A Technical Report
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CONCEPTUAL MODELS OF INTERACTIONS OF MINING AND WATER RESOURCE SYSTEMS IN THE SOUTHEASTERN IDAHO PHOSPHATE FIELD

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A Thesis
Presented in Partial Fulfillment of the Requirement for the
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in the
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by

MICHAEL RAY CANNON
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CONCEPTUAL MODELS OF INTERACTIONS OF MINING AND WATER RESOURCE SYSTEMS IN THE SOUTHEASTERN IDAHO PHOSPHATE FIELD

ABSTRACT

by

Michael Ray Cannon

Complex water resource systems occur within the southeastern Idaho phosphate field. Environmental factors such as the geologic, topographic, hydrogeologic, chemical, and climatic characteristics of the area largely control the occurrence, movement and quality of these water resource systems. Mining operations have the potential to impact the water resource systems through alteration of the existing environmental characteristics. At certain mine sites the water resource systems have the potential to interfere with mining operations through mine pit flooding and through pit and waste dump stability problems. Potential hydrogeologic impacts from mining and potential hydrologic limitations to mining are often difficult to predict because of the many variables involved.

Hydrogeologic studies in the southeastern Idaho phosphate field show that there are definite relationships between geologic, topographic, hydrogeologic, and climatic factors and existing ground water flow systems. Analysis of existing mine sites shows that relationships exist between the water resource systems which occur at a mine site and the potential hydrologic impacts from mining. Hydrologic limitations to mining are also related to the water resource systems which occur at the mine site.

Ground water flow system theory and observed water resource systems relationships were used to develop conceptual models that identify water resource systems at mine sites and evaluate mine sites for potential hydrologic impacts and mining limitations. The conceptual models can be used for existing or proposed mine sites. The models are expected to yield highly reliable results when used as specified.

CHAPTER I

INTRODUCTION

Statement of the Problem

Southeastern Idaho encompasses a large portion of the western phosphate field. The Idaho phosphate deposits contain about 80 percent of the ore reserves of the western phosphate field, or about 35 percent of the United States reserves (U.S. Department of the Interior, U.S. Department of Agriculture, 1977). Phosphate ore is mined by open-pit methods along outcrops of the Meade Peak member of the Phosphoria Formation, where it has been exposed through folding, faulting, and erosion (fig. I-1).

Water resources within the phosphate field exist in complex ground water and surface water flow systems. These complex water resource systems have developed over geologic time, through the interaction of many environmental factors. Factors such as the geologic, topographic, hydrogeologic, chemical, and climatic characteristics of the area influence the occurrence, movement, and quality of the water resource systems.

Mining activities within the phosphate field alter the existing environmental characteristics and therefore will, or have the potential to, impact the water resource systems. The water resource systems also have the potential to hamper mining operations in certain areas through pit flooding and through pit and waste dump stability problems.

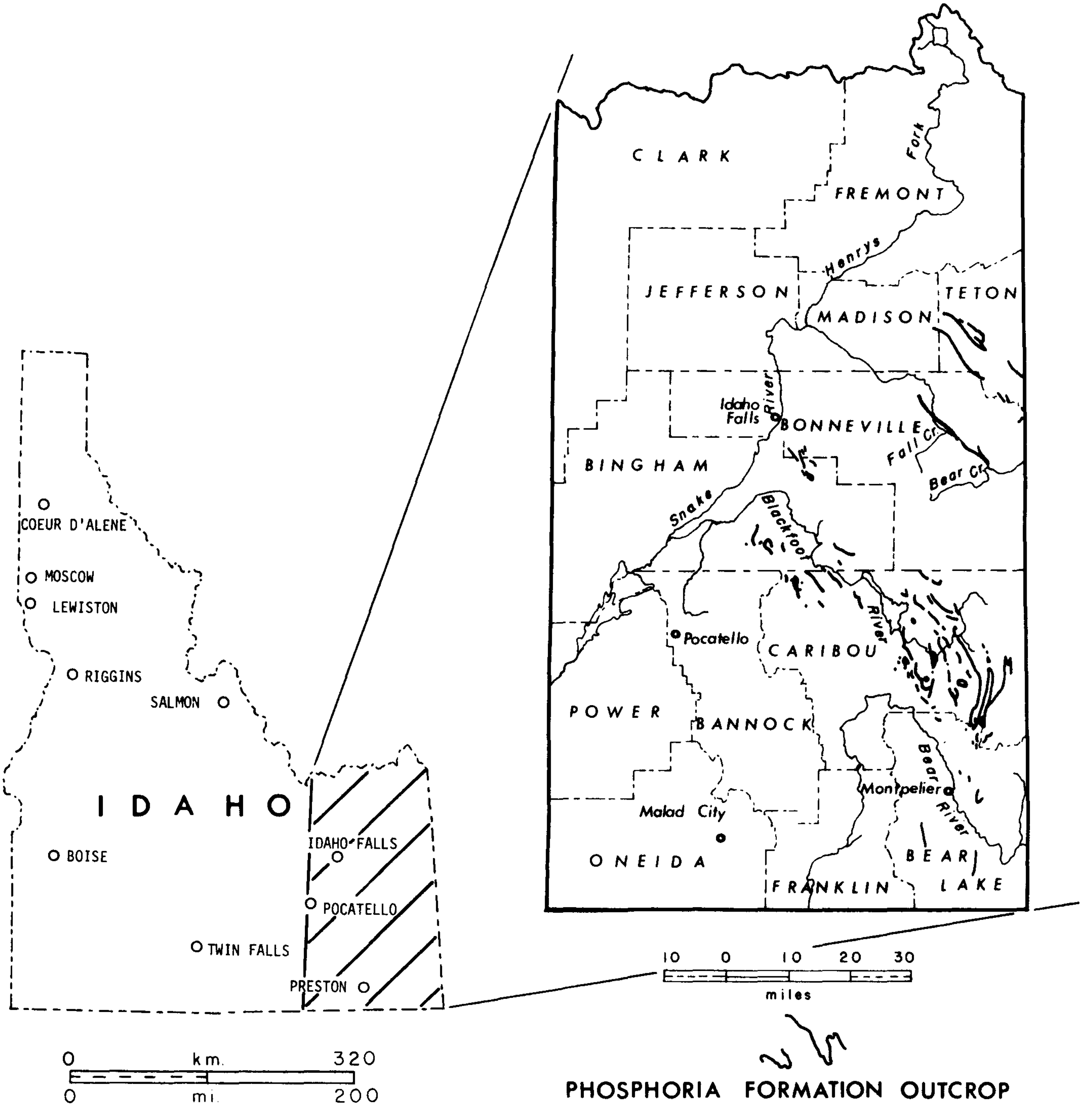


Figure I-1. Location of Phosphoria Formation outcrops in the southeastern Idaho phosphate field (after Ralston, et al., 1977).

Mining activities within the southeastern Idaho phosphate field are expected to greatly increase by the year 2000, through the expansion of existing mines and opening of new mines (U.S. Department of the Interior; U.S. Department of Agriculture, 1977). An expected future increase in mining activities increases the potential for impacts to the water resource systems. It is evident that a thorough understanding of the many interrelated factors which control the water resource systems is necessary before potential mining impacts can be predicted and assessed. A definite need exists for a systematic method of identifying water resource systems at mine sites and evaluating mine sites for potential hydrologic impacts.

Purpose and Objectives

The purpose of this study is to formulate conceptual models of water resource systems of the southeastern Idaho phosphate field that can be used to systematically identify water resource systems at mine sites and evaluate mine sites for potential hydrologic impacts. The conceptual models are to be based on ground water flow theory and on observations of existing flow systems and mining impacts. The models can be used to evaluate present and potential mining impacts on the water resource systems and also to predict potential limitations to mining imposed by the water resource systems. The evaluation method should be of benefit to both mining interests and resource administration.

Objectives of this study are to:

1. Present the basic flow system theory on which the models are based.

2. Identify and analyze the environmental and mining factors which control or affect water resource systems.
3. Identify potential impacts of phosphate mining on hydrologic systems.
4. Identify regional relationships between environmental factors and hydrologic systems development.
5. Identify site specific relationships between existing hydrologic systems, water resource impacts, and mining activities.
6. Use the regional hydrologic data, the site specific hydrologic data, and flow system theory to construct conceptual qualitative models of flow systems.
7. Demonstrate how the models can be used to systematically analyze a mine site for potential hydrologic impacts.

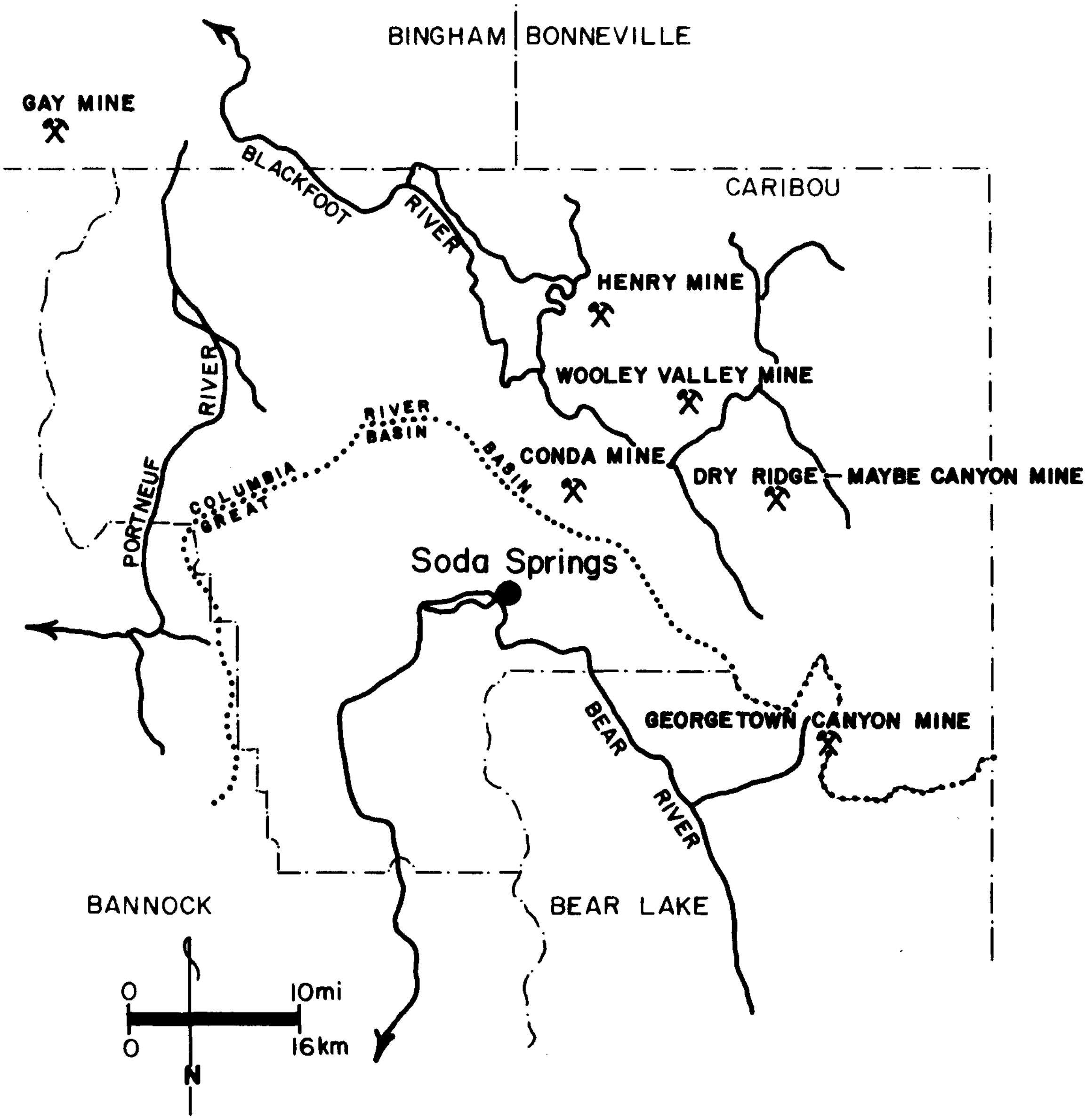
Description of the Phosphate Mining Region

Location

The area considered in this report includes portions of Bannock, Bingham, Caribou, and Bear Lake counties, with Caribou County occupying the largest portion of the study area. Four of the six mine sites examined in this study are located in Caribou County. They are the Henry Mine, Conda Mine, Wooley Valley Mine, and Dry Ridge-Maybe Canyon Mine (fig. I-2). Georgetown Canyon Mine is located in northeast Bear Lake County, and the Gay Mine is located in southern Bingham County near the northern border of Bannock County. Most of the study area is within the boundaries of the Caribou National Forest. The Gay Mine, in the northwestern portion of the study area, is located within the Fort Hall Indian Reservation.

Geographic Features

The study area lies within the Northern Rocky Mountain and the Basin and Range physiographic provinces. The Northern Rocky Mountain


BINGHAM
BONNEVILLE
GAY MINE
BLACKFOOT RIVER
CARIBOU
HENRY MINE
WOOLEY VALLEY MINE
PORTNEUF RIVER
RIVER BASIN
COLUMBIA GREAT
BASIN
CONDA MINE
DRY RIDGE – MAYBE CANYON MINE
Soda Springs
GEORGETOWN CANYON MINE
BEAR RIVER
BANNOCK
BEAR LAKE
0
10mi
0
16km
N

province is characterized by an almost continuous expanse of mountainous country with extensive mountain ranges and narrow valleys. Mountain ranges of the study area which are within the Northern Rocky Mountain province are the Preuss Range, Aspen Range, Webster Range, Wooley Range, Grays Range, and Caribou Range.

The Basin and Range province is characterized by isolated, subparallel mountain ranges that rise abruptly above desert plains. Isolated, nearly parallel mountain ranges, which are presumably fault blocks, are also distinctive of the province (Mansfield, 1927). Mountain ranges of the study area which lie within the Basin and Range province are the Portneuf Mountains, Chesterfield Range, and Blackfoot Mountains.

Principal drainage systems of the study area are the Blackfoot, Bear, and Portneuf rivers. The Blackfoot and Portneuf rivers drain into the Snake River to the northwest of the study area. The Bear River enters the area from the south and flows northward towards Soda Springs. Near Soda Springs, the Bear River turns and flows back to the south, eventually to the Great Salt Lake. The surface drainage divide between the Columbia River Basin and the Great Basin cuts through the area from east to west (fig. I-2).

Several important, major valleys and ridges occupy the central portion of the study area (fig. I-3). These ridge and valley systems trend predominantly northwest-southeast. Dry Ridge dominates the landscape and extends in a curving course southward, from the Blackfoot River, for a distance of nearly 27 miles.

Elevations in the study area range from a low of about 5200 feet in the Fort Hall Indian Reservation area to a high of 9957 feet at Meade

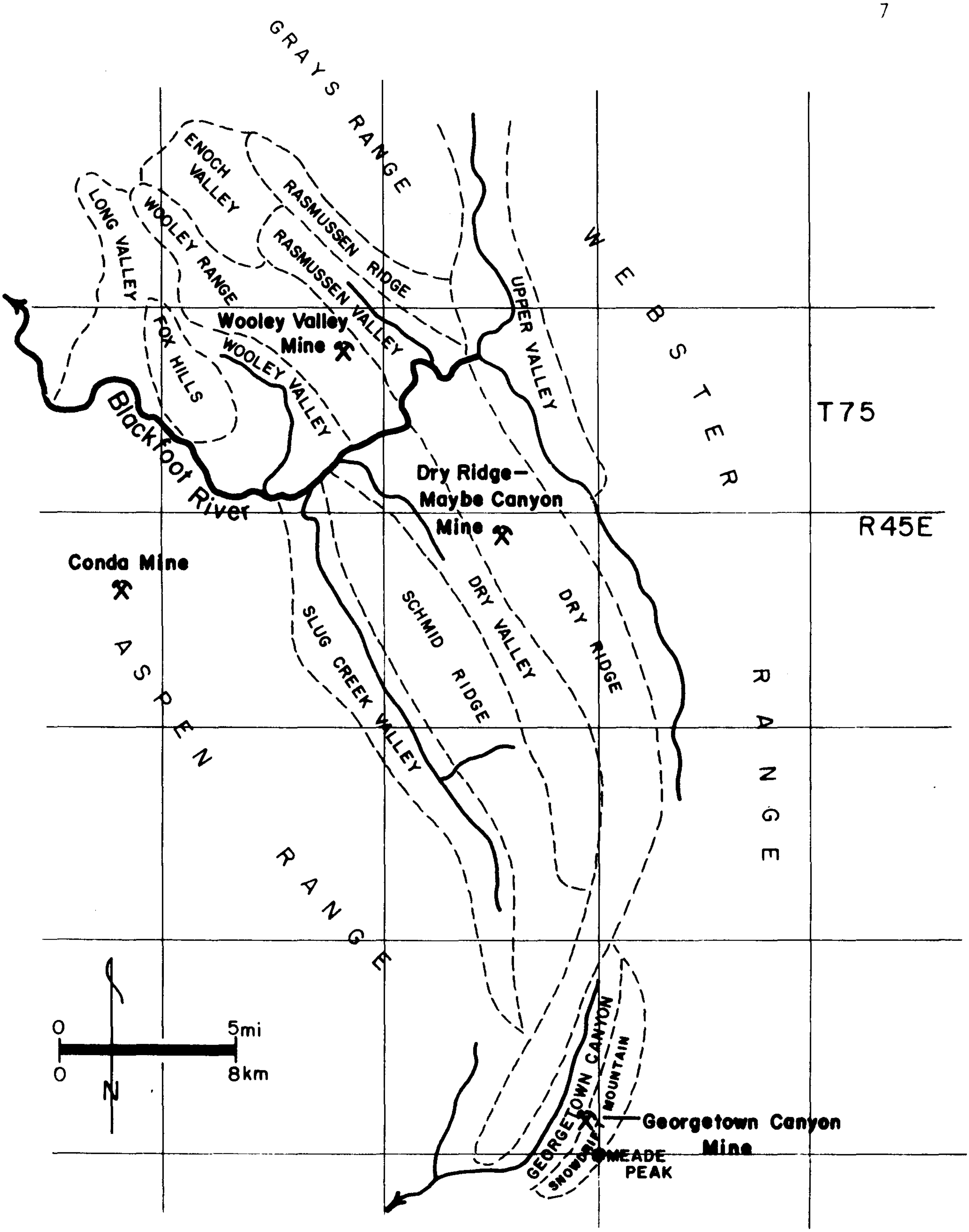


Figure I-3. Major ridge and valley systems in the central portion of the study area.

Peak, near the southern end of Snowdrift Mountain. Local relief is as much as 3,300 feet near Meade Peak and between 2,000 and 3,000 feet throughout much of the Preuss Range, but is only about 1,600 feet in the Aspen Range (Cressman, 1964). In the northwestern portion of the study area, local relief is generally less than 1,000 feet, where the ranges are lower and where lavas and volcanic ash have partially filled the valleys (U.S. Department of the Interior; U.S. Department of Agriculture, 1977).

Ridges and ranges in the study area are from 5 to nearly 40 miles long and from 1 to 10 miles wide. Elevations of ridge tops range from 7,000 feet to nearly 10,000 feet. The valleys as a rule are narrower and shorter than the ridges and range in altitude from about 5,800 to 7,500 feet.

Climate and Vegetation

Climatic conditions of the study area are dominated by a Pacific-Marine climate (U.S.D.A. Forest Service, 1978). Consequently, Pacific air masses somewhat moderate winter and summer temperatures. Occasionally, climatic conditions are influenced by Arctic air masses which may keep winter temperatures well below 0° F (-17.7°C) for several days.

Generally, summer months are characterized by warm to hot days and cool nights. Considerable diurnal ranges of temperature may result during periods of clear summer days and nights. Temperatures below freezing have been recorded for every month of the year at the weather station in Conda. Precipitation during the summer months is generally in the form of local thundershowers.

Average annual precipitation in the study area ranges from about 15 inches or less at the lower elevations, to more than 35 inches on the higher ridge tops. In the southern and eastern portions of the study area, an average of 54 percent of the annual precipitation falls between November 1 and April 30, mainly as snow (U.S.D.A. Forest Service, 1978, p. 57). Snow accumulations on the lee (northeast) side of ridges may create drifts up to 30 feet or more in depth.

Vegetation distribution in the region is controlled by climate, elevation, and slope aspect. Conifers and quaking aspen dominate at higher elevations and on north and east facing slopes. Lower and drier areas are dominated by sagebrush and grass type cover. Several species of short brush thrive on most slope aspects at lower elevations, and on south and west facing slopes at higher elevations (U.S.D.A. Forest Service, 1978). Wet and marshy areas typically support growths of grasses, sedges, willows, and cattails.

Geology

Rocks exposed in the study area range in age from Precambrian to Recent; however, the marine sedimentary rocks of Carboniferous, Permian and Triassic age are of primary importance to the phosphate mining industry. Phosphate ore is mined from the Meade Peak member of the Phosphoria Formation, which is of Permian age. The geologic section of pertinent formations of the study area is summarized in Table I-1.

