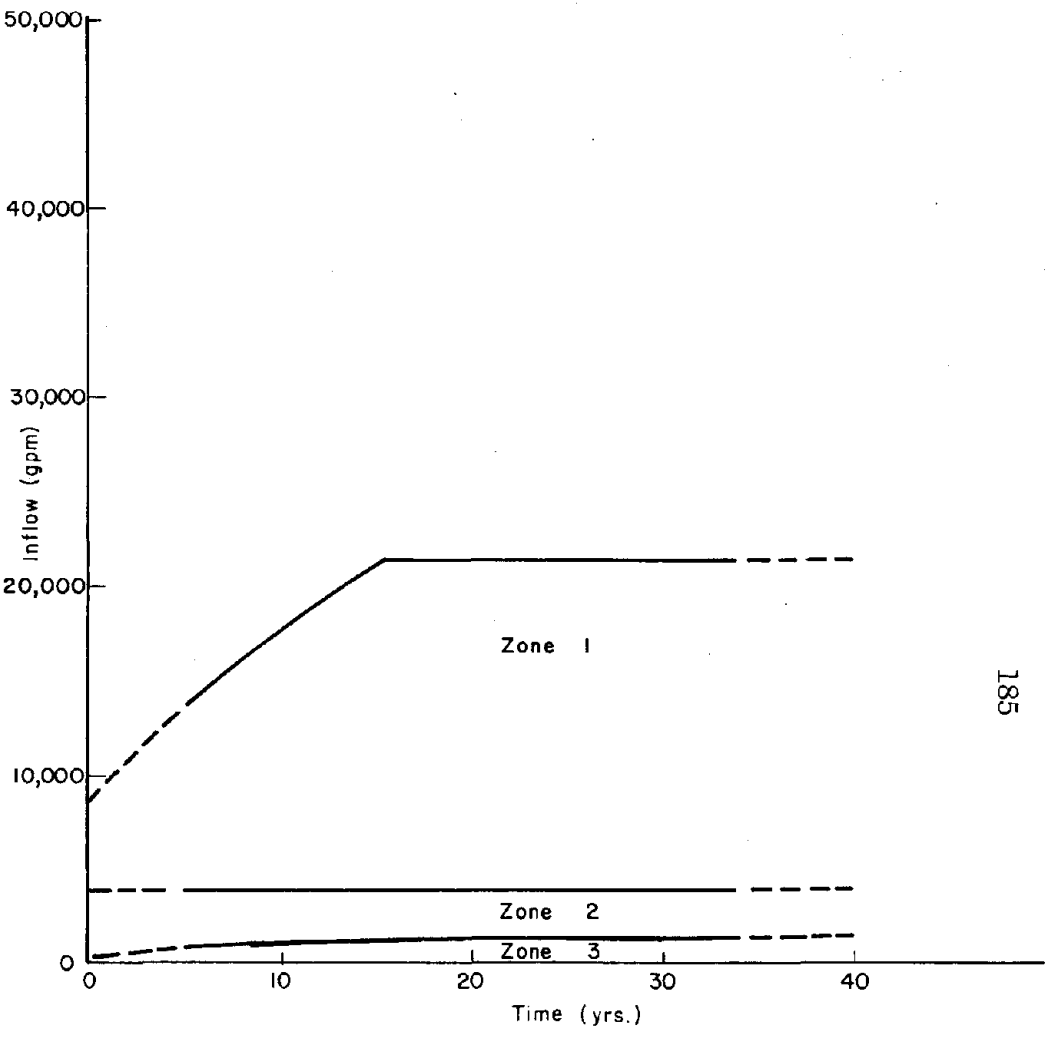
Expansion Rate: .023 mi^2/yr

Initial Radius: 200 ft

Mining Rate: 100,000 ton/day

Figure D-30 MINE INFLOW - SITE I





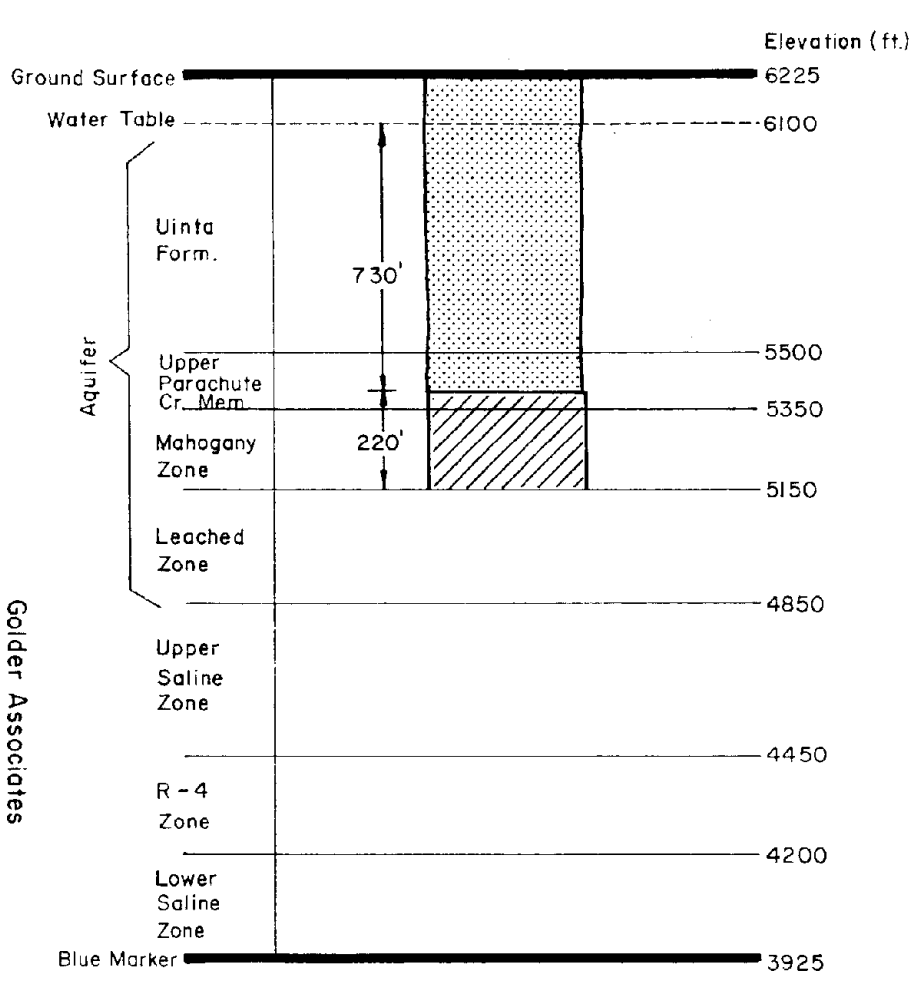
Golder Associates

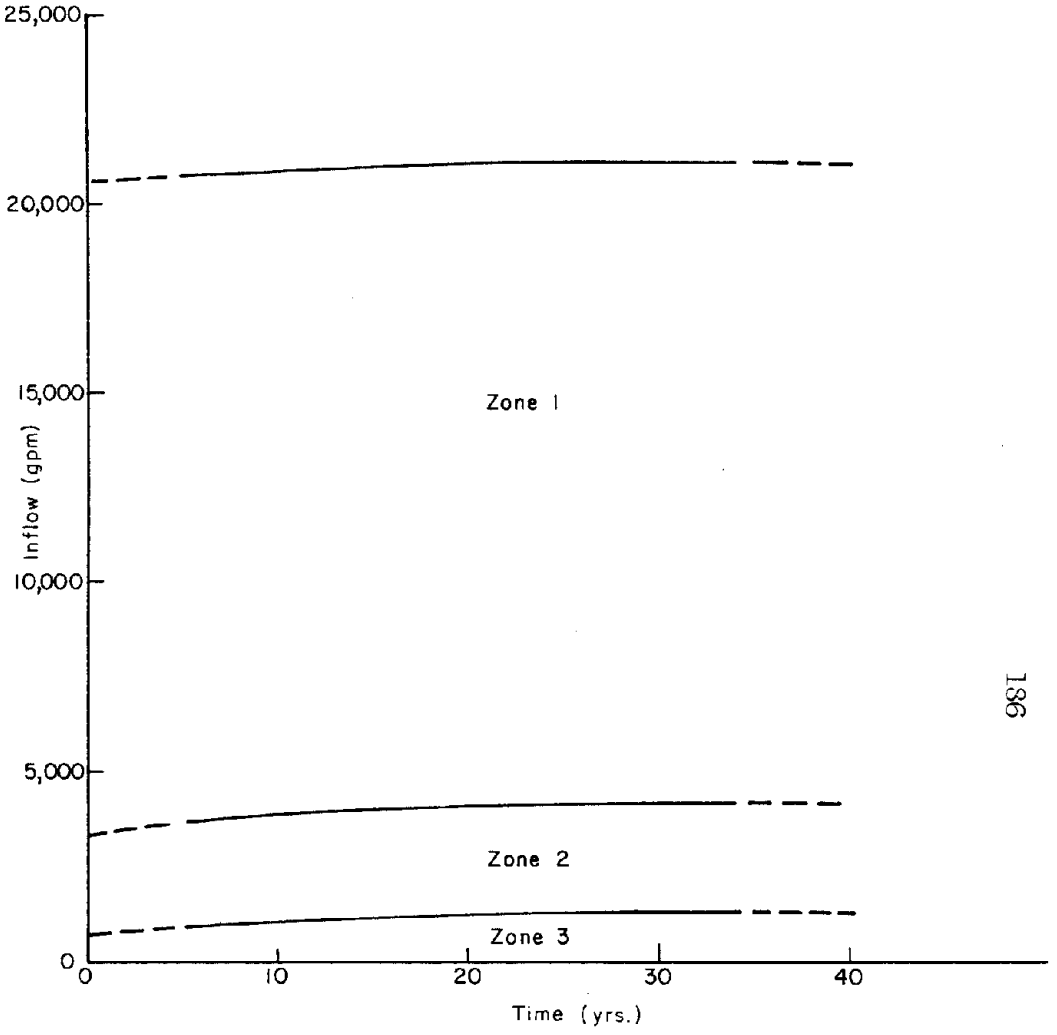
185

Time - yrs.	Radius - ft.	MINE INFLOW (gpm) Zone 1	(drain) Zone 1	Zone 2	Zone 3	Total
5	2063	9,584	-	2876	815	13,280
10	2910	13,266	-	2874	1062	17,200
20	4111	16,946	-	2874	1254	21,070
30	5033	16,946	-	2873	1335	21,150

DESCRIPTION:
Mining Method: Sublevel Stoping With Backfill, No Subsidence
Number of Passes: 1
Location: Mahogany
Mining Height: 220 ft
Expansion Rate: .095 mi^2/yr
Initial Radius: 200 ft
Mining Rate: 50,000 ton/day

Figure D-31 MINE INFLOW - SITE 1





Time - yrs.	Radius - ft.	MINE INFLOW (gpm) Zone 1	(drain) Zone 1	Zone 2	Zone 3	Total
5	2063	14,745	2201	2876	815	20,640
10	2910	14,745	2201	2874	1062	20,880
20	4111	14,745	2201	2874	1254	21,070
30	5033	14,745	2201	2873	1335	21,150

DESCRIPTION: Sublevel Stoping With Backfill,

Mining Method: Full Subsidence

Number of Passes: 1

Location: Mahogany

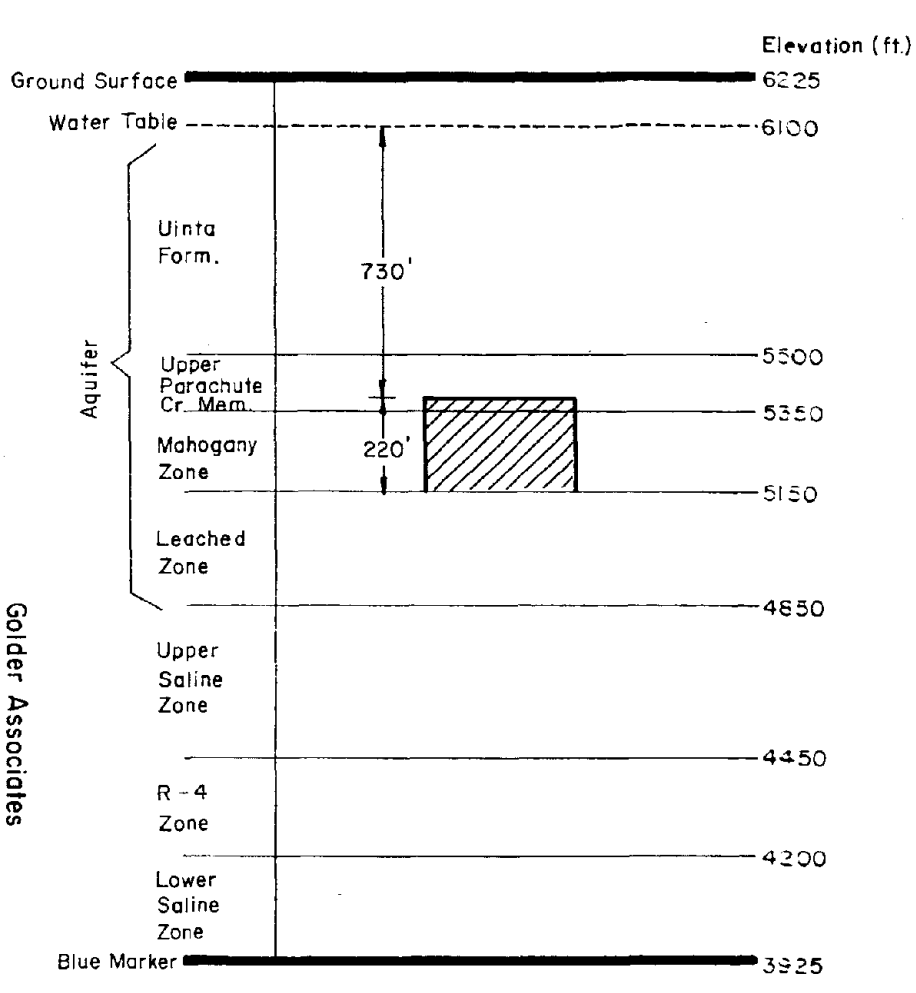
Mining Height: 220 ft

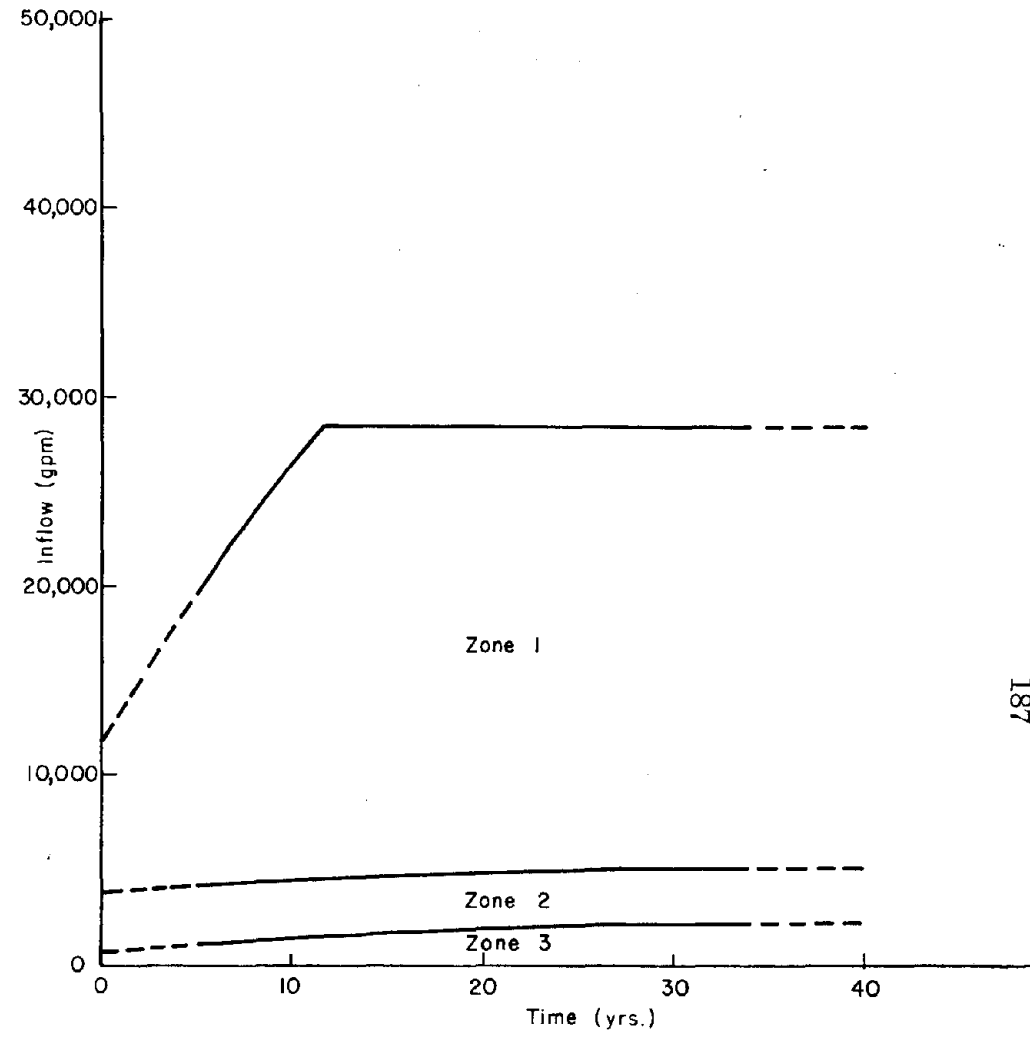
Expansion Rate: .095 mi^2/yr

Initial Radius: 200 ft

Mining Rate: 50,000 ton/day

Figure D-32 MINE INFLOW - SITE I





Time - yrs.	Radius - ft.	MINE INFLOW (gpm) Zone 1	(drain) Zone 1	Zone 2	Zone 3	Total
5	2918	14,590	-	3037	1137	18,760
10	4122	21,627	-	3037	1359	26,020
20	5826	23,620	-	3036	1507	28,160
30	7134	23,620	-	3036	1564	28,220

DESCRIPTION: Sublevel Stoping With Backfill, No Subsidence

Mining Method: No Subsidence

Number of Passes: 1

Location: Mahogany

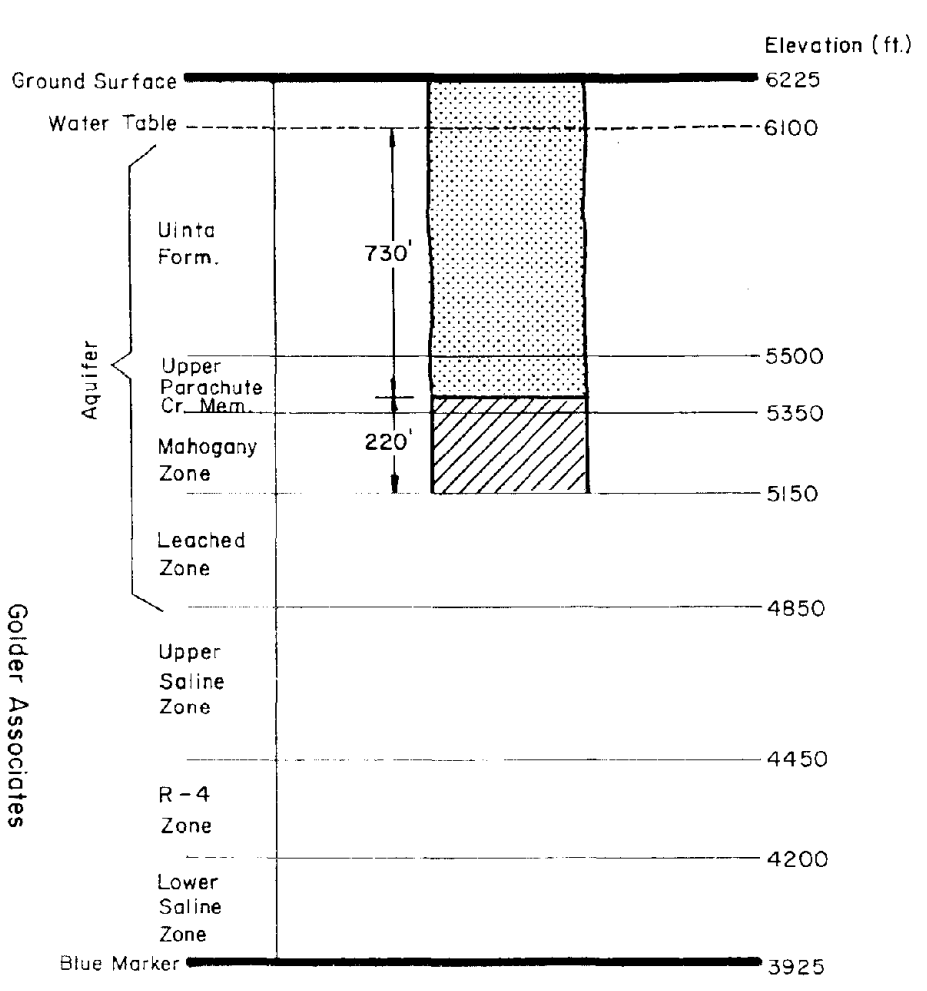
Mining Height: 220

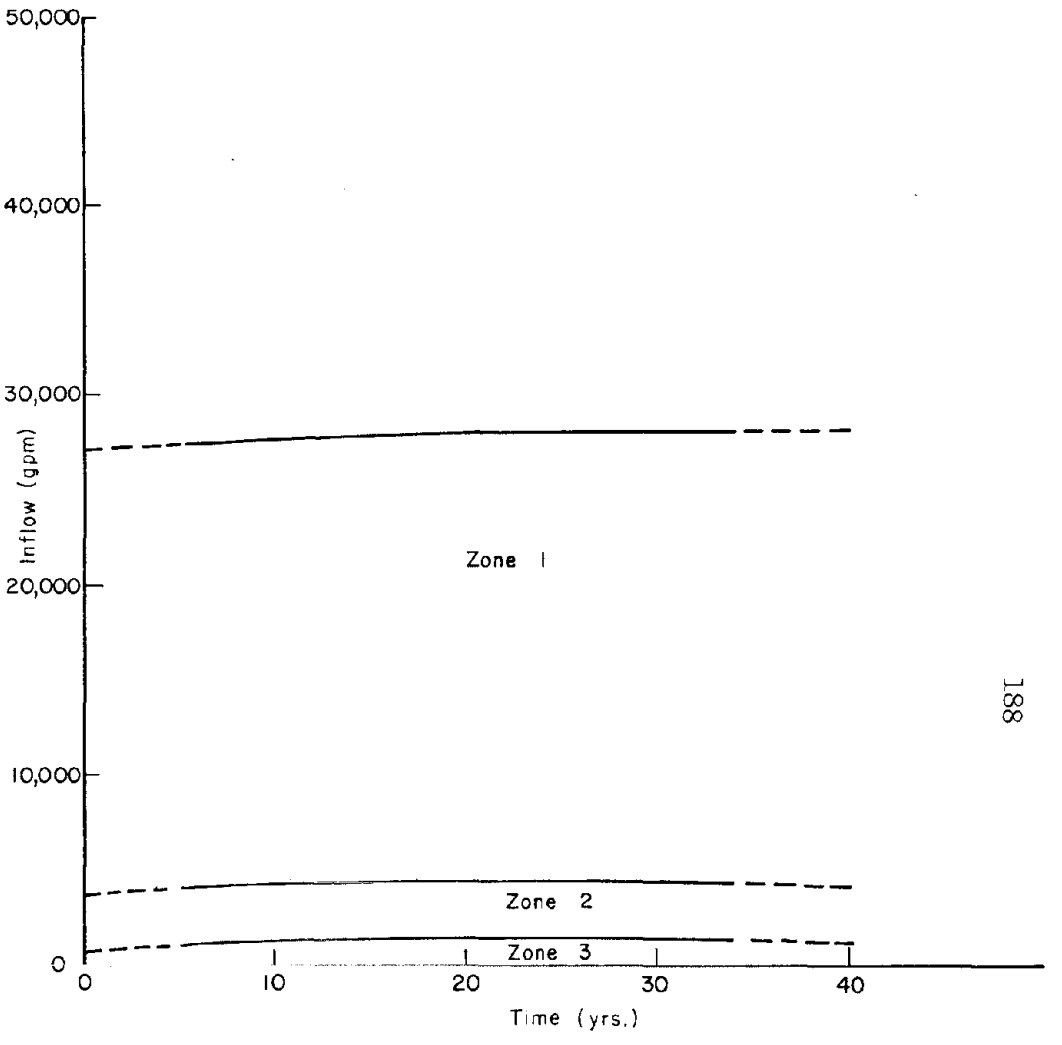
Expansion Rate: .191 mi^2/yr

Initial Radius: 200 ft

Mining Rate: 100,000 ton/day

Figure D-33 MINE INFLOW - SITE 1





Time - yrs.	Radius - ft.	MINE INFLOW (gpm) Zone 1	(drain) Zone 1	Zone 2	Zone 3	Total
5	2918	19,195	4425	3037	1137	27,790
10	4122	19,195	4425	3037	1359	28,020
20	5826	19,195	4425	3036	1507	28,160
30	7134	19,195	4425	3036	1564	28,220

DESCRIPTION: Sublevel Stoping With Backfill, Full Subsidence

Mining Method

Number of Passes 1

Location Mahogany

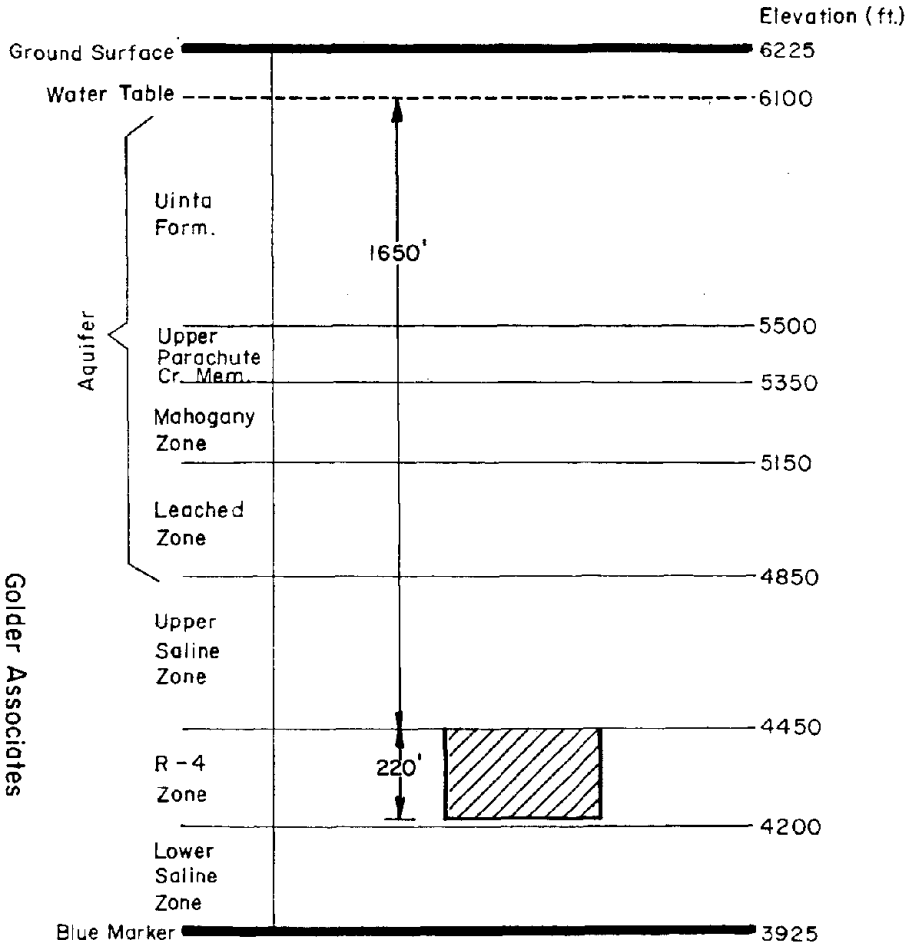
Mining Height 220 ft

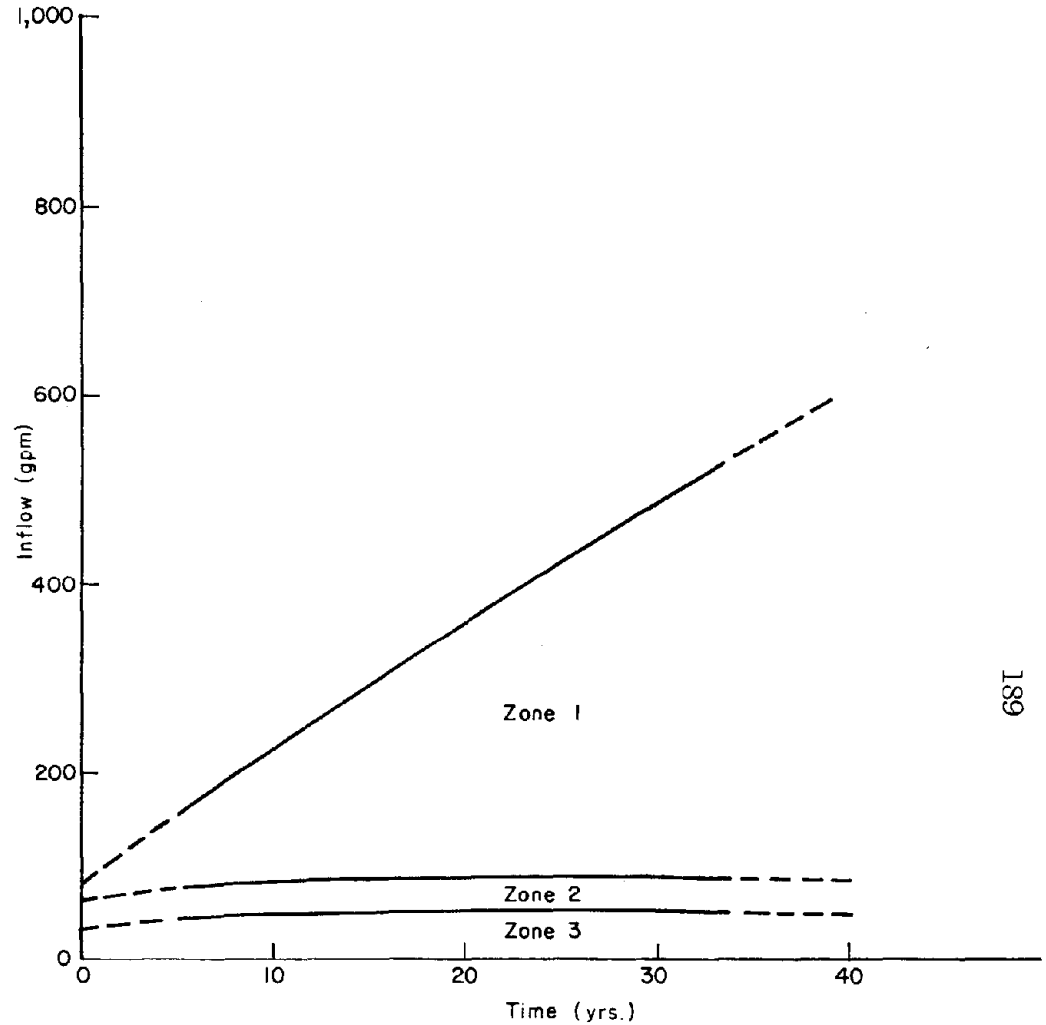
Expansion Rate .191 mi^2/yr

Initial Radius 200 ft

Mining Rate 100,000 ton/day

Figure D-34 MINE INFLOW – SITE 1





Time - yrs.	Radius - ft.	MINE INFLOW (gpm) Zone 1	(drain) Zone 1	Zone 2	Zone 3	Total
5	2063	65	-	33	45	140
10	2910	130	-	33	49	210
20	4111	259	-	33	51	340
30	5033	388	-	33	51	470

DESCRIPTION: Sublevel Stoping With Backfill, No Subsidence

Mining Method

Number of Passes 1

Location R-4

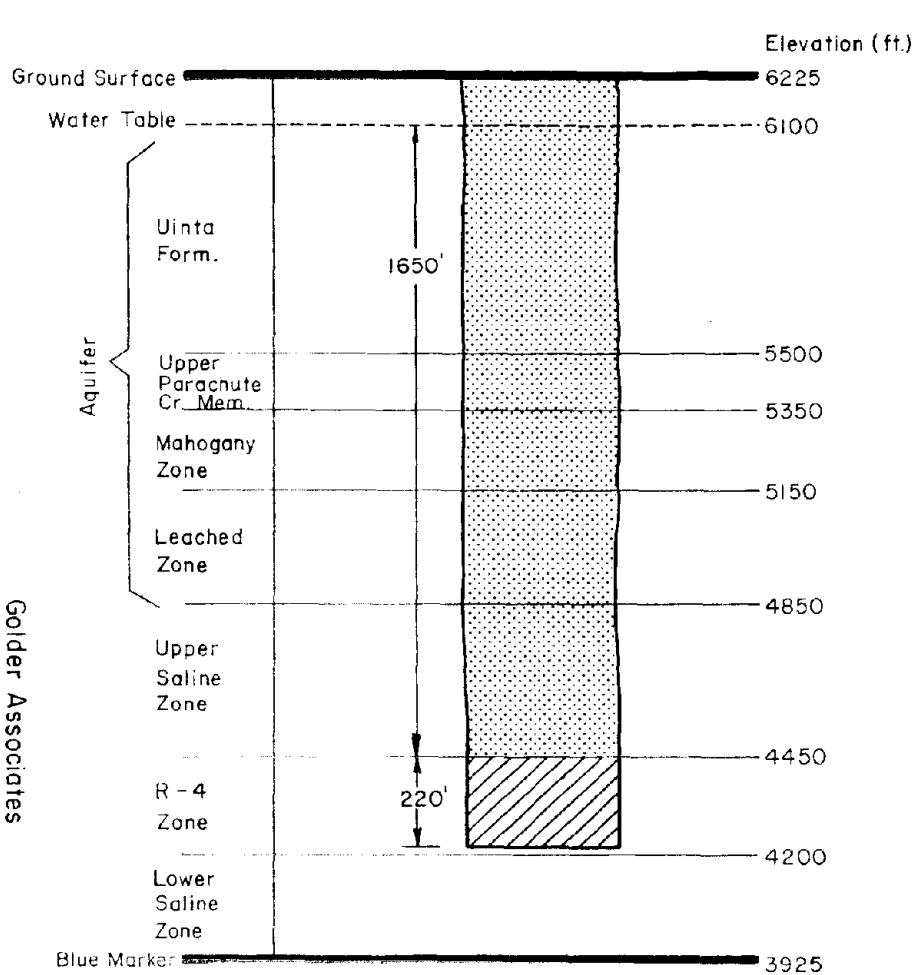
Mining Height 220 ft

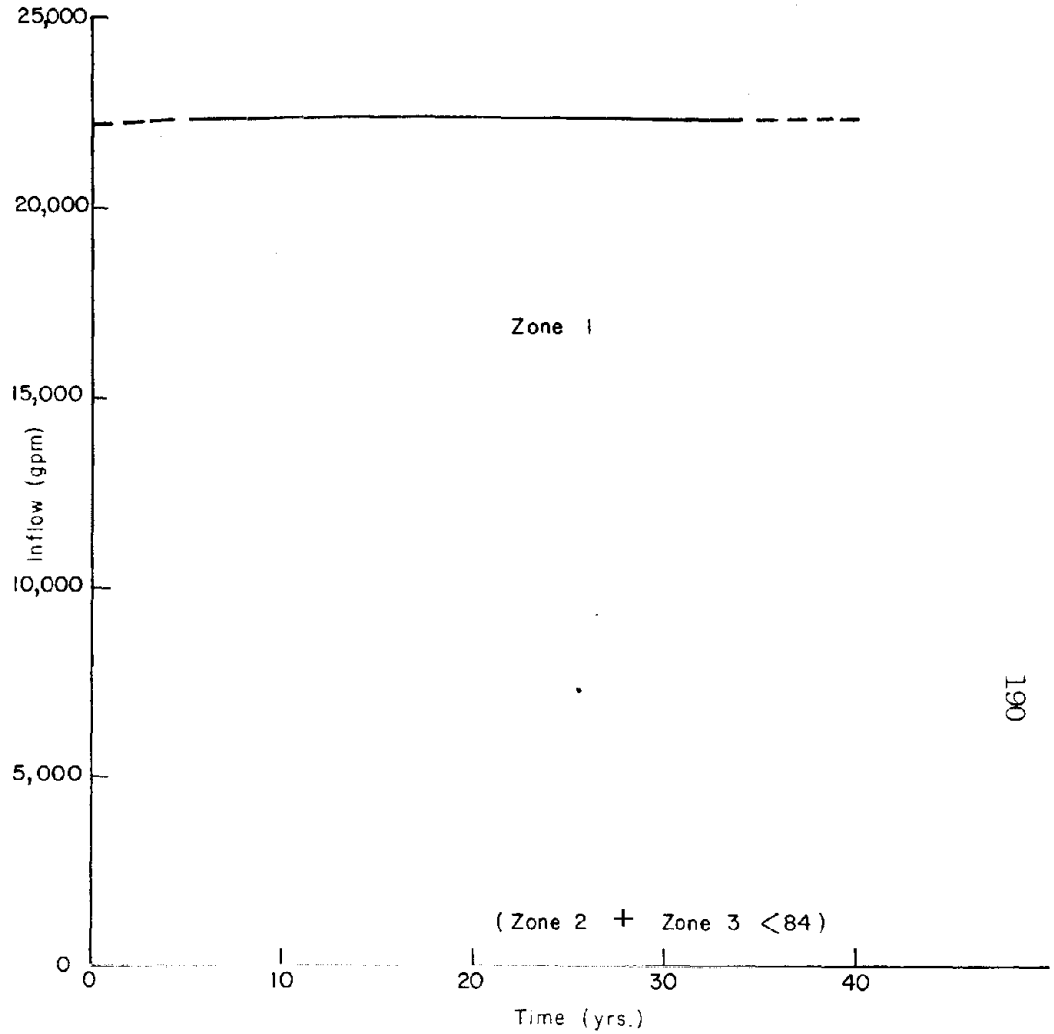
Expansion Rate .095 mi^2/yr

Initial Radius 200 ft

Mining Rate 50,000 ton/day

Figure D-35 MINE INFLOW - SITE I

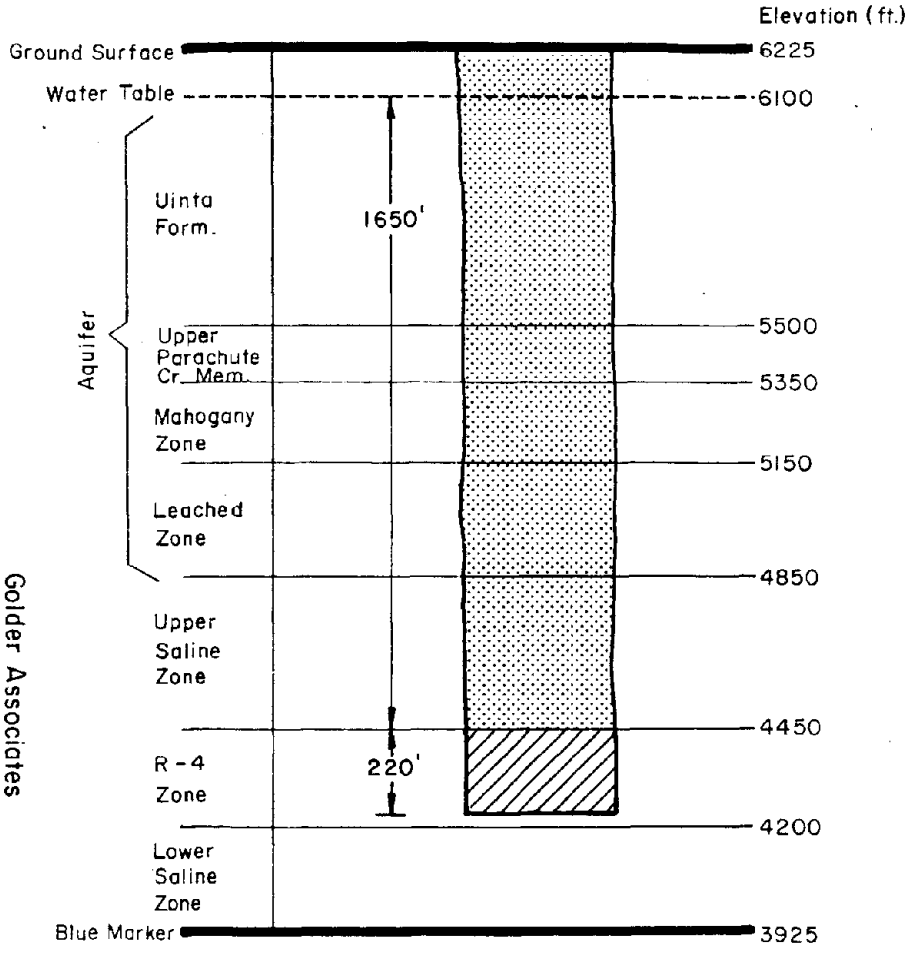


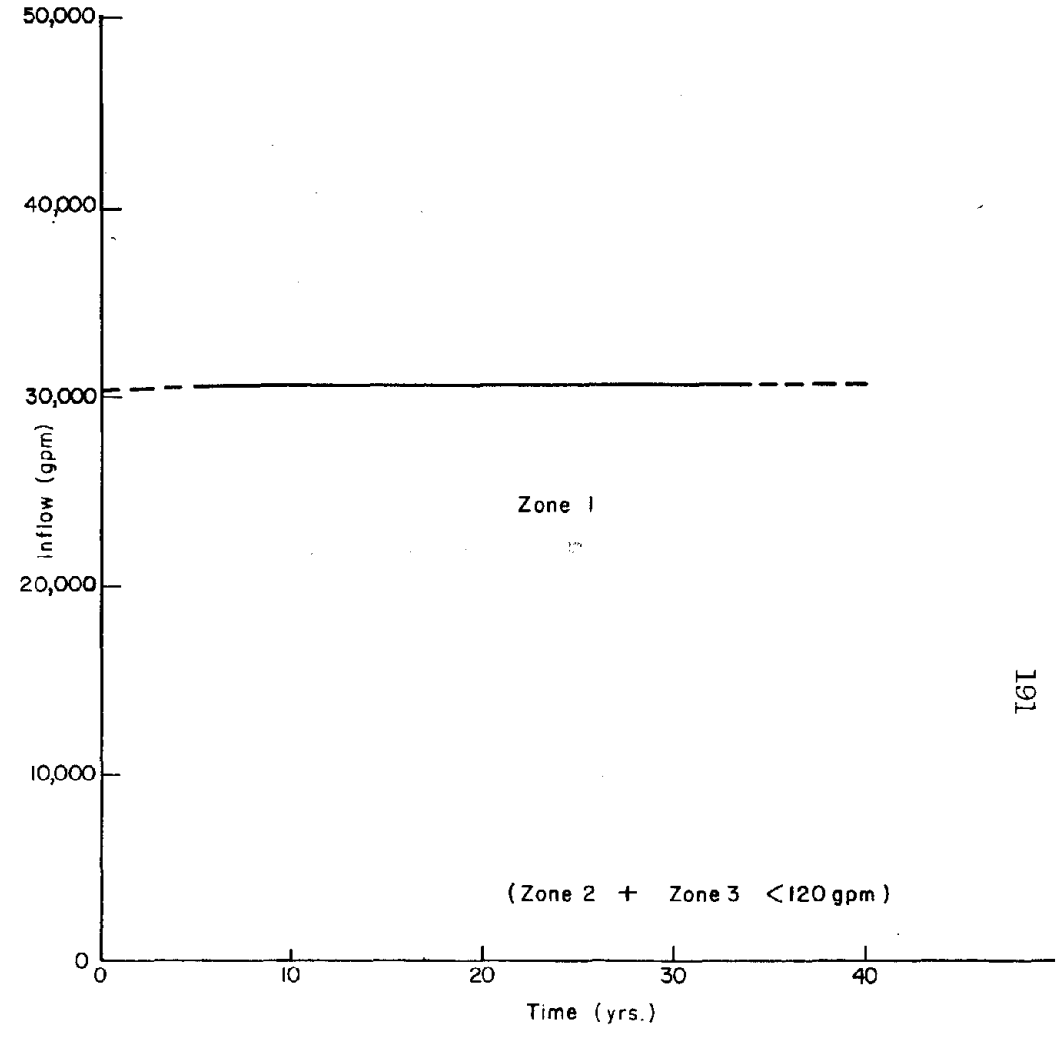


Time - yrs.	Radius - ft.	MINE INFLOW (gpm) Zone 1	Zone 1 (drain)	Zone 2	Zone 3	Total
5	2063	19,124	3110	33	45	22,310
10	2910	19,124	3110	33	49	22,320
20	4111	19,124	3110	33	51	22,320
30	5033	19,124	3110	33	51	22,320

DESCRIPTION: Sublevel Stoping With Backfill,
Mining Method: Full Subsidence
Number of Passes: 1
Location: R-4
Mining Height: 220 ft
Expansion Rate: .095 mi^2/yr
Initial Radius: 200 ft
Mining Rate: 50,000 ton/day

Figure D-36 MINE INFLOW - SITE 1





Time - yrs.	Radius - ft.	MINE INFLOW (gpm) Zone 1	Zone 1 (drain)	Zone 2	Zone 3	Total
5	2918	23,994	6252	45	63	30,350
10	4122	23,994	6252	45	67	30,360
20	5826	23,994	6252	45	69	30,360
30	7134	23,994	6252	45	70	30,360

DESCRIPTION: Sublevel Stoping With Backfill,

Mining Method: Full Subsidence

Number of Passes: 1

Location: R-4

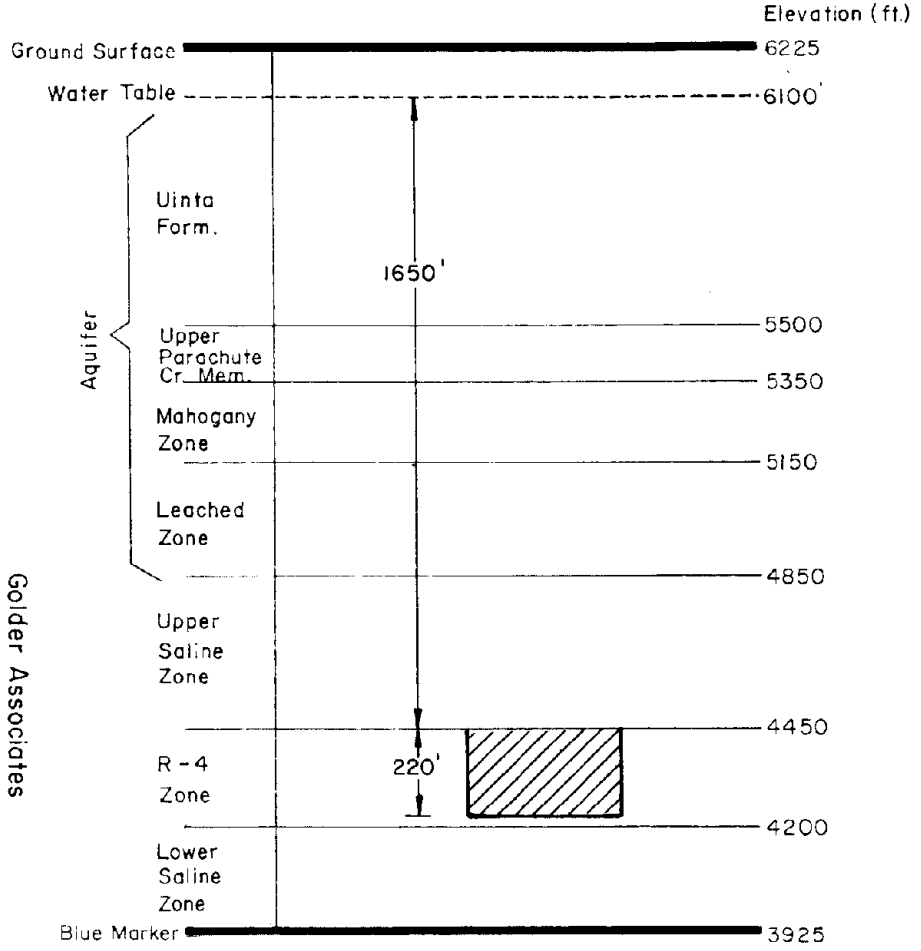
Mining Height: 220 ft

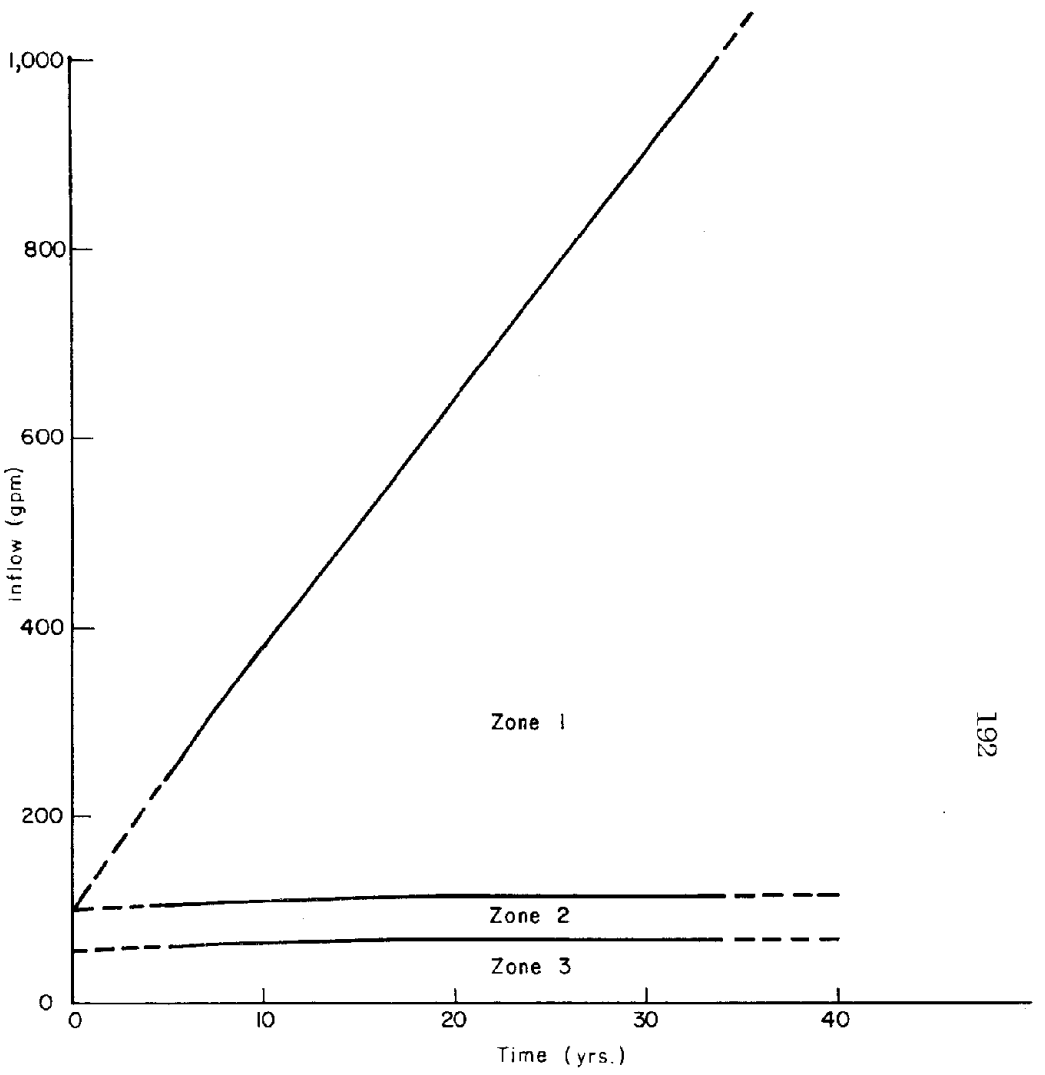
Expansion Rate: .191 mi^2/yr

Initial Radius: 200 ft

Mining Rate: 100,000 ton/day

Figure D-37 MINE INFLOW - SITE 1





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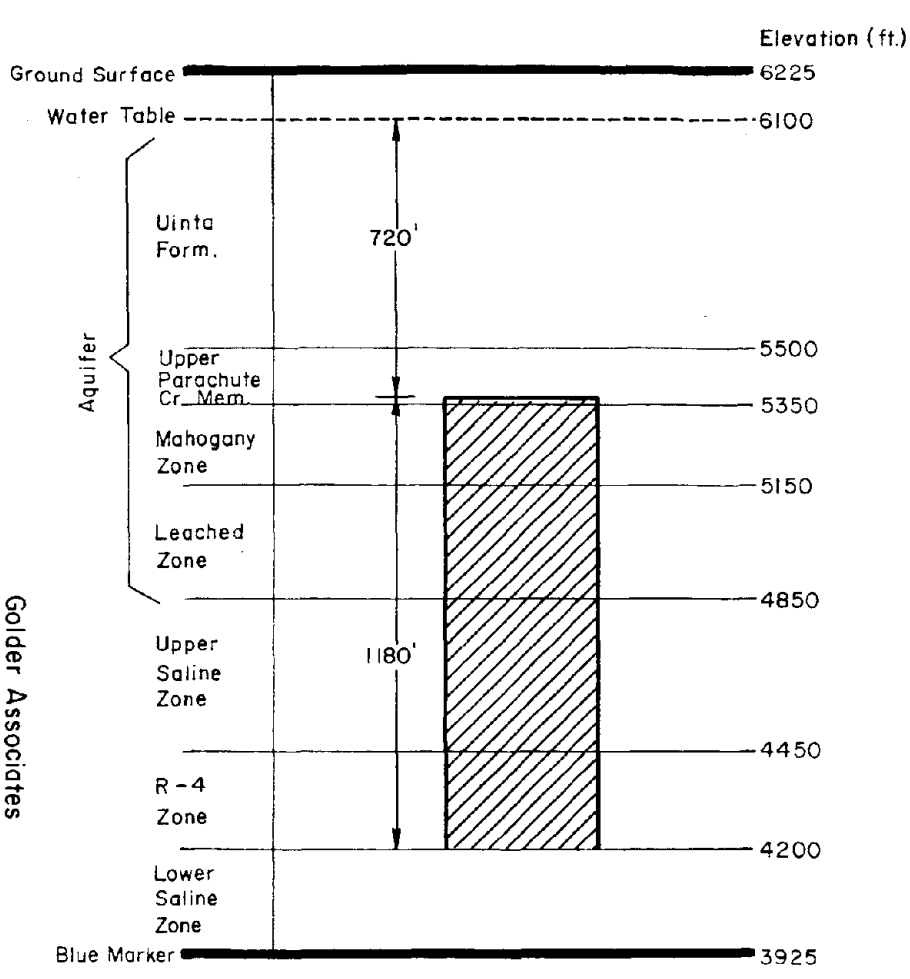
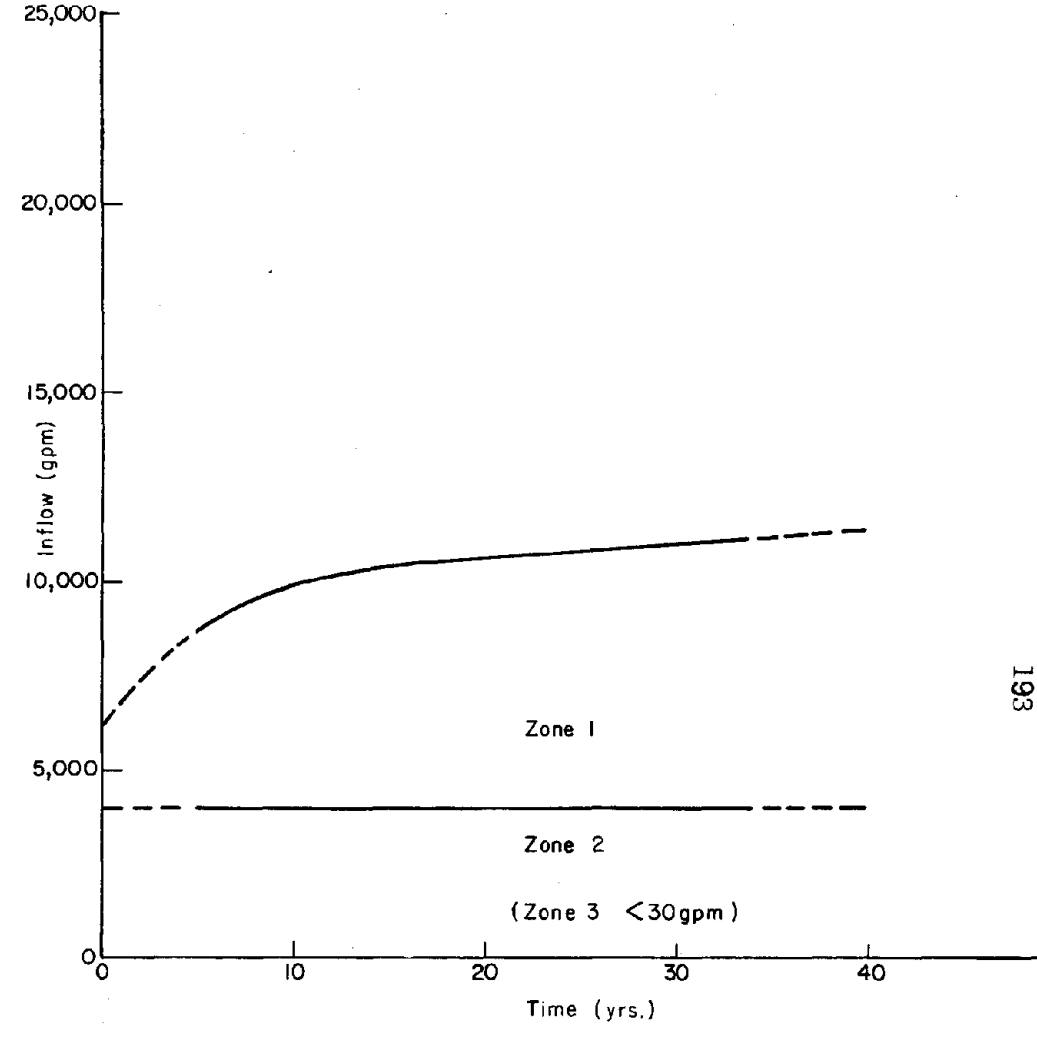
Golder Associates

Time - yrs.	Radius - ft.	MINE INFLOW (gpm) Zone 1	(drain) Zone 1	Zone 2	Zone 3	Total
5	2918	130	-	45	63	240
10	4122	260	-	45	67	370
20	5826	519	-	45	69	630
30	7134	779	-	45	70	890

DESCRIPTION: Sublevel Stoping With Backfill,
Mining Method No Subsidence
Number of Passes 1
Location R-4
Mining Height 220 ft
Expansion Rate .191 mi^2/yr
Initial Radius 220 ft
Mining Rate 100,000 ton/day

Figure D-38 MINE INFLOW - SITE I





MINE INFLOW (gpm)

Time - yrs.	Radius - ft.	Zone 1	Zone 1 (drain)	Zone 2	Zone 3	Total
5	1051	4543	-	4025	22	8,590
10	1473	5948	-	4020	25	9,990
20	2074	6739	-	4014	28	10,780
30	2536	6927	-	4007	28	10,960

DESCRIPTION: Sublevel Stoping With Backfill, No Subsidence

Mining Method

Number of Passes 4

Location R-4 to Mahogany

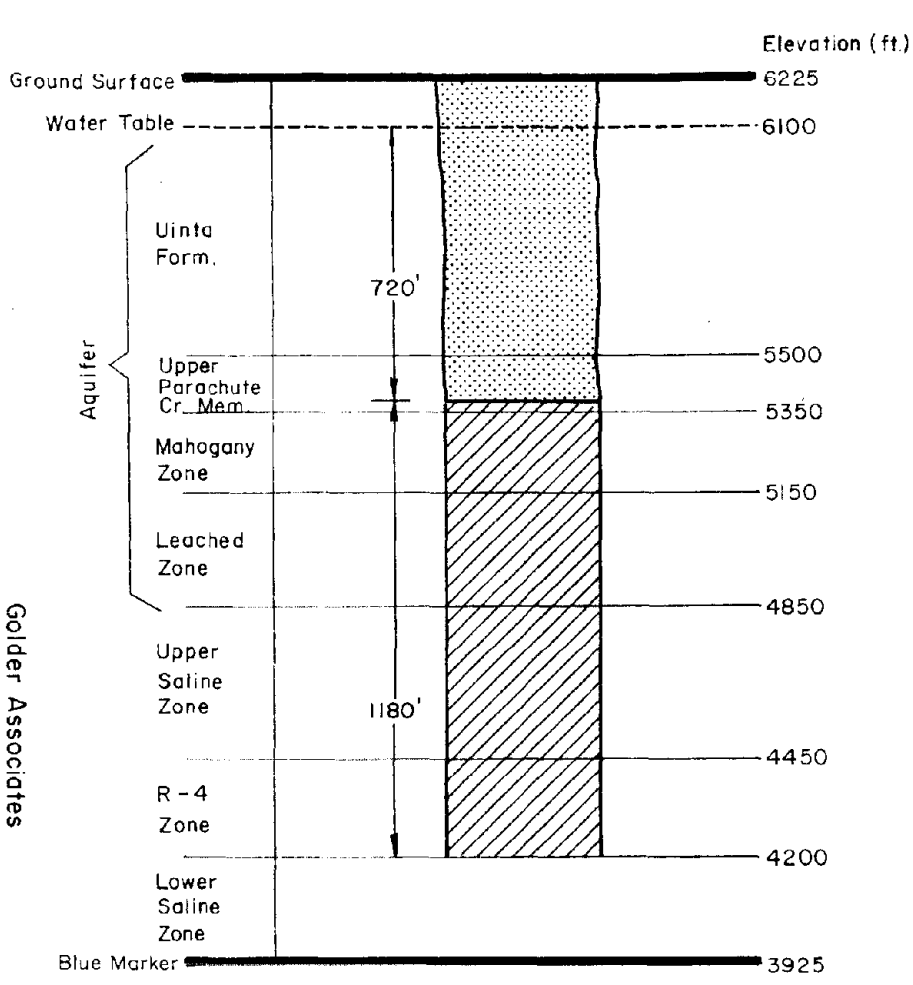
Mining Height 220 ft, 100 ft sills, total = 1180 ft

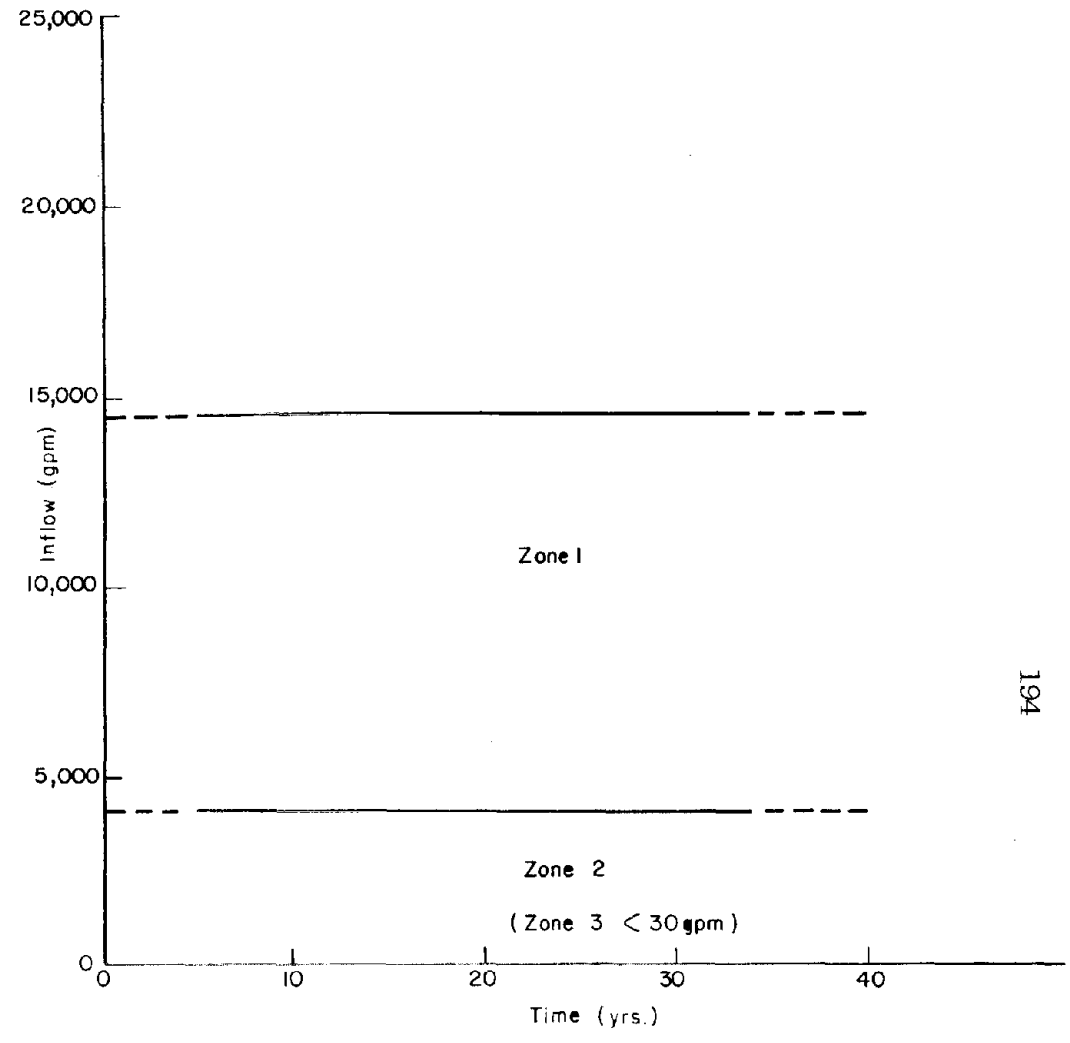
Expansion Rate .024 mi^2/yr

Initial Radius 200 ft

Mining Rate 50,000 ton/day

Figure D-39 MINE INFLOW - SITE I





Time - yrs.	Radius - ft.	MINE INFLOW (gpm) Zone I	(drain) Zone I	Zone 2	Zone 3	Total
5	1051	9800	617	4025	22	14,460
10	1473	9800	617	4020	25	14,460
20	2074	9800	617	4014	28	14,460
30	2536	9800	617	4007	28	14,450

DESCRIPTION: Sublevel Stoping With Backfill, Full Subsidence

Mining Method: Full Subsidence

Number of Passes: 4

Location: R-4 to Mahogany

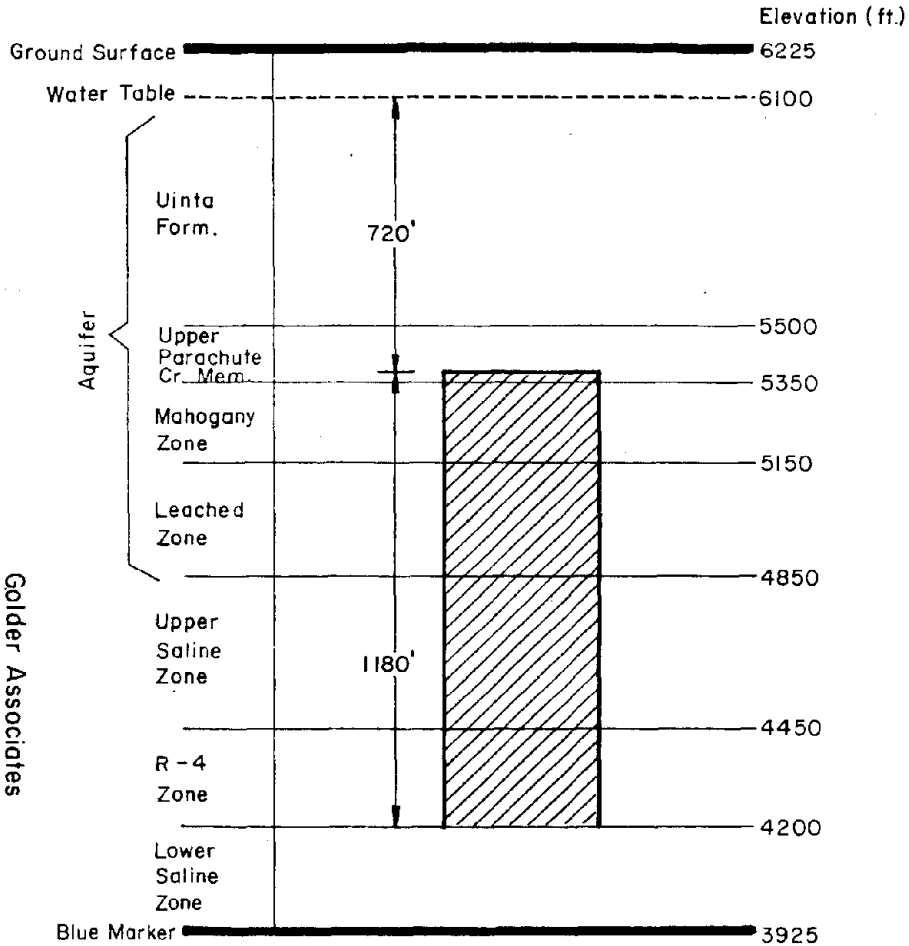
Mining Height: 220 ft, 100 ft sills, total = 1180 ft

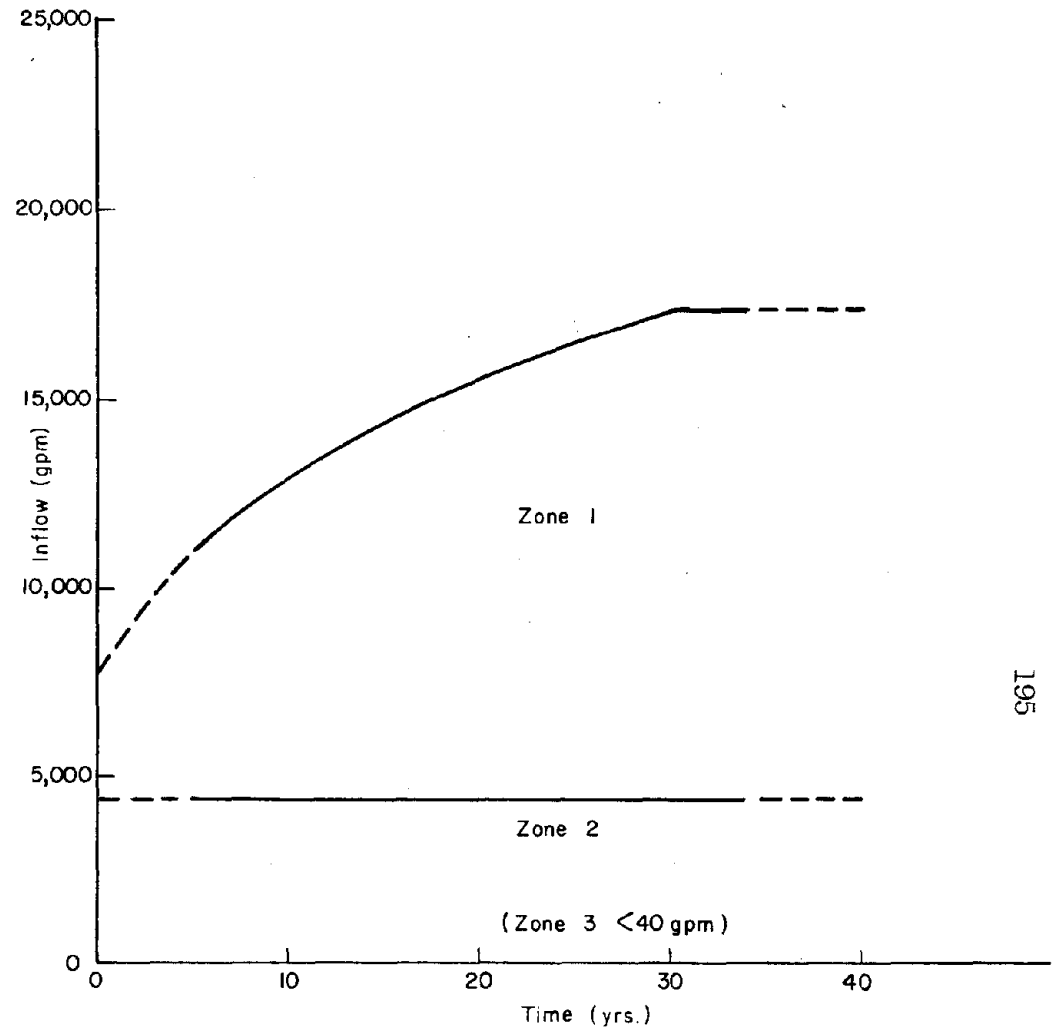
Expansion Rate: 0.024 mi^2/yr

Initial Radius: 200 ft

Mining Rate: 50,000 ton/day

Figure D-40 MINE INFLOW - SITE I





Time - yrs.	Radius - ft.	MINE INFLOW (gpm) Zone 1	(drain) Zone 1	Zone 2	Zone 3	Total
5	1473	6,480	-	4334	30	10,840
10	2074	8,634	-	4332	33	13,000
20	2936	10,898	-	4328	35	15,260
30	3580	12,863	-	4326	36	17,230

DESCRIPTION: Sublevel Stoping With Backfill, No Subsidence

Mining Method

Number of Passes 4

Location R-4 to Mahogany

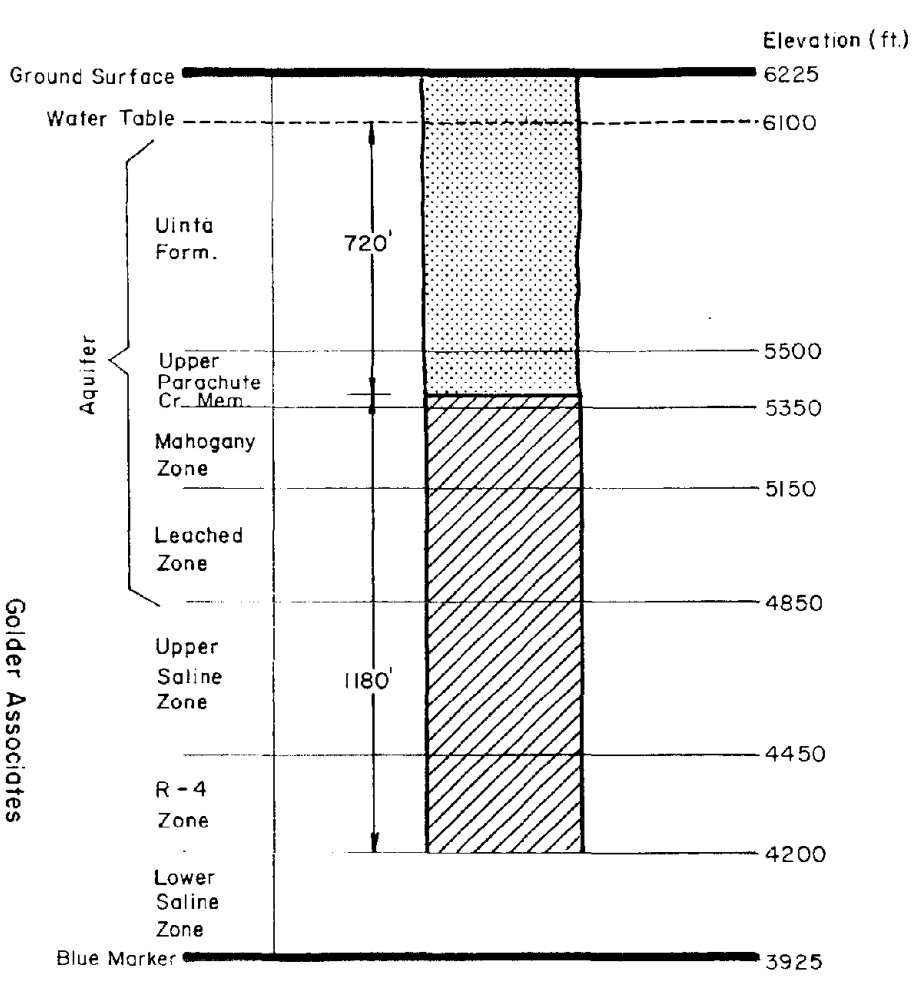
Mining Height 220 ft, 100 ft sills, total = 1180 ft

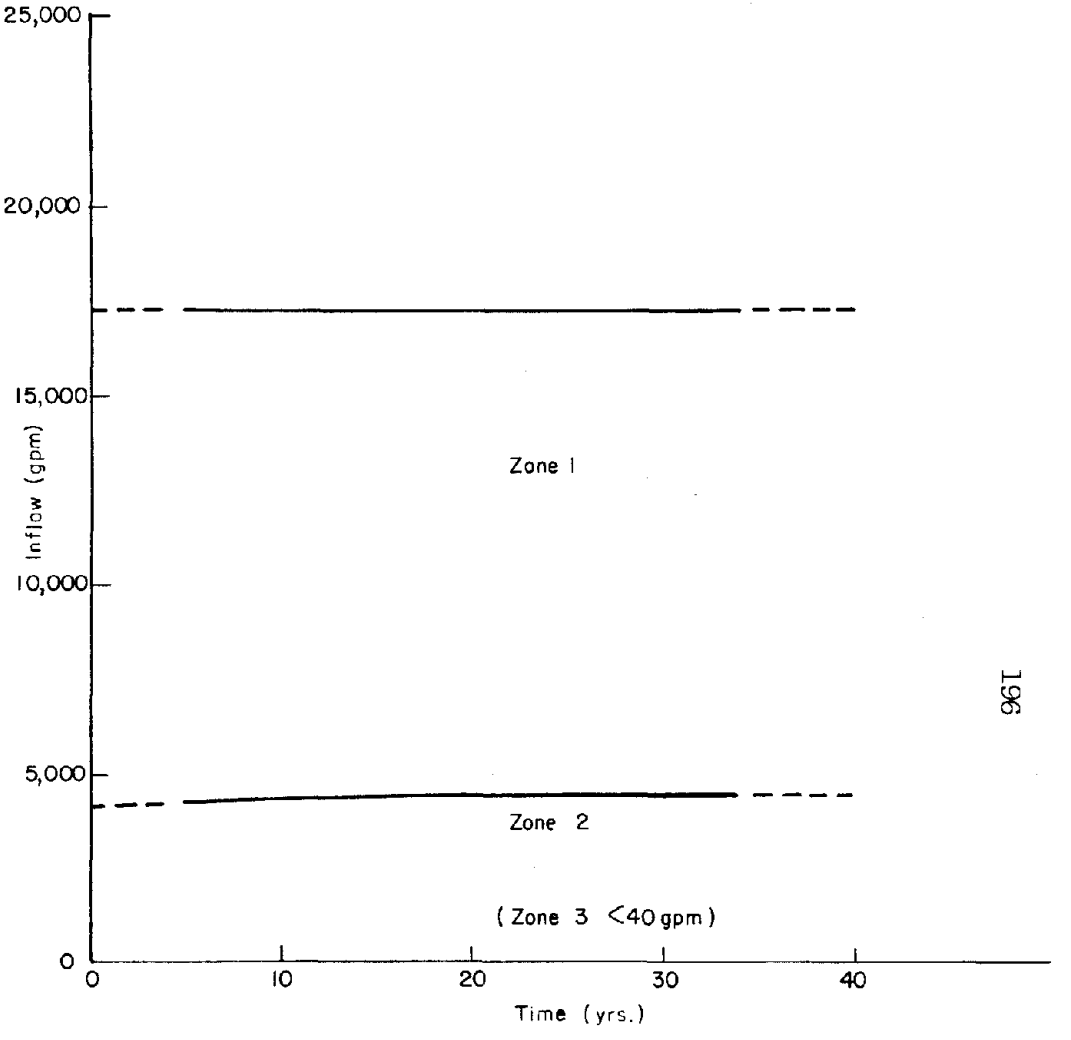
Expansion Rate .048 mi^2/yr

Initial Radius 200 ft

Mining Rate 100,000 ton/day

Figure D-41 MINE INFLOW - SITE 1





MINE INFLOW (gpm)

Time - yrs.	Radius - ft.	Zone 1	(drain) Zone 1	Zone 2	Zone 3	Total
5	1473	11,677	1234	4334	30	17,280
10	2074	11,677	1234	4332	33	17,280
20	2936	11,677	1234	4328	35	17,270
30	3580	11,677	1234	4326	36	17,270

DESCRIPTION: Sublevel Stoping With Backfill,

Mining Method: Full Subsidence

Number of Passes: 4

Location: R-4 to Mahogany

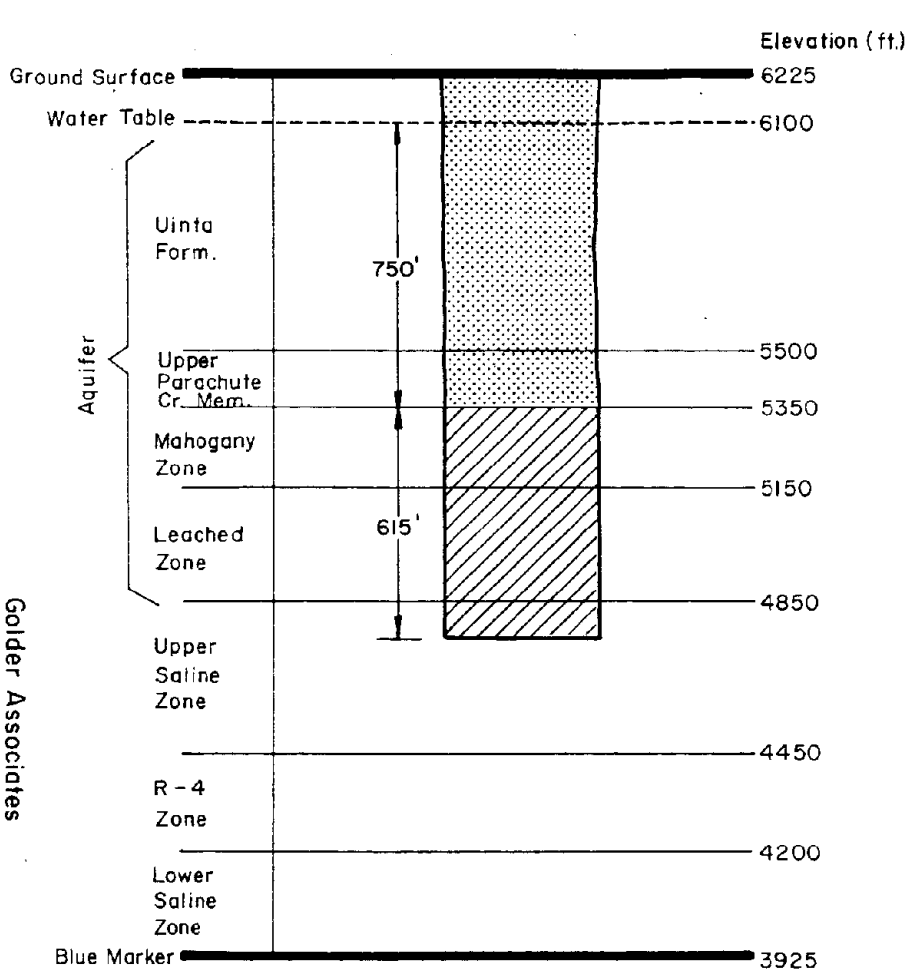
Mining Height: 220 ft, 100 ft sills, total = 1180 ft