Geology of the study area is extremely complex. The general northwest-southeast linear trend of the mountains and valleys can be attributed to major thrusting and deformation during the Laramide Orogeny of Cretaceous age. Structure of the study area is dominated by several

Table I-1. Geologic section.

Age	Formation Name	Unit Name	Symbol	Thickness (ft)	Thickness (m)	Description
Quaternary			Qal			Alluvium or colluvium
Quaternary or Tertiary	Basalt		Qtb	Varies		Olivine basalt
Tertiary	Salt Lake		Tsl			Light-gray fine-grained pebble conglomerate mostly chert and limestone
Upper Triassic	Higham Grit*1		Trh		200 to 250	Sandstone-conglomeratic, light-gray, pink, buff and pale green, medium to coarse grained
Lower Triassic	Thaynes	Timothy Sandstone Member	Trtt		200 to 250	Buff to gray and maroon sandstone
		Upper Part of Portneuf Limestone Member	Trtpv		250 to 300	Dark-gray and gray limestone, thin to thick bedded with yellowish-gray to yellowish-brown sandstone
Lower Triassic	Ankareh*1	Lanes Tongue	Tral		500	Red to reddish brown, very fine grained to fine grained, thin bedded sandstone
Lower Triassic	Thaynes	Lower Part Portneuf Limestone Member	Trtpl	300 to 400		Gray, finely crystalline, massive limestone and gray to yellowish-gray and fine grained sandstone
		Nodular Siltstone Member	Trtn	400		Olive to brownish-gray siltstone and shale, contains small dark-gray limestone nodules; interbedded with sandstone and limestone
		Black Shale Member	Trtb	300		Gray to black, fissile, hard platy shale; interbedded with thin dark-gray limestone and brownish-gray siltstone in lower part; a few thin bedded shaly and silty black limestone beds in upper part
		Platy Siltstone Member	Trts	650 to 750		Yellowish-brown to olive-gray, calcareous, thin bedded, platy siltstone; a few thin beds of shale and limestone
		Black Limestone Member	Trtl	550 to 800		Dark-gray to black shale and siltstone interbedded with dark-gray to black limestone over dark-gray

Table I-1. cont'd

Age	Formation Name	Unit Name	Symbol	Thickness		Description
				(ft)	(m)	
Lower Triassic (cont'd)	Thaynes (cont'd)	Black Limestone Member (cont'd)	Trtl (cont'd)	550 (cont'd)		to black limestone with a few thin beds of dark-gray shale over dark-gray to black shale and siltstone over gray limestone with Meekoceras ammonite zone at base
	Dinwoody[*2]	Upper Member	Trdu	700		Gray fossiliferous limestone interbedded with soft olive-brown calcareous siltstone, contains tongues of Woodside Formation as red siltstone or green and maroon shale
	Woodside		Trw	150		
	Dinwoody	Lower Member	Trdl	500 to 900		Olive-brown calcareous siltstone and shale with thin bedded limestone
Permian	Phosphoria	Cherty Shale Member[*3]	Ppc	170		Thin-bedded dark brown to black cherty mudstone, siliceous shale and argillaceous chert
		Rex Chert Member[*3]	Ppr	80		Thick-bedded black to white chert with some mudstone, some limestone lenses near top and bottom
		Meade Peak Phosphatic Shale Member	Ppm	100 to 200		Dark-brown to black mudstone, limestone, and phosphorite
	Park City	Grandeur Tongue[*4]	Ppg	100		Light-gray dolomite and cherty dolomite and minor amounts of sandstone
Permian and Pennsylvanian	Wells	Upper Member	PPwu	1000 to 1400		Light-gray to reddish-brown sandstone, some interbedded gray limestone and dolomite
Pennsylvanian		Lower Member	Pwl	500 to 950		Medium bedded gray cherty limestone, some interbedded sandstone
Mississippian	Monroe Canyon Limestone (also referred to as Brazer Limestone)		Mb	800 to 1600		Light-gray limestone with interbedded sandstone, occasionally with gray and green shale
	Madison Limestone (or Lodgepole Limestone)		Mn	1000		Dark-gray to black finely crystalline to aphanitic limestone in thin beds

Table I-1. cont'd

Note: *1 = Appear on geologic maps, not of importance to study.
*2 = Occasionally mapped as one unit (Trd).
*3 = Occasionally mapped as one unit.
*4 = Usually mapped as part of upper Wells.

(Armstrong, F., 1969, 2 plates; Cressman, E., 1964, 105 p.; Cressman, E. and Gulbrandsen, R., 1955, 18 p.; Gulbrandsen, R., and others, 1956, 23 p.; Lowell, W., 1952, 53 p.; Montgomery, K. and Cheney, T., 1967, 63 p.; Rioux, R., and others, 1975, 6 p.)

major northwest-southeast trending synclines, anticlines, and associated faults. Subsequent erosion formed many major valleys along anticlinal fold axes. Normal faulting of the region during late Tertiary and throughout the Quarternary further complicates the structure. Quarternary basalts blanket a portion of the study area and form the Blackfoot lava field in the vicinity of the Blackfoot Reservoir. Most valleys of the study area contain Quarternary deposits of colluvium and alluvium.

Previous Investigations

There have been several published reports concerning the geology and mineral resources of the southeastern Idaho phosphate field. One of the first and most comprehensive investigations of the area was conducted by Mansfield (1927). More recent geologic mapping and mineral resource studies have been conducted by several investigators. Cressman and Gulbrandsen (1955) mapped the Dry Valley quadrangle in detail. The Johnson Creek quadrangle, to the west of Dry Valley, was mapped by Gulbrandsen and others (1956). Cressman (1964) investigated the geology and mineral resources of the Georgetown Canyon-Snowdrift Mountain area. Montgomery and Cheney (1967) mapped the geology of the Stewart Flat quadrangle, located east of the Dry Valley area. The geology of the Gay Mine, in the Fort Hall Indian Reservation, has been studied by Lehman (1963).

A four volume environmental impact statement addressing most aspects of phosphate mining in southeastern Idaho has been prepared jointly by the U.S. Department of the Interior and the U.S. Department of Agriculture (1977).

Hydrologic investigations have been conducted at several sites within the southeastern Idaho phosphate field. Precipitation studies in Dry Valley and Little Long Valley were made by Ralston and Trihey (1975). Sylvester (1975) made a preliminary investigation of ground water in upper Dry Valley and in Little Long Valley. Mohammad (1977) made an evaluation of the present and potential impacts of open pit phosphate mining on the ground water resource systems in the southeastern Idaho phosphate field. Edwards (1977) investigated the hydrologic systems in Diamond Creek Valley, while Robinette (1977) delineated ground water flow systems in Lower Dry Valley. Vandell (1978) analyzed the hydrologic characteristics of the Phosphoria formation in Lower Dry Valley. These hydrologic studies were all part of a continuous research program at the University of Idaho. A completion report which summarizes these hydrologic investigations has been published through the College of Mines, University of Idaho, by Ralston and others (1977).

Present hydrogeologic investigations are being conducted at the Henry Mine by Brooks (1979) and at the Gay Mine by Corbet (1979). Winter (1979) is investigating the ground water flow systems and hydrologic characteristics of the phosphate sequence in Caribou County. A three-year study on snow accumulation and soil erosion in the phosphate mining region is being conducted by the Agricultural Engineering Department, Univerity of Idaho (Chacho, 1977, 1978).

CHAPTER II

A SYSTEMS MODELING APPROACH TO PHOSPHATE HYDROLOGY

Introduction to Systems and Modeling Concepts

The study of ground water hydrology includes analysis of the occurrence, movement, and quality of ground water. In the study of these hydrologic problems, the scientist makes the hypothesis that all processes and phenomena are interrelated and obey certain physical laws. This scientific approach to a hydrologic problem forces one to look at the problem as a whole or as a "system," rather than as a collection of unrelated parts. A ground water system is therefore concerned with ground water in its natural state and the interrelationships of parts which form the system. To help define a ground water system, Domenico (1972, p. 5) states "a more precise definition of a ground water system would take cognizance of the fact that hydrologists are concerned with the transport of matter, energy, and information, suggesting that a system is an interrelation of parts, which behaves according to some description and whose function is to operate on matter, energy, or information, or on any two or all three."

The systems approach to hydrologic problems gives the hydrologist a much better understanding of hydrologic phenomena and their underlying causes and relationships, than does the study of isolated hydrologic events. The use of a systems concept in ground water hydrology allows the hydrologist to predict changes to the hydrologic system, from specified stresses or inputs applied to the system.

Use of Systems Concepts

A systems concept in ground water hydrology can be used to help solve the hydrologic problems facing the phosphate mining industry in southeastern Idaho. Problems relating to ground water occurrence, movement, and quality are of primary concern to the phosphate mining industry. Hydrologic problems facing the mining industry include the occurrence of ground water in mine pits and waste dumps, the movement of ground water into or from the mine area, and water quality within the mine area. The occurrence of water within the mining pits is a definite problem because it interferes with mining operations, requires a method of dewatering the pits and disposing of the pumped water, and in some cases requires the abandonment of the pit with valuable ore reserves unrecovered. Ground water flow through the mine waste dumps may lead to stability problems in the waste dumps or problems of poor quality water leaching from the waste dumps.

Solutions to mine related hydrologic problems can best be achieved through an understanding of the hydrologic systems and their interrelationships with mining factors. The first step towards solving mine related hydrologic problems is to understand the many factors which control a hydrologic system. For example, a limestone formation might support a relatively large ground water flow where the limestone is areally extensive, has high hydraulic conductivity, and is favorably situated to capture large amounts of recharge. Obviously, if a mine pit were to penetrate this limestone formation near a ground water discharge area, pit flooding may result and dewatering of the pit could prove difficult. If the factors which control this ground water flow system are known and understood before the commencement of mining, the mining operation will know how much pit flooding can be expected and the mine plans can be designed accordingly.

Model Concepts

There are almost an unlimited number of physical environmental factors or variables which control the ground water and surface water flow systems within the southeastern Idaho phosphate field. Likewise, there are a myriad of man-made mining variables which act to modify these flow systems. Because the hydrologic systems or "water resource systems" in the phosphate field are so complex, it is necessary to operate with a simplification or model of the real situation.

A model of a water resource system should be based on all physical data available on the real system and on theoretical concepts. Ideally, a model should delineate all pertinent ground water flow systems, based on the controlling environmental factors. For instance, as in the example above, a model should delineate the large ground water flow system through the limestone formation because the environmental factors of high hydraulic conductivity, available recharge, and large areal extent are favorable to the existence of the flow system. In short, a model is a simplification of the real system, yet it should be able to delineate all pertinent flow systems, based upon the controlling environmental factors.

Mining variables can likewise be introduced into a model of a water resource system. A properly formulated model should react to these mining variables and show how the mining variables affect the system. When a model accurately represents a real hydrologic system, it should react to variable inputs in a predictable manner and should agree with observed field conditions. When a model is proven to give reliable results, it can be used to evaluate present and potential impacts of mining on the water resource system, and also limitations to mining imposed by the water resource system.

Theoretical Basis for System Models

Models of the water resource systems for the southeastern Idaho phosphate field must be based on both field observations and theoretical concepts. Field data for a water resource system model can be obtained through typical field investigations based on the principles of geology, hydrology, geophysics, and geochemistry. Theoretical concepts for a water resource system model must be obtained from literature on flow system theory. Theoretical concepts of ground water flow, when applied to observed field data, aid in the delineation of flow systems and give regularity, predictability, and wholeness to a system model.

Flow systems theory, which is based on the concepts of fluid potential theory, was first presented by Hubbert (1940). In this classical paper, Hubbert outlined in detail the theory of ground water motion. He demonstrated that the property of a fluid which determines the dynamic flow system at any point in that system is the mechanical energy of fluid per unit of mass, and referred to it as the "potential" of the fluid. Through his fluid potential concepts, Hubbert (1940) showed that a flow system is a region within saturated earth materials where there is a dynamic movement of ground water from a source (recharge area) to a sink (discharge area). Each water molecule which enters the flow system at the source has the potential to move towards the sink of the flow system. Hubbert's fluid potential concept as the driving force in a ground water flow system established the theoretical background necessary for a ground water flow system model that reliably portrays the flow pattern from source to sink.

Hubbert (1940, p. 801) quantified the property of fluid potential in the equation:

$$\phi = gz + \int_{P_0}^{P} \frac{dP}{\rho} + \frac{v^2}{2} \qquad (1)$$

where ϕ is the fluid potential or mechanical energy per unit of mass, g is the acceleration of gravity at the position of consideration, z is the altitude of the position of consideration, P_0 and P are limiting values of pressure over the interval considered, ρ is the density of fluid, and v is the velocity of the fluid. This equation may be simplified to:

$$\phi = gh \qquad (2)$$

based on the assumptions that ground water velocities are negligible and that water is essentially an incompressible fluid. In Equation (2), head (h) is the measure of potential energy per unit weight of fluid or:

$$h = z + \frac{P}{\rho g} \qquad (3)$$

Under conditions of constant gravity, Equation (2) may be rearranged to:

$$\frac{\phi}{g} = h \qquad (4)$$

Since fluid potential is the property of a fluid which determines the dynamic flow system at any point in that system, the measure of fluid potential of ground water is one of the most reliable measures of ground water flow. Equation (4) shows that the measure of fluid potential can be made through the measure of head. Head (h) is the quantity commonly approximated in the field by measurement of static water elevations in wells, or by the measurement of elevation of recharge or discharge areas of ground water.

It can be seen from Hubbert's work that the delineation of a ground water flow system includes locating the source of the system, the sink of the system, and reliably linking these parts of the system together by establishing a potential gradient from the source area to the sink area. Establishment of the potential gradient can be made through measurements of head at various points within the flow system. Mifflin (1968) adds that ideal delineation of flow systems should establish the boundaries between adjacent flow systems, depth of flow circulation, character of water at various positions in the system, and any other useful information concerning the flow system. Domenico (1972, p. 254) states "the delineation of such systems is the act of representing, portraying, or describing graphically or verbally the region of ground water flow and interrelated processes."

Flow System Models

To help understand the concepts of flow system models it is first necessary to define several terms commonly used in ground water flow system literature.

Recharge area. A recharge area is an area where the direction of ground water flow is away from the water table.

Discharge area. A discharge area is an area where the direction of ground water flow is toward the water table.

Ground water basin. A ground water basin is a three-dimensional closed system that contains the entire flow paths followed by all the water recharging the basin. The flow pattern within a given basin may be simple, involving only one recharge area and one discharge area, or complex, involving many (Freeze and Witherspoon, 1967).

Water table. The water table is considered to be an imaginary surface beneath ground level at which the absolute pressure is atmospheric. It is assumed to be the upper boundary of the saturated flow system (Freeze and Witherspoon, 1966).

Probably the most important work done on the theoretical aspects of ground water flow systems and models was conducted by Toth (1962, 1963) and by Freeze and Witherspoon (1966, 1967). The ground water flow system models presented by these investigators establishes the basis for the work presented in this paper on water resource systems in the southeastern Idaho phosphate field.

Toth (1963) outlined the theory by which ground water flow in small drainage basins can be analyzed. Toth recognized three distinct types of ground water flow systems that can occupy a basin (fig. II-1):

1. A local system has its recharge area at a topographic high and its discharge area at a topographic low adjacent to each other.
2. An intermediate system has one or more topographic highs and lows located between its recharge and discharge area.

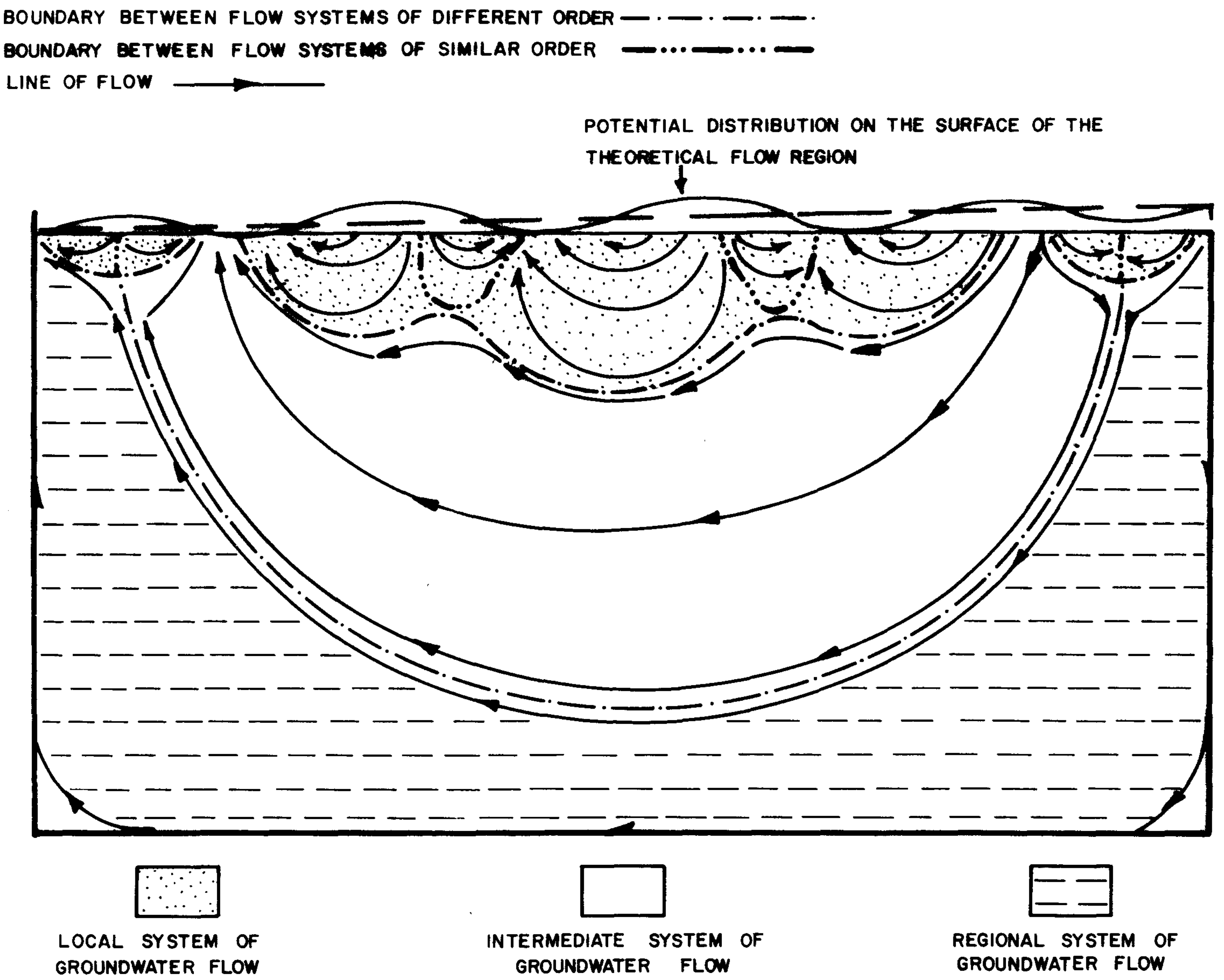


Figure II-1. Distribution of local, intermediate, and regional ground water flow systems in a homogeneous, isotropic basin (after Toth, 1963).

3. A regional system has its recharge area at the major topographic high and its discharge area at the bottom of the basin.

Factors which influence the development of these flow systems in a homogeneous, isotropic ground water basin include the slope of the basin, the amount of local topographic relief, and the depth to impermeable basement within the basin. Toth (1963) concluded from his study that these factors have the following effects on development of ground water flow systems:

1. If local relief is negligible, and there is a general slope of topography, only regional systems will develop.
2. If the topography has a well defined local relief, local flow systems originate. The greater the relief, the deeper are the local systems. Pronounced local relief suggests that no extensive, unconfined regional systems of flow can extend across valleys of large rivers or highly elevated watersheds.
3. A general increase in the slope of the valley flank will result in an increased lateral flow towards the bottom of the valley.
4. As a result of the local systems, alternating recharge and discharge areas are found across a valley. This means that the origins of waters obtained from closely located places may not even be related. Rapid changes in chemical quality may thus be expected.
5. Water levels at shallow depths (in local flow systems) are most affected by seasonal recharge or discharge.

Freeze and Witherspoon (1966, 1967) extended the work of Toth and developed flow system models for the more general conditions of interlayered strata of homogeneous, isotropic earth materials and also for nonhomogeneous, anisotropic conditions. From the flow system models and theory presented by Freeze and Witherspoon (1966, 1967), it is possible to construct a ground water flow system model for any basin for which the pertinent data are available. The models can be developed from mathematical solutions or qualitative models can be drawn based on flow system concepts. Data requirements for model development include (1) hydraulic conductivity distribution of the geologic units within the basin, (2) geometry of the basin including variations in topography and location of basin boundaries, and (3) configuration of the water table. Freeze and Witherspoon (1967, p. 634) cited the most important factors which affect steady-state regional ground water flow patterns within a nonhomogeneous, anisotropic basin are (1) the ratio of basin depth to lateral extent, (2) the configuration of the water table, and (3) the stratigraphy and resulting subsurface variations in permeability. They also concluded that:

1. The presence of a major valley will tend to concentrate discharge in the valley. Where the regional water table slope is uniform, the entire upland area is a recharge area. In hummocky terrain, numerous sub-basins will be superimposed on the regional system.
2. The presence of a buried aquifer of significant permeability will have a profound effect on regional ground water flow. It acts as a highway that transmits water to the principal discharge area and affects the magnitude and position of the recharge areas.
3. Stratigraphic pinchouts at depth can create recharge or discharge areas where they would not be anticipated on the basis of the water table configuration.
4. There is some depth in regions of reasonably horizontal sedimentation below which equipotential lines remain vertical.

Summary of Theoretical Modeling Concepts

The theoretical concepts of Hubbert (1940), Toth (1962, 1963), and Freeze and Witherspoon (1966, 1967) can be used to develop ground water flow system models for any basin for which the pertinent data are available. Models can be used to delineate ground water flow systems under steady-state conditions for either homogeneous earth materials or layered, nonhomogeneous anisotropic conditions. Flow system models can be developed mathematically (Freeze and Witherspoon, 1966) or qualitative models can be constructed based on theoretical flow system concepts. Data requirements for model development include (1) hydraulic conductivity distribution of the geologic units within the basin, (2) geometry of the basin including variations in topography and location of basin boundaries, and (3) configuration of the water table. The configuration of the water table is best determined by measurement of fluid potential (ϕ). Hubbert (1940) demonstrated that the measure of the fluid potential can be made through the measure of head (h). Head is commonly approximated in the field by measurement of static water elevations in wells and by the measurement of elevation of recharge and discharge areas.

Environmental Factors Which Affect Water Resource Systems

Water resource systems include both ground water and surface water flow systems. Ground water and surface water flow systems develop in the natural environment over geologic time. The flow systems indigenous to the phosphate field of southeastern Idaho are the result of the interaction of the many physical factors actively at work within the environment. These environmental factors include geologic, topographic, hydrogeologic, climatic, chemical, and biotic factors. Identification of these environmental factors and determination of their influence on flow system processes is important to the development of flow system models of the phosphate mining areas. Prediction of impacts of mining on water resource systems can only be accomplished if the relationships between environmental factors and flow system development are understood. For example, potential impacts of mining to a ground water flow system can only be predicted if it is known how changes in geologic, topographic, and hydrogeologic factors affect a ground water flow system, because mining alters these factors.

Geologic Factors

Geologic factors greatly influence the location and development of ground water and surface water flow systems. Some of the geologic factors which affect the development of flow systems are:

1. Areal extent and thickness of rock units. These factors influence the development of local, intermediate, or regional ground water flow systems. Thick, areally extensive rock units are sometimes conducive to the development of regional flow systems. Freeze and Witherspoon (1967) noted that one of the most important factors which affects steady-state regional ground water flow patterns is the ratio of basin depth to areal extent. They also noted that stratigraphic pinchouts at depth can create recharge or discharge areas where they would not be anticipated, based on water table configuration.

2. Dips of rock units. Dips of rock units control the location of outcrops and influence the direction of ground water flow paths.

3. Orientation of rock units relative to topography. The location of rock units relative to topography can affect the amount of ground water contained in the rock unit, the direction of flow within the rock unit, and the rate of ground water flow through the rock unit.

4. Folding of rock units. Folding controls the location of outcrops, and influences the direction of ground water flow paths.

5. Fracturing and faulting. These can create openings in rock that increase its storativity and allow ground water flow systems to develop.

6. Outcrop patterns. Outcrop patterns can influence the location of recharge and discharge areas.

Topographic Factors

Topographic factors influence the geometry of a basin and the development of local, intermediate, or regional flow systems. Some of the topographic factors which affect the development of flow systems are:

1. The regional slope of valley flanks within a basin. A general increase inthe slope of the valley flank will result in an increased lateral flow towards the bottom of the valley (Toth, 1963).
2. The amount of local relief. Local relief affects the development of local flow systems.
3. Relative size of basins. This can affect the size of flow systems that can develop.
4. Orientation of valleys and ridges. Orientation affects climatic conditions which in turn affect erosion, vegetation, snow accumulation, runoff, and recharge areas.

Hydrogeologic Factors

Hydrogeologic factors within a basin directly affect ground water flow rates, flow capacities of rock units, and location of major flow systems. Hydrogeologic factors include:

1. Relative hydraulic conductivities of rock units. The hydraulic conductivity distribution of geologic units within a basin is necessary for delineation of ground water flow systems. Flow models developed by Freeze and Witherspoon (1967) demonstrate that the relative hydraulic conductivity distribution is one of the most important factors controlling ground water flow systems.
2. Relative hydraulic conductivities parallel and perpendicular to bedding planes. This affects the preferred direction of flow and rate of flow within a rock unit.
3. Specific yield or storage of rock units. Storage values determine the amount of ground water contained in saturated materials. This value is especially pertinent in dewatering operations at mine sites.
4. Fluid potential within rock units. Fluid potential determines direction of ground water flow. Measurement of head is used to determine fluid potential at various points within a system.

Climatic Factors

Climatic factors include:

1. Precipitation. Precipitation in the form of rain and snow directly affects the availability of recharge in hydrologic systems. Temporal and spatial distributions of precipitation affect the timing of recharge events and the location of recharge and discharge areas.
2. Wind velocity and direction. These affect snow accumulation in winter.
3. Evaporation potential. This affects the amount of surface water removed from flow systems and lost to the atmosphere.

Chemical Factors

Chemical factors are of primary importance to water quality.

Chemical factors include:

1. Available nutrients, radioactive elements, and heavy metals in the rock, soil, and water.
2. Chemical stability of earth materials. The chemical stability of earth materials is of special concern to water qualtiy where water percolates through fractured waste rock as in mine waste piles.
3. pH balance betweeen ground water and earth materials. The pH value of ground water greatly affects its leaching capability.

Biotic Factors

Biotic factors include:

1. Vegetal cover. Vegetal cover aids in erosion control and helps maintain the quality of surface flow systems.
2. Transpiration potential of plants. This affects the amount of ground water and surface water removed from flow systems and lost to the atmosphere.
3. Storage capacity of vegetation. Vegetation storage directly affects surface water runoff rates and water available for recharge.

Mining Factors Which Affect Water Resource Systems

Mining activities alter or have the potential to alter the existing geology, topography, hydrogeology, biology, and chemical equilibrium within a basin. Changes to these factors will, in turn, affect the water resource system, based on the theory outlined in this section. Potential impacts to water resource systems include changes in the occurrence, movement, and quality of ground water and surface water flow systems. Mining factors which have the largest potential to affect water resource systems occur from the development of open pits and waste dumps. Pits and waste dumps have the greatest potential to affect water resource systems because they create the largest changes in geology, topography, and hydrogeology.

Open Pit Factors

Excavation of mine pits necessarily alters the geology and topography. Some factors of pit construction include:

1. Areal extent.
2. Depth.
3. Wall slopes.
4. Location relative to geologic structure.
5. Location relative to topography (Mohammad, 1977).

1. Areal extent.
2. Thickness.
3. Slopes of waste dump surfaces.
4. Hydraulic conductivity of waste rock.
5. Location relative to topography.
6. Location relative to geologic structure.
7. Chemical stability of waste rock to leaching (Mohammad, 1977).

CHAPTER III

POTENTIAL IMPACTS OF PHOSPHATE MINING ON WATER RESOURCE SYSTEMS

Introduction

The purpose of this chapter is to describe the major potential impacts of mining on the water resources and to identify some of their underlying causes and relationships. Causes and relationships of the hydrologic impacts are stressed in order to emphasize the system concepts involved. To predict impacts of mining on water resource systems, under specified conditions, these relationships between system parts must be understood.

A complete description of all potential mining impacts on the water resources is not given in this chapter because adequate publications already exist on this subject. Two of these publications are (1) the final environmental impact statement, "Development of Phosphate Resources in Southeastern Idaho," by the U.S. Department of Interior and U.S. Department of Agriculture (1977) and (2) a University of Idaho Ph.D. dissertation on "Evaluation of Present and Potential Impacts of Open Pit Phosphate Mining on Groundwater Resource Systems in the Southeastern Idaho Phosphate Field" (Mohammad, 1977). The report by Mohammad (1977) investigated in detail the many existing and potential impacts on ground water created by pits and waste dumps. The factors which create the impacts are also identified by Mohammad.

General Analysis of Potential Impacts

Phosphate mining operations in southeastern Idaho have the potential to impact the ground water and surface water resources. Investigations conducted by Mohammad (1977) indicate that phosphate mining impacts on ground water flow systems may include changes in recharge, discharge, storage, water quality, and flow patterns. The greatest potential impacts to surface water resources are changes in flow patterns and water quality.

Investigations at several mine sites in the study area indicated that excavation of open pits and construction of waste dumps are the most influencing factors leading to water resource impacts (Mohammad, 1977). Open pits and waste dumps have the greatest potential to affect water resources because they create the largest changes in the existing geology, topography, hydrogeology, vegetal cover, and chemical equilibrium of the mine site. Some of the potential hydrologic impacts from mining activities are presented in Table III-1.

Water Quality

Surface Water

Increased concentration of suspended sediments in surface waters is potentially the greatest water quality problem from mining operations in the study area (U.S. Dept. of Interior; U.S. Dept. of Agriculture, 1977). Increased sediments are due to increased erosion on lands disturbed by mining. Removal of protective vegetal cover and alteration of existing topography make the land vulnerable to erosion, especially in areas of heavy precipitation and rapid surface runoff. Waste dump areas are particularly vulnerable to erosion.

Table III-1. Potential hydrologic impacts from mining activities.

X Designates Variable Interaction POTENTIAL HYDROLOGIC IMPACTS MINING ACTIVITY FACTORS	Exploration Phase			Construction Phase						Operation Phase						Reclamation Phase			
	Exploratory Drilling	Access Road Construction and Vehicular Travel	Ore Sampling	Haul and Access Road Construction	Parking Lots	Stockpile Areas	Equipment Yards	Ore Processing Areas	Haulage Areas	Overburden Removal	Ore Removal	Ore Storage Areas	Waste Dump Construction	Surface Water Diversions	Pit Dewatering	Grading of Waste Dumps	Revegetation of Waste Dumps	Backfilling of Pits	Removal of Surface Water Diversions
I. Water Quality Degradation																			
A. Surface Water																			
1. Increased Suspended Sediments Concentrations		X	X	X	X	X	X	X	X	X	X	X	X	X		X			X
2. Increased Nutrient Concentrations						X						X	X						
3. Increased Heavy Metals Concentrations						X						X	X						
B. Ground Water																			
1. Increased Nutrient Concentrations						X						X	X					X	
2. Increased Heavy Metals Concentrations						X						X	X					X	
3. Increased Total Dissolved Solids						X						X	X					X	
II. Quantitative Alterations																			
A. Surface Water																			
1. Spatial Alterations in Seep, Spring, and Stream Flows					X					X	X		X	X	X				X
2. Temporal Alterations in Seep, Spring, and Stream Flows										X	X		X		X				
3. Alteration of Surface Water to Ground Water or Ground Water to Surface Water Flows	X				X					X	X		X	X	X	X	X	X	X
4. Increased Erosional Capabilities, Channel Scouring		X		X	X	X				X	X	X	X	X					X
B. Ground Water																			
1. Alteration of Ground Water to Surface Water or Surface Water to Ground Water Flows	X				X					X	X		X	X	X	X	X	X	X
2. Creation of New Flow Paths	X					X				X	X	X	X		X	X		X	
3. Alteration of Quantity, Rate, and Direction of Ground Water Flow	X									X	X		X	X	X			X	X

Increased concentrations of nutrients, radioactive elements, trace elements, and heavy metals could be produced under certain conditions. The phosphate-bearing sediments contain the trace elements arsenic, cadmium, chromium, copper, lead, molybdenum, selenium, vanadium, and zinc, and the radioactive elements uranium and radium. Nutrients of nitrogen and phosphorous are also found within the sediments. It appears, however, that natural factors tend to prevent toxic elements and nutrients from dissolving to form high concentrations in the water. The presence of large amounts of carbonate materials associated with the Phosphoria sediments generally maintains a water pH in the range of approximately 6 to 8 (U.S. Dept. of Interior; U.S. Dept. of Agriculture, 1977). In this range, many trace elements exhibit their minimum solubility.

Ground Water

Ground water quality may be altered due to mining operations. Increased concentrations of nutrients, radioactive elements, and trace elements could be produced under certain conditions. It is not known how far these contaminants could travel in a particular ground water flow system. However, concentrations of these contaminants would probably decrease with an increase in distance from the source area, through adsorption of ions by sediments, by dispersion, and by pH control from carbonate materials.

Changes in Flow Patterns

Mining operations have the potential to alter both ground water and surface water flow patterns. Changes may include creation of new flow systems, destruction of existing flow systems, displacement of existing flow systems, and alteration of surface water to ground water flows or ground water to surface water flow relationships.

Waste dumps have the potential to create local ground water and surface water flow systems where recharge is available to the waste dump. Recharge to a waste dump, from precipitation or flow interception, may percolate through the waste and exit at the toe of the dump in the form of seeps or springs.

Mine pits can convert surface water flow to ground water flow where they intercept streams or other surface water. The surface water captured by the pit may infiltrate and form a ground water flow system, and/or it may be lost through evapotranspiration. Likewise, pits can intercept ground water flow systems and through pit dewatering processes, the water may end up as surface flow. Pit dewatering may lower local ground water levels, thereby affecting spring and streamflows.

The number of combinations of potential impacts to ground water and surface water flow patterns is almost infinite. To effectively minimize these impacts it is most important to understand the underlying causes and the relationships between impact-producing factors.

Causes and Relationships

All mine related impacts on the water resource systems are the result of alterations to the existing natural environment. Before influence by man, hydrologic systems are in dynamic equilibrium with the many physical factors controlling them. When these physical factors are changed, the dynamic equilibrium is temporarily upset and impacts to the hydrologic systems result. (In this context, the term impact means a change to the hydrologic system, and it carries no qualitative connotation such as good or bad.) Each type of impact on a hydrologic system is the result of a specific combination of factors. If it is understood which combination of factors leads to a particular hydrologic impact, then it is possible to design a mine site which minimizes any potentially harmful impacts.

For example, a mine waste dump has the potential to (1) increase the sediment load of nearby surface waters, (2) increase the trace element and nutrient concentrations of surface and ground waters, and (3) change the flow patterns of surface and ground water. These are definite impacts to the water resources which may or may not be harmful to the environment. If resource administration agencies determine that a given level of sediment load is a harmful impact to the water resources, steps can be taken which mitigate the factors producing erosion. Obviously, one of the major factors is the availability of water to the waste dump, since without water there would be no hydrologic impact. Water may be available to the waste dump from either precipitation, surface water discharge onto the waste dump, ground water discharge onto the waste dump, or a combination of these. The rate of water availability to the waste dump affects runoff and erosion rates. A second major factor affecting erosion is the topography of the waste dump. Topographic features include the steepness and configuration of slopes. Other major factors relating to erosion are vegetal cover, geologic characteristics of the waste rock, and the hydrogeologic characteristics of the waste rock. To minimize sediment concentrations from erosion, runoff rates are controlled with vegetation, contouring of slopes, and control of water to the waste dump area. If leaching of trace elements and waste dump stability are not problems, surface runoff rates can be controlled further by inducing infiltration into the waste dump through the control of waste dump topography and hydraulic conductivity.

This is a rather simple example of minimizing water resource impacts through the control of producing factors, but the same logic can be applied to more complex problems. When analyzing complex hydrologic problems, it is important to realize the relationships between water resource system impacts and the factors which produce the impacts. Knowledge of these relationships can be used to minimize the detrimental hydrologic impacts at existing mine sites and to predict impacts at future mine sites.

The potential for increased concentrations of trace elements and nutrients in surface and ground waters is a fairly complex example of a hydrologic impact from a waste dump. Again, the availability of water to the waste dump is a major factor in leaching of trace elements and nutrients from the waste. The time of contact between the water and the waste rock also determines the amount and types of materials leached from the waste dump. Furthermore, the time of contact between the water and waste rock is controlled by the length, width, thickness, and hydraulic conductivity of the waste dump and by the fluid potential gradient within the waste dump. Efforts aimed at minimizing the amount of water flow through the waste dump and/or minimizing the travel time for water through the waste act to decrease the potential for leaching of trace elements and nutrients.

CHAPTER IV

WATER RESOURCE SYSTEMS OF THE PHOSPHATE STUDY AREA

Introduction

Previous hydrogeologic investigations conducted in Little Long Valley, Lower Dry Valley, and Diamond Creek Valley have suggested that definite relationships exist between geologic formation type and ground water flow systems. In each of these areas it was found that the Thaynes and Dinwoody formations support significant ground water flow systems. It was also determined that the Phosphoria Formation does not support any major ground water flow systems but the underlying Wells Formation does support such flow systems (Ralston et al., 1977). A comprehensive hydrogeologic study conducted by Winter (1979) further demonstrated that definite relationships exist between ground water flow systems and geologic formation type. Winter's study analyzed many spring locations and stream flows in eastern Caribou County. Winter (1979) concluded from his study that the "Phosphate Sequence" of sedimentary rock units (Dinwoody Formation, Phosphoria Formation, and Wells Formation) exhibit similar hydrogeologic properties over a large area. He also concluded that those formations which occur above the Meade Peak Member of the Phosphoria Formation support local and intermediate ground water flow systems while those formations below it support regional type ground water flow systems.

Similarities in geologic, topographic, hydrogeologic, and climatic factors of the study area and their relationships with flow systems are discussed in this chapter. It will be shown that definite surface water and ground water flow systems have developed in the study area due to the influence of these factors.

Factors of Flow System Development within the Region

Geology and Hydrogeology

The sedimentary sequence of the Dinwoody, Phosphoria, and Wells formations forms the basic stratigraphic sequence at all mine sites within the study area. These sedimentary rock units, together with the unconsolidated deposits of colluvium and alluvium, form the most important geologic units of the study area, with respect to water resource systems at mine sites.

Dinwoody Formation. The Dinwoody Formation of Triassic age (Trd) consists of an upper member (Trdu) and a lower member (Trdl). Both members of the Dinwoody Formation act as aquifers in the study area and support major ground water flow systems. The upper and lower Dinwoody formations are classified as aquifers based on their ability to intercept recharge, transmit ground water, and discharge ground water to adjacent geologic formations or to springs and other surface water bodies. Winter (1979) was able to identify 25 springs discharging from the Dinwoody Formation in eastern Caribou County. Of these 25 springs, 20 were discharging from the lower member. Cressman (1964) noted that many small springs issue at the contact of the Dinwoody and Phosphoria formations on both flanks of the Georgetown and Webster synclines. Stream gain-loss studies conducted by Winter (1979) show that on most streams measured, stream flows increased across exposures of the Dinwoody Formation due to ground water discharge into the stream. Hydrogeologic investigations suggest that both members of the Dinwoody Formation will support ground water flow systems throughout the study area, provided that recharge is available to the formation.

Phosphoria Formation. The Phosphoria Formation of Permian age (Pp) consists of the cherty shale member (Ppc), the Rex Chert Member (Ppr), and the Meade Peak Phosphatic Shale Member (Ppm). For the purpose of this study, the cherty shale member is considered to be a portion of the Rex Chert Member. The Rex Chert Member of the Phosphoria Formation generally has a very low hydraulic conductivity except where it has been significantly altered by fracturing and jointing. Aquifer tests conducted in Lower Dry Valley by Vandell (1978) demonstrated that highly fractured zones within the Rex Chert can support ground water flow, but these zones are discontinuous localized features that are not widespread and not characteristic of ground water flow conditions throughout Lower Dry Valley. From spring analysis and stream gain-loss studies, Winter (1979) concluded that the Rex Chert Member and the Meade Peak Member of the Phosphoria Formation do not support any major ground water flow systems in eastern Caribou County. His conclusion was based on the limited number and size of springs that can be found which discharge from the Phosphoria Formation. Stream flows generally do not gain or lose across exposures of the Phosphoria Formation due to the low hydraulic conductivity of the formation. Further evidence to suggest that the Phosphoria Formation does not support any major ground water flow systems in the study area can be found in the hydrogeologic studies in

Little Long Valley (Mohammad, 1977), Lower Dry Valley (Robinette, 1977), and Diamond Creek Valley (Edwards, 1977). No measurable springs were found to issue directly from either the Rex Chert or Meade Peak members of the Phosphoria Formation in any of these study areas.