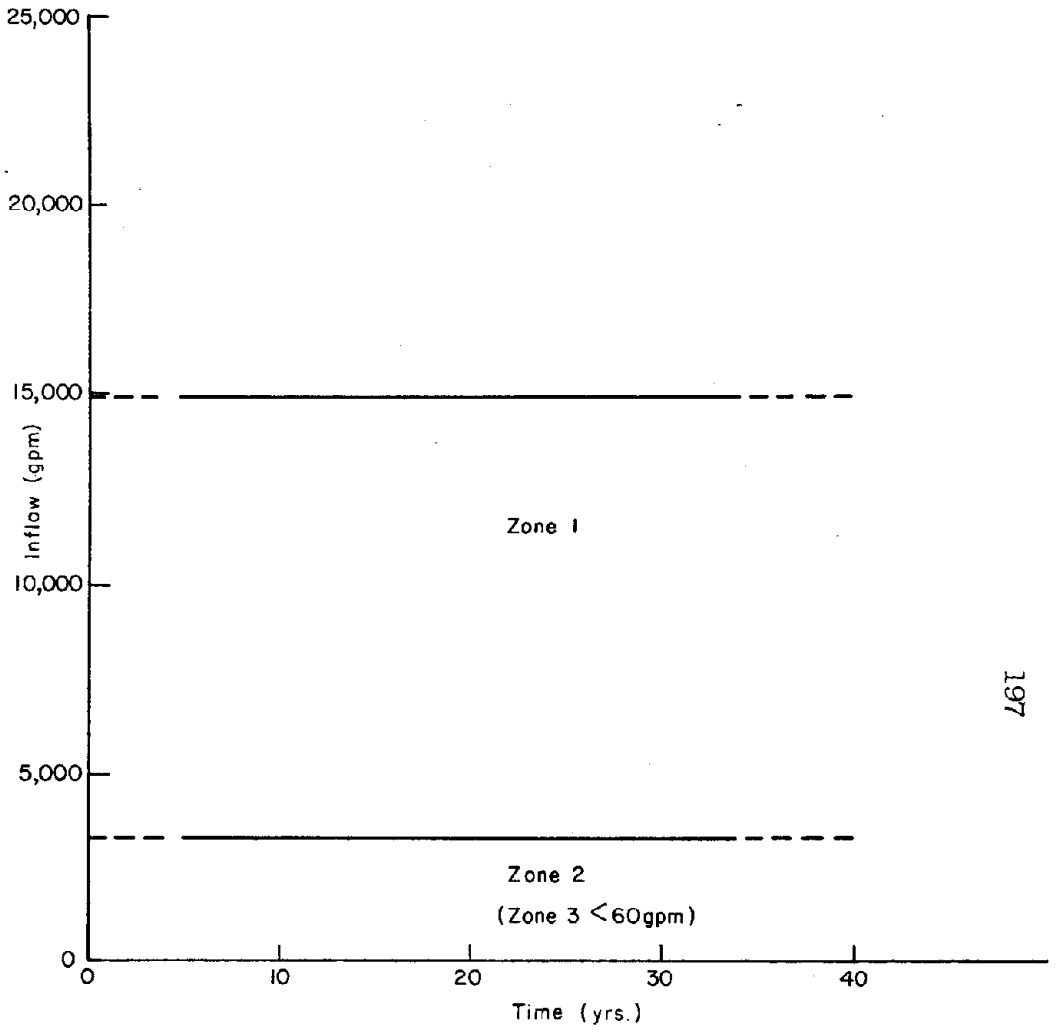
Expansion Rate: .048 mi^2/yr

Initial Radius: 200 ft

Mining Rate: 100,000 ton/day

Figure D-42 MINE INFLOW - SITE I





Time - yrs.	Radius - ft.	MINE INFLOW (gpm) Zone 1	(drain) Zone 1	Zone 2	Zone 3	Total
5	1051	11,125	571	3242	21	14,960
10	1473	11,125	571	3236	33	14,970
20	2074	11,125	571	3234	46	14,980
30	2536	11,125	571	3232	53	14,980

DESCRIPTION:

Mining Method: Block Caving, Full Subsidence

Number of Passes: 1

Location: Mahogany

Mining Height: 615 ft

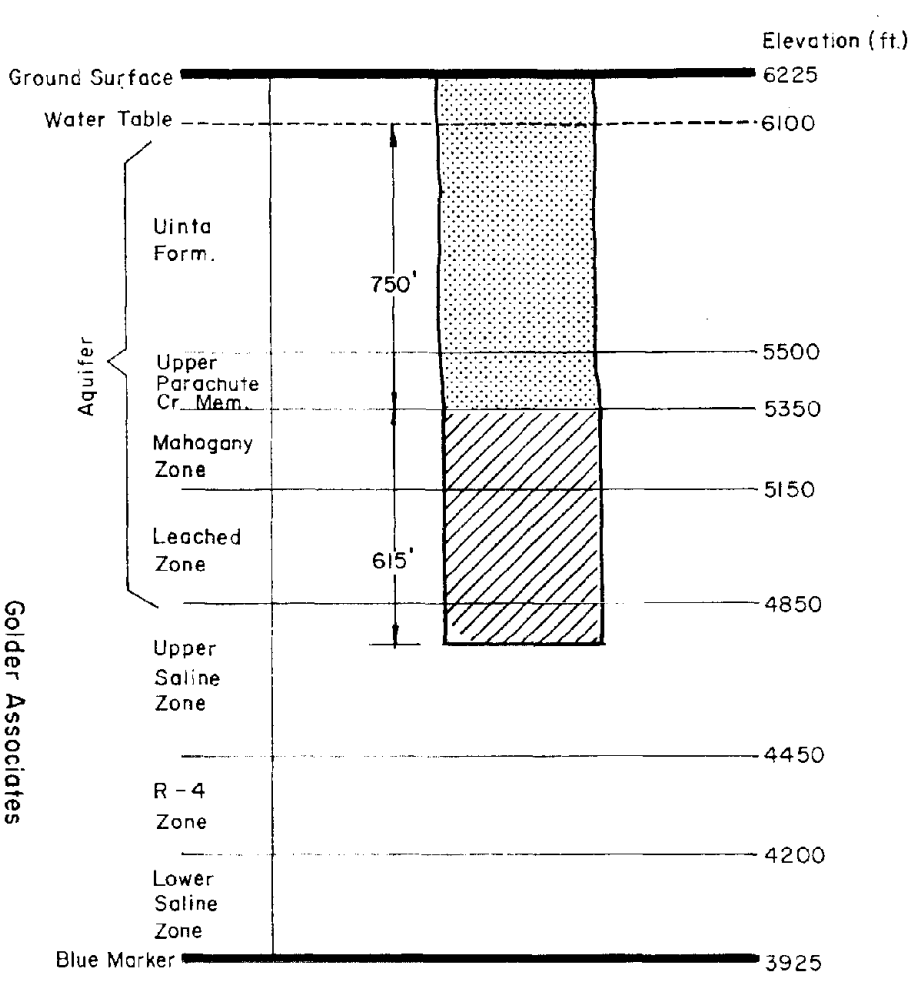
Expansion Rate: .024 mi^2/yr

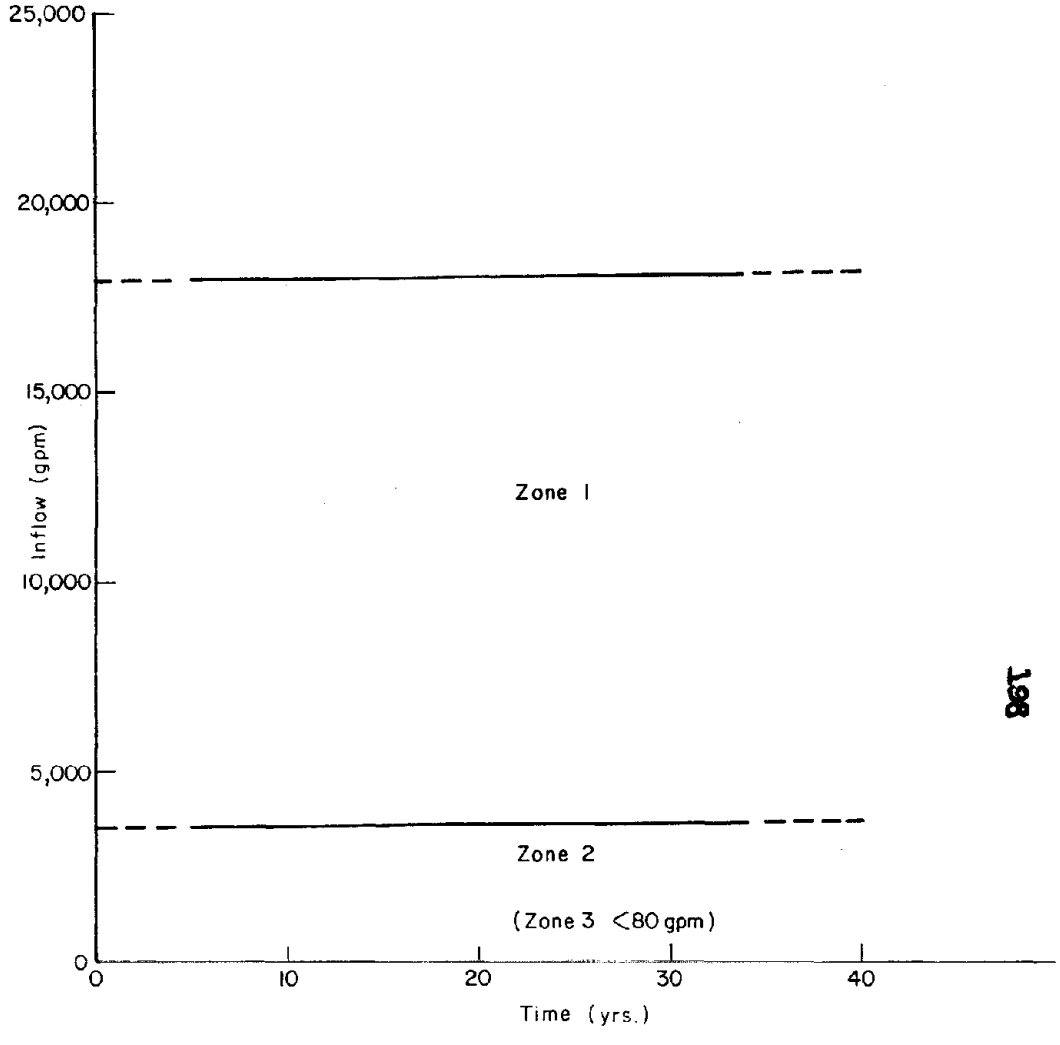
Initial Radius: 200 ft

Mining Rate: 50,000 ton/day

Figure D-43 MINE INFLOW - SITE I

Golder Associates





Golder Associates

Time - yrs.	Radius - ft.	MINE INFLOW (gpm) Zone 1	(drain) Zone 1	Zone 2	Zone 3	Total
5	1473	13,301	1143	3492	36	17,970
10	2074	13,301	1143	3489	52	17,990
20	2926	13,301	1143	3487	67	18,000
30	3580	13,301	1143	3486	74	18,000

DESCRIPTION:

Mining Method: Block Caving, Full Subsidence

Number of Passes: 1

Location: Mahogany

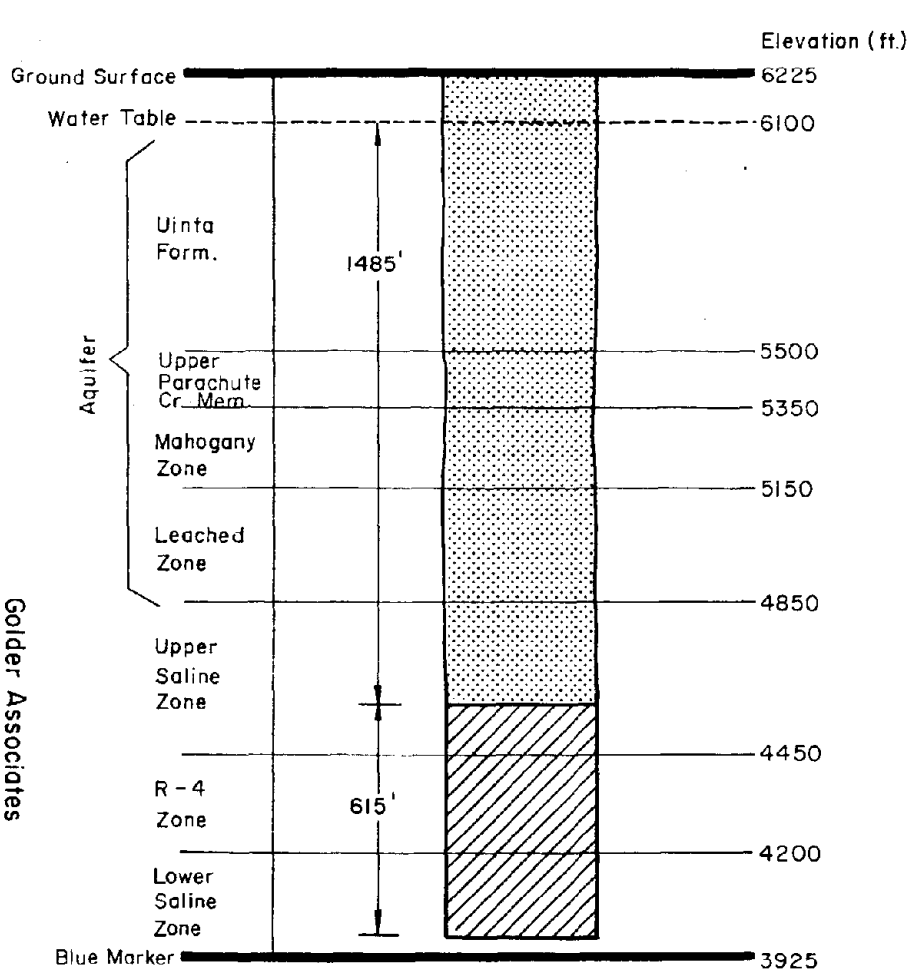
Mining Height: 615 ft

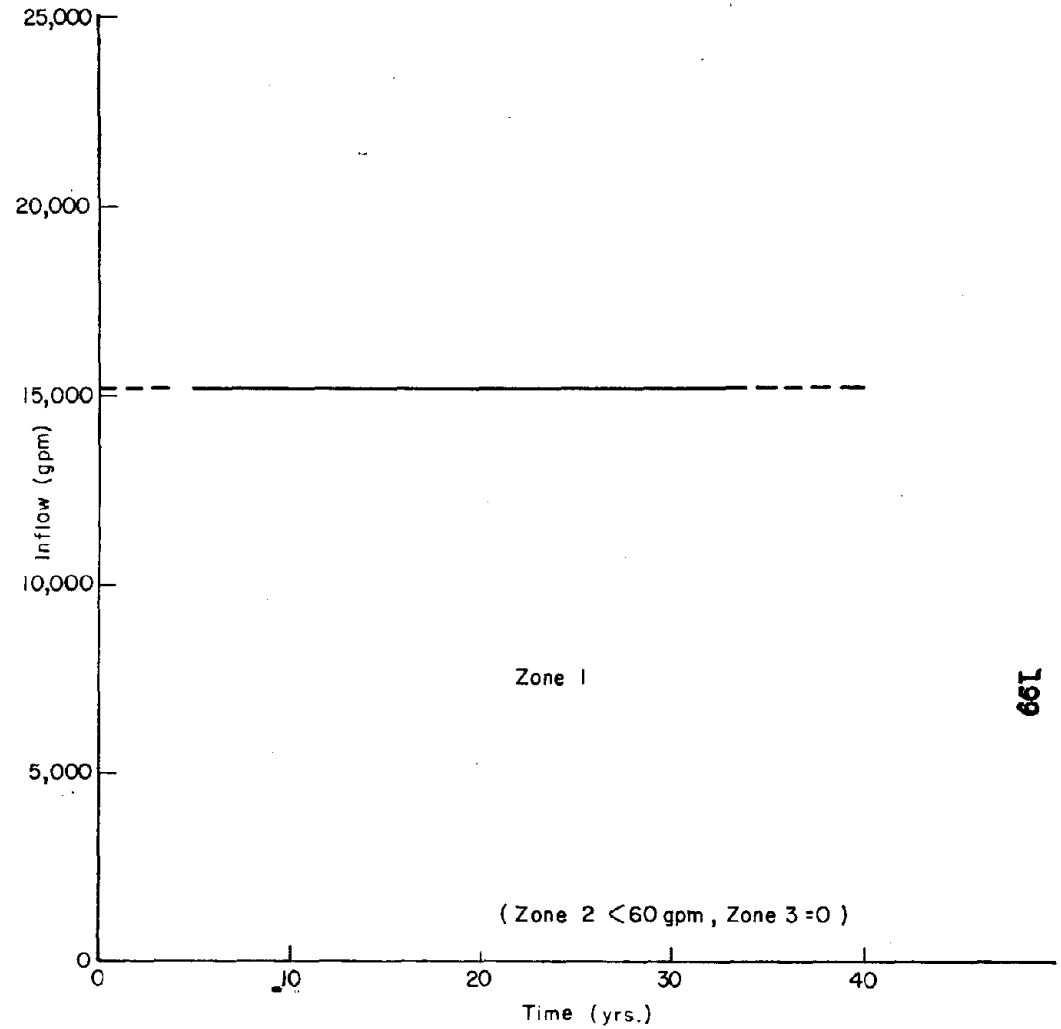
Expansion Rate: .048 mi^2/yr

Initial Radius: 200 ft

Mining Rate: 100,000 ton/day

Figure D-44 MINE INFLOW - SITE 1





Golder Associates

Time - yrs.	Radius - ft.	MINE INFLOW (gpm) Zone 1	(drain) Zone 1	Zone 2	Zone 3	Total
5	1051	14,362	707	59	-	15,130
10	1473	14,362	707	59	-	15,130
20	2074	14,362	707	59	-	15,130
30	2536	14,362	707	59	-	56,130

DESCRIPTION:

Mining Method: Block Caving, Full Subsidence

Number of Passes: 1

Location: R-4

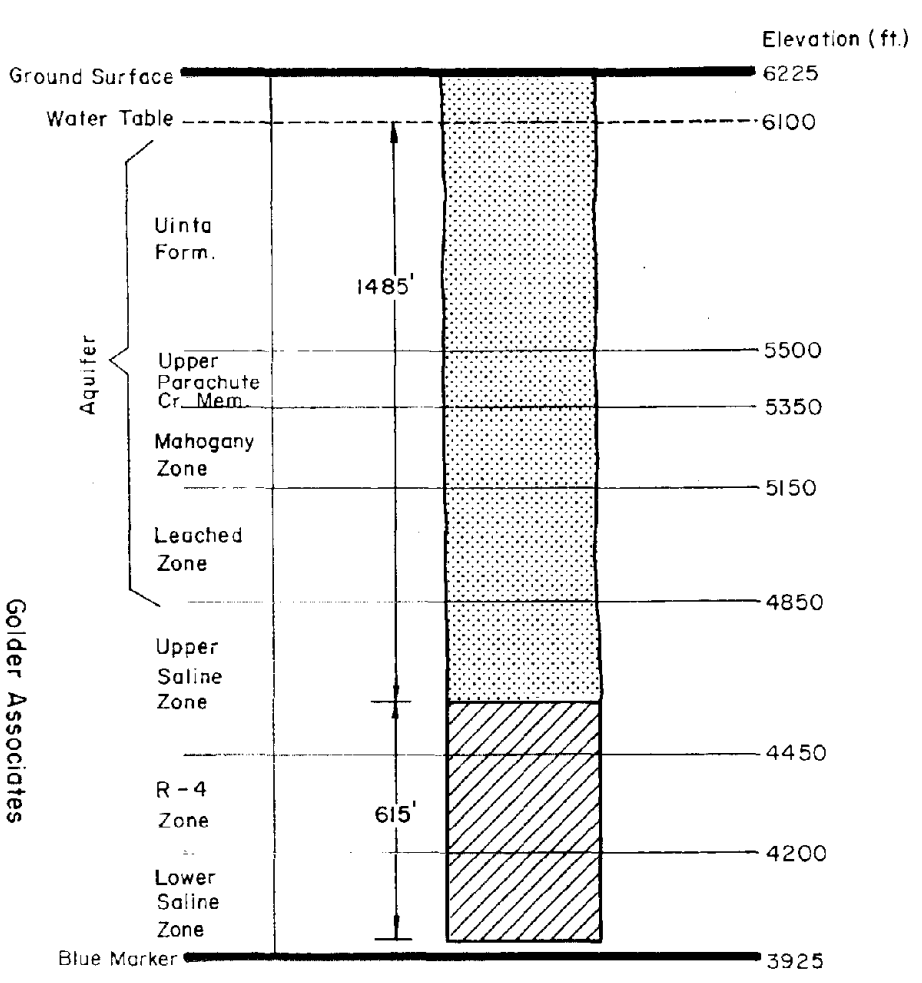
Mining Height: 615 ft

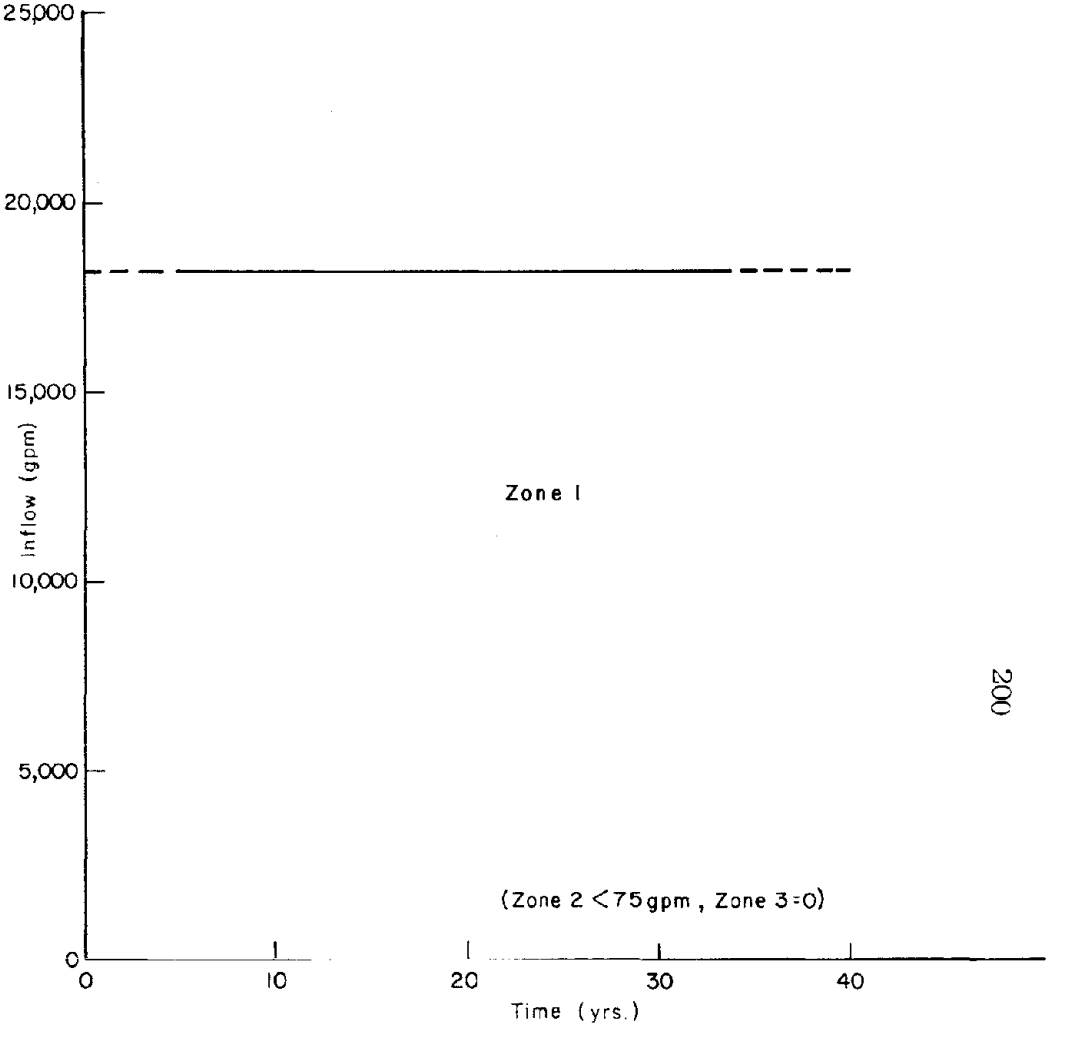
Expansion Rate: .024 mi^2/yr

Initial Radius: 200 ft

Mining Rate: 50,000 ton/day

Figure D-45 MINE INFLOW - SITE 1





Golder Associates

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MINE INFLOW (gpm)

Time - yrs.	Radius - ft.	Zone I	(drain) Zone I	Zone 2	Zone 3	Total
5	1473	16,794	1414	73	-	18,280
10	2074	16,797	1414	73	-	18,280
20	2926	16,794	1414	73	-	18,280
30	3580	16,794	1414	73	-	18,280

DESCRIPTION:

Mining Method: Block Caving, Full Subsidence

Number of Passes: 1

Location: R-4

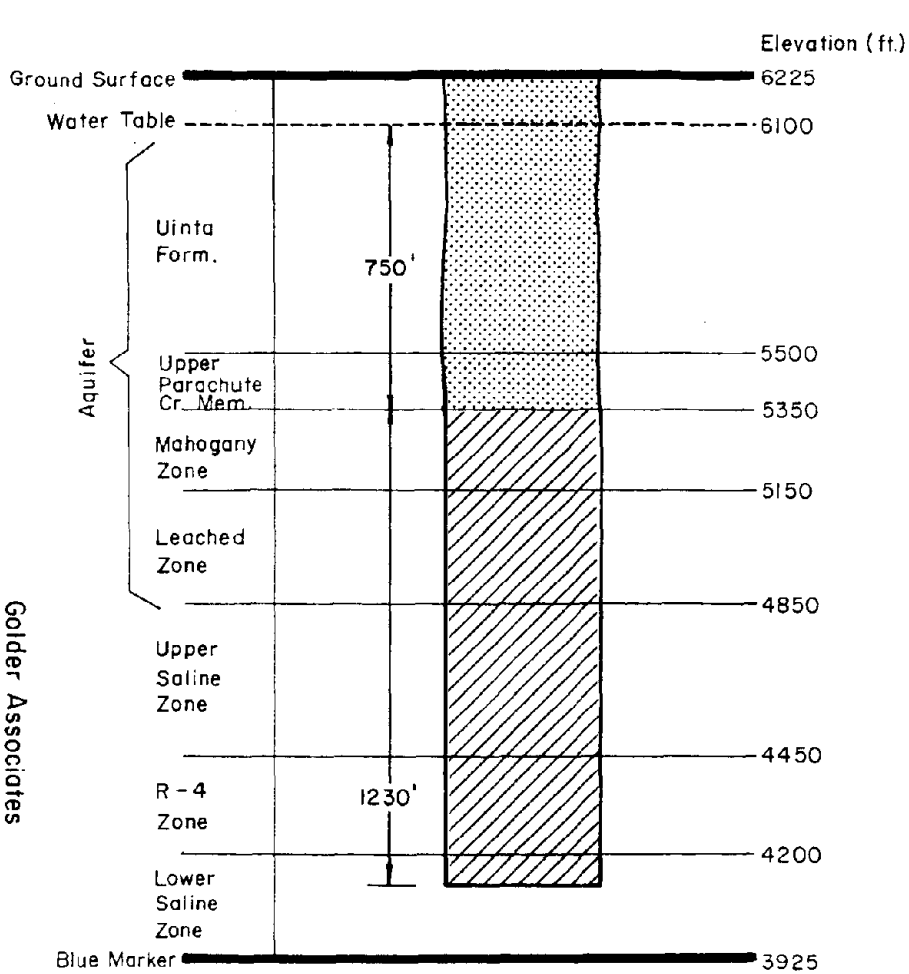
Mining Height: 615 ft

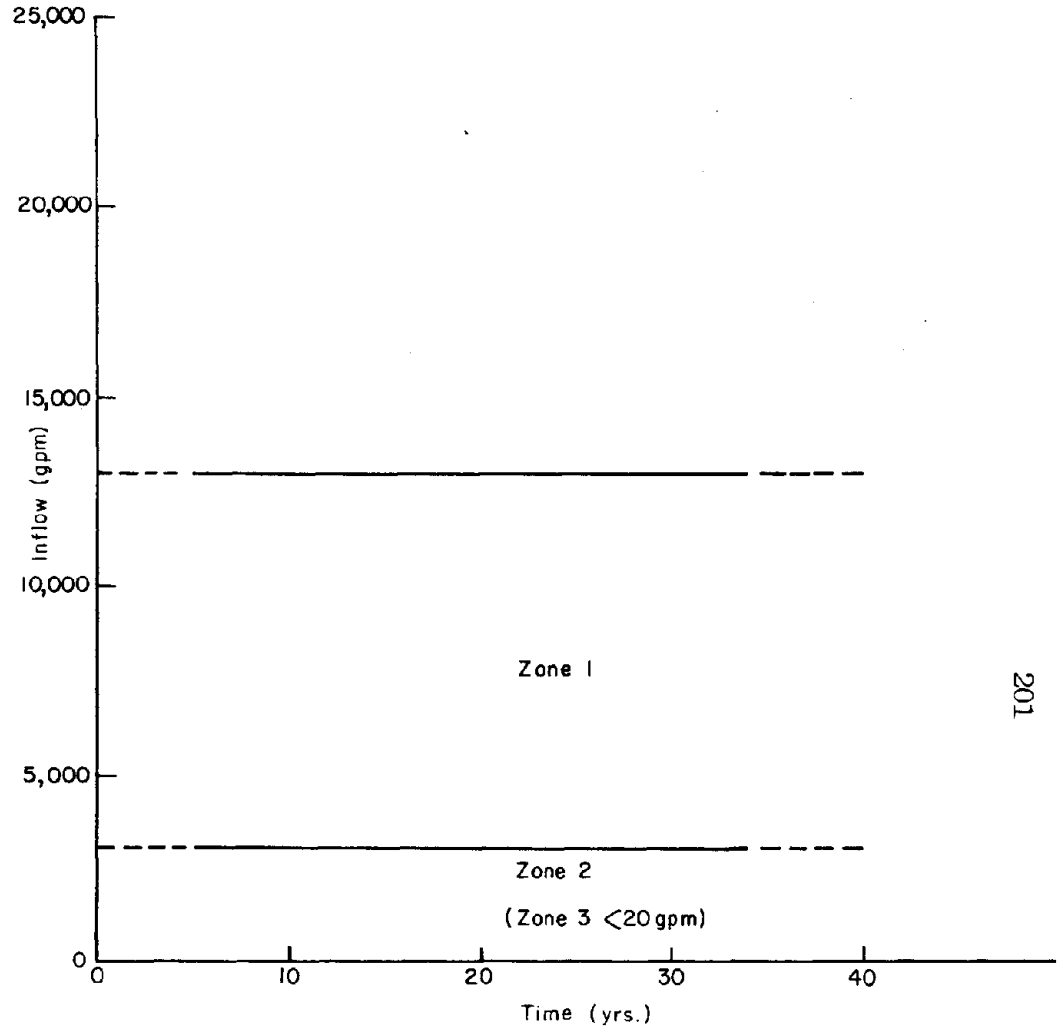
Expansion Rate: .048 mi^2/yr

Initial Radius: 200 ft

Mining Rate: 100,000 ton/day

Figure D-46 MINE INFLOW - SITE I





Time - yrs.	Radius - ft.	MINE INFLOW (gpm) Zone 1	(drain) Zone 1	Zone 2	Zone 3	Total
5	757	9599	286	3078	14	12,980
10	1051	9599	286	3067	16	12,970
20	1473	9599	286	3063	17	12,970
30	1799	9599	286	3059	17	12,960

DESCRIPTION:

Mining Method: Block Caving, Full Subsidence

Number of Passes: 2

Location: R-4 to Mahogany

Mining Height: 1230 ft

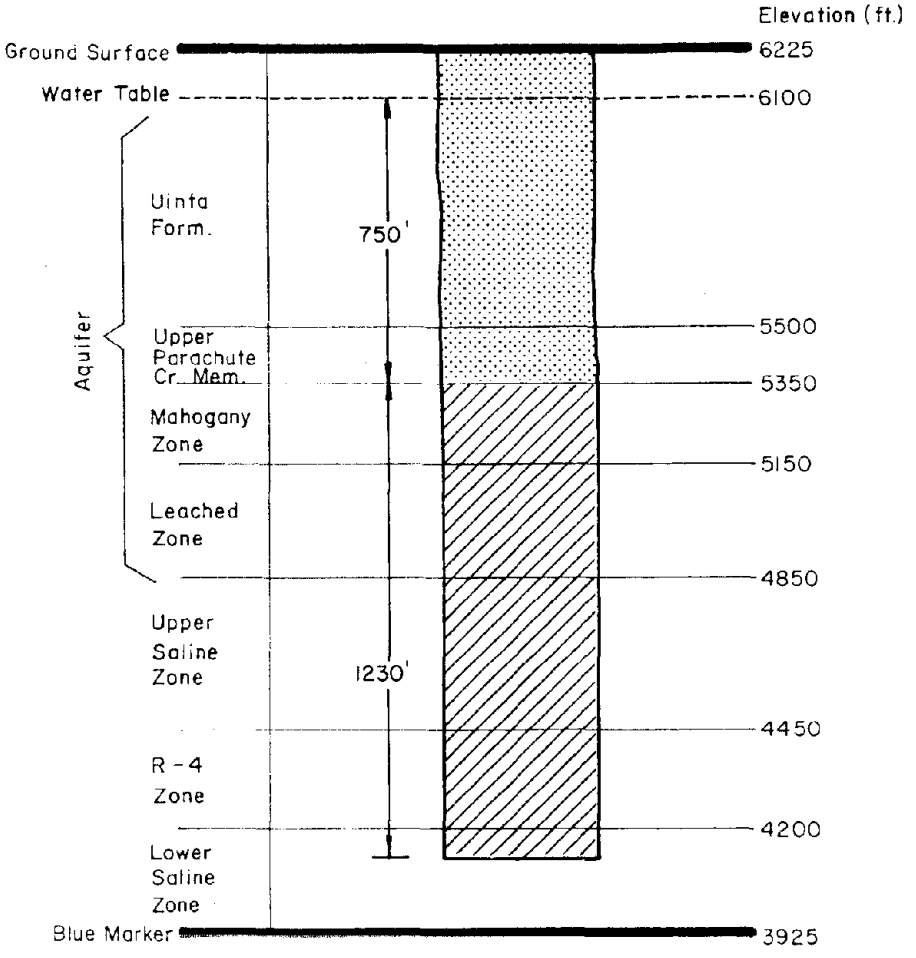
Expansion Rate: .012 mi^2/yr

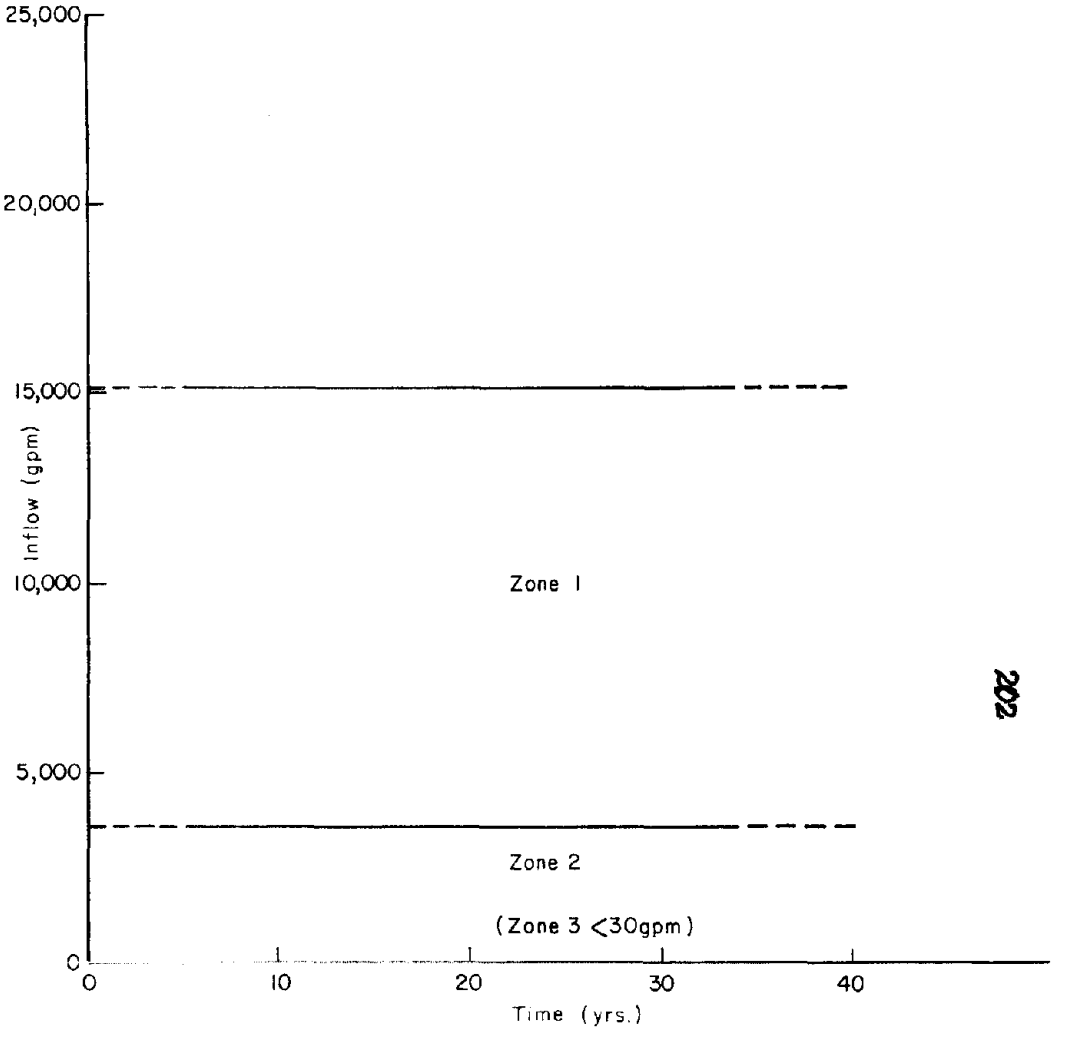
Initial Radius: 200 ft

Mining Rate: 50,000 ton/day

Figure D-47 MINE INFLOW - SITE I

Golder Associates





202

MINE INFLOW (gpm)

Time - yrs.	Radius - ft.	Zone 1	(drain) Zone 1	Zone 2	Zone 3	Total
5	1051	11,125	571	3298	20	15,010
10	1473	11,125	571	3291	22	15,010
20	2074	11,125	571	3289	23	15,010
30	2536	11,125	571	3287	23	15,010

DESCRIPTION:

Mining Method: Block Caving, Full Subsidence

Number of Passes: 2

Location: R-4 to Mahogany

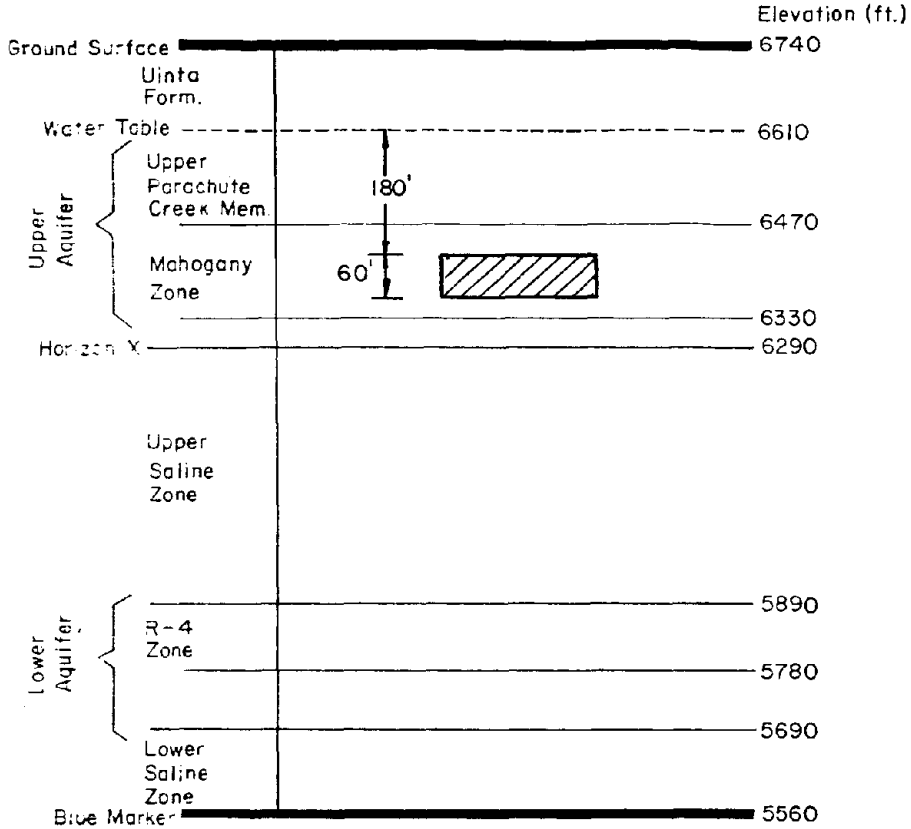
Mining Height: 1230 ft

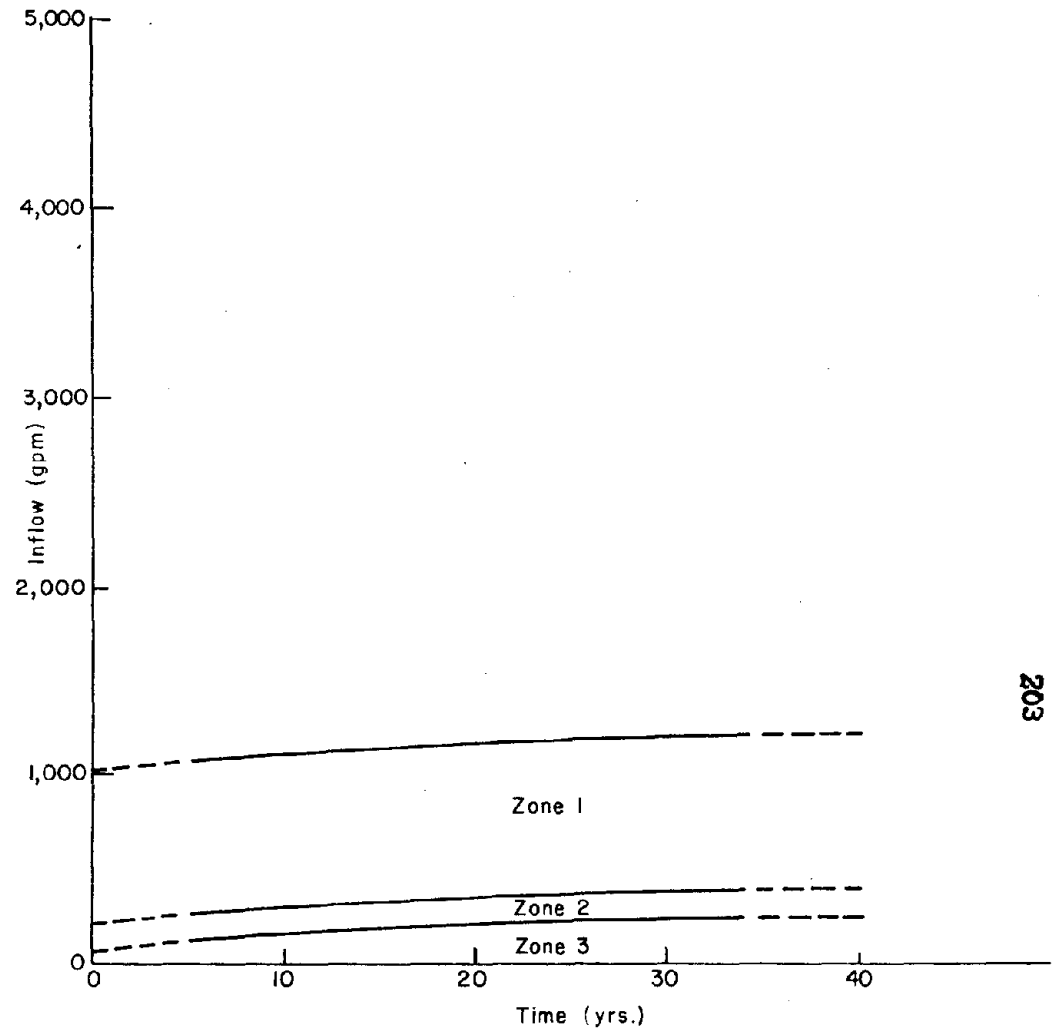
Expansion Rate: .024 mi^2/yr

Initial Radius: 200 ft

Mining Rate: 100,000 ton/day

Figure D-48 MINE INFLOW - SITE 1





		MINE INFLOW (gpm)				
Time -yrs	Radius-ft.	Zone 1	(drain) Zone 1	Zone 2	Zone 3	Total
5	3422	830	-	149	104	1080
10	4835	830	-	149	150	1130
20	6835	830	-	149	191	1170
30	8370	830	-	149	211	1190

DESCRIPTION:

Mining Method: Room & Pillar, No Subsidence

Number of Passes: 1

Location: Mahogany

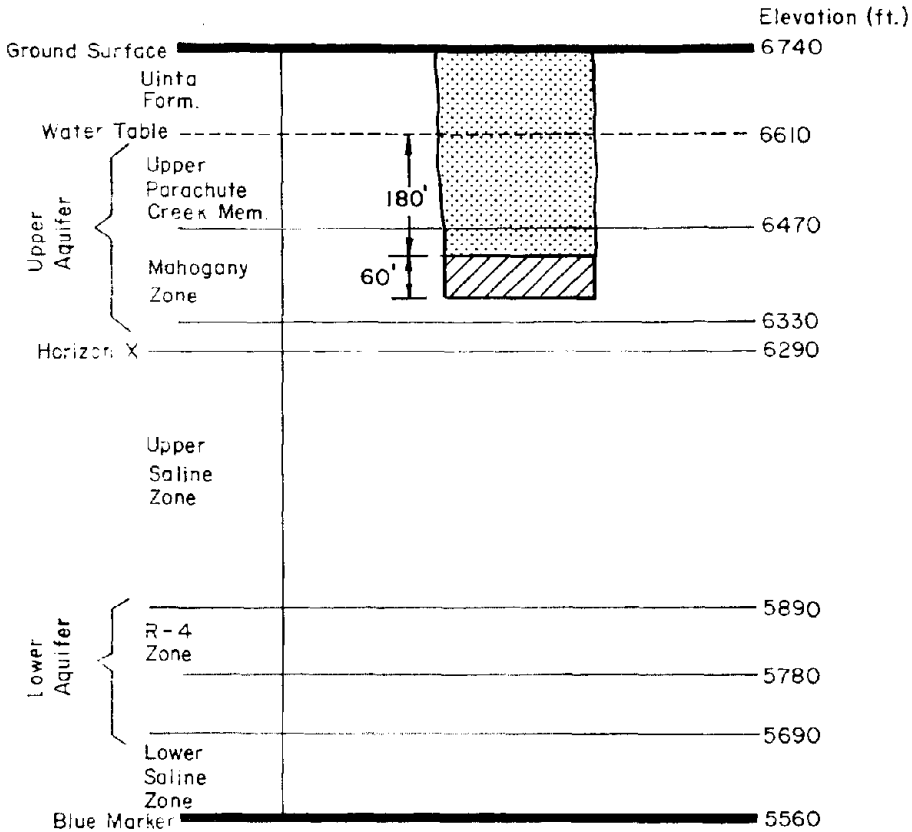
Mining Height: 60 ft

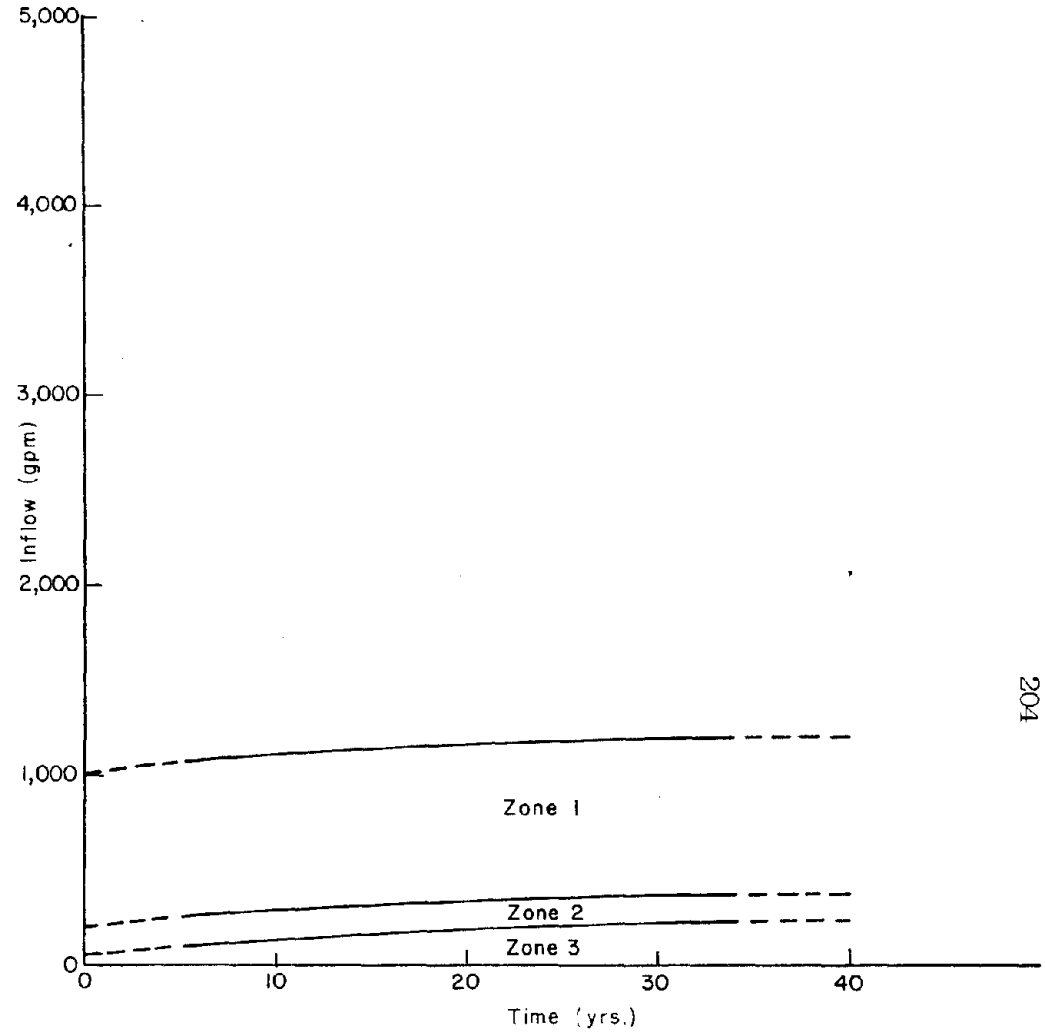
Expansion Rate: .263 mi^2/yr

Initial Radius: 200 ft

Mining Rate: 50,000 ton/day

Figure D-49 MINE INFLOW - SITE 2





MINE INFLOW (gpm)

Time -yrs	Radius-ft.	Zone 1	(drain) Zone 1	Zone 2	Zone 3	Total
5	3422	642	188	149	104	1080
10	4835	642	188	149	150	1130
20	6835	642	188	149	191	1170
30	8370	642	188	149	211	1190

DESCRIPTION:

Mining Method: Room & Pillar, Full Subsidence

Number of Passes: 1

Location: Mahogany

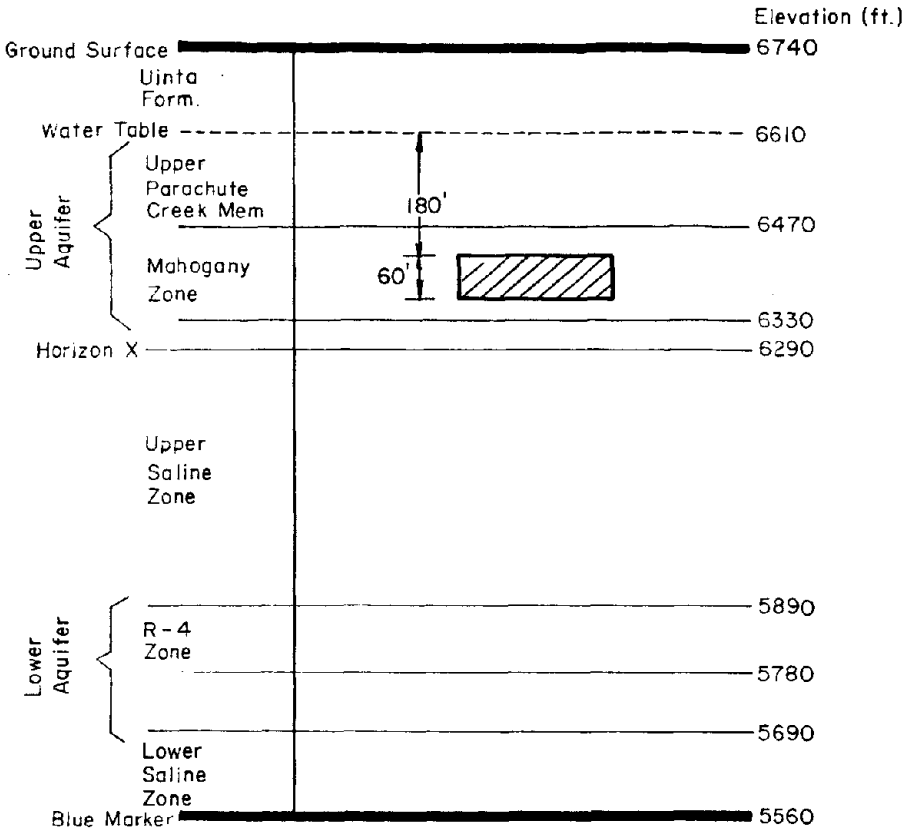
Mining Height: 60 ft

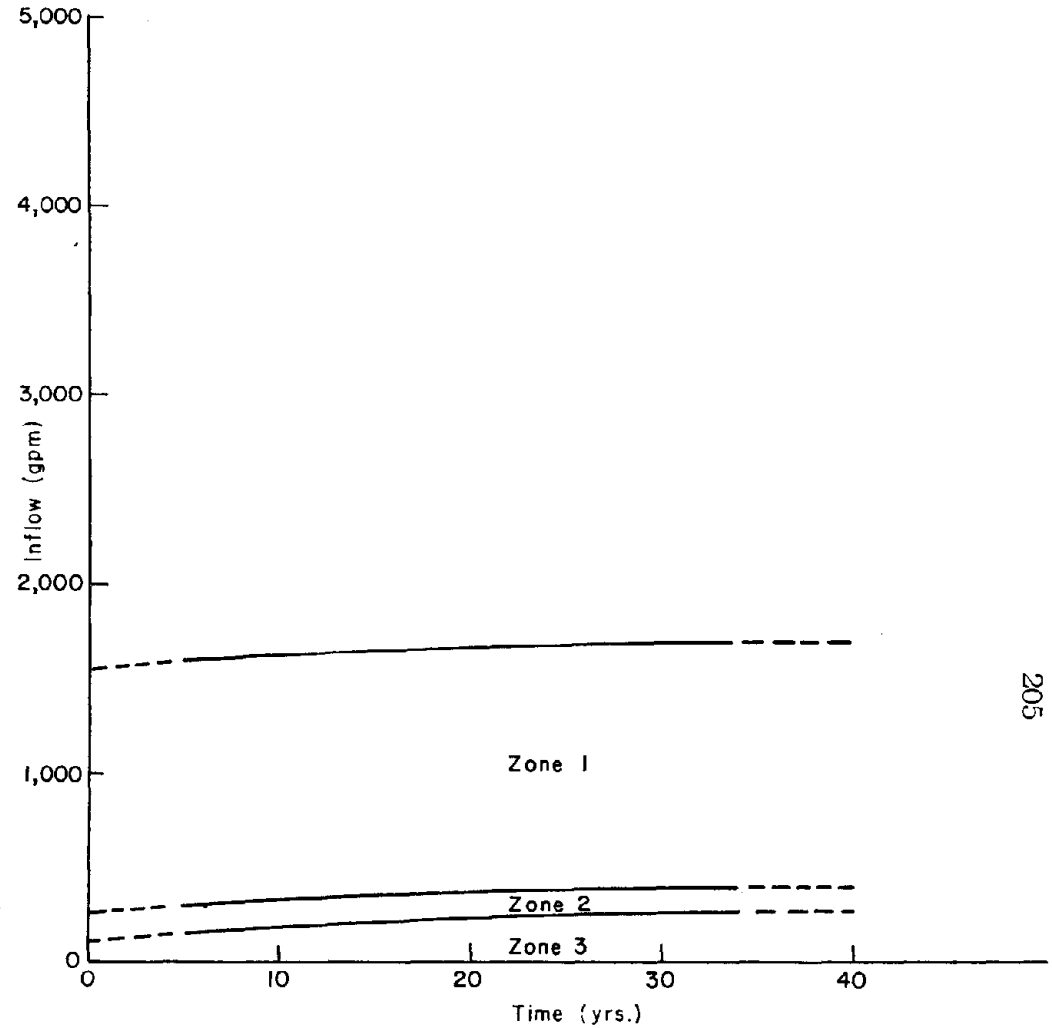
Expansion Rate: .263 mi^2/yr

Initial Radius: 200 ft

Mining Rate: 50,000 ton/day

Figure D-50 MINE INFLOW - SITE 2





Time -yrs	Radius-ft.	MINE INFLOW (gpm) Zone 1	(drain) Zone 1	Zone 2	Zone 3	Total
5	4,831	1265	-	164	158	1590
10	6,828	1265	-	164	205	1630
20	9,655	1265	-	164	241	1670
30	11,824	1265	-	164	256	1690

DESCRIPTION:

Mining Method: Room & Pillar, No Subsidence

Number of Passes: 1

Location: Mahogany

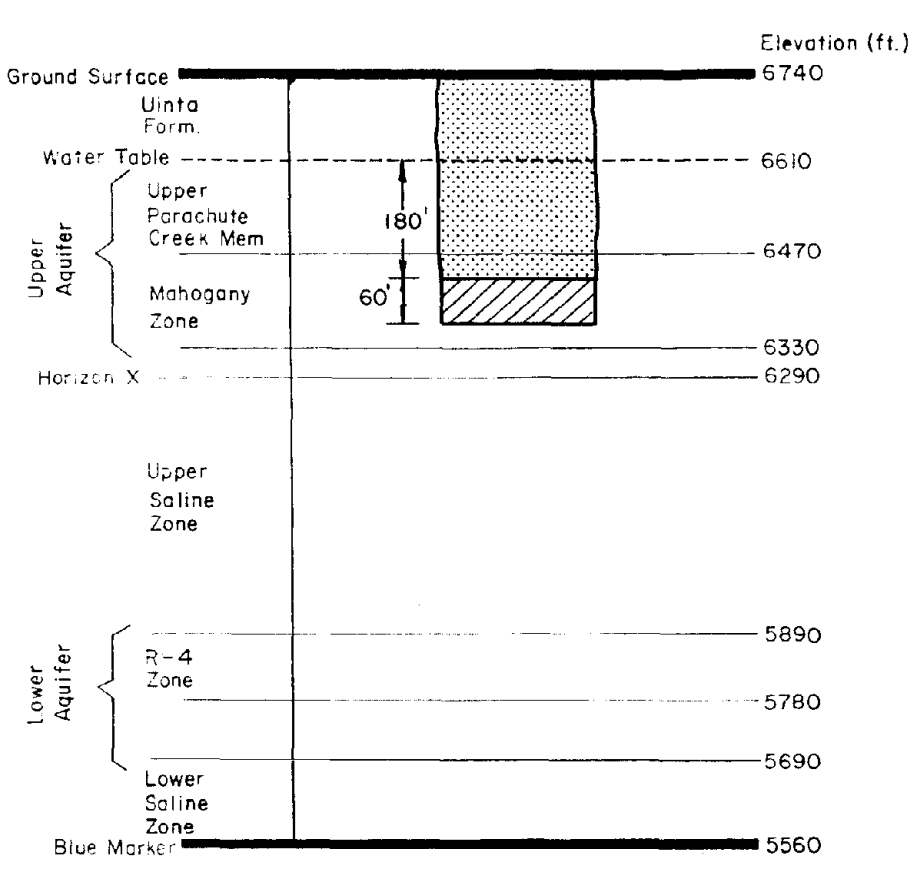
Mining Height: 60 ft

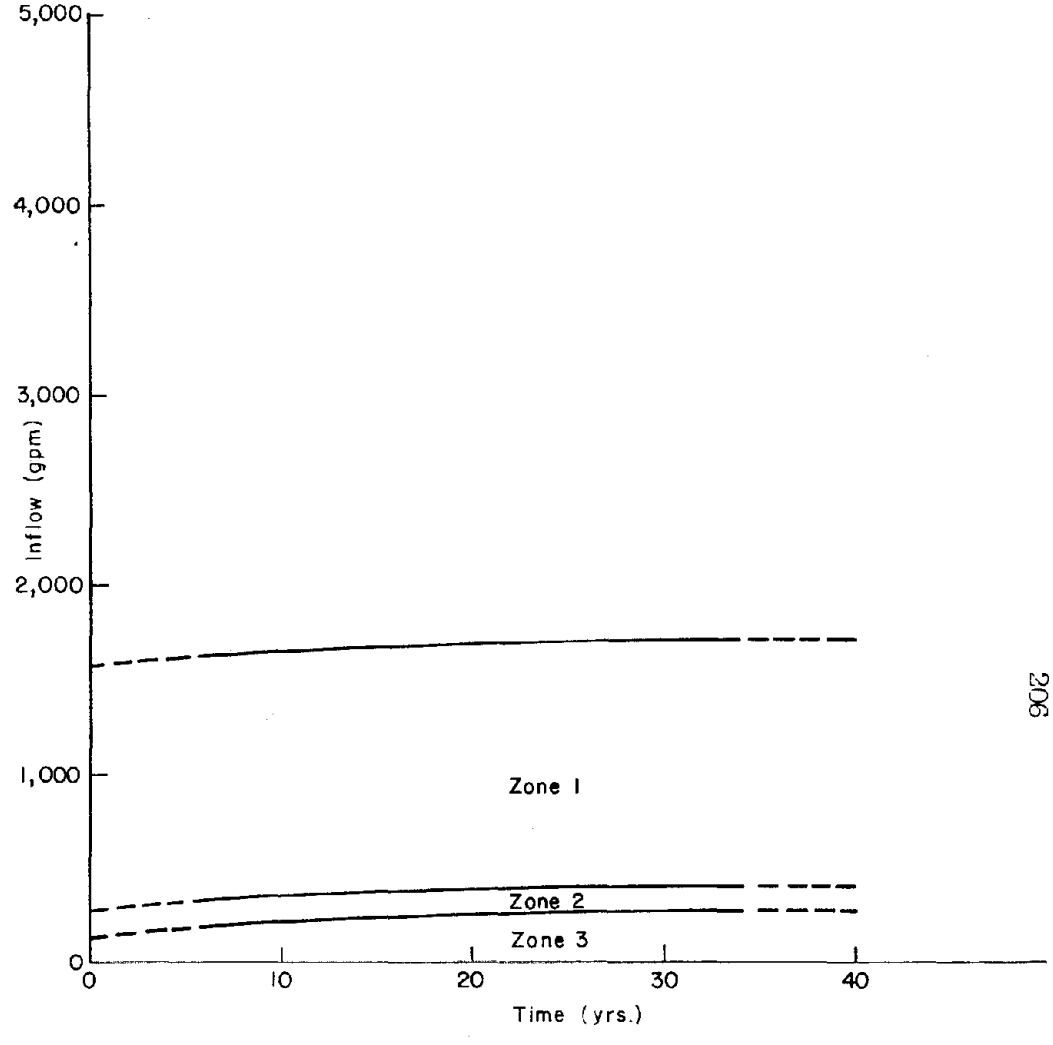
Expansion Rate: .525 mi^2/yr

Initial Radius: 200 ft

Mining Rate: 100,000 ton/day

Figure D-51 MINE INFLOW - SITE 2





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MINE INFLOW (gpm)

Time -yrs	Radius-ft.	Zone 1	(drain) Zone 1	Zone 2	Zone 3	Total
5	4,831	890	375	164	158	1590
10	6,828	890	375	164	205	1630
20	9,655	890	375	164	241	1670
30	11,824	890	375	164	256	1690

DESCRIPTION:

Mining Method: Room & Pillar, Full Subsidence

Number of Passes: 1

Location: Mahogany

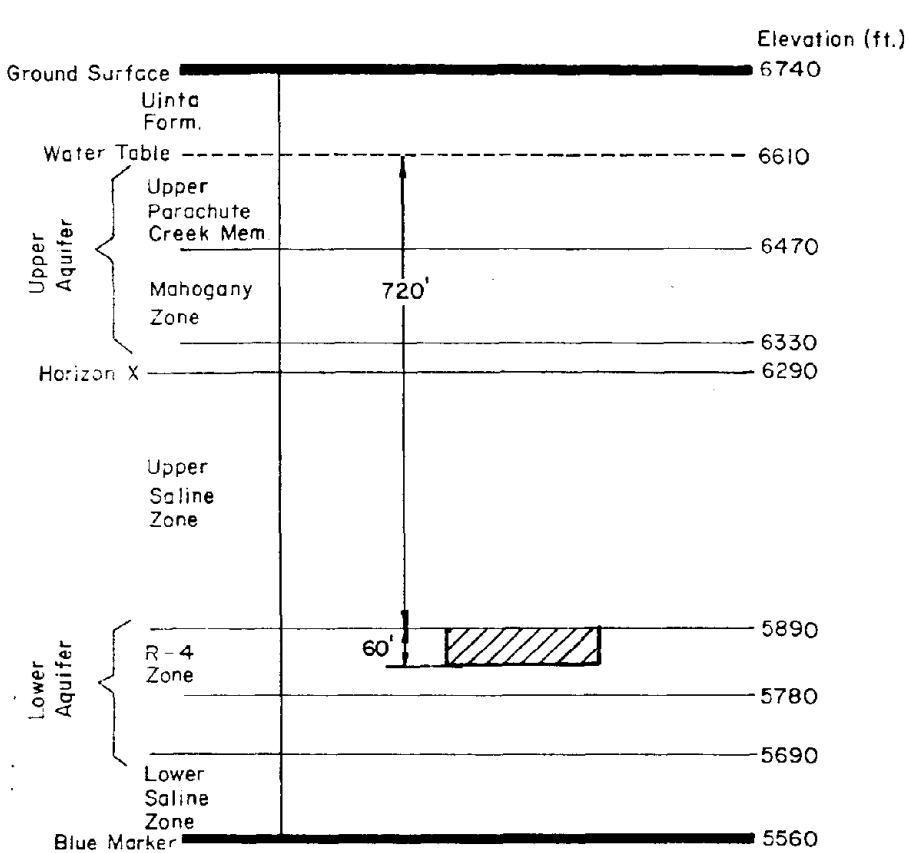
Mining Height: 60 ft

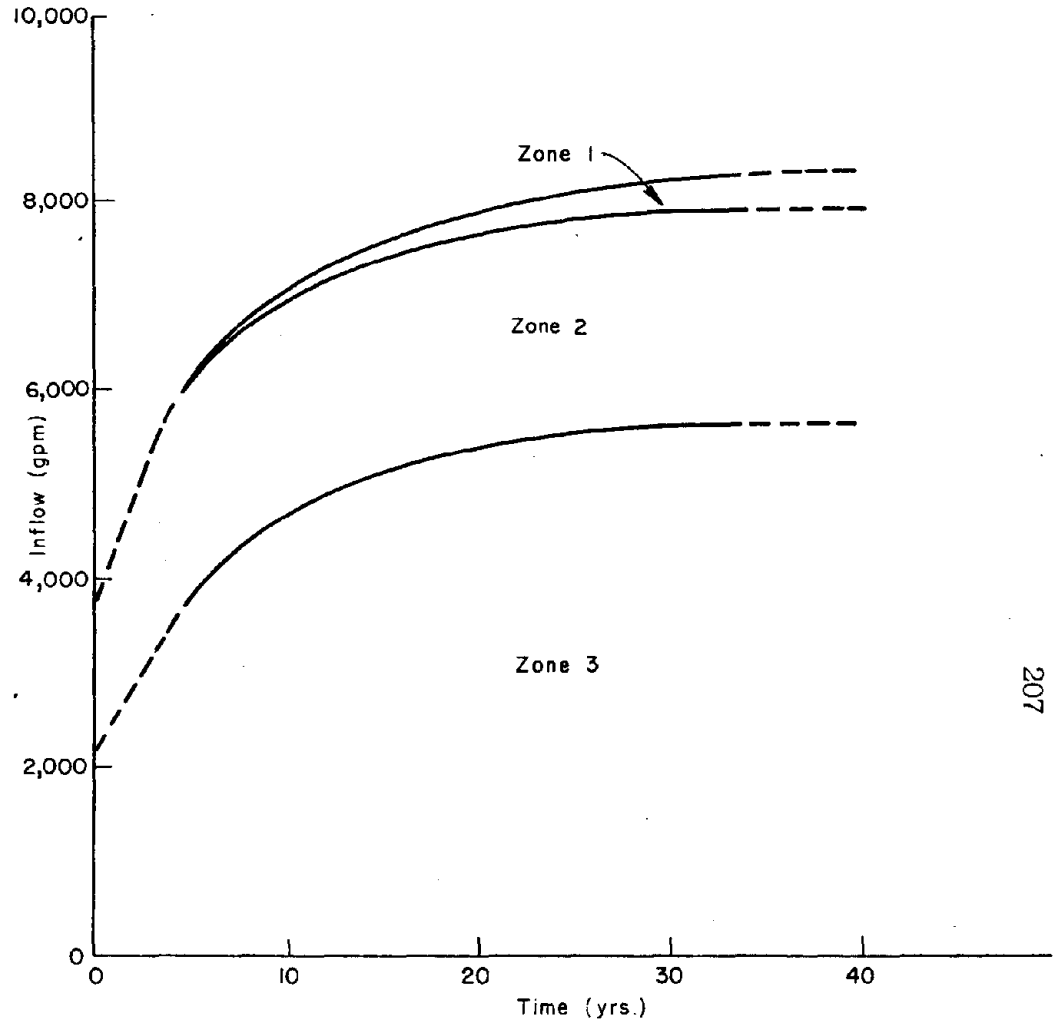
Expansion Rate: .525 mi^2/yr

Initial Radius: 200 ft

Mining Rate: 100,000 ton/day

Figure D-52 MINE INFLOW - SITE 2





Time -yrs	Radius-ft.	MINE INFLOW (gpm) Zone 1	(drain) Zone 1	Zone 2	Zone 3	Total
5	3422	46	-	2282	3705	6030
10	4835	92	-	2282	4675	7050
20	6835	183	-	2281	5380	7840
30	8370	274	-	2281	5666	8220

DESCRIPTION:

Mining Method: Room & Pillar, No Subsidence

Number of Passes: 1

Location: R-4

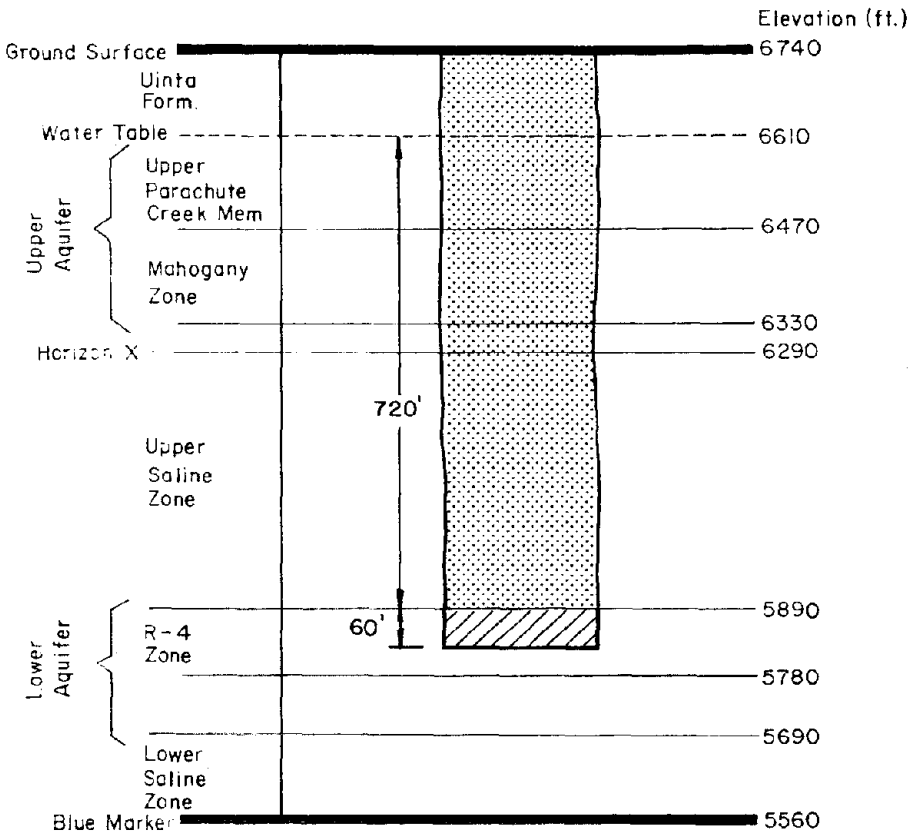
Mining Height: 60 ft

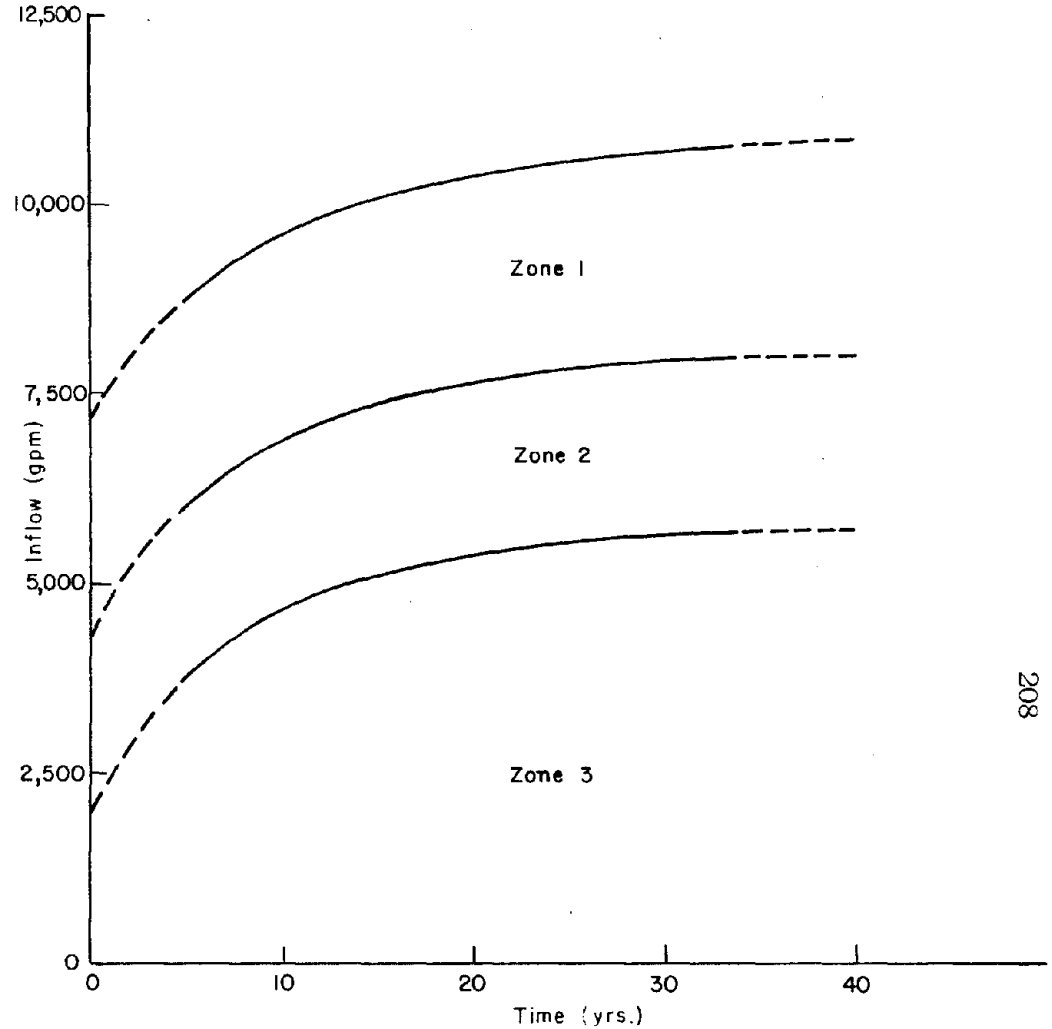
Expansion Rate: .263 mi^2/yr

Initial Radius: 200 ft

Mining Rate: 50,000 ton/day

Figure D-53 MINE INFLOW - SITE 2





Time -yrs	Radius-ft.	MINE INFLOW (gpm) Zone I	(drain) Zone I	Zone 2	Zone 3	Total
5	3422	1982	751	2282	3705	8,720
10	4835	1982	751	2282	4675	9,690
20	6835	1982	751	2281	5380	10,400
30	8370	1982	751	2281	5666	10,680

DESCRIPTION:

Mining Method: Room & Pillar, Full Subsidence

Number of Passes: 1

Location: R-4

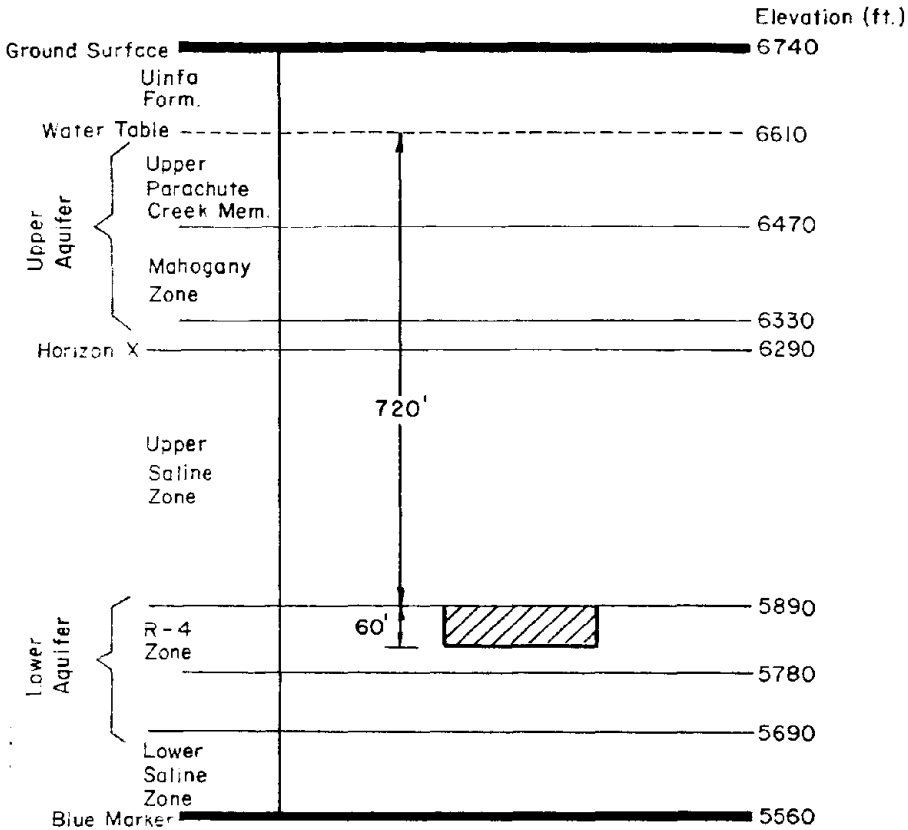
Mining Height: 60 ft

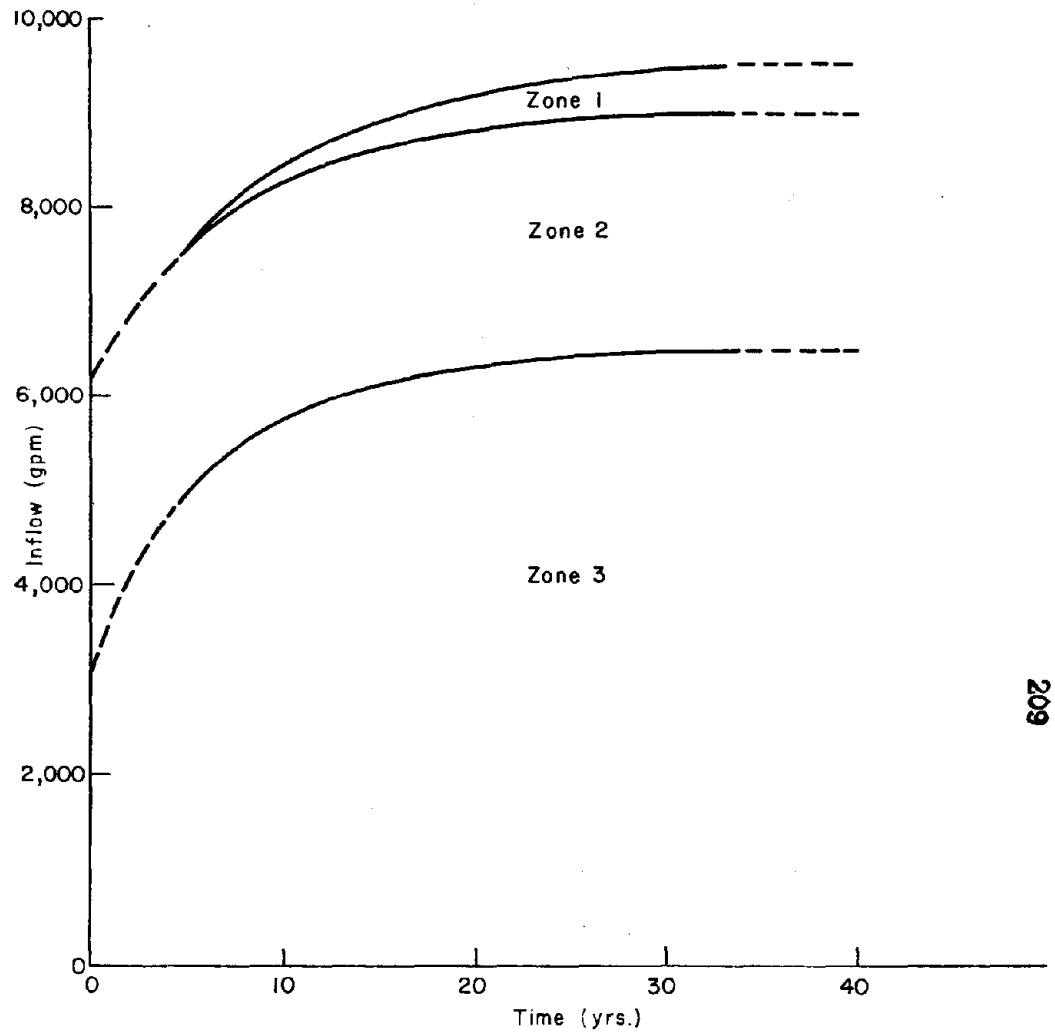
Expansion Rate: .263 mi^2/yr

Initial Radius: 200 ft

Mining Rate: 50,000 ton/day

Figure D-54 MINE INFLOW - SITE 2





MINE INFLOW (gpm)