Wells Formation. The Wells Formation of Pennsylvanian age (PPw) is divided into an upper member (PPwu) and a lower member (PPwl). Both members of the Wells Formation support major ground water flow systems in the study area. Sections of the Wells Formation exhibit high hydraulic conductivity and readily accept recharge. Stream gain-loss measurements made by Winter (1979) showed that stream flow was always lost to some degree, if not entirely, when streams crossed exposures of the upper member of the Wells Formation. Winter located several springs which issue from the upper and lower members of the Wells Formation.

Several large springs in the study area issue from the Wells Formation or from the underlying Brazer Limestone (Mb). Formation Springs in sections 27 and 28 of T8S R42E and Woodall Springs in sections 27 and 34 of T7S R42E are large tufa-depositing springs which appear to originate from the Wells Formation. Both springs appear to be fault controlled and both are located on the western flank of the Aspen Range. The location of Woodall Spring is most likely controlled by a large fault zone and associated basaltic dike mapped by Mansfield (1927). Flows of Woodall Spring and Formation Spring were measured by the U.S. Geological Survey during the summer of 1923. At this time, the flow of Woodall Spring averaged 26 cubic feet per second (cfs) and Formation Spring averaged 25 cfs (Mansfield, 1927). These springs have relatively constant discharge, suggesting that discharge is from regional ground water flow systems.

Other large springs which originate from the Wells Formation are located at the lower end of the Blackfoot River Reservoir in sections 31 and 32 of T4S R41E. These springs appear to be fault controlled. Directly upslope from these springs, on the south slope of Wilson Ridge, there is a large sink hole in the Wells Limestone and overlying colluvium. The sinkhole is approximately 40 feet in diameter and 80 feet deep with vertical walls. Water stands in the bottom of the sink hole.

Queedup Spring in the Gay Mine area is another relatively large spring that issues from the Wells Formation. Water from Queedup Spring is warm and somewhat mineralized. Several warm mineralized springs discharge from the Wells Formation into the lower Little Blackfoot River near Henry, Idaho. Warm mineralized water is often characteristic of spring discharge from the Wells Formation.

<u>Alluvium and Colluvium</u>. Quarternary deposits of colluvium (Qc) and alluvium (Qal) support ground water flow systems in the study area. Valley fill alluvium consisting of gravel, sand, silt, and clay constitutes many important aquifers. Major valleys such as Upper Valley, Blackfoot River Valley, Dry Valley, Slug Creek Valley, and Georgetown Canyon, and many other smaller valleys, contain aquifers within alluvium which play important roles in ground water-surface water relationships. Major springs which contribute to surface water flow issue from alluvium in Upper Valley, Slug Creek Valley, and Georgetown Canyon. Unconsolidated colluvial materials support many small springs and seeps throughout the study area.

<u>Hydraulic Conductivity</u>. Limited tests have been made in the study area to measure the hydraulic conductivities of various geologic

formations. Tests conducted in Dry Valley, Little Long Valley, and Diamond Creek Valley are summarized in table IV-1. From the table it can be seen that the highest hydraulic conductivity was measured in a fractured section of the Rex Chert Member of the Phosphoria Formation. This test was conducted in Lower Dry Valley by Vandell (1978), and it was concluded that the high hydraulic conductivity zone was localized and was not characteristic of flow conditions in Lower Dry Valley. The most important information gained by the hydraulic conductivity tests is the consistently low hydraulic conductivity of the Meade Peak Member of the Phosphoria Formation. The Meade Peak Member uniformly exhibits a low hydraulic conductivity over a large area as shown by the spring analysis and stream gain-loss studies of Winter (1979).

Relative hydraulic conductivity of geologic units in the study area can be estimated from flow system characteristics observed in the field and by examination of the hydrogeologic characteristics of the geologic units. Spring and stream studies conducted by Winter (1979) indicate that portions of the Thaynes, Dinwoody, and Wells formations have moderate to high hydraulic conductivities. The Phosphoria Formation, as a whole, has a low hydraulic conductivity. Unconsolidated colluvium and alluvium may have locally low, moderate, or high hydraulic conductivity depending upon local grain size distribution. From a regional standpoint, however, unconsolidated sediments have a relatively high hydraulic conductivity, especially in some of the major river and tributary valleys. Table IV-2 presents a hydrostratigraphic columnar section of the geologic units investigated in the study area. Relative hydraulic conductivity of each unit is given in terms of low, moderate, or high. The units are

Table IV-1. Summary of hydraulic conductivity data for the phosphate area (modified after Ralston and others, 1977, p. 112 and Vandell, 1978, p. 38, 59, 64, 89 and 94).

					Transmissivity T		Hydraulic Conductivity K		
Formation	Unit	Symbol	Study Area	Test Procedure	ft^2/day	M^2/day	ft/day	M/day	Storage S
Dinwoody	Middle of Formation	Trd	Little Long Valley	Field-Slug Test	83	7.7	--	--	--
Phosphoria	Rex Chert Member (fractured)	Ppr	Lower Dry Valley	Field-Pump Test	12,000	1,100	75	23	0.0003
					2,300	210	28	8.5	0.001
	Rex Chert Member	Ppr	Lower Dry Valley	Field-Pump Test	450	42	2.2	0.67	--
			Diamond Creek	Field-Pump Test	750	70	2.5	0.76	0.007
	Meade Peak Phosphatic Shale Member (fractured)	Ppm	Lower Dry Valley	Field-Pump Test	2,000	190	25	7.6	0.0005
	Meade Peak Phosphatic Shale Member (unfractured)	Ppm	Lower Dry Valley	Field-Slug Test	8.0	0.74	0.3	0.09	--
					64	5.9	1.6	0.49	--
					23	2.1	0.4	0.1	--
					16	1.5	0.14	0.043	--
					63	5.9	0.44	0.13	--
					6.0	0.56	0.07	0.02	--
	Meade Peak Phosphatic Shale Member (middle waste)	Ppm	Lower Dry Valley	Field-Pump Test	300	28	4.0	1.2	0.0013
	Meade Peak Phosphatic Shale Member (ore)	Ppm	Little Long Valley	Field-Slug Test	11	1.0	2.2	0.67	--
	Meade Peak Phosphatic Shale Member (middle waste with bedding)	Ppm	Little Long Valley	Lab	--	--	5.2	1.6	--
	Meade Peak Phosphatic Shale Member (middle waste across bedding)	Ppm	Little Long Valley	Lab	--	--	0.4	0.12	--
Alluvium	Alluvium	Qal	Diamond Creek	Field-Pump Test	3,200	300	55	17	--

Table IV-2. Hydrostratigraphic columnar section in the investigated areas in southeastern Idaho (after Ralston et al., 1977).

	Formation	Member	Thickness feet	Lithology	Hydrogeologic Characteristics (Permeability)	Hydrogeologic Classification
Triassic	Thaynes	Upper	900-1200	Limestone and sandstone with some shale siltstone layers	moderate to high	Aquifer
		Middle	2000	Limestone facies interbedded with greater portion of siltstone and shale	low to moderate	
		Lower	2000	Limestone facies interbedded with greater portion of siltstone and shale	low to moderate	
	Dinwoody	Upper	900	Interbedded limestone and siltstone with discontinuous shaly zones	moderate for limestone and siltstone, low for shale and silt	Aquifer
		Lower		Calcareous shale and siltstone with few thin limestone beds.		
Permian	Phosphoria	Rex Chert Unit	120- 150	Chert and cherty limestone, thick bedded	permeable when fractured	Aquifer or Aquitard
		Meade Peak Unit	150- 200	Phosphatic shale, mudstone and phosphatic rock. Some limestone and siltstone	low to semi-permeable	Aquiclude
Carboniferous	Wells	Upper	50	Siliceous limestone	Moderate	Aquifer
		Middle	1500	Sandy limestone, sandstone	high	
		Lower		Limestone, mostly sandy and cherty	moderate to high	
	Brazer	Upper	200	Black and white laminated	very low	Aquifer
		Middle	1000	Thick bedded limestone	high	
		Lower	600-1000	Thin bedded limestone	high	

classified as aquifers, aquitards, or aquicludes based on their regional ability to accept recharge, store, transmit and discharge ground water. Aquifers readily accept, transmit, and discharge ground water, where as aquicludes do not. Aquitards accept and store ground water but discharge ground water at low rates and in small quantities.

Structure. Geologic structure of the study area is dominated by folds and faults. Structural features have greatly influenced the development of ground water and surface water flow systems. Major surface drainages parallel fold axes or follow fault structures. Stream valleys generally occur within the eroded cores of anticlines and ridges generally follow synclinal axes. Good examples of these are Dry Ridge, Dry Valley, Schmid Ridge, and Slug Creek Valley. An exception to this pattern is found in the Fort Hall Indian Reservation area where extensive block faulting has precluded the development of a well defined ridge and valley system.

Structural features control to a large extent the location of ground water recharge and discharge areas. Ground water entering a geologic formation tends to follow bedding planes because hydraulic conductivities are higher parallel with bedding than across bedding planes. Valleys in the study area often lie on anticlinal axes, which provides a structural avenue for ground water to flow from one valley to another under ridges. Recharge to permeable rock outcrops on ridges may also follow fold structures and discharge in distant valleys. Fault structures affect the location of many springs. Locations of some of these springs have been discussed. Locations of springs in valley alluvium are often controlled by underlying structure. Cressman (1964) attributes two large alluvial springs in Georgetown Canyon to constrictions in the valley floor by the underlying bedrock.

Topography and Climate

Topography and climate greatly influence flow system development in the study area. Basically, the topography is dominated by ridge and valley systems which trend northwest-southeast. Climate characteristics of the area cause major precipitation in the form of snow to accumulate on the eastern and northern slopes of these ridge systems. Snow drifts on ridges may accumulate to more than 30 feet in depth and be as long as six miles (U.S.D.A. Forest Service, 1978). Eastern and northern ridge slopes, and other lee slopes, accumulate a large snowpack; therefore these areas become major recharge areas for ground water and surface water flow systems.

Topography and basin configuration affect the development of local, intermediate, and regional flow systems as described in Chapter II. Dominant topographic profiles of the study area can be divided into three major divisions based on scale of observation or basin size. In the largest division are the major drainage basins of the Snake River and Bear River. The drainage divide between these basins cuts across the study area in an east-west direction (fig. I-2). The largest portion of the study area lies within the Snake River drainage basin. The overall topographic profile of the study area within the Snake River drainage consists of a general slope from the drainage divide in the southeast to the Snake River in the northwest. Maximum relief along this profile is about 5,400 feet. The overall topographic profile of the area within the Bear River drainage basin consists of a general southwestern slope from the drainage divide to the Bear River valley with a maximum relief of about 4,000 feet.

Superimposed on the overall topographic slope is the second major topographic division of the main tributary basins such as Diamond Creek, Lanes Creek, Dry Valley Creek, Slug Creek, Angus Creek, Georgetown Creek, and several others. Topographic relief of these basins is in the range of 1,000 to 3,000 feet.

The third major topographic division encompasses the small localized drainage basins that have developed on the slopes of major tributary basins. These drainages are characteristic of broken topography such as that found around Sulfur Peak and other portions of the Aspen Range and in the hilly, broken topography of the Fort Hall Indian Reservation. Topographic reliefs of these features are in the order of hundreds of feet.

This topographic configuration of the study area influences the development of local, intermediate, and regional flow systems. If the study area were composed entirely of homogeneous isotropic materials, the ground water flow systems could easily be delineated based on the theoretical concepts of Toth (1963). Regional ground water flow systems would develop from the upland areas of the major basins to the Snake and Bear river valleys. Intermediate flow systems would exist from the major ridges to the major tributary valleys and local flow systems would be found in the areas of local relief. A cross-sectional view of this situation is presented as figure IV-1. Obviously, the study area is not homogeneous and isotropic, but the topographic profile as described will largely influence the development of ground water flow systems.

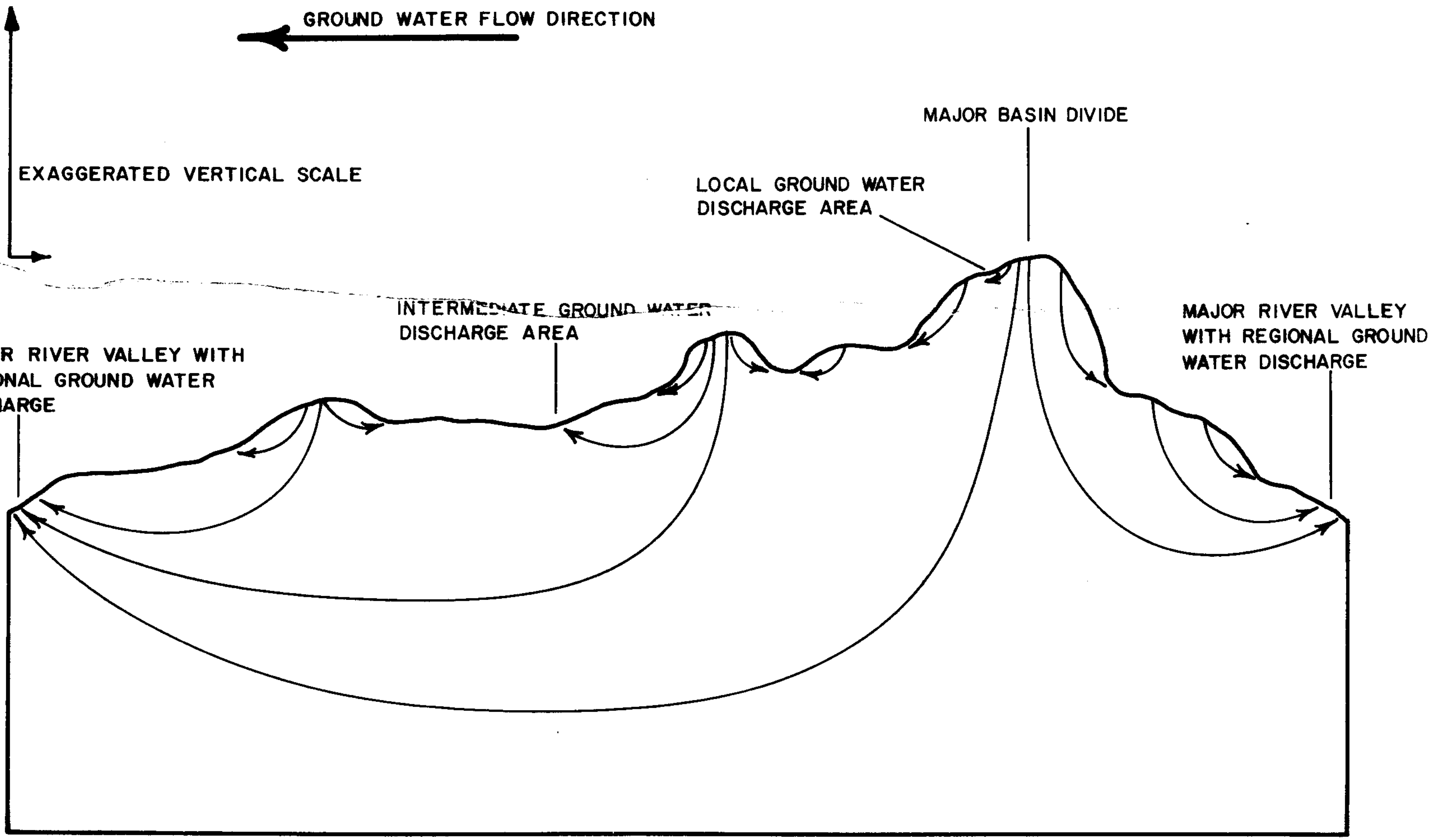


Figure IV-1. Hypothetical cross-section of ground water flow with local and intermediate systems superimposed on regional systems.

It is interesting to note that the ridge and valley systems within the study area are predominantly of two types. One type of ridge and valley system has very even slopes with few topographic irregularities. The best examples of this are the Dry Ridge-Dry Valley system and the Snowdrift Ridge-Georgetown Canyon system. The other type of ridge and valley system is very broken by local topography. The Sulfur Peak area in T9S R43E is an example of this type of topography. From flow systems theory, ridge systems with few local topographic irregularities could be expected to have few local ground water flow systems. The areas with broken, irregular topography could be expected to have many local flow systems.

General Flow Systems of the Study Area

Local Flow Systems

Local ground water flow systems are typically characterized by intrabasin flow, short flow paths, small springs and seeps, and intermediate size springs with a large annual range in discharge. Local ground water flow systems have relatively small quantities of water in storage. During summer months and periods of drought, springs of local ground water flow systems often dry up. Local flow systems are most often associated with areas of high precipitation, and they are more frequent in hummocky terrain than in terrain of constant slope.

Local flow systems are found on the side slopes of most ridges in the study area. They are most frequent on north and east facing slopes of ridges where the heaviest snowpacks accumulate. Southwest facing slopes with low precipitation and with smooth regular slopes have the fewest local ground water flow systems.

Mohammad (1977) identified several local flow systems on the western ridge of Little Long Valley in unconsolidated colluvial materials. These flow systems receive recharge from snowmelt on the ridge and generally dry up during the summer. Robinette (1977) identified several similar local ground water flow systems on the northeast slope of Schmid Ridge. Winter (1979) identified local flow systems in sections of the Thaynes and Dinwoody formation in many areas of eastern Caribou County.

Intermediate Flow Systems

Intermediate ground water flow systems are characterized by predominantly intrabasin flow and by intermediate to large springs which show an annual fluctuation in discharge. Some springs of intermediate flow systems may dry up during periods of extreme drought. Intermediate flow systems generally have large amounts of water in storage. They often discharge into alluvial valleys and support base flows of perennial streams. The source of intermediate ground water flow systems is typically the highland area receiving major precipitation. Ground water circulation depths are greater than in local flow systems. Geologic structure, topography, and hydraulic conductivity of rock units greatly affect the location of intermediate flow system discharge points. Stratigraphic units of high hydraulic conductivity act as conduits to flow. Discharge points often occur at the contact of two geologic units with large variations in relative hydraulic conductivity. Faults may intercept intermediate flow systems and create channels for surface discharge.

In the study area, intermediate ground water flow systems will generally occur from the major snowpack areas on the ridge tops to discharge areas near the bottom of ridge slopes or into creeks or alluvium in valley floors. The Dinwoody Formation typically supports intermediate flow systems. The formation contact between the Dinwoody and Phosphoria formations is a likely discharge area for these systems because of the large difference in relative hydraulic conductivity between the formations.

Mohammad (1977) identified an intermediate ground water flow system in the Dinwoody Formation on the eastern ridge of Little Long Valley. Recharge to the system is from snowmelt at the top of the eastern ridge. Discharge areas are at the base of the ridge in adjacent Rasmussen Valley and in Little Long Valley. Discharge is believed to occur both as springs and as subsurface flow into Angus Creek. This flow system supports most of the base flow of upper Angus Creek.

Intermediate ground water flow systems were identified by Edwards (1977) in the Dinwoody Formation on the western slope of the Webster Range. Springs which issue from the Dinwoody Formation form Old Cabin Spring, Cabin Creek, and Yellowjacket Creek. The springs which discharge from this flow system form small streams which infiltrate the alluvium in Diamond Creek Valley.

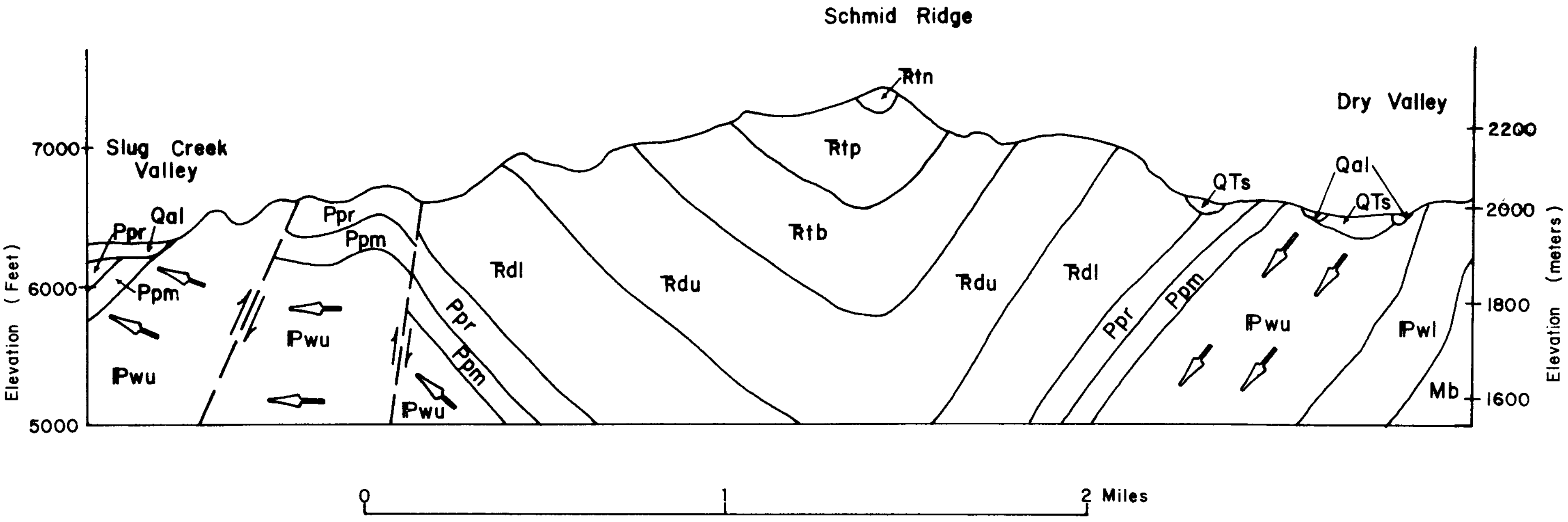
Regional Flow Systems

Regional ground water flow systems are characterized by interbasin flow, long flow paths, and large springs with nearly constant annual flows. Recharge areas for regional flow systems are upland areas of high precipitation and upper valleys that contain large amounts of ground water. Discharge areas are in valleys of adjacent or distant basins and in major topographic lows of the region. Regional flow systems contain large amounts of ground water in storage. Springs which issue from regional flow systems are sometimes thermal or highly mineralized because of deep circulation and long flow paths. Thick, arealy extensive geologic formations with high hydraulic conductivity are conducive to development of large regional ground water flow systems.

In the study area, the Wells Formation and the underlying Brazer Limestone have characteristics favorable to development of regional flow systems. These formations have zones of high hydraulic conductivity, are several thousand feet thick, and probably underlie the entire study area. Outcrops of these formations are found on ridges in the study area where they receive recharge from snowmelt and, probably even more important, they underlie some of the high tributary valleys such as Upper Valley, Dry Valley, and Slug Creek Valley.

Hydrogeologic studies by Robinette (1977) and Vandell (1978) have determined that a regional ground water flow system exists between Dry Valley and Slug Creek Valley through the Wells Formation. Ground water enters the Wells Formation through the unconsolidated deposits in Dry Valley. Ground water follows the structure of the Wells Formation under Schmid Ridge and exits as spring flow, stream flow, and under flow in Slug Creek Valley. A cross-sectional view of this interbasin flow system is presented as fig. IV-2.

Additional regional ground water flow systems in the Wells Formation can be postulated based on topography, geology, hydrogeology, and spring flow. The large springs on the western edge of the Aspen Range are most likely discharge points for regional flow systems from the Wells Formation and possibly from the Brazer Limestone. Woodall Spring and



Mb	Brazer Limestone	Ꞧdu	Upper Dinwoody Formation
Ꝑwl	Lower Wells Formation	Ꞧtb	Lower Thaynes Formation
Ꝑwu	Upper Wells Formation	Ꞧtp	Middle Thaynes Formation
Ppm	Meade Peak Member of the Phosphoria Formation	Ꞧtn	Nodular Siltstone Member of the Thaynes Formation
Ppr	Rex Chert Member of the Phosphoria Formation	QTs	Sedimentary Deposits
Ꞧdl	Lower Dinwoody Formation	Qal	Alluvium
		◁━	Postulated Flow Path

Figure IV–2 Postulated Dry Valley-Slug Creek Valley ground-water flow system

Formation Spring are large tufa-deposition springs with rather constant flow. Discharge of these springs is greater than what could be expected from the topographic basins which they occupy, suggesting recharge from distant sources. The same is true for the large springs at the base of Wilson Ridge near the Blackfoot River reservoir. The source areas for Woodall and Formation springs may be Slug Creek Valley or Dry Valley.

Very large regional ground water flow systems probably occur all the way from the headwaters of the Blackfoot River to the Snake River Valley. The high mountains and tributary valleys in the upper Blackfoot River, which receive the greatest amount of precipitation, are probably the primary recharge areas for these regional flow systems. The dominant ground water flow direction for these regional flow systems is most likely to the northwest, parallel to the direction of the dominant structural features of the area. Discharge from regional flow systems may be to the Snake River or to geologic formations in the Snake River Valley.

Additional regional ground water flow systems probably occur from the Columbia River Basin-Great Basin Divide (see fig. I-2) to the Bear River Valley. Theoretical ground water flow concepts and basin structure support this theory. Studies by Dion (1974) demonstrated regional ground water flow in the Blackfoot lava field from the Blackfoot River reservoir to the Bear River valley south of Soda Springs.

Summary of Water Resource Systems and Flow Patterns

Definite patterns of surface water and ground water flow systems are evident from hydrologic studies in the southeastern Idaho phosphate field. These ground water and surface water flow patterns are largely controlled by geology, hydrogeology, topography, and availability of recharge.

Precipitation on lee slopes supports flow in small surface channels and recharges ground water flow systems in the Thaynes, Dinwoody, and Wells formations and in colluvial deposits. Recharge which enters the colluvium generally percolates downward within the colluvium to the bedrock contact. Ground water within saturated colluvium moves down slope forming local flow systems. These local flow systems discharge to small springs, seeps, and to vegetation. Many of these local ground water flow systems dry up during summer months.

Recharge which enters the Thaynes and Dinwoody formations forms local and intermediate ground water flow systems. Recharge comes mostly from direct precipitation and from discharge by small local ground water flow systems. Ground water within these formations moves down gradient following bedding planes and fault structures. Discharge from the flow systems is to springs and streams where bedding planes and faults intercept the topographic surface. Some of the ground water within these flow systems moves across bedding planes to enter the lower member of the Dinwoody Formation. Further cross bedding flow is virtually prevented by the relatively low hydraulic conductivity of the Phosphoria Formation. Ground water within the lower member of the Dinwoody Formation then commonly discharges along the Dinwoody-Phosphoria contact in the form of springs and increased stream flow (Winter, 1979).

The Meade Peak member of the Phosphoria Formation supports no significant ground water flow systems. The Rex Chert member may support localized flow systems where it is highly fractured. The Phosphoria Formation forms an effective hydrologic barrier between flow systems within the Thaynes and Dinwoody formations from those within the Wells Formation and Brazer Limestone. A possible exception to this is where considerable displacement has occurred due to faulting.

The Wells Formation supports major ground water flow systems within the study area. Evidence suggests that these flow systems are regional in extent. Recharge to regional ground water flow systems in the Wells Formation occurs as precipitation, streamflow loss, and from alluvial valley aquifers. The high mountains and valleys, which receive the greatest precipitation, are the principal recharge areas for regional flow systems. Discharge from regional flow systems is controlled largely by topography and structure. The Snake River Valley and the Bear River Valley are probably primary discharge areas for regional ground water flow systems.

Alluvial materials in valleys contain large quantities of ground water. Surface water and ground water flow systems within alluvial materials readily interact. Some stream reaches within valleys lose to underlying alluvium while other reaches gain water from the alluvium.

CHAPTER V

WATER RESOURCE SYSTEMS OF SELECTED MINE SITES

Introduction

It has been demonstrated that surface water and ground water flow systems within the study area exhibit many similar flow patterns and characteristics which are largely controlled by geology, hydrogeology, topography, and availability of recharge. The purpose of this chapter is to present additional similarities, which exist on a local level, between flow systems at mine sites and environmental and mining factors. Six mine sites within the southeastern Idaho phosphate field were examined to achieve this purpose. The six mine sites were studied to (1) determine relationships between environmental controlling factors and flow systems development and (2) determine relationships between mining factors and flow system impacts. The six mine sites examined during this study are the (1) Henry Mine, (2) Dry Ridge-Maybe Canyon Mine, (3) Conda Mine, (4) Gay Mine, (5) Wooley Valley Mine, and (6) Georgetown Canyon Mine (see fig. I-2). The first five mines listed are currently in operation; Georgetown Canyon Mine is not.

Relationships between Environmental Factors and Flow Systems of Mine Sites

Geology

All mine sites studied contain the "Phosphoria Sequence" of sedimentary rock units consisting of the Wells Formation, Phosphoria

Formation, and Dinwoody Formation. The sedimentary rock units in each area, except the Gay Mine, are part of a steeply dipping syncline-anticline sequence. In the Gay Mine area, the sedimentary sequence occurs in a broad gently dipping syncline which has been extensively block faulted. A generalized geologic cross section of each mine area is presented in figures V-1 through V-6. These cross sections are intended to show only the basic geologic structure and topographic profile characteristics of each mine site so that any similarities and contrasts between mine sites will be evident.

The geologic sections which occur at these mine sites may be grouped into three basic types. The types are where (1) the sedimentary sequence dips into the major slope of the ridge and the Dinwoody and Phosphoria formations occur topographically higher than the Wells Formation, (2) the sedimentary sequence dips with the major ridge slope and the Wells Formation occurs topographically higher than the Phosphoria and Dinwoody formations, and (3) extensive faulting has occurred and the formations may dip with or against the topographic slope or lie almost horizontal. These three types of geologic structure significantly affect ground water flow systems.

Dip Contrary to Slope Type. The first geologic section type is characteristic of the Dry Ridge-Maybe Canyon Mine site and of the proposed mine sites in Lower Dry Valley and Diamond Creek Valley. At each of these sites the Phosphoria Formation dips into the ridge slope and the Thaynes and Dinwoody formations occupy the top of the ridges. The Dry Ridge-Maybe Canyon Mine is located on the southwest slope of Dry Ridge, which is the western limb of the Georgetown Syncline. Here,

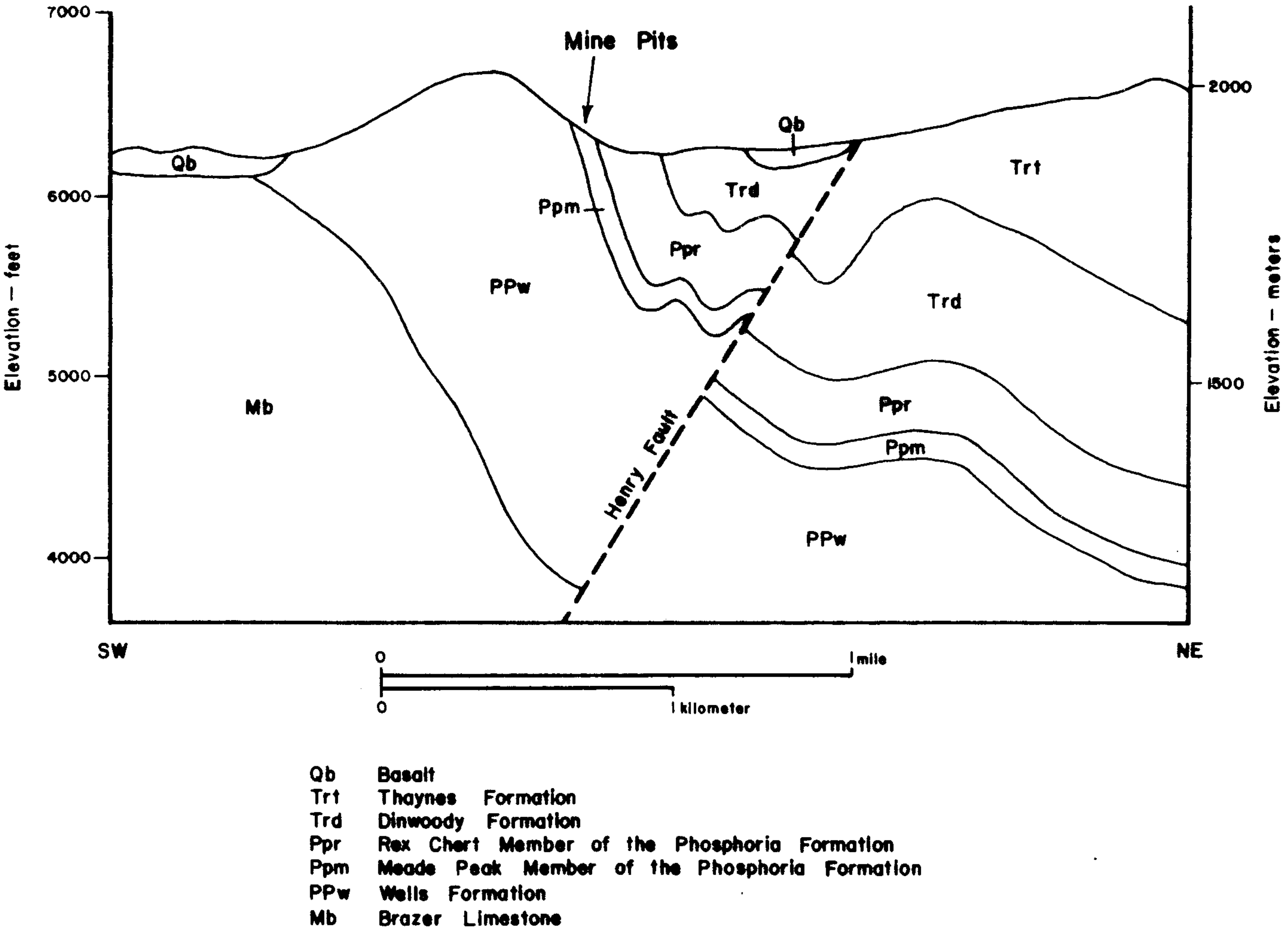


Figure V-1. Generalized geologic section through North Henry Mine site (after Mansfield, 1927).

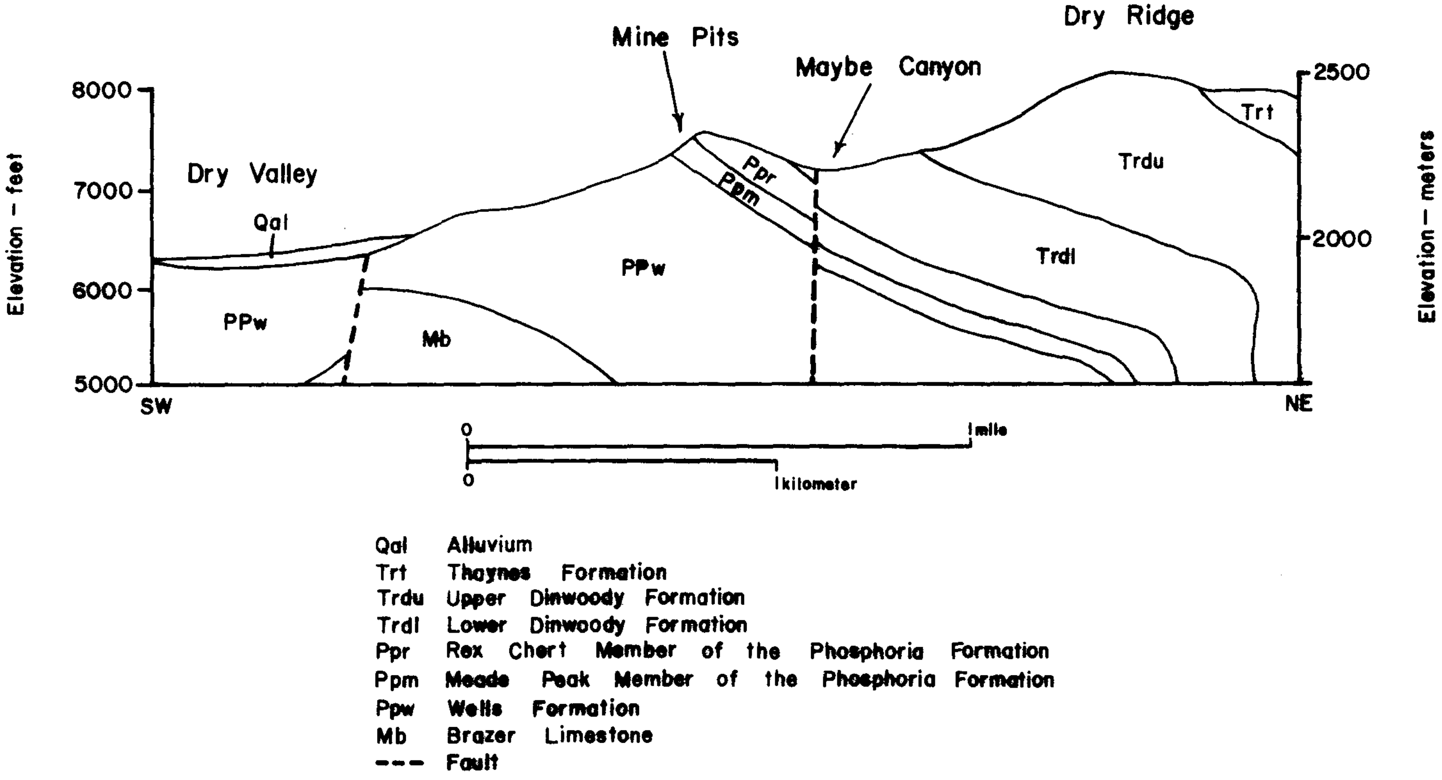


Figure V-2. Generalized geologic section through Dry Ridge-Maybe Canyon Mine site (after Cressman and Gulbrandsen, 1955).

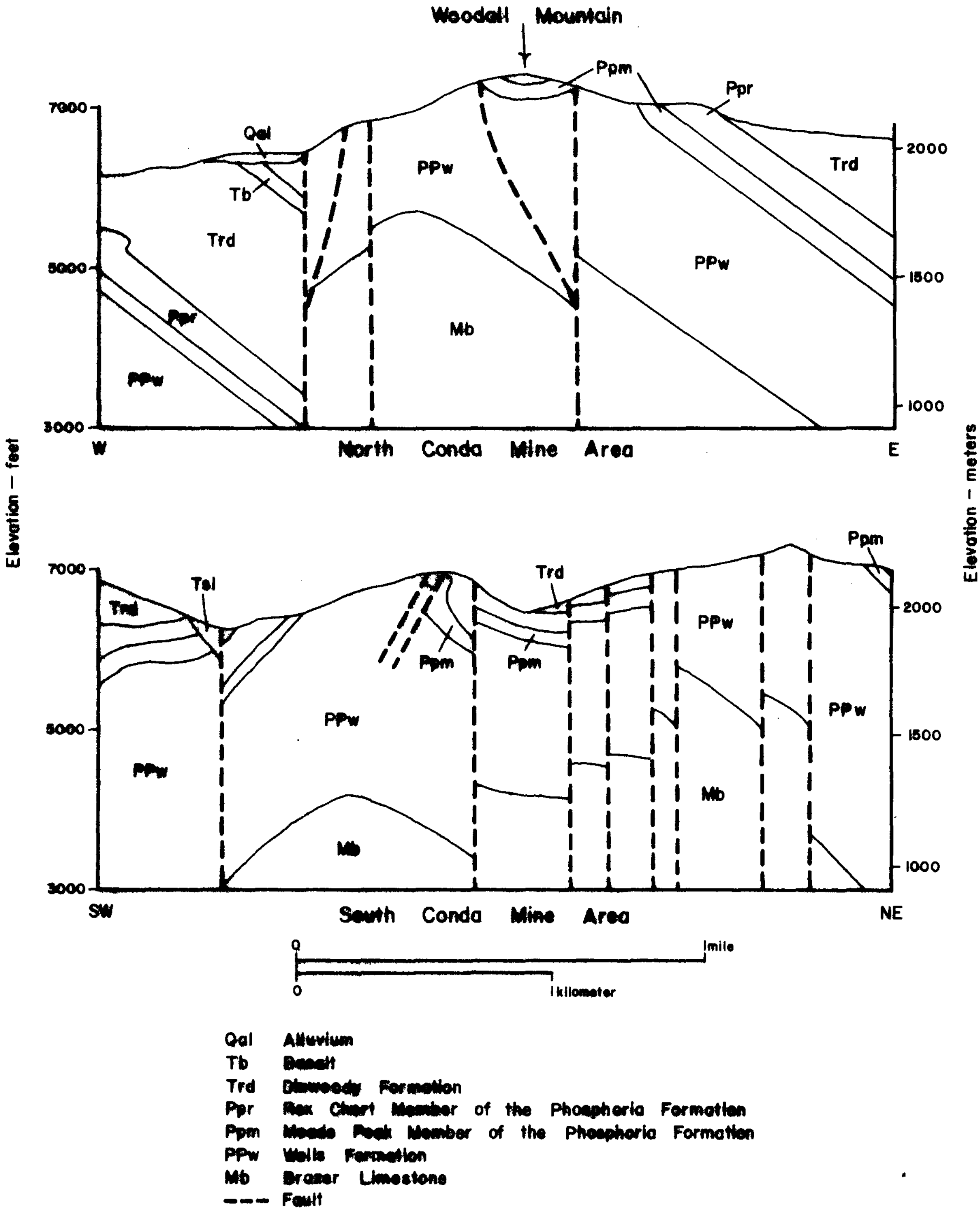


Figure V-3. Geologic sections through north and south Conda Mine areas (after Armstrong, 1969).