Time-yrs	Radius-ft.	Zone I	(drain) Zone I	Zone 2	Zone 3	Total
5	4,831	91	-	2471	4963	7530
10	6,828	183	-	2471	5767	8420
20	9,655	365	-	2471	6276	9110
30	11,824	547	-	2471	6467	9490

DESCRIPTION:

Mining Method: Room & Pillar, No Subsidence

Number of Passes: 1

Location: R-4

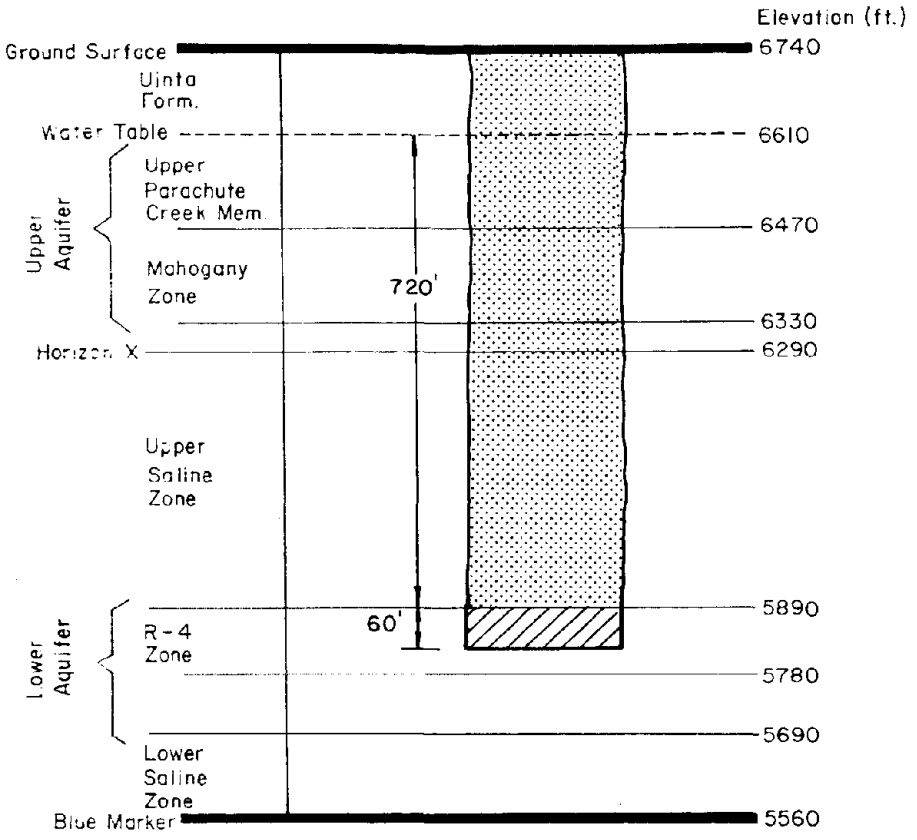
Mining Height: 60 ft

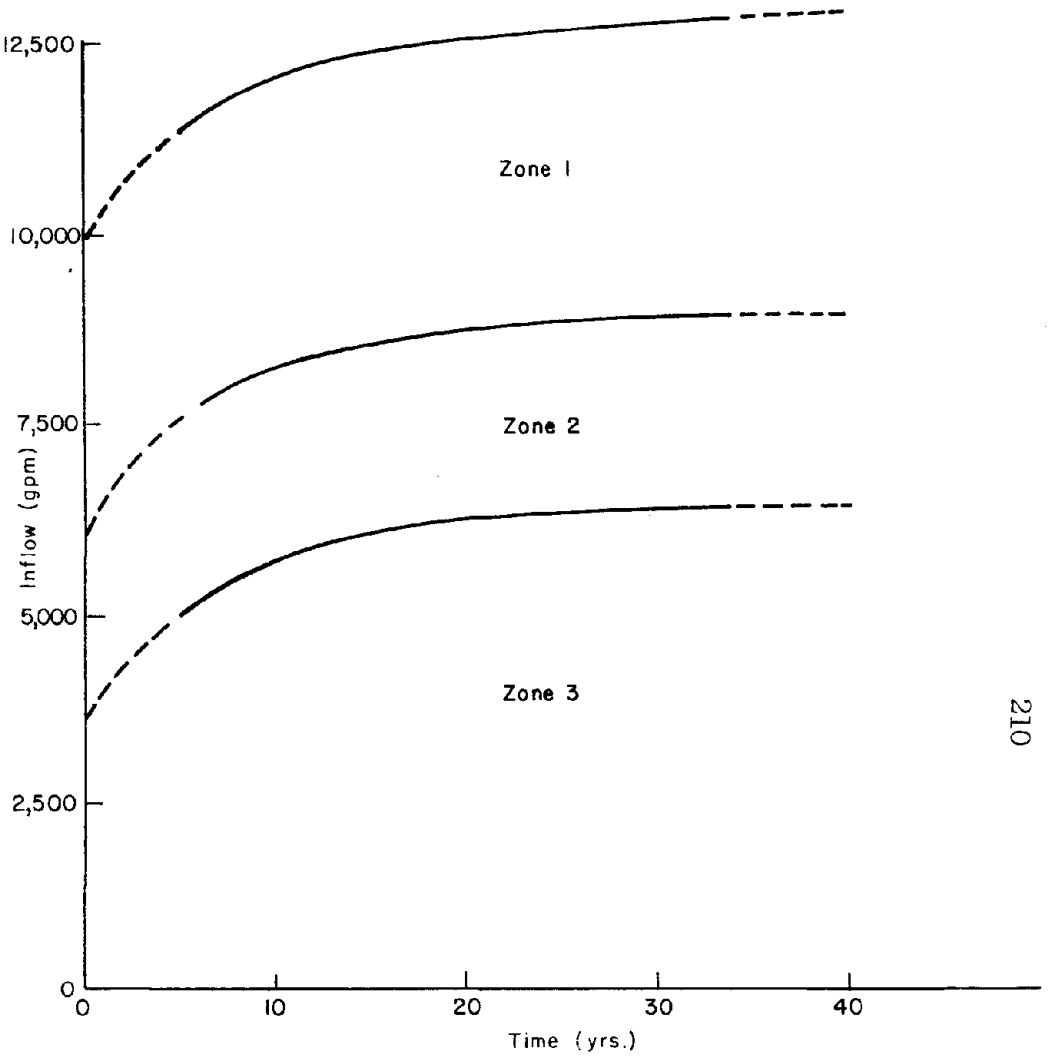
Expansion Rate: .525 mi^2/yr

Initial Radius: 200 ft

Mining Rate: 100,000 ton/day

Figure D-55 MINE INFLOW - SITE 2





210

Time -yrs	Radius-ft.	MINE INFLOW (gpm) Zone 1	(drain) Zone 1	Zone 2	Zone 3	Total
5	4,831	2279	1500	2471	4963	11,210
10	6,828	2279	1500	2471	5767	12,010
20	9,655	2279	1500	2471	6276	12,530
30	11,824	2279	1500	2471	6467	12,720

DESCRIPTION:

Mining Method: Room & Pillar, Full Subsidence

Number of Passes: 1

Location: R-4

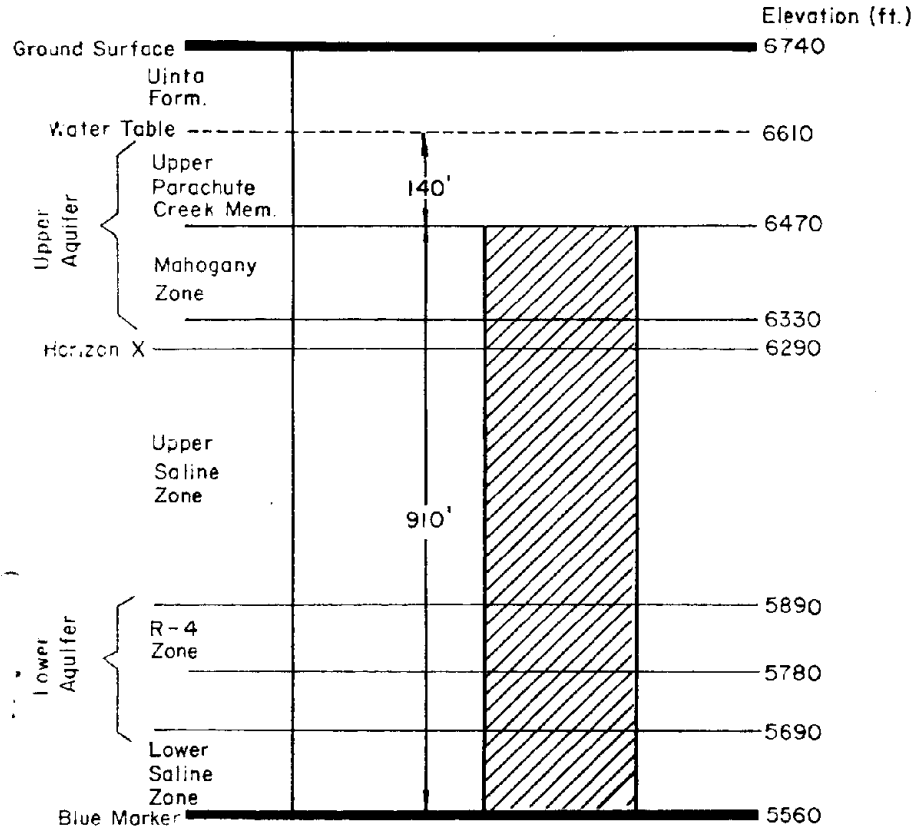
Mining Height: 60 ft

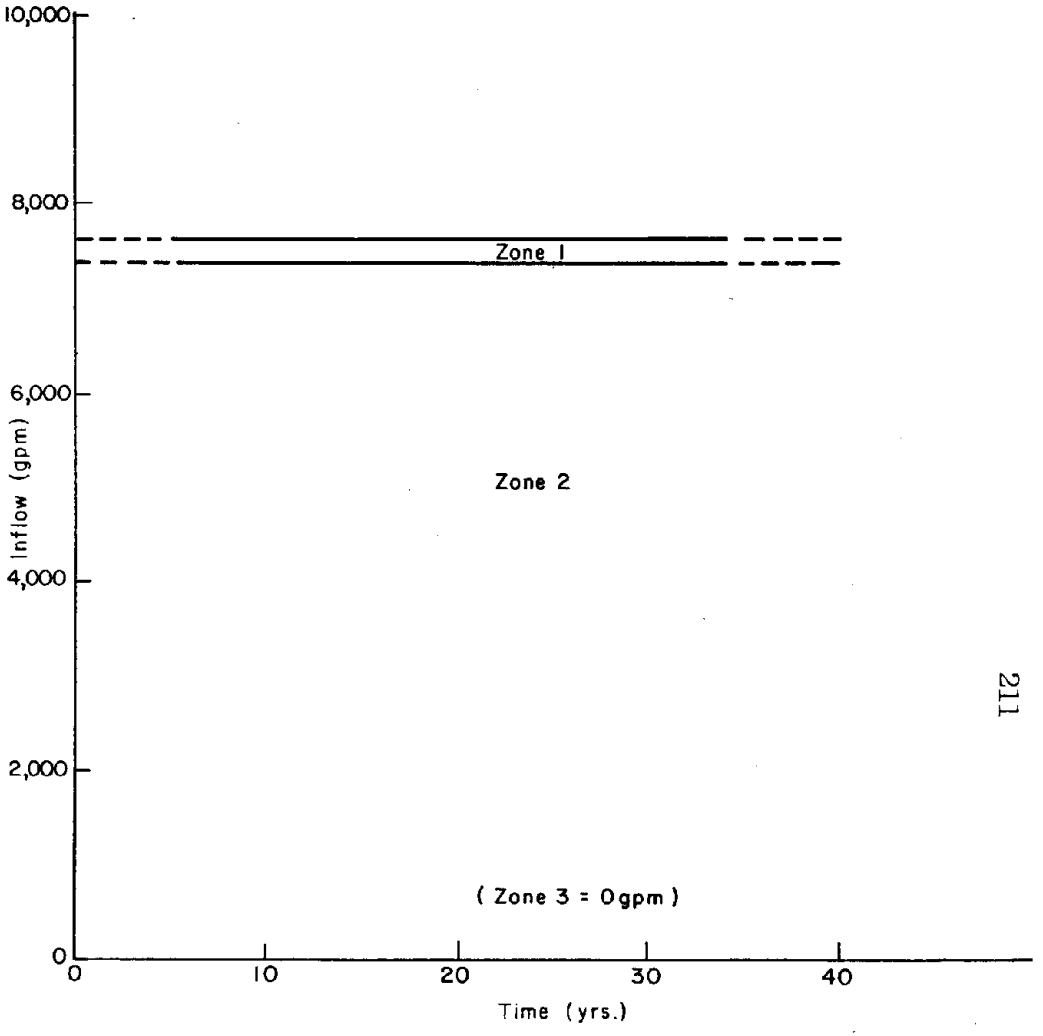
Expansion Rate: .525 mi^2/yr

Initial Radius: 200 ft

Mining Rate: 100,000 ton/day

Figure D-56 MINE INFLOW - SITE 2





MINE INFLOW (gpm)

Time -yrs	Radius-ft.	Zone 1	(drain) Zone 1	Zone 2	Zone 3	Total
5	1152	225	-	7366	-	7590
10	1617	225	-	7356	-	7580
20	2277	225	-	7350	-	7580
30	2786	225	-	7348	-	7570

DESCRIPTION:

Mining Method: Room & Pillar, No Subsidence

Number of Passes: 9

Location: Blue Marker to Mahogany

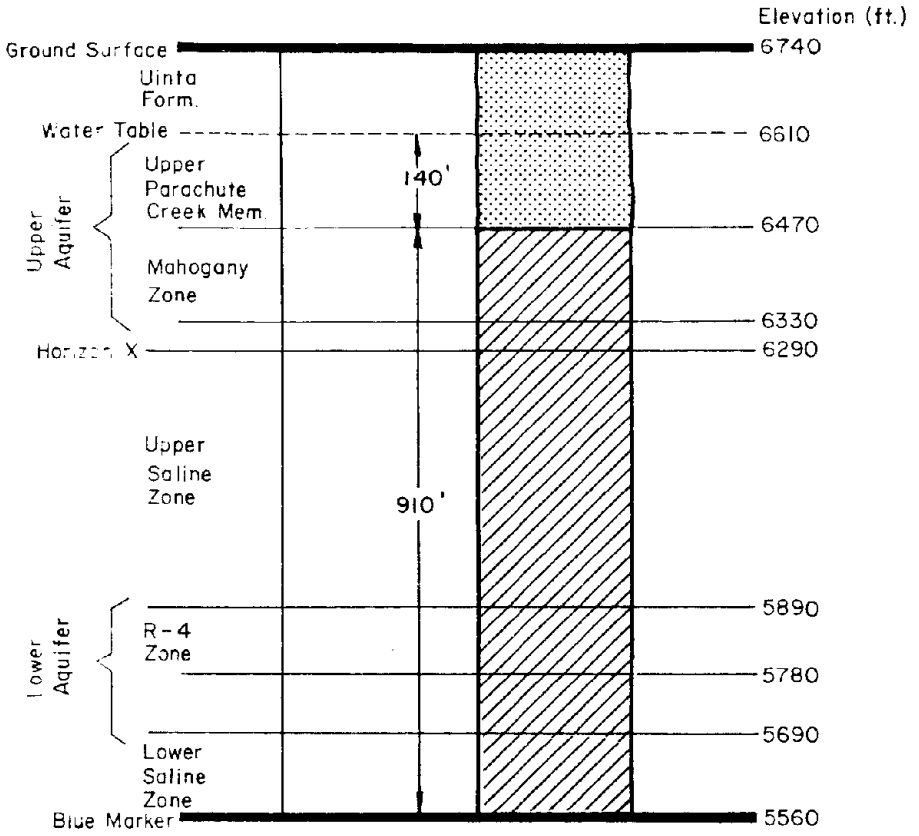
Mining Height: 60 ft, 40 ft sills, total = 910 ft

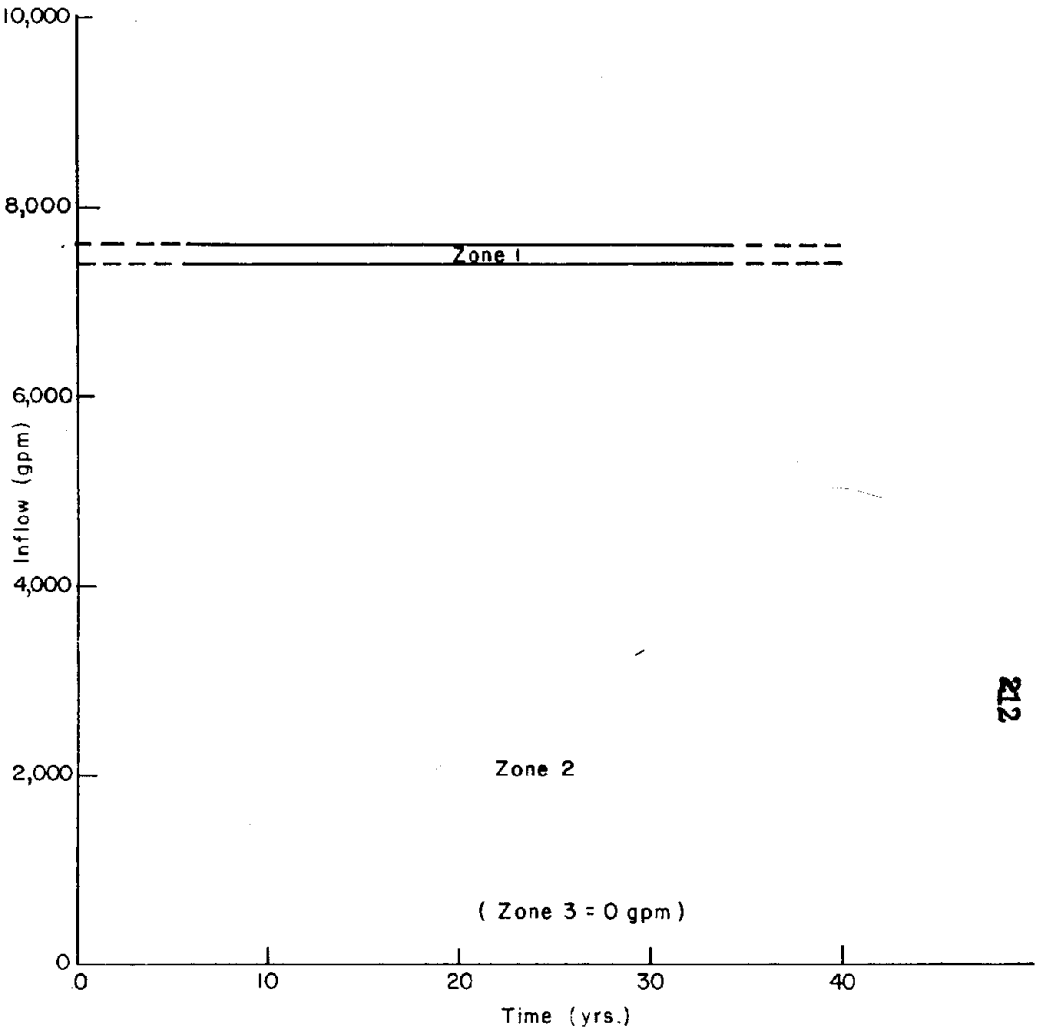
Expansion Rate: .029 mi^2/yr

Initial Radius: 200 ft

Mining Rate: 50,000 ton/day

Figure D-57 MINE INFLOW - SITE 2





212

Time -yrs	Radius-ft.	MINE INFLOW (gpm) Zone 1	(drain) Zone 1	Zone 2	Zone 3	Total
5	1152	209	16	7366	-	7590
10	1617	209	16	7356	-	7580
20	2277	209	16	7350	-	7580
30	2786	209	16	7348	-	7570

DESCRIPTION:

Mining Method: Room & Pillar, Full Subsidence

Number of Passes: 9

Location: Blue Marker to Mahogany

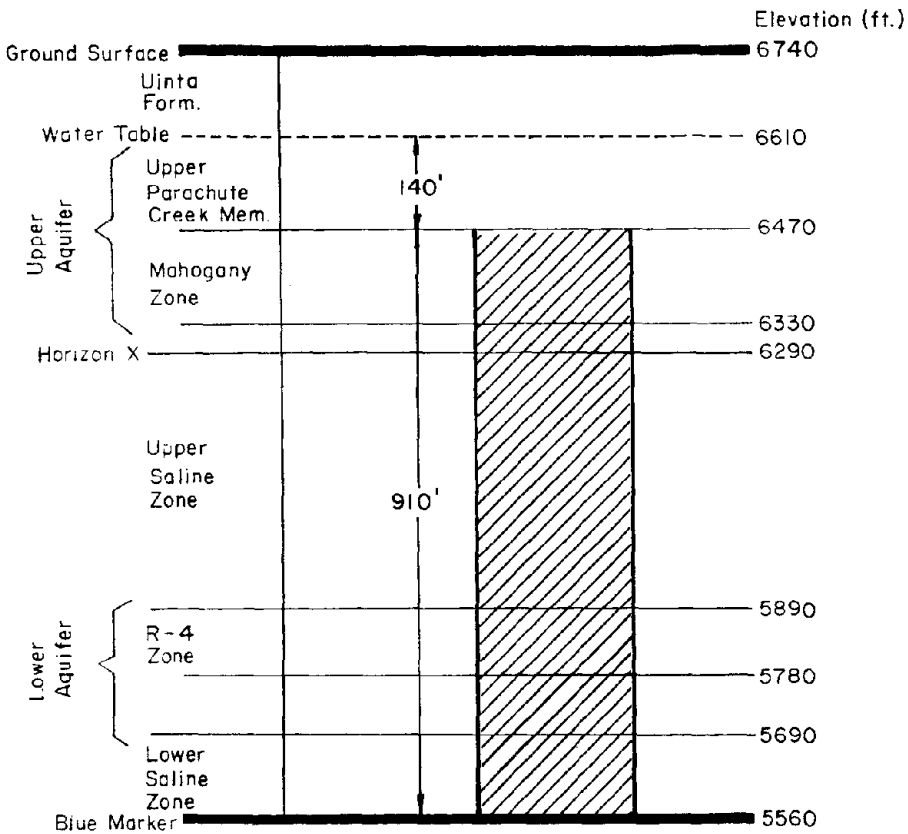
Mining Height: 60 ft, 40 ft sills, total = 910 ft

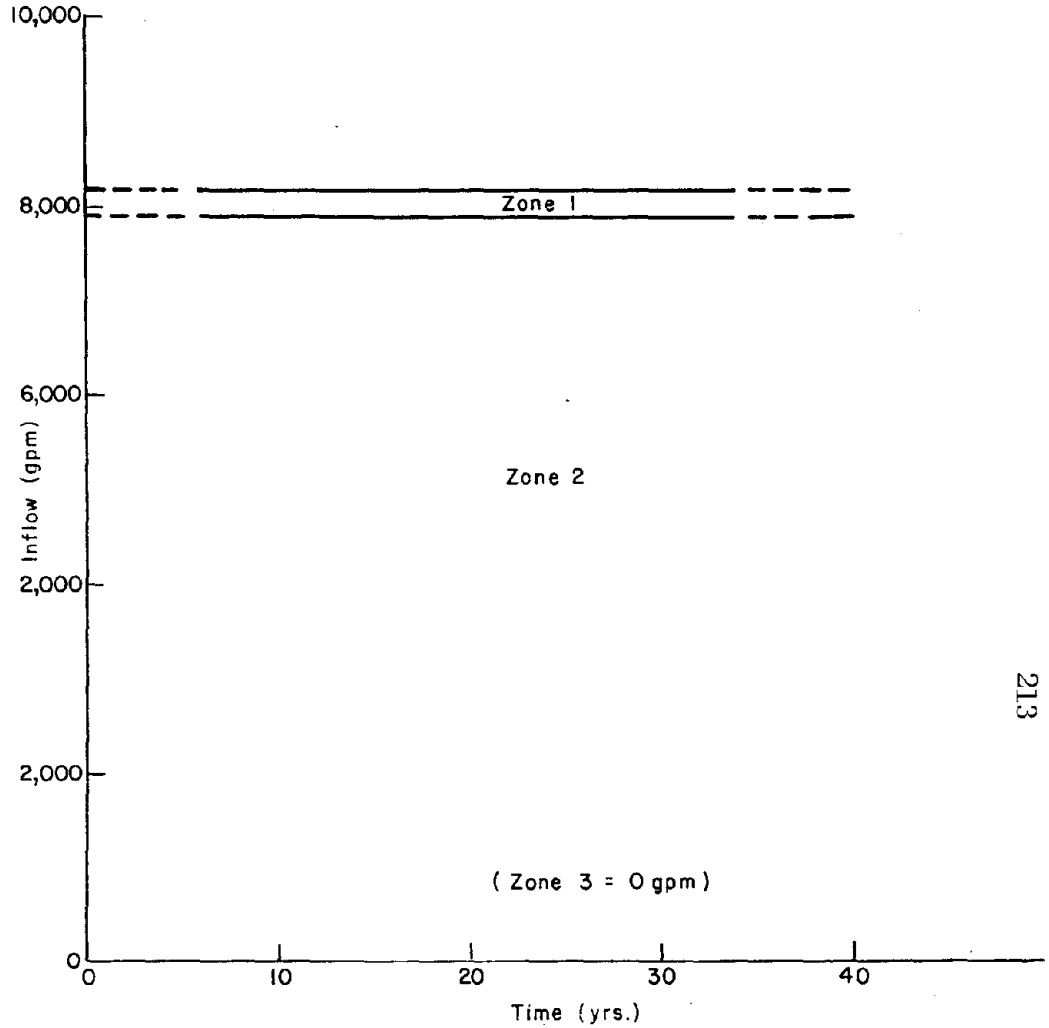
Expansion Rate: .029 mi^2/yr

Initial Radius: 200 ft

Mining Rate: 50,000 ton/day

Figure D-58 MINE INFLOW - SITE 2





MINE INFLOW (gpm)

Time-yrs	Radius-ft.	Zone 1	(drain) Zone 1	Zone 2	Zone 3	Total
5	1617	282	-	7858	-	8140
10	2277	282	-	7853	-	8140
20	3215	282	-	7850	-	8130
30	3935	282	-	7848	-	8130

DESCRIPTION:

Mining Method: Room & Pillar, No Subsidence

Number of Passes: 9

Location: Blue Marker to Mahogany

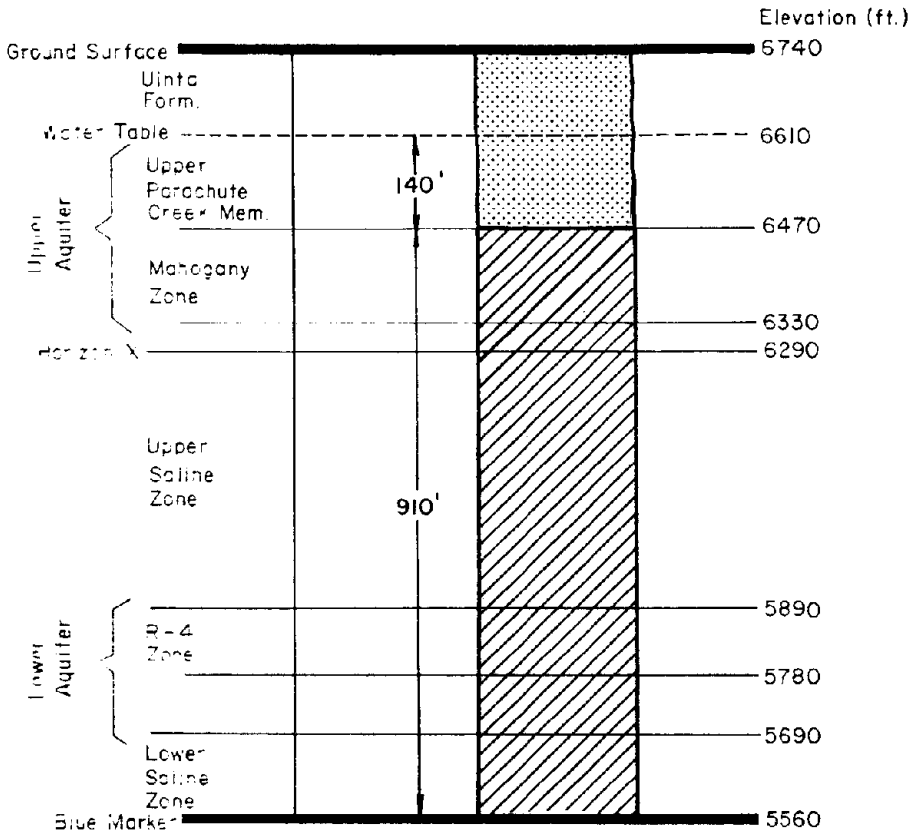
Mining Height: 60 ft, 40 ft sills, total = 910 ft

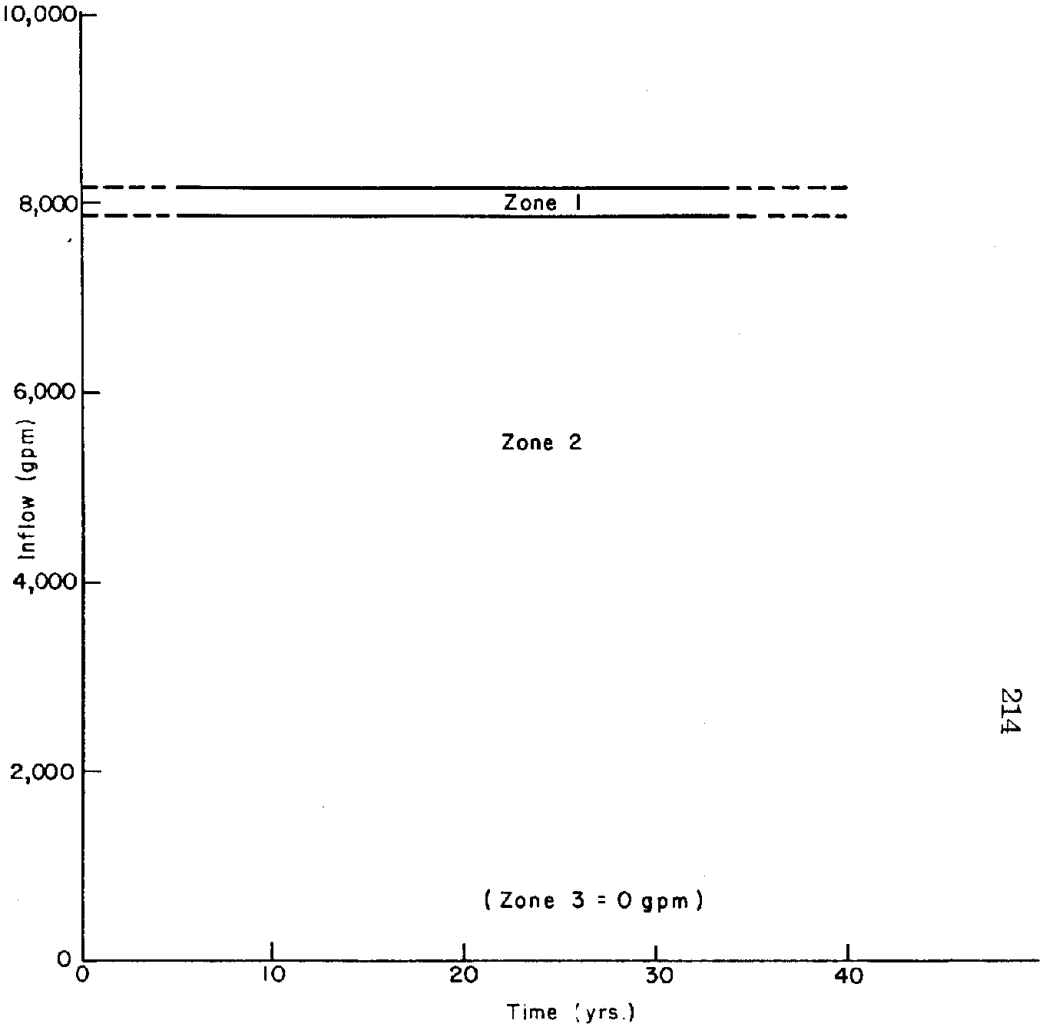
Expansion Rate: .058 mi^2/yr

Initial Radius: 200 ft

Mining Rate: 100,000 ton/day

Figure D-59 MINE INFLOW - SITE 2





Time - yrs	Radius - ft.	MINE INFLOW (gpm) Zone 1	Zone 1 (drain)	Zone 2	Zone 3	Total
5	1617	250	32	7858	-	8140
10	2277	250	32	7853	-	8140
20	3215	250	32	7850	-	8130
30	3935	250	32	7848	-	8130

DESCRIPTION:

Mining Method: Room & Pillar, Full Subsidence

Number of Passes: 9

Location: Blue Marker to Mahogany

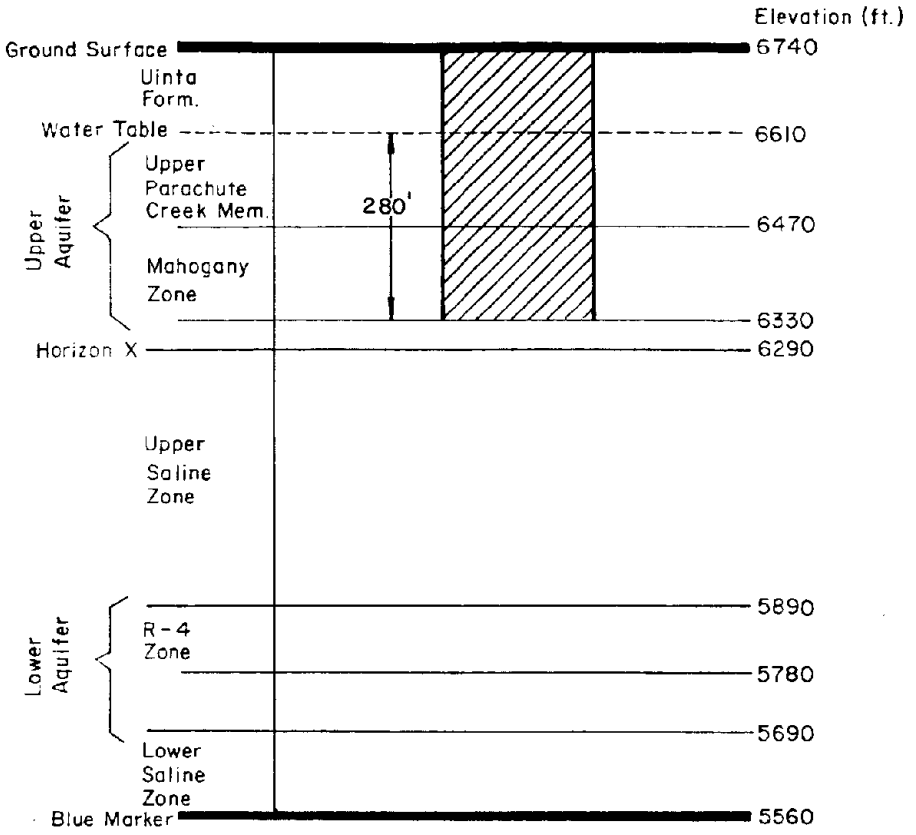
Mining Height: 60 ft, 40 ft sills, total = 910 ft

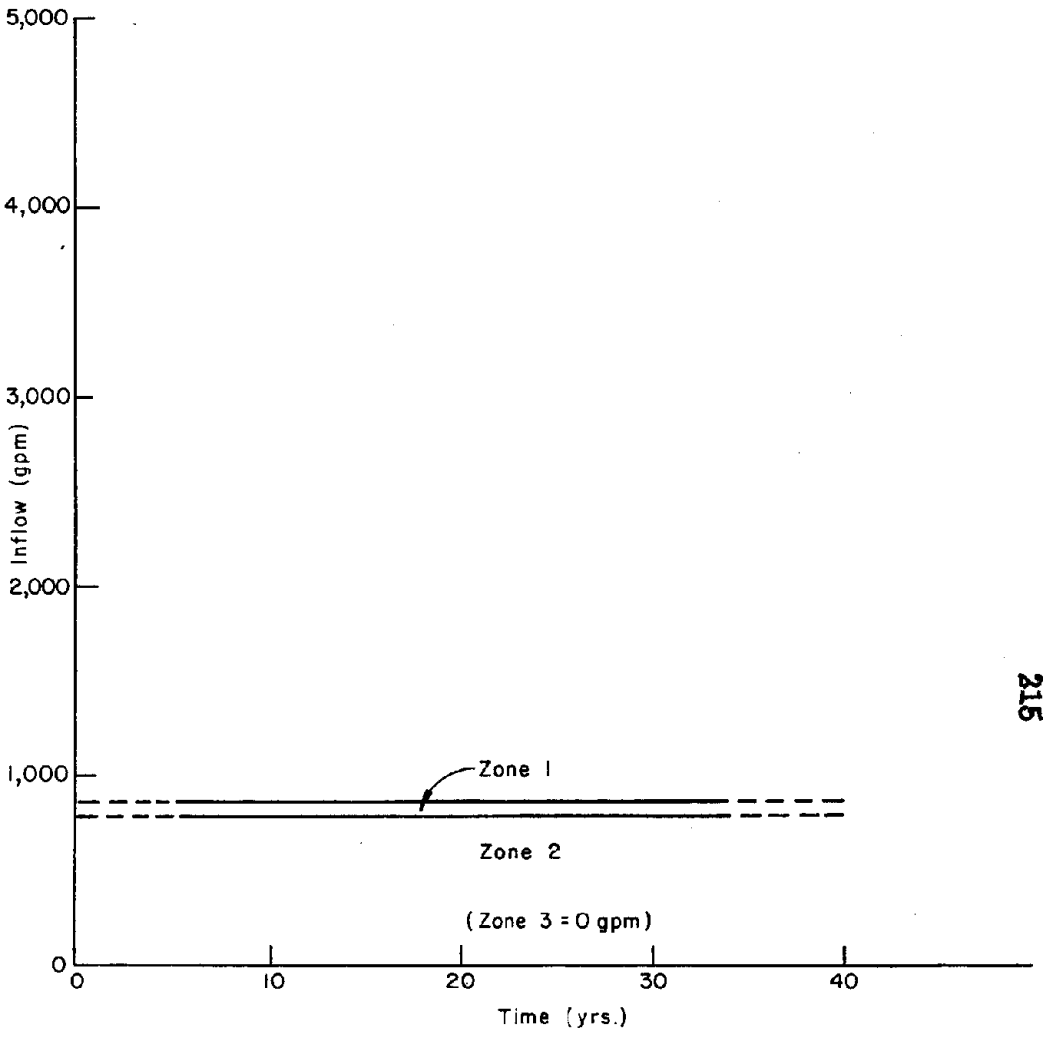
Expansion Rate: .058 mi^2/yr

Initial Radius: 200 ft

Mining Rate: 100,000 ton/day

Figure D-60 MINE INFLOW - SITE 2





MINE INFLOW (gpm)

Time-yrs	Radius-ft.	Zone 1	(drain) Zone 1	Zone 2	Zone 3	Total
5	1496	-	56	803	-	860
10	2111	-	56	803	-	860
20	2982	-	56	803	-	860
30	3651	-	56	803	-	860

DESCRIPTION:

Mining Method: Open Pit

Number of Passes: 1

Location: Shallow

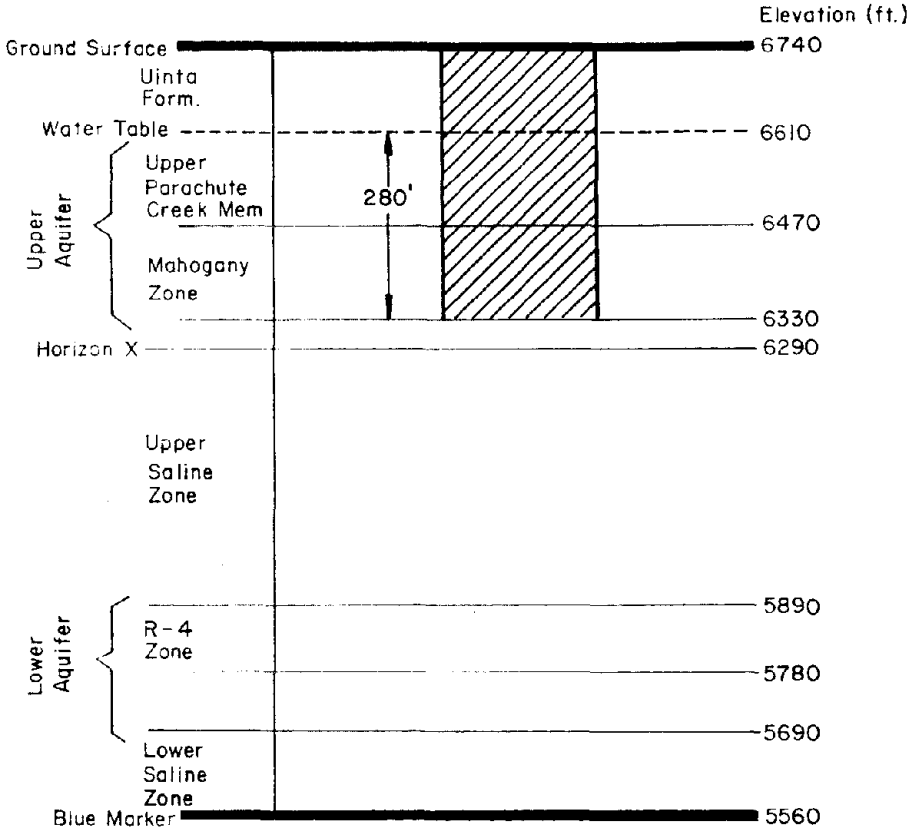
Mining Height: 410 ft, 280 ft open to aquifer

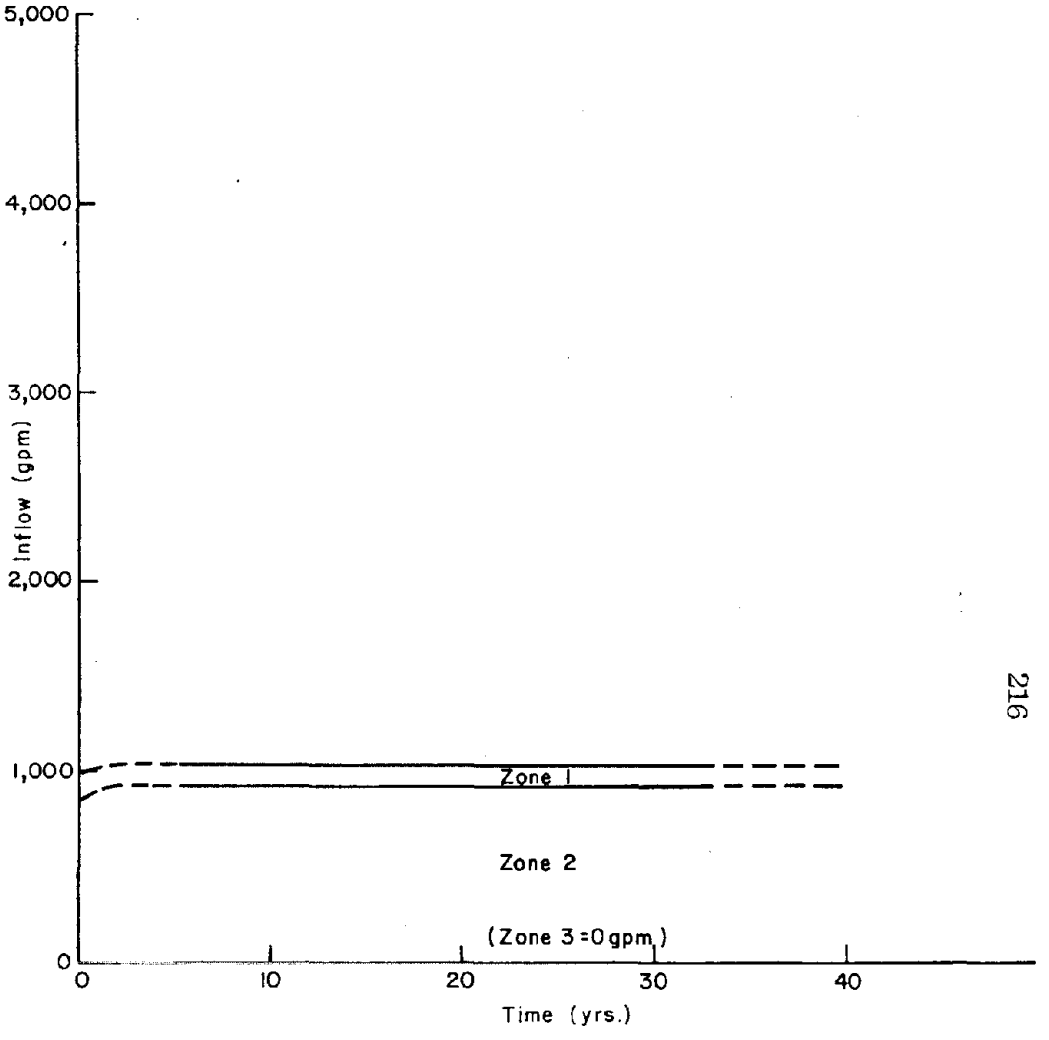
Expansion Rate: .050 mi^2/yr

Initial Radius: 140 ft

Mining Rate: 50,000 ton/day

Figure D-61 MINE INFLOW - SITE 2





MINE INFLOW (gpm)

Time - yrs	Radius - ft.	Zone 1	(drain) Zone 1	Zone 2	Zone 3	Total
5	2111	-	111	953	-	1060
10	2982	-	111	953	-	1060
20	4215	-	111	953	-	1060
30	5162	-	111	953	-	1060

DESCRIPTION:

Mining Method: Open Pit

Number of Passes: 1

Location: Shallow

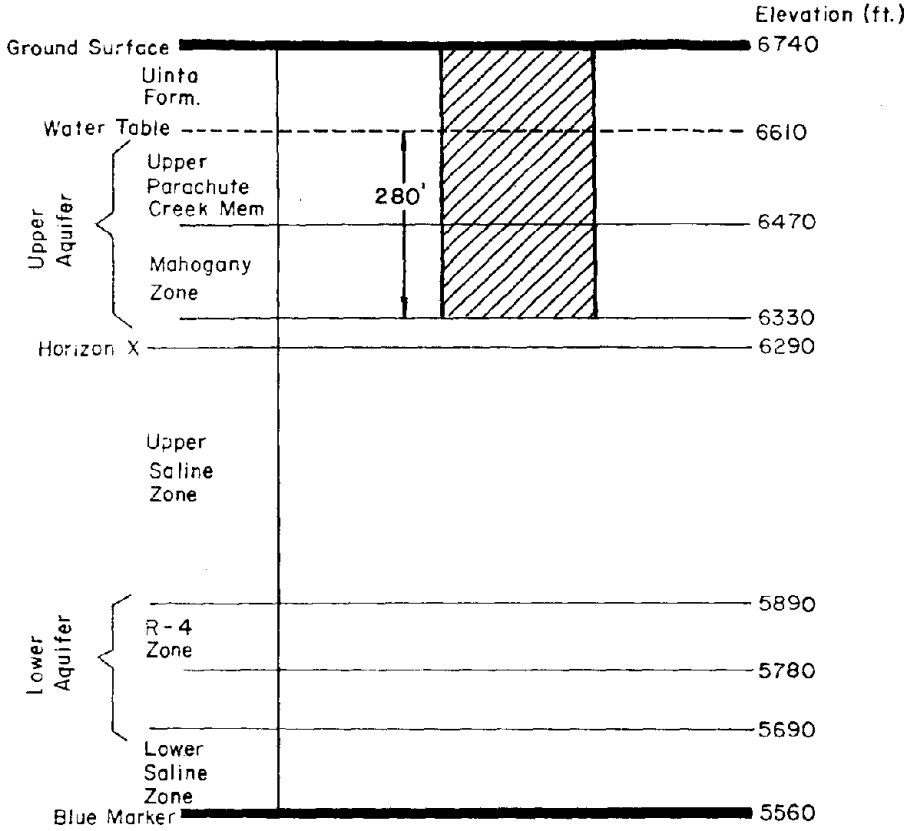
Mining Height: 410 ft, 280 ft open to aquifer

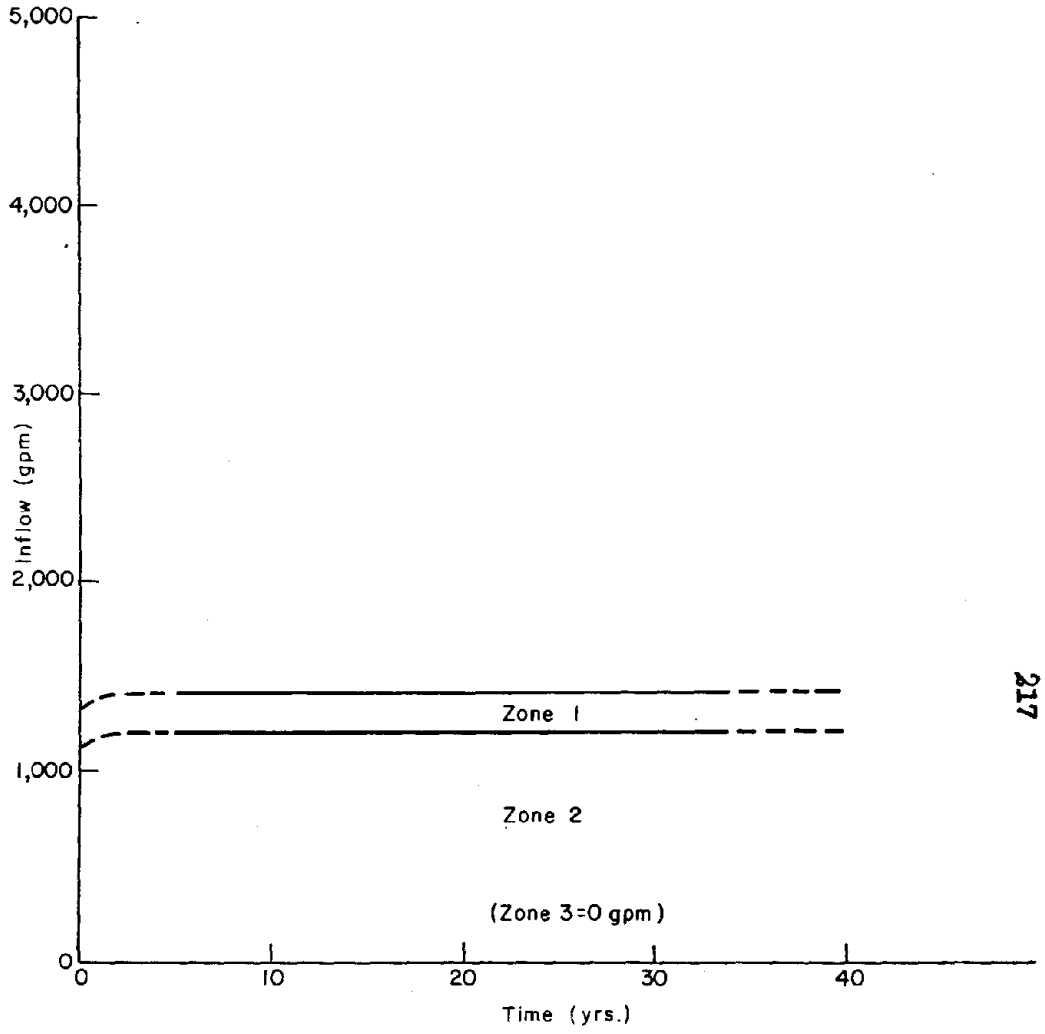
Expansion Rate: .100 mi^2/yr

Initial Radius: 140 ft

Mining Rate: 100,000 ton/day

Figure D-62 MINE INFLOW - SITE 2





Time -yrs	Radius-ft.	MINE INFLOW (gpm) Zone 1	Zone 1 (drain)	Zone 2	Zone 3	Total
5	2975	-	221	1182	-	1400
10	4205	-	221	1182	-	1400
20	5945	-	221	1182	-	1400
30	7280	-	221	1182	-	1400

DESCRIPTION:

Mining Method: Open Pit

Number of Passes: 1

Location: Shallow

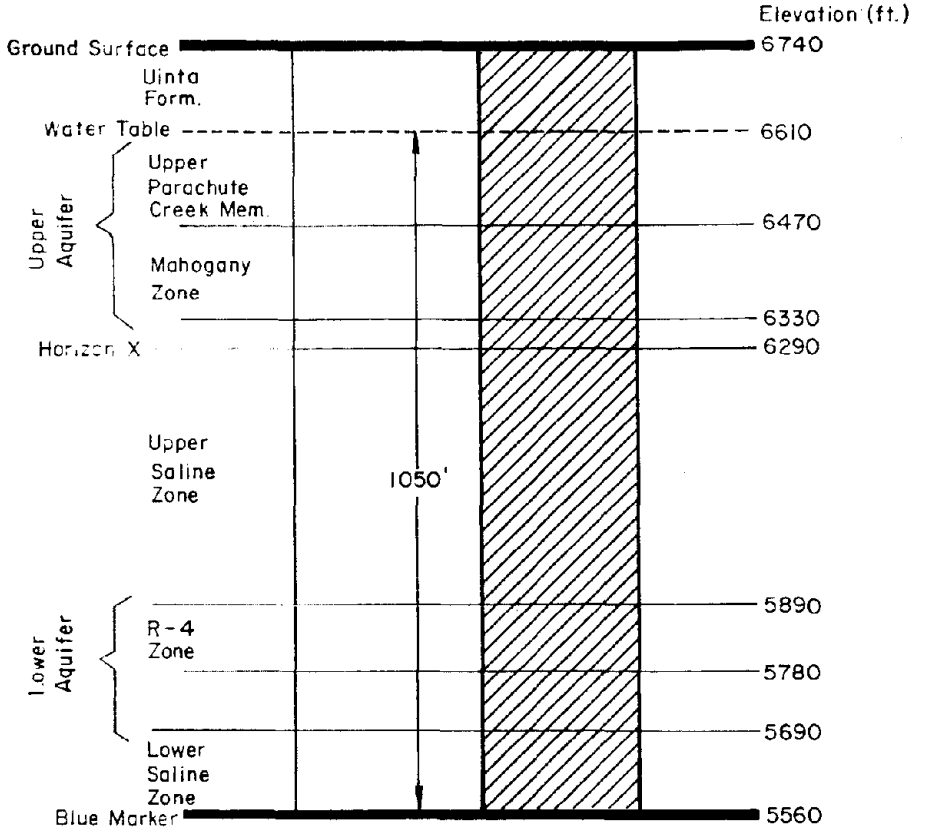
Mining Height: 410 ft, 280 ft open to aquifer

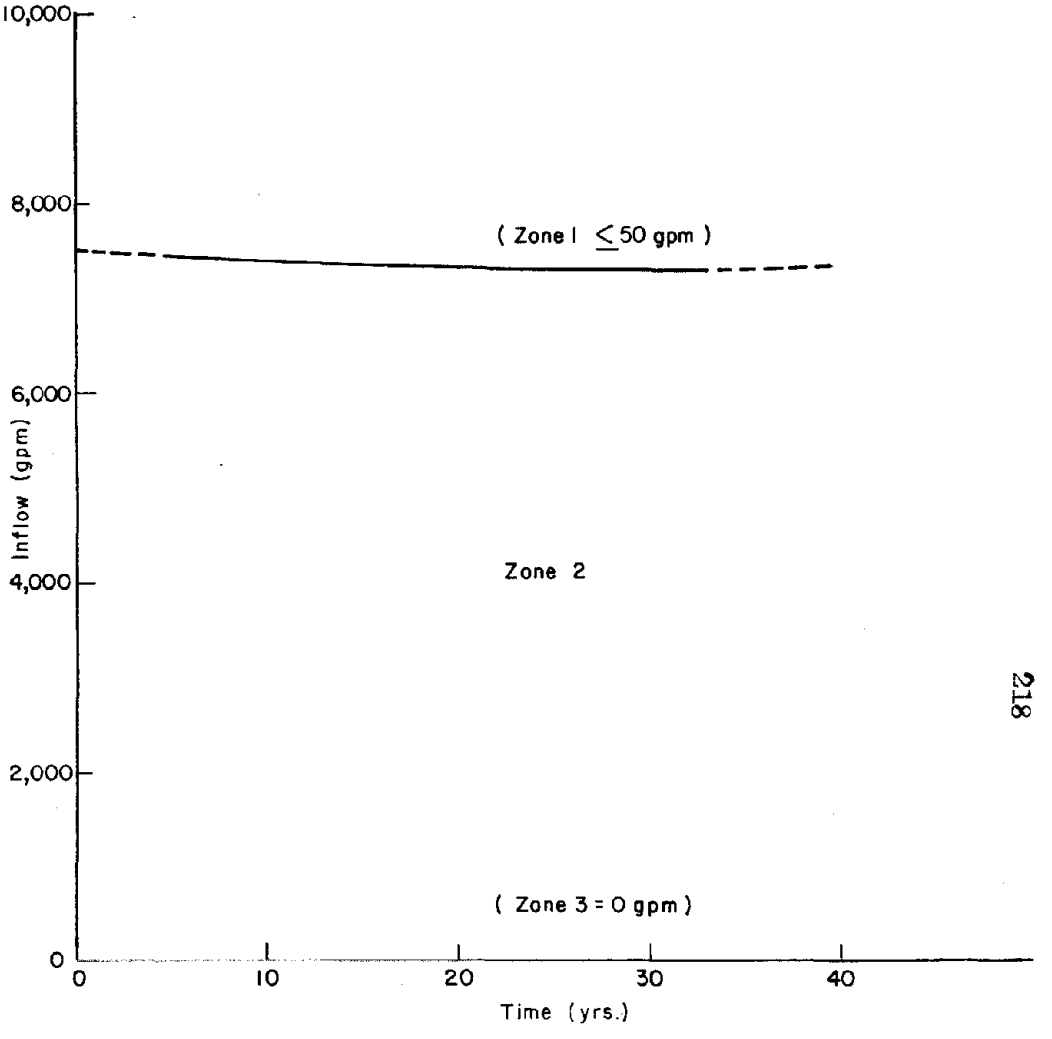
Expansion Rate: .199 mi^2/yr

Initial Radius: 140 ft

Mining Rate: 200,000 ton/day

Figure D-63 MINE INFLOW- SITE 2





		MINE INFLOW (gpm)				
Time -yrs	Radius-ft.	Zone I	(drain) Zone I	Zone 2	Zone 3	Total
5	899	-	50	7465	-	7520
10	1158	-	50	7349	-	7400
20	1551	-	50	7283	-	7330
30	1863	-	50	7260	-	7310

DESCRIPTION:

Mining Method: Open Pit

Number of Passes: 1

Location: Deep

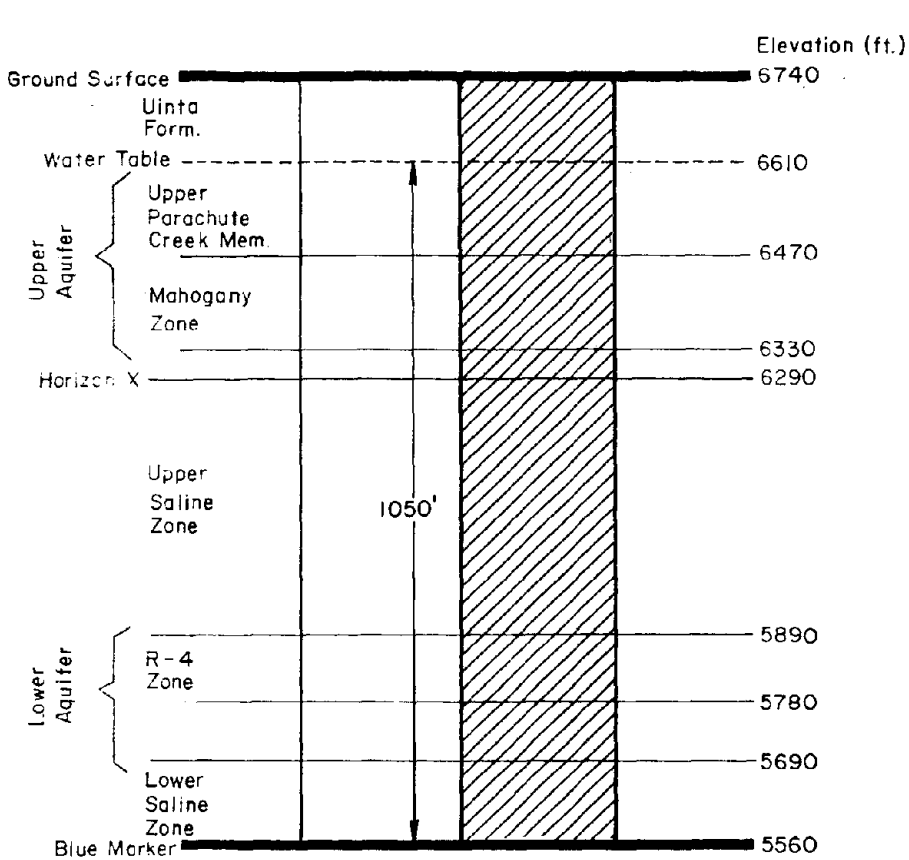
Mining Height: 1180 ft, 1050 ft open to aquifer

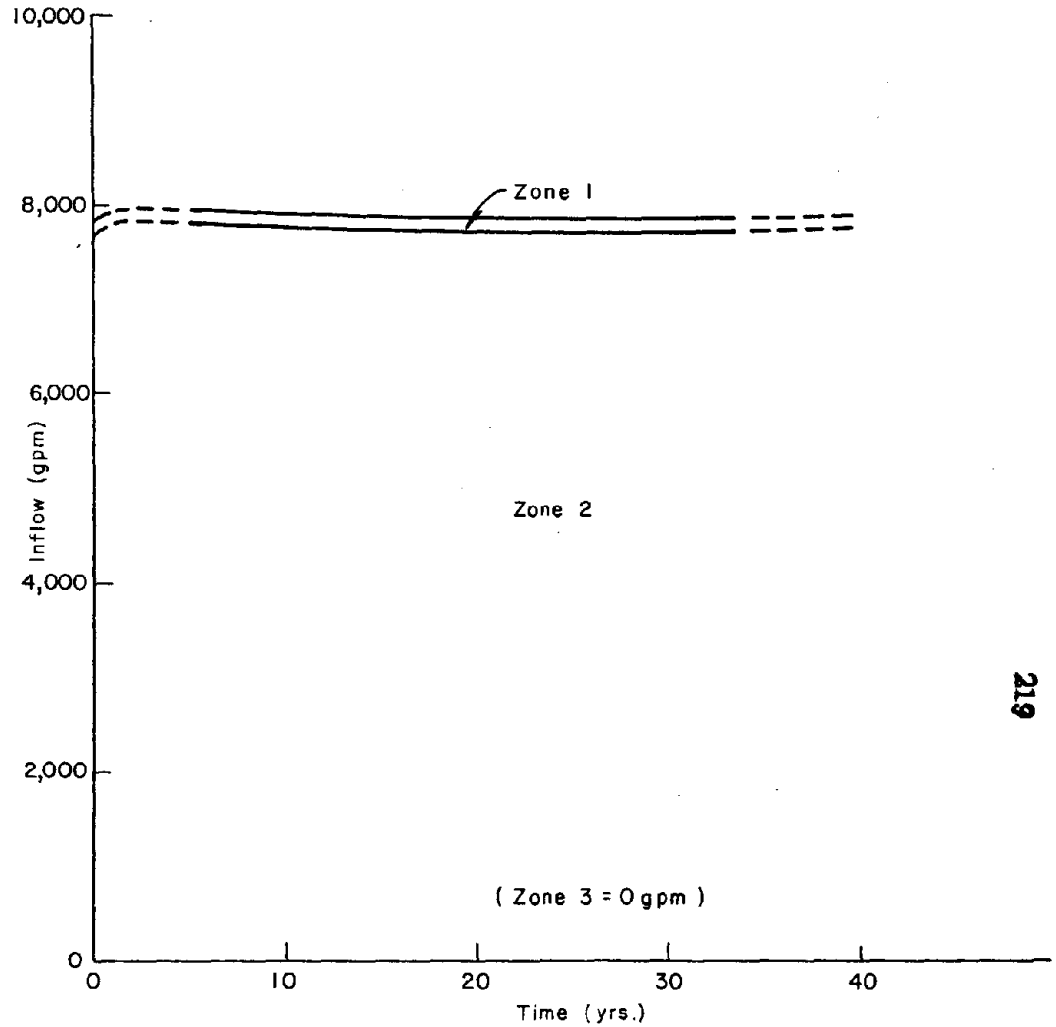
Expansion Rate: .012 mi^2/yr

Initial Radius: 525 ft

Mining Rate: 50,000 ton/day

Figure D-64 MINE INFLOW - SITE 2





MINE INFLOW (gpm)

Time-yrs	Radius-ft.	Zone 1	Zone 1 (drain)	Zone 2	Zone 3	Total
5	1158	-	100	7875	-	7980
10	1551	-	100	7801	-	7900
20	2130	-	100	7761	-	7860
30	2582	-	100	7748	-	7850

DESCRIPTION:

Mining Method: Open Pit

Number of Passes: 1

Location: Deep

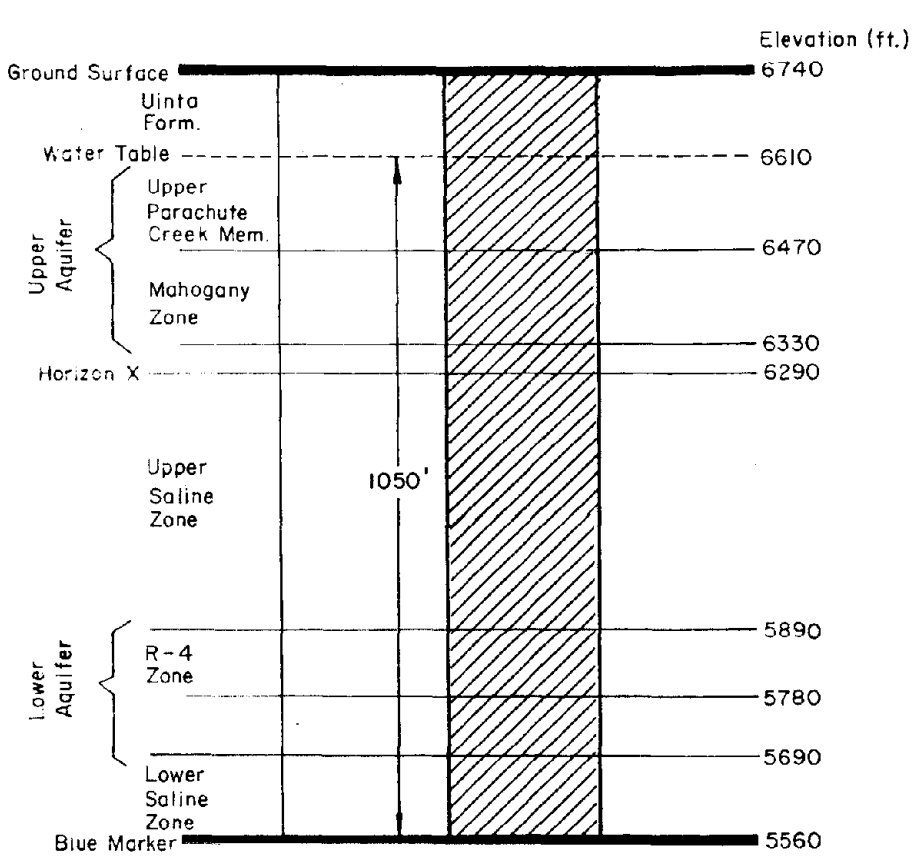
Mining Height: 1180 ft, 1050 ft open to aquifer

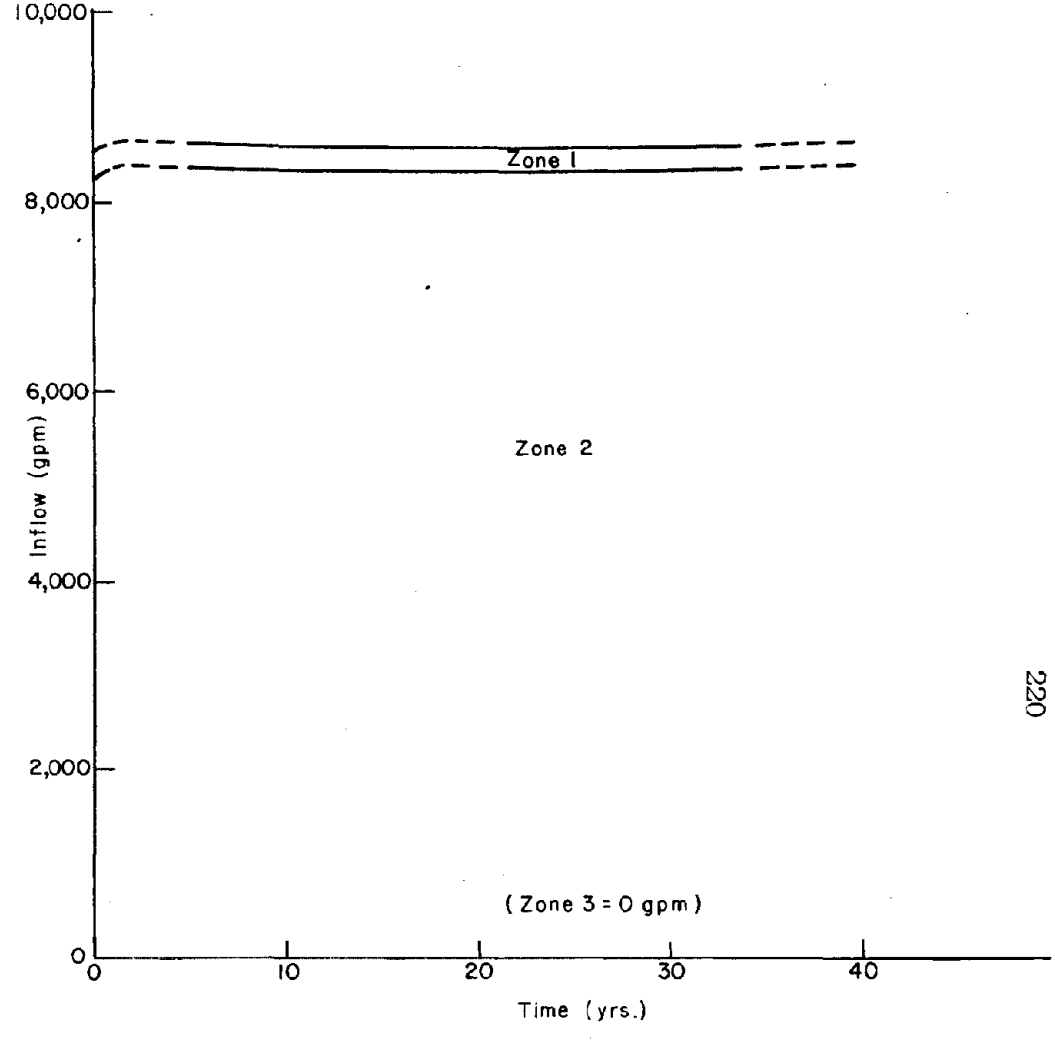
Expansion Rate: .024 mi^2/yr

Initial Radius: 525 ft

Mining Rate: 100,000 ton/day

Figure D-65 MINE INFLOW - SITE 2





MINE INFLOW (gpm)

Time -yrs	Radius-ft.	Zone 1	(drain) Zone 1	Zone 2	Zone 3	Total
5	1551	-	200	8405	-	8610
10	2130	-	200	8360	-	8560
20	2966	-	200	8336	-	8540
30	3613	-	200	8328	-	8530

DESCRIPTION:

Mining Method: Open Pit

Number of Passes: 1

Location: Deep

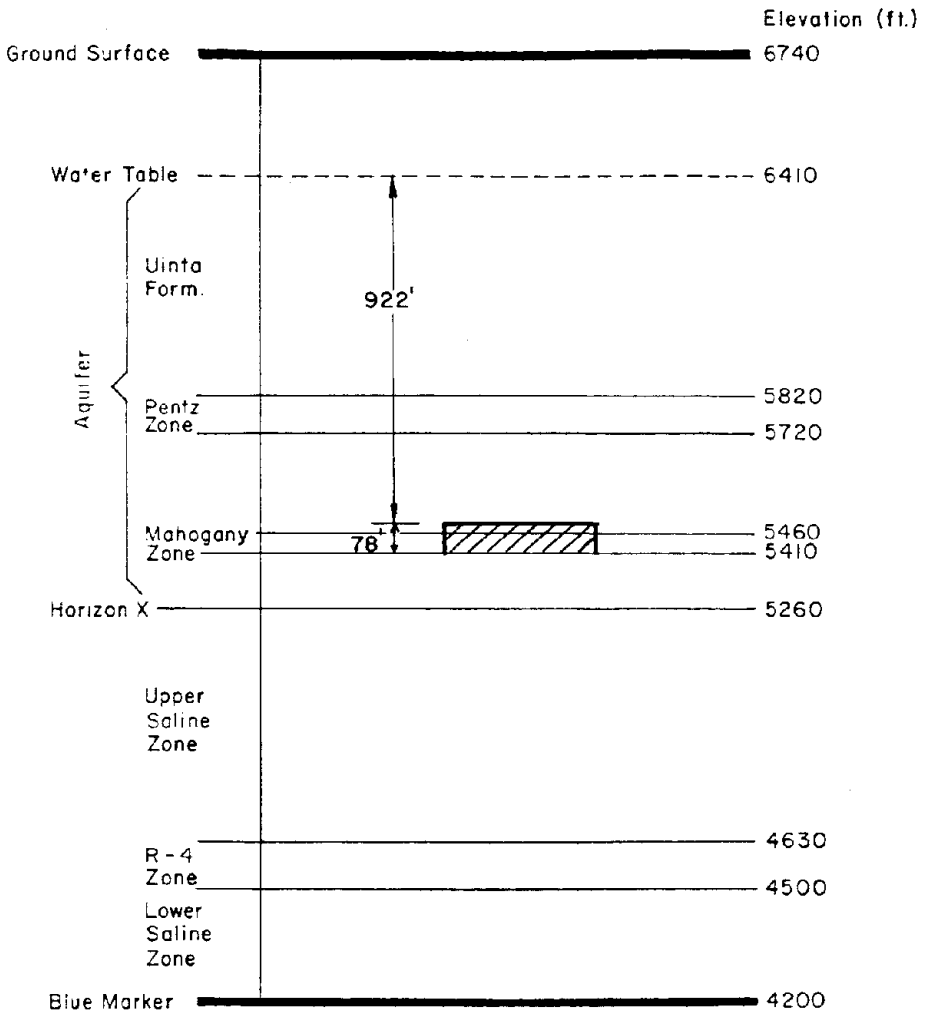
Mining Height: 1180 ft, 1050 ft open to aquifer

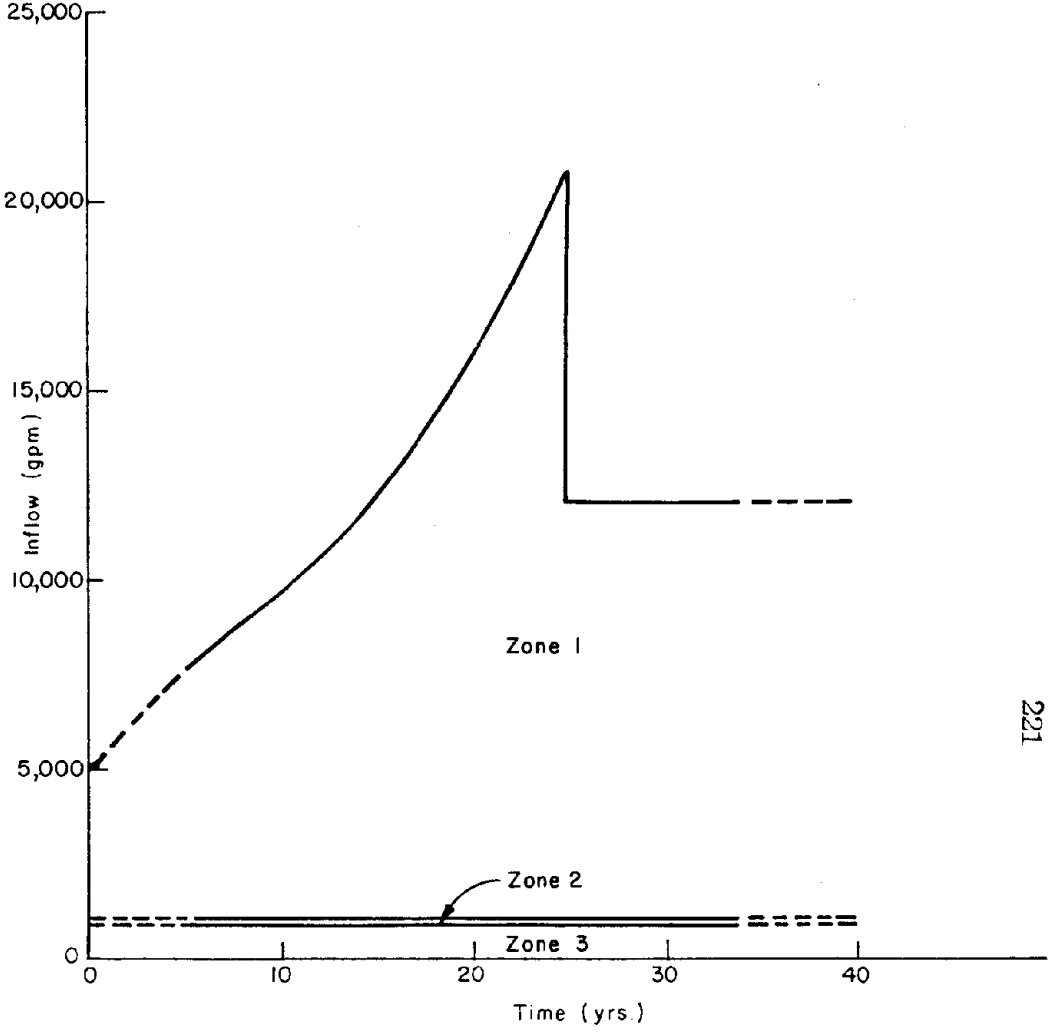
Expansion Rate: .048 mi^2/yr

Initial Radius: 525 ft

Mining Rate: 200,000 ton/day

Figure D-66 MINE INFLOW - SITE 2





MINE INFLOW (gpm)

Time - yrs	Radius - ft.	Zone 1	Zone 1 (drain)	Zone 2	Zone 3	Total
5	3672	6,469	-	158	960	7,590
10	5189	11,073	-	158	963	12,190
20	7336	19,672	-	158	964	20,790
30	8984	10,972	-	158	964	12,090

DESCRIPTION:

Mining Method: Room & Pillar, No Subsidence

Number of Passes: 1

Location: Mahogany

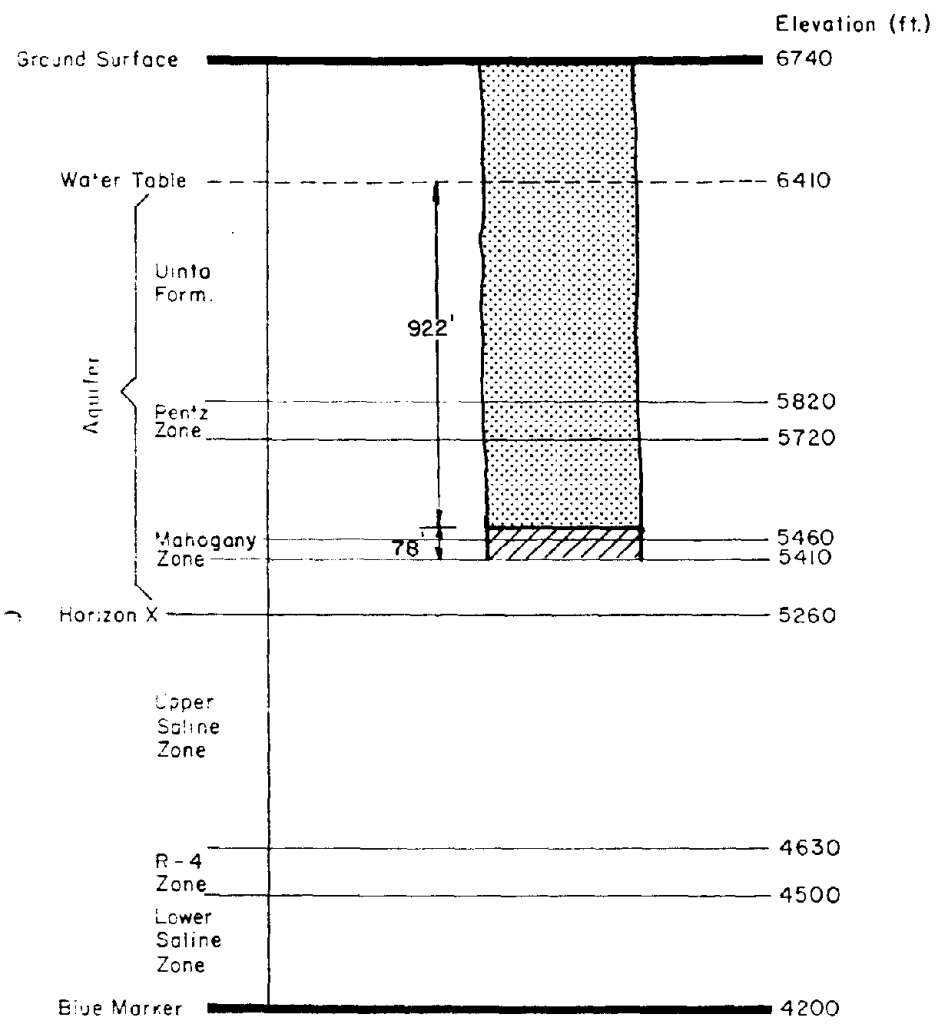
Mining Height: 78 ft

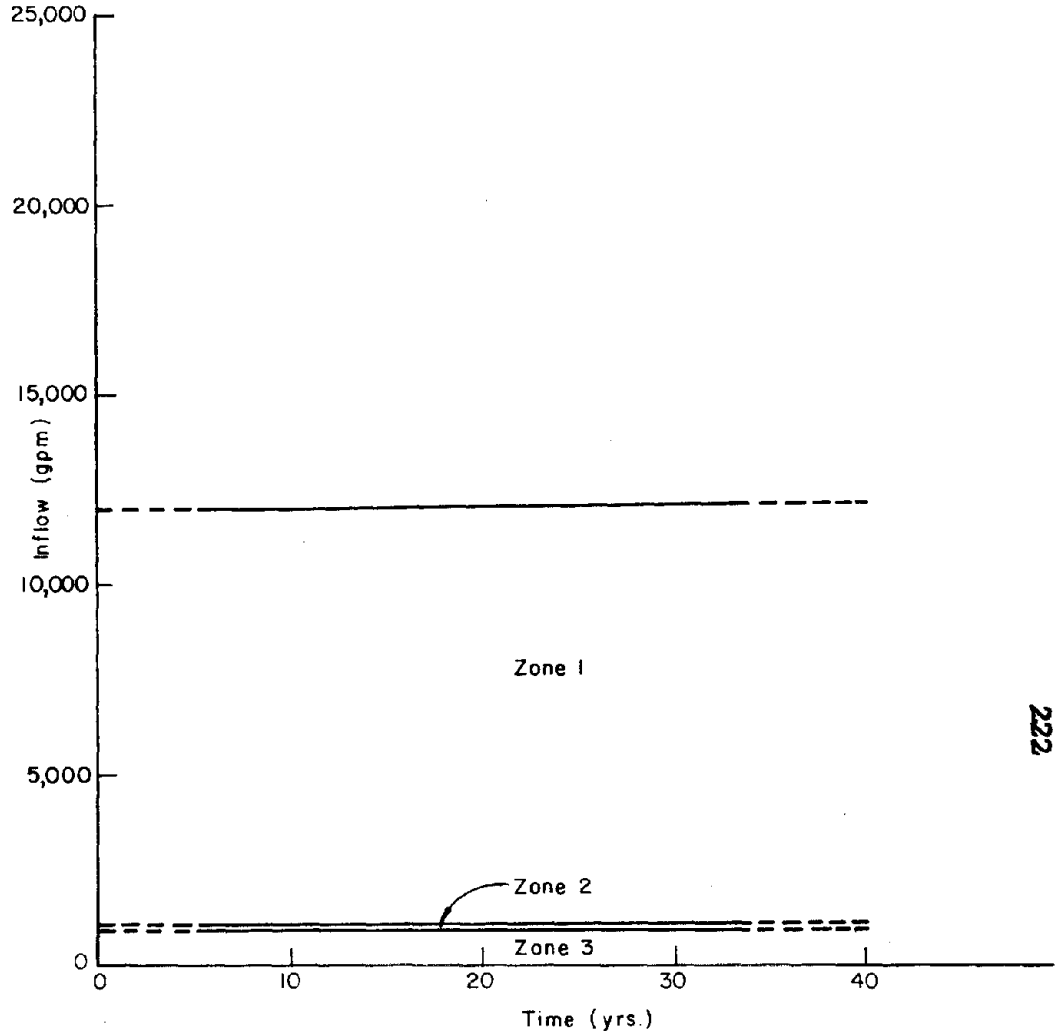
Expansion Rate: .303 mi^2/yr

Initial Radius: 200 ft

Mining Rate: 50,000 ton/day

Figure D-67 MINE INFLOW - SITE 3





222

Time - yrs	Radius - ft.	MINE INFLOW (gpm) Zone 1	Zone 1 (drain)	Zone 2	Zone 3	Total
5	3672	3213	7759	158	960	12,090
10	5189	3213	7759	158	963	12,090
20	7336	3213	7759	158	964	12,090
30	8984	3213	7759	158	964	12,090

DESCRIPTION:

Mining Method: Room & Pillar, Full Subsidence

Number of Passes: 1

Location: Mahogany

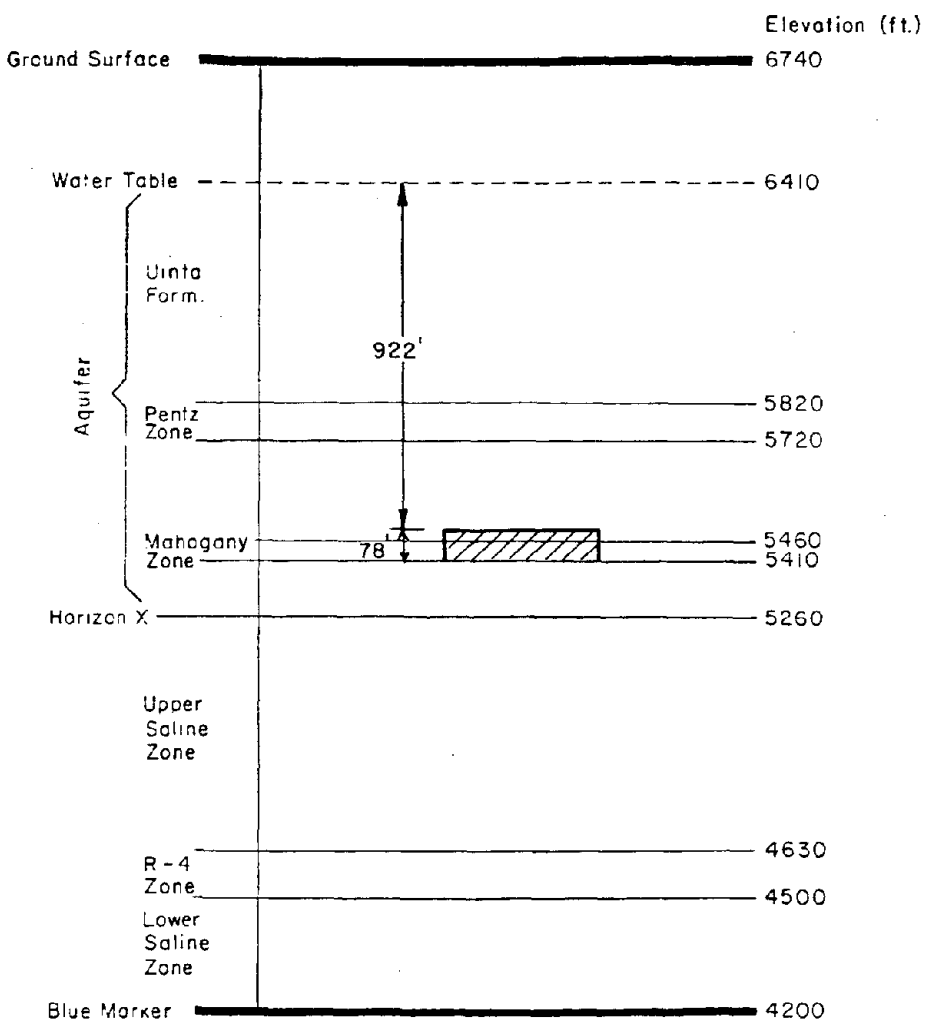
Mining Height: 78 ft

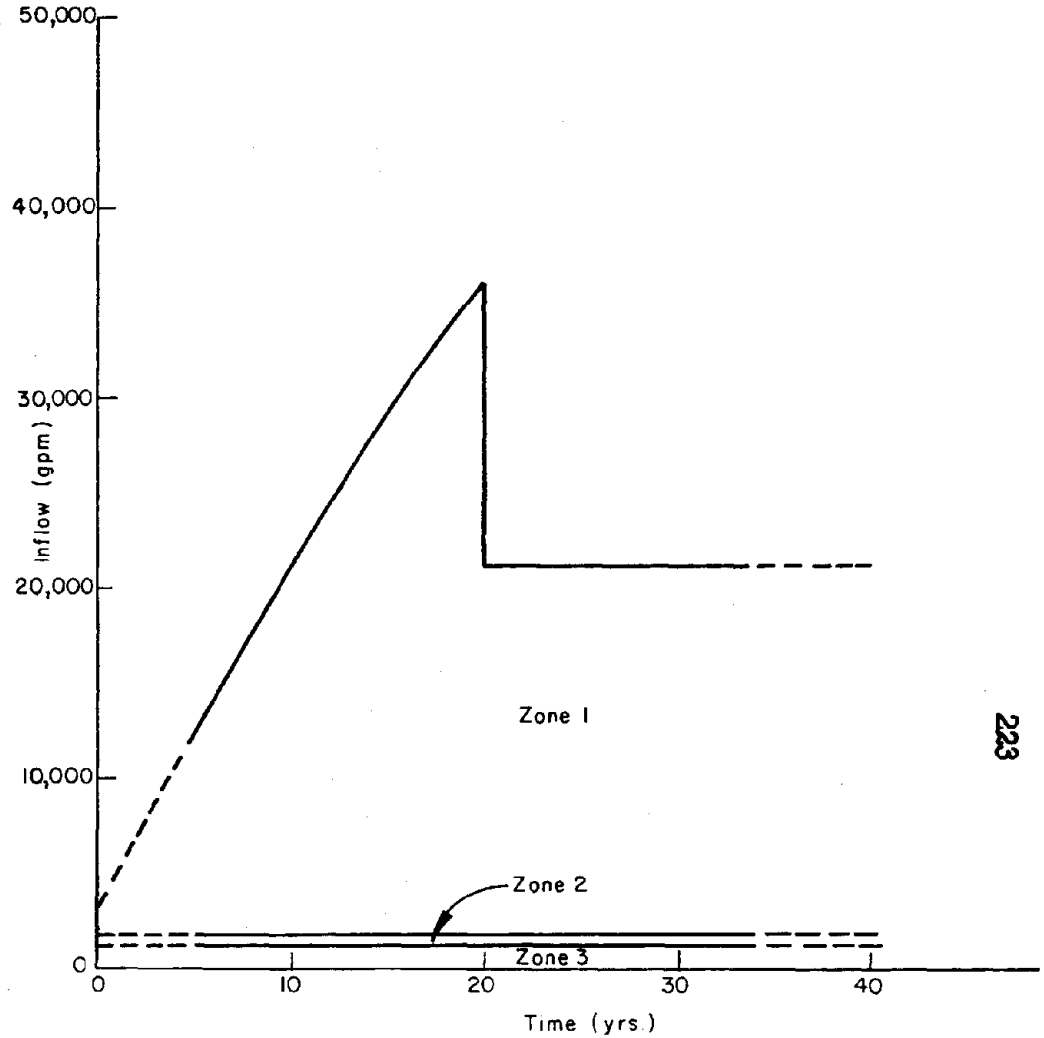
Expansion Rate: .303 mi^2/yr

Initial Radius: 200 ft

Mining Rate: 50,000 ton/day

Figure D-68 MINE INFLOW - SITE 3





MINE INFLOW (gpm)

Time-yrs	Radius-ft.	Zone 1	Zone 1 (drain)	Zone 2	Zone 3	Total
.5	5,189	11,073	-	182	1081	12,340
10	7,336	19,672	-	182	1082	20,940
20	10,373	34,415	-	182	1083	35,680
30	12,703	20,212	-	182	1083	21,470

DESCRIPTION:

Mining Method: Room & Pillar, No Subsidence

Number of Passes: 1

Location: Mahogany

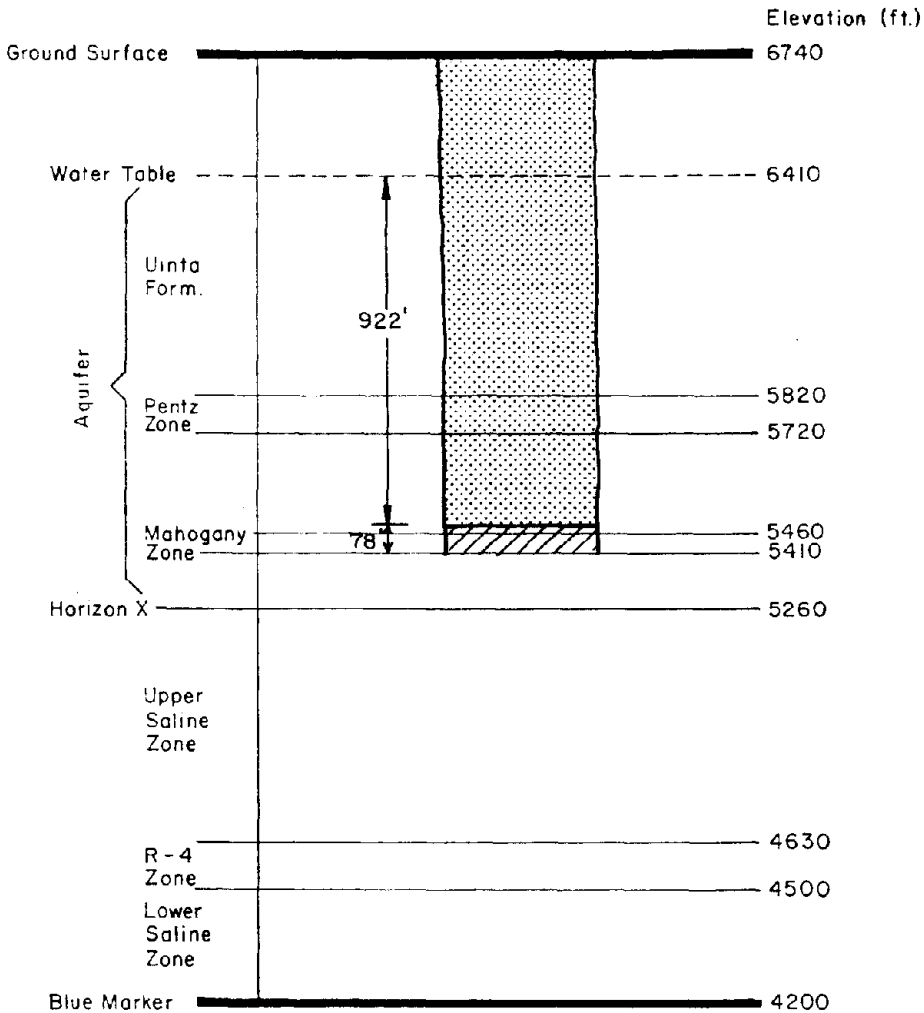
Mining Height: 78 ft

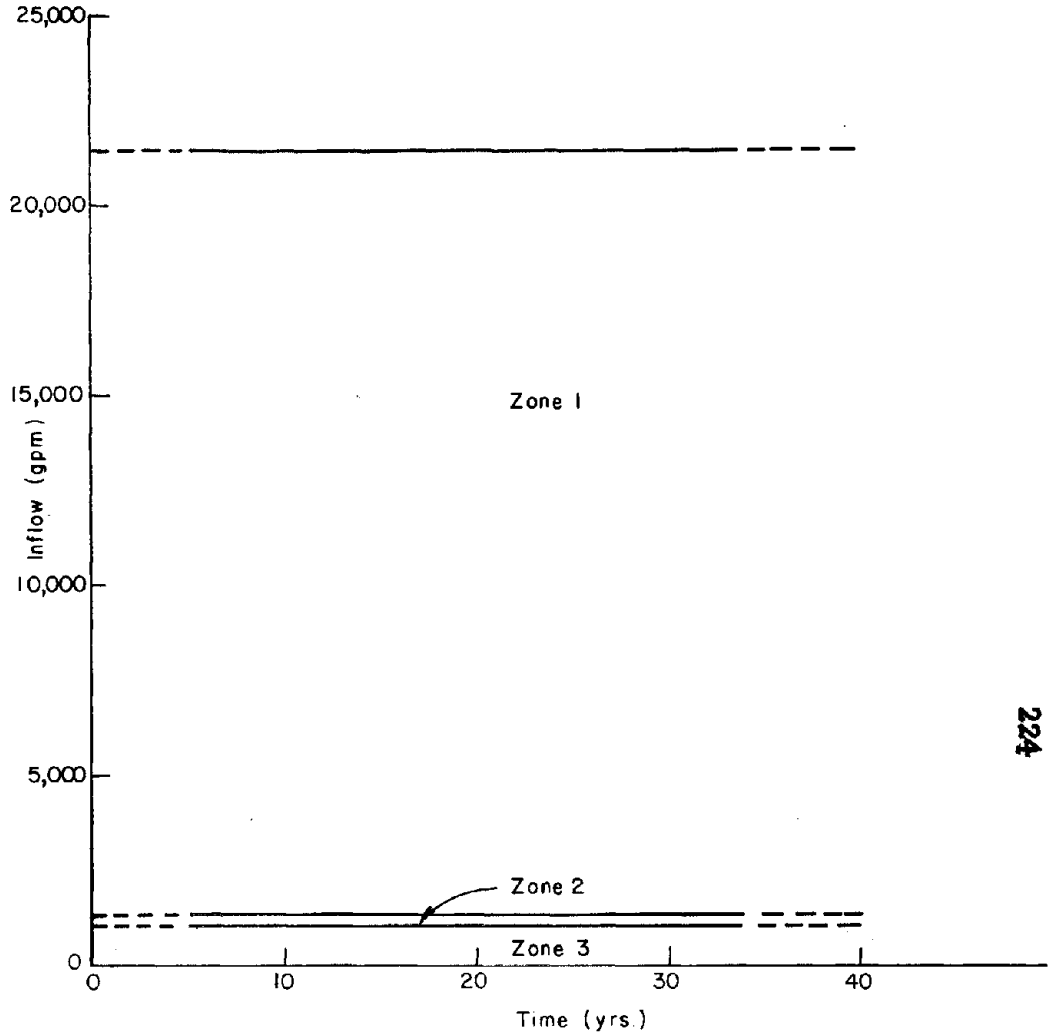
Expansion Rate: .606 mi^2/yr

Initial Radius: 200 ft

Mining Rate: 100,000 ton/day

Figure D-69 MINE INFLOW - SITE 3





MINE INFLOW (gpm)

Time - yrs	Radius - ft.	Zone 1	Zone 1 (drain)	Zone 2	Zone 3	Total
5	5,189	4695	15,517	182	1081	21,480
10	7,336	4695	15,517	182	1082	21,480
20	10,373	4695	15,517	182	1083	21,480
30	12,703	4695	15,517	182	1083	21,480

DESCRIPTION:

Mining Method: Room & Pillar, Full Subsidence

Number of Passes: 1

Location: Mahogany

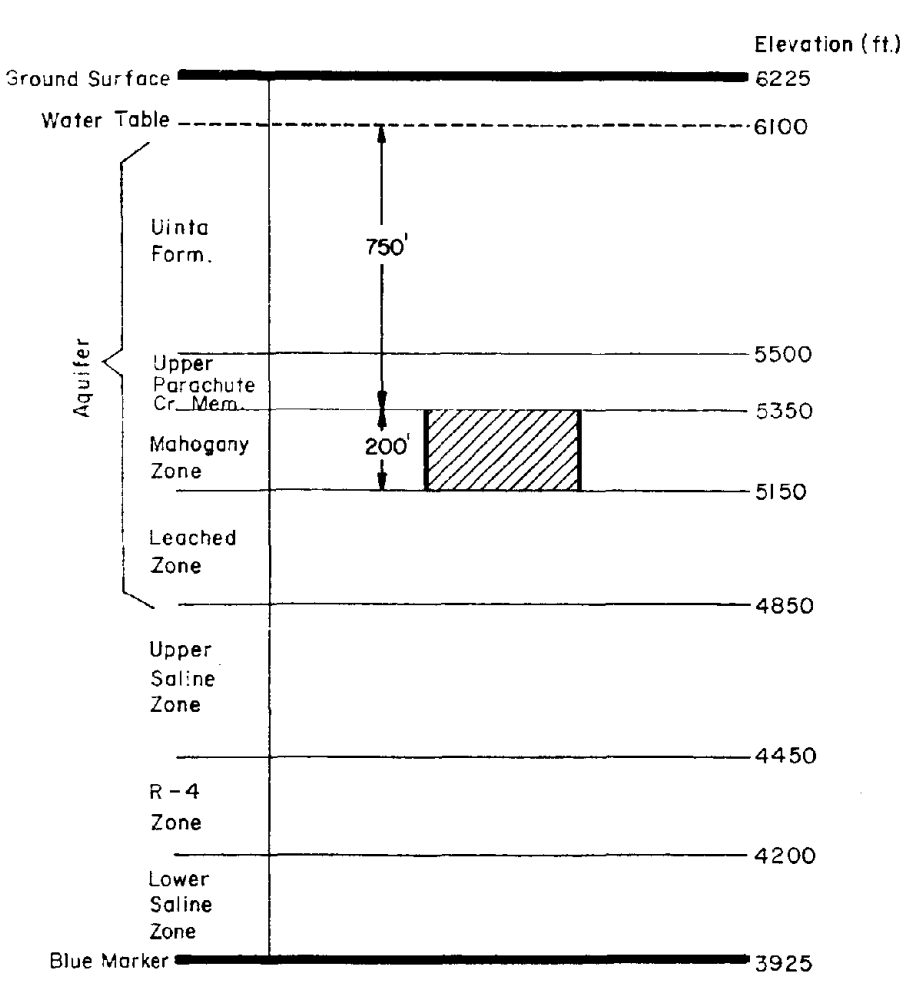
Mining Height: 78 ft

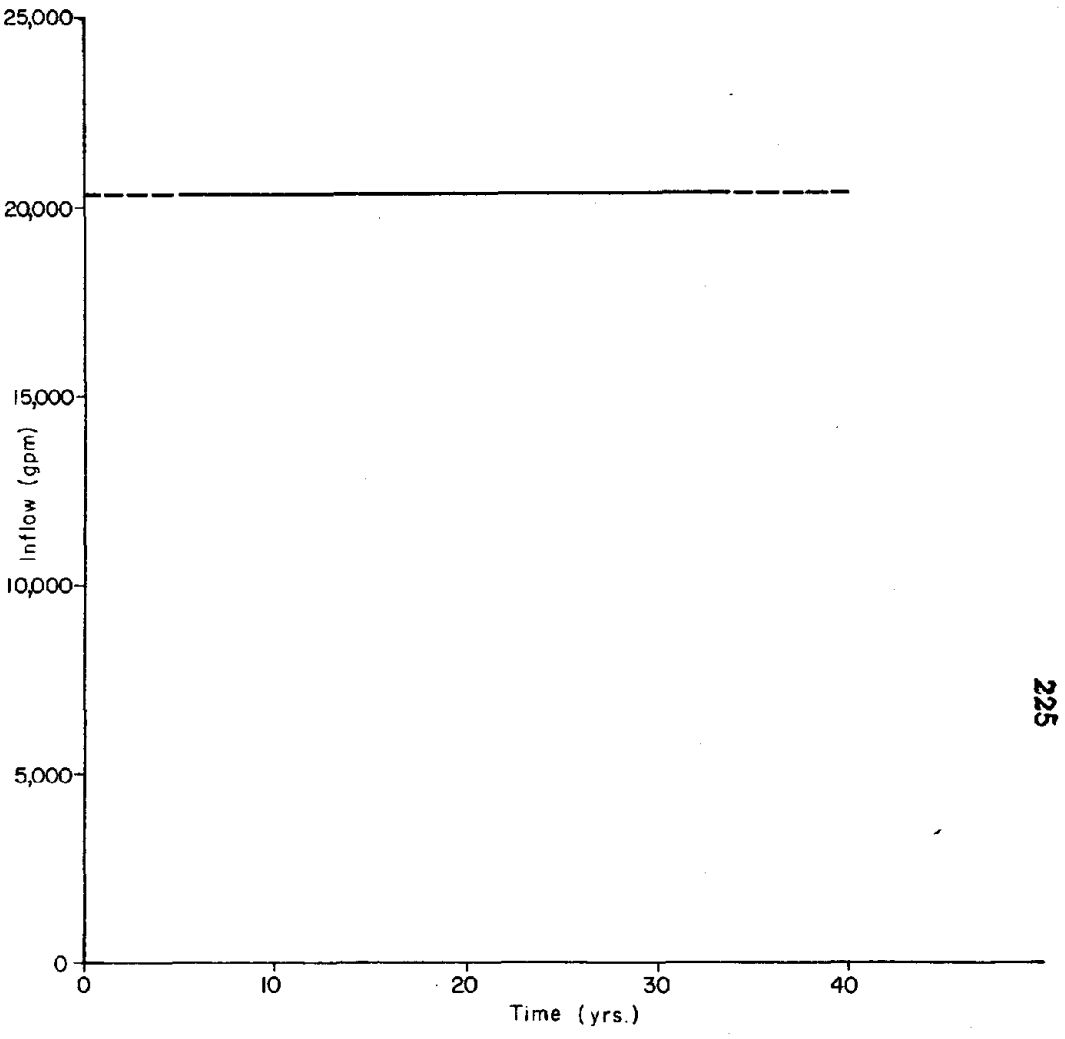
Expansion Rate: .606 mi^2/yr

Initial Radius: 200 ft

Mining Rate: 100,000 ton/day

Figure D-70 MINE INFLOW - SITE 3





Time - yrs.	Radius - ft.	MINE INFLOW (gpm) Zone I	(drain) Zone I	Zone 2	Zone 3	Total
5	2117	-	-	-	-	20,330
10	2994	-	-	-	-	20,330
20	4234	-	-	-	-	20,330
30	5185	-	-	-	-	20,330

DESCRIPTION:

Mining Method: True In-Situ

Number of Passes: 1

Location: Mahogany

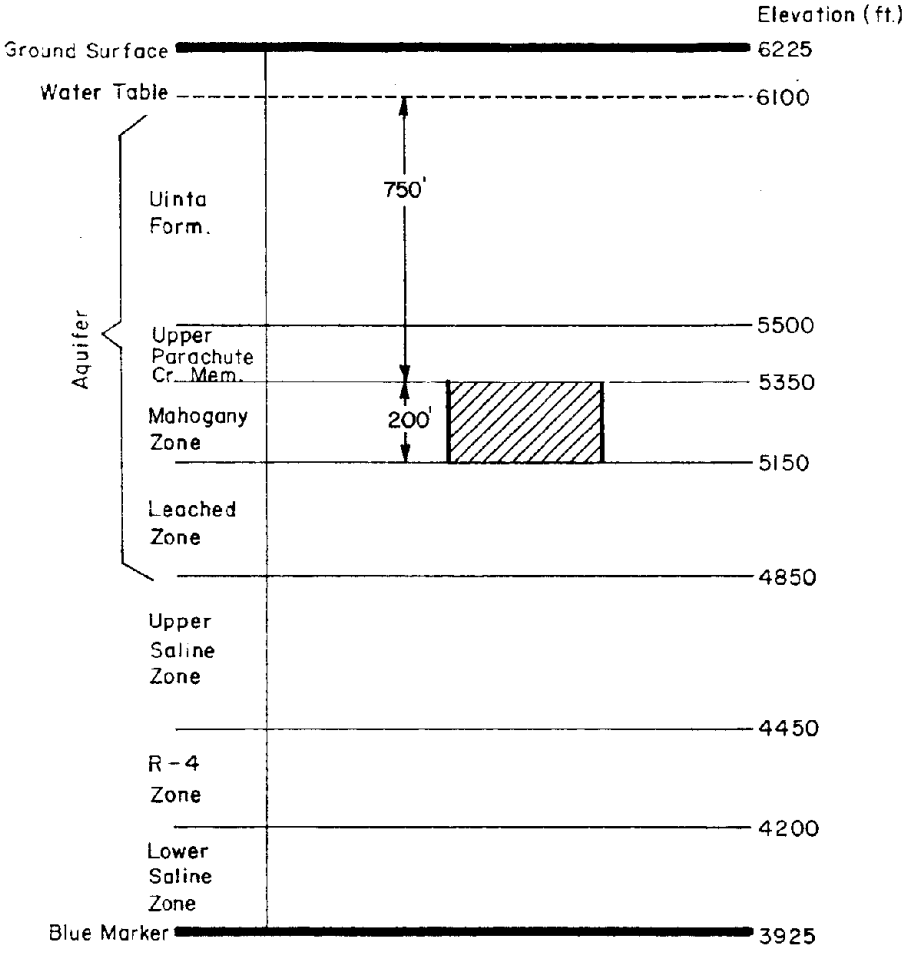
Mining Height: 200 ft

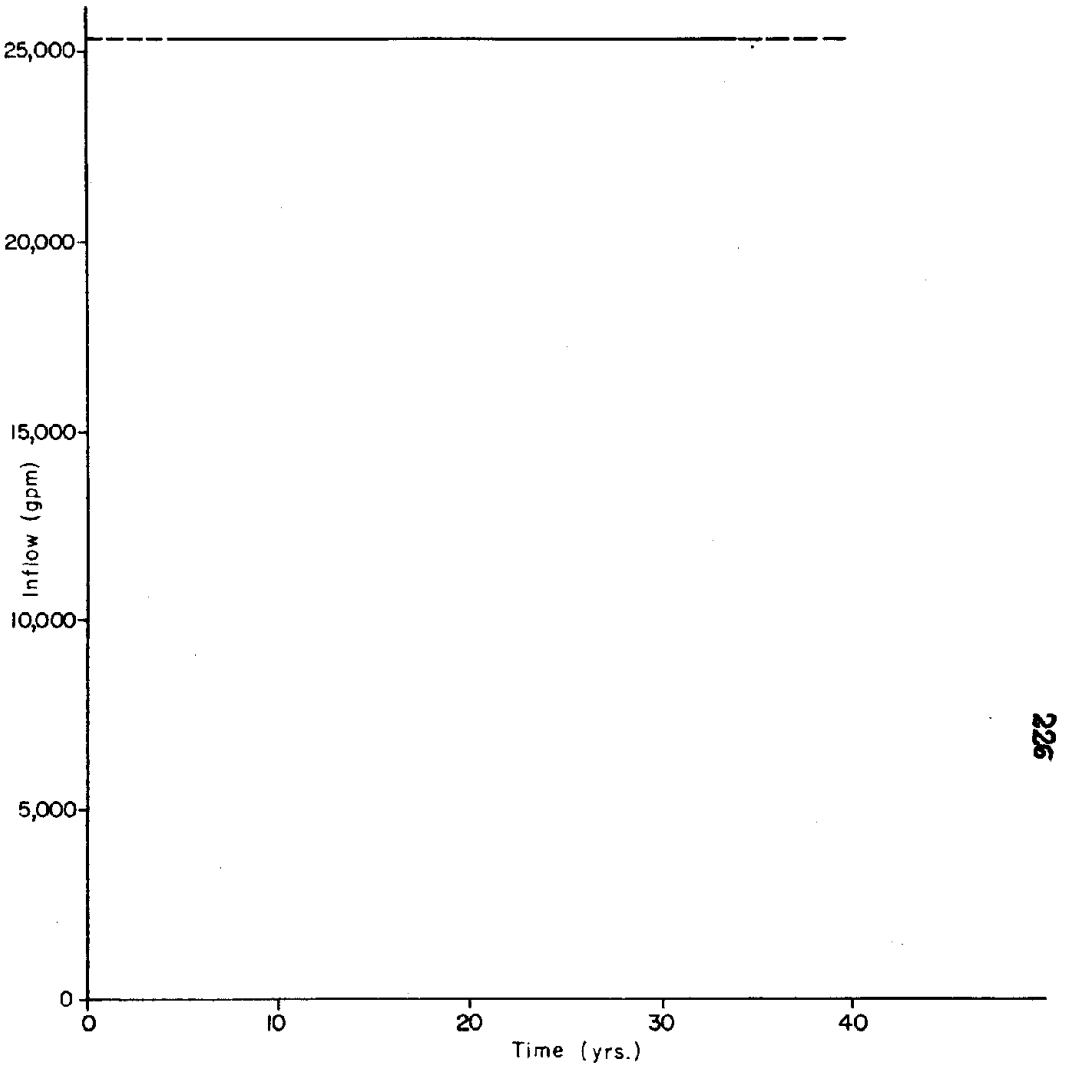
Expansion Rate: .101 mi^2/yr

Initial Radius: 0

Mining Rate: 50,000 ton/day

Figure D-71 MINE INFLOW - SITE I





Time - yrs.	Radius - ft.	MINE INFLOW (gpm) Zone I	(drain) Zone I	Zone 2	Zone 3	Total
5	2994	-	-	-	-	25,320
10	4234	-	-	-	-	25,320
20	5988	-	-	-	-	25,320
30	7333	-	-	-	-	25,320

DESCRIPTION:

Mining Method: True In-Situ

Number of Passes: 1

Location: Mahogany

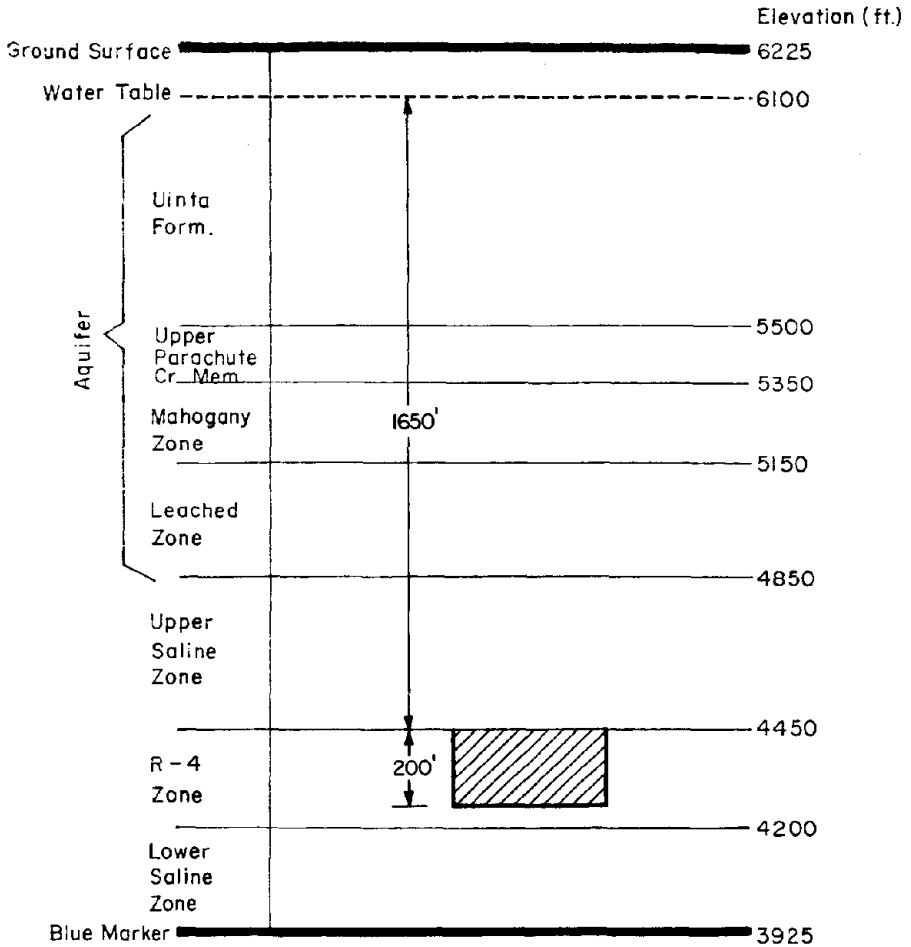
Mining Height: 200 ft

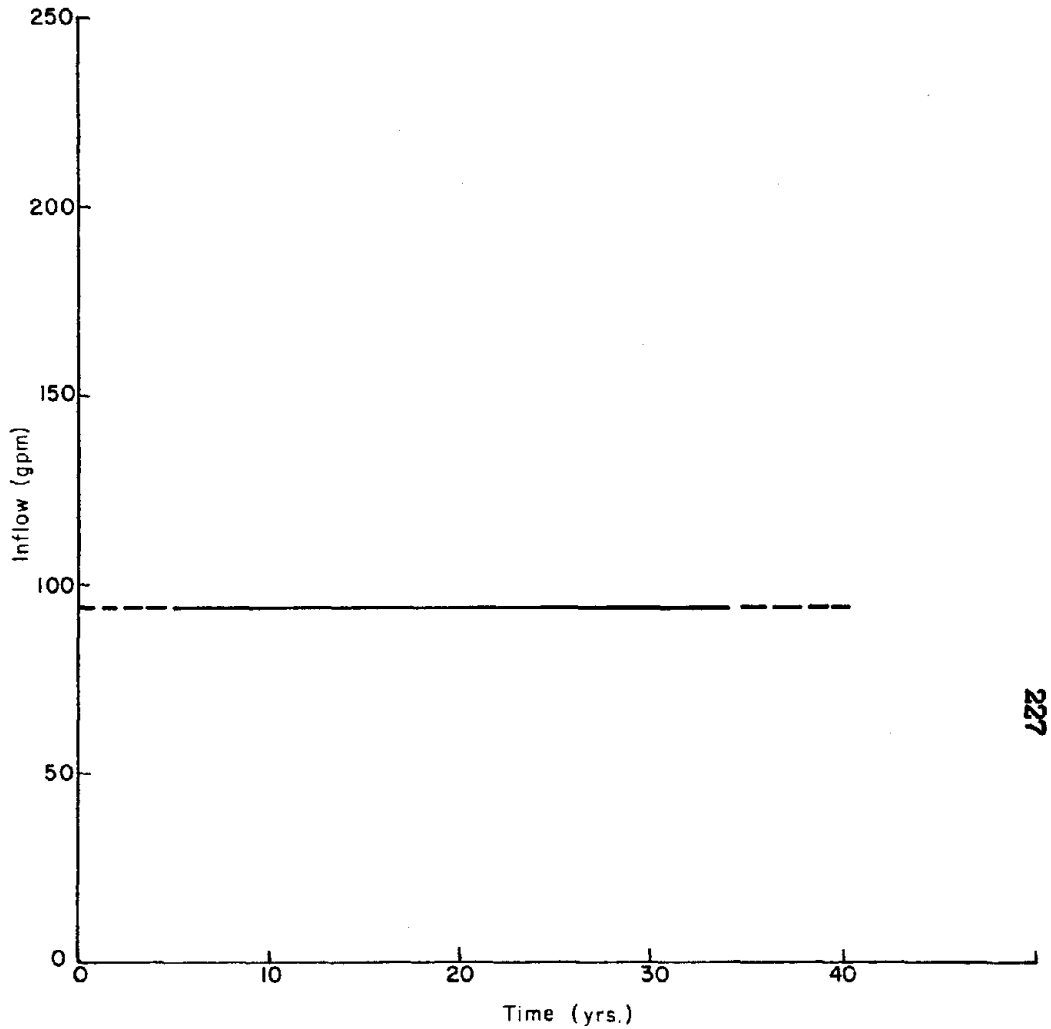
Expansion Rate: .202 mi^2/yr

Initial Radius: 0

Mining Rate: 100,000 ton/day

Figure D-72 MINE INFLOW - SITE I





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Time - yrs.	Radius - ft.	MINE INFLOW (gpm) Zone I	(drain) Zone I	Zone 2	Zone 3	Total
5	-	-	-	-	-	90
10	-	-	-	-	-	90
20	-	-	-	-	-	90
30	-	-	-	-	-	90

DESCRIPTION:

Mining Method: True In-Situ

Number of Passes: 1

Location: R-4

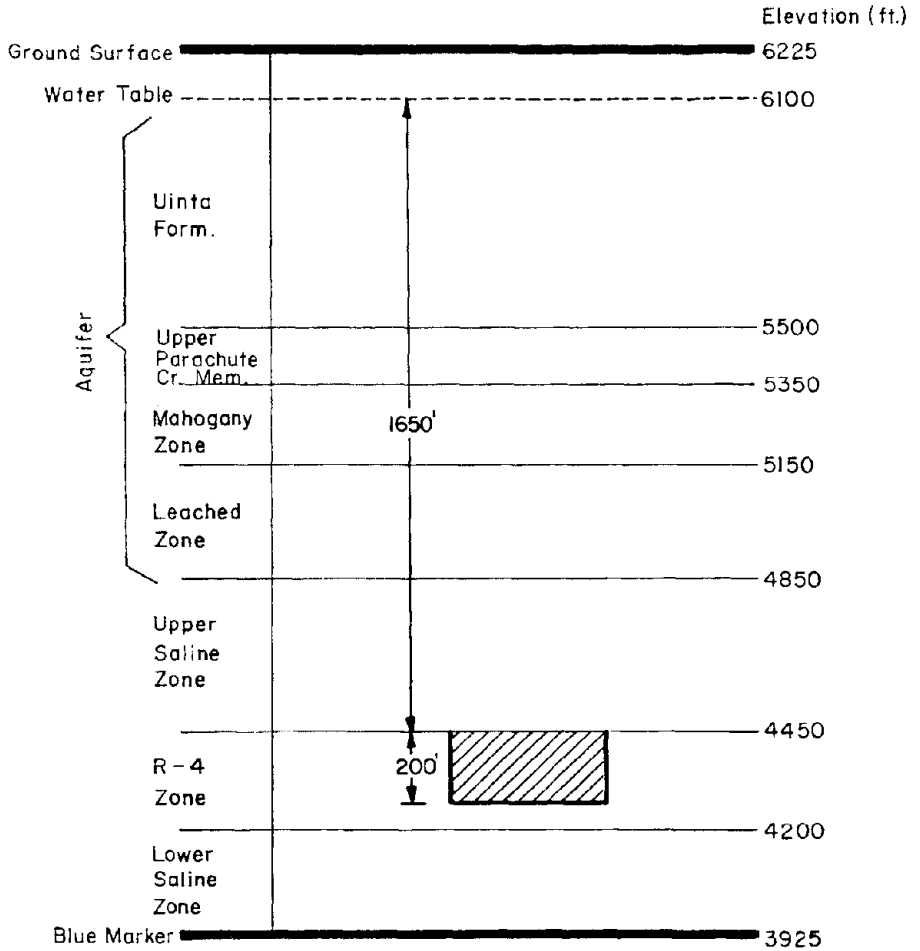
Mining Height: 200 ft

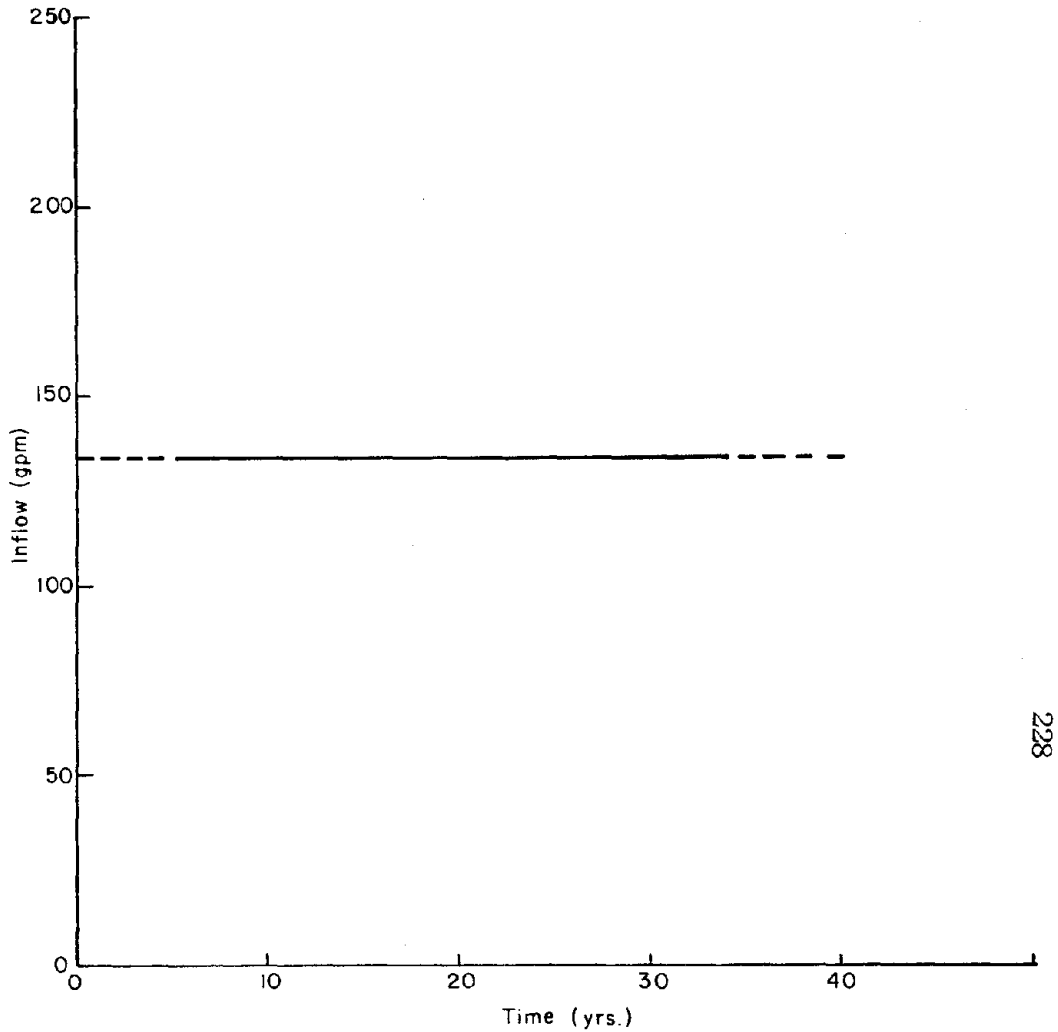
Expansion Rate: .101 mi^2/yr

Initial Radius: 0

Mining Rate: 50,000 ton/day

Figure D-73 MINE INFLOW - SITE I





Time - yrs.	Radius - ft.	MINE INFLOW (gpm) Zone 1	(drain) Zone 1	Zone 2	Zone 3	Total
5	-	-	-	-	-	130
10	-	-	-	-	-	130
20	-	-	-	-	-	130
30	-	-	-	-	-	130

DESCRIPTION:

Mining Method: True In-Situ

Number of Passes: 1

Location: R-4

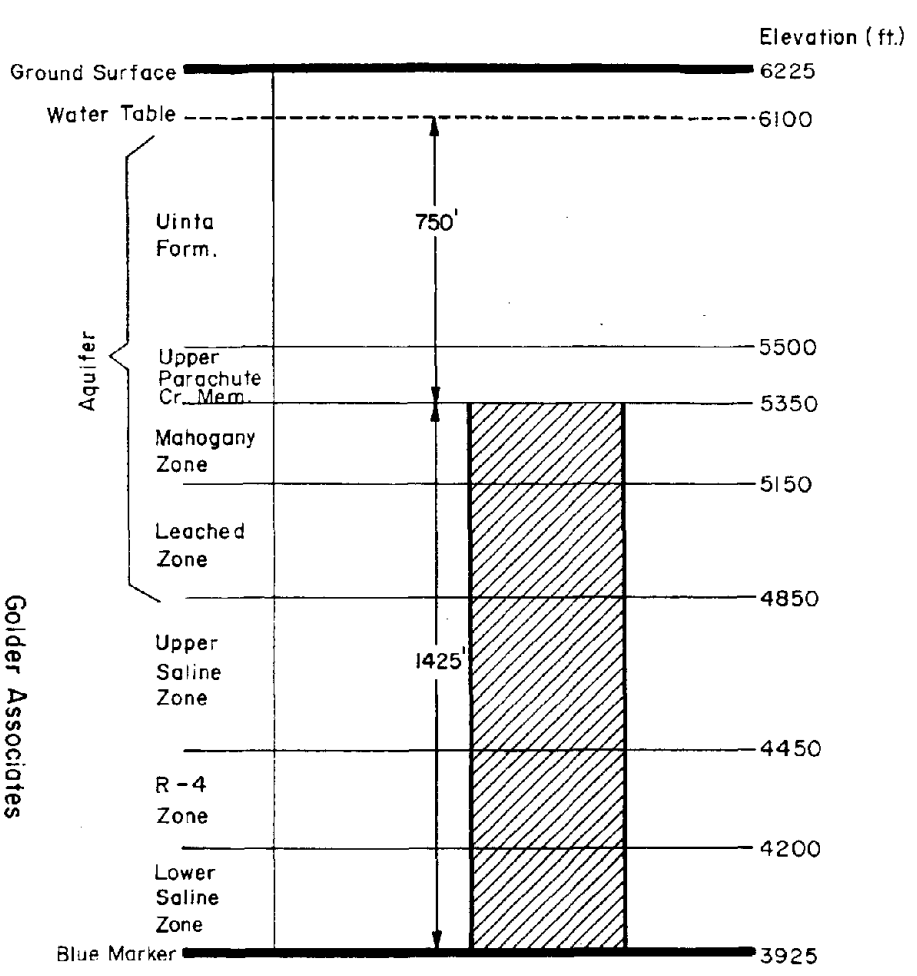
Mining Height: 200 ft

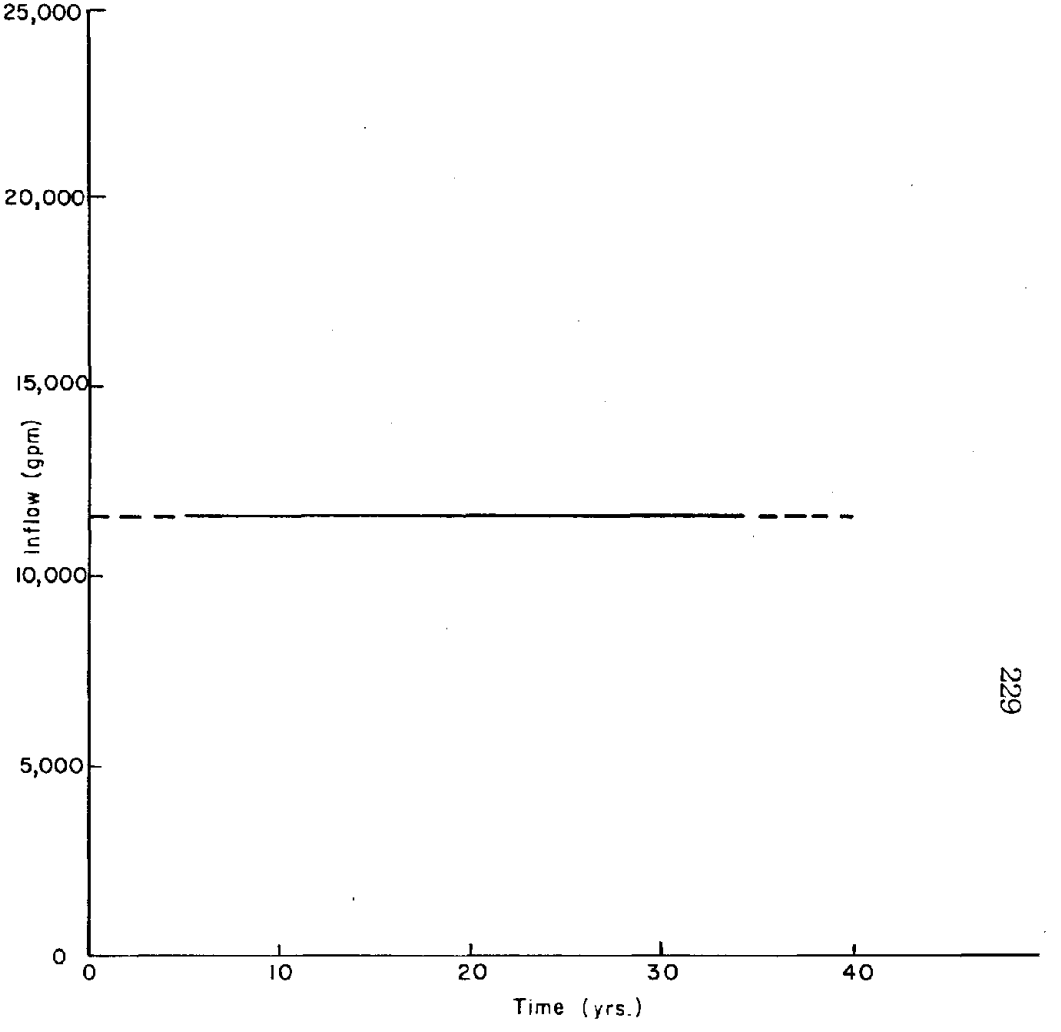
Expansion Rate: .202 mi^2/yr

Initial Radius: 0

Mining Rate: 100,000 ton/day

Figure D-74 MINE INFLOW - SITE I





Time - yrs.	Radius - ft.	MINE INFLOW (gpm) Zone I	Zone I (drain)	Zone 2	Zone 3	Total
5	557	-	-	-	-	11,600
10	788	-	-	-	-	11,600
20	1115	-	-	-	-	11,600
30	1365	-	-	-	-	11,600

DESCRIPTION:

Mining Method: True In-Situ

Number of Passes: 1

Location: Blue Marker to Mahogany

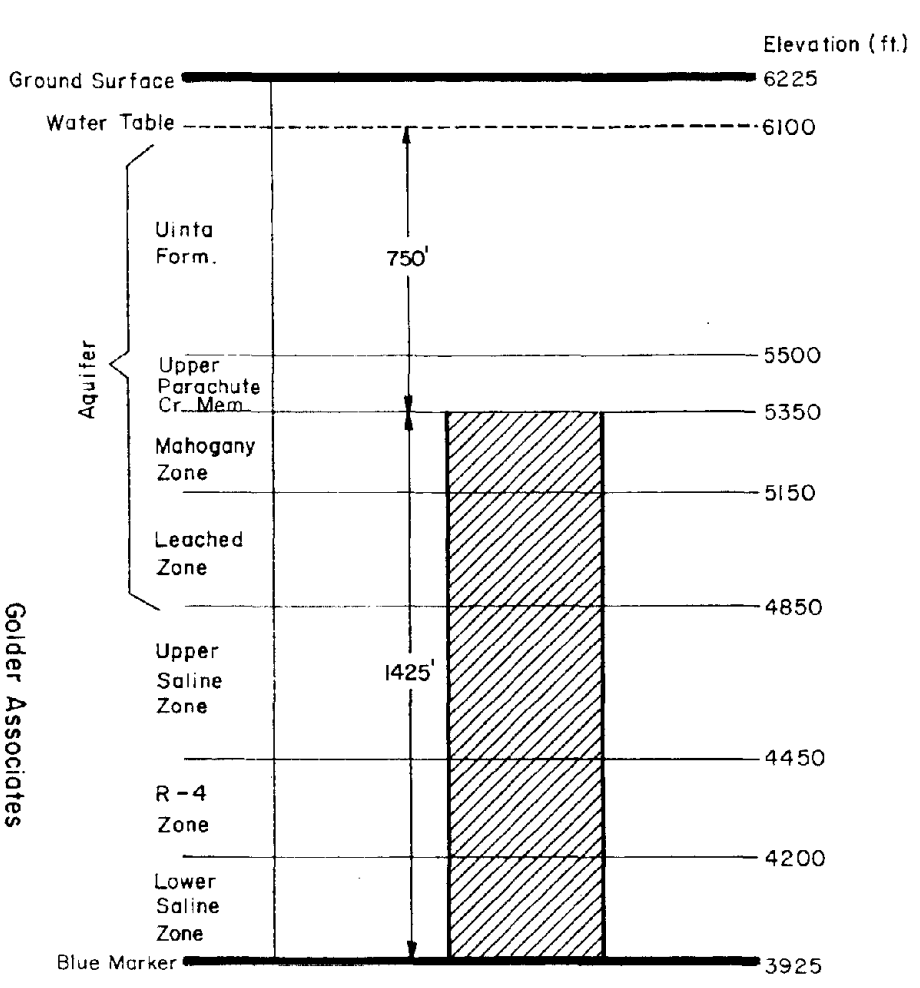
Mining Height: 1425 ft

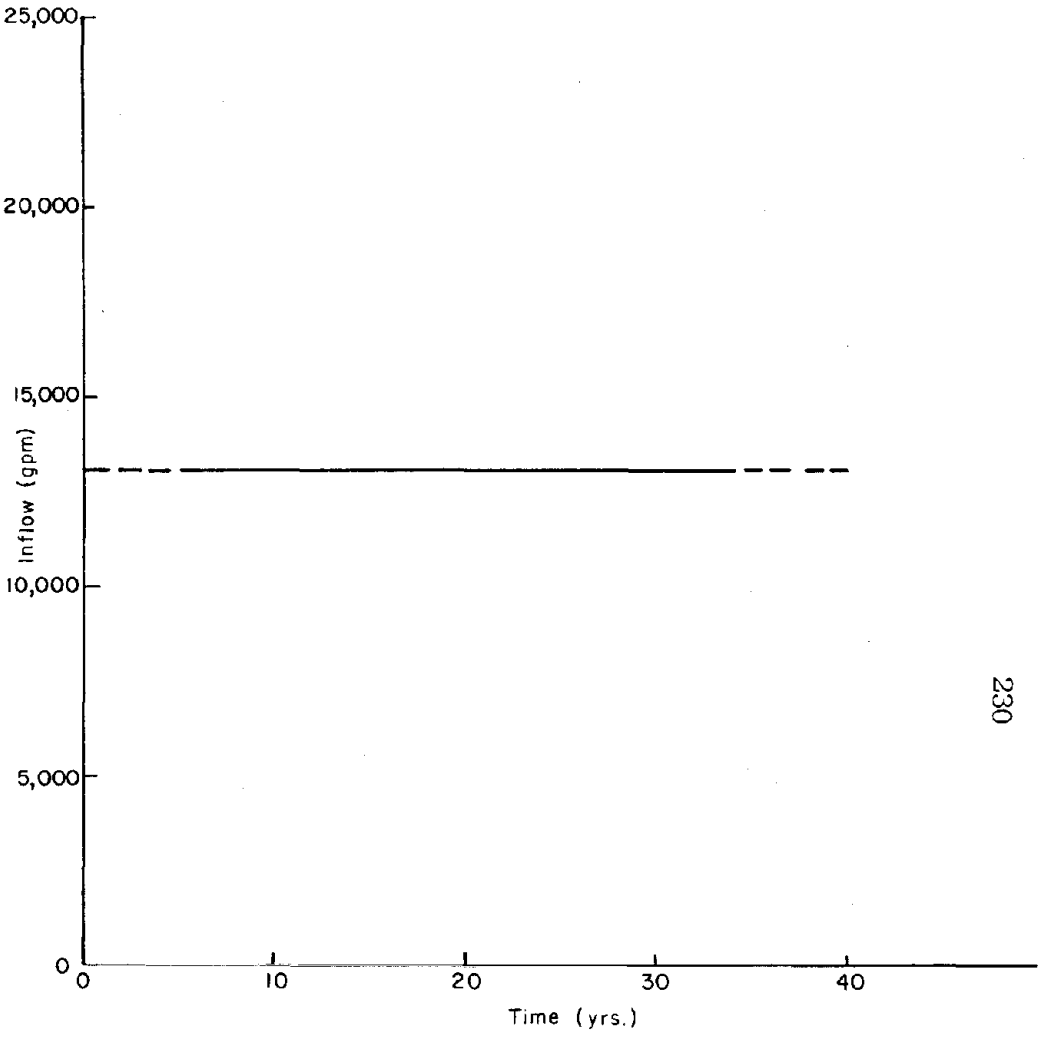
Expansion Rate: .007 mi^2/yr

Initial Radius: 0

Mining Rate: 50,000 ton/day

Figure D-75 MINE INFLOW - SITE I





Golder Associates

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Time - yrs.	Radius - ft.	MINE INFLOW (gpm) Zone 1	(drain) Zone 1	Zone 2	Zone 3	Total
5	788	-	-	-	-	13,040
10	1115	-	-	-	-	13,040
20	1576	-	-	-	-	13,040
30	1931	-	-	-	-	13,040

DESCRIPTION:

Mining Method: True In-Situ

Number of Passes: 1

Location: Blue Marker to Mahogany

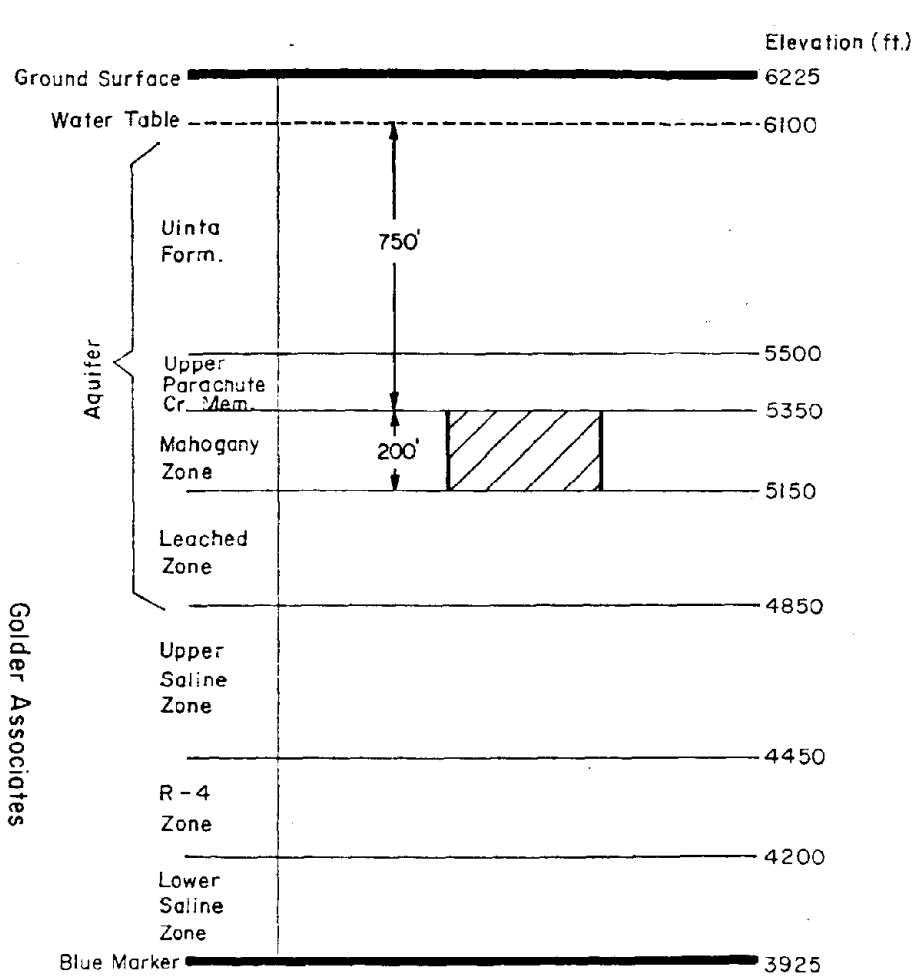
Mining Height: 1425 ft

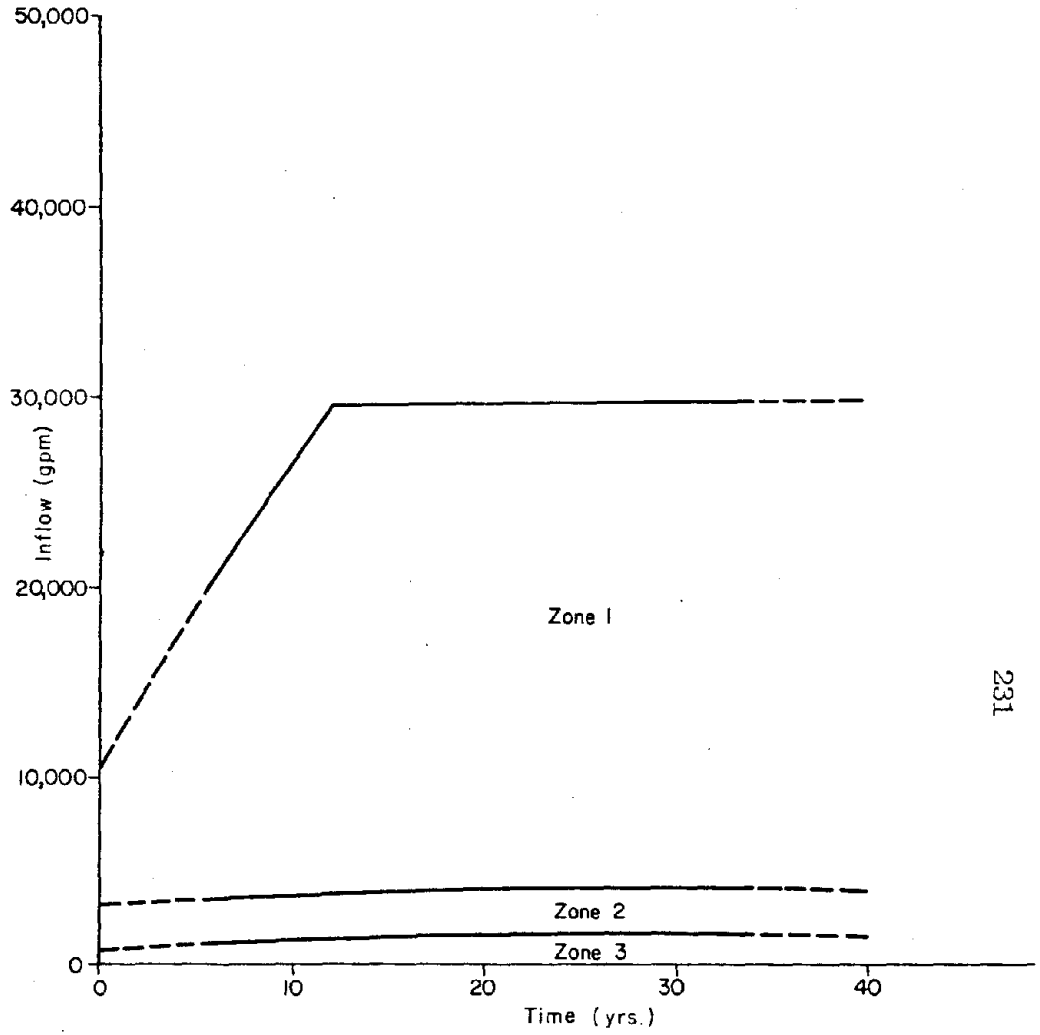
Expansion Rate: .014 mi^2/yr

Initial Radius: 0

Mining Rate: 100,000 ton/day

Figure D-76 MINE INFLOW - SITE 1





Time - yrs.	Radius - ft.	MINE INFLOW (gpm) Zone 1	(drain) Zone 1	Zone 2	Zone 3	Total
5	2896	15,192	-	2444	1131	18,770
10	4095	22,576	-	2444	1355	26,380
20	5792	25,311	-	2444	1503	29,260
30	7093	25,311	-	2444	1561	29,320

DESCRIPTION:

Mining Method: Modified In-Situ, No Subsidence

Number of Passes: 1

Location: Mahogany

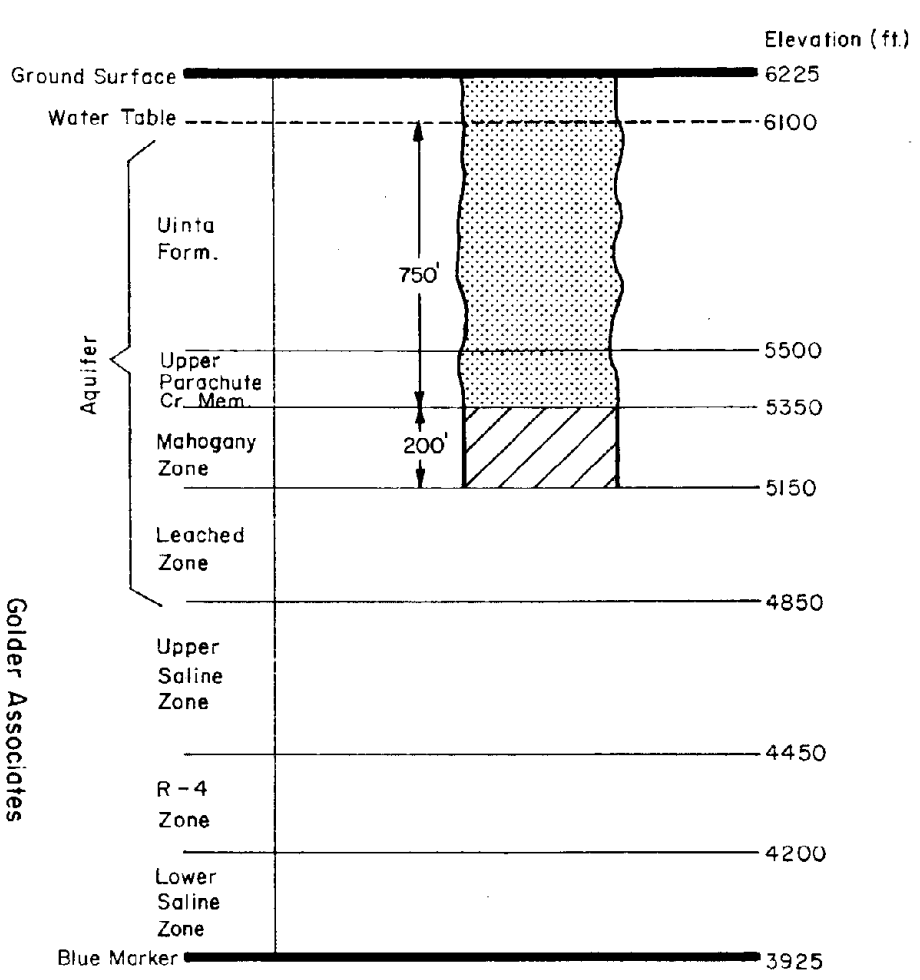
Mining Height: 200 ft

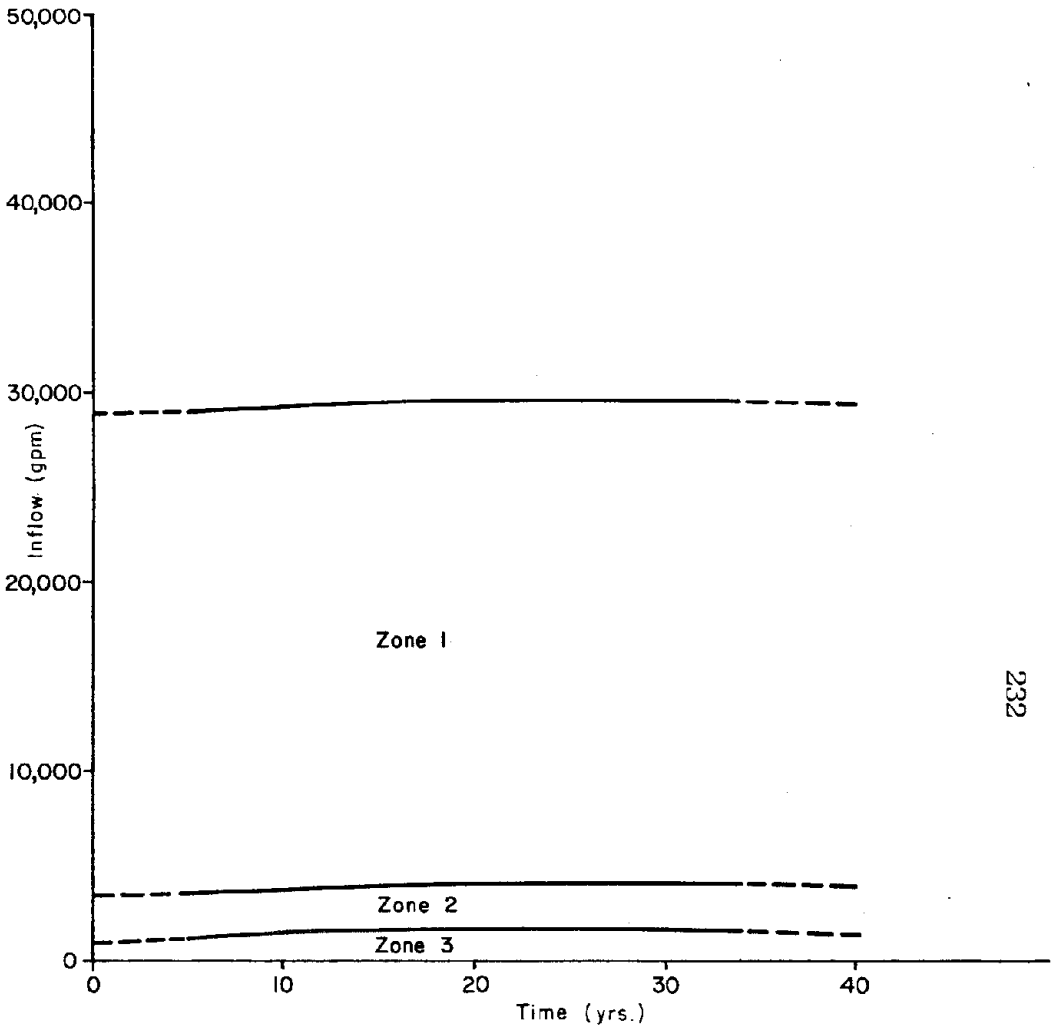
Expansion Rate: .189 mi^2/yr

Initial Radius: 0

Mining Rate: 50,000 ton/day

Figure D-77 MINE INFLOW - SITE I





Time - yrs.	Radius - ft.	MINE INFLOW (gpm) Zone 1	Zone 1 (drain)	Zone 2	Zone 3	Total
5	2896	20,812	4499	2444	1131	28,890
10	4095	20,812	4499	2444	1355	29,110
20	5792	20,812	4499	2444	1503	29,260
30	7093	20,812	4499	2444	1561	29,320

DESCRIPTION:

Mining Method: Modified In-Situ, Full Subsidence

Number of Passes: 1

Location: Mahogany

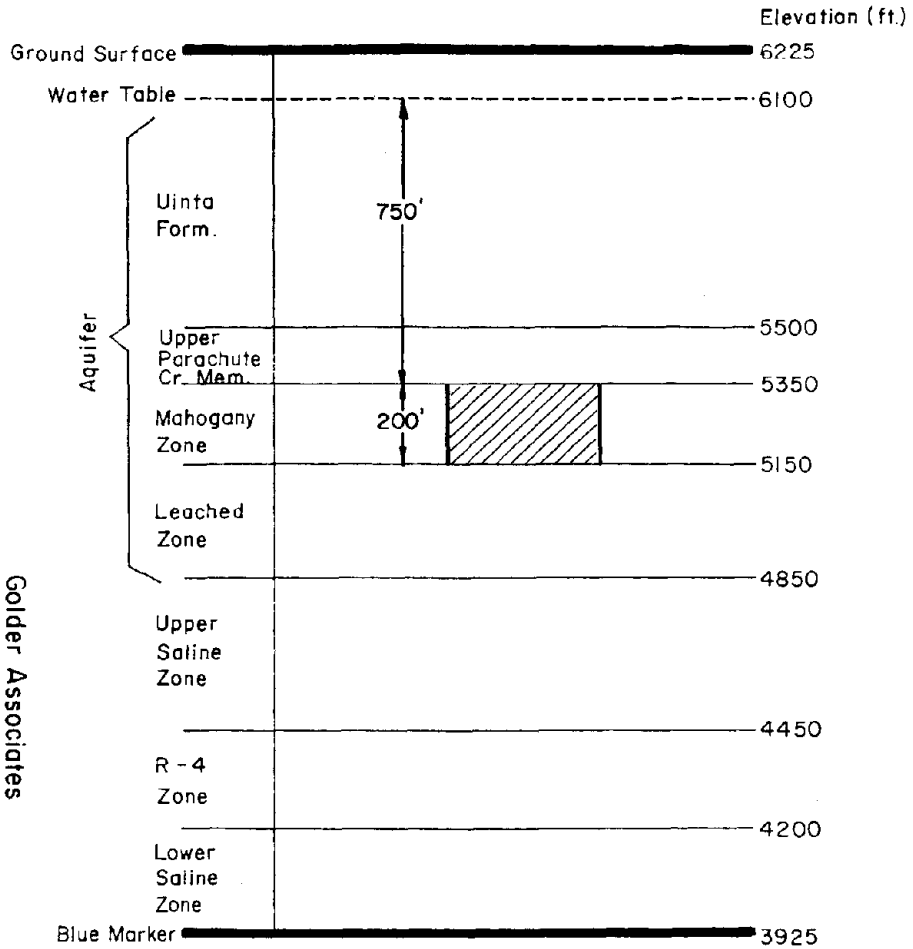
Mining Height: 200 ft

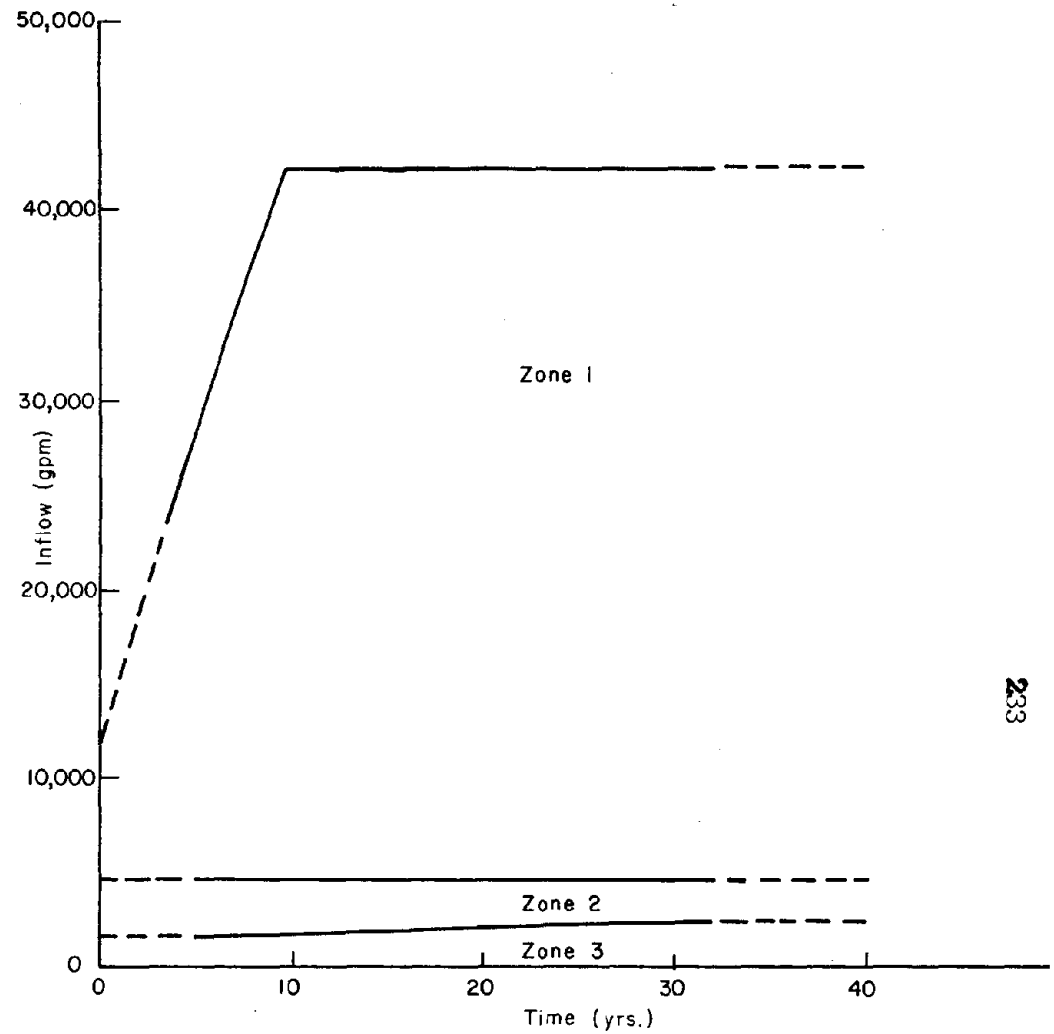
Expansion Rate: .189 mi^2/yr

Initial Radius: 0

Mining Rate: 50,000 ton/day

Figure D-78 MINE INFLOW - SITE 1





MINE INFLOW (gpm)