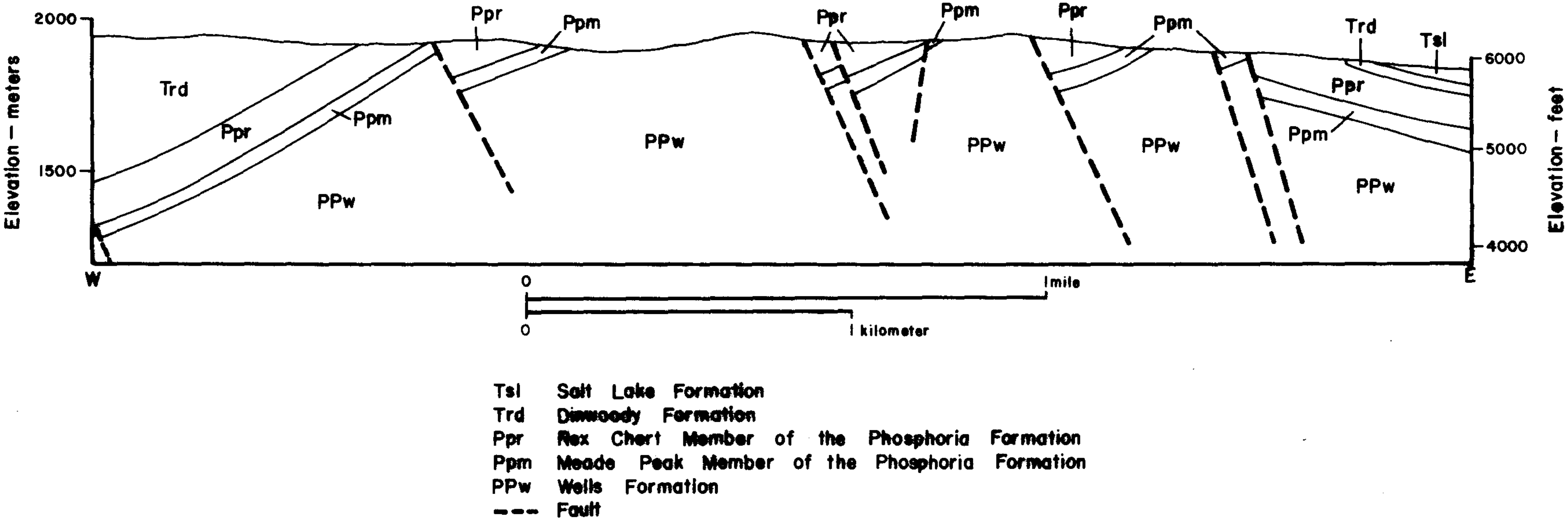


Figure V-4. Generalized west-east geologic section through the Gay Mine (after Lehman, 1963, section J-J')

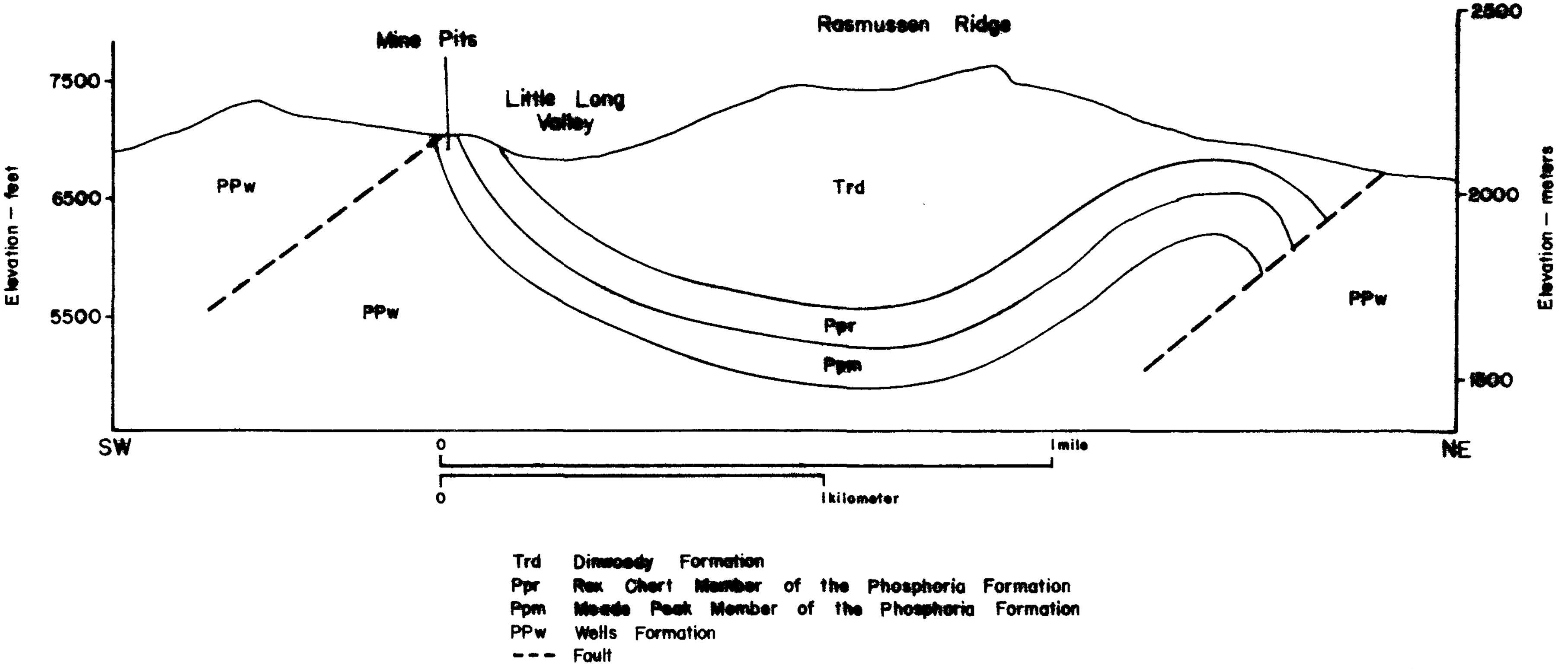
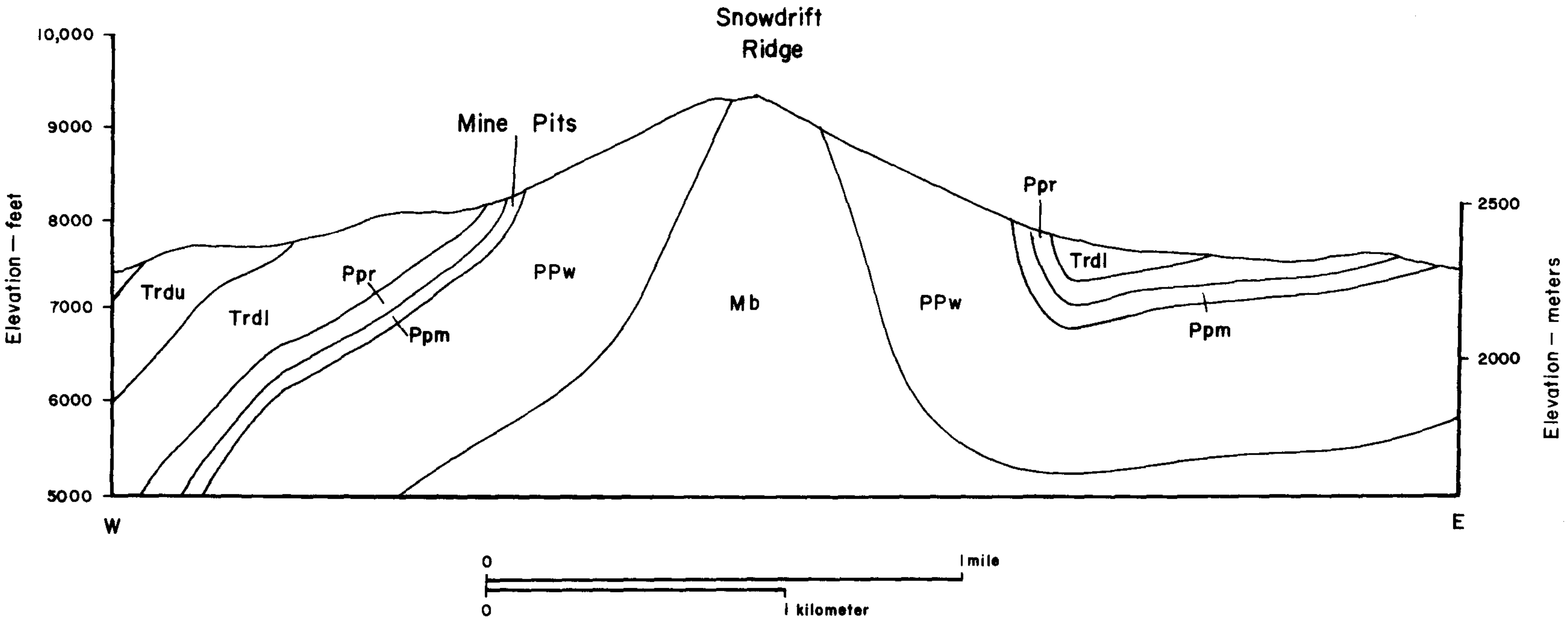


Figure V-5. Generalized geologic section of the Wooley Valley Mine area (after Mohammad, 1977).



Trdu	Upper Dinwoody Formation
Trdl	Lower Dinwoody Formation
Ppr	Rex Chert Member of the Phosphoria Formation
Ppm	Meade Peak Member of the Phosphoria Formation
PPw	Wells Formation
Mb	Brazer Limestone

Figure V-6. Geologic section through the Georgetown Canyon Mine site (after Cressman, 1964).

mining occurs along the crest of a secondary ridge system which is located between Maybe Canyon and Dry Valley. The crest of this ridge is capped by the resistant Rex Chert Member of the Phosphoria Formation, which forms massive dip slopes into Maybe Canyon. The summit of Dry Ridge is located east of Maybe Canyon and is composed of the Thaynes and Dinwoody formations. In the vicinity of the mine pits, the Meade Peak Member of the Phosphoria Formation dips approximately 25° to 40° east.

Synclinal structures under ridges are generally found where rock units dip into the topographic slope. These synclinal structures, combined with the relatively low hydraulic conductivity of the Phosphoria Formation, act as basins which may hold significant quantities of ground water within the Dinwoody Formation. These factors apparently contribute to the many local and intermediate ground water flow systems which are found in the Dinwoody Formation in Schmid Ridge, on the west flank of the Webster Range in Diamond Creek Valley (Edwards, 1977) and along both flanks of the Webster Syncline in the southern portion of the Webster Range (Winter, 1979). A similar flow system was identified by Mohammad (1977) on the eastern ridge of Little Long Valley. On the eastern ridge, the Dinwoody Formation receives recharge from snow melt which follows the synclinal structure under the ridge and discharges into upper Angus Creek.

Dip with Slope Type. The second geologic section type is characteristic of the Henry Mine, Georgetown Canyon Mine, Wooley Valley Mine and the northern portion of the Conda Mine. At these mine sites rock units dip with the ridge slope. Outcrops of the Wells Formation occur topographically higher than the Phosphoria and Dinwoody formations. The Wells Formation and sometimes the Wells and Brazer Limestone formations occupy the ridge tops and slopes above the mine pits and the Dinwoody Formation is found on slopes below the mine pits.

In mine areas where rock units dip with the topographic slope, ground water flow systems are significantly influenced by structure and outcrop pattern. The high hydraulic conductivity of the Wells and Brazer Limestone formations permits rapid infiltration of snow melt on the ridge tops. Recharge which enters these formations percolates downward along bedding planes or zones of high hydraulic conductivity directly into regional ground water flow systems. The factors of high hydraulic conductivity, steep dip angles, and large thickness and areal extent of the formations all contribute to the formation of flow systems that rapidly transmit water from the ridge tops to regional ground water flow systems. Mine sites which are located downslope from the Wells Formation have amazingly little surface runoff which enters the mine areas. This is especially true at the Georgetown Canyon Mine where a very large snowpack accumulates on the ridge top and slopes above the mine pits. The Wells Formation, including the Grandeur Tongue of the Park City Formation, and the Brazer Limestone are so permeable in this area that very little surface runoff from snowmelt reaches the mine pits. Streams on the slope above the mine pits rapidly lose flow to these formations. Mansfield (1927) noted the development of small sinkholes on Snowdrift Ridge. Large solution channels and a cave are evident in the footwall of mine pits in Georgetown Canyon Mine, revealing very high hydraulic conductivity.

In mine areas where rock units dip with the topographic slope, the Dinwoody Formation is located downslope from the mine pit area.

In this topographic position, the Dinwoody Formation is not favorably situated to receive large amounts of recharge from precipitation. Under this condition the Dinwoody Formation supports fewer or smaller ground water flow systems than when it occupies synclinal structures under ridge tops. Springs and seeps which issue from the Dinwoody Formation below the mine pit areas of the Georgetown Canyon Mine, Henry Mine, and Wooley Valley Mine are generally very small.

Fault Block Type. The third type of geologic section occurs in the Gay Mine area. Here extensive block faulting has created an irregular topography where dips of rock units are moderate but may occur in almost any direction with respect to topographic slope. Either the Wells Formation or the Dinwoody Formation may occur topographically above the Phosphoria Formation. Complex geologic structure of this area greatly complicates ground water flow systems. The influence of fault structures on ground water flow systems is not clear. Definite relationships between geologic factors and ground water flow systems are difficult to identify.

Pit dewatering operations and pump tests conducted in the Gay Mine area indicate that intermediate ground water flow systems exist in the Dinwoody Formation (Corbet, 1979). Evidence for this is based on the quantity of water which can be pumped from some sections of the Dinwoody Formation. The amount and location of recharge to the Dinwoody Formation is not known; however, a decrease in fluid potential with an increase in depth noted in some shallow wells and drill holes indicates that some recharge is derived locally from precipitation. The synclinal structure of the Gay Mine phosphate deposits, combined with the low hydraulic conductivity of the Phosphoria Formation, may retard horizontal movement of ground water in a direction perpendicular to the synclinal axis. Fault blocks within the structural syncline further retard horizontal ground water movement by bringing the Phosphoria Formation to the surface, forming effective hydrologic barriers. For ground water to escape from the synclinal structure it must either flow downward along faults or follow the synclinal axis to the north or south. Ground water will not likely flow south because topography is higher in that direction, the area gets greater amounts of precipitation, and the area has higher fluid potentials based on elevations of large spring flows. In fact, the area south of the Gay Mine, towards Putnam Mountain, may contribute ground water recharge to the Gay Mine. Geology to the north of the synclinal structure is not well known, and it is possible that a large portion of ground water flow out of the Gay Mine area is to the north.

A regional ground water flow system appears to exist in the Gay Mine at an elevation of about 5,730 feet (Corbet, 1979). This is based on the occurrence of a large, mineralized and slightly thermal spring (Queedup Spring) which issues from the Wells Formation at the western edge of the mine area. Recharge to the regional flow system may be from downward percolating ground water or from the topographically higher area to the south. A possible explanation for the thermal, mineralized spring water is the deep circulation and long travel time necessary for ground water to pass through or under the Phosphoria Formation within the fault blocks of the synclinal structure. At Queedup Spring the Wells Formation intersects the topographic surface along a large fault structure. The deeply circulating ground water may follow this fault to the surface and discharge at Queedup Spring.

Geologic structure appears to greatly affect ground water flow paths in fault block regions, based on Gay Mine observations. In particular, it appears that the location of the Phosphoria Formation within fault blocks affects the direction and rate of ground water movement. Ground water is more likely to flow along bedding planes within fault blocks than across bedding planes. Discontinuous zones of high and low hydraulic conductivity result from the offset of geologic formations by faults. Under these conditions, ground water flow systems may follow tortuous paths and ground water potentials may be greatly different than expected. The net effect of fault block structure may be to reduce the rate of horizontal ground water flow, thereby increasing the elevation of the water table.

Topography

All mine areas examined in this study, except the Gay Mine, are located on definite ridge systems with adjacent valleys. The mine sites which occupy ridges may be classified into three basic types based on the location of the mine pits relative to the topography of the ridge. These types are (1) mine sites which occupy ridge tops, (2) mine sites which occupy the flank of a ridge, and (3) mine sites which occupy the base of a ridge or the edge of a valley floor. A fourth topographic type is needed for areas such as the Gay Mine where definite ridge and valley systems do not exist and mine pits may occupy several topographic positions. Each of these topographic classifications has associated with it distinct types of surface water and ground water flow systems.

Ridge Top Mine Type. The first classification includes all mine sites on ridge tops. Only recharge to flow systems can occur at these mine sites. Recharge may be to local, intermediate, and regional ground water flow systems, through direct precipitation and snow melt. All fluid potential gradients are directed downward and laterally; none are directed upward. This means that no ground water discharge points can occur on ridge tops except for relatively small seeps at a distance downslope. The Dry Ridge-Maybe Canyon Mine, which occupies the ridge top between Maybe Canyon and Dry Valley, falls into this category as does a portion of the Conda Mine on Woodall Mountain. No significant ground water flow systems discharge into mine pits along these ridge tops. Precipitation and snow melt entering the mine pits either recharge ground water flow systems through seepage or are lost to evapotranspiration.

Ridge Flank Mine Type. The second topographic classification encompasses all mine sites on the flanks of major ridges. Fluid potential gradients at these sites may be directed either upward or downward depending upon local topographic irregularities and geologic structure. Fluid potential gradients within these ridges are dominantly downward because the ridges are primarily recharge areas for local, intermediate, and regional ground water flow systems. Upward fluid potential gradients occur at ground water discharge points such as springs. Small discharge points in the form of seeps and springs are found on the ridge slopes of several mine sites including the Wooley Valley Mine, Conda Mine, and South Henry Mine.

Seeps and small springs are more prevalent on slopes with broken local topography than on those with continuous smooth slopes. This is particularly evident when comparison is made between the Sulphur Peak area and the Georgetown Canyon Mine area. The regular smooth slopes of the Georgetown Canyon have few springs, where the Sulphur Peak area has many. Mine pits located on ridge flanks may intercept ground water discharge or they may induce ground water recharge depending upon their location relative to pertinent flow systems. Ground water flow systems which discharge into mine pits are generally local in extent on the upper portions of ridge slopes and become local to intermediate near the lower portions of ridge slopes, based on flow systems theory.

Ridge Base Mine Type. The third topographic classification, for mine sites located at the base of a ridge or at the edge of a valley floor, is characteristic of proposed mine sites in Lower Dry Valley and in Diamond Creek Valley. Proposed mine pits in the North Henry Mine area also fall into this classification. Fluid potential gradients at mine sites in this classification may have either upward, downward, or lateral components.

Fluid potential gradients which have been measured in these locations show dominantly downward gradients. Measurements made by Edwards (1977) at the proposed mine site in Diamond Creek Valley show a downward gradient within the Phosphoria Formation. Ground water elevation measurements made by Brooks (1979) in the vicinity of the proposed North Henry Mine, show downward potential gradients from the overlying basalt. and alluvium, through the Dinwoody and Phosphoria formations, and into the Wells Formation. Measurements made in Lower Dry Valley by Vandell (1978) also show downward gradients towards the Wells Formation. Very little information is available concerning fluid potential gradients within the Wells Formation.

Mine pits which penetrate significantly below the elevation of nearby valley floors may intercept regional ground water flow systems within the Wells Formation. A good indication of the elevation of regional ground water flow is the elevation of springs in valley floors which discharge water that is either thermal or mineralized or that have high volumes of flow. Valleys in which the water table is at or near the ground surface have characteristics of broad, level valley floors with meandering streams. Significant pit dewatering operations could be required where pits penetrate below the water table.

The elevation of Slug Creek can be assumed to be near the level of the water table for areas of Slug Creek Valley and western Schmid Ridge. Evidence for this is the regional ground water discharge into Slug Creek Valley (Vandell, 1978). In the Enoch Valley and Henry areas, the water table probably occurs at an elevation of 6,100 feet or higher, based on the elevation of thermal and mineralized springs in lower Little Blackfoot River and on ground water elevations measured by Dion (1974) in the Blackfoot Reservoir area.

Gay Mine Topographic Type. Relationships between topographic factors and flow systems are more difficult to identify in mine types characterized by the Gay Mine. The topographic profile of the Gay Mine area has the greatest influence on local ground water flow systems. Many shallow local ground water flow systems occur in the area on northern and eastern slopes of small hills and valleys. These are created where a snowpack accumulates behind topographic wind barriers. The local flow systems in the Gay Mine are easily identified by groves of quaking aspen and by small seeps and springs. These local ground water flow systems offer no known hydrologic problems to mining, with the possible exception of small seeps into mine pits or waste dumps.

Relationships between topographic factors and intermediate and regional ground water flow systems are not clear. The topographic high in the northern Portneuf Mountains area may contribute to recharge of intermediate and regional ground water flow systems of the Gay Mine.

Climate

The primary climatic factor affecting surface water and ground water flow systems at mine sites is precipitation in the form of snow. As previously explained, north and east facing ridges accumulate the greatest snowpack. The primary relationship between climate and water resource systems at mine sites is the greater abundance of recharge available to north and east facing slopes, due to the precipitation distribution.

North and east facing slopes have many more local ground water flow systems and surface streams than do south and west facing slopes. They also support greater growths of vegetation. These conditions are readily apparent when comparisons are made between east and west facing slopes of either Dry Ridge, Schmid Ridge, or the Aspen Range.