Time - yrs.	Radius - ft.	Zone 1	(drain) Zone 1	Zone 2	Zone 3	Total
5	4,095	23,808	-	2663	1475	27,950
10	5,792	37,400	-	2663	1654	41,720
20	8,191	37,400	-	3663	1760	41,820
30	10,031	37,400	-	2663	1799	41,860

DESCRIPTION:

Mining Method: Modified In-Situ, No Subsidence

Number of Passes: 1

Location: Mahogany

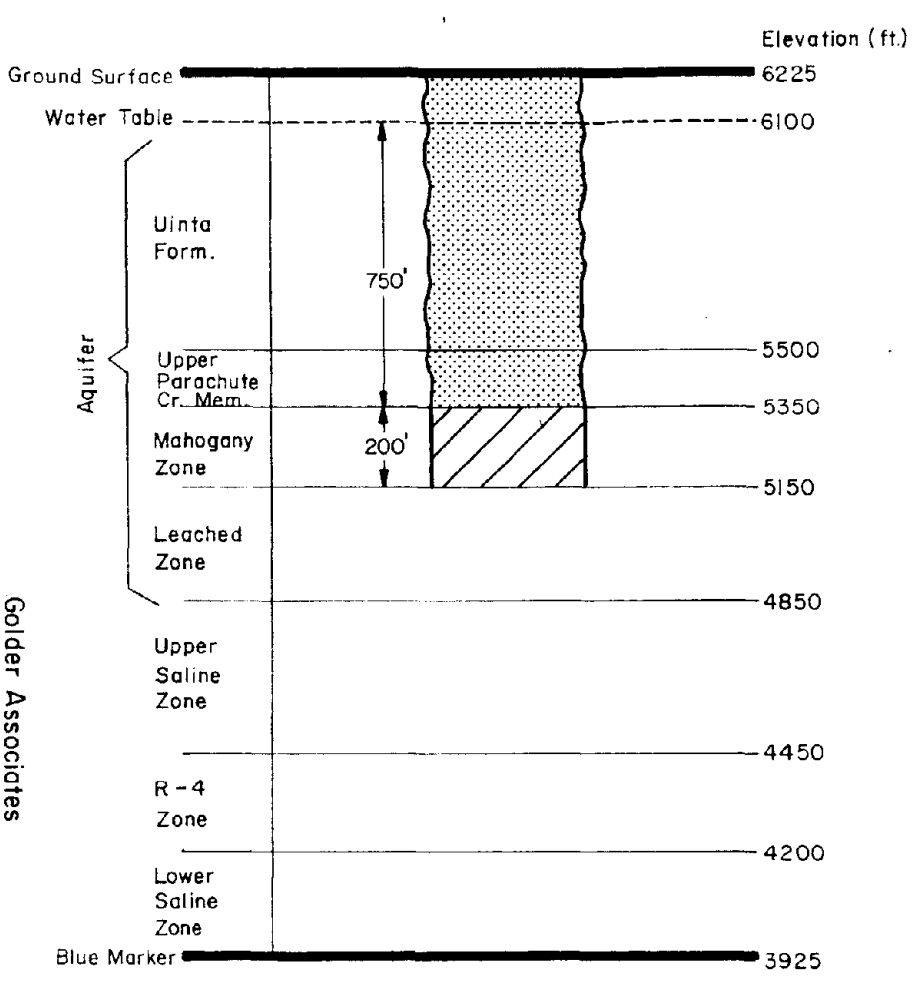
Mining Height: 200 ft

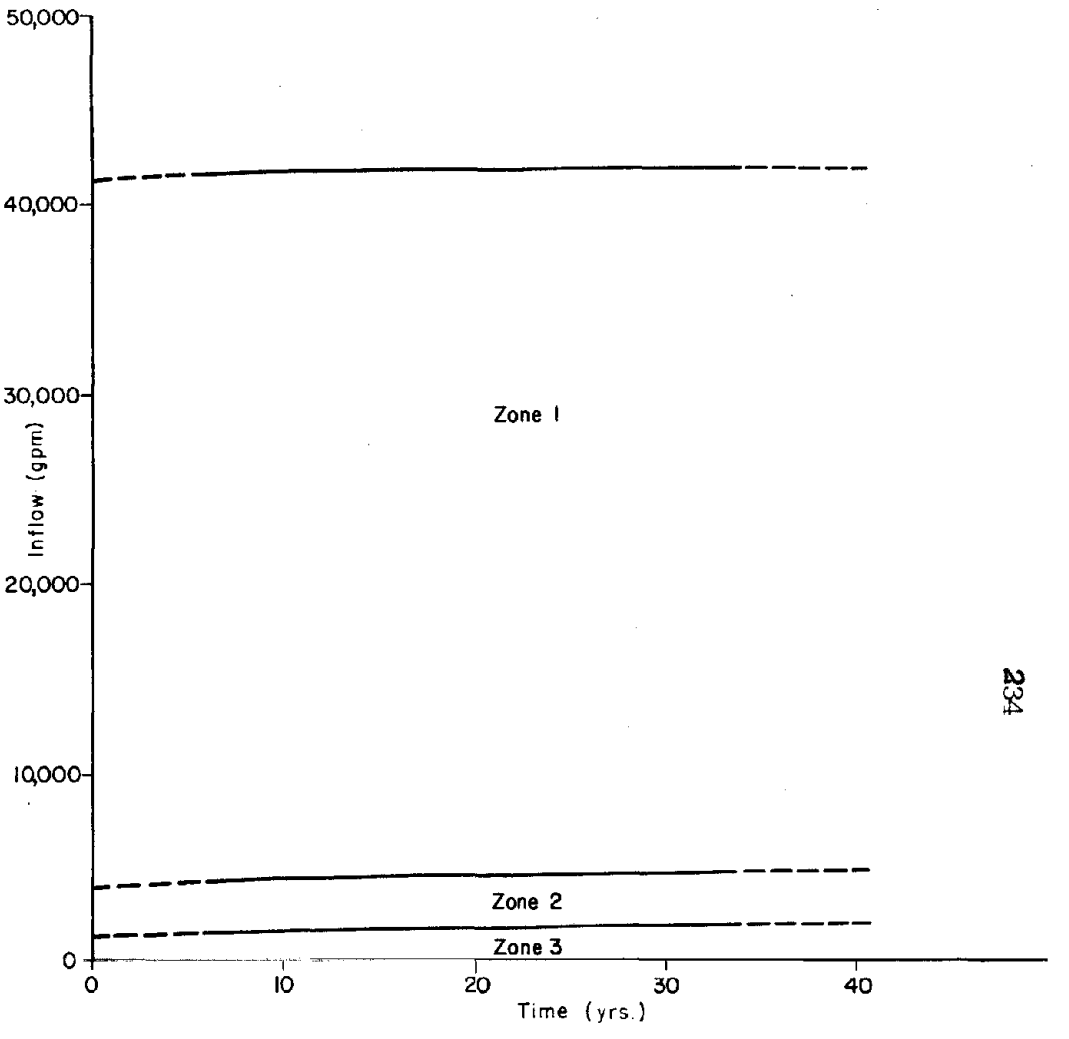
Expansion Rate: .378 mi^2/yr

Initial Radius: 0

Mining Rate: 100,000 ton/day

Figure D-79 MINE INFLOW - SITE 1





MINE INFLOW (gpm)

Time - yrs.	Radius - ft.	Zone 1	Zone 1 (drain)	Zone 2	Zone 3	Total
5	4,095	28,402	8998	2663	1475	41,540
10	5,792	28,402	8998	2663	1654	41,720
20	8,191	28,402	8998	2663	1760	41,820
30	10,031	28,402	8998	2663	1799	41,860

DESCRIPTION:

Mining Method: Modified In-Situ, Full Subsidence

Number of Passes: 1

Location: Mahogany

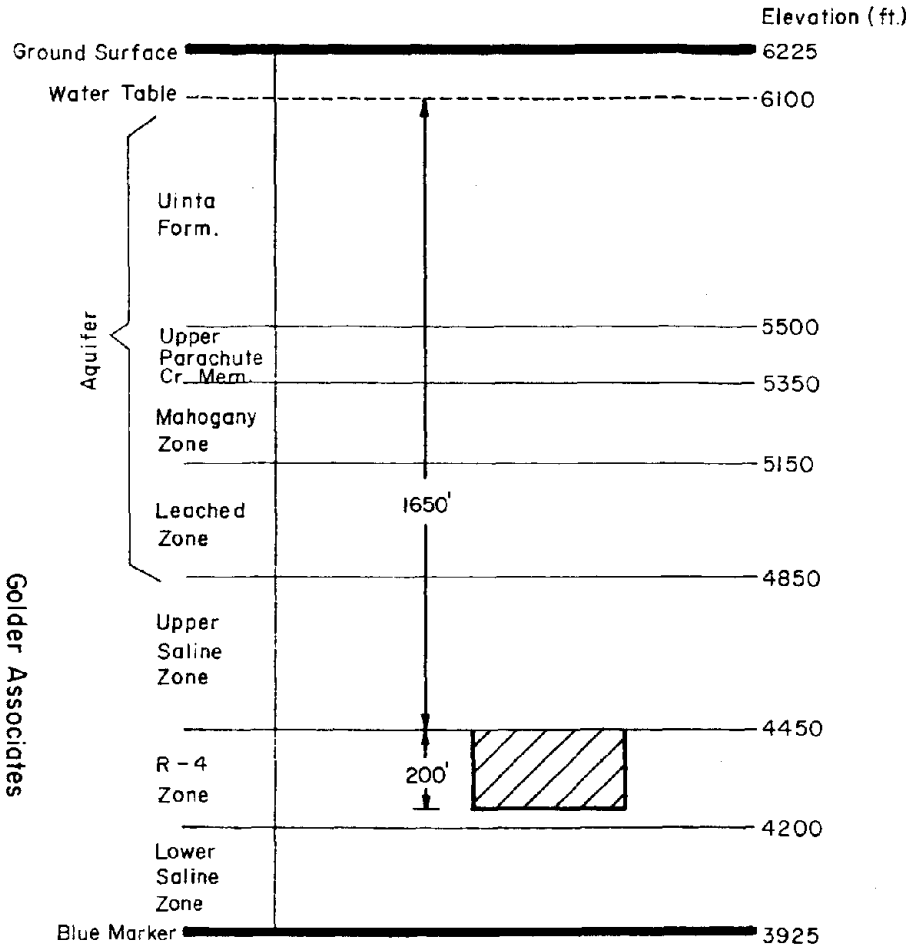
Mining Height: 200 ft

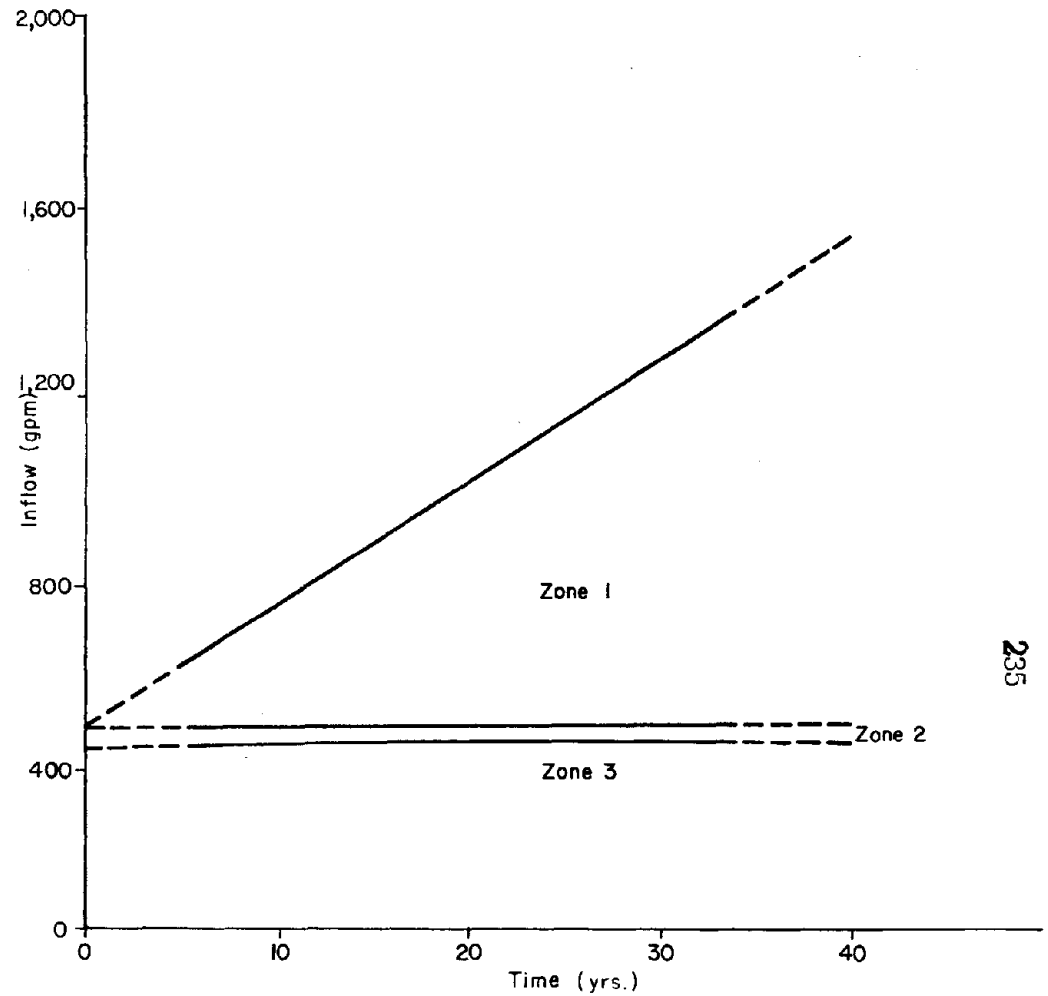
Expansion Rate: .189 mi^2/yr

Initial Radius: 0

Mining Rate: 100,000 ton/day

Figure D-80 MINE INFLOW - SITE I





Time - yrs.	Radius - ft.	MINE INFLOW (gpm) Zone 1	(drain) Zone 1	Zone 2	Zone 3	Total
5	2896	128	-	40	61	230
10	4095	257	-	40	65	360
20	5792	513	-	40	67	620
30	7093	770	-	40	68	880

DESCRIPTION:

Mining Method: Modified In-Situ, No Subsidence

Number of Passes: 1

Location: R-4

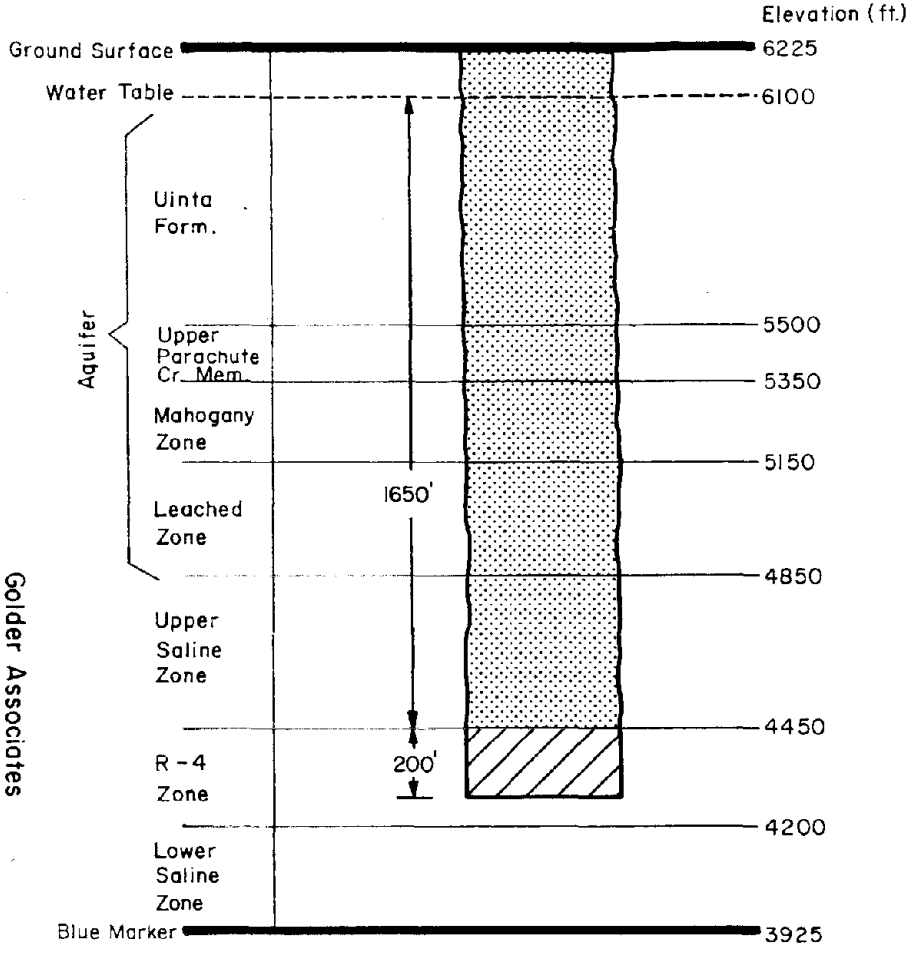
Mining Height: 200 ft

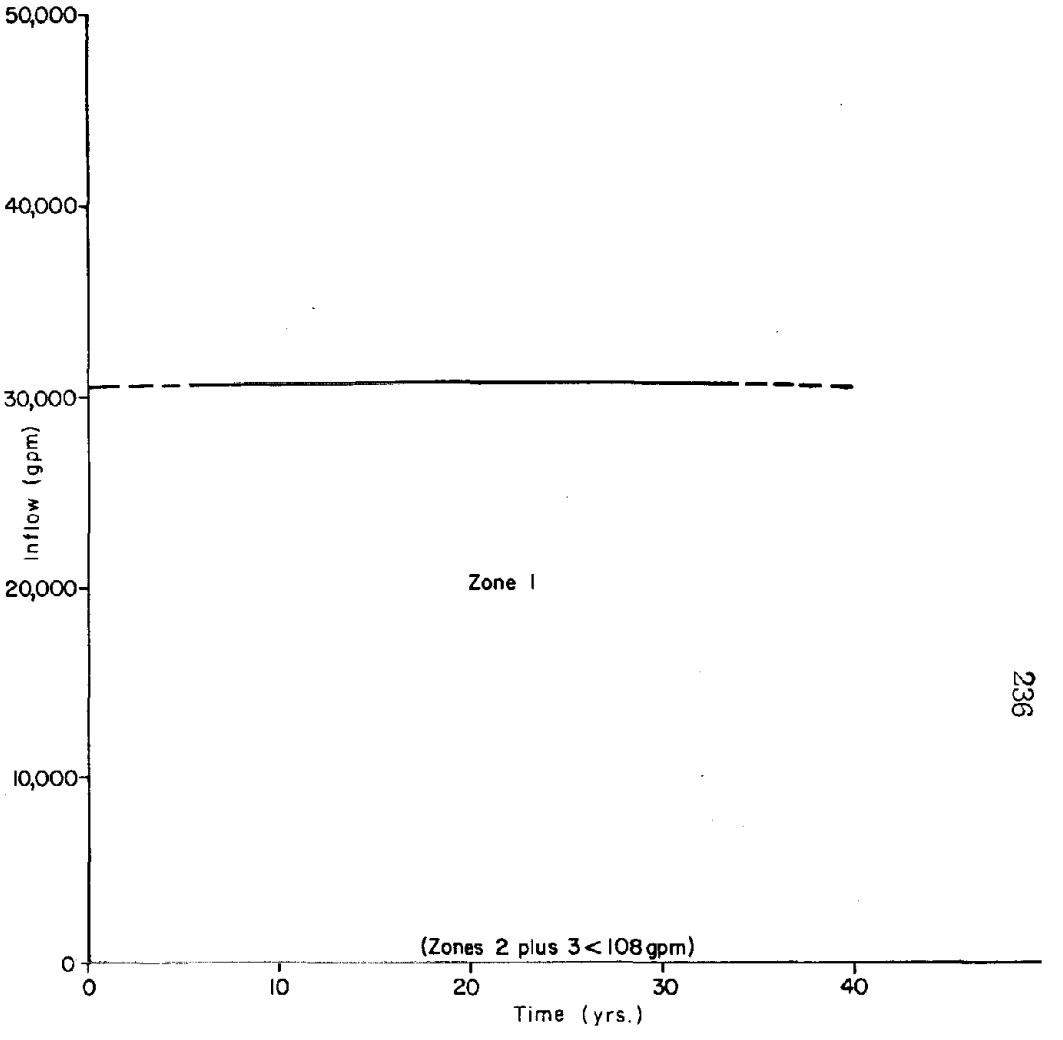
Expansion Rate: .189 mi^2/yr

Initial Radius: 0

Mining Rate: 50,000 ton/day

Figure D-81 MINE INFLOW - SITE I





Time - yrs.	Radius - ft.	MINE INFLOW (gpm) Zone I	(drain) Zone I	Zone 2	Zone 3	Total
5	2896	24,997	4949	40	61	30,050
10	4095	24,997	4949	40	65	30,050
20	5792	24,997	4949	40	67	30,050
30	7093	24,997	4949	40	68	30,050

DESCRIPTION:

Mining Method: Modified In-Situ, Full Subsidence

Number of Passes: 1

Location: R-4

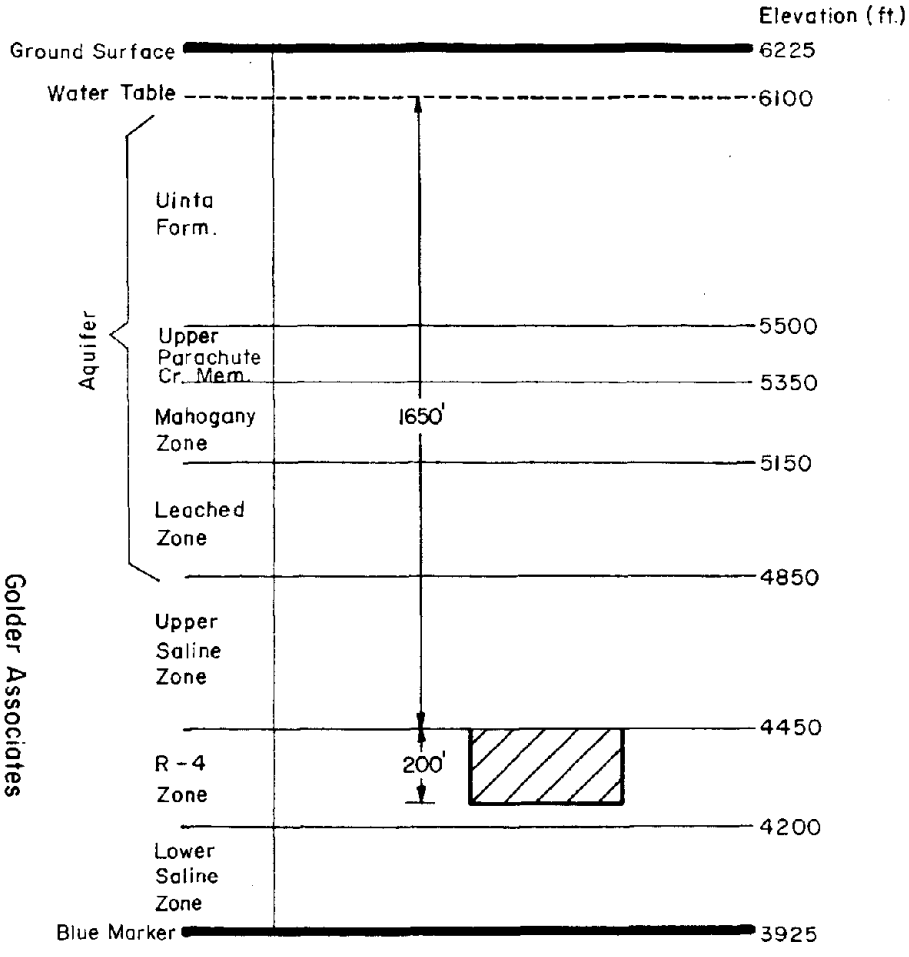
Mining Height: 200 ft

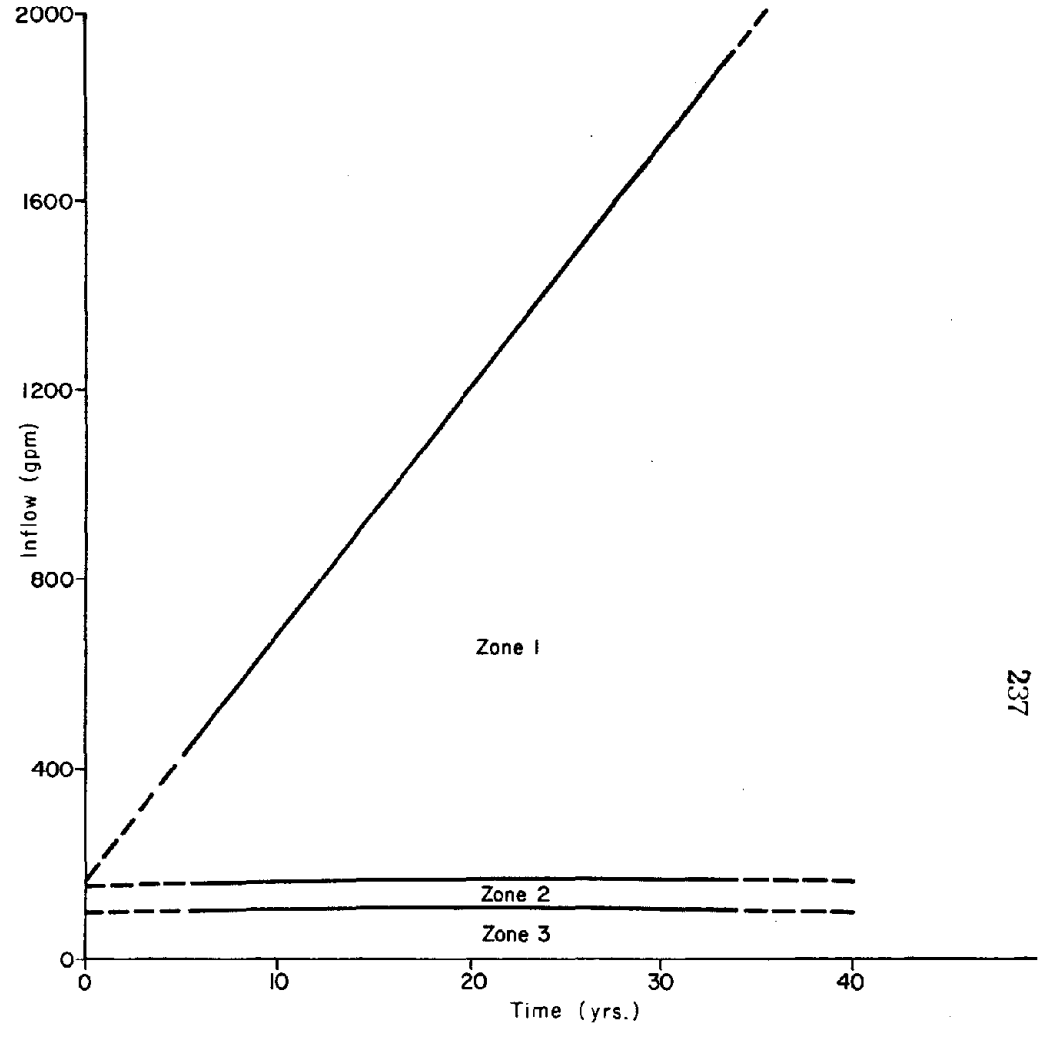
Expansion Rate: .189 mi^2/yr

Initial Radius: 0

Mining Rate: 50,000 ton/day

Figure D-82 MINE INFLOW - SITE I





Time - yrs.	Radius - ft.	MINE INFLOW (gpm) Zone 1	(drain) Zone 1	Zone 2	Zone 3	Total
5	4,095	257	-	62	97	420
10	5,792	513	-	62	101	680
20	8,191	1026	-	62	104	1190
30	10,031	1539	-	62	104	1710

DESCRIPTION:

Mining Method: Modified In-Situ, No Subsidence

Number of Passes: 1

Location: R-4

Mining Height: 200 ft

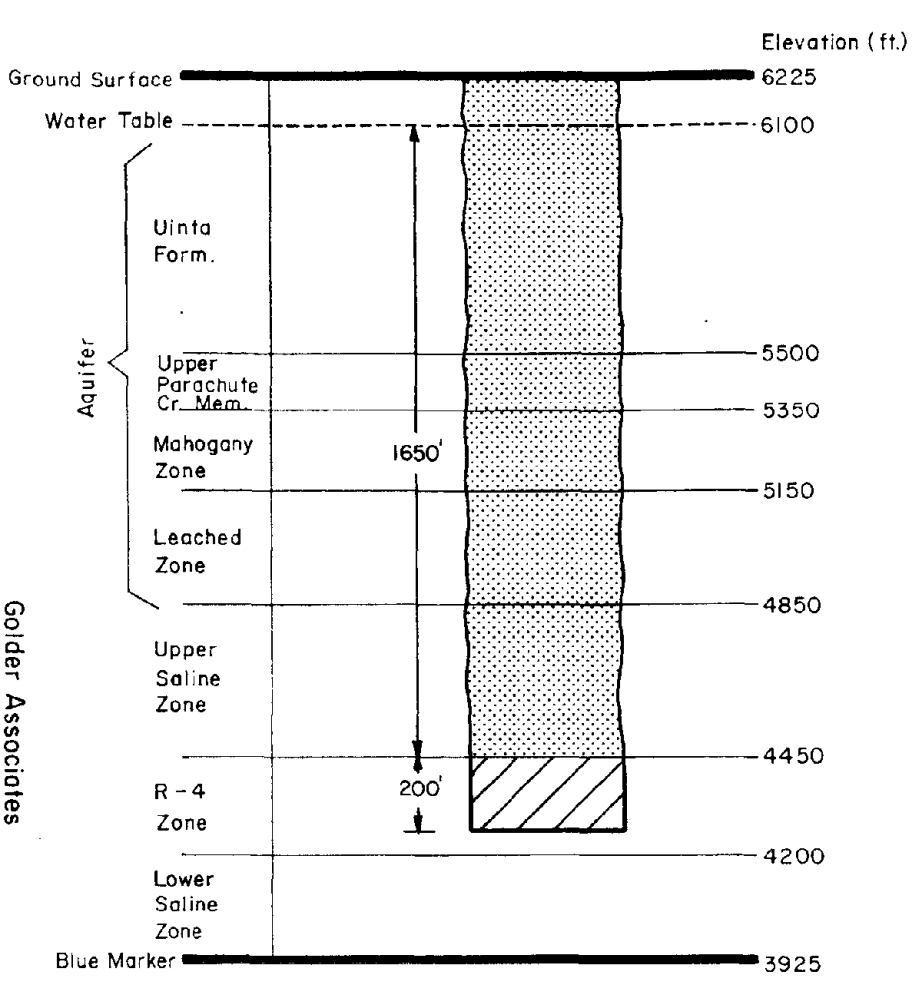
Expansion Rate: .378 mi^2/yr

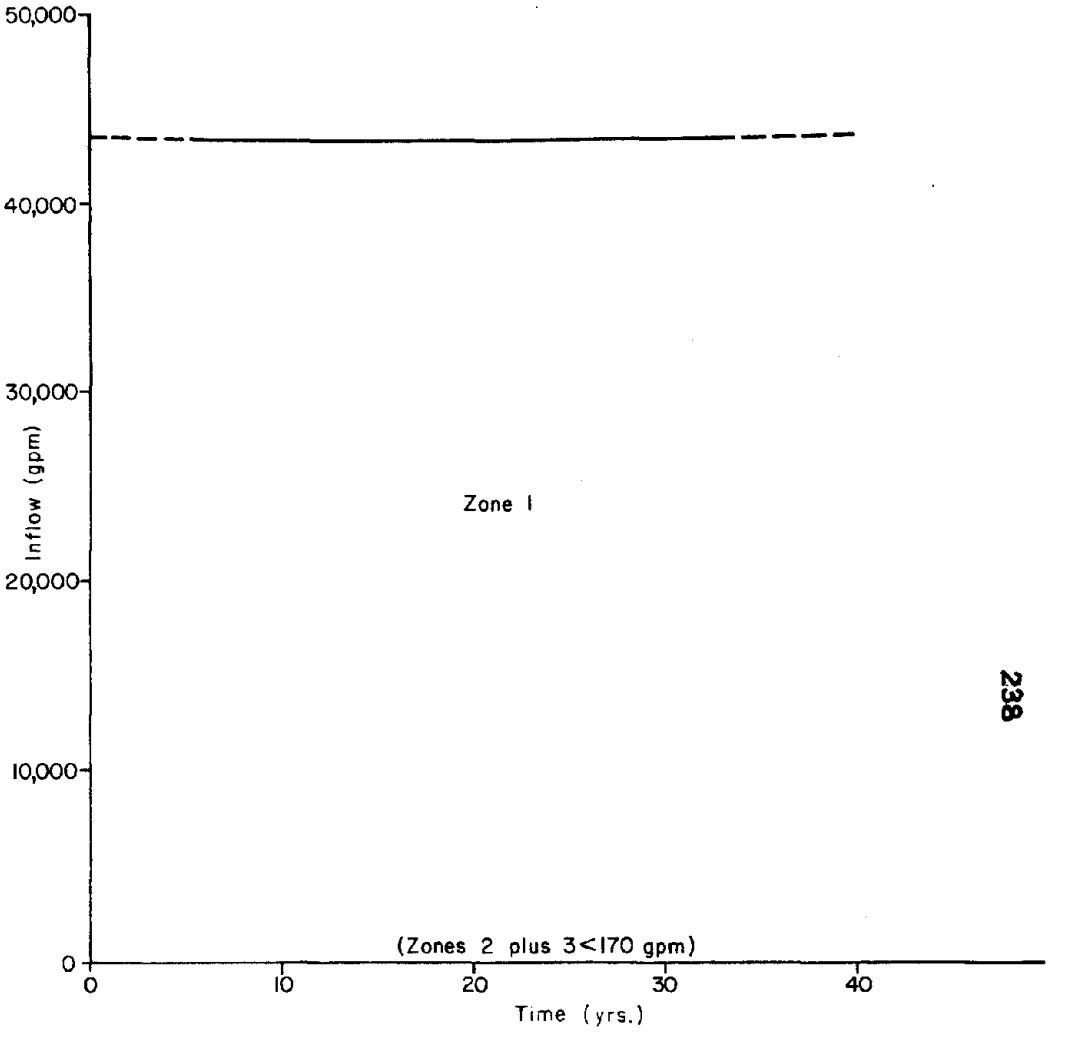
Initial Radius: 0

Mining Rate: 100,000 ton/day

Figure D-83 MINE INFLOW - SITE I

Golder Associates





MINE INFLOW (gpm)

Time - yrs.	Radius - ft.	Zone 1	(drain) Zone 1	Zone 2	Zone 3	Total
5	4,095	33,048	9898	62	97	43,110
10	5,792	33,048	9898	62	101	43,110
20	8,191	33,048	9898	62	104	43,110
30	10,031	33,048	9898	62	104	43,110

DESCRIPTION:

Mining Method: Modified In-Situ, Full Subsidence

Number of Passes: 1

Location: R-4

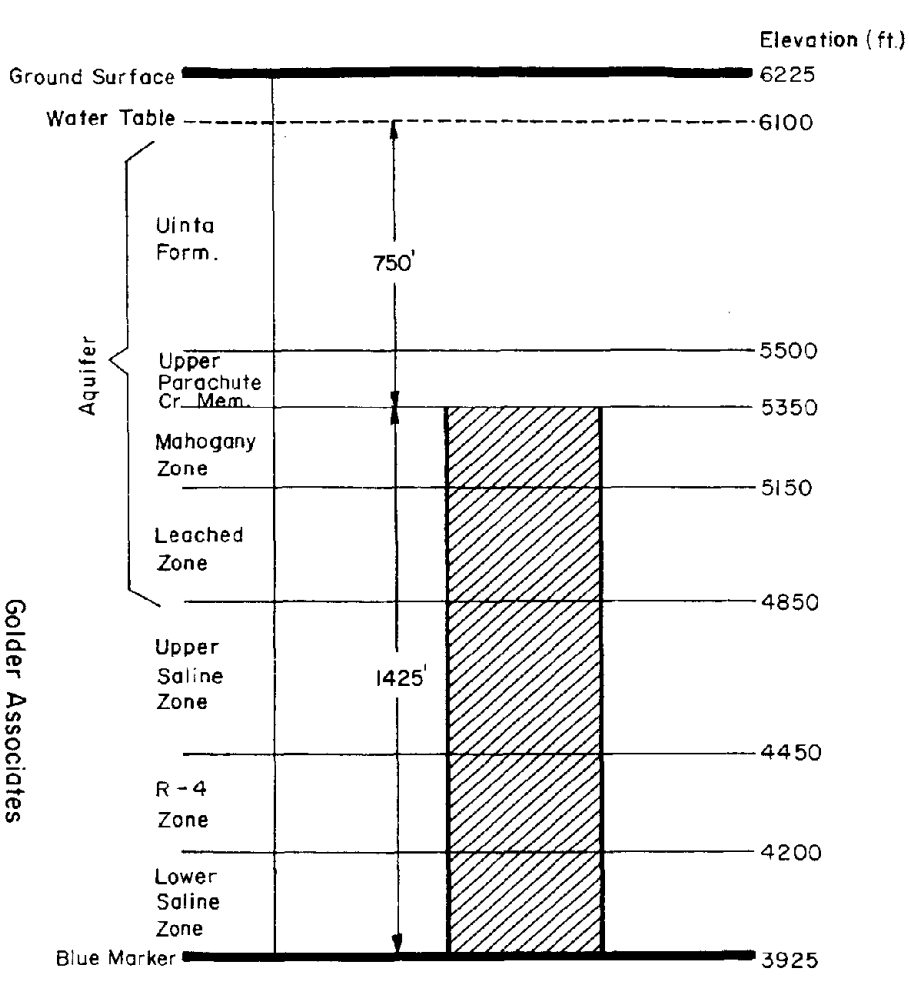
Mining Height: 200 ft

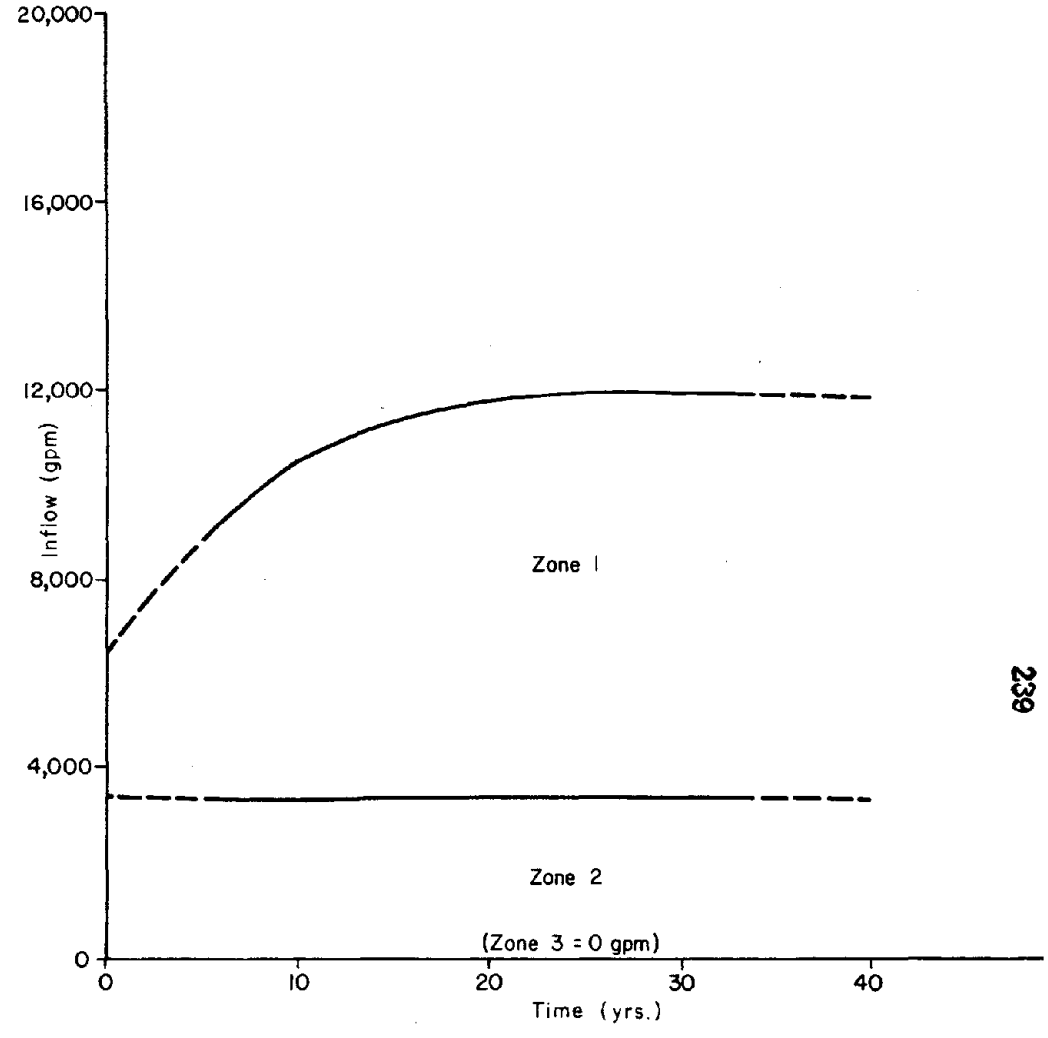
Expansion Rate: .378 mi^2/yr

Initial Radius: 0

Mining Rate: 100,000 ton/day

Figure D-84 MINE INFLOW – SITE 1





Time - yrs.	Radius - ft.	MINE INFLOW (gpm) Zone 1	(drain) Zone 1	Zone 2	Zone 3	Total
5	1134	5288	-	3420	-	8,710
10	1604	7054	-	3420	-	10,470
20	2269	8318	-	3420	-	11,740
30	2779	8507	-	3420	-	11,930

DESCRIPTION:

Mining Method: Modified In-Situ, No Subsidence

Number of Passes: 1

Location: Blue Marker to Mahogany

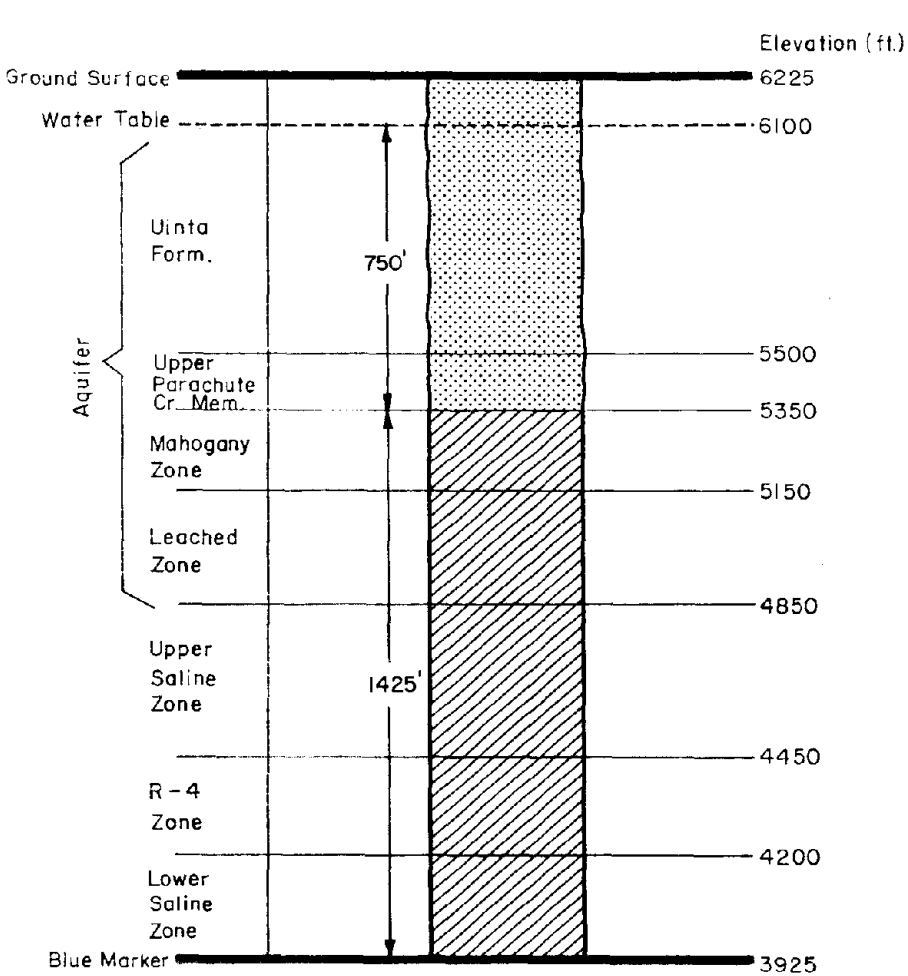
Mining Height: 1425 ft.

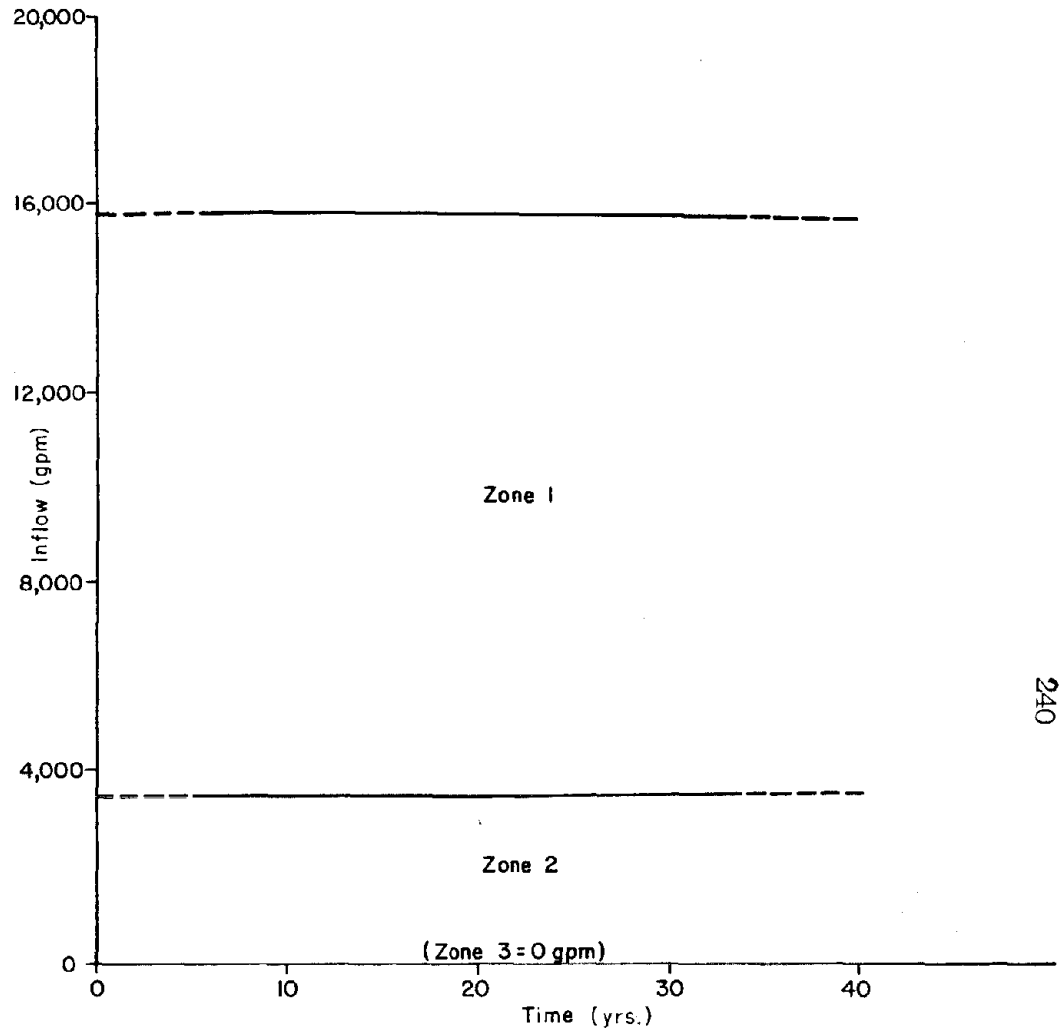
Expansion Rate: .029 mi^2/yr

Initial Radius: 0

Mining Rate: 50,000 ton/day

Figure D-85 MINE INFLOW - SITE I





Time - yrs.	Radius - ft.	MINE INFLOW (gpm) Zone 1	(drain) Zone 1	Zone 2	Zone 3	Total
5	1134	11,635	690	3420	-	15,750
10	1604	11,635	690	3420	-	15,750
20	2269	11,635	690	3420	-	15,750
30	2779	11,635	690	3420	-	15,750

DESCRIPTION:

Mining Method: Modified In-Situ, Full Subsidence

Number of Passes: 1

Location: Blue Marker to Mahogany

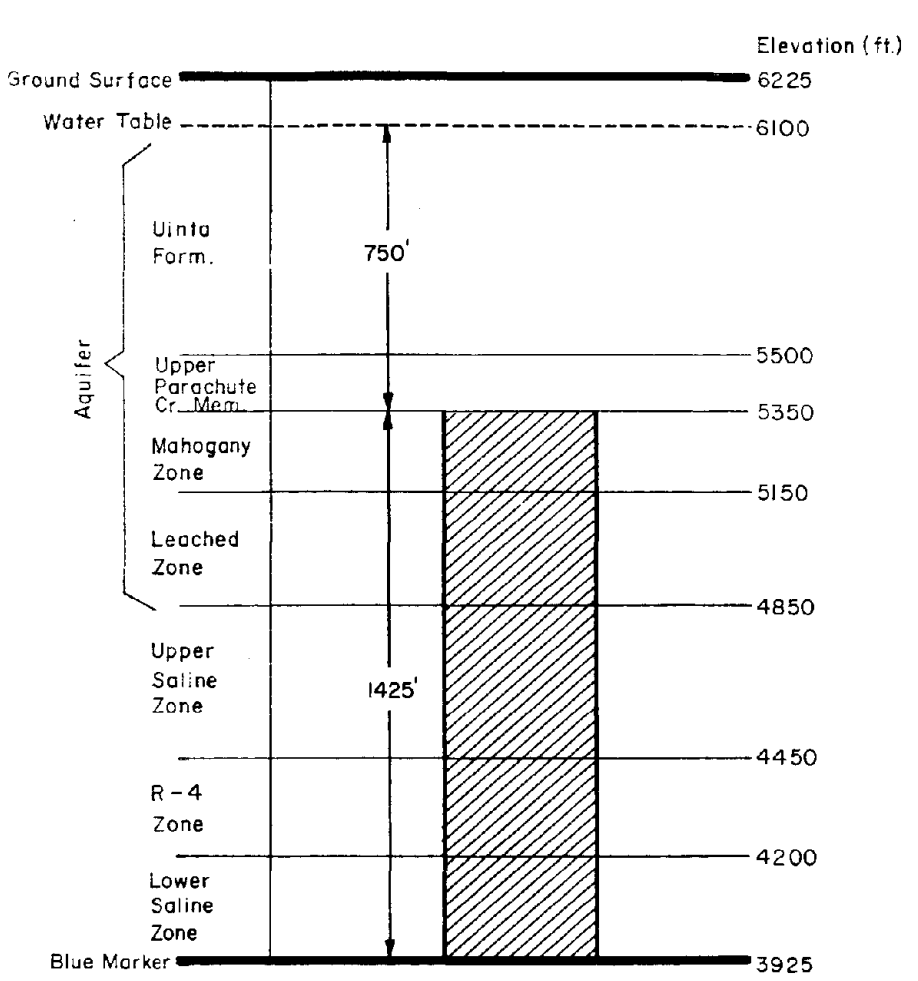
Mining Height: 1425 ft

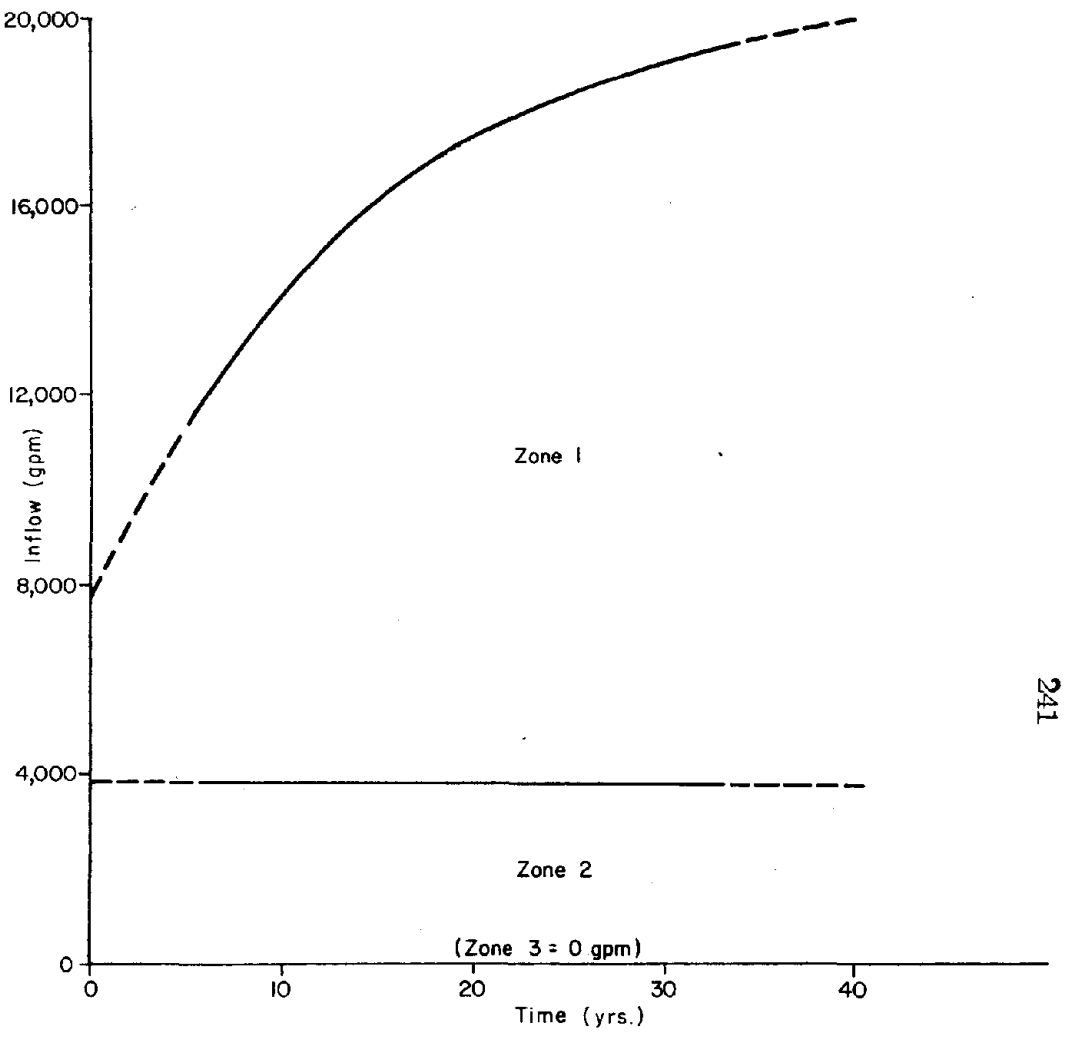
Expansion Rate: .029 mi^2/yr

Initial Radius: 0

Mining Rate: 50,000 ton/day

Figure D-86 MINE INFLOW – SITE I





Time - yrs.	Radius - ft.	MINE INFLOW (gpm) Zone 1	(drain) Zone 1	Zone 2	Zone 3	Total
5	1604	7,683	-	3703	-	11,390
10	2269	10,334	-	3703	-	14,040
20	3208	13,603	-	3703	-	17,310
30	3929	15,335	-	3703	-	19,040

DESCRIPTION:

Mining Method: Modified In-Situ, No Subsidence

Number of Passes: 1

Location: Blue Marker to Mahogany

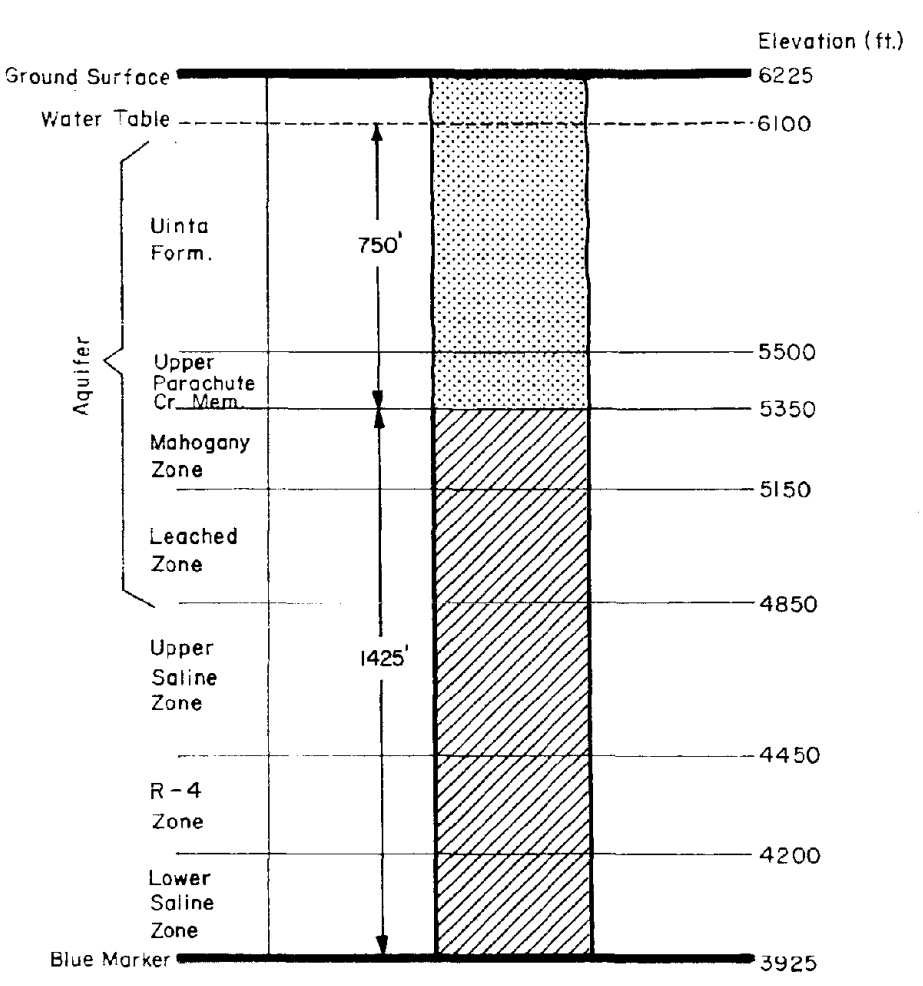
Mining Height: 1425 ft

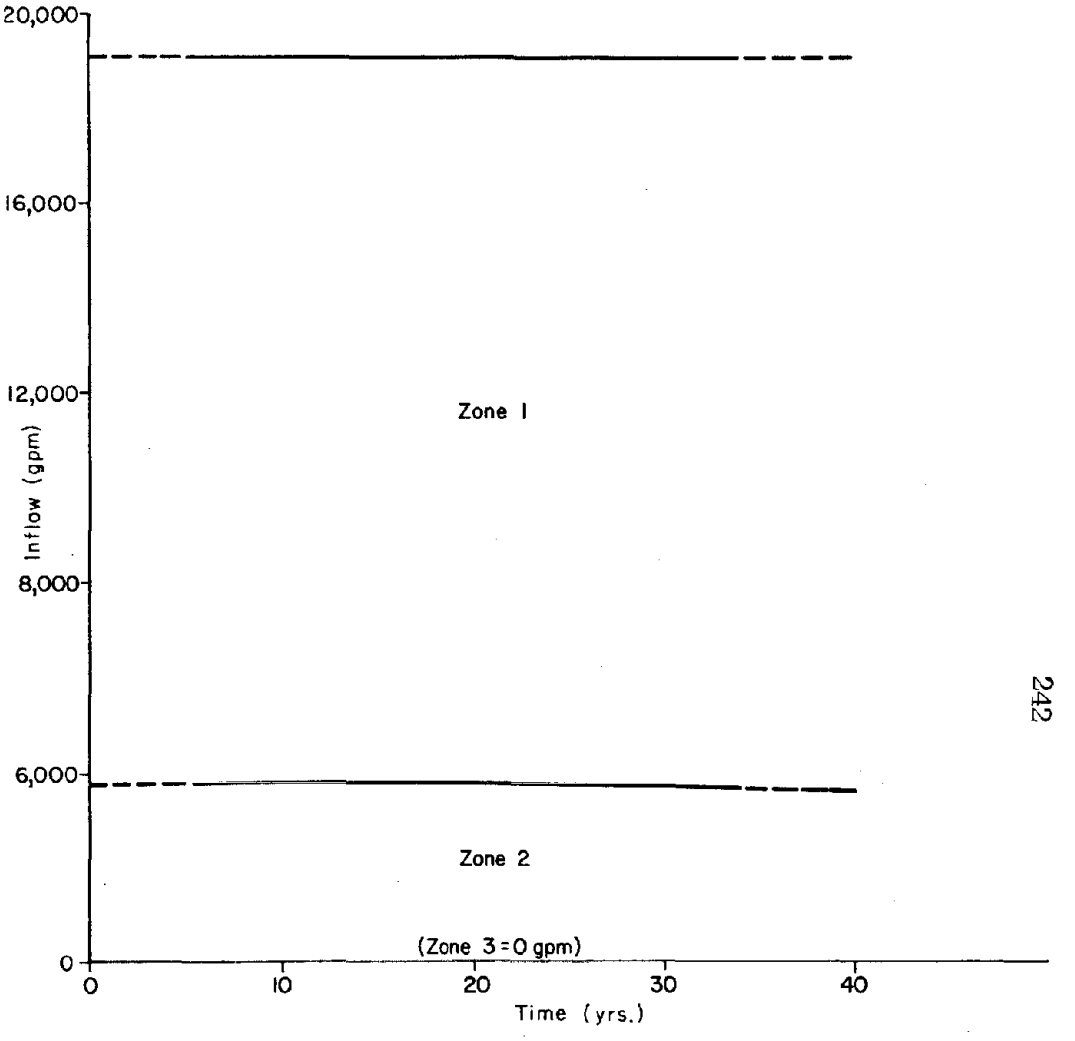
Expansion Rate: .058 mi^2/yr

Initial Radius: 0

Mining Rate: 100,000 ton/day

Figure D-87 MINE INFLOW - SITE I





Time - yrs.	Radius - ft.	MINE INFLOW (gpm) Zone 1	(drain) Zone 1	Zone 2	Zone 3	Total
5	1604	13,955	1380	3703	-	19,040
10	2269	13,955	1380	3703	-	19,040
20	3208	13,955	1380	3703	-	19,040
30	3929	13,955	1380	3703	-	19,040

DESCRIPTION:

Mining Method: Modified In-Situ, Full Subsidence

Number of Passes: 1

Location: Blue Marker to Mahogany

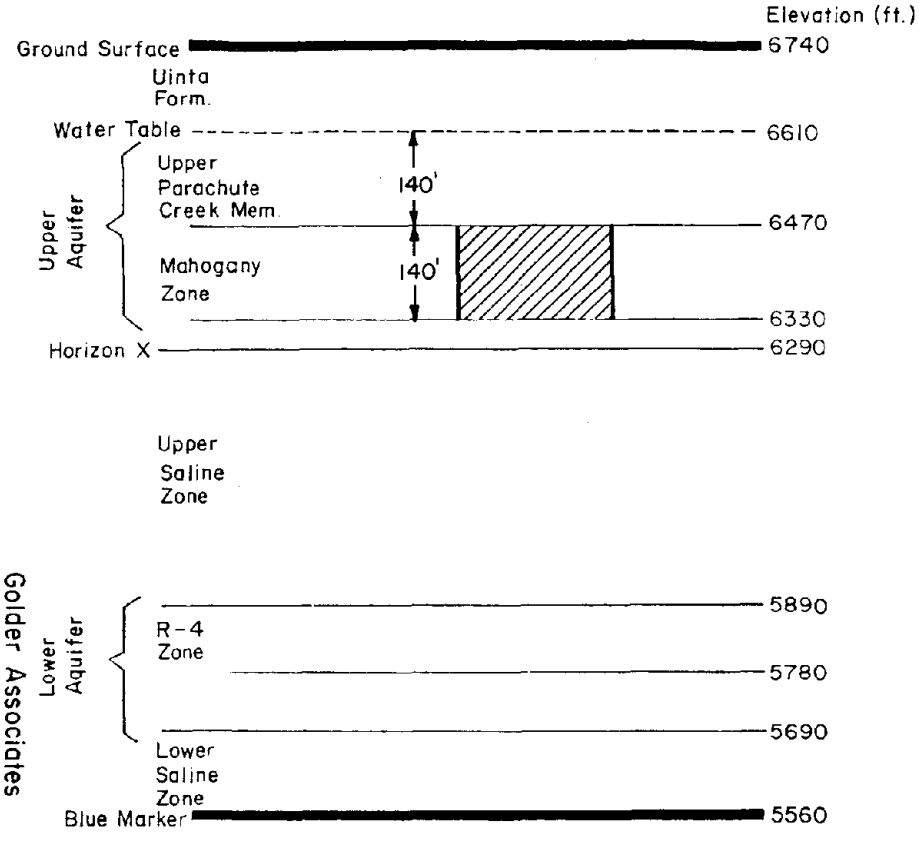
Mining Height: 1425 ft

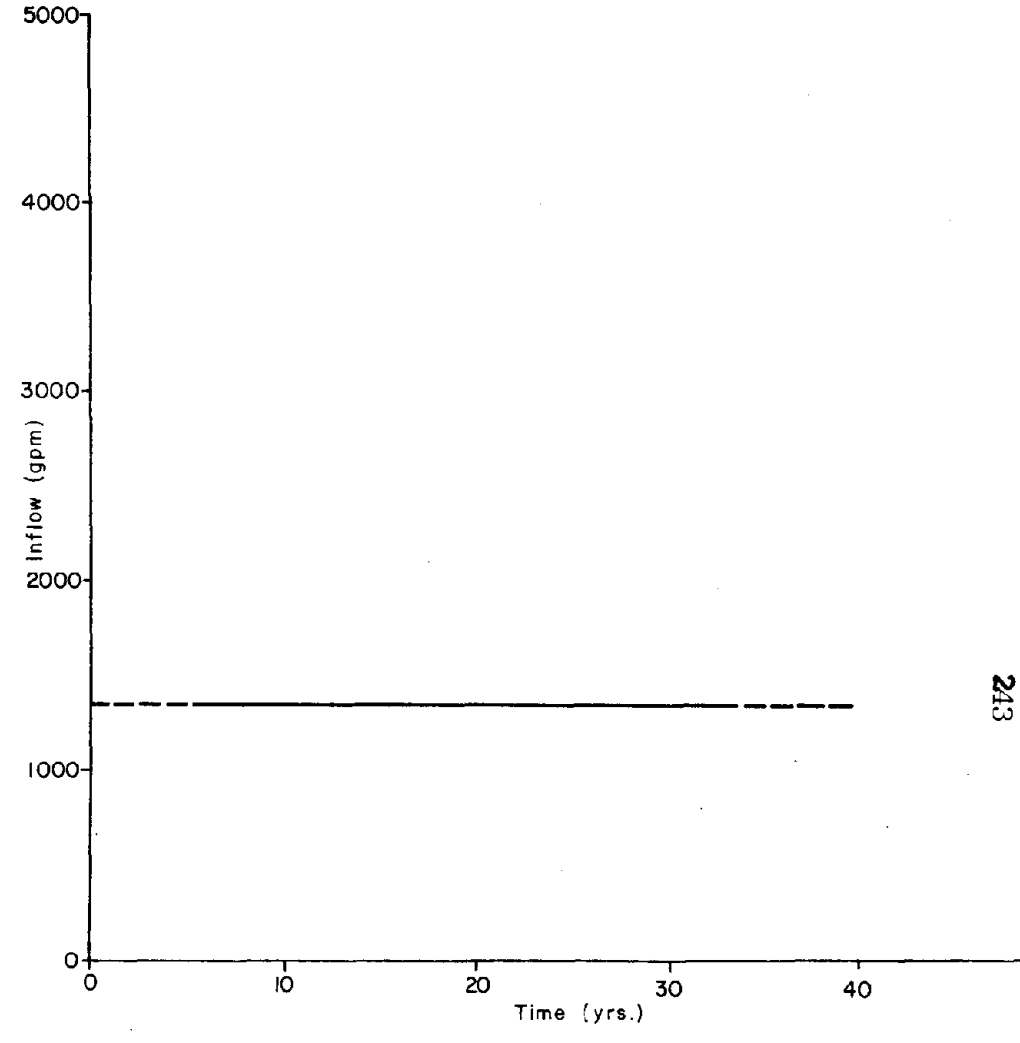
Expansion Rate: .058 mi^2/yr

Initial Radius: 0

Mining Rate: 100,000 ton/day

Figure D-88 MINE INFLOW - SITE I





Time -yrs	Radius-ft.	MINE INFLOW (gpm) Zone I	(drain) Zone I	Zone 2	Zone 3	Total
5	2536	-	-	-	-	1350
10	3587	-	-	-	-	1350
20	5073	-	-	-	-	1350
30	6213	-	-	-	-	1350

DESCRIPTION:

Mining Method: True In-Situ

Number of Passes: 1

Location: Mahogany

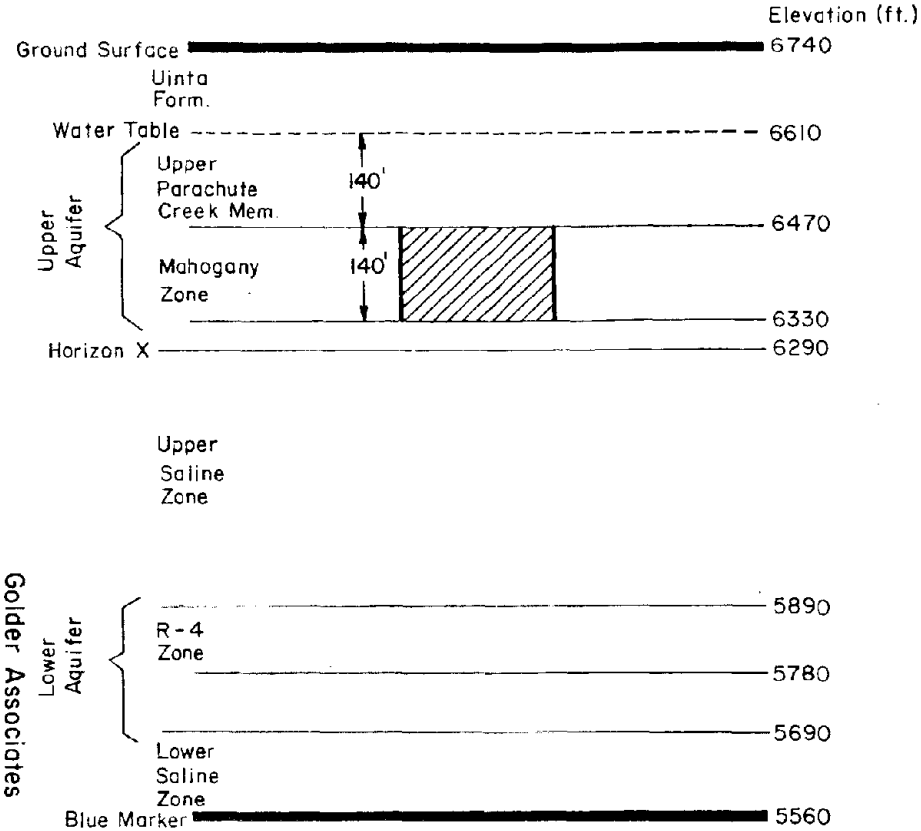
Mining Height: 140 ft

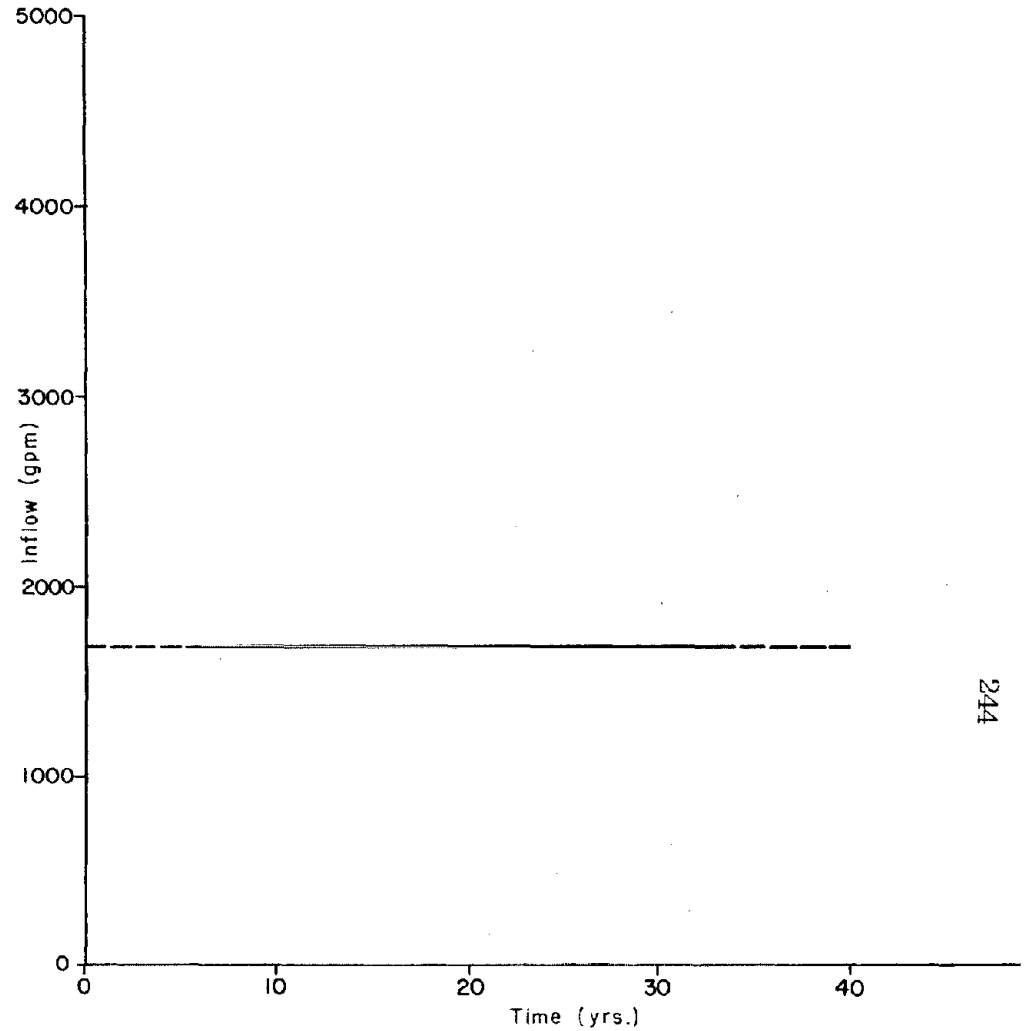
Expansion Rate: .145 mi^2/yr

Initial Radius: 0

Mining Rate: 50,000 ton/day

Figure D-89 MINE INFLOW - SITE 2





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MINE INFLOW (gpm)

Time -yrs	Radius-ft.	Zone 1	(drain) Zone 1	Zone 2	Zone 3	Total
5	3587	-	-	-	-	1680
10	5073	-	-	-	-	1680
20	7174	-	-	-	-	1680
30	8787	-	-	-	-	1680

DESCRIPTION:

Mining Method: True In-Situ

Number of Passes: 1

Location: Mahogany

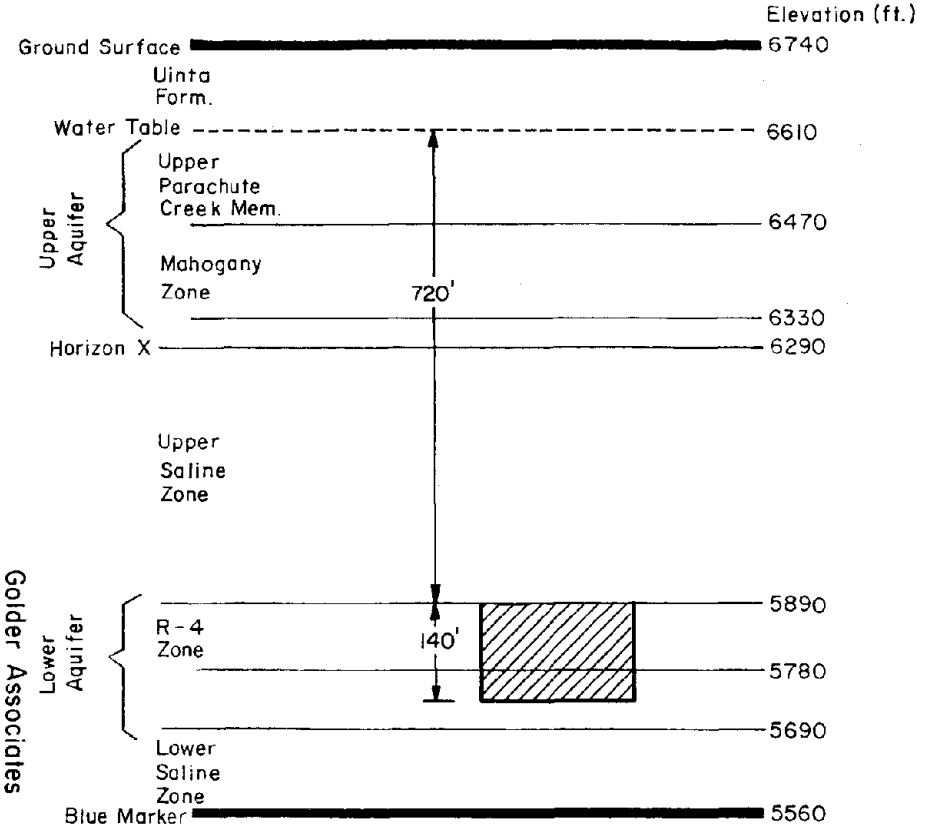
Mining Height: 140 ft

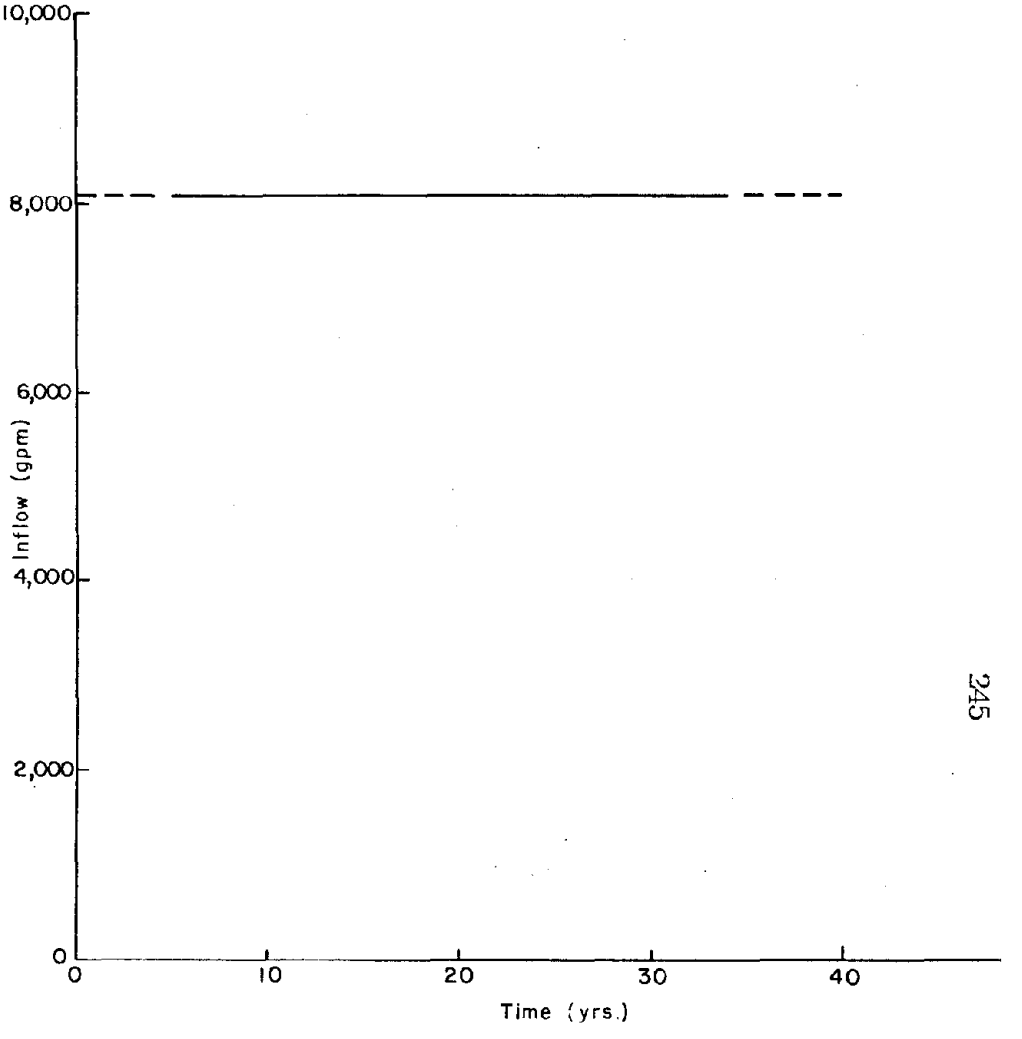
Expansion Rate: .290 mi^2/yr

Initial Radius: 0

Mining Rate: 100,000 ton/day

Figure D-90 MINE INFLOW - SITE 2





Time-yrs	Radius-ft.	MINE INFLOW (gpm) Zone 1	(drain) Zone 1	Zone 2	Zone 3	Total
5	2536	-	-	-	-	8060
10	3587	-	-	-	-	8060
20	5073	-	-	-	-	8060
30	6213	-	-	-	-	8060

DESCRIPTION:

Mining Method: True In-Situ

Number of Passes: 1

Location: R-4

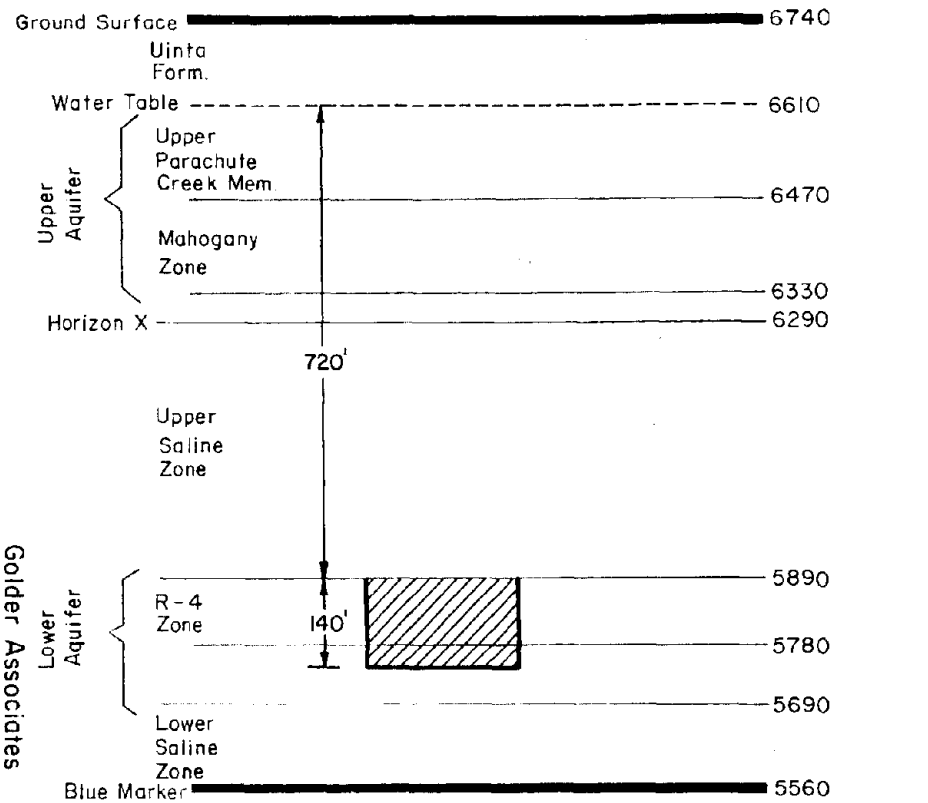
Mining Height: 140 ft

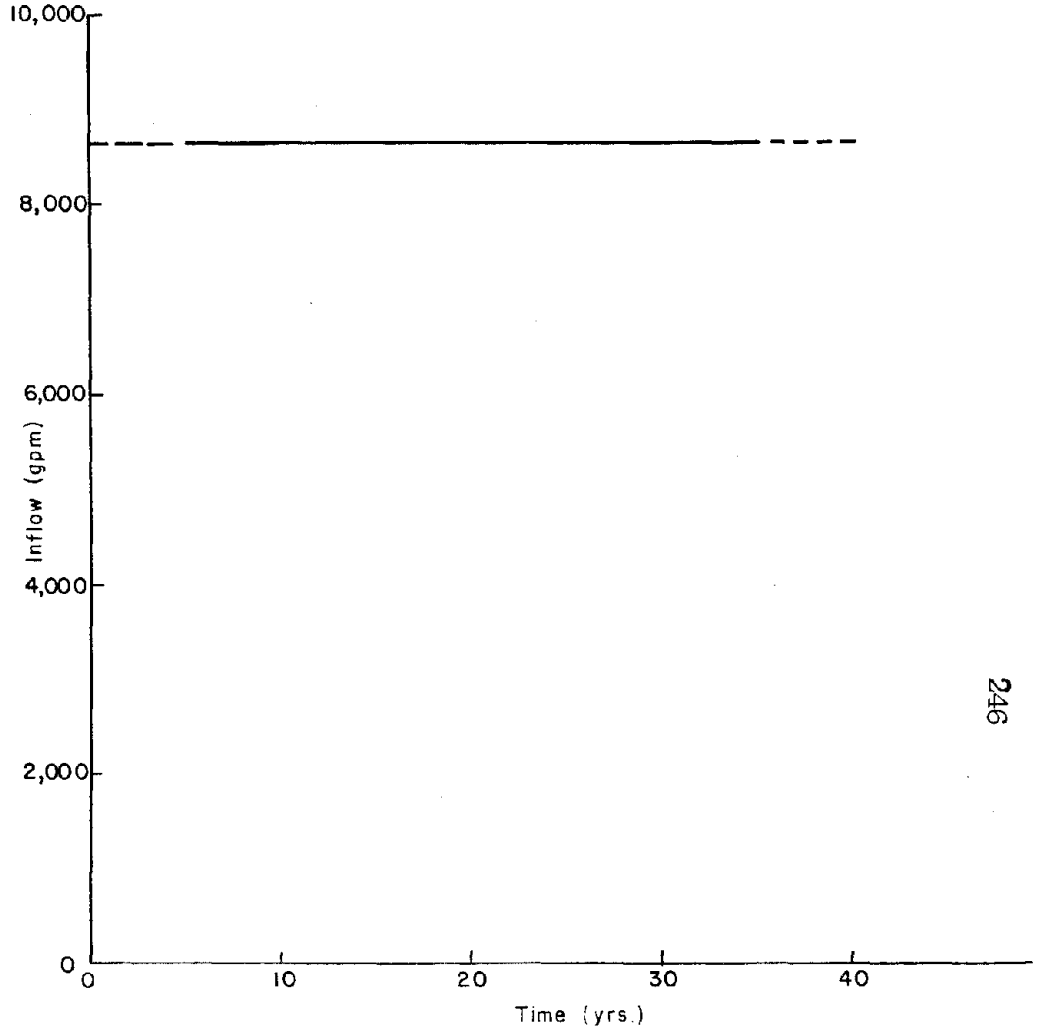
Expansion Rate: .145 mi^2/yr

Initial Radius: 0

Mining Rate: 50,000 ton/day

Figure D-91 MINE INFLOW - SITE 2





MINE INFLOW (gpm)

Time -yrs	Radius-ft.	Zone 1	Zone 1 (drain)	Zone 2	Zone 3	Total
5	3587	-	-	-	-	8680
10	5073	-	-	-	-	8680
20	7174	-	-	-	-	8680
30	8787	-	-	-	-	8680

DESCRIPTION:

Mining Method: True In-Situ

Number of Passes: 1

Location: R-4

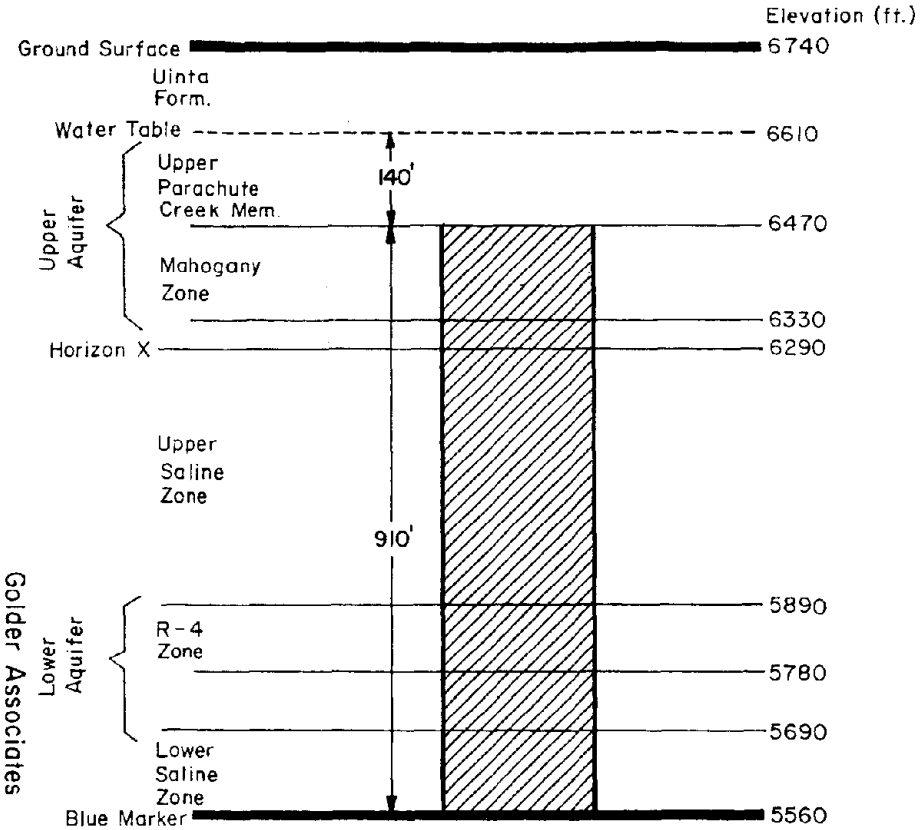
Mining Height: 140 ft

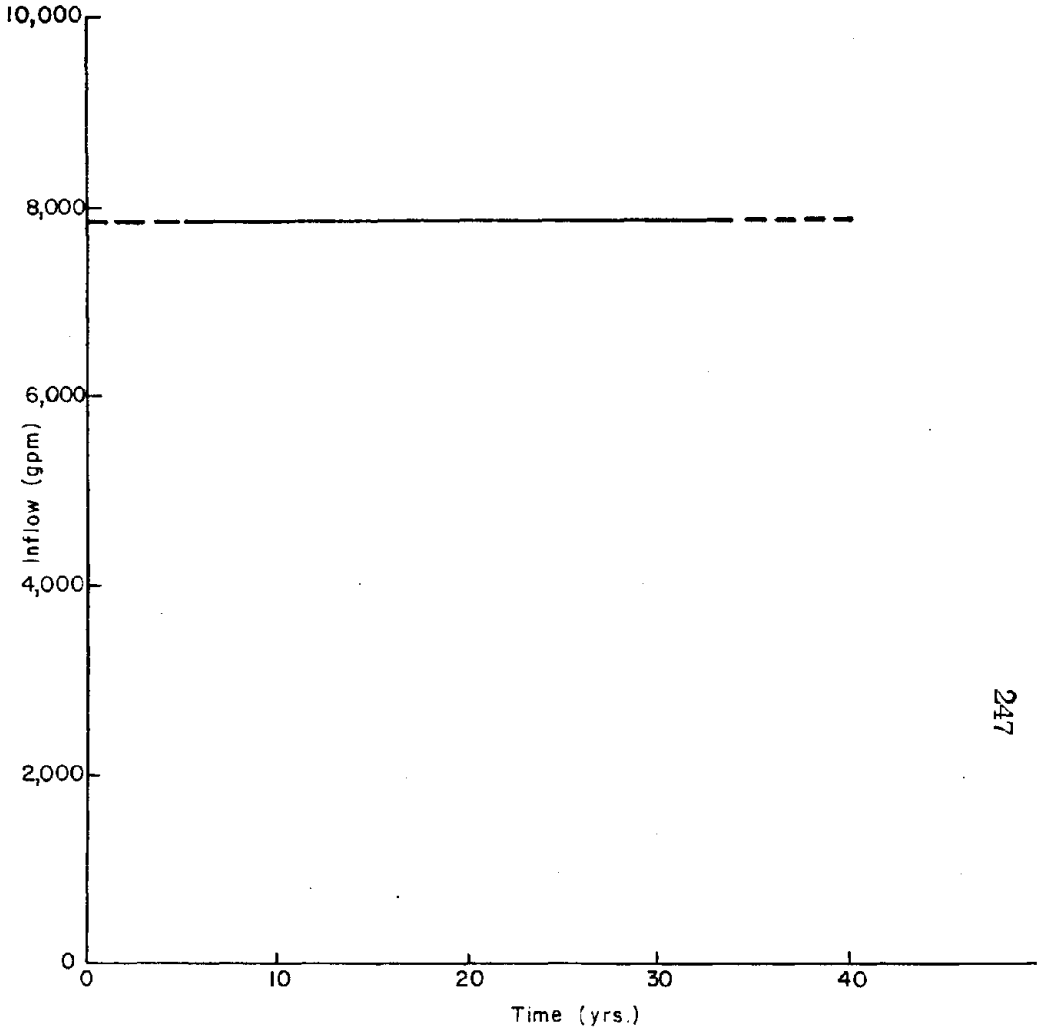
Expansion Rate: .290 mi^2/yr

Initial Radius: 0

Mining Rate: 100,000 ton/day

Figure D-92 MINE INFLOW - SITE 2





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MINE INFLOW (gpm)

Time-yrs	Radius-ft.	Zone 1	(drain) Zone 1	Zone 2	Zone 3	Total
5	988	-	-	-	-	7840
10	1397	-	-	-	-	7840
20	1976	-	-	-	-	7840
30	2420	-	-	-	-	7840

DESCRIPTION:

Mining Method: True In-Situ

Number of Passes: 1

Location: Blue Marker to Mahogany

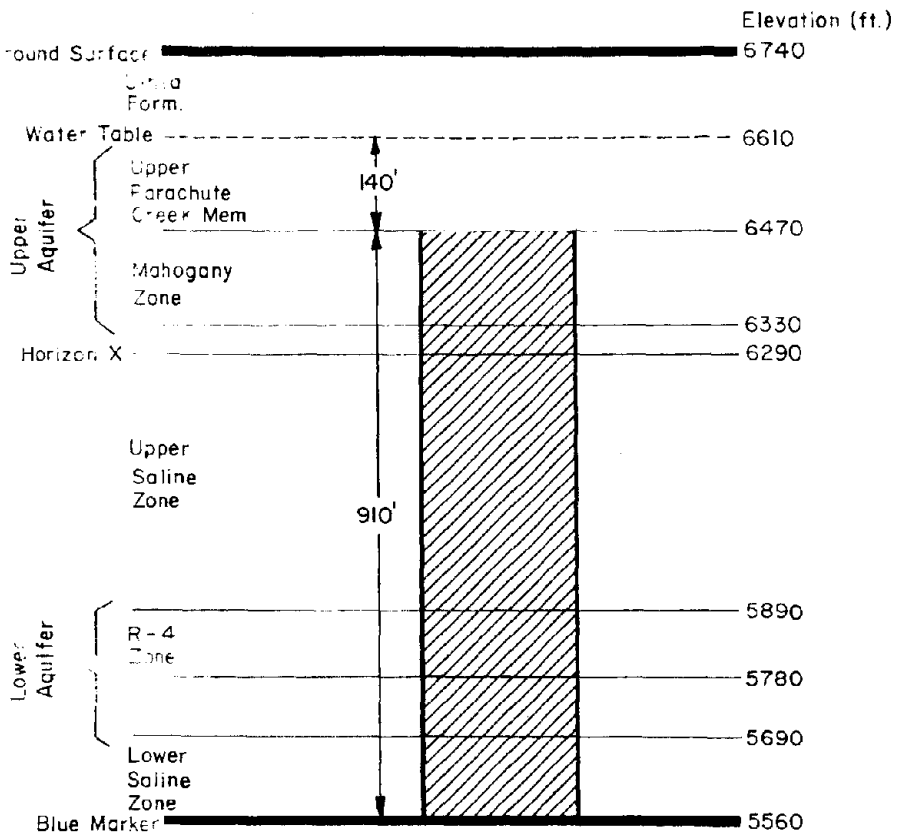
Mining Height: 910 ft

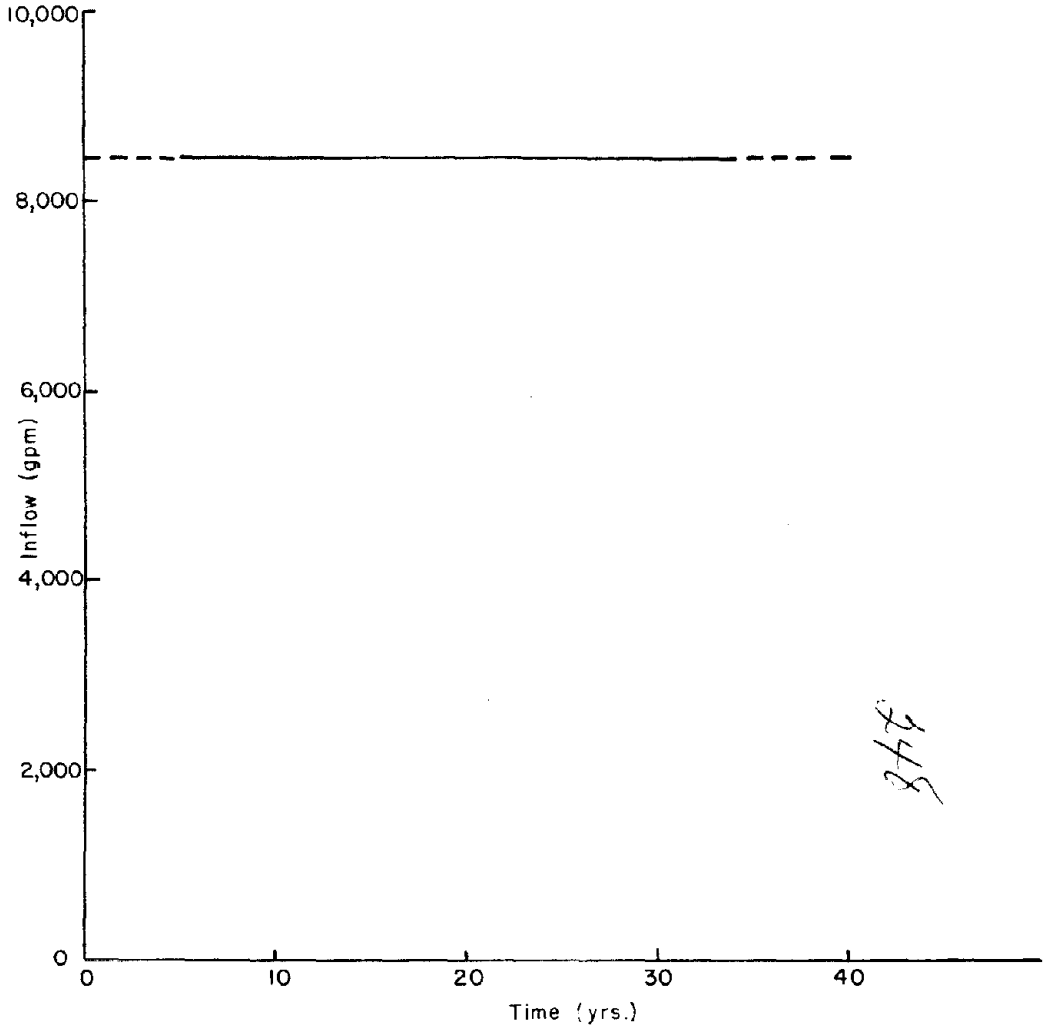
Expansion Rate: .022 mi^2/yr

Initial Radius: 0

Mining Rate: 50,000 ton/day

Figure D-93 MINE INFLOW - SITE 2





MINE INFLOW (gpm)

Time-yrs	Radius-ft.	Zone I	Zone I (drain)	Zone 2	Zone 3	Total
5	1397	-	-	-	-	8450
10	1976	-	-	-	-	8450
20	2794	-	-	-	-	8450
30	3423	-	-	-	-	8450

DESCRIPTION:

Mining Method: True In-Situ

Number of Passes: 1

Location: Blue Marker to Mahogany

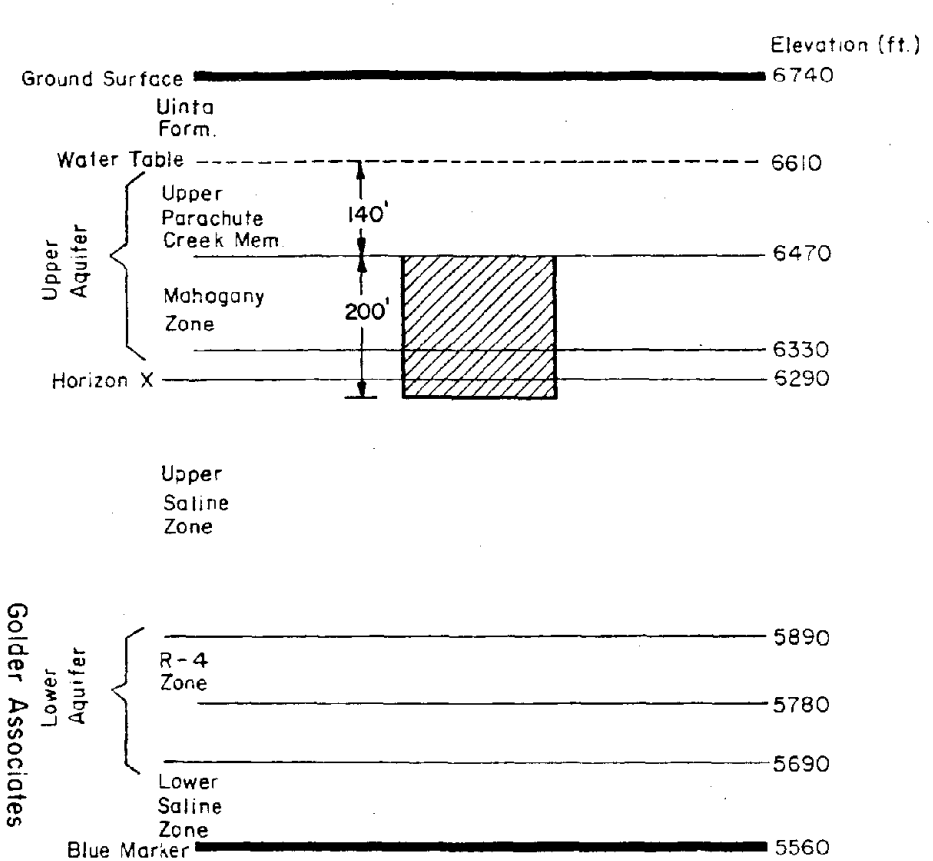
Mining Height: 910 ft

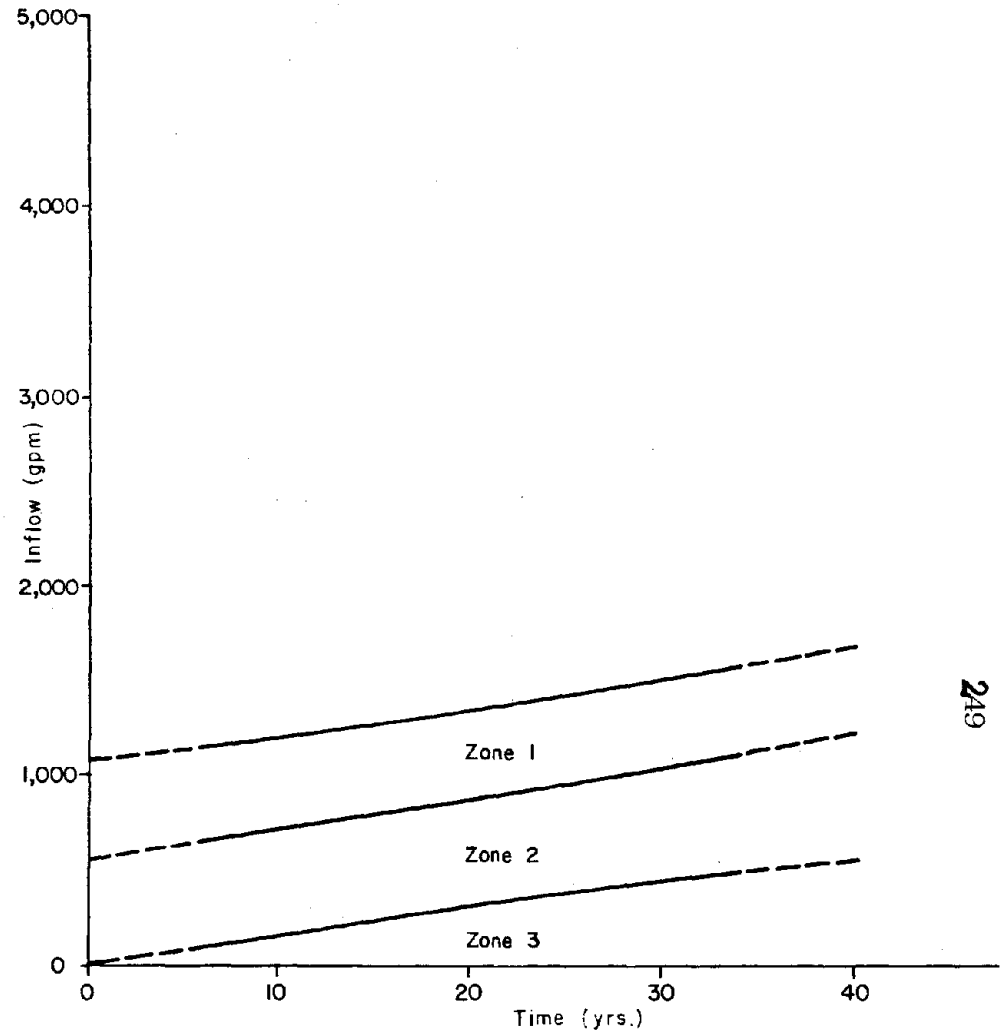
Expansion Rate: .044 mi^2/yr

Initial Radius: 0

Mining Rate: 100,000 ton/day

Figure D-94 MINE INFLOW - SITE 2





MINE INFLOW (gpm)

Time -yrs	Radius-ft.	Zone 1	(drain) Zone 1	Zone 2	Zone 3	Total
5	2896	481	-	564	78	1120
10	4095	481	-	564	156	1200
20	5792	481	-	564	311	1360
30	7093	481	-	564	467	1510

DESCRIPTION:

Mining Method: Modified In-Situ, No Subsidence

Number of Passes: 1

Location: Mahogany

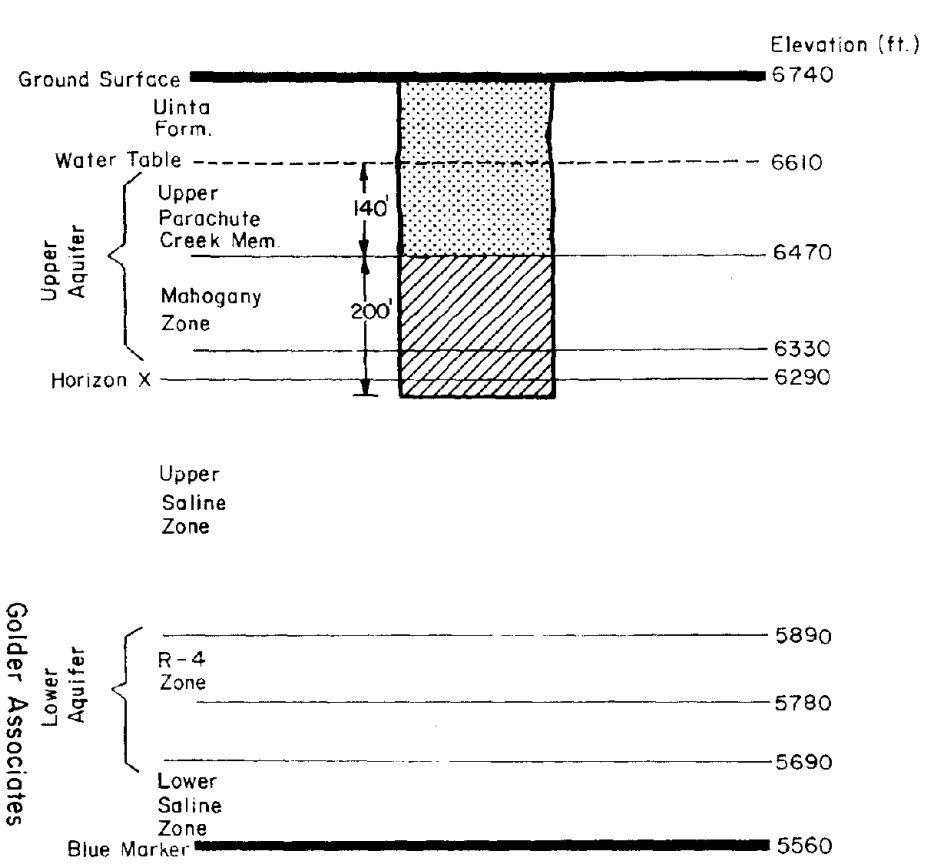
Mining Height: 200 ft

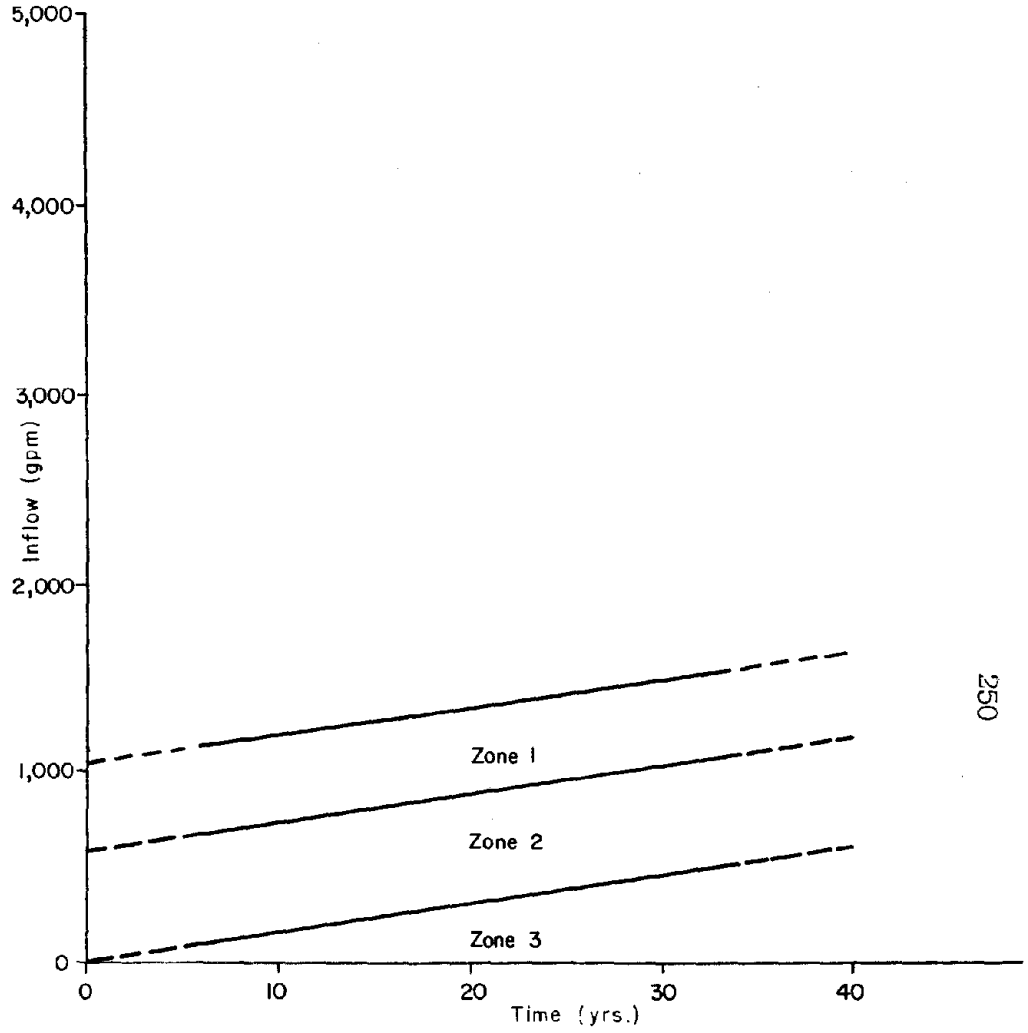
Expansion Rate: .189 mi^2/yr

Initial Radius: 0

Mining Rate: 50,000 ton/day

Figure D-95 MINE INFLOW - SITE 2





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Time -yrs	Radius-ft.	MINE INFLOW (gpm) Zone 1	(drain) Zone 1	Zone 2	Zone 3	Total
5	2896	376	105	564	78	1120
10	4095	376	105	564	156	1200
20	5792	376	105	564	311	1360
30	7093	367	105	564	467	1510

DESCRIPTION:

Mining Method: Modified In-Situ, Full Subsidence

Number of Passes: 1

Location: Mahogany

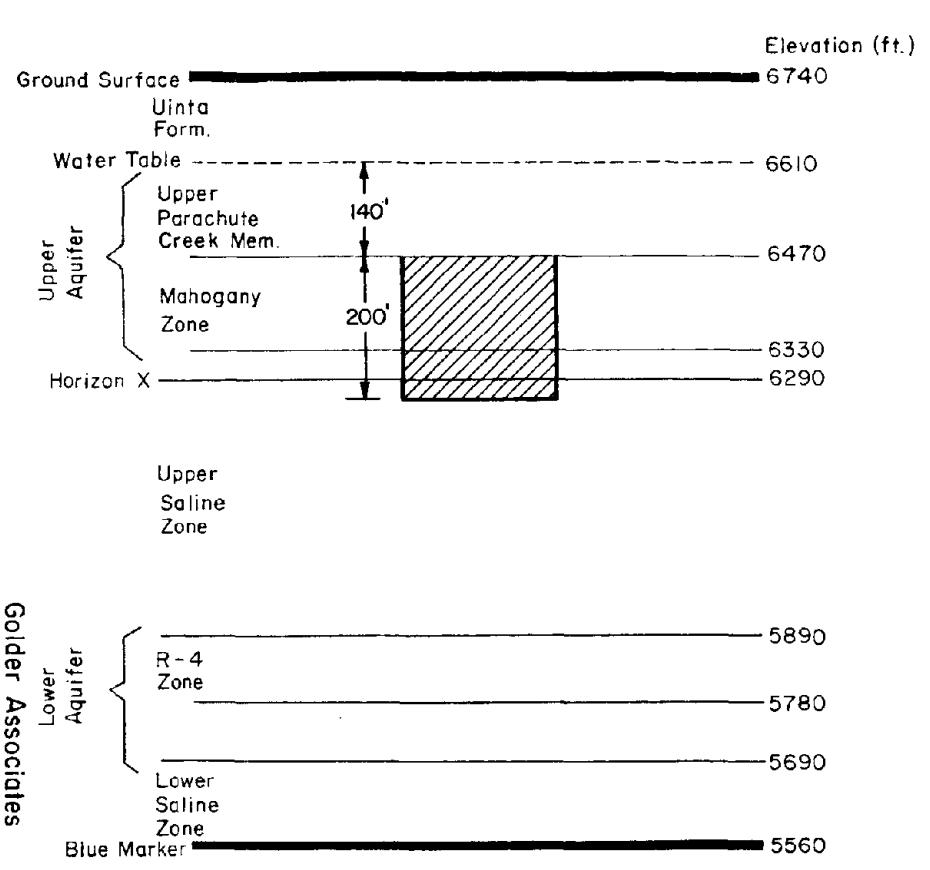
Mining Height: 200 ft

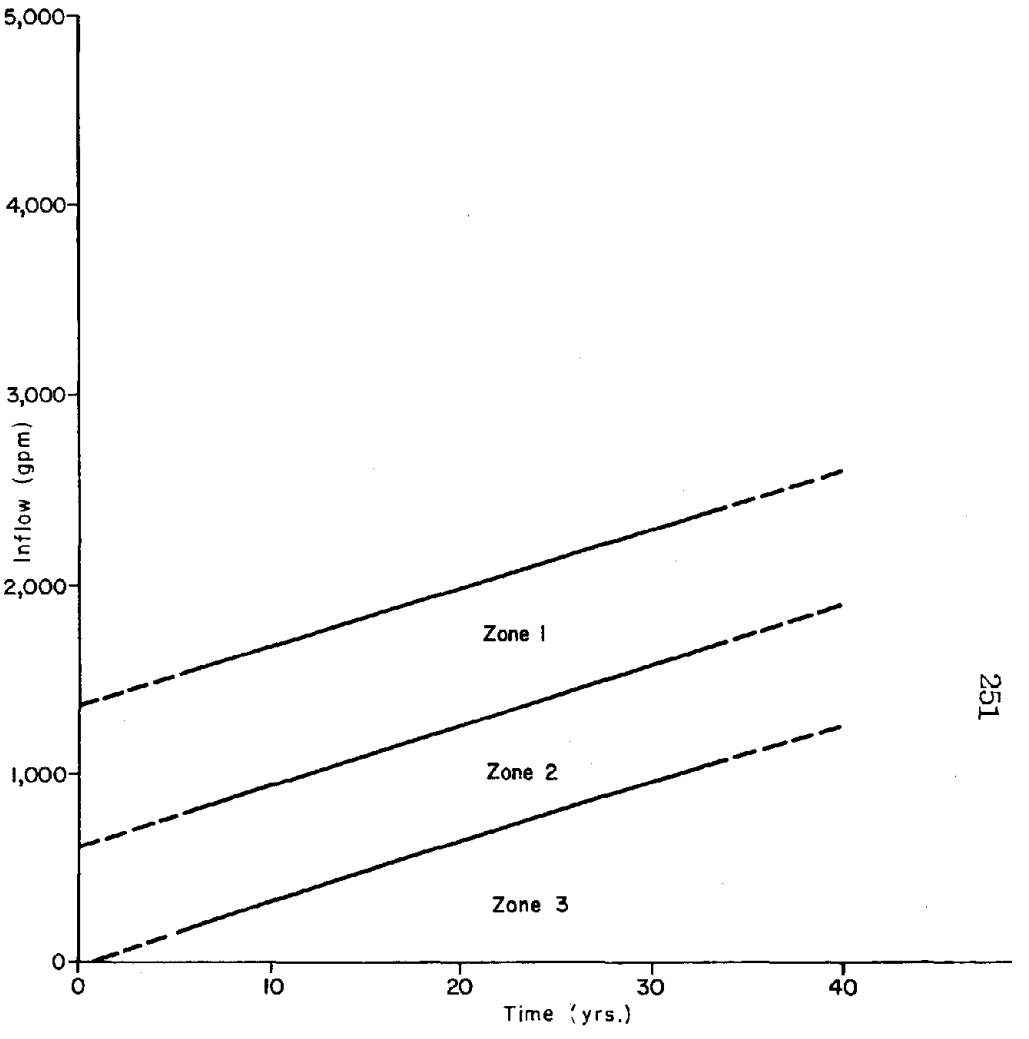
Expansion Rate: .189 mi^2/yr

Initial Radius: 0

Mining Rate: 50,000 ton/day

Figure D-96 MINE INFLOW - SITE 2





Time-yrs	Radius-ft.	MINE INFLOW (gpm) Zone 1	(drain) Zone 1	Zone 2	Zone 3	Total
5	4,095	725	-	622	156	1500
10	5,792	725	-	622	311	1660
20	8,191	725	-	622	622	1970
30	10,031	725	-	622	933	2280

DESCRIPTION:

Mining Method: Modified In-Situ, No Subsidence

Number of Passes: 1

Location: Mahogany

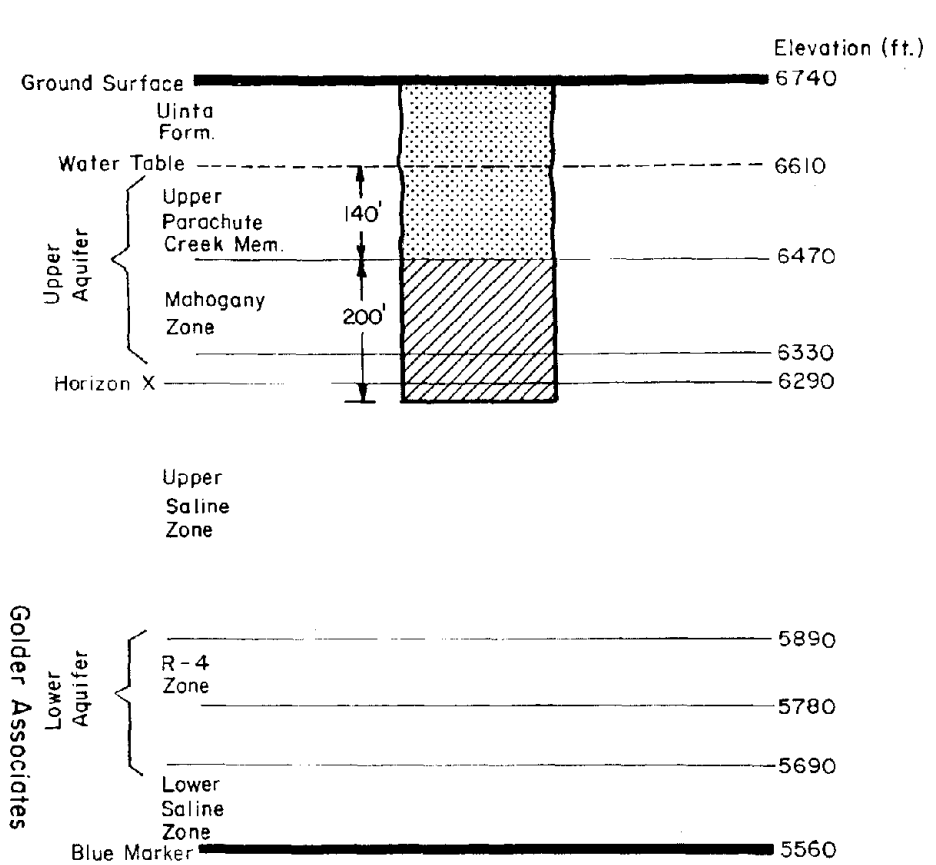
Mining Height: 200 ft

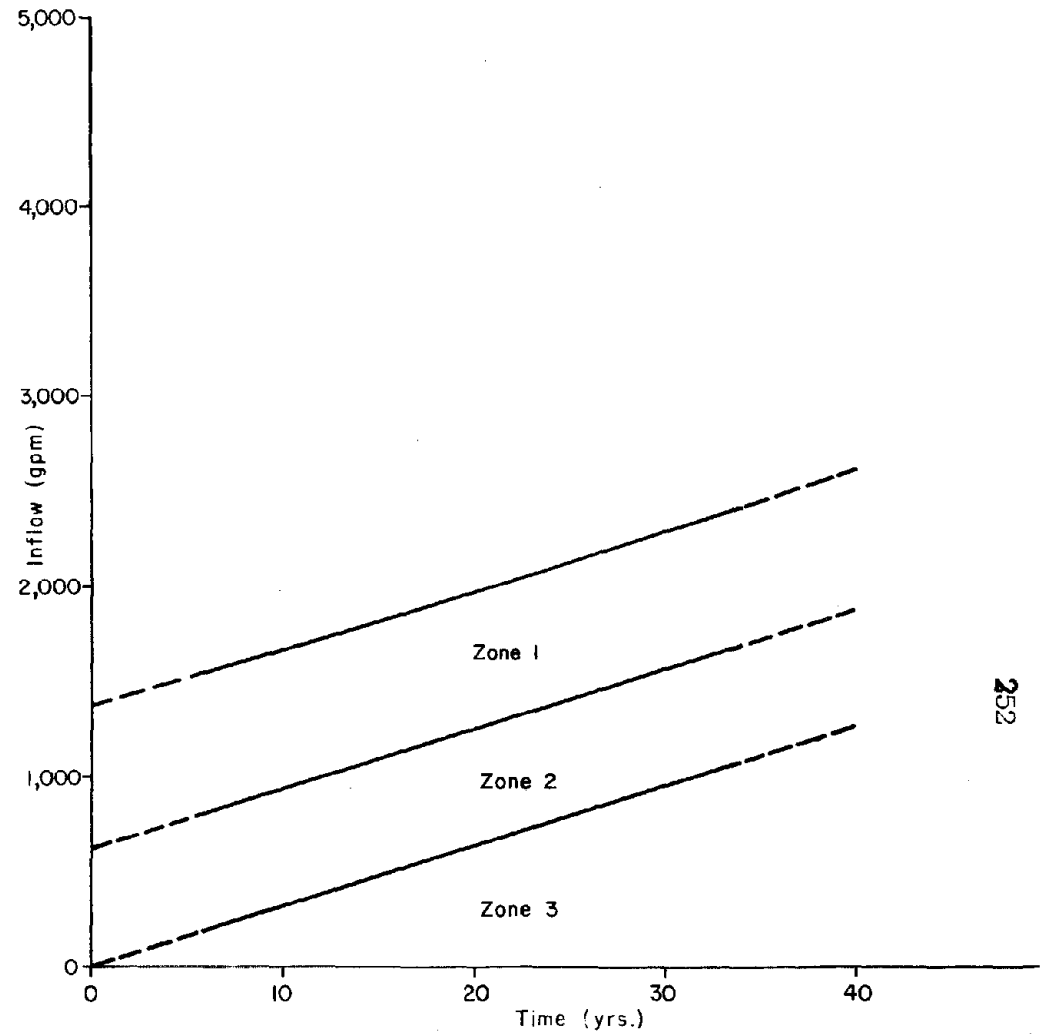
Expansion Rate: .378 mi^2/yr

Initial Radius: 0

Mining Rate: 100,000 ton/day

Figure D-97 MINE INFLOW - SITE 2





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MINE INFLOW (gpm)

Time-yrs	Radius-ft.	Zone 1	Zone 1 (drain)	Zone 2	Zone 3	Total
5	4,095	515	210	622	156	1500
10	5,792	515	210	622	311	1660
20	8,191	515	210	622	622	1970
30	10,031	515	210	622	933	2280

DESCRIPTION:

Mining Method: Modified In-Situ, Full Subsidence

Number of Passes: 1

Location: Mahogany

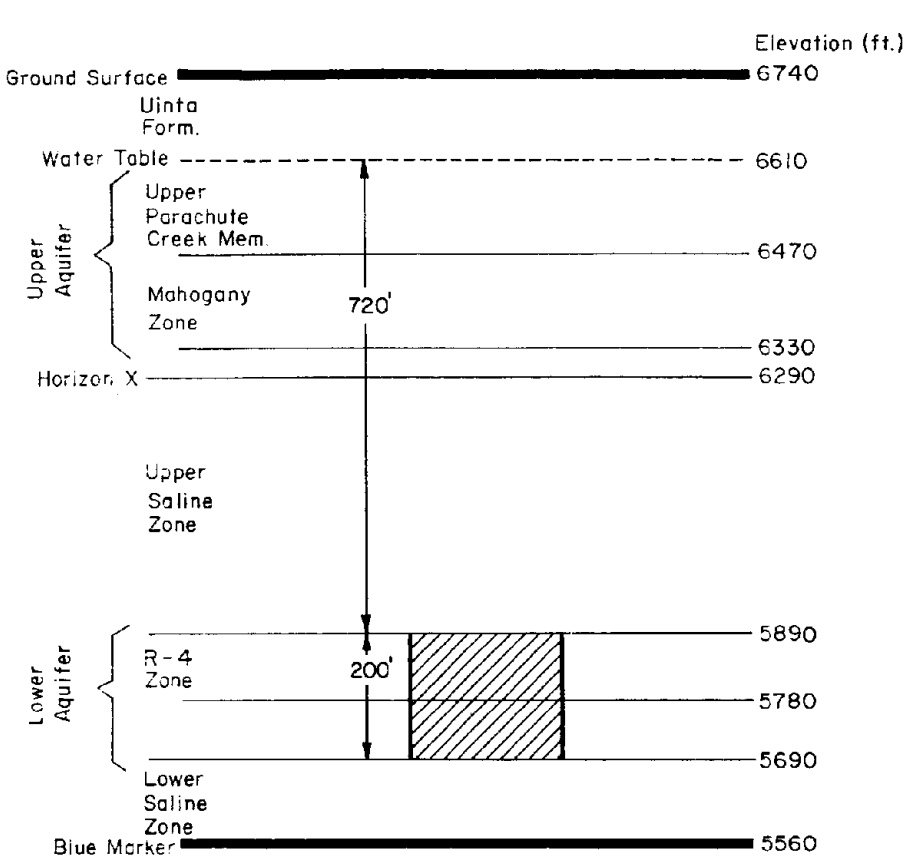
Mining Height: 200 ft

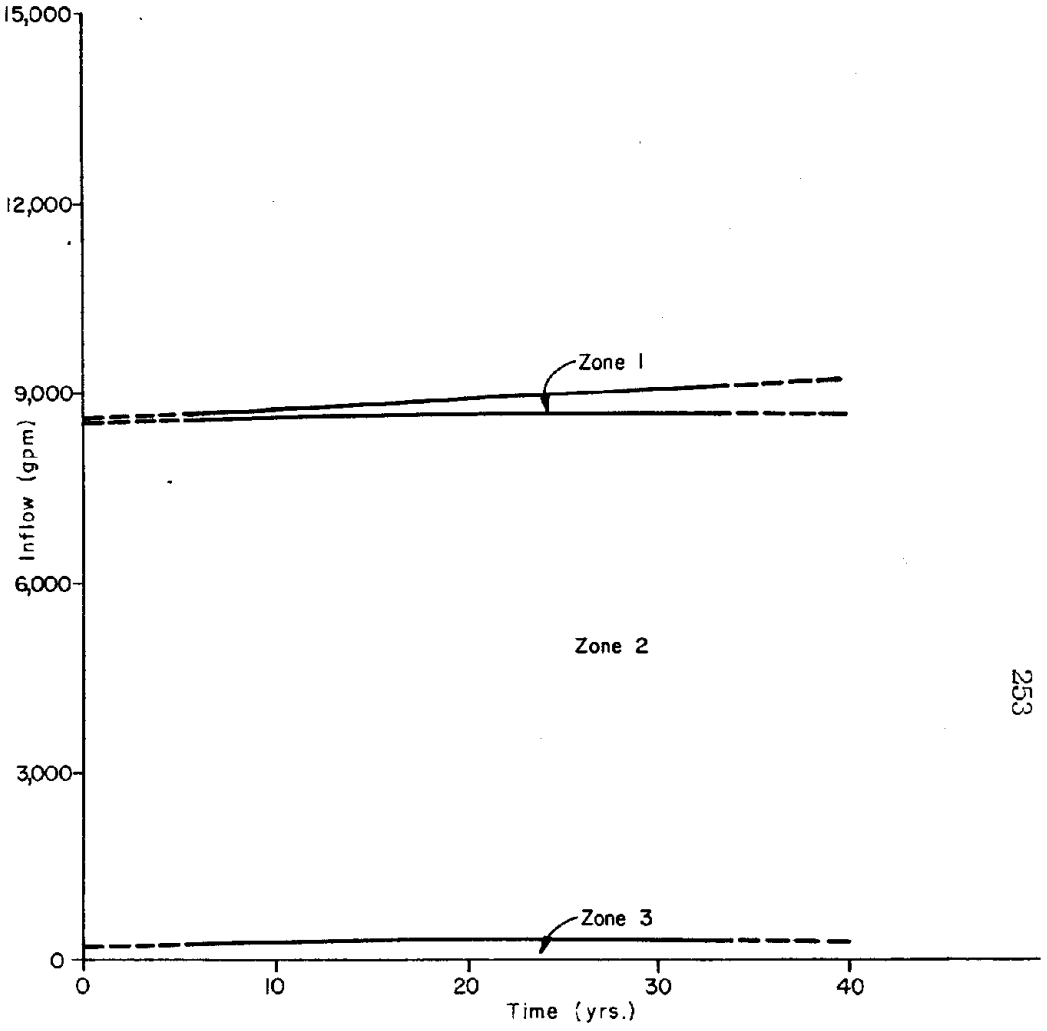
Expansion Rate: .378 mi^2/yr

Initial Radius: 0

Mining Rate: 100,000 ton/day

Figure D-98 MINE INFLOW - SITE 2





Time -yrs	Radius-ft.	MINE INFLOW (gpm) Zone 1	(drain) Zone 1	Zone 2	Zone 3	Total
5	2896	74	-	8326	290	8690
10	4095	148	-	8326	297	8770
20	5792	296	-	8326	300	8920
30	7093	443	-	8326	302	9070

DESCRIPTION:

Mining Method: Modified In-Situ, No Subsidence

Number of Passes: 1

Location: R-4

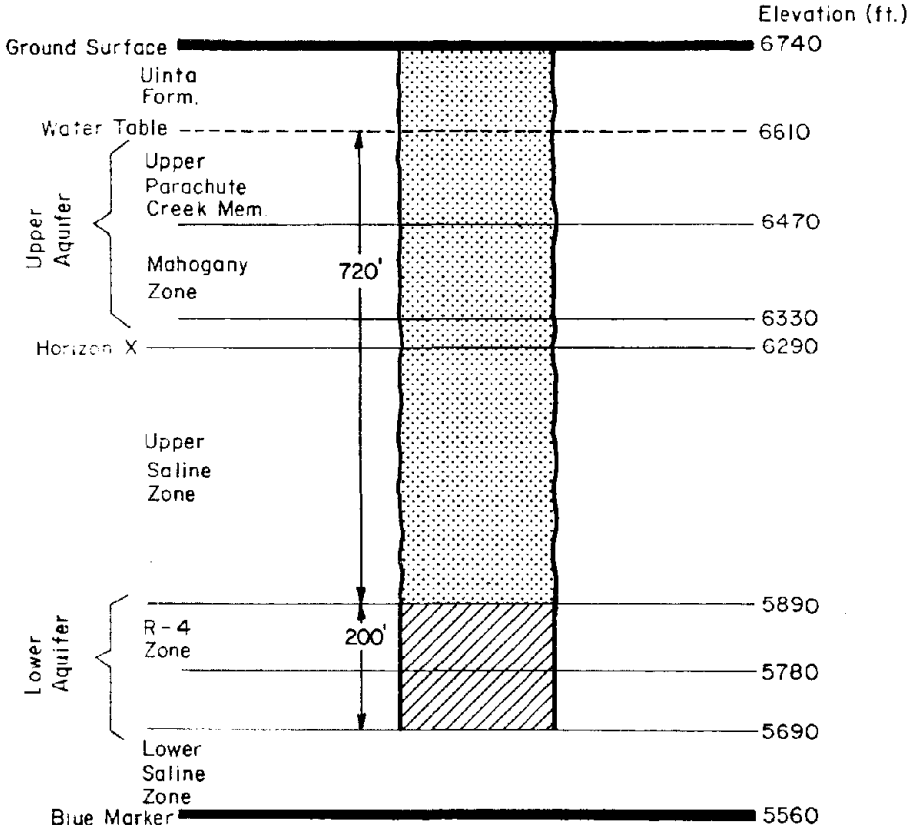
Mining Height: 200 ft

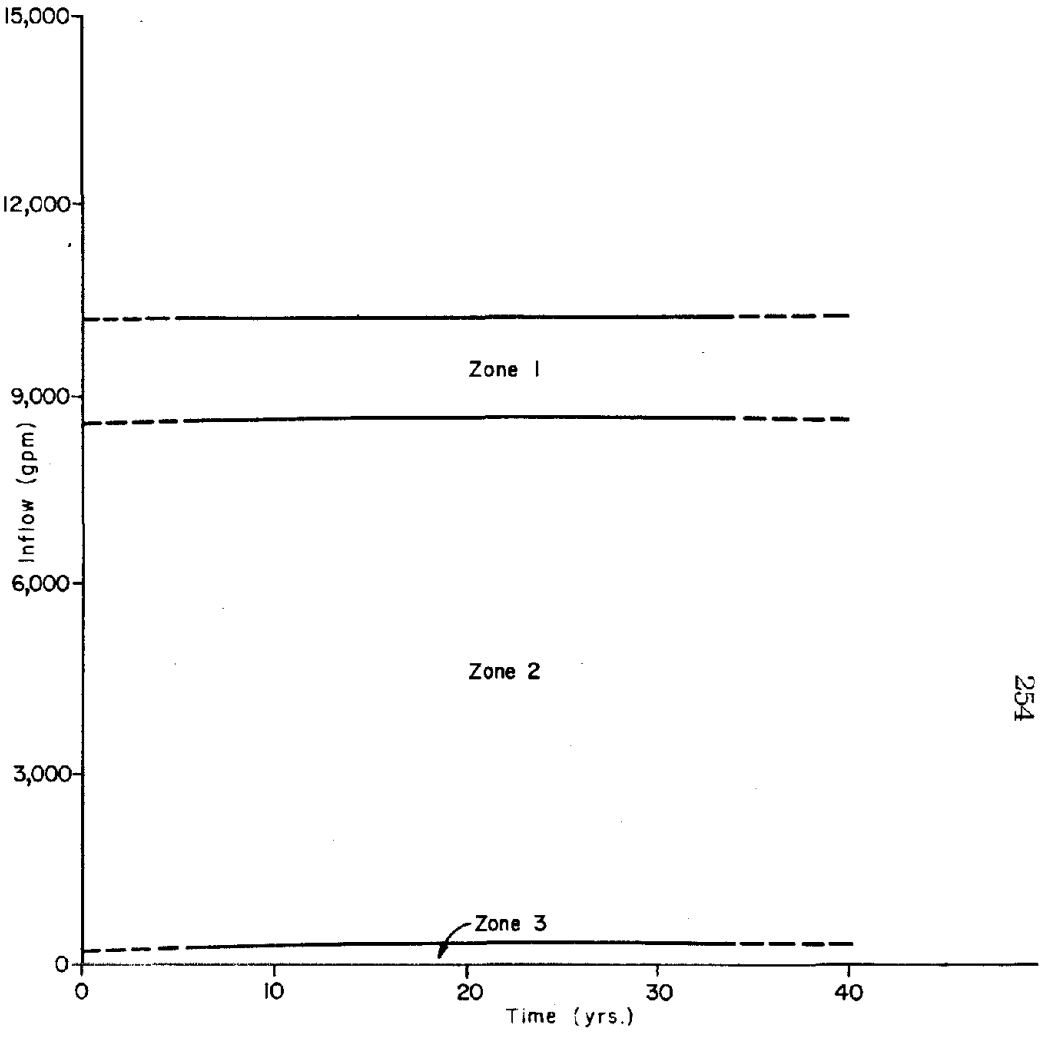
Expansion Rate: .189 mi^2/yr

Initial Radius: 0

Mining Rate: 50,000 ton/day

Figure D-99 MINE INFLOW- SITE 2





Time-yrs	Radius-ft.	MINE INFLOW (gpm) Zone 1	(drain) Zone 1	Zone 2	Zone 3	Total
5	2896	1053	540	8326	290	10,210
10	4095	1053	540	8326	297	10,220
20	5792	1053	540	8326	300	10,220
30	7093	1053	540	8326	302	10,220

DESCRIPTION:

Mining Method: Modified In-Situ, Full Subsidence

Number of Passes: 1

Location: R-4

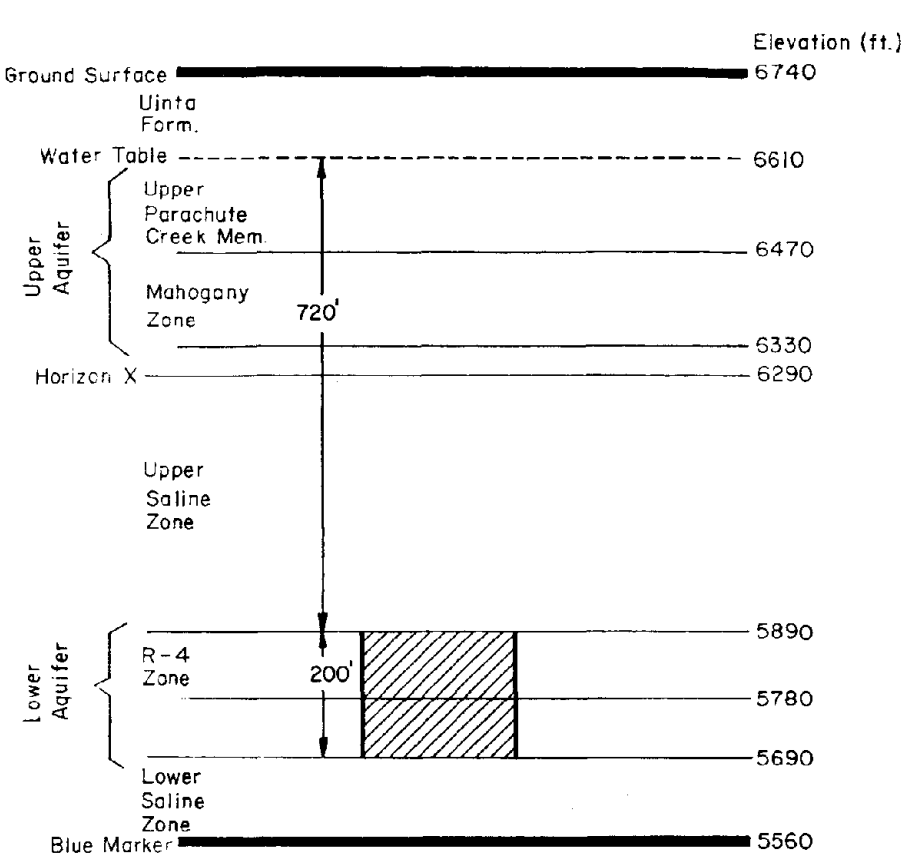
Mining Height: 200 ft

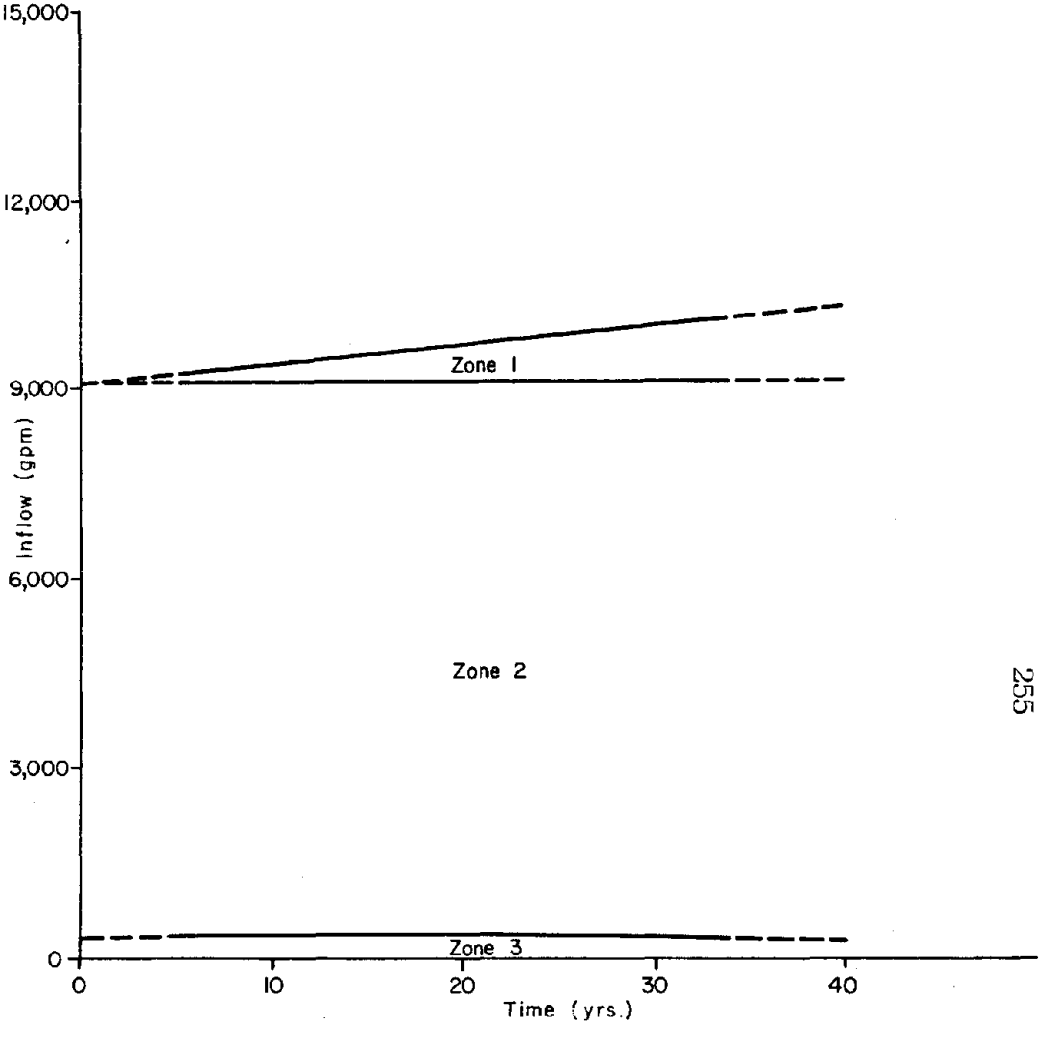
Expansion Rate: .189 mi^2/yr

Initial Radius: 0

Mining Rate: 50,000 ton/day

Figure D-100 MINE INFLOW - SITE 2





MINE INFLOW (gpm)

Time -yrs	Radius-ft.	Zone 1	(drain) Zone 1	Zone 2	Zone 3	Total
5	4,095	148	-	8775	339	9,260
10	5,792	296	-	8775	342	9,410
20	8,191	591	-	8775	346	9,710
30	10,031	887	-	8775	346	10,010

DESCRIPTION:

Mining Method: Modified In-Situ, No Subsidence

Number of Passes: 1

Location: R-4

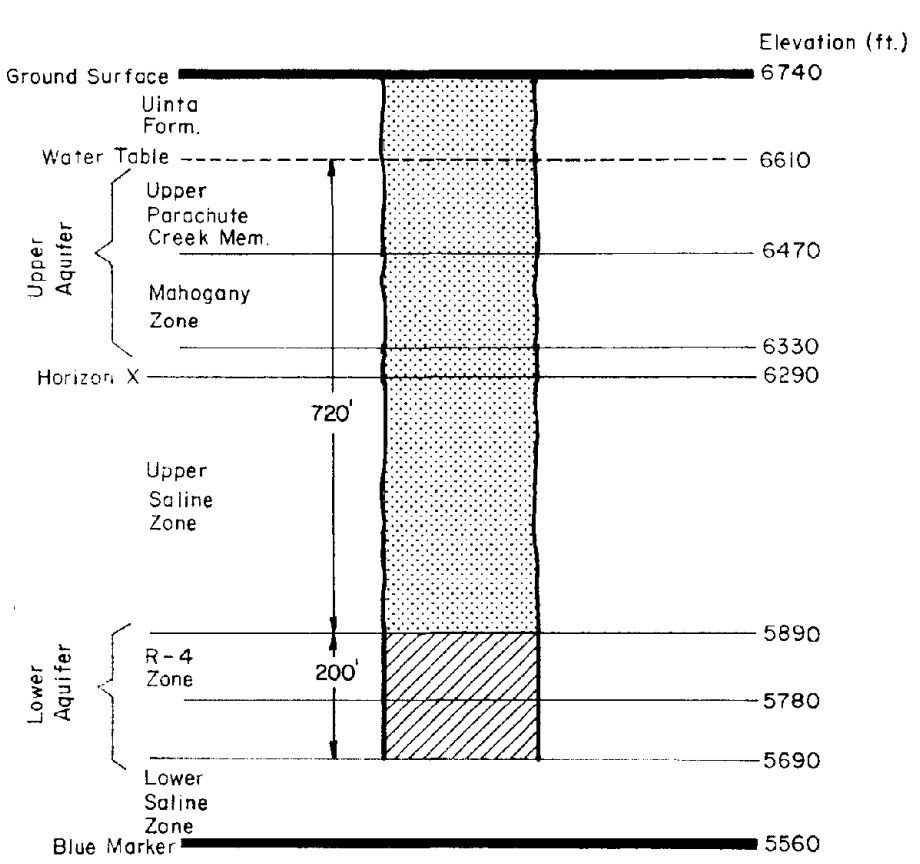
Mining Height: 200 ft

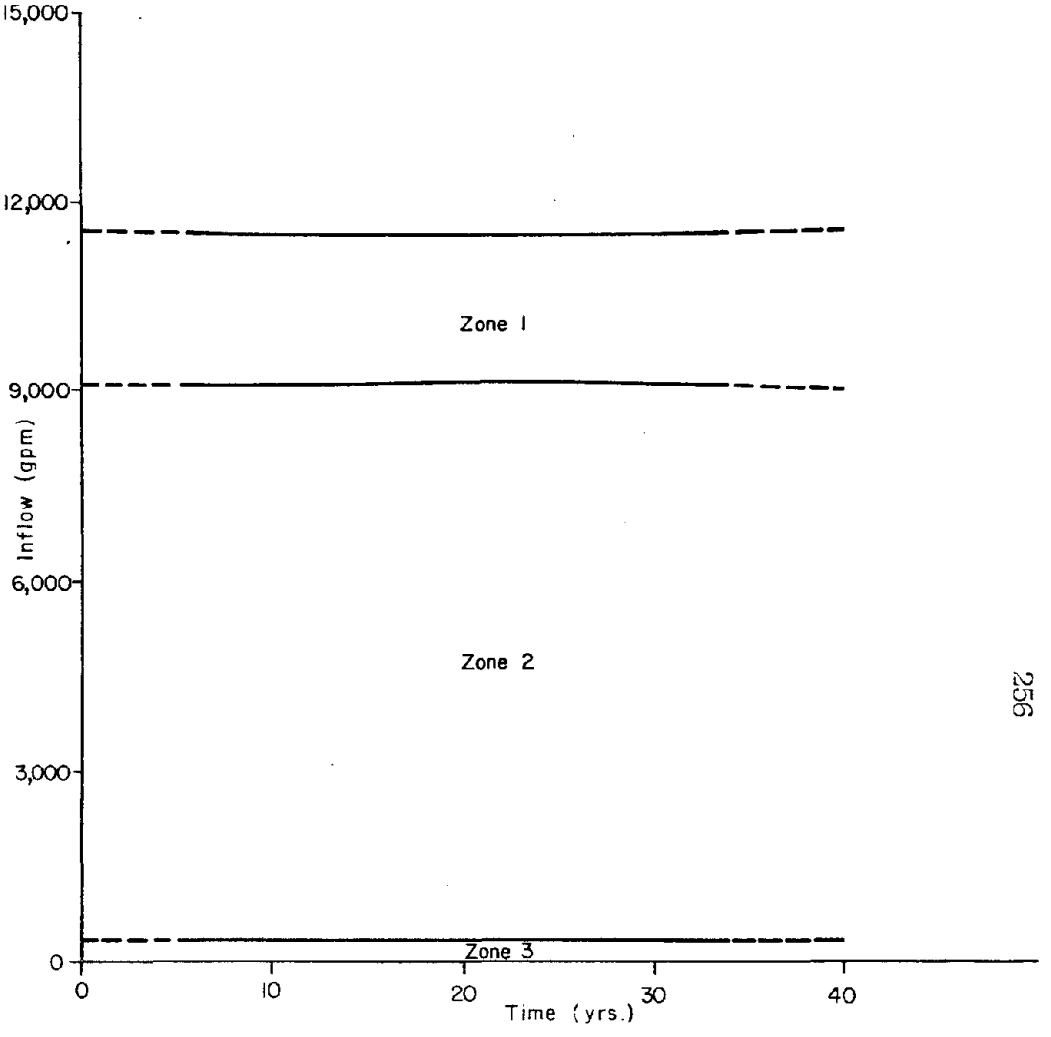
Expansion Rate: .378 mi^2/yr

Initial Radius: 0

Mining Rate: 100,000 ton/day

Figure D-101 MINE INFLOW - SITE 2





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MINE INFLOW (gpm)

Time -yrs	Radius-ft.	Zone 1	(drain) Zone 1	Zone 2	Zone 3	Total
5	4,095	1276	1080	8775	339	11,470
10	5,792	1276	1080	8775	342	11,470
20	8,191	1276	1080	8775	346	11,480
30	10,031	1276	1080	8775	346	11,480

DESCRIPTION:

Mining Method: Modified In-Situ, Full Subsidence

Number of Passes: 1

Location: R-4

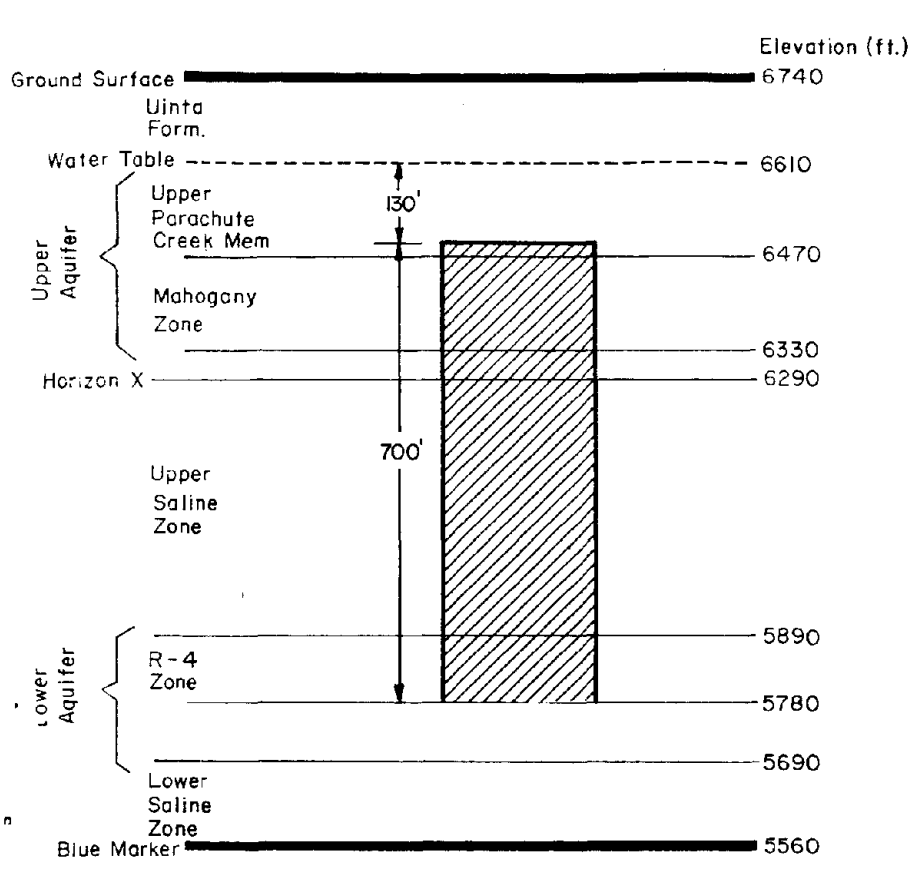
Mining Height: 200 ft

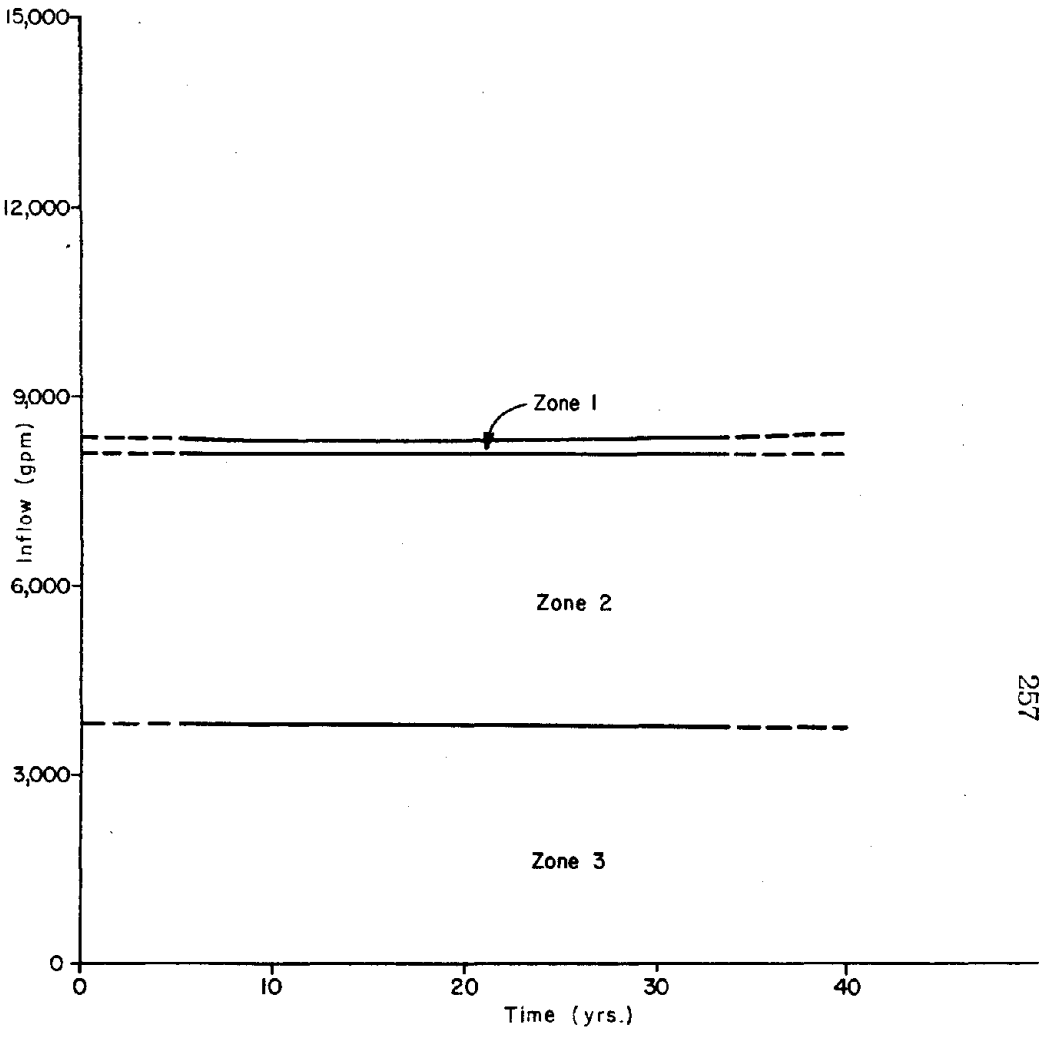
Expansion Rate: .378 mi^2/yr

Initial Radius: 0

Mining Rate: 100,000 ton/day

Figure D-102 MINE INFLOW - SITE 2





Time -yrs	Radius-ft.	MINE INFLOW (gpm) Zone 1	(drain) Zone 1	Zone 2	Zone 3	Total
5	1576	247	-	4308	3753	8310
10	2229	247	-	4308	3753	8310
20	3153	247	-	4308	3753	8310
30	3861	247	-	4308	3753	8310

DESCRIPTION:

Mining Method: Modified In-Situ, No Subsidence

Number of Passes: 1

Location: R-4 to Mahogany

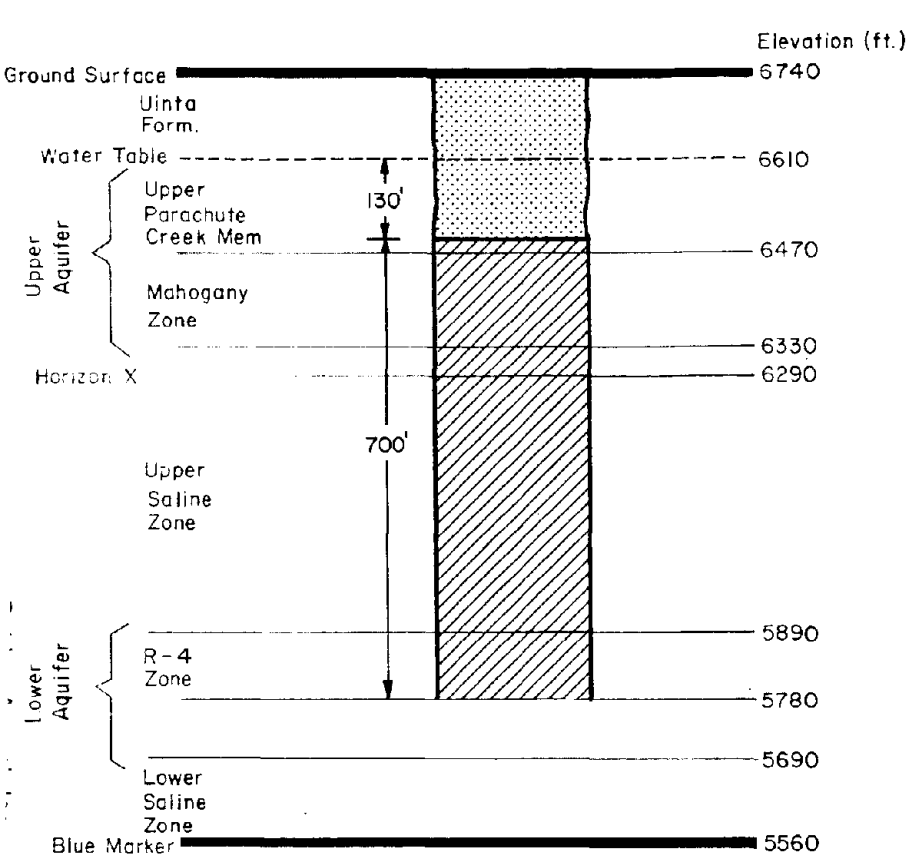
Mining Height: 700 ft

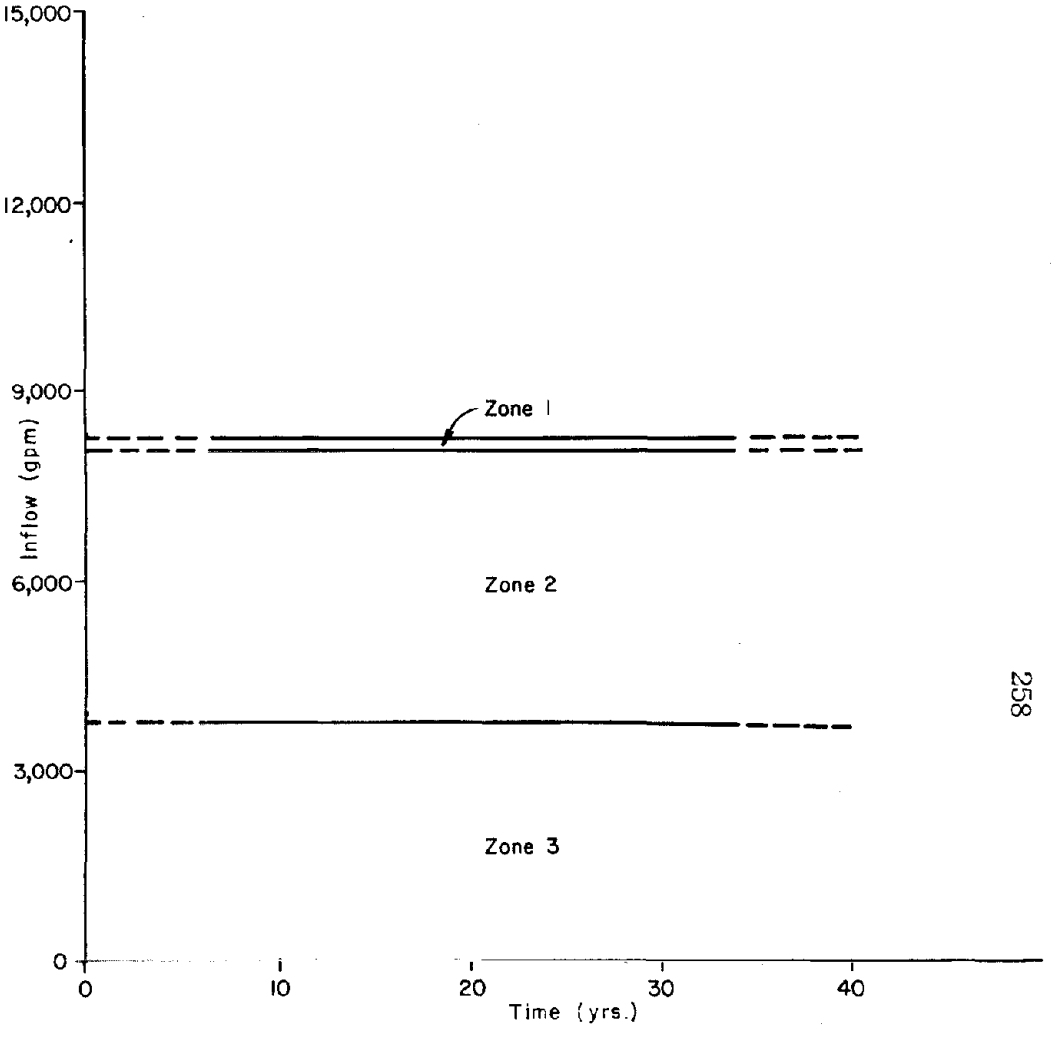
Expansion Rate: .056 mi^2/yr

Initial Radius: 0

Mining Rate: 50,000 ton/day

Figure D-103 MINE INFLOW - SITE 2





Time-yrs	Radius-ft.	MINE INFLOW (gpm) Zone 1	(drain) Zone 1	Zone 2	Zone 3	Total
5	1576	218	29	4308	3753	8310
10	2229	218	29	4308	3753	8310
20	3153	218	29	4308	3753	8310
30	3861	218	29	4308	3753	8310