Relationships between Mining Factors and Flow System Impacts

Mine Pits

Impacts of mine pits on water resource systems are dependent on the type (surface water or ground water) and size (local, intermediate, or regional) of flow systems intercepted by the pits. The impacts of water resource systems on mining operations are dependent on the same factors.

Throughout the study area, surface water and ground water flow systems are closely related. Surface water enters ground water flow systems in some areas while in others, ground water discharges at the surface to form surface flow systems. For this reason, mine pits which intercept ground water flow may also affect surface water flow.

Interception of local ground water flow systems by mine pits cause few problems to mine operations and produce the least hydrologic impacts. Mine pits may intercept local ground water flow systems within the upper colluvium and soil. This may lead to small amounts of water in pits or it may cause pit wall stability problems. These conditions are most likely to occur in the spring during times of rapid snow melt. This type of local flow system enters some mine pits at the Wooley Valley Mine during spring runoff. Interception of local ground water flow systems by mine pits may dry up small seeps or springs down gradient of pits and possibly deplete moisture in soil cover below the pits.

Interception of intermediate ground water flow systems by mine pits could in some cases lead to significant dewatering operations. Intermediate ground water flow systems are most likely to occur within the Dinwoody Formation. Winter (1979) noted that a considerable number of springs and streams are supported by ground water discharge from intermediate flow systems within the Dinwoody Formation. Mine pits which intercept intermediate ground water flow systems have the greatest potential to affect the flows of small springs and streams. Intermediate flow systems contain more ground water flow near the base of ridge slopes and near the Dinwoody-Phosphoria contact than in other locations.

Regional ground water flow systems have the largest potential to flood mine pits. Discharge from regional ground water flow systems into mine pits is most likely to occur in the Wells Formation and in valley fill material when mine pits extend below the elevation of valley floors. Pits which intercept regional ground water flow systems probably have little impact on spring flows unless extensive pit dewatering operations are carried out. Experience at the Gay Mine in "W Pit" indicates that if regional flow systems are intercepted, dewatering operations may not be economically feasible.

Surface water flow systems are easy to recognize and control before pit construction. Stream channels which cross proposed mine pits can be controlled by diversions or underdrains with minimum environmental impacts. For these reasons, no significant impacts caused by surface flows into mine pits were observed in this study. Procedures for controlling surface water flows with minimum impacts are well documented and may be found in several government publications (United States EPA, Oct., 1973; United States EPA, Dec., 1977).

Surface water bodies are created in some pits when they have been "abandoned." This water is due to ground water or surface water flow into the pit and from direct precipitation. No detrimental impacts to ground water flow systems due to the flooded pits were observed in this study.

Waste Dumps

Some definite relationships exist between waste dump factors and hydrologic impacts. Mohammad (1977) conducted studies on more than twenty waste dumps in the southeastern Idaho phosphate mining area. Six of the waste dumps developed local ground water flow systems. Factors which led to the development of flow systems within the waste dumps included the availability of water for recharge, suitable infiltration rates at the dump surface, and favorable waste dump characteristics such as large catchment areas, low topographic slope of the underlying land surface, and flat or very gentle waste dump surface.

The slope stability of waste dumps is controlled to a large extent by the amount of water contained within the dumps, by the steepness of the underlying topographic surface, by the engineering properties of the waste, and by the geologic characteristics of the underlying surface. Waste dumps which receive large amounts of recharge and are located on steep dip-slopes are much more likely to have slope stability problems from basal movement of the dump than those which receive little recharge and are located on slopes where the geologic units dip into the slope. Reasons for this are the smooth surfaces associated with dip slopes and the greater amount of water moving through the base of the waste dump. The hydraulic conductivity and structure of the geologic units underlying waste dumps affect to a large extent the ability of water to drain vertically from the waste dump, thereby affecting water content and stability of waste dumps. In the study area, waste dumps located on the Wells Formation have a greater potential to drain into the underlying formation than those located on the Dinwoody or Thaynes formations because of the higher hydraulic conductivity of the Wells

Formation. Waste dumps located on the Rex Chert Member of the Phosphoria Formation have a low potential to drain vertically because of the generally low hydraulic conductivity of the formation. Additionally, waste dumps will drain better if water can enter the formation parallel to bedding planes rather than perpendicular to bedding planes, thus dumps located on formations which dip into the slope drain better than those located on dip slopes.

For waste dump stability purposes, good sites for waste dumps in the study area are on gentle southeastern slopes composed of the Wells Formation or on dry portions of valley floors. Gentle slopes and valley floors are good sites because gentle slopes of the underlying topographic surface are better for waste dump stability than steep slopes. Southeastern slopes are preferred for waste dump sites because of their generally drier condition than northeastern slopes and location on the Wells Formation allows for vertical drainage of dumps. Valley floor locations are good for waste dump stability if the underlying geologic formation allows good vertical drainage of the waste dump and if the site is not a ground water discharge area. Poor locations for waste dumps are on steep dip-slopes composed of low hydraulic conductivity rock such as the Rex Chert. Northeastern slopes which accumulate large snowdrifts are also poor locations.

Factors in the location and construction of waste dumps also affect the potential for erosion of waste dumps. The contouring of waste dumps to minimize the rate of surface runoff reduces the potential for erosion, but it also induces infiltration into the waste dump. This situation increases the potential for instability problems and leaching of undesirable constituents from the waste dump. Efforts aimed at minimizing the amount of water reaching waste dumps minimize both the problems of erosion and of water flow through waste dumps. If waste dump stability is not a problem, waste dumps should be contoured to minimize surface runoff because hydrologic impacts created by waste dumps within the study area appear to be related more to erosion, with resulting sediment load to surface waters, than to poor chemical quality of water leaching from waste dumps. Water quality analyses conducted by Mohammad (1977) on water leached through waste dumps show higher concentrations of salts and some metals than does natural spring water; however, the concentrations measured were not determined to be harmful.

Laboratory studies are being conducted to determine the quality of water which has leached through samples of mine waste. Preliminary findings show that water leaching through the waste material soon becomes basic due to the presence of large quantities of carbonate minerals (Dr. C. M. Wai, personal communication, 1979). Under basic pH conditions, many trace elements contained in waste material exhibit very low solubilities and therefore do not reach high concentrations in ground water. Table V-1 shows the concentrations of cadmium, lead, and zinc leached from soil samples collected from phosphate mine waste dumps in southeastern Idaho.

Summary of Relationships

All mine sites studied contain the "Phosphoria Sequence" of sedimentary rock units consisting of the Wells Formation, Phosphoria Formation, and Dinwoody Formation. These formations are generally found in three structural configurations. The formations are found to either (1) dip with ridge slopes, (2) dip contrary to ridge slopes, or (3) occur in areas of complex fault blocks.

Table V-1. Concentrations of Cd, Pb, and Zn leached from soil samples collected from phosphate mine waste dumps in southeastern Idaho (after Wai, 1979).

	Metal Concentrations (Parts Per Million) in Solution**								
	5 hours			23 hours			117 hours		
Sample Description*	Cd	Pb	Zn	Cd	Pb	Zn	Cd	Pb	Zn
Henry Mine waste dump soil	<0.01	<0.05	0.07	<0.01	<0.05	0.10	<0.01	<0.05	0.18
Carbonaceous rich soil from Gay Mine waste dump	<0.01	<0.05	0.09	<0.01	<0.05	0.12	<0.01	<0.05	0.17
Weathered waste dump soil from Gay Mine	<0.01	<0.05	0.09	<0.01	<0.05	0.12	<0.01	<0.05	0.16

* Soil particle size for this experiment is less than 80 mesh.

** Initial pH of water 6.8. Final pH of solution 7.5-8.0.

Each structural configuration has different effects on ground water flow systems. Where rock formations dip with the ridge slope, the Wells Formation conducts water directly from recharge areas on ridge tops to regional ground water flow systems. Large volumes of snow melt do not reach the Dinwoody Formation because much of the recharge water enters the Wells Formation.

Synclinal structures under ridges are generally found where rock formations dip into the topographic slope. The synclinal structure, combined with the low hydraulic conductivity of the Phosphoria Formation, control the development of numerous local and intermediate ground water flow systems within the Dinwoody Formation. Spring discharge is most frequent in the lower Dinwoody member.

In complex fault block areas, geologic structure and the location of the Phosphoria Formation appear to greatly influence intermediate and regional ground water flow systems. Within fault block areas, lateral ground water flow may be retarded due to the vertical displacement of zones of high and low hydraulic conductivity.

Mine areas may occupy three general topographic positions on ridges. Mines may be located on ridge tops, on the flank of a ridge, or at the base of a ridge. Each topographic position affects the occurrence of flow systems within mine sites. Mines on ridge tops are within recharge zones only. Mines on ridge flanks may be in discharge areas for local or intermediate ground water flow systems; they may be in recharge areas for local, intermediate, or regional flow systems. Mines at the base of a ridge may be in the discharge area for regional, intermediate, or local ground water flow systems; they may be in the recharge area for regional flow systems.

Regional ground water discharge from the Wells Formation could cause significant pit flooding.

Broken local topography on ridge flanks induces local ground water recharge and discharge. Climatic conditions produce more local ground water flow systems and small streams on north and east facing slopes than on south and west facing slopes.

Impacts of mine pits on water resource systems depend on the type and size of flow systems intercepted by mine pits. Local ground water flow systems cause few problems to mine operations and produce the least hydrologic impacts. Intermediate ground water flow systems within the Dinwoody Formation may cause significant dewatering problems. Pit dewatering may affect spring and stream flows supported by the Dinwoody Formation. Regional ground water flow systems have the greatest potential to flood mine pits. Spring flow from regional flow systems will not likely be affected by mining unless significant dewatering operation are undertaken. Few impacts are observed from surface water flow into pits.

Flow systems within waste dumps show definite relationships to waste dump factors. Erosion of waste dumps, with a resulting increase in suspended sediments in surface waters, appears to be a greater hydrologic impact than quality of water which has leached through waste dumps.

CHAPTER VI

WATER RESOURCE SYSTEMS MODELS

Introduction

The most difficult task in predicting potential hydrologic impacts from mining is to identify the water resource systems which occur at the mine site. In particular, the ground water flow systems of proposed mine areas are difficult to identify before mining operations begin. The conceptual, qualitative models presented in this chapter can be used to identify the ground water flow systems that are most likely to occur at any given mine site. Furthermore, the models evaluate potential hydrologic impacts to the water resource systems from mining and they identify possible limitations to mining, based on the size and types of flow systems within the mine site.

The models presented in this chapter are based on ground water flow systems theory and on the regional, intermediate, and local flow system relationships outlined in chapters IV and V. The factors found to exert the greatest influence on flow systems within the study area are variations in topography, geology, climate, and hydraulic conductivity of geologic formations. Combinations of these factors are used to determine the ground water flow systems which are most likely to occur at any given mine site. The models are valid only for areas which contain the "Phosphate Sequence" of sedimentary rock units in well defined ridge and valley systems such as those found in the southern and eastern portions of the study area. The models cannot be used to reliably predict ground water flow systems in areas which are dominantly fault controlled and show no definite ridge and valley systems, such as the Gay Mine area.

Assumptions

Several assumptions are necessary for application of these models to ground water flow systems. It is assumed that the relative hydraulic conductivities of the geologic units are consistent over the study area; the Thaynes and Dinwoody formations exhibit moderate hydraulic conductivity, the Phosphoria Formation exhibits low hydraulic conductivity, and the Wells and Brazer Limestone formations exhibit high hydraulic conductivity. The hydrogeologic study conducted by Winter (1979), on ground water flow systems in the phosphate sequence, indicates that this is a valid assumption.

It is assumed that relationships between the environmental factors of geology, topography, hydrogeology and climate, and ground water flow system development are the same wherever the same combination of factors exists. Analysis of six existing mine sites in the area indicates that areas which have similar environmental characteristics have similar ground water flow systems. Ground water flow system theory also supports this assumption.

It is assumed that relationships between water resource systems, mining factors, and hydrologic impacts are similar, wherever the same combination of factors exists. Analysis of six existing mine sites in the area indicates that a given hydrologic impact is caused by a given combination of mining factors and water resource system factors. For example, a mine pit may reduce the flow of a spring issuing from the Dinwoody Formation if the mine pit intercepts the ground water flow to that spring.

Procedure

Mine Type Designation

To use the water resource systems models, follow the steps outlined below and enter the pertinent mine site information where indicated.

Step 1. Is the mine site located within a definite ridge and valley system (Example: Dry Ridge-Dry Valley, Schmid Ridge-Slug Creek Valley, Wooley Range-Enoch Valley, or Webster Range-Upper Valley)? Answer: Yes or No. If the answer is no the models do not directly apply (see the discussion on flow systems in fault block areas in chapter V). If the answer is yes continue.

Step 2. From fig. VI-1 select the topographic location of the mine site on the major ridge system. Choices are (1) ridge top, (2) ridge flank, or (3) ridge bottom. Selection should be made based on the location of the mine pits. If the bottoms of the mine pits will be no more than about 300 feet (90 meters) below the top of the major ridge, it is classified as "ridge top." For example, the Dry Ridge-Maybe Canyon Mine is classified as ridge top, even though it is not located at the summit of Dry Ridge. The mine occupies the crest of a large secondary ridge. Do not classify a mine as ridge top unless it is at the crest of the major ridge or unless it occupies a secondary ridge and the bottom of the mine pits will be substantially above adjacent valley floors. Mines are classified as "ridge bottom" if mine pits will extend below

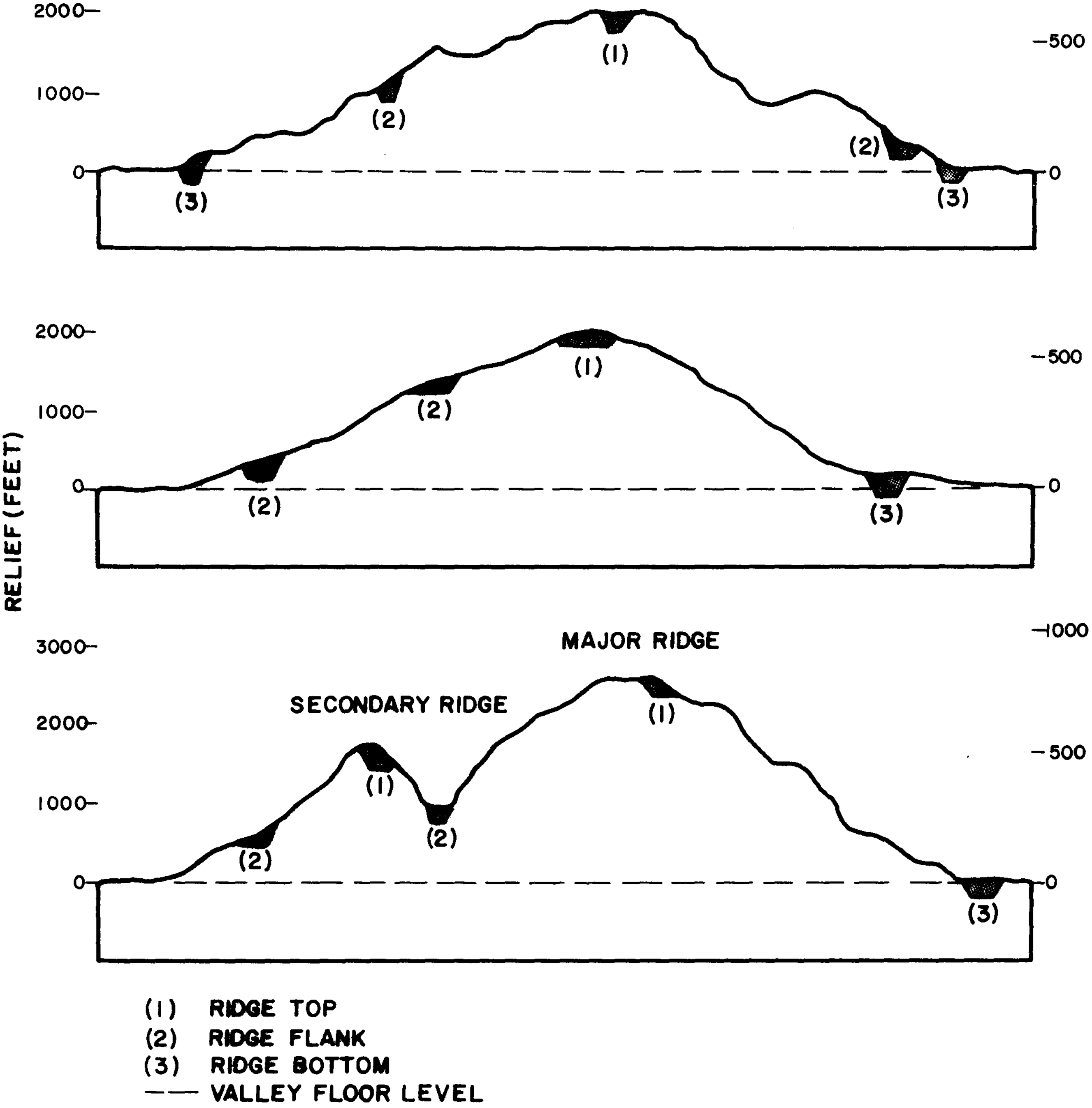


Figure VI-1. Diagrammatic sections showing possible topographic locations of mine sites.

the elevation of the adjacent valley floor. All mine sites located between ridge top or ridge bottom are classified as "ridge flank."

Step 3. From fig. VI-2, select the local topographic condition of the major ridge slopes. Choices are (A) broken ridge slopes and (B) smooth ridge slopes. Broken ridge slopes are characterized by numerous valleys, small ridges, and knolls which interrupt the major slope of the ridge. These topographic irregularities are in the order of 100 to 300 feet (30 to 90 meters) in relief. Many portions of the Aspen Range fit this classification. The western slopes of Dry Ridge and Snowdrift Mountain are good examples of smooth ridge slopes.

Step 4. From fig. VI-3, select the geologic configuration of the rock units at the mine site. Choices are (A) dip with slope and (B) dip contrary to slope. Geologic donfiguration should be chosen with respect to the location of the mine pits on the ridge. If geologic formations are slightly overturned and the Wells Formation or Brazer Limestone is located at the top of the ridge, choose dip with slope (A). If the geologic units are horizontal and the Dinwoody Formation is located upslope from the mine pits, choose dip contrary to slope (B).

Step 5. Select the slope aspect of the mine site. This should be the slope aspect of the major ridge slope. Choices are (A) north and/or east facing, and (B) south and/or west facing.

Step 6. The mine site should now have a one digit, three letter code which designates a specific mine type. An example is 2ABB. This particular designation means that the mine pits will be located on a ridge flank with broken local topography, the formations dip contrary to the topographic slope, and the slope faces either south or west or both.

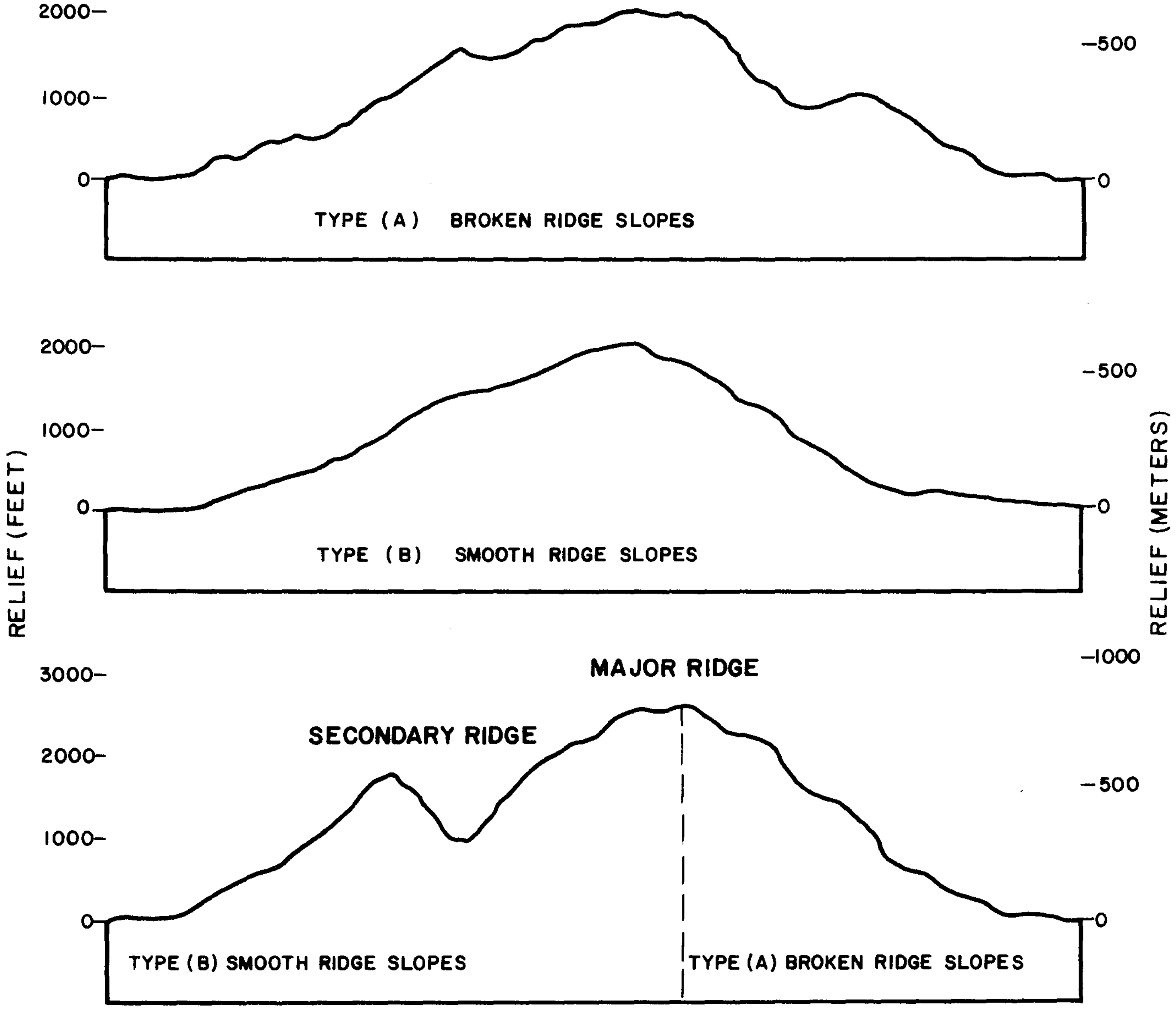


Figure VI-2. Diagrammatic sections showing possible topographic conditions of major ridge slopes.