DESCRIPTION:

Mining Method: Modified In-Situ, Full Subsidence

Number of Passes: 1

Location: R-4 to Mahogany

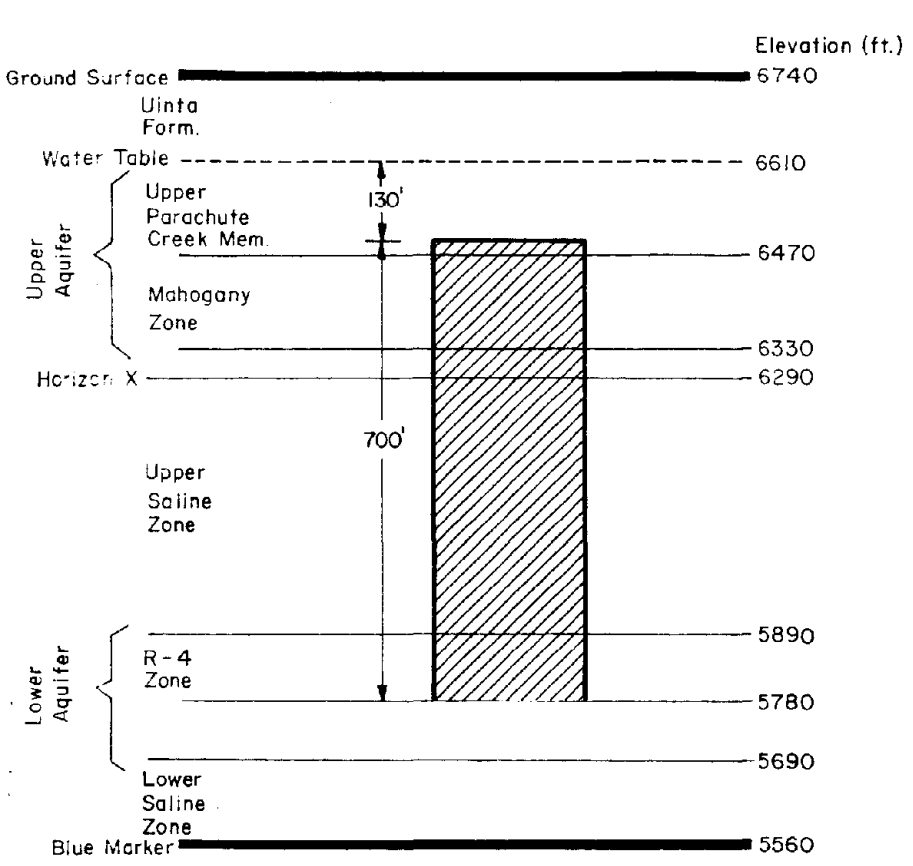
Mining Height: 700 ft

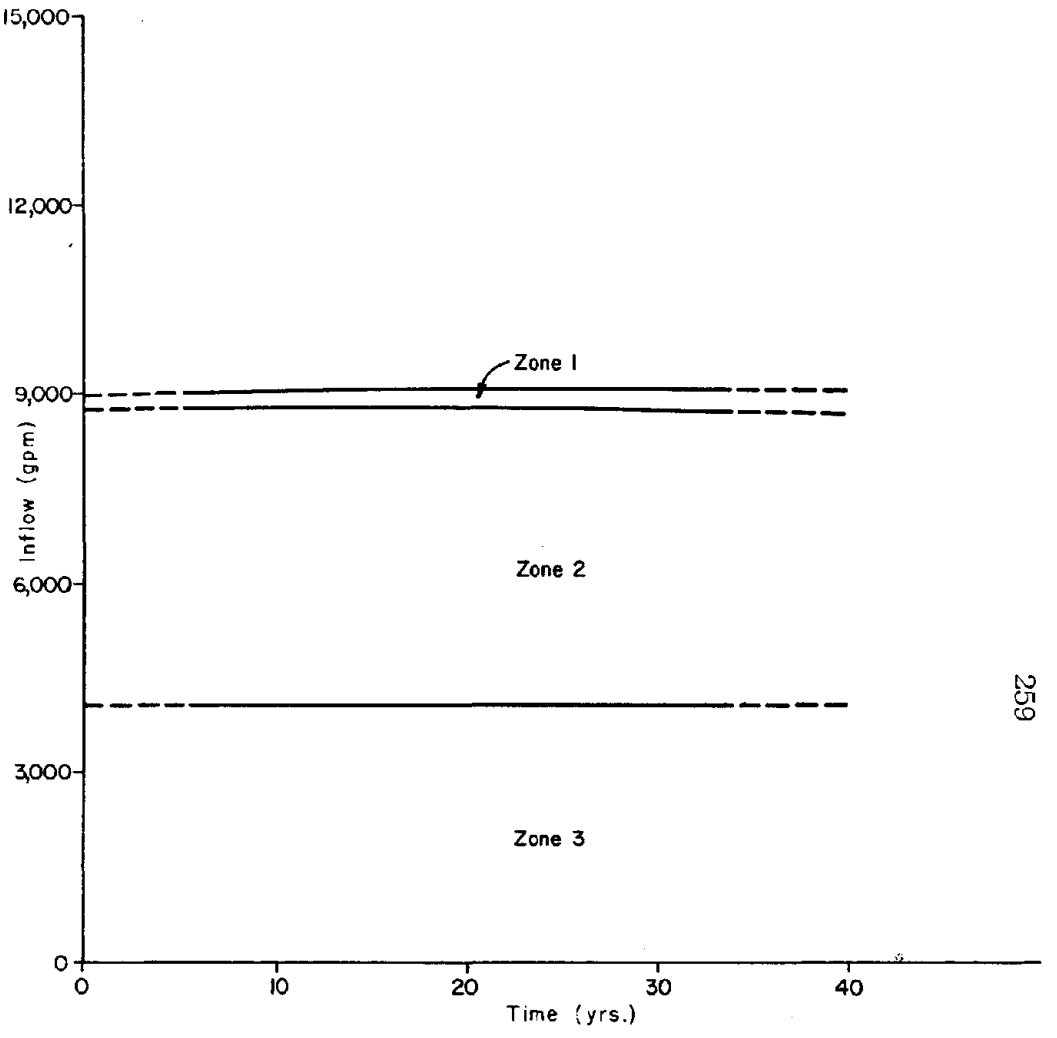
Expansion Rate: .056 mi^2/yr

Initial Radius: 0

Mining Rate: 50,000 ton/day

Figure D-104 MINE INFLOW - SITE 2





Time -yrs	Radius-ft.	MINE INFLOW (gpm) Zone 1	(drain) Zone 1	Zone 2	Zone 3	Total
5	2229	330	-	4638	4039	9010
10	3153	330	-	4638	4039	9010
20	4458	330	-	4638	4039	9010
30	5460	330	-	4638	4039	9010

DESCRIPTION:

Mining Method: Modified In-Situ, No Subsidence

Number of Passes: 1

Location: R-4 to Mahogany

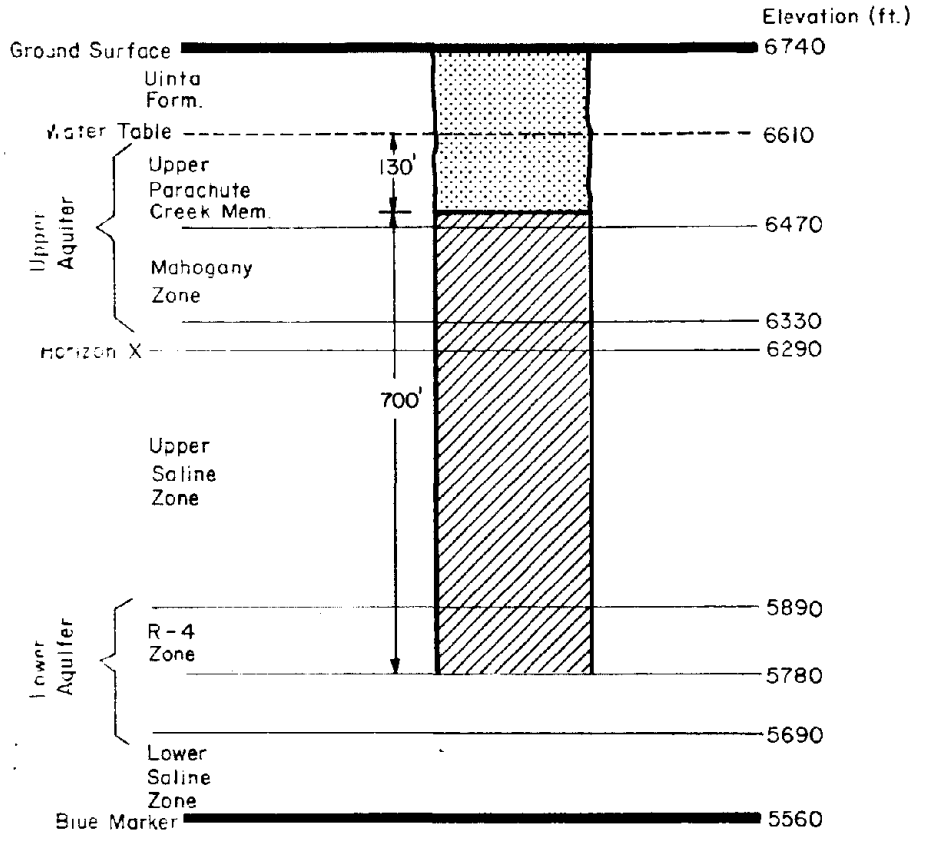
Mining Height: 700 ft

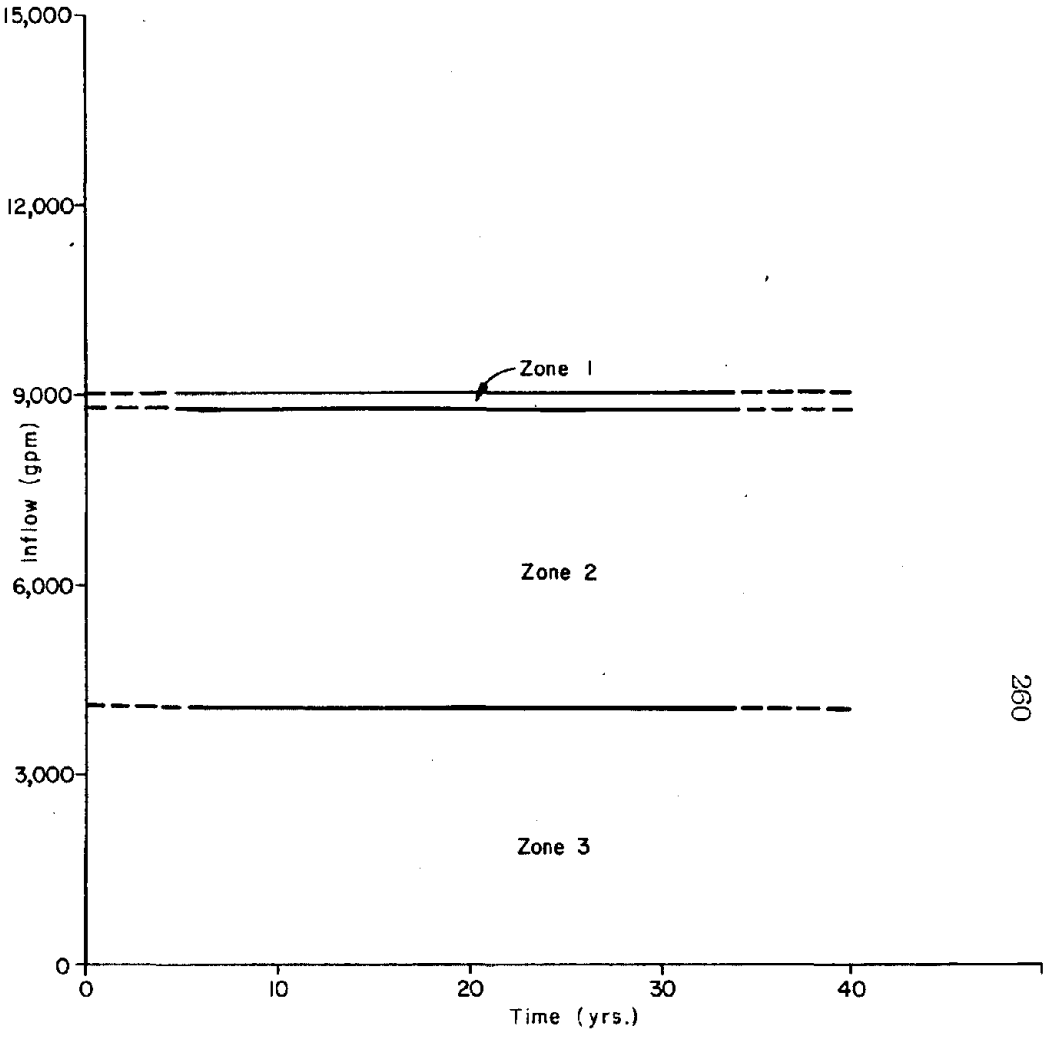
Expansion Rate: .112 mi^2/yr

Initial Radius: 0

Mining Rate: 100,000 ton/day

Figure D-105 MINE INFLOW - SITE 2





MINE INFLOW (gpm)

Time -yrs	Radius-ft.	Zone 1	(drain) Zone 1	Zone 2	Zone 3	Total
5	2229	272	58	4638	4039	9010
10	3153	272	58	4638	4039	9010
20	4458	272	58	4638	4039	9010
30	5460	272	58	5638	4039	9010

DESCRIPTION:

Mining Method: Modified In-Situ, Full Subsidence

Number of Passes: 1

Location: R-4 to Mahogany

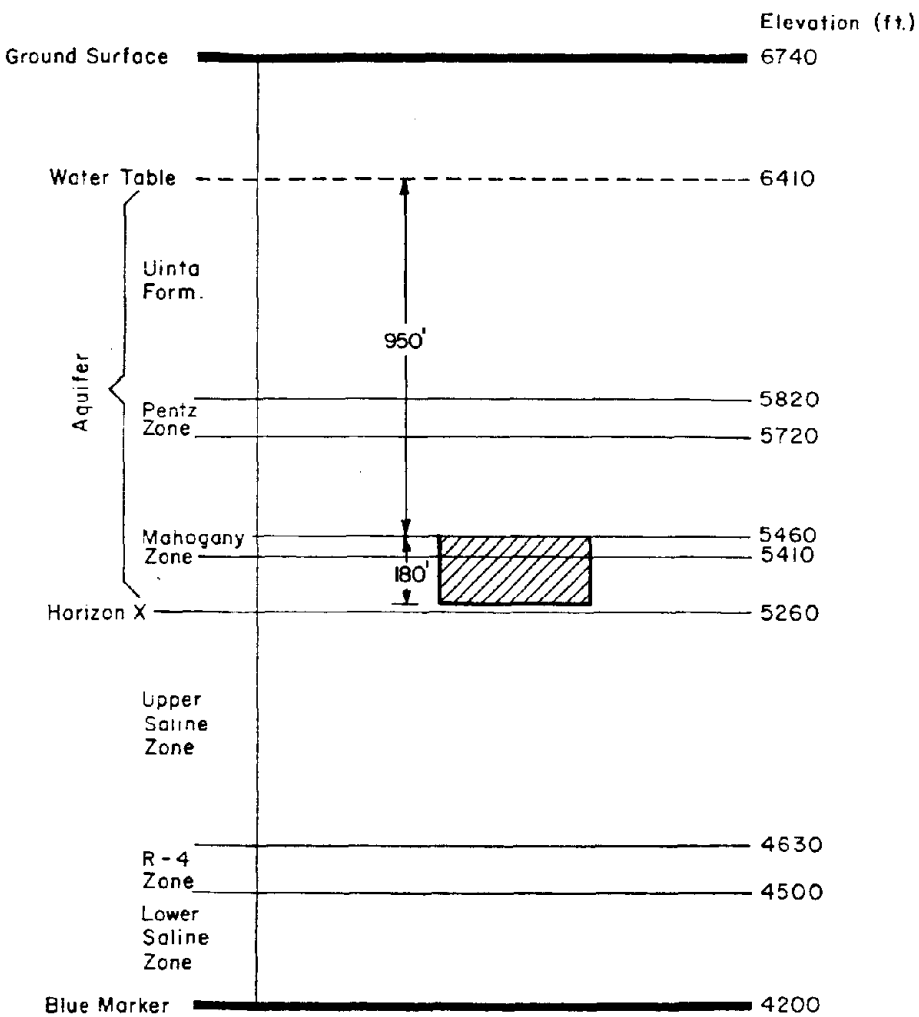
Mining Height: 700 ft

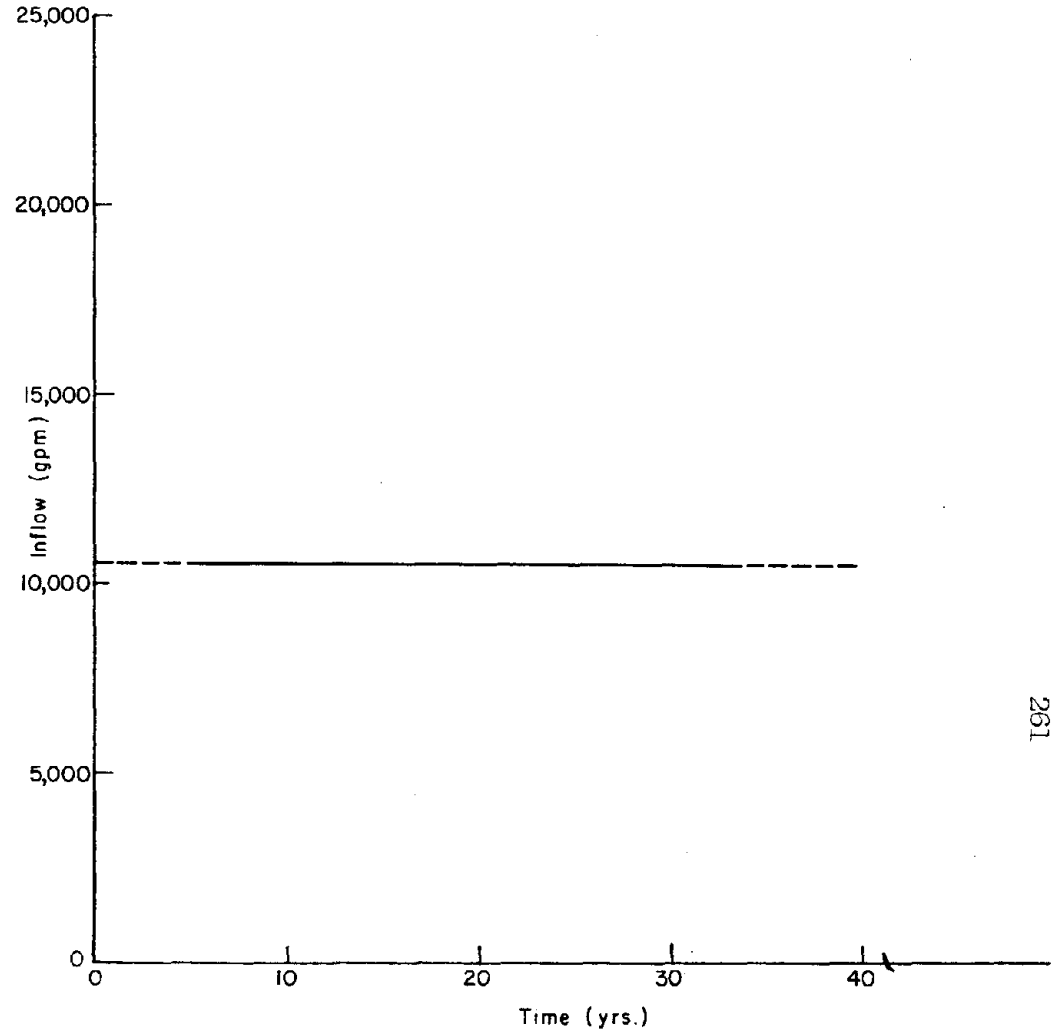
Expansion Rate: .112 mi^2/yr

Initial Radius: 0

Mining Rate: 100,000 ton/day

Figure D-106 MINE INFLOW – SITE 2





MINE INFLOW (gpm)

Time - yrs	Radius-ft.	Zone 1	Zone 1 (drain)	Zone 2	Zone 3	Total
5	2239	-	-	-	-	10,560
10	3167	-	-	-	-	10,560
20	4478	-	-	-	-	10,560
30	5485	-	-	-	-	10,560

DESCRIPTION:

Mining Method: True In-Situ

Number of Passes: 1

Location: Mahogany

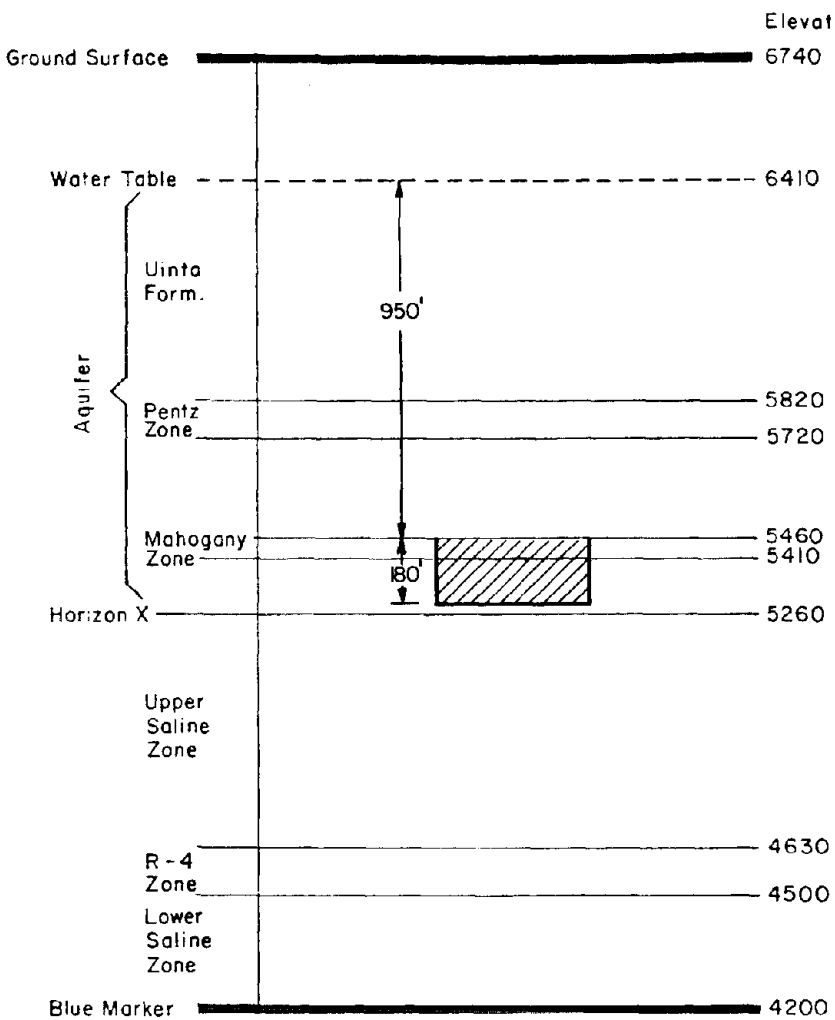
Mining Height: 180 ft

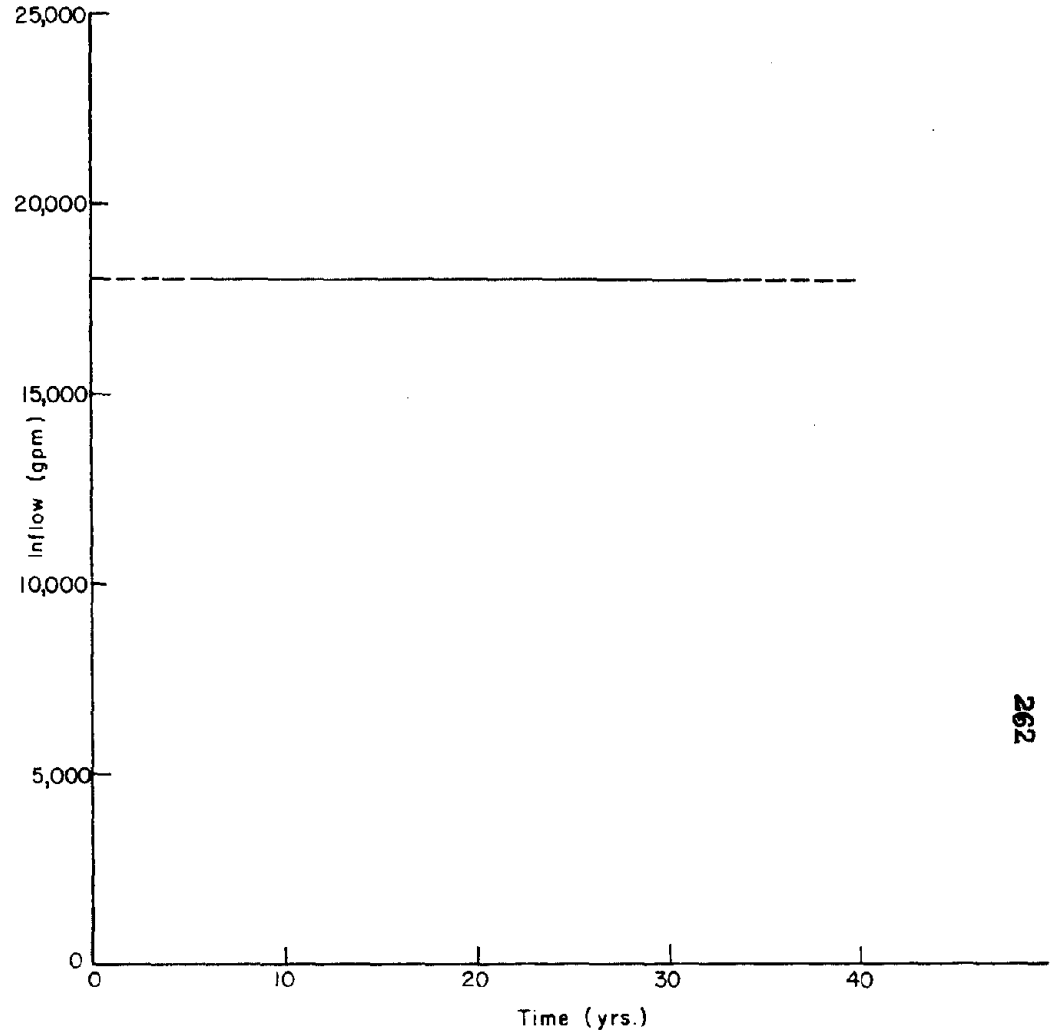
Expansion Rate: .113 mi^2/yr

Initial Radius: 0

Mining Rate: 50,000 ton/day

Figure D-107 MINE INFLOW - SITE 3





		MINE INFLOW (gpm)				
Time - yrs	Radius - ft.	Zone I	Zone I (drain)	Zone 2	Zone 3	Total
5	3167	-	-	-	-	18,050
10	4478	-	-	-	-	18,050
20	6333	-	-	-	-	18,050
30	7757	-	-	-	-	18,050

DESCRIPTION:

Mining Method: True In-Situ

Number of Passes: 1

Location: Mahogany

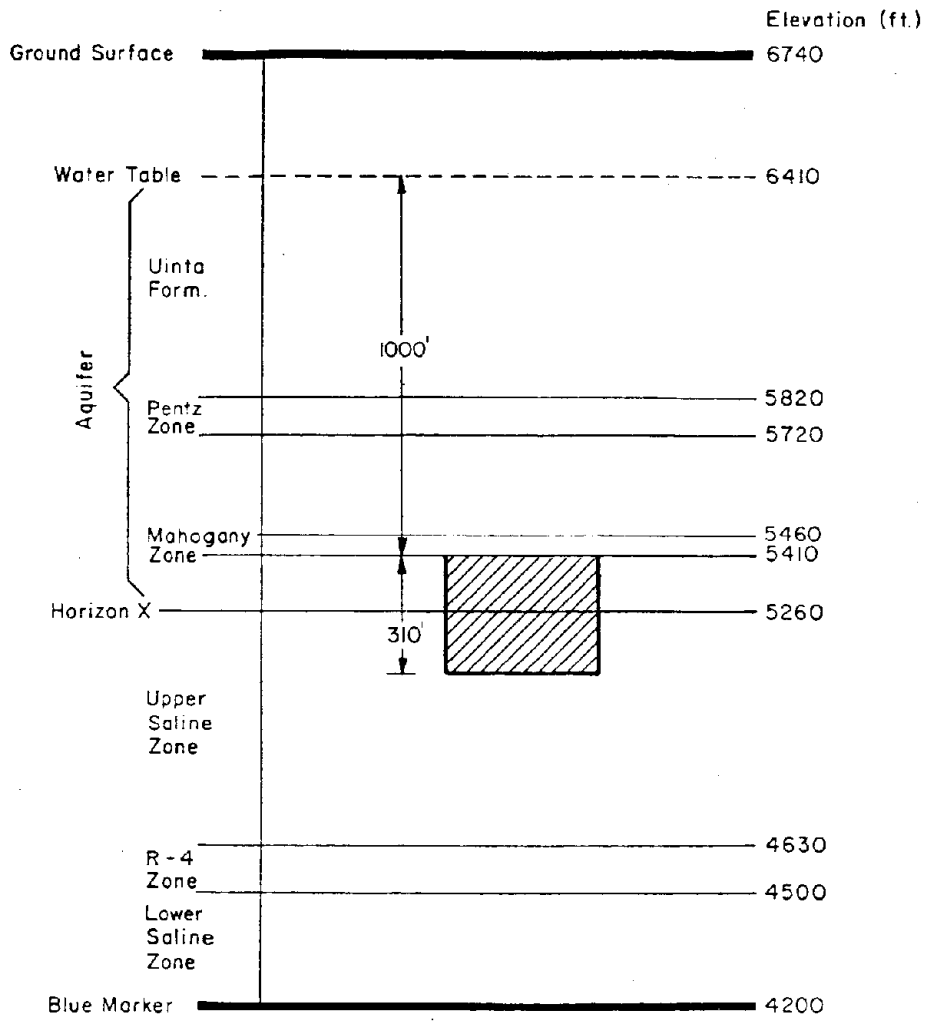
Mining Height: 180 ft

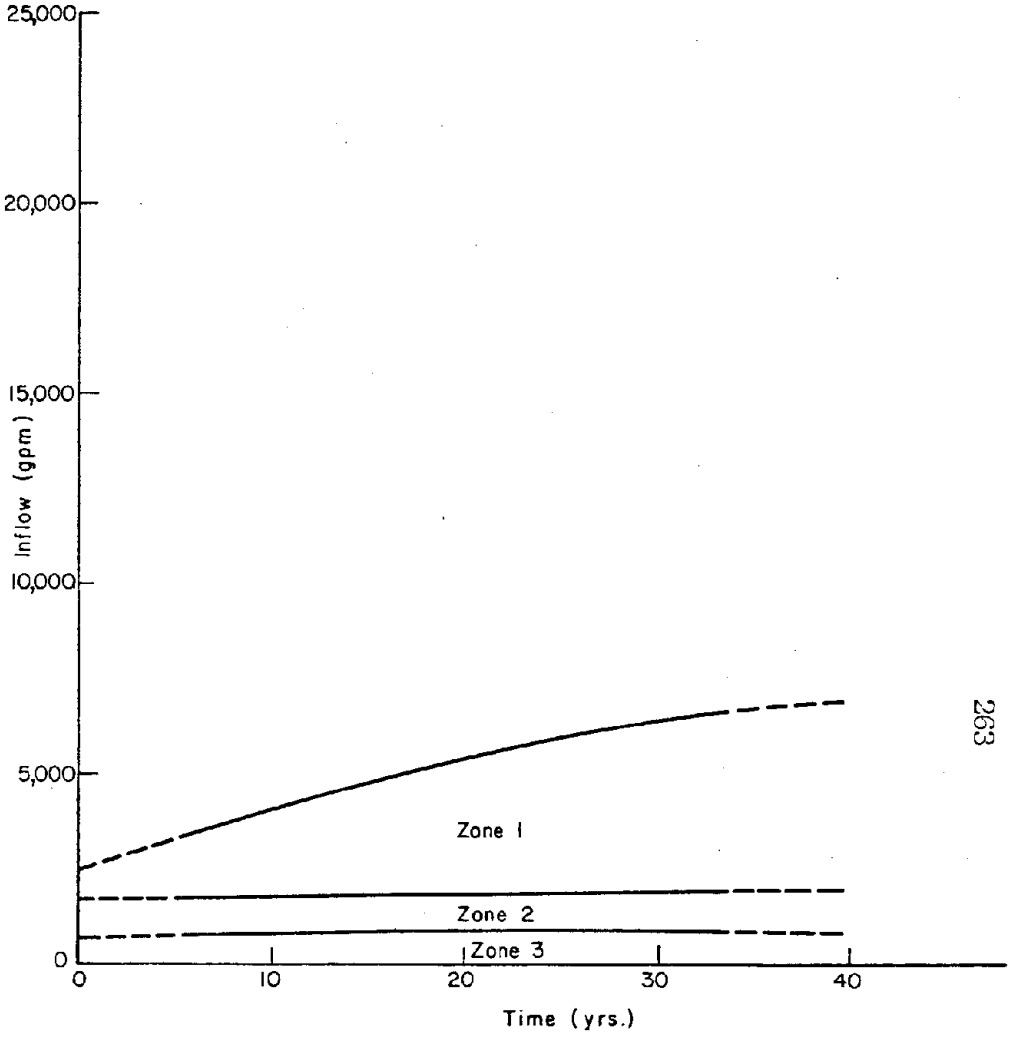
Expansion Rate: .226 mi^2/yr

Initial Radius: 0

Mining Rate: 100,000 ton/day

Figure D-108 MINE INFLOW - SITE 3





MINE INFLOW (gpm)

Time - yrs	Radius-ft	Zone 1	(drain) Zone 1	Zone 2	Zone 3	Total
5	2064	1502	-	1038	729	3270
10	2919	2225	-	1038	841	4100
20	4128	3448	-	1038	911	5400
30	5055	4504	-	1038	937	6480

DESCRIPTION:

Mining Method: Modified In-Situ, No Subsidence

Number of Passes: 1

Location: Mahogany

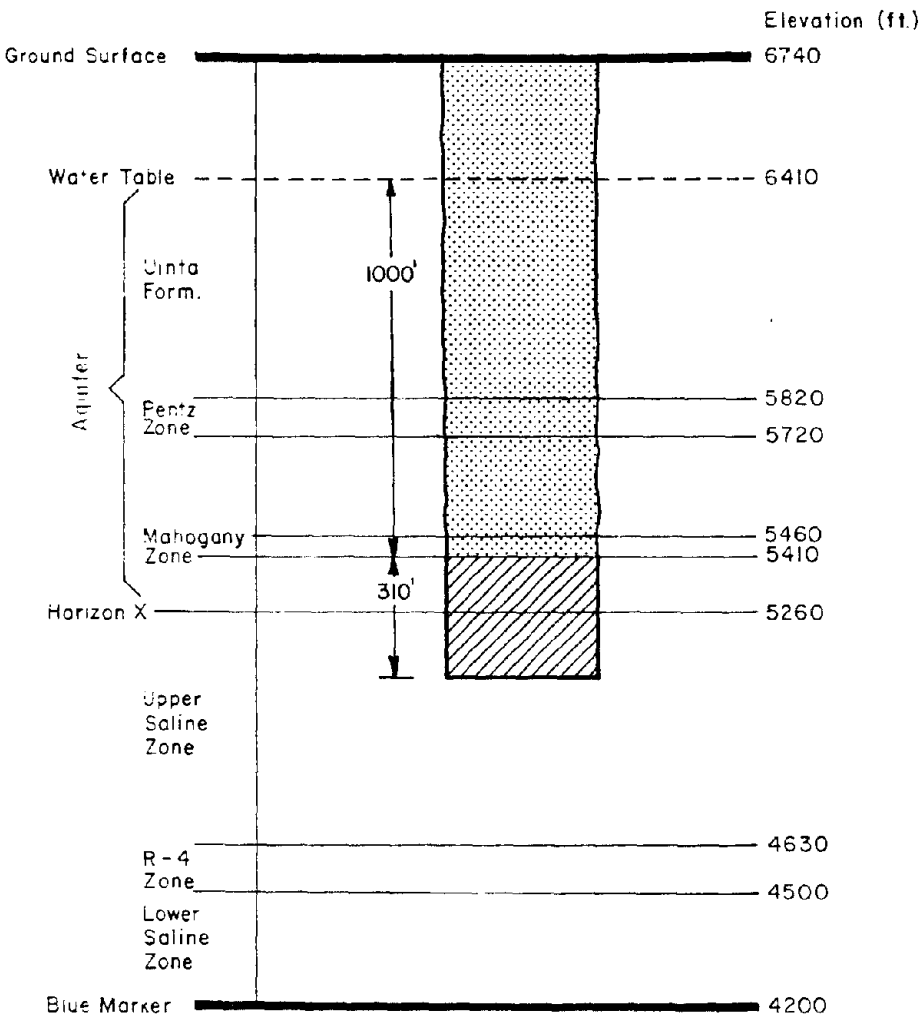
Mining Height: 310 ft

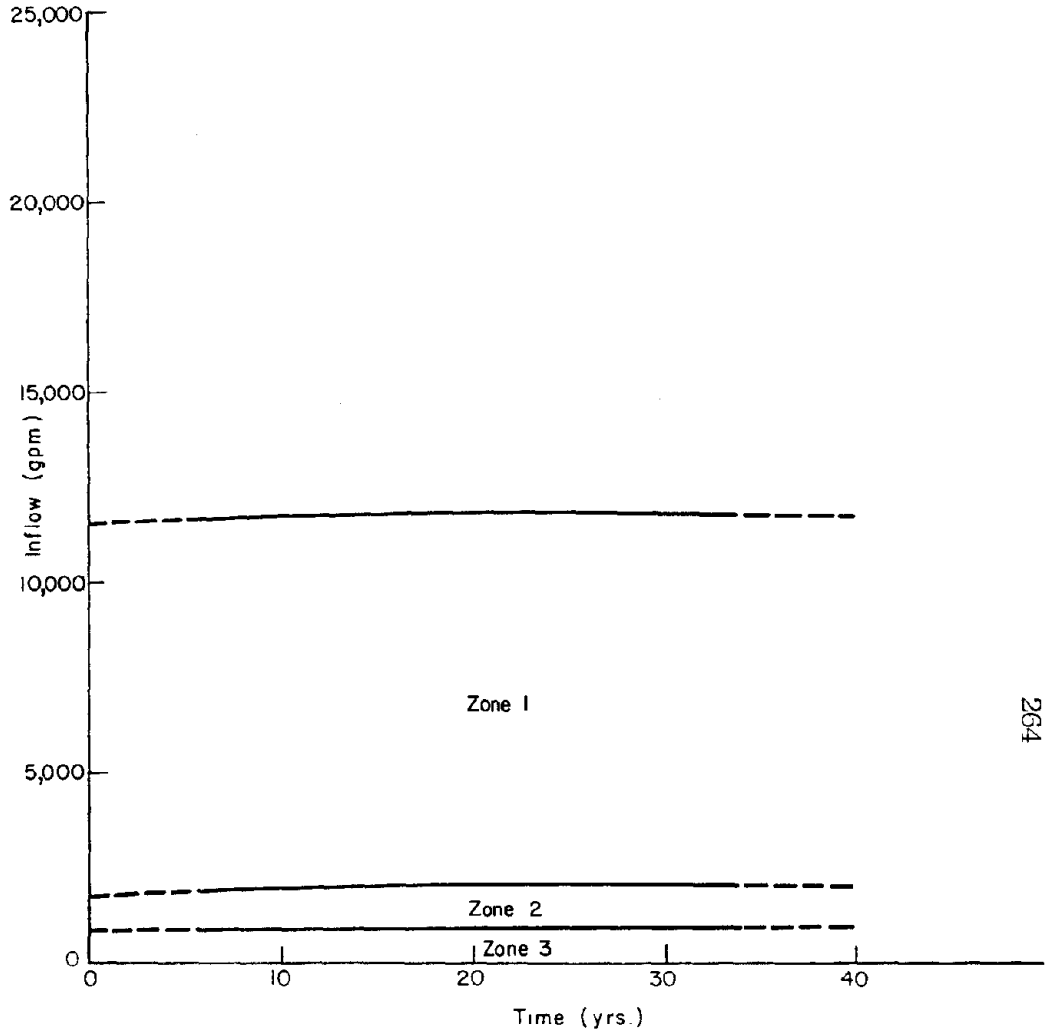
Expansion Rate: .096 mi^2/yr

Initial Radius: 0

Mining Rate: 50,000 ton/day

Figure D-109 MINE INFLOW - SITE 3





MINE INFLOW (gpm)

Time - yrs	Radius - ft.	Zone 1	Zone 1 (drain)	Zone 2	Zone 3	Total
5	2064	7173	2666	1038	729	11,610
10	2919	7173	2666	1038	841	11,720
20	4128	7173	2666	1038	911	11,790
30	5055	7173	2666	1038	937	11,810

DESCRIPTION:

Mining Method: Modified In-Situ, Full Subsidence

Number of Passes: 1

Location: Mahogany

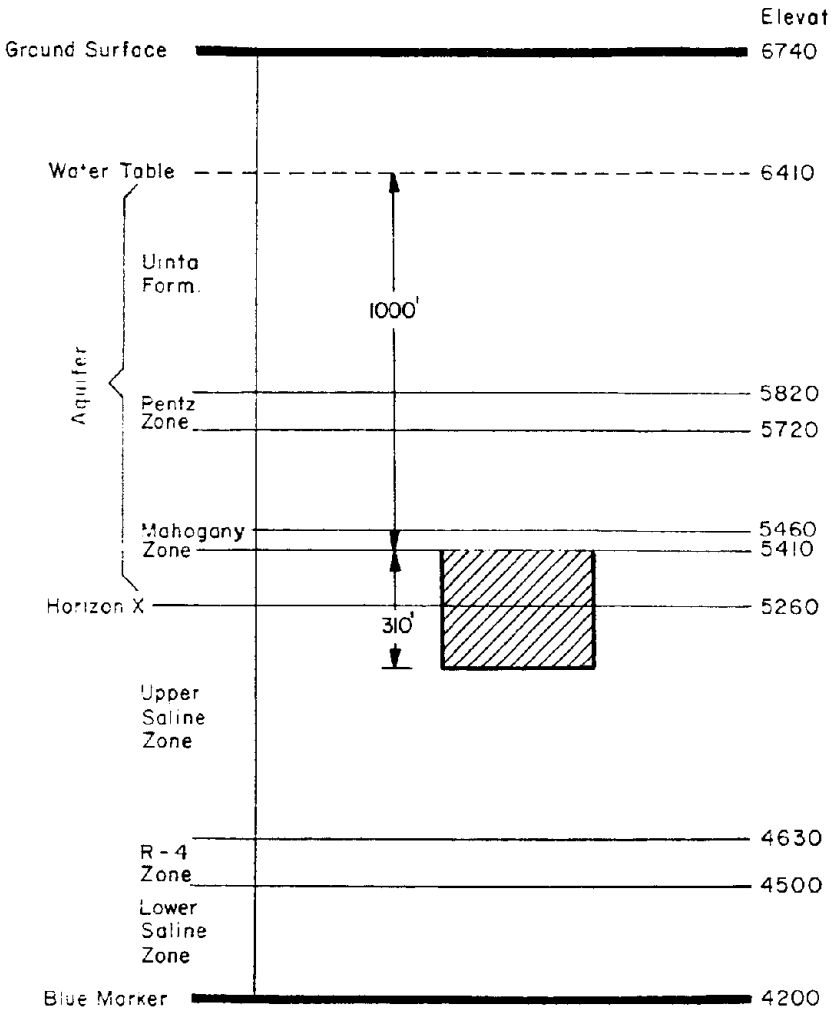
Mining Height: 310 ft

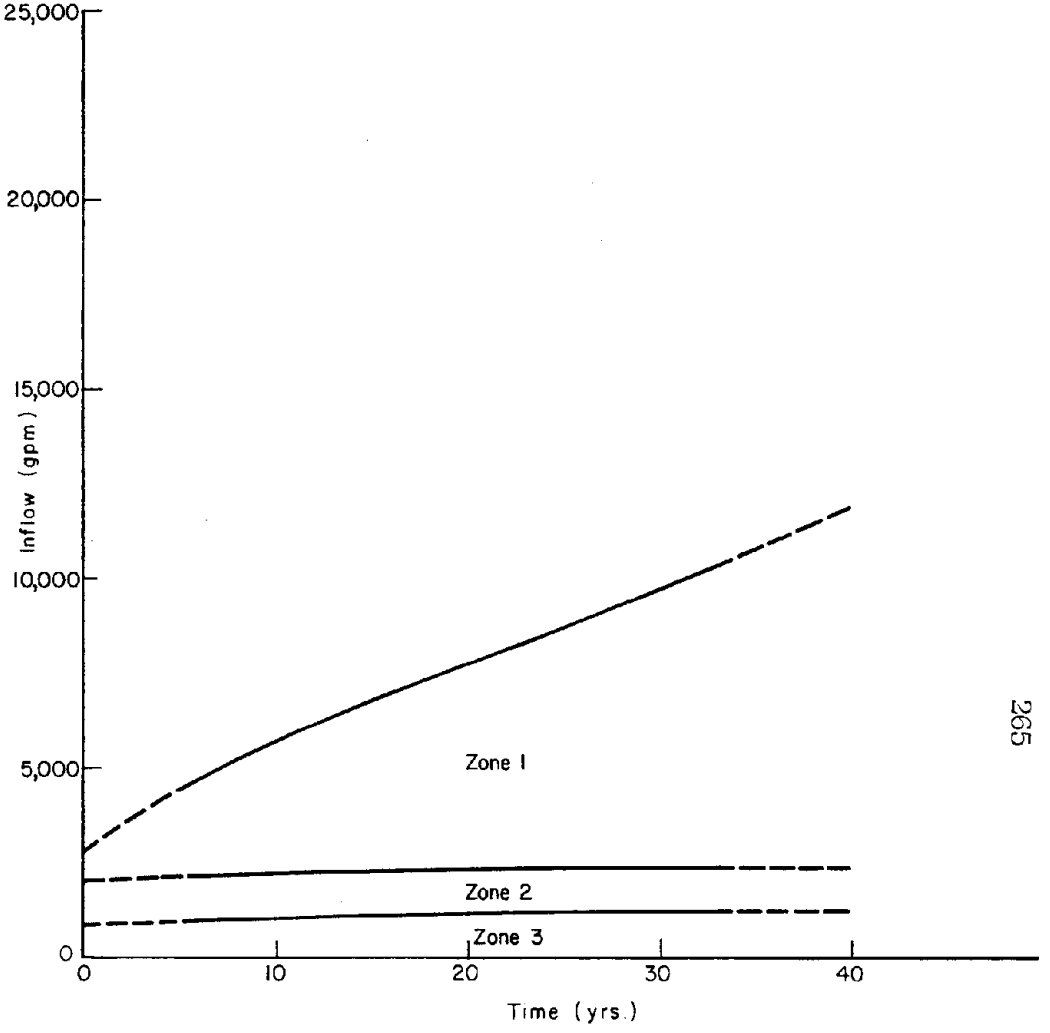
Expansion Rate: .096 mi^2/yr

Initial Radius: 0

Mining Rate: 50,000 ton/day

Figure D-110 MINE INFLOW - SITE 3





MINE INFLOW (gpm)

Time - yrs	Radius - ft.	Zone 1	Zone 1 (drain)	Zone 2	Zone 3	Total
5	2919	2280	-	1154	942	4380
10	4128	3504	-	1154	1031	5690
20	5837	5449	-	1154	1083	7690
30	7149	7339	-	1154	1101	9590

DESCRIPTION:

Mining Method: Modified In-Situ, No Subsidence

Number of Passes: 1

Location: Mahogany

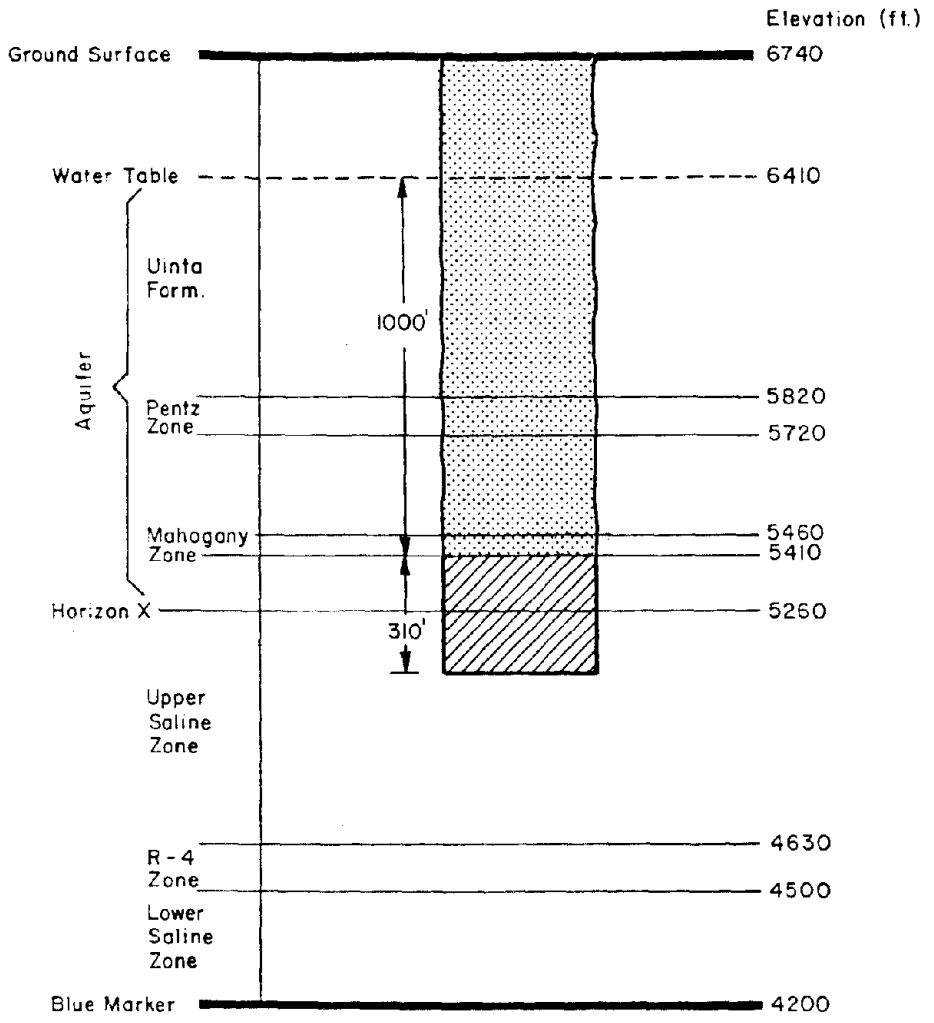
Mining Height: 310 ft

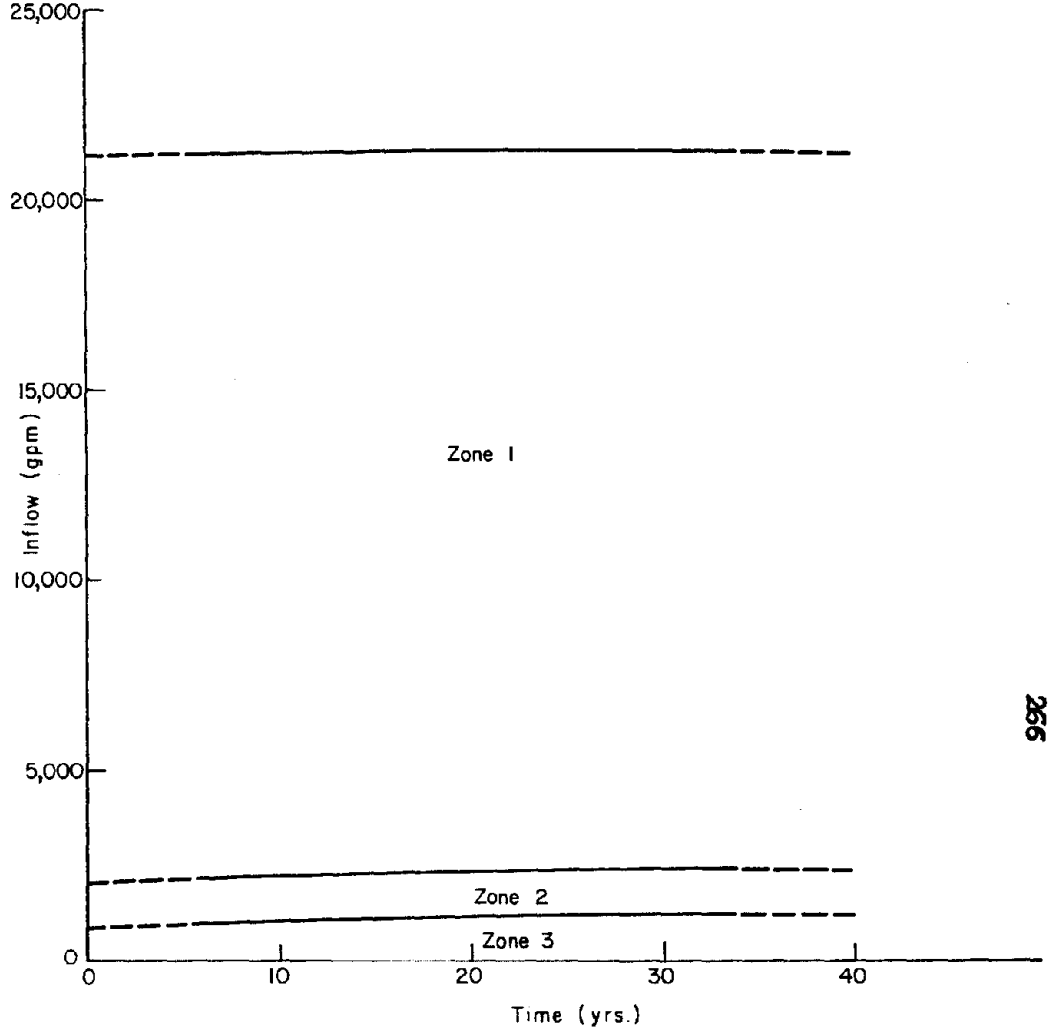
Expansion Rate: .192 mi^2/yr

Initial Radius: 0

Mining Rate: 100,000 ton/day

Figure D-III MINE INFLOW - SITE 3





MINE INFLOW (gpm)

Time - yrs	Radius - ft.	Zone 1	Zone 1 (drain)	Zone 2	Zone 3	Total
5	2919	13,773	5332	1154	942	21,200
10	4128	13,773	5332	1154	1031	21,290
20	5837	13,773	5332	1154	1083	21,340
30	7149	13,773	5332	1154	1101	21,360

DESCRIPTION:

Mining Method: Modified In-Situ, Full Subsidence

Number of Passes: 1

Location: Mahogany

Mining Height: 310 ft

Expansion Rate: .192 mi^2/yr

Initial Radius: 0

Mining Rate: 100,000 ton/day

Figure D-112 MINE INFLOW - SITE 3

APPENDIX E

GOLDER ASSOCIATES' FINITE ELEMENT COMPUTER PROGRAMS FOR GROUNDWATER FLOW

GOLDER ASSOCIATES'

FINITE ELEMENT COMPUTER PROGRAMS FOR GROUNDWATER FLOW

1. "FPM" Computer Program

Purpose

The analysis of transient and steady-state two-dimensional planar and axi-symmetric groundwater flow conditions using the finite element method.

Technical Details

The "FPM" program determines fluid potentials, fluid pressures, flow rates, quantities, and directions in both steady-state and transient groundwater regimes. The geometrical nature of these regimes must be either:

a. planar flow in a vertical section, or
b. axi-symmetric flow with a vertical axis.

The flow regime itself may be inhomogeneous with many different materials present. The following significant material property relationships must apply:

a. permeability - linear isotropic, or
   - linear anisotropic
b. specific storage - zero (i.e. incompressible), or
   - constant
c. specific yield - constant

The flow regime is sub-divided into triangular and rectangular elements (prismoidal toroid shapes in the case of axisymmetric regimes) which have appropriate material properties assigned. Boundary conditions of either known flow rates or fluid pressure may be applied (and altered at any time for transient problems).

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For steady-state analyses the "FPM" program will automatically compute:

a. the location of the phreatic surface for unconfined flow problems (by an iterative procedure).
b. fluid potentials, pressures, and stream function values at nodes throughout the flow regime.
c. elemental flow rates and directions.

For transient analyses the "FPM" computer program will compute for specified times:

a. the location of the phreatic surface for unconfined flow problems (taking into account the release or storage of water thereby involved).
b. fluid potentials and pressures at nodes throughout the flow regime.
c. elemental flow rates and directions.
d. the net inflow/outflow of fluid (taking into account the effects of material compressibility).
e. nodal settlements due to primary consolidation caused by compressible flow effects.

To minimize user involvement in data set-up and run control, the "FPM" program will:

a. generate some finite element mesh data.
b. automatically regenerage the finite element mesh and related boundary conditions during unconfined flow analyses.
c. automatically select element material properties from input zone descriptions.
d. automatically store intermediate and final analysis results for subsequent analysis restarts or plotting and contouring operations.

To minimize computer time required to perform analyses, the "FPM" computer program:

a. can be directed to internally re-number nodes to reduce the size of the conductivity matrix and thus minimize computer memory and equation solution time requirements.
b. will automatically increase or decrease central computer memory allocation based on the complexity of the problem to be solved.
c. uses an efficient out-of-core equation solver for all problem sizes (with no loss of efficiency for problem sizes that would have been solvable by an in-core method).
d. uses an unconditionally stable transient equation solution algorithm that converges to a specified accuracy for any time interval.

2. "AFPM" Computer Program

Purpose

The analysis of transient and steady-state layered aquifer groundwater flow conditions using the finite element method.

Technical Details

The "AFPM" program determines fluid potentials, fluid pressures, flow rates, quantities, and directions in both steady-state and transient groundwater regimes. The flow regime must be approximately geometrically represented as a layered system of confined, unconfined, and leaky aquifers. Interaction with streams or rivers on the ground surface can be modelled.

The flow regime itself may be inhomogeneous with many different materials present. The following significant material property relationships must apply:

a. permeability - linear isotropic, or
   - linear anisotropic
b. specific storage - zero (i.e. incompressible), or
   - constant
c. specific yield - constant

The flow regime is sub-divided into triangular and rectangular elements of prismoidal shape which have appropriate material properties assigned. The layer finite elements may vary in thickness and may dip slightly. Boundary conditions of either known flow rates or fluid pressure may be applied (and altered at any time for transient problems).

For steady-state analyses the "AFPM" program will automatically compute:

a. the location of the phreatic surface in the top aquifer layer for unconfined flow problems (by an iterative procedure).
b. fluid potentials and pressures at nodes throughout the flow regime.
c. elemental flow rates and directions.
d. connected surface stream flows.

For transient analyses the "AFPM" computer program will compute at specified times:

a. the location of the phreatic surface in the top aquifer for unconfined flow problems (taking into account the release or storage of water thereby involved).
b. fluid potentials and pressures at nodes throughout the flow regime.
c. elemental flow rates and directions.
d. the net inflow/outflow of fluid (taking into account the effects of material compressibility).

e. nodal settlements due to primary consolidation caused by compressible flow effects.
f. connected surface stream flow rates.

To minimize user involvement in data set-up and run control, the "AFPM" program will:

a. generate some finite element mesh data.
b. automatically regenerate the finite element mesh and related boundary conditions in the top aquifer layer during unconfined flow analyses.
c. automatically select element material properties from input zone descriptions for individual layers.
d. automatically store intermediate and final analysis results for subsequent analysis restarts or plotting and contouring operations.

To minimize computer time required to perform analyses, the "AFPM" computer program:

a. can be directed to internally re-number nodes to reduce the size of the conductivity matrix and thus minimize computer memory and equation solution time requirements.
b. will automatically increase or decrease central computer memory allocation based on the complexity of the problem to be solved.
c. uses an efficient out-of-core equation solver for all problem sizes (with no loss of efficiency for problem sizes that would have been solvable by an in-core method).
d. uses an unconditionally stable transient equation solution algorithm that converges to a specified accuracy for any time interval.

Simple printer plots for both transient and steady-state two-dimensional layered aquifer analyses can be prepared by the "AFPM" program at the user's discretion.

3. "FLOCON" Computer Program

Purpose

To produce contour and other plots (or displays) of groundwater flow analysis results previously generated by the "FPM" or "AFPM" computer programs.

Technical Details

The "FLOCON" computer program prepares Calcomp type plots or printer-plots of groundwater flow analysis results. The type of contour plots that can be generated for two-dimensional planar and axi-symmetric finite element analyses are:

a. fluid pressure contours
b. fluid potential contours
c. stream function contours
d. flownets (a combined plot of fluid potential and stream function contours)
e. elemental flow directions

In addition, plots shown the finite element mesh can be prepared.

The following plots can be prepared for individual aquifers analyzed by the two-dimensional layered aquifer analysis program:

a. fluid pressure contours
b. fluid potential contours
c. aquifer elevation and thickness contours
d. elemental flow directions
e. primary consolidation settlement contours
f. finite element mesh plots

All plots may be individually scaled with the plot size limits dictated only by plotter hardware characteristics. Plot windows (i.e. limited areas of finite element meshes) are readily specified.

Figure 1 (a) MODELLING OF LAYERED AQUIFER SYSTEM — AQUIFER DIAGRAM

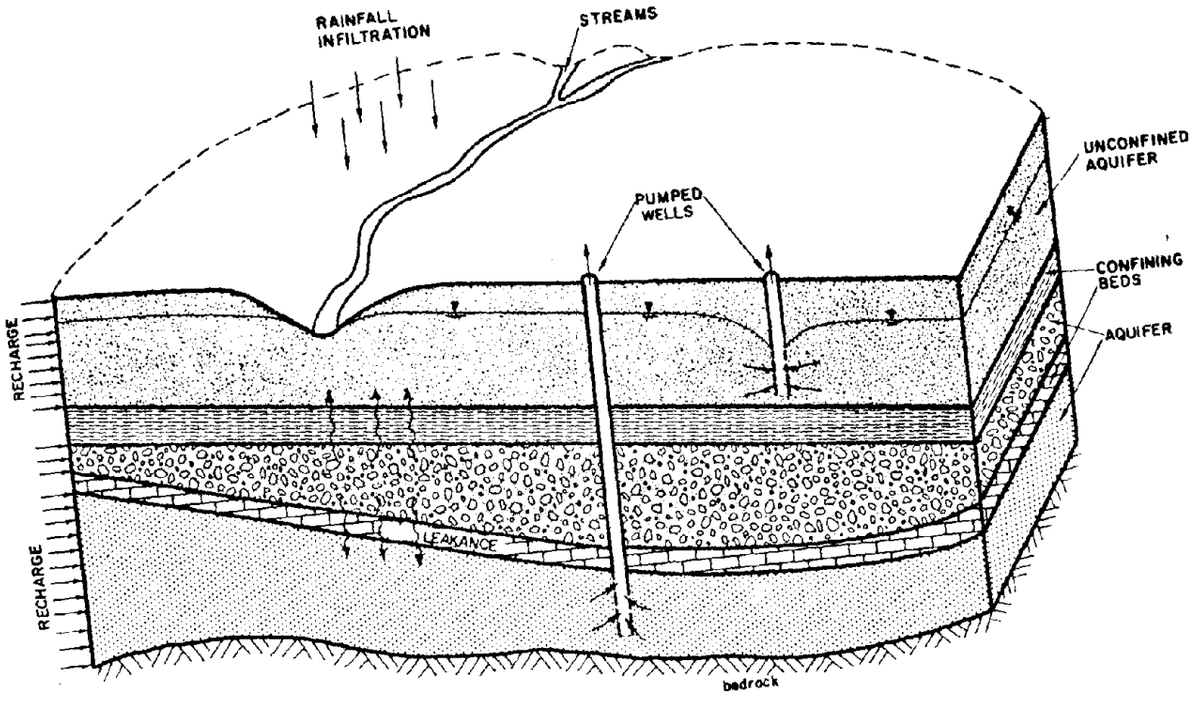


Figure 1 (b) MODELLING OF LAYERED AQUIFER SYSTEM — FINITE ELEMENT MODEL

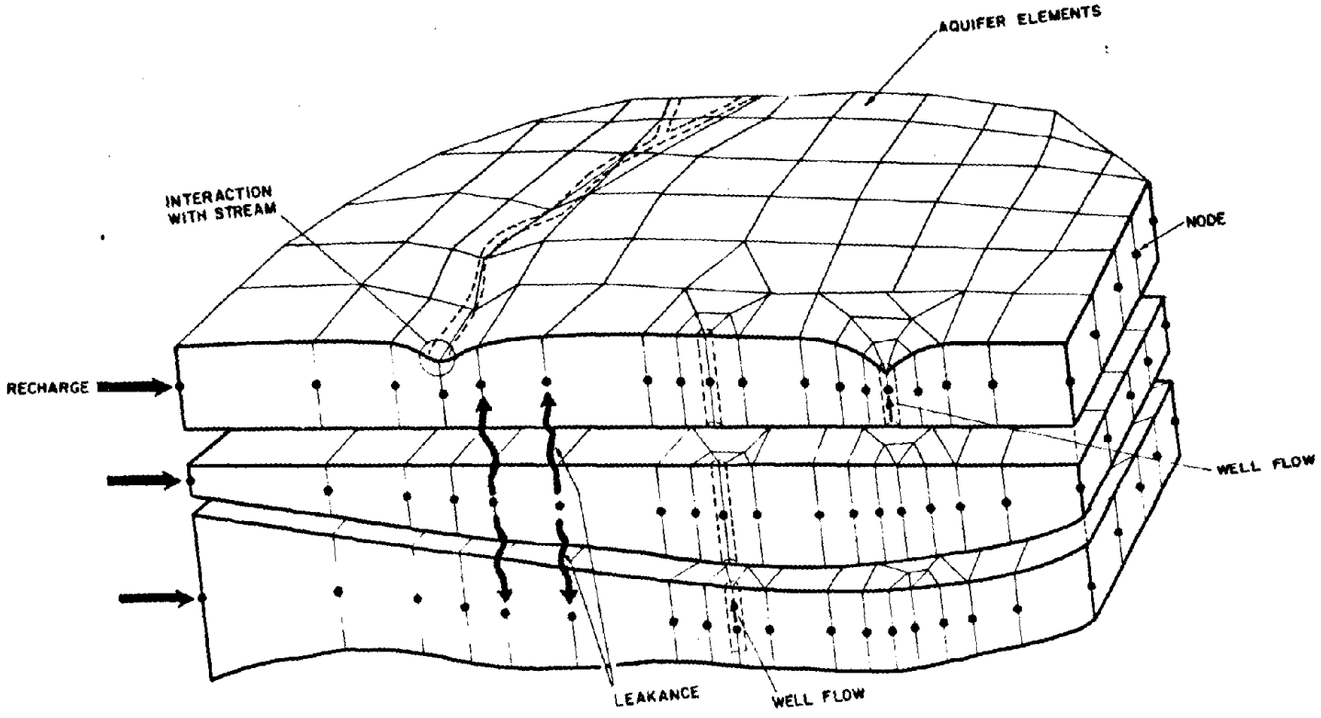


Figure 1(c) MODELLING OF LAYERED AQUIFER SYSTEM - DETAIL OF WEDDING CAKE MODEL

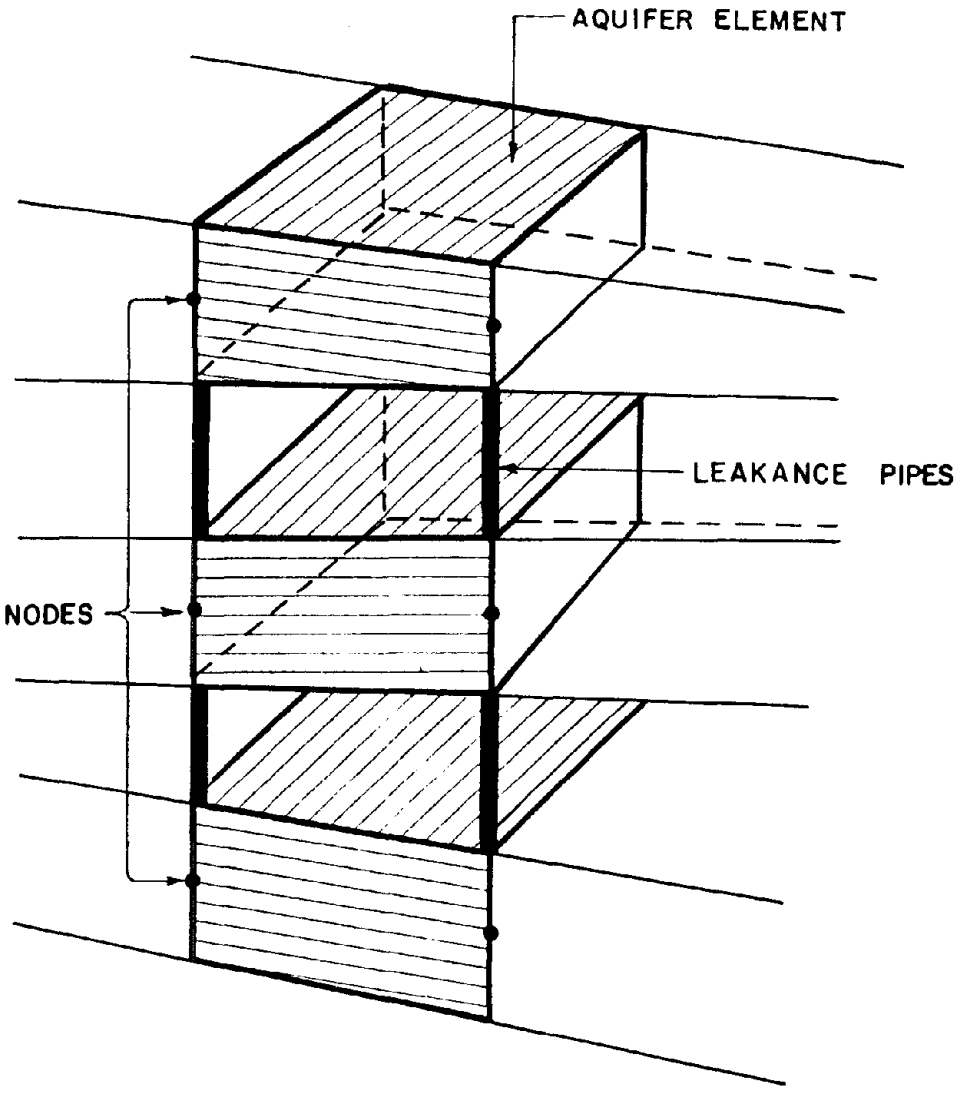
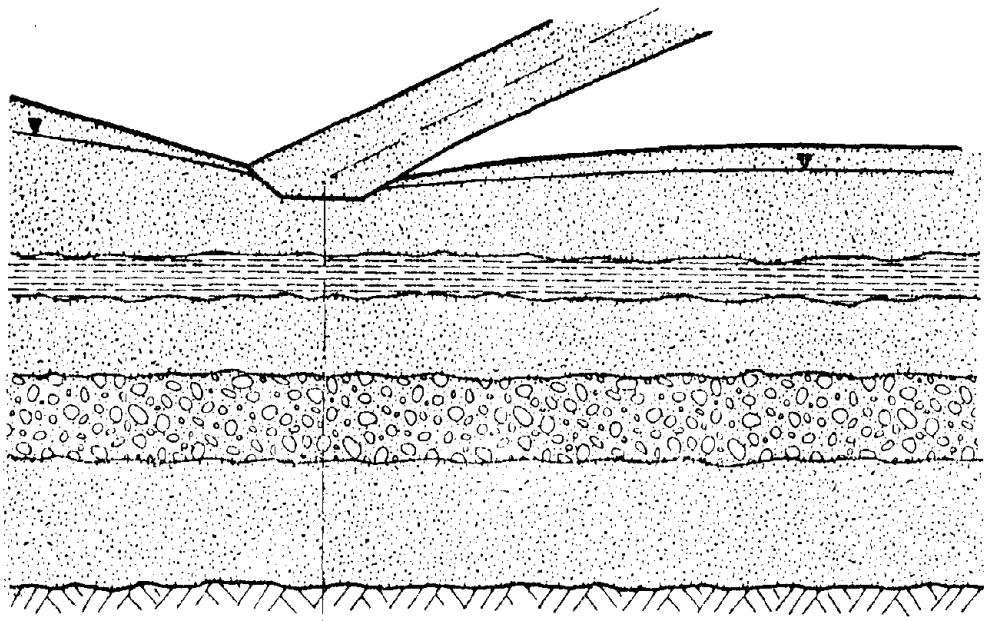
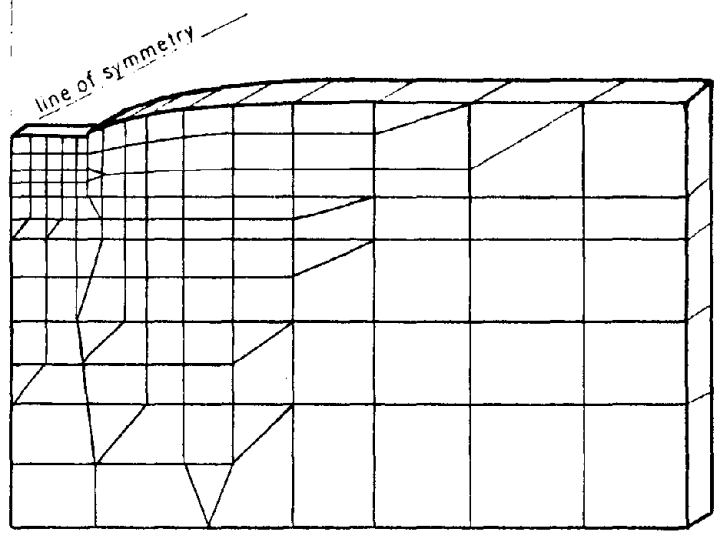


Figure 2 TWO-DIMENSIONAL HYDRAULIC FLOW

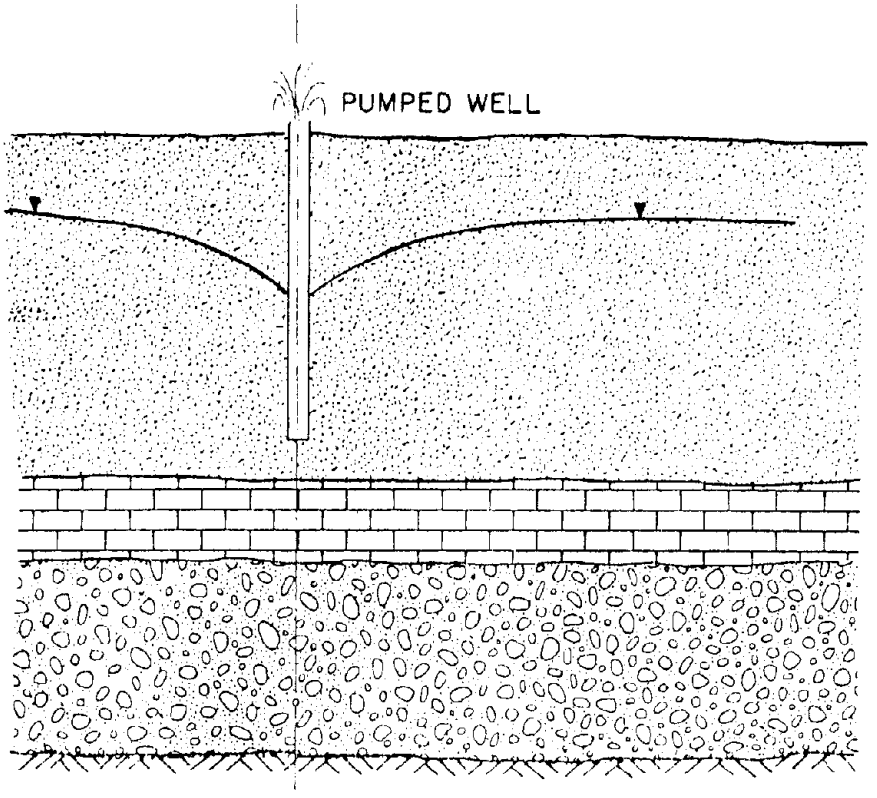


(a) PLANAR TWO DIMENSIONAL FLOW

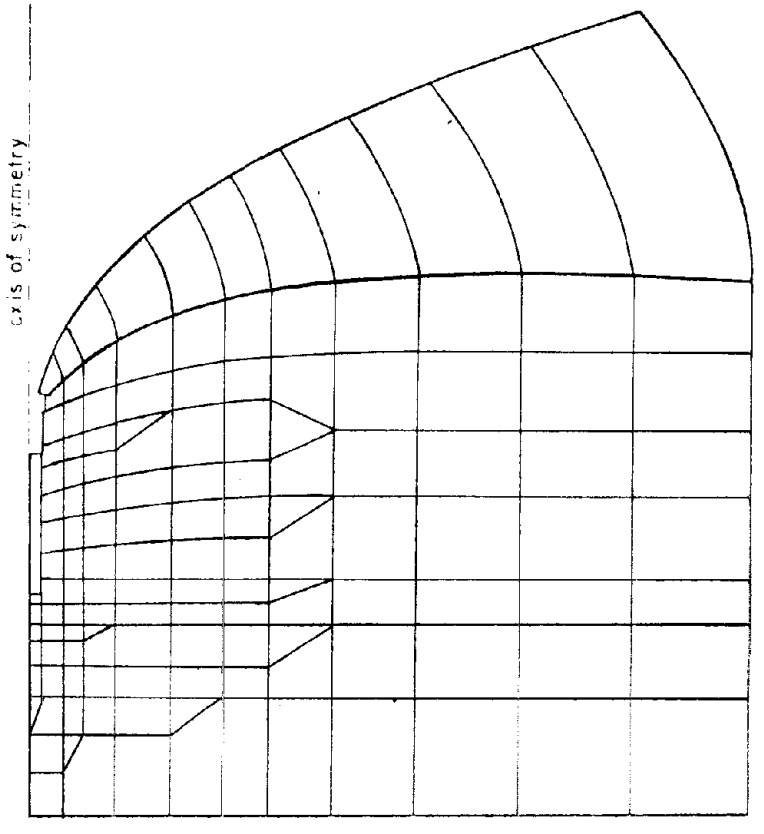


(b) FINITE ELEMENT MODEL

Figure 3 RADIALLY SYMMETRIC FLOW



(a) RADIAL FLOW



(b) FINITE ELEMENT MODEL

APPENDIX F

HOLES WITH HYDROLOGY INFORMATION, PICEANCE CREEK BASIN, COLORADO

PREFACE

The following is a list of holes (oil shale coreholes, assayed oil or gas wells, and water wells) in the Piceance Creek Basin, Colorado, for which there is hydrology information available, either publicly or privately. These holes are keyed by labels to an accompanying map. This listing indicates owner, hole name, ground elevation, depth, location, and source of hydrology information (subdivided into the following categories: permeability, static water level, production, and other).

Some of these holes were taken from a map and index of Coreholes and Assayed Wells, Piceance Creek Basin, Colorado, published by Cameron Engineers, Inc., in December 1973. The other holes are our additions. The numbers under the heading "Hydrology Information" in the listings refer to the source documents in the list of references in this appendix. Where an asterisk (*) appears in these columns it indicates that the data is known to exist, but could not be obtained for this study. The degree of public availability of the data is indicated in the reference list.

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REFERENCES

1. Cordes, E.H. Hydraulic Testing and Sampling of USBM-AEC Colorado Core Hole 3, Rio Blanco County, Colorado. U.S. Geol. Survey Open-File Rept. Oil Shale-6, December 1969, 42 pp.

2. Dana, G.F. Bureau of Mines - Atomic Energy Commission Colorado Corehole No. 2, Rio Blanco County, Colorado. BuMines Open-File Rept., December 1966, 44 pp.

3. Dana, G.F. Bureau of Mines - Atomic Energy Commission Colorado Corehole No. 3, Rio Blanco County, Colorado. BuMines Open-File Rept., July 1968, 55 pp.

4. Ege, J.R., Carroll, R.D., and Welder, F.A. Preliminary Report on the Geology, Geophysics, and Hydrology of USBM/AEC Colorado Core Hole No. 2, Piceance Creek Basin, Rio Blanco County, Colorado. U.S. Geol. Survey Open-File Rept. TEI-870, March 1967, 52 pp.

5. Ficke, J.F., Weeks, J.B., and Welder, F.A. (comps.). Hydrologic Data from the Piceance Basin, Colorado. Colo. Water Cons. Board, Colo. Water Resources Basic-Data Release No. 31, 1974, 246 pp.

6. Golder Associates, Inc. An Evaluation of the Mineability of Federal Oil Shale Tract C-b, Rio Blanco County, Colorado, U.S.A. Kirkland, Washington, October 1975, 6 Vols. (Not publicly available)

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MAP KEY NO.	WELL OR COREHOLE NAME OR NO.	GROUND ELEVATION	DEPTH	LOCATION	HYDROLOGY INFORMATION: PERMEABILITY	STATIC WATER LEVEL	PRODUCTION	OTHER
AMOCO PRODUCTION CO.								
AP 1	Corehole CH-2A	7,245'	1,990'	SESESE 157'NSL,330'WEL Sec.9,T2S,R99W Rio Blanco Co.	19,21	10,19,21	19,21	16,19,21
AP 2	Corehole CH-3	6,924'	1,345'	NWSENE 1750'SNL,1038'WEL Sec.8,T2S,R99W Rio Blanco Co.	19,21	10,19,21	19,21	16,19,21
AP 3	Corehole CH-4	7,135'	1,990'	NESWNE 1837'SNL,1734'WEL Sec.10,T2S,R99W Rio Blanco Co.	19,21	19,21	19,21	16,19,21
ATLANTIC RICHFIELD CO.								
AR 1	Corehole	7,250'	3,088'	NENWSE Sec.10,T3S,R96W Rio Blanco Co.		8,13		
AR 5	Corehole ARCO-Mobil Fig.4,#31-1	7,814'	2,420'	SWSWNE 2000'FEL,2600'FNL Sec.31,T3S,R98W Rio Blanco Co.	5,11,16	5,8,11, 13	11	5,11,16
AR 7	Corehole ARCO-Mobil Fig.4,#36-1	7,478'	450'	SESENW 2451'FWL,2373'FNL Sec.36,T3S,R99W Rio Blanco Co.		13	11	
BARODYNAMICS, INC.								
BI 1	Corehole 72-1	5,956'	1,025'	SWSWNE 2460'FEL,2000'FNL Sec.20,T2N,R98W Rio Blanco Co.	16	5,8,12, 13,16		5,12,17
BUREAU OF MINES								
BM 15	Corehole Barcus Creek Corehole No. 1	7,315'		NENENW 2588'EWL,488'SNL Sec.21,T1N,R99W Rio Blanco Co.		11	11	5,11
BM 16	Corehole Colorado Corehole No. 1	6,003'	3,133'	NWNESE Sec.13,T1N,R98W Rio Blanco Co.		5,8,11, 13	11	5,11

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MAP KEY NO.	WELL OR COREHOLE NAME OR NO.	GROUND ELEVATION	DEPTH	LOCATION	HYDROLOGY INFORMATION: PERMEABILITY	STATIC WATER LEVEL	PRODUCTION	OTHER
BUREAU OF MINES (CONT.)								
BM 17	Corehole Colorado Corehole No. 2	6,597'	2,480'	SWNWNE Sec.14,T1S,R99W Rio Blanco Co.	4,5,11	4,5,8, 11,13	2,4,5, 11	4,5,11
BM 18	Corehole Colorado Corehole No. 3	6,356'	3,797'	SWSWSW 146'FWL,588'FSL Sec.14,T1N,R98W Rio Blanco Co.	1,5,11	1,5,11	1,3,5, 11	1,3,5,11
BM a	Corehole USBM-01	6,254'	2,382.5'	SWSE Sec.31,T1S,R97W Rio Blanco Co.			15	15
BM b	Corehole USBM-01A	6,234'	2,610'	NWSW Sec.29,T1S,R97W Rio Blanco Co.	15	15	15	
BM c	Corehole USBM-02A	6,224'	2,660'	NWSW Sec.29,T1S,R97W Rio Blanco Co.	15	15	15	15
BM d	Corehole USBM Pilot Hole "X"	6,284.87'	2,483'	SWNWSW Sec.29,T1S,R97W Rio Blanco Co.	7	7		7
CAMERON ENGINEERS, INC.								
CE 1	Corehole CE-701A	6,997.3'	1,220'	SENWNE 1838'FEL,1150'FNL Sec,32,T1S,R99W Rio Blanco Co.	18,21	5,8,12, 18,21	5,12, 18,21	5,12,18, 21
CE 2	Corehole CE-702	6,654'	1,797'	NWSENE 868'FEL,1621'FNL Sec.34,T1S,R99W Rio Blanco Co.	5,16,18, 21	5,8,10, 16,18,21	16,18, 21	5,16,18, 21
CE 3	Corehole CE-703	7,005.1'	1,345'	SWSENW 1336'FWL,2790'FSL Sec.5,T2S,R99W Rio Blanco Co.	5,16,18, 21	5,8,12, 16,18,21	5,12, 18,21	5,12,16,18, 21
CE 4	Corehole CE-704C	6,760'	1,946'	SENESW 2150'FWL,1700'FSL Sec.16,T1S,R99W Rio Blanco Co.	5,16,18, 21	5,8,12, 16,18,21	5,12, 18,21	5,12,16,18 21

MAP KEY NO.	WELL OR COREHOLE NAME OR NO.	GROUND ELEVATION	DEPTH	LOCATION	HYDROLOGY INFORMATION: PERME-ABILITY	STATIC WATER LEVEL	PRODUC-TION	OTHER
CAMERON ENGINEERS, INC. (CONT.)								
CE 5	Corehole CE-705A	6,741.2'	1,550'	SESENE 97'FEL,2108'FNL Sec.4,T2S,R99W Rio Blanco Co.	5,18,21	5,8,12, 18,21	5,12, 18,21	5,12,18, 21
CE 6	Corehole CE-706A	7,030'	1,521'	SWNWNE 2151'FEL,798'FNL SEC.7,T1S,R99W Rio Blanco Co.	5,18,21	5,8,12, 13,21	5,12, 21	5,12,21
CE 7	Corehole CE-707	7,181.9'	1,385'	NWSESE 1065'FEL,1004'FSL Sec.32,T1S,R99W Rio Blanco Co.	18,21	8,10,16, 18,21	16,18, 21	5,16,18, 21
CE 8	Corehole CE-708	6,917.9'	1,311'	SWNENE 1034'FEL,1218'FNL Sec.5,T2S,R99W Rio Blanco Co.	5,18,21	8,10,18, 21	18,21	5,18,21
CE 9	Corehole CE-709	6,771'	1,489	SENWSE 1794'FEL,1642'FSL Sec.33,T1S,R99W Rio Blanco Co.	5,18,21	5,8,10, 16,18,21	18,21	5,16,18, 21
C-b CONSORTIUM								
CB a	Corehole SG-1	6,429'	2,525'	1942'FEL,1413'FSL Sec.2,T3S,R96W Rio Blanco Co.	6	6,20	6	6
CB b	Corehole SG-1-A	6,428.5'	1,180'	1942'FEL,1489'FSL Sec.7,T3S,R96W Rio Blanco Co.	6	6	6	6
CB c	Corehole SG-6	6,888'	2,220.7'	2251'FWL,2523'FSL Sec.7,T3S,R96W Rio Blanco Co.	6	6,20	6	6
CB d	Corehole SG-8	6,538'	2,606'	2600'FWL,2301'FSL Sec.9,T3S,R96W Rio Blanco Co.	6	6,20	6	6
CB e	Corehole SG-9	6,870'	2,750'	461'FEL,22.2'FSL Sec.11,T3S,R97W Rio Blanco Co.	6	6,20	6	6
CB f	Corehole SG-10	6,950'	2,210'	184'FEL,97'FNL Sec.13,T3S,R97W Rio Blanco Co.	6	6,20	6	6

MAP KEY NO.	WELL OR COREHOLE NAME OR NO.	GROUND ELEVATION	DEPTH	LOCATION	HYDROLOGY INFORMATION: PERMEABILITY	STATIC WATER LEVEL	PRODUCTION	OTHER
C-b CONSORTIUM (CONT.)								
CB g	Corehole SG-10-A	6,950'	1,333'	194'FEL,97'FNL Sec.13,T3S,R97W Rio Blanco Co.	6	6,20	6	6
CB h	Corehole SG-11	6,900'	2,826'	160'FEL,12'FSL Sec.7,T3S,R96W Rio Blanco Co.	6	6,20	6	6
CB i	Corehole SG-17	7,036'	2,460'	438'FWL,181'FSL Sec.16,T3S,R96W Rio Blanco Co.	6	6,20	6	6
CB j	Corehole SG-18	7,382.6'	1,426'	365.7'FEL,1240.4'FSL Sec.25,T3S,R97W Rio Blanco Co.	6	6	6	6
CB k	Corehole SG-18-A	7,383'	1,331'	375'FEL,1240'FSL Sec.25,T3S,R97W Rio Blanco Co.	6	6,20	6	6
CB l	Corehole SG-19	6,381.8'	980.5'	456.8'FWL,139.8'FNL Sec.5,T3S,R96W Rio Blanco Co.	6	6,20	6	6
CB m	Corehole SG-20	6,358'	982'	1599'FEL,261'FSL Sec.31,T3S,R96W Rio Blanco Co.	6	6	6	6
CB n	Corehole SG-21	6,811.2'	1,037'	152.8'FEL,210.6'FSL Sec.13,T3S,R97W Rio Blanco Co.	6	6,20	6	6
CB o	Corehole AT-1	6,909.1'	1,706'	1584.7'FWL,1410.9'FSL Sec.7,T3S,R96W Rio Blanco Co.	6	6,20	6	6
CB p	Corehole AT-1-A	6,909'	1,620'	1509.2'FWL,1389.1'FSL Sec.7,T3S,R96W Rio Blanco Co.	6	6	6	6
CB q	Corehole AT-1-B	6,909'	1,638'	1676'FWL,1365.1'FSL Sec.7,T3S,R96W Rio Blanco Co.	6	6	6	6
CB r	Corehole AT-1-C	6,905'	6,905'	1661.8'FWL,1477.1'FSL Sec.7,T3S,R96W Rio Blanco Co.	6	6,20	6	6
CB s	Corehole AT-1-D	6,905'	1,640'	1531.9'FWL,1527'FSL Sec.7,T3S,R96W Rio Blanco Co.	6	6	6	6

MAP KEY NO.	WELL OR COREHOLE NAME OR NO.	GROUND ELEVATION	DEPTH	LOCATION	HYDROLOGY INFORMATION: PERMEABILITY	STATIC WATER LEVEL	PRODUCTION	OTHER
C-b CONSORTIUM (CONT.)								
CB t	Corehole NQ-4	6,653'	1,328'	642'FEL,1970'FNL Sec.11,T3S,R97W Rio Blanco Co.				
CB u	Corehole NQ-7-B	6,880'	1,538'	2179'FEL,2448'FNL Sec.8,T3S,R96W Rio Blanco Co.				
CB v	Corehole NQ-12-D	6,952'	1,435'	1582'FEL,2121'FSL Sec.18,T3S,R96W Rio Blanco Co.				
CB w	Corehole NQ-22	6,910'	1,486'	1442'FWL,1341'FSL Sec.7,T3S,R96W Rio Blanco Co.				
EQUITY OIL CO.								
EQ 2	Well Johnson No. 1	6,276'	2,563'	SENENW 2600'FWL,1650'FSL Sec.27,T2S,R97W Rio Blanco Co.		8,11,13		5,11
EQ 11	Well Sulphur Creek No. 8	6,500'	1,543'	NWSENE Sec.17,T2S,R98W Rio Blanco Co.		8,13		
EQ 15	Well Black Sulphur No. 13	7,020'	1,690'	NENENE 610'FNL,610'FEL Sec.30,T2S,R98W Rio Blanco Co.		5,8,11, 13		5,11
EQ 17	Corehole Boies Corehole No. 1	6,284'	2,010'	NWSESW Sec.19,T2S,R97W Rio Blanco Co.		8,13		
Eq 25	Well Oldland Water Well No. 2	6,520'	1,005'	SESWSW 1150'FWL,300'FSL Sec.26,T3S,R96W Rio Blanco Co.	5	5,11	11	5,11
EQ 26	Corehole Oldland No. 3	6,470'	2,395'	NENENE 530'FEL,630'FNL Sec.10,T3S,R96W Rio Blanco Co.	5	5		16
EQ 30	Well Boies No. 1	6,284'		SWSWNE Sec.22,T3S,R98W Rio Blanco Co.		16		16

MAP KEY NO.	WELL OR COREHOLE NAME OR NO.	GROUND ELEVATION	DEPTH	LOCATION	HYDROLOGY INFORMATION: PERMEABILITY	STATIC WATER LEVEL	PRODUCTION	OTHER
EQUITY OIL CO.								
EQ 37	Corehole South Sulphur 1-A	7,070'	675'	SENWNE Sec.22,T3S,R98W Rio Blanco Co.		8,13,16		16
EQ 41	Well BX No. 1	6,629'	1,276'	SENESE 425'FEL,1870'FSL Sec.6,T3S,R98W Rio Blanco. Co.		8,13		
EQ 43	Well CER RB-D-01	6,644'	1,651'	SENWNW 1210'FWL,974'FNL Sec.14,T3S,R98W Rio Blanco Co.	5,11	5,12,13	5,11,12	5,12
GENERAL PETROLEUM CORP.								
GP a	17X8-G	6,729'	2,608'	NWSWSW Sec.8,T3S,R95W Rio Blanco Co.		8		16
GP b	88-26	6,812'	1,691'	SESESE Sec.26,T1N,R99W Rio Blanco Co.		8,13		11,16
HUMBLE OIL CO.								
HU a	Humble			SW Sec.9,T2S,R97W Rio Blanco Co.				16
MARATHON OIL CO.								
MT 1	Corehole Marathon No. 1	6,122'	2,235'	NWNWNW Sec.4,T2S,R97W Rio Blanco Co.		8,13,16		16
MT a	Marathon 1-A			NWNWNW Sec.4,T2S,R97W Rio Blanco Co.				16
MOBIL OIL CORP. (SEE ALSO ATLANTIC RICHFIELD CO. FOR COREHOLES DRILLED JOINTLY BY ARCO & MOBIL)								
MO 33	Corehole Mobil No. 5	6,509'	1,742'	NENWSW 760'FWL,2020'FSL Sec.34,T2S,R97W Rio Blanco Co.		5,8,11, 13		5,11
MO 42	Well 52-19-G	6,690'		SWNWNE 2200'FEL,1100'FNL Sec.19,T2S,R96W Rio Blanco Co.		5		5

MAP KEY NO.	WELL OR COREHOLE NAME OR NO.	GROUND ELEVATION	DEPTH	LOCATION	HYDROLOGY INFORMATION: PERMEABILITY	STATIC WATER LEVEL	PRODUCTION	OTHER
MOBIL OIL CORP. (CONT.)								
MO a	Mobil No. 1	6,510'	1,654'	SWNWNW Sec.33,T2S,R97W Rio Blanco Co.		8,11,13		5,11
MO b	Mobil No. 2	6,480'	1,504'	NESENW Sec.21,T2S,R97W Rio Blanco Co.		5,8,11,13		5,11
MO c	Mobil No. 3	6,618'	1,650'	NESWNE Sec.28,T2S,R97W Rio Blanco Co.		5,8,11,13		5,11
MO d	Mobil No. 4	6,486'	1,745'	SWSWNE Sec.33,T2S,R97W Rio Blanco Co.		5,8,11,13		5,11
OCCIDENTAL PETROLEUM CORP. (INCLUDES GARRETT RESEARCH & DEVELOPMENT CO.)								
OC 2	Corehole Stake Springs Draw No. 1	6,560'	1,594'	NENWNE 1750'FEL,620'FNL Sec.12,T2S,R99W Rio Blanco Co.	12		5,12	5,12,16
RIO BLANCO OIL SHALE PROJECT								
CA a	Corehole GS-1	7,248'	1,404.3'	SENESW 1490'NSL,1280'EWL Sec.32,T1S,R99W Rio Blanco Co.	9,21	9,10,21	9,21	9,21
CA b	Corehole GS-2-3	6,876'	1,424.2'	NESWNW 3810'NSL,840'EWL Sec.33,T1S,R99W Rio Blanco Co.	9,21	9,10,21	9,21	9,21
CA c	Corehole GS-4-5	6,717'	1,663.1'	SWSENW 3106'NSL,1329'EWL Sec.34,T1S,R99W Rio Blanco Co.	9,21	9,10,21	9,21	9,21
CA d	Corehole GS-6	6,658'	1,781.5'	NESESE 1050'NSL,110'WEL Sec.34,T1S,R99W Rio Blanco Co.	9,21	9,10,21	9,21	9,21
CA e	Corehole GS-7	6,984'	1,200.3'	SWSENW 2650'NSL,1850'EWL Sec.5,T2S,R99W Rio Blanco Co.	9,21	9,21	9,21	9,21
CA f	Corehole GS-8	7,268'	1,615.9'	NESESE 950'NSL, 950'WEL Sec.5,T2S,R99W Rio Blanco Co.	9,21	9,10,21	9,21	9,21

MAP KEY NO.	WELL OR COREHOLE NAME OR NO.	GROUND ELEVATION	DEPTH	LOCATION	HYDROLOGY INFORMATION: PERMEABILITY	STATIC WATER LEVEL	PRODUCTION	OTHER
RIO BLANCO OIL SHALE PROJECT (CONT.)								
CA g	Corehole GS-9	7,131'	1,600'	NWSENW 1805'SNL,3520'WEL Sec.4,T1S,R99W Rio Blanco Co.	9,21	9,10,21	9,21	9,21
CA h	Corehole GS-10	7,006'	1,902.7'	SENWSE 3630'SNL,3795'EWL Sec.3,T2S,R99W Rio Blanco Co.	21	10,21	21	21
CA i	Corehole GS-11	7,340'	1,885.8'	SESWSW 600'NSL,780'EWL Sec.9,T2S,R99W Rio Blanco Co.	21	10,21	21	21
CA j	Corehole GS-12	7,266'	1,800'	NENESW 2300'NSL,2125'EWL Sec.9,T2S,R99W Rio Blanco Co.	9,21	9,10,21	9,21	9,21
CA k	Corehole GS-13	7,191'	1,751'	SWNWNE 4530'NSL,3220'EWL Sec.9,T2S,R99W Rio Blanco Co.	21	10,21	21	21
CA l	Corehole GS-14	7,081'	1,794.1'	NESWNW 3800'NSL,810'EWL Sec.10,T2S,R99W Rio Blanco Co.	21	21	21	21
CA m	Corehole GS-15	6,980'	1,835.4'	SWSESE 400'NSL,4450'EWL Sec.10,T2S,R99W Rio Blanco Co.	21	10	21	21
CA n	Corehole GS-D16			SW Sec.9,T2S,R99W Rio Blanco Co.	*	*	21	21
CA o	Corehole GS-D17			NW Sec.32,T1S,R99W Rio Blanco Co.	*	*	21	21
CA p	Corehole GS-D18			NE Sec.34,T1S,R99W Rio Blanco Co.	*	*	21	21
CA q	Corehole GS-D19			NW Sec.3,T1S,R99W Rio Blanco Co.	*	*	21	21

MAP KEY NO.	WELL OR COREHOLE NAME OR NO.	GROUND ELEVATION	DEPTH	LOCATION	HYDROLOGY INFORMATION: PERMEABILITY	STATIC WATER LEVEL	PRODUCTION	OTHER
RIO BLANCO OIL SHALE PROJECT (CONT.)								
CA r	Corehole GS-M-1			SW Sec.29,T1S,R99W Rio Blanco Co.	21	10,21	21	21
CA s	Corehole GS-M-2			NWNENE Sec.24,T1S,R99W Rio Blanco Co.	21	10,21	21	21
CA t	Corehole GS-M-3			SWNWNE Sec.29,T1S,R98W Rio Blanco Co.	21	10,21	21	21
CA u	Corehole GS-M-4			SWNWSE Sec.21,T1S,R99W Rio Blanco Co.	21	10,21	21	21
CA v	Corehole GS-M-5			SWNWSW Sec.8,T1S,R98W Rio Blanco Co.	*	*	*	*
SHELL OIL CO.								
SH 7	Corehole Shell 23X-2	6,520'	2,699'	NWNESW 1628'FWL,2311'FSL Sec.2,T2S,R98W Rio Blanco Co.	5,16	5,8,11, 13,16	5,11	5,11
SH 11	Corehole Shell 41-9	6,547'	3,000'	NENENE 640'FEL,370'FNL Sec.9,T1S,R97W Rio Blanco Co.	5	5,8,12, 13	12	5,12
SH a	Shell Greeno 4-4	6,417'	2,074'	NENENE Sec.4,T3S,R97W Rio Blanco Co.	16	5,8,13		5,16
SINCLAIR OIL CORP.								
SN 3	Corehole Cross V No. 1	6,281'	2,917'	CNWNE Sec.21,T1S,R98W Rio Blanco Co.		11		5,11
THE CARTER OIL CO.								
CT 2	Corehole Yellow Creek Corehole No. 1	6,224'	700'	NWNENE 1124'FEL,200'FNL Sec.2,T1S,R98W Rio Blanco Co.		8,13		

MAP KEY NO.	WELL OR COREHOLE NAME OR NO.	GROUND ELEVATION	DEPTH	LOCATION	HYDROLOGY INFORMATION: PERMEABILITY	STATIC WATER LEVEL	PRODUCTION	OTHER
THE CARTER OIL CO. (CONT.)								
CT 4	Corehole Hunter Creek Corehole No. 1	6,990'	443'	SWSESE 756'FEL,522'FSL Sec.36,T3S,R98W Rio Blanco Co.		8,13		
THE OIL SHALE CORP.(TOSCO)								
TO 1	Corehole TG2-3	6,829.6'		SWSWSW 311'FWL,109'FSL Sec.23,T3S,R96W Rio Blanco Co.		11	11	5,11
TO 8	Corehole TG71-1	6,660'	2,530'	SENENW 2262'FWL,927'FNL Sec.13,T3S,R97W Rio Blanco Co.	5,6,17	5,6,8, 12,13,17	5,6,12, 17	5,12,17
TO 9	Corehole TG71-2	6,605'	1,158'	NWNENE 1054'FEL,252'FNL Sec.17,T3S,R96W Rio Blanco Co.	5,6,17	6,8,12, 13,17	5,6,12 17	5,12,17
TO 10	Corehole TG71-3	6,849'	1,086'	NWNENW 1710'FWL,540'FNL Sec.29,T3S,R96W Rio Blanco Co.	5,17	12,13,17	5,12,17	5,12,17
TO 11	Corehole TG71-4	7,089'	2,050'	NWNWSE 105'FWL,2610'FSL Sec.6,T4S,R96W Rio Blanco Co.	5,17	5,8,12, 13,17	5,12,17	5,12,17
TO 12	Corehole TG71-5	6,880'	902'	SWNENE 1205'FEL,875'FNL Sec.33,T3S,R96W Rio Blanco Co.	5,17	8,12,13, 17	5,12,17	5,12,17
TO 13	Corehole Butte #25	7,042'		SWSENE 1070'FEL,2278'FNL Sec.9,T4S,R96W Rio Blanco Co.				16
TO 15	Corehole Cb-1	6,759.6'	2,104'	NESWSW 1015.4'FWL,1152.9'FSL Sec.1,T3S,R97W Rio Blanco Co.	5,6	5,6,8, 16,20	5,6	5,16
TO 16	Corehole Cb-2	6,737.2'	1,482'	SWNESE 1300'FEL,1589.3'FSL Sec.6,T3S,R96W Rio Blanco Co.	5,6	5,6,8, 16,20	5,6	5,16

MAP KEY NO.	WELL OR COREHOLE NAME OR NO.	GROUND ELEVATION	DEPTH	LOCATION	HYDROLOGY INFORMATION: PERMEABILITY	STATIC WATER LEVEL	PRODUCTION	OTHER
THE OIL SHALE CORP. (TOSCO) (CONT.)								
TO 17	Corehole Cb-3	6,743.1'	2,122'	NWSWSE 2530.6'FEL,1088.2'FSL Sec.5,T3S,R96W Rio Blanco Co.	5,6	6,8,20	5,6	5
TO 18	Corehole Cb-4	7,054'	1,470'	SENWSW 1451'FSL,960'FWL Sec.17,T3S,R96W Rio Blanco Co.	5,6	5,6,8, 16,20	5,6	5,16
TO 19	Corehole Liberty Bell #12	7,393'	943'	NESESE 533'FEL,1040'FSL Sec.18,T4S,R95W Rio Blanco Co.	16	8,13,16		16
TO 21	Corehole Ca-1	6,741'	1,198	SESENE 73'FEL,2062'FNL Sec.4,T2S,R99W Rio Blanco Co.		10,21		
TO 22	Corehole Ca-2	6,993'	1,130	SENWNE 1760'FEL,4182'FSL Sec.32,T1S,R99W Rio Blanco Co.		10,21		
TO 23	Corehole Ca-3	6,652'	1,561	NWSENE 815'FEL,1626'FNL Sec.34,T1S,R99W Rio Blanco Co.		21		
THE SUPERIOR OIL CO.								
TS 1	Corehole CH-1-PC	6,080'	1,606'	SENWNW Sec.15,T1N,R97W Rio Blanco Co.		5,8,12,13		12
TS 3	Corehole CH-3-PC		6,391'	SESESE 450'WEL,683'NSL Sec.10,T1N,R97W Rio Blanco Co.				5
TS 4	Corehole CH-4-PC	6,174'	2,387'	CSWSE 1980'WEL,660'NSL Sec.16,T1N,R97W Rio Blanco Co.	16	12,16	16	5,12,16
TS 6	Corehole CH-6-PC	5,976'	1,383'	NESESW 2035'EWL,990'NSL Sec.14,T1N,R97W Rio Blanco Co.	16	8,12,13,16		5,12,16

MAP KEY NO.	WELL OR COREHOLE NAME OR NO.	GROUND ELEVATION	DEPTH	LOCATION	HYDROLOGY INFORMATION: PERMEABILITY	STATIC WATER LEVEL	PRODUCTION	OTHER
THE SUPERIOR OIL CO. (CONT.)								
TS 7	Corehole CH7-PC	6,402'		SESESW 2000'FWL,430'FSL Sec.8,T1N,R97W Rio Blanco Co.		5	5	5
TS a	RBST 14	5,953'	1,775	NENESE Sec.27,T1N,R97W Rio Blanco Co.		8,13		5
TS b	NFW			SE Sec.22,T1N,R97W Rio Blanco Co.				16
TS c	SFW			SE Sec.22,T1N,R97W Rio Blanco Co.				16
TS d	CH-20-PC			NE Sec.22,T1N,R97W Rio Blanco Co.				16
U.S. GEOLOGICAL SURVEY								
US a	Well TH75-1A	6,138'	1,060'	SENESW Sec.21,T1N,R97W Rio Blanco Co.		14	14	14
US b	Well TH75-1B	6,138'	1,540'	SENESW Sec.21,T1N,R97W Rio Blanco Co.		14	14	14
US c	Well TH75-2A	6,715'	1,122'	NWNWSE Sec.20,T1N,R98W Rio Blanco Co.		14	14	14
US d	Well TH75-2B	6,715'	1,510'	NWNWSE Sec.20,T1N,R98W Rio Blanco Co.		14	14	14
US e	Well TH75-4A	6,650'	790'	NENWNW Sec.31,T1S,R95W Rio Blanco Co.		14	14	14
US f	Well TH75-5A	7,178'	895'	NWNWSW Sec.31,T1S,R96W Rio Blanco Co.		14	14	14
US g	Well TH75-5B (also called CR-1)	7,178'	2,800'	NWNWSW Sec.31,T1S,R96W Rio Blanco Co.		14	14	14

MAP KEY NO.	WELL OR COREHOLE NAME OR NO.	GROUND ELEVATION	DEPTH	LOCATION	HYDROLOGY INFORMATION: PERMEABILITY	STATIC WATER LEVEL	PRODUCTION	OTHER
U.S. GEOLOGICAL SURVEY (CONT.)								
US h	Well TH75-6A	6,440.4'	1,260'	SWSENE Sec.14,T1S,R98W Rio Blanco Co.		14	14	14
US i	Well TH75-6B	6,439.7'	1,755'	SWSENE Sec.14,T1S,R98W Rio Blanco Co.		14	14	14
US j	Well TH75-7A	6,360.9'	1,080'	SWNENE Sec.20,T1S,R98W Rio Blanco Co.		14	14	14
US k	Well TH75-7B	6,362.4'	1,485'	SWNENE Sec.20,T1S,R98W Rio Blanco Co.		14	14	14
US l	Well TH75-9A	7,350'	1,180'	NESWSW Sec.8,T2S,R95W Rio Blanco Co.		14	14	14
US m	Well TH75-9B	7,350'	1,575'	NESWSW Sec.8,T2S,R95W Rio Blanco Co.		14	14	14
US n	Well TH75-10A	6,840'	495'	NWSWNE Sec.19,T2S,R95W Rio Blanco Co.		14	14	14
US o	Well TH75-10B	6,840'	853'	NWSWNE Sec.19,T2S,R95W Rio Blanco Co.		14	14	14
US p	Well TH75-11A	6,691'	1,185'	SENWNE Sec.3,T2S,R98W Rio Blanco Co.		14	14	14
US q	Well TH75-11B	6,691'	1,715'	SENWNE Sec.3,T2S,R98W Rio Blanco Co.		14	14	
US r	Well TH75-13A	6,390'	640'	NWNWSW Sec.24,T2S,R98W Rio Blanco Co.		14	14	14
US s	Well TH75-13B	6,390	1,160'	NWNWSW Sec.24,T2S,R98W Rio Blanco Co.		14	14	14

MAP KEY NO.	WELL OR COREHOLE NAME OR NO.	GROUND ELEVATION	DEPTH	LOCATION	HYDROLOGY INFORMATION: PERMEABILITY	STATIC WATER LEVEL	PRODUCTION	OTHER
U.S. GEOLOGICAL SURVEY (CONT.)								
US t	Well TH75-15A	6,805'	655'	SWSWNE Sec.30,T3S,R97W Rio Blanco Co.		14	14	14
US u	Well TH75-15B	6,805'	1,040'	SWSWNE Sec.30,T3S,R97W Rio Blanco Co.		14	14	14
US v	Well TH75-17B (also called CR-2)	6,100'	2,400'	SWSENE 1300'FEL,2650'FSL Sec.36,T1N,R97W Rio Blanco Co.		14	14	14
US w	Well TH75-18A	6,740'	810'	SWNENE Sec.15,T1S,R97W Rio Blanco Co.		14	14	14
US x	Well TH75-18B	6,740'	1,375'	SWNENE Sec.15,T1S,R97W Rio Blanco Co.		14	14	14
WOLF RIDGE MINERALS								
WR 1	Corehole Colorado Minerals 14-1	6,303.2'	2,489'	NENWNE 1698.76'WEL,641.22'SWL Sec.14,T1S,R98W Rio Blanco Co.		5,8,13		5
WR 4	Corehole D-20-1	6,376'		SWNENE 1172.25'WEL,1197.37'SNL Sec.20,T1S,R98W Rio Blanco Co.				5
WR 6	Corehole 24-1	6,584.9'		NENENE 331.71'WEL,342.94'SNL Sec.24,T1S,R98W Rio Blanco Co.		5		5
THE OWNERS OF THE FOLLOWING ARE UNKNOWN:								
X a	Colorado Division of Wildlife	6,342'	1,600'	NWSESE Sec.10,T1S,R96W Rio Blanco Co.	5	5,8,13		16
X b	Well Resources 22-15F	7,228'	636'	NESWSE Sec.22,T2S,R95W Rio Blanco Co.		5,8		5

MAP KEY NO.	WELL OR COREHOLE NAME OR NO.	GROUND ELEVATION	DEPTH	LOCATION	HYDROLOGY INFORMATION: PERMEABILITY	STATIC WATER LEVEL	PRODUCTION	OTHER
THE OWNERS OF THE FOLLOWING ARE UNKNOWN: (CONT.)								
X c	BLM-SSD			NW Sec.14,T2S,R99W Rio Blanco Co.				16
X d	CER RB-S-03	6,630'	631'	SENWNW Sec.14,T3S,R98W Rio Blanco Co.		8,13		16
X e	CER RB-D-02	6,580'		SWSESW Sec.11,T3S,R98W Rio Blanco Co.		13,16	16	16
X f	CER RB-D-03	6,580'		SWSESW Sec.11,T3S,R98W Rio Blanco Co.		13		16
X g	CER RB-W-2			SE Sec.30,T2S,R97W Rio Blanco Co.				16
X h	CER RB-W-3			NE Sec.30,T2S,R97W Rio Blanco Co.				16
X i	CER RB-W-4			SW Sec.20,T2S,R97W Rio Blanco Co.				16
X j	CER RB-W-5			SW Sec.27,T2S,R98W Rio Blanco Co.				16
X k	CER RB-W-6			NE Sec.27,T2S,R98W Rio Blanco Co.				16
X l	CER RB-W-7			SW Sec.23,T2S,R98W Rio Blanco Co.				16
X m	CER RB-W-8			NW Sec.4,T2S,R97W Rio Blanco Co.				16
X n	CER RB-W-9E			SW Sec.20,T2S,R97W Rio Blanco Co.				16
X o	CER RB-W-9W			SW Sec.20,T2S,R97W Rio Blanco Co.				16

MAP KEY NO.	WELL OR COREHOLE NAME OR NO.	GROUND ELEVATION	DEPTH	LOCATION	HYDROLOGY INFORMATION: PERMEABILITY	STATIC WATER LEVEL	PRODUCTION	OTHER
THE OWNERS OF THE FOLLOWING ARE UNKNOWN: (CONT.)								
X p	Dean Burke			SW Sec.11,T1S,R97W Rio Blanco Co.				16
X q	Dick Burke			NE Sec.11,T1S,R97W Rio Blanco Co.				16
X r	El Paso Natural Gas			NW Sec.8,T2S,R96W Rio Blanco Co.				16
X s	Flowing Well YC			NE Sec.26,T2N,R98W Rio Blanco Co.				16
X t	Little Hills CG			SW Sec.31,T1N,R96W Rio Blanco Co.				16
X u	Little Hills HQ			SE Sec.32,T1N,R96W Rio Blanco Co.				16
X v	Little Hills IR			SE Sec.10,T1S,R96W Rio Blanco Co.				16
X w	P73-1			SE Sec.2,T1N,R97W Rio Blanco Co.				16
X x	P73-2			NW Sec.14,T1N,R97W Rio Blanco Co.				16
X y	P73-3			SW Sec.35,T1N,R97W Rio Blanco Co.				16
X z	P73-4			NE Sec.28,T1S,R97W Rio Blanco Co.				16
X aa	P73-5			SW Sec.25,T2S,R97W Rio Blanco Co.				16
Xbb	Y73-1			NE Sec.1,T1N,R98W Rio Blanco Co.				16

MAP KEY NO.	WELL OR COREHOLE NAME OR NO.	GROUND ELEVATION	DEPTH	LOCATION	HYDROLOGY INFORMATION: PERME-ABILITY	STATIC WATER LEVEL	PRODUC-TION	OTHER
THE OWNERS OF THE FOLLOWING ARE UNKNOWN: (CONT.)								
X cc	Y73-2			NE Sec.24,T1N,R98W Rio Blanco Co.				16
X dd	Y73-3			NW Sec.36,T1N,R98W Rio Blanco Co.				16
X ee	Y73-4			SE Sec.2,T1S,R98W Rio Blanco Co.				16
X ff		6,072'		NWSWNW Sec.6,T1S,R97W Rio Blanco Co.		8,13		
X gg		6,950'	425'	SESWNE Sec.21,T3S,R98W Rio Blanco Co.		8		
X hh		5,485'	180'	SESESW Sec.28,T6S,R95W Garfield Co.		8		
X ii		5,660'	105'	SENWSE Sec.25,T6S,R99W Garfield Co.		8		
X jj		5,050'	19'	NWSWNE Sec.23,T7S,R96W Garfield Co.		8		
X kk		6,348'	3,786'	SWSWSW Sec.14,T1N,R98W Rio Blanco Co.		13		
X ll		6,414'	2,642'	SWSWNE Sec.1,T2S,R98W Rio Blanco Co.		13		

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APPENDIX G

PREDICTED INFLOW TO A PROPOSED BLOCK CAVING DEMONSTRATION MINE, HORSE DRAW, PICEANCE BASIN, COLORADO

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CHAPTER 1
INTRODUCTION

As an extension to Contract J0265019, "Water Management in Oil Shale Mining", Golder Associates have contracted to make an evaluation of the likely inflow to the caving demonstration which the USBM proposes to carry out at Horse Draw, Piceance Basin, Colorado (Figure 1).

The proposed caving will be performed in the R4 Zone, some 1,800 ft. below ground level. Groundwater pressures at the Site location are believed to be approximately hydrostatic, with the "water table" (defined as the top of the zone of saturation) at a depth of about 125 ft. below ground level. We understand that the proposed caving experiment will be conducted over an area of about 250 ft. square.

Golder Associates' responsibility in this evaluation is limited to the inflow analysis. Data on the extent and speed of caving, and the permeability of the caved material, has been supplied by Cleveland-Cliffs Iron Company, the relevant portion of which is appended as Exhibit 1.

This report reviews past water inrush experiences in various geological and mining situations, analyzes the expected Horse Draw situation, and discusses the degree of confidence which can be placed upon the results.

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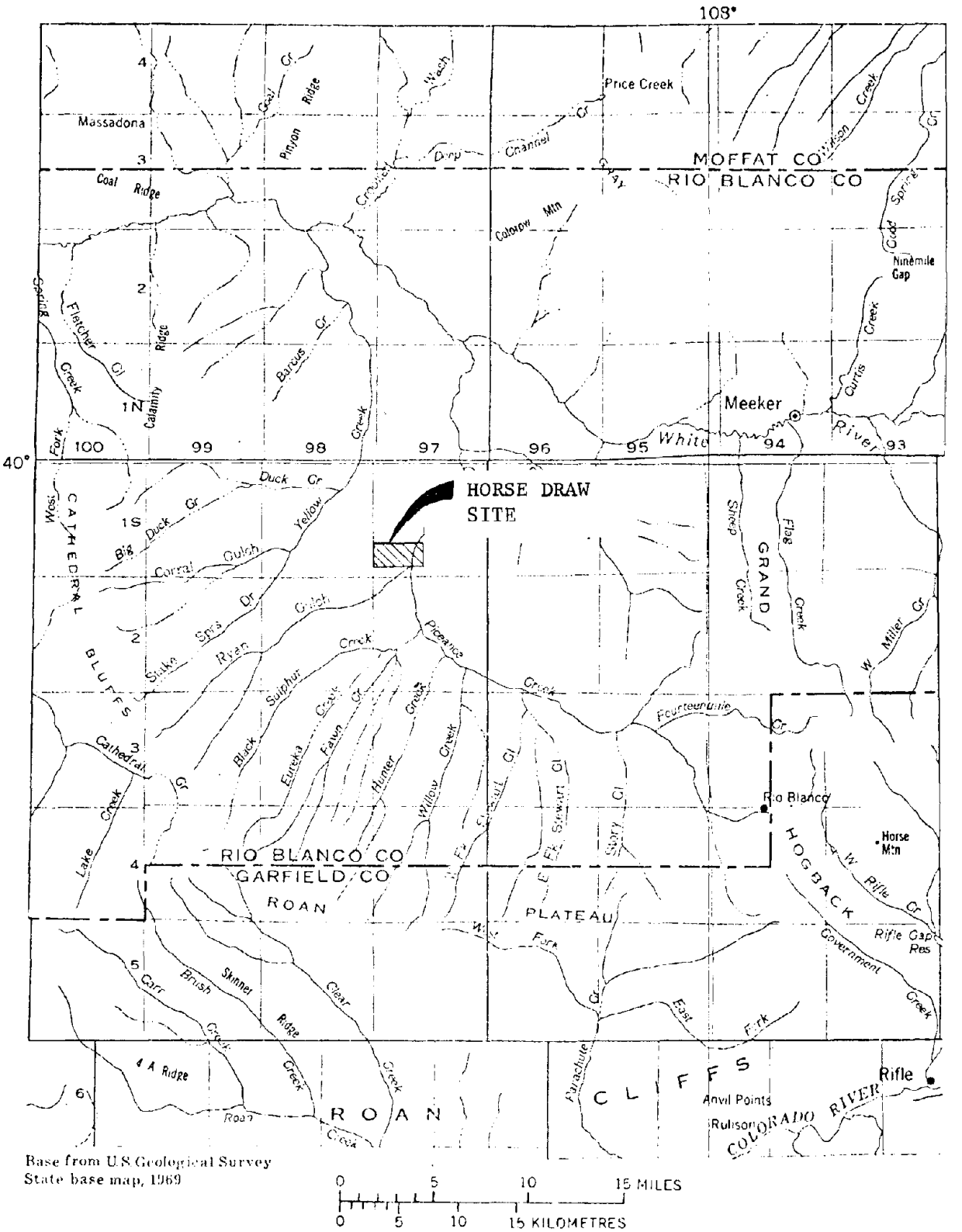
FIGURE 1 SITE LOCATION



CHAPTER 2
REVIEW OF SOME REPORTED INRUSHES

An idea of the possible extent of actual inrushes can only be obtained by reference to past experience in other materials, as there is no field experience of caving available from past oil shale mining.

2.1 SAN ANTONIO MINE, SANTA EULALIA, MEXICO

This mine produced lead, tin, and vanadium from a sulphide intrusive orebody in a dolomitic host rock. It was subject to an inrush in 1945, as described by Signer and Hewitt (1952):

> "On the night of Nov. 10, 1945, after blasting of a dry face at the south end of the ninth level, some 1,450 ft. beneath the surface, water with the volume and horror of a tidal wave engulfed the lower levels, and in the short period of 2-1/2 hours rose to within 6 ft. of the 8th level. Thirty men were trapped by the surging waters. Miraculously 24 escaped....The remaining six were drowned."

The mine inflow rose from a normal 150-220 gpm to about 1,300 gpm. Subsequent pumping at 3,000 gpm reduced the water level by only 3 to 4 inches per week. Water entered the mine through a hole 2 ft. wide by 4 ft. high.

This inrush was not related to caving but illustrates the potential for sudden inflow to hitherto "dry" mines from relatively small solution conduits. The inrush potential was not detected by substantial exploratory drilling ahead of the working face.

2.2 MUFILIRA MINE, ZAMBIA

On 25th September 1970, tailings, which had been deposited in the surface depression caused by a block caving ore extraction technique, flowed into the subsurface mine workings of the Mufilira Mine, Zambia, killing 89 miners.

Mine water inflow before the disaster was 11,500 gpm, and the estimated mud inflow was the equivalent of 8,000,000 gpm. As a result of this disaster, Zambia altered its mining regulations to prohibit mine caving "under rivers, lakes, swamps, drainage channels, unconsolidated water logged formations, or accommodation of tailings or other materials" (Engineering and Mining Journal, December 1971, p. 102).

2.3 WEST DRIEFONTEIN MINE, SOUTH AFRICA

This mine is located in the Wonderfontein Valley, and was at the time of the inrush the biggest gold producer in the world. Inflow before the inrush was 12,500 gpm, and after the inrush it rose to 83,000 gpm. The inrush was caused by interception of a single fissure, fed by water from near-surface solution cavities in the dolomite host rock. All of the 13,500 persons working in the mine were able to escape without injury. Recovery required less than a month.

2.4 JERRERSON CITY MINE, EAST TENNESSEE

This case illustrates the potential of a single fracture zone to endanger a mine. A single 1-1/4 in. diameter hole was drilled into a known water-bearing fracture zone, and flow from it could not be controlled. Mine inflow, normally 300 gpm for the whole mine, increased progressively to 3,800 gpm.

> "The water potential of this fracture zone was under-estimated and proved to be far in excess of any previously known in the district. An excellent property was rendered non-productive overnight...." (Miller and Jolley, 1964).

The mine took 10 months to be brought back into production, as a result of the mud and sand carried into the mine by the inflow. No lives were lost.

2.5 REVIEW OF INRUSH HISTORIES

All but one of these inrushes occurred in dolomitic or limestone environments. It is likely that these are amongst the most unpredictable environments for mine water inflow. Only one case (Mufilira) resulted from caving. Table 1 summarizes the cases studied.

TABLE 1
SUMMARY OF INRUSH HISTORIES

Case	Host Rock	Ore	Inflows Normal (gpm)	Inflows Inrush (gpm)	Depths (ft.)
San Antonio	Dolomite	Lead/Tin	200	1,100	1,450
Mufilira	Quartz Porphry	Copper	11,500	8,000,000	1,650
West Dreifontein	Dolomite	Gold	12,500	70,000	2,830
Jefferson City	Sphalerite/ Dolomite	Zinc	300	3,500	1,220

CHAPTER 3
GEOHYDROLOGIC INFORMATION AT THE SITE

The information available for the evaluation of the geohydrology of the Site of the present study comes from several sources, as follows:

3.1 GEOLOGY OF THE SITE

The geology of the Site is well understood. Four exploratory holes, three of them cored, have been drilled in the vicinity. The geology from holes USBM 01, 01-A, and 02-A is shown on Table 2. This geologic data was developed by the USGS (Ege, et al., 1976). Subsequently, Pilot Hole "X" was drilled near the vent shaft location, and a report on the geology of the entire area incorporating this new data was prepared (Golder Associates, January 1977).

3.2 GEOHYDROLOGY OF THE SITE

Information of the geohydrology of the Site also comes from a variety of sources. Primary information on horizontal permeability was determined by the USGS (Weeks, 1976) in two pumping tests performed by pumping just above and below the Mahogany Zone in USBM 02-A, then with observation in the same zones in USBM 01-A. Re-analysis of this data by Golder Associates produced substantially the same parameters as were developed by Weeks. The results of our assessment are presented in an informal report to the USBM (Golder Associates, July 1977).

In addition to this information, a test of the material in the region of the proposed mine was made by the USBM during the drilling of USBM 02-A; 822 ft. of the saline zone (from 1,458 ft.

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Table 2.-- Depths in drill holes USBM-01, USBM-01A, and USBM-02A to selected marker beds

Marker bed	USBM-01 Elev. 6,254[1]		USBM-01A Elev. 6,236		USBM-02A Elev. 6,224	
	Depth to top	Depth to bottom	Depth to top[2]	Depth to bottom	Depth to top	Depth to bottom
Uinta Formation		700		720		720
A groove	850	870	880	900	865	885
Mahogany zone	870	1,050	900	1,080	885	1,060
Mahogany marker	900±		936		935	
Mahogany bed	915±		950.5		950	
B groove	1,050	1,070	1,080	1,100	1,060	1,080
Leached zone	-	1,325	-	1,400	-	1,396
Blue marker	2,284		2,322		2,300	
Orange marker	2,453		2,485		2,465	
R-6	1,070	1,240	1,100	1,290	1,090	1,260
R-5	1,324	1,680	1,380	1,726	1,330	1,705
R-4	1,742	1,990	1,790	2,036	1,770	2,015
R-3	2,026	2,163	2,068	2,202	2,050	2,182
R-2	2,180	2,284	2,220	2,322	2,204	2,300
R-1	2,308	[3] 2,372	2,341	2,402	2,322	2,382
R-0	[3] 2,379	[3] 2,433	2,410	2,462	2,388	2,442

1) Depths in feet.

2) Depths from geophysical logs, L. G. Trudell, U.S. Energy Research and Development Administration, Laramie, Wyo.

3) Depth estimates projected from -01A.

4) Data obtained from S. Terry of U.S.G.S. Denver, and is preliminary.

to 2,280 ft.) was isolated and blown dry. Inflow to the section was 2-1/2 ft. of water in the 7-7/8 in. diameter hole in 4 hours. This computes to a maximum permeability of $2x10^{-9}$ cm/sec. or $4x10^{-6}$ ft./day. While the validity of this test can be questioned due to the introduction of grout into the hole to seal off the lower section of the hole, we feel that it probably represents a reasonable lower bound of permeability in this zone. We have, however, assumed a conservative value of $3x10^{-3}$ ft./day in Figure 2.

Other data obtained during drilling of the holes on the Site provide some secondary backup for the tests above, but have not, in general, been used in the present evaluation.

3.3 GEOHYDROLOGIC MODEL OF THE SITE

Based on this information, and on parameters typical of the Basin where test data is not available for the Site, the geohydrologic model shown in Figure 2 has been developed. It should be noted that some of the parameters are based on inadequate data; the degree of confidence for the various items of the figure is indicated. It is also assumed that the Site material is reasonably homogeneous, and that Figure 2 reflects the average geohydrologic properties of the Site. The testing performed is largely inadequate to determine the existence of a nearby fault or prolific water conduit at depth.

Figure 2 GEOHYDROLOGY MODEL OF SITE I

Geol. Unit	Feature Description	Elevation (Above M.S.L.)	Permeability		Drainable Porosity	Specific Storage ($ft.^{-1}$)
			Horizontal (ft./day)	Vertical (ft./day)		
Uinta Formation	Ground Surface	6225				
	Water Table	6100				
	Uinta Sandstone		0.89	0.03	0.10	3×10^{-7}
		5500				
GREEN RIVER FORMATION — Parachute Creek Member	Upper Parachute Cr. Member		5.71	0.03	0.01	3×10^{-7}
	A Groove	5350				
	Mahogany Marker	5300	1.74	0.009	0.01	3×10^{-7}
	B Groove	5150	0.53	0.003	0.025	3×10^{-7}
	Horizon X	4850				
	R-4 Zone	4450	0.003	0.0003	0.01	3×10^{-7}
		4200				
	Blue Marker	3925				
Garden Gulch Member	Orange Marker	3750	Assumed Functionally Impervious			

NOTES:

1. Geology based on USBM 01-A and USBM 02-A
2. Hydrology data primarily from USBM 01-A, USBM 02-A, and USBM pilot hole "X" testing.
3. All elevations rounded to nearest 25 feet.
4. Not to scale.
5. Quality of information for the purposes of this evaluation:
   - ▭ "Based on acceptable test data"
   - ▨ "Estimated or based on poor data"
   - ▩ "Experiential guess"
6. Available data indicates that this model is not valid at points 3 to 4 miles distance from Horse Draw. It should be used only with great caution, and with a complete understanding of the data upon which it is based.

CHAPTER 4
INFLOW ANALYSES

Three scenarios for inflow to a caved room are considered. They are shown on Figure 3, and comprise:

- Case A: Inflow due to a cave entirely within the saline zone, upward penetration almost to the base of the "lower aquifer".
- Case B: Inflow due to a cave which fully penetrates the saline zone and the lower aquifer, but which stops at the base of the Mahogany Zone.
- Case C: Inflow due to a cave which penetrates to the water table.

4.1 ASSUMPTIONS

In each analysis the following assumptions are made:

i. The caved "pipe" is assumed to have a constant cross-sectional area.

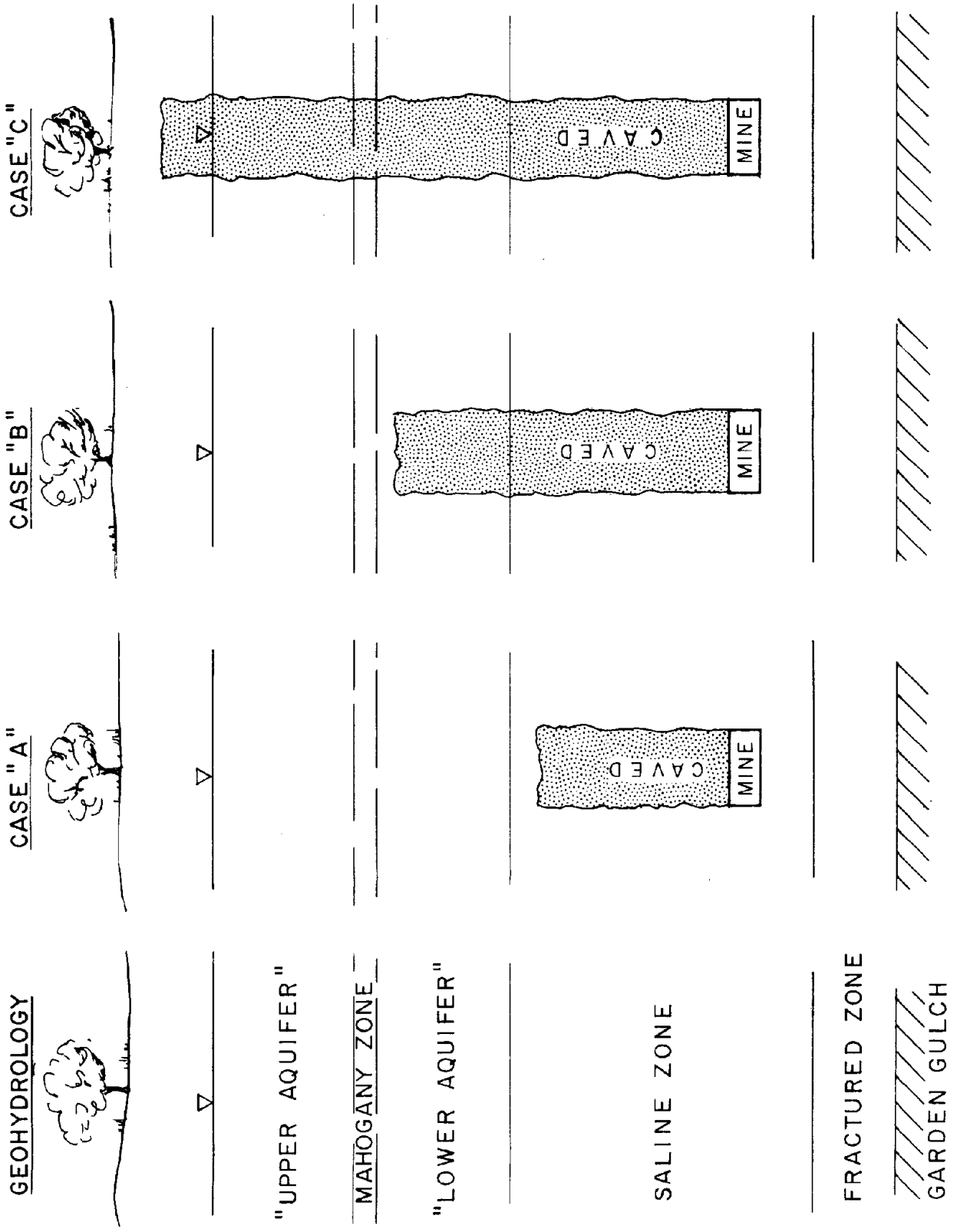
ii. The caved material is assumed to have a permeability of 30 ft./day (10^{-2} cm/sec.), which is equivalent to a highly fractured, disturbed rock.

iii. The mine is assumed to be at atmospheric pressure throughout.

iv. Geohydrology is assumed to be as shown in Figure 2.

v. Flow in all undisturbed strata is assumed to be substantially horizontal, and in the caved zone flow is assumed to be vertical.

Figure 3 CAVING CASES CONSIDERED IN ANALYSES



vi. Inflow to the uncaved mine is not considered in this analysis.

vii. The inflow due to drainage of the caved material is ignored, and caving is assumed to be instantaneous.

viii. The materials in each layer of the geohydrologic model are assumed to be homogeneous; that is free from large local defects, faults, or major water conduits.

The impact of these assumptions is discussed in Section 4.7 below.

4.2 METHOD OF ANALYSIS

The inflow system basically comprises horizontal flow through an "aquifer" to a caved pipe, and flow down the caved pipe into the mine. There is resistance to flow in the aquifer, and there is resistance to flow in the pipe. The sum of the resistances is equal to the head difference between the aquifer remote from the mine and the mine opening, except when the flow in the pipe is unsaturated. In this case only the resistance of the aquifer is effective.

In order to calculate the flow to the mine, the following limit cases were computed.

i. Flow from the aquifer to the caved pipe assuming that the pipe is unsaturated (i.e. is at atmospheric pressure). This defines the maximum flow to the pipe.

ii. Flow in the caved pipe assuming that it is just saturated. This defines the highest flow the pipe can take without reducing flow from the aquifer.

iii. Flow in the caved pipe assuming that all of the head loss takes place in the pipe and none in the aquifer. This defines the upper limit of flow in the pipe and defines the maximum flow possible in the system.

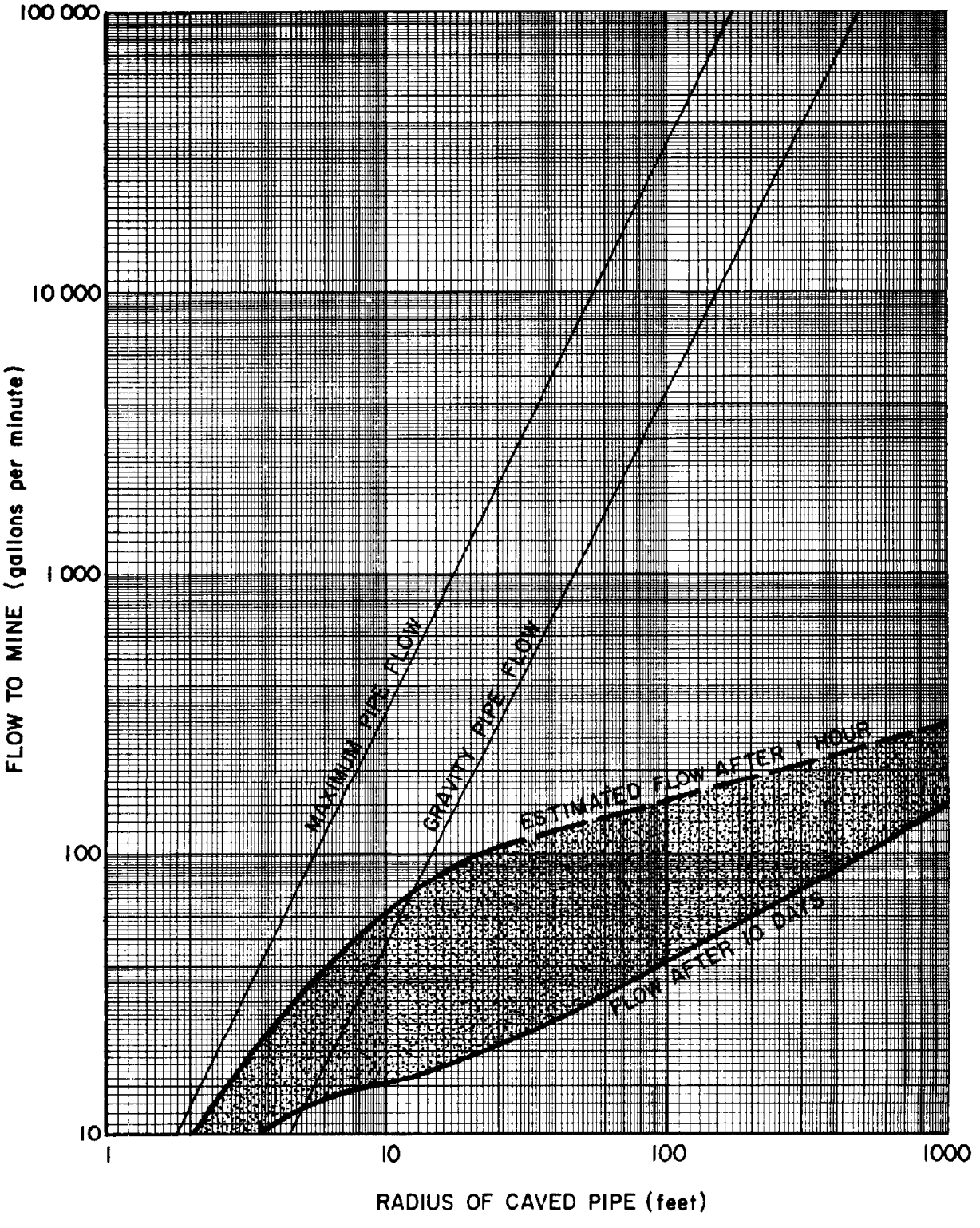
All cases were computed for a range of caved pipe radii, at a time of 1 hour after caving occurs (which approximates the maximum inrush) and for a time of 10 days after caving occurs (approximately steady state flow). Aquifer flows are computed from the standard constant-drawdown aquifer equations (Walton, 1972) and the flow in the caved pipe is computed from the standard Darcy flow equation.

4.3 CASE A - CAVE TO THE TOP OF THE SALINE ZONE

The results of the analysis of this inflow are presented in Figure 4. They are complicated by the very high flows which are computed for early times. After 1 hour, flows are almost certainly non-linear near the cave, and are also probably limited by drainage of water from the caved material. Accordingly, we have estimated the flows after 1 hour by assuming a limit hydraulic gradient around the cave of about 5 ft. of head drop per foot of radial distance.

Flows are relatively low, as should be expected. The flow is approximately proportional to the horizontal permeability assumed for the saline zone. If the value of 0.003 ft./day 10^{-6} cm/sec.) used is in fact conservatively high, then the inflows computed might also be several orders of magnitude too high.

Figure 4 FLOW TO MINE - CASE A



From Figure 4, flows at 150 ft. caving radius (which approximates the area of a 250 ft. square caved are) are 60 gpm at steady state and about 200 gpm at 1 hour.

4.4 CASE B - CAVE TO THE MAHOGANY ZONE

In this case the cave intersects the lower aquifer only. The computation treated the lower aquifer as a leaky confined aquifer, with leakage coming through the Mahogany Zone from the upper aquifer. In this case, flow is more controlled by the head losses in the conduit formed by the caved material.

From Figure 5, the results show that flows at 150 ft. caving radius are about 1,700 gpm at 10 days, and 2,800 gpm at 1 hour.

4.5 CASE C - CAVE TO THE SURFACE

Analysis for Case C involved assuming that the sandstone section of the upper aquifer was unconfined, and that the rest of the upper aquifer and the lower aquifer were confined. The results of the analysis are shown on Figure 6. The flows are even more influenced by the resistance to flow presented by the caved pipe.

For the maximum expected radius of 150 ft., flow after 10 days is computed to be 8,000 gpm, and after 1 hour flow is computed to be 12,000 gpm.

4.6 COMPARISON OF CASES

The three cases are presented on the same sheet (Figure 7) to allow comparison. A number of conclusions are evident:

Figure 5 FLOW TO MINE - CASE B

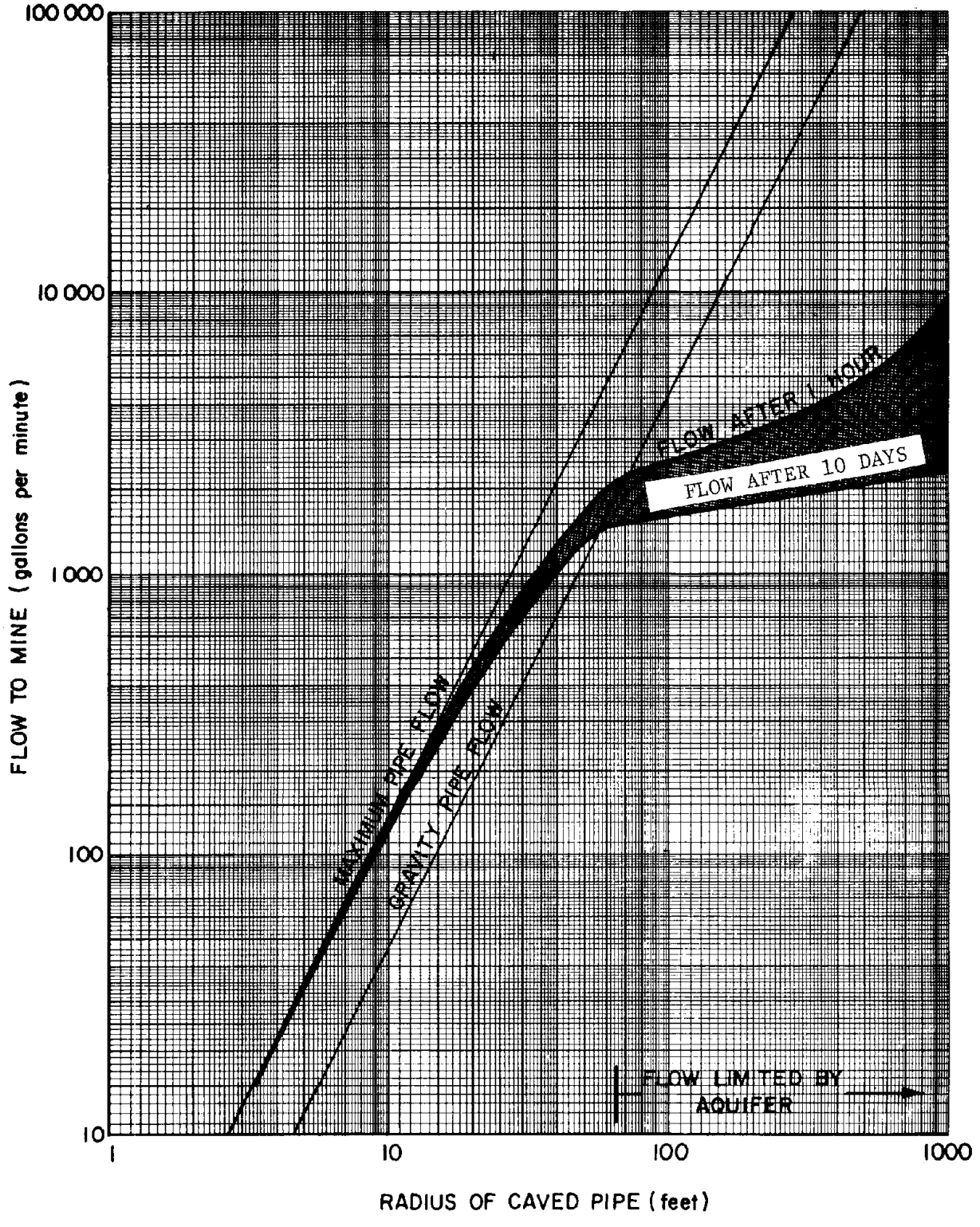


Figure 6 FLOW TO MINE - CASE C

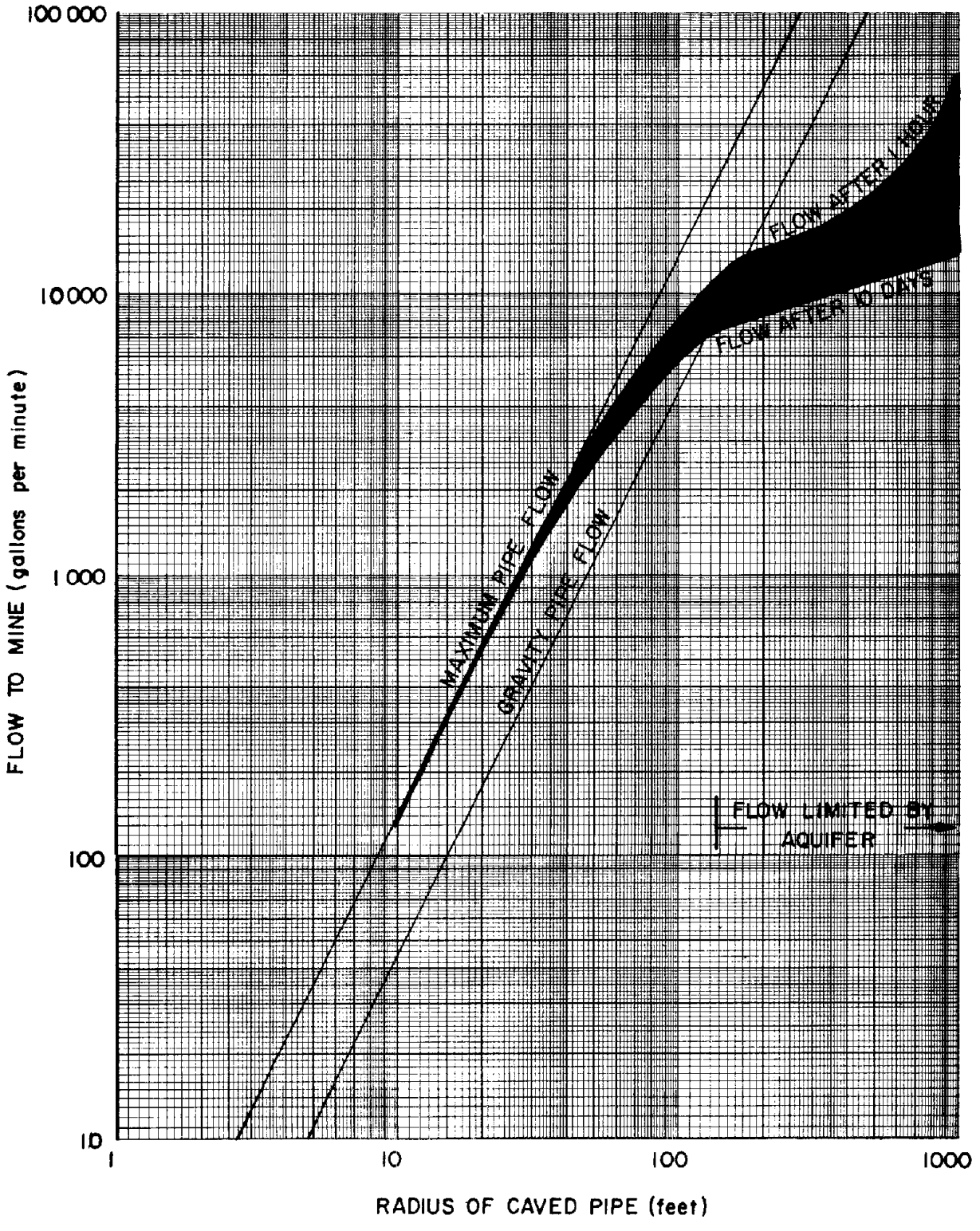
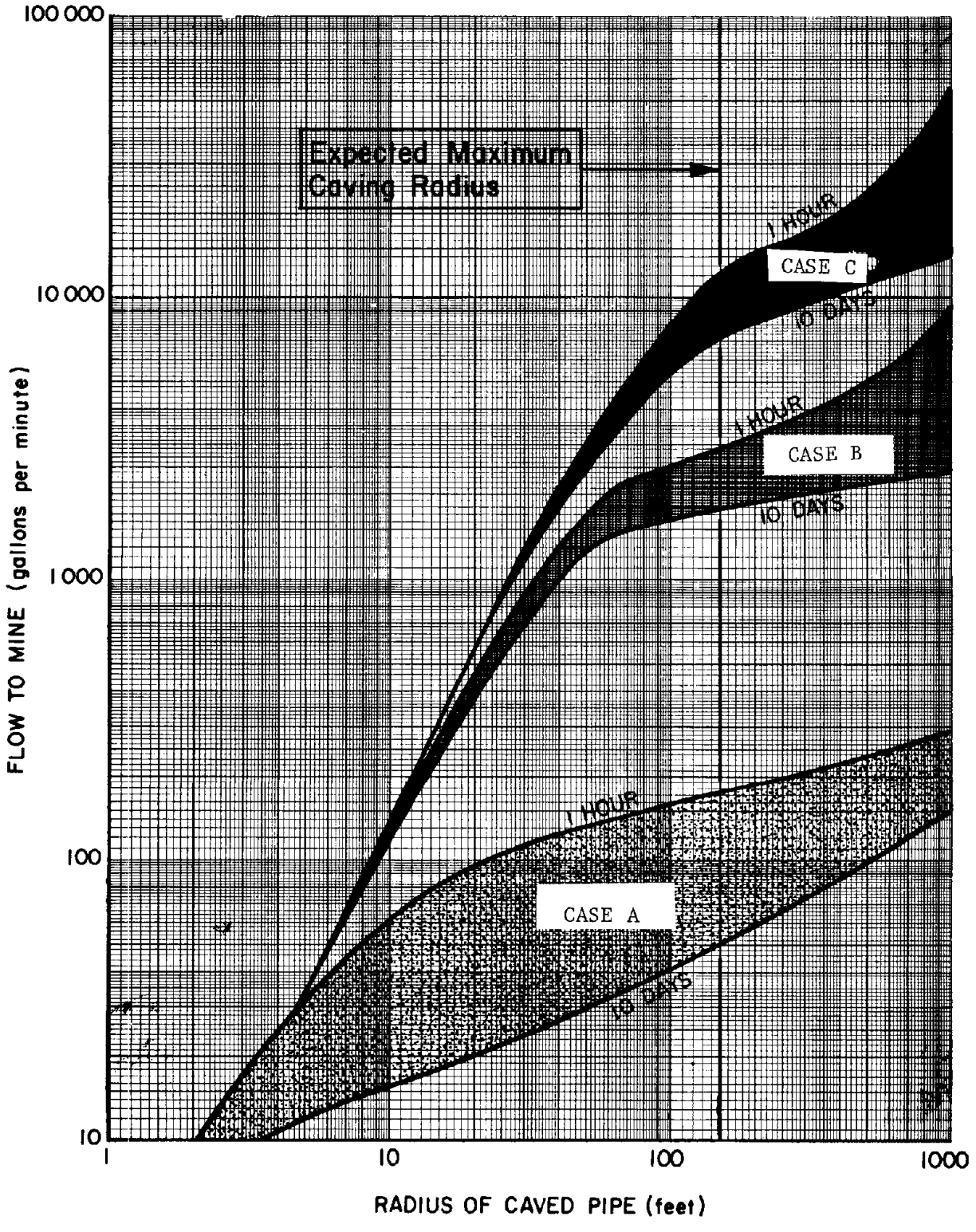


Figure 7 FLOW TO MINE - SUMMARY



i. There is about an order of magnitude difference between each case. Thus it would appear critical to control caving in the proposed demonstration mine.

ii. Flow rates, particularly early flow rates, are strongly influenced by the radius of the caved area. This factor is thus worthy of investigation in the proposed demonstration mine.

iii. Inrushes are about twice the rate of the steady-state post-caving flows. This suggests that emergency pump capacity can be reduced by the provision of water storage capacity in the proposed demonstration mine.

4.7 IMPORTANCE OF ASSUMPTIONS

Seven assumptions were listed in Section 4.1, and it is necessary to evaluate the importance of these assumptions in the final results.

i. Constant Area Caved Pipe. This assumption is not critical to the development of the results, provided a reasonable average area is used. If the area increased with distance above the mine, under an angle of draw mechanism, we would anticipate that the average permeability of the caved material would drop correspondingly. If the product of area and permeability remains sensibly constant for the caved zone, then the results will not be significantly affected by the constant area assumption.

ii. Caved Material Permeability. Flow conditions in the caved material are largely determined by the permeability of the caved material (subject to assumption i. above).

If the permeability were lower, this would reduce flows by moving the "maximum pipe flow" and "gravity pipe flow" lines of Figures 4, 5, and 6 to the right. The values obtained for "maximum flows" are determined by aquifer characteristics alone in the present study, and thus the only effect of changing caved permeability would be a reduction of computed inflow, if the caved permeability turned out to be lower than expected.

iii. Pressure in Mine. Assuming atmospheric pressure in the mine is considered conservative. The in-mine pressure could be raised by bulkheads, thus reducing inflow, but cannot be significantly lowered. This is a minor assumption.

iv. Geohydrology. The assumed geohydrology is critical in Case A, and relatively unimportant for Cases B and C. As these latter two cases are likely to define inrush design requirements, this assumption is not regarded as major. Parameters used in computing Cases B and C are regarded as being relatively reliable.

v. Direction of Flow. As it is expected that the vertical permeability of the site rock sequence will be several orders of magnitude less than the horizontal permeability, it is considered that this assumption is entirely realistic.

vi. Inflow to the Uncaved Mine. This was defined as being beyond the scope of this evaluation.

vii. Pore Water Drainage. The assumption that the effect of drainage of pore volume in the caved pipe can be ignored,

and the assumption that caving is instantaneous are both linked, and they are critical to the validity of the results.

There is a considerable amount of water contained in the caved material, if the porosities assumed in Figure 2 are valid. For a cave radius of 150 ft., the Case A caved material holds 2 million gallons, Case B holds 6 million gallons, and Case C holds 40 million gallons. These quantities depend upon the material porosities, which are basically guesses (Figure 2). Some authors have postulated very much lower porosities for rock (Snow, 1962), so that values of 0.01 percent or lower might be appropriate. If this were the case, clearly the volumes of water involved in even a large cave would be much smaller than the above.

The quantity of water which will flow into the mine through a 150 ft. radius cave under gravity flow (unit hydraulic gradient) when the permeability is 30 ft./day is 11,000 gpm. If this permeability, and the porosities given in Figure 2 are reasonably valid, then caving will have to proceed reasonably slowly if flows of this magnitude are to be avoided. Theoretically caving rates of only a few feet per hour could double Case A flows. Unfortunately caving rates in oil shale are unknown, so the value to be chosen is somewhat arbitrary. However, it should be noted that even rapid caving will not increase flows beyond the computed Case C maximum flow of 12,000 gpm. Thus, providing the mine can be made safe under this inflow condition, this assumption is not critical to the analysis.

viii. Homogeneity. If a major water-bearing conduit is encountered by the caving process, inflows will almost certainly exceed the values given in this report. The limited drilling information which is available at present does not allow any assessment of the likelihood of this occurring. However, discontinuities of this kind are not uncommon in other parts of the Basin, so it must be presumed that there is a finite risk that a discontinuity will be intersected by a major cave. It is assumed that a major exploration and instrumentation effort will be undertaken to evaluate this eventuality, prior to the experimental cave being initiated. Thus it is considered to be beyond the scope of this evaluation to include allowance of the effects of inhomogeneity of the rock materials which will be caved.

CHAPTER 5
CONCLUSIONS

A brief review of likely mine water inflows which would follow various degrees of caving from the USBM's proposed demonstration mine has been undertaken, by reviewing several case studies, and by computational methods. Although the available information on such parameters as cave propagation rate, post-caving material permeability, and in-situ rock porosity are largely lacking, the likely inflows have been realistically bracketed, with the following general results for predicted maximum flows:

i. Case A - cave extends to top of saline zone
   Predicted flows - after 1 hour: 200 gpm
   - after 10 days: 60 gpm

ii. Case B - cave extends to base of Mahogany Zone
   Predicted flows - after 1 hour: 2,800 gpm
   - after 10 days: 1,600 gpm

iii. Case C - cave extends to surface
   Predicted flows - after 1 hour: 12,000 gpm
   - after 10 days: 8,000 gpm

The analysis has a large number of inherent assumptions. Providing the value of 12,000 gpm is used as a design value for inflow, all except one assumption will not influence the validity of the result. The outstanding assumption is that no major water-bearing conduits are intersected by the induced cave. It is presumed that an exploratory program will be initiated prior to caving to define the likelihood of such an occurrence.

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EXHIBIT 1

Information on Block Caving in Oil Shale Provided by P.W. McKie, Superintendent of Cleveland-Cliffs Iron Company, Western Division, Rifle, Colorado, April 1977

BLOCK CAVING ANALYSIS

The block caving demonstration unit will be situated in the R4 zone and will affect the lower aquifer as caving progresses upward. To predict the hydrological conditions, that would be encountered during block caving operations, three cases were analyzed. The following assumptions were made:

1. Controlled drawing will be practiced throughout the demonstration, allowing only a minimal void to develop above the broken rock in the stope.

2. Effects associated with undercutting and ore withdrawal will be monitored from two levels above the cave and from surface holes drilled into the block.

A geotechnical model for the block caving analysis is shown in Figure 1. The three cases analyzed are discussed below, with respect to strata disturbance and hydrological effects.

A. Best Case: In this case, the cave will progress upward at a controlled rate until a pre-determined horizon is reached. Ore withdrawal will be stopped and this may halt the upward progress of the cave. Fractures will not propagate between the cave zone and the lower aquifer, thus restricting water inflow to the transmissivity of the undisturbed strata.

B. Expected Case: In this case, caving will progress at a controlled rate to a pre-determined horizon and then, ore withdrawal will

be stopped. However, upward fracturing above the block will continue as beds settle and approach equilibrium. Fracturing will mainly be vertical, caused by tensile failure of the strata, and may intersect the lower aquifer. The rate of advance of the fractures may be gradual and will depend on the extent of block caving activity. Vertical permeability due to fracturing of the R5 zone is expected to be small, since the core index for the zone is low. Figure 2 shows the expected effects resulting from the caving operation. Inflows from the lower aquifer may be quite limited.

C. Worst Case: Although ore withdrawal is controlled and an attempt is made to stop the caving action at a pre-determined horizon, the cave may continue upward to the lower aquifer. Once the aquifer is reached, the cave can be expected to progress through the zone at a rapid rate, possibly requiring less than a day, even though ore withdrawal has been stopped. The rapid caving would result in large inflows from the area of the aquifer directly above the demonstration unit. Subsequently, the horizontal permeability of the lower aquifer would result in a reduced, but constant, inflow into the mine.

P. W. McKie
Superintendent
April 1977