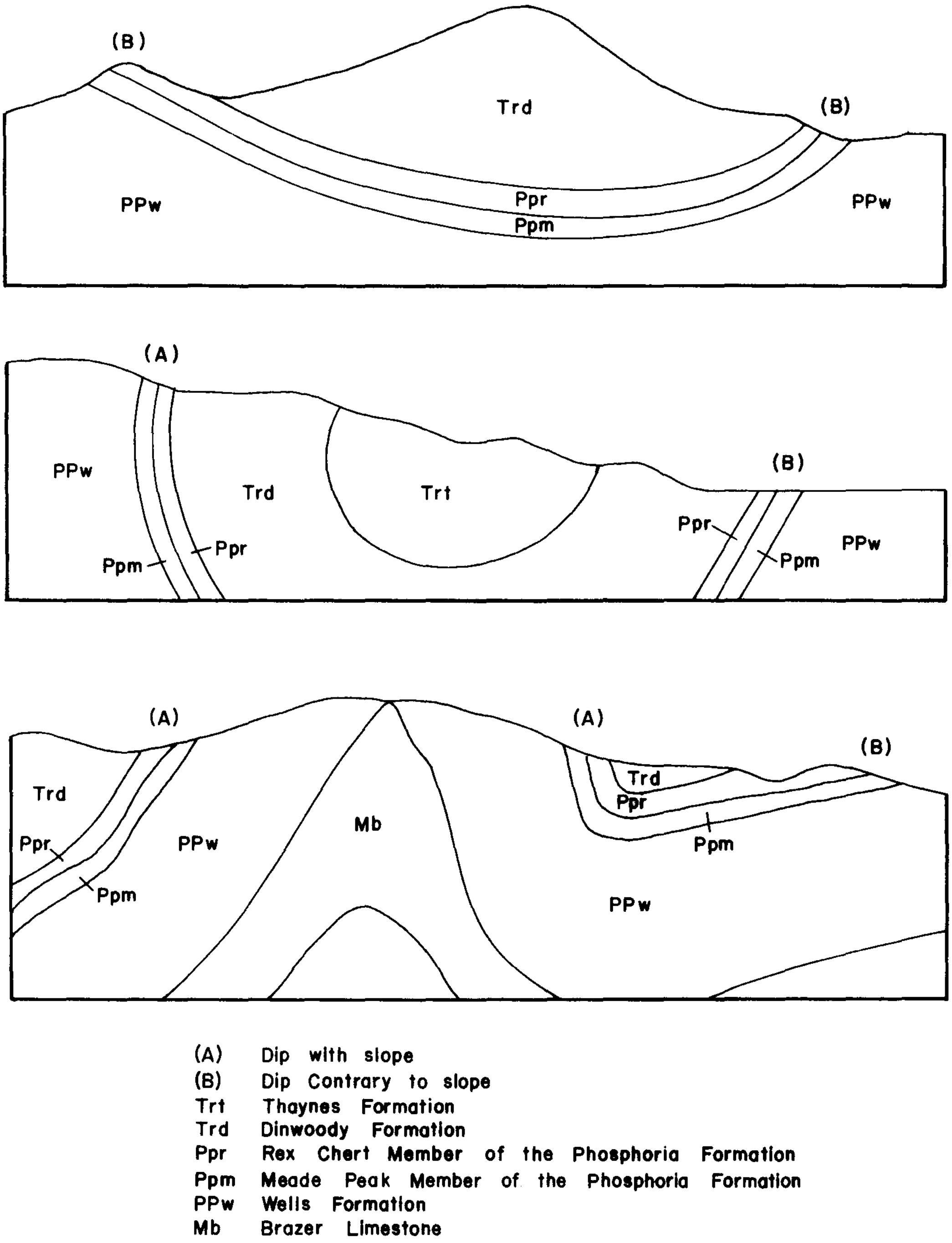


Figure VI-3. Diagrammatic sections showing possible geologic configuration of mine sites.

Flow Systems, Mining Limitations, and Hydrologic Impacts by Mine Type

Mine types are listed below for every combination of code symbols and a diagrammatic sketch of each mine type is presented in fig. VI-4. For each mine type there is a description of the probable ground water flow systems that will be encountered at the mine site. Expected limitations to mining created by ground water flow systems and expected impacts to ground water and surface water flow systems are also given.

Mine Types 1AAA, 1ABA, 1BAA, and 1BBA. These mine types all have similar ground water and surface water flow systems. The most dominant factors controlling flow systems at mine sites within this group are the ridge top location of the mine site and the amount of precipitation, in the form of snow, which accumulates at the mine site. All mine pits and waste dumps located on or near the ridge top are within recharge zones for local, intermediate, and regional ground water flow systems. They are also in the primary recharge area for small streams. Ground water discharge areas do not occur at these sites, with the exception of very small local flow systems. Discharges from these local flow systems dry up during summer months after the entire snowpack has melted.

There are few hydrologic limitations to mining created by discharge of surface water and ground water flow systems into mine pits because of the ridge top location. Water entering pits can only come from direct precipitation and snowmelt in the immediate area. Water discharge into pits during summer months is negligible. The greatest hydrologic problems to mining may be stability problems in pit walls and in waste dumps during periods of rapid runoff. Waste dumps located on

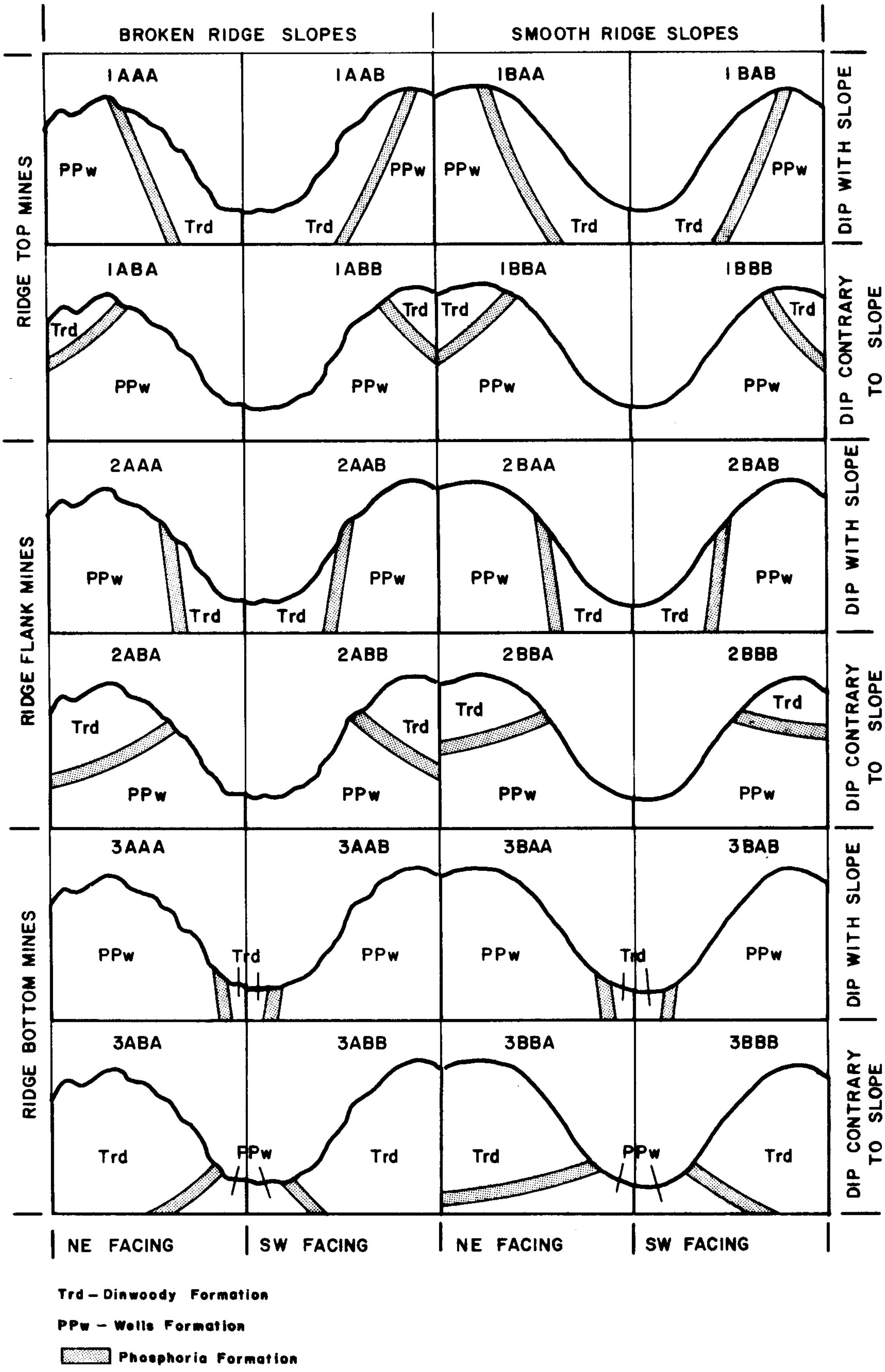


Figure VI-4. Diagrammatic section for each mine type.

steep dip-slopes and in areas of high snow accumulation are especially prone to instability during periods of rapid snowmelt. Pits may accumulate vast quantities of snow which could restrict mining operations to summer months only.

Hydrologic impacts from these mine sites will be caused primarily from interception of recharge by pits and waste dumps. Precipitation and local runoff captured by mine pits could reduce local surface water flow and increase recharge to ground water flow systems; however, the magnitude of this change is probably small. Waste dumps which collect large snowdrifts may develop local ground water flow systems during the snowmelt season. These waste dump flow systems may discharge water that is of lower quality than natural spring water. Erosion of unvegetated waste dumps during periods of rapid snowmelt is likely and increased sediment load of small local streams may result. For these mine types, waste dumps will have greater impacts to the local water resource systems than will mine pits. Impacts to intermediate and regional ground water flow systems are expected to be minimal.

Mine Types 1AAB, 1ABB, 1BAB, and 1BBB. These mine sites are also located on ridge tops. They have the same characteristics as the first group, with the exception of having a south or west slope aspect. Mine sites in this group will have the same types of flow systems, mining limitations, and hydrologic impacts as the first group, but the magnitude of the mining limitations and hydrologic impacts will be less because of less snow accumulation on southern and western slopes.

Mine Type 2AAA. Ground water flow systems encountered in the mine pits will be local in extent. No regional ground water discharge will be present in the mine area. Small seeps, springs, and streams within the Dinwoody Formation may be numerous downslope from mine pits.

Hydrologic limitations to mining are minimal in pit areas. Ground water discharge into pits will be small. Pit wall stability problems could be caused by local ground water and surface water flow during spring months. Large snow accumulations could occur in pit areas. Waste dumps downslope from mine pits could develop stability problems if they are on steep dip-slopes and if they accumulate large quantities of snow.

Mine pits may cause hydrologic impacts where they intercept local ground water flow systems. Small seeps and springs immediately downslope from mine pits may dry up or have reduced flow; however, the affected springs do not generally support base flow for perennial streams. Waste dumps could develop local ground water flow systems by intercepting recharge from precipitation or from seeps and springs. Erosion of unvegetated waste dumps is likely, especially where they occupy steep dip-slopes.

<u>Mine Type 2AAB</u>. Characteristics of this mine type are similar to those of 2AAA except that this type has a southern or western slope aspect. Hydrologic limitations to mining and impacts to water resource systems are similar but smaller in magnitude because of less recharge available to local ground water flow systems.

<u>Mine Types 2BAA and 2BAB</u>. These mine types are located within recharge zones for almost all ground water flow systems. Few, if any, springs are found in the vicinity of the mine pits. If springs do exist they are from shallow flow systems which generally dry up during summer months. No regional ground water discharge will be present in the mine

area. Water discharge into mine pits may occur in the spring during periods of rapid runoff; most water entering mine pits will be from direct precipitation into pits and from snowmelt a short distance upslope from the pits. Small seeps and springs may occur within the Dinwoody and Thaynes formations downslope from the mine pits. Seeps and springs are more likely in type 2BAA than in type 2BAB.

No serious limitations to mining are caused by discharge of ground water or surface water flow systems into mine pits. Pits in mine type 2BAA may accumulate large quantities of snow. Waste dumps may have stability problems if they are deposited on smooth dip-slopes.

The largest potential hydrologic impact is from poor quality water produced by erosion of waste dumps. Waste dumps in mine type 2BAA may develop local ground water flow systems. Mine pits will not reduce the flow of springs which supply stream baseflow.

<u>Mine Types 2ABA and 2BBA</u>. Discharge from local and intermediate ground water flow systems is likely to be encountered, especially if the mine site is located near the lower portion of the ridge flank. Mine type 2ABA will have more local ground water flow systems than type 2BBA because of the broken topography. Discharge from regional ground water flow systems is not likely to occur at these mine sites.

Spring and stream flows which issue from the lower Dinwoody Formation above the mine pits may interfere with mining operations. Discharge will be greatest during spring runoff and early summer. The quantity of water entering the pits will not be too great to control, but it may create erosion and stability problems in pit walls. Water entering mine pits could possibly be drained into the underlying Wells Formation through drill holes.

Impacts to water resources could be in the form of reduced spring and stream flow in the immediate area because of ground water intercepted by pits. Diversion of small streams may be required in some pit areas. Some springs affected by mining may support base flow for small streams, but the springs and streams affected usually flow only short distances and infiltrate into the Wells Formation. Erosion of waste dumps has a high potential to increase sediment load of small streams.

Mine Types 2ABB and 2BBB. The hydrologic condition of these mine types is similar to that of types 2ABA and 2BBA, except these mines have a southern or western exposure. Shallow, local ground water flow systems may contain less flow because of the slope aspect, especially in type 2BBB. The lower Dinwoody Formation is likely to support intermediate ground water flow systems which discharge to springs above mine pits. Regional ground water discharge is not likely to occur at these mine sites.

Limitations to mining will be primarily from discharge of ground water into mine pits from the lower Dinwoody Formation. Water entering mine pits could possibly be drained into the underlying Wells Formation.

Impacts to water resource systems are similar to those in types 2ABA and 2BBA.

Mine Types 3AAA and 3BAA. Ground water flow systems encountered at these mine sites will be predominantly regional in extent. Broken topography of type 3AAA may develop local ground water flow systems if enough recharge is available.

Serious limitations to mining will occur if mine pits intercept discharge from regional ground water flow systems. Regional ground water flow will likely to encountered if mine pits extend significantly below the elevation of nearby valley floors. Elevation of the water table should be measured with test wells before final pit depths are planned. Elevations of nearby springs with large discharges should be noted. The Wells Formation, Dinwoody Formation, and valley alluvium could all contribute to ground water discharge into mine pits. The shallow, local ground water flow systems upslope from mine pits will not significantly influence mining operations.

Discharge of regional ground water flow systems into mine pits should not affect regional ground water elevations and spring flows unless extensive dewatering operations are carried out. Local seeps and springs may be eliminated; however, these small discharge points generally do not supply base flow for perennial streams. Large waste dumps deposited on the valley floor may develop local ground water flow systems. Erosion of waste dumps on valley floors should be minimal if they are revegetated and do not occupy a flood plain.

Mine Types 3AAB and 3BAB. Ground water flow systems encountered at these mine sites are likely to be only regional in extent. Type 3AAB may have some shallow local flow systems that discharge to seeps or springs during the snowmelt season. Mining limitations and impacts are similar to types 3AAA and 3BAA.

Mine Types 3ABA, 3BBA, 3ABB, and 3BBB. Ground water flow systems encountered at these mine sites will likely be local, intermediate, and regional in extent. Local and intermediate ground water flow systems are located within the colluvium and Dinwoody Formation upslope from the mine pits. Regional ground water flow occurs within the Wells Formation and possibly within the valley alluvium. Discharge from all types of ground water flow systems and from streams may occur in the mine area. Intermediate flow systems from the Dinwoody Formation discharge at springs which support base flow for small streams.

Hydrologic problems to mining could be great. Spring and stream discharge from the Dinwoody Formation is likely to enter mine pits. Erosion and stability problems in pit walls may result. Diversion structures may be needed for some streams. Regional ground water discharge may enter pits if they extend significantly below the valley floor and large scale dewatering operations could be required.

Hydrologic impacts may be greatest to local and intermediate ground water flow systems which support base flow for perennial streams. Impacts to regional spring discharge should be minimal unless extensive pit dewatering operations are conducted. Large waste dumps in valley floors may develop local ground water flow systems. Erosion potential for valley floor waste dumps is low if dumps are revegetated and do not occupy a flood plain.

Discussion of Model Predictions

The descriptions for each mine type give the probable ground water flow systems which will be encountered. The expected mining limitations and impacts on the water resource systems are based on the predicted ground water flow systems. Mining limitations and hydrologic impacts at any particular mine site may be more or less depending upon the exact location and type of ground water flow systems which occur in the area. Field investigation of the mine site to measure spring discharge, stream flow, and ground water elevations in all geologic formations should be made to verify the presence of the predicted flow systems. If the ground water flow systems exist at the mine site as shown by the models, then the limitations to mining and the pit-related hydrologic impacts will occur as given by the models. Hydrologic problems caused by pit construction are difficult to mitigate because pit location and construction are governed by location of the phosphate ore. Impacts relating to waste dumps may vary from those predicted depending upon waste dump placement and construction techniques.

Table VI-1 shows the rank of each mine type, from highest to lowest, for the parameters of (1) potential discharge of local ground water flow systems into pits, (2) potential discharge of intermediate ground water flow systems into pits, (3) potential discharge of regional ground water flow systems into pits, (4) potential hydrologic limitations to mining due to flow systems entering pits, (5) potential impacts to springs which supply base flow for perennial streams, and (6) potential waste dump erosion and instability from water movement through dump (assuming waste dump is unvegetated and downslope from pits).

The information contained in chapters IV and V should be used to obtain more detailed information on flow systems, mining limitations, and hydrologic impacts for each mine type. Information is given in these chapters for each parameter of the mine type code (topographic

Table VI-1. Rank of mine types for various parameters.

RANK	PARAMETER					
	Potential for discharge of ground water flow systems into pits				Potential for impacts to springs which supply base flow to perennial streams	Potential for waste dump erosion and instability from water movement through dump
	Local	Intermediate	Regional	Limitations to mining		
HIGH	3ABA	3ABA	3ABA	3ABA	3ABA	1BAA
	2ABA	3BBA	3BBA	3BBA	3BBA	1AAA
	3BBA	3ABB	3ABB	3ABB	3ABB	1BBA
	2BBA	3BBB	3BBB	3BBB	3BBB	1ABA
	3ABB	2ABA	3AAA	3AAA	2ABA	2BAA
	2ABB	2BBA	3BAA	3BAA	2BBA	2AAA
	3BBB	2ABB	3AAB	3AAB	2AAB	2BBA
	2BBB	2BBB	3BAB	3BAB	2BBB	2ABA
	2AAA			2ABA		1BAB
	2AAB			2BBA		1AAB
	2BAA			2ABB		1BBB
				2BBB		1ABB
MEDIUM	2BAB			2AAA		2BAB
	3AAA			2BAA		2AAB
	3BAA			2AAB		2BBB
	3AAB			2BAB		2ABB
	3BAB					
LOW	1ABA	All Others	All Others	1AAA	All Others	3AAA
	1BBA			1ABA		3BAA
	1AAA			1BAA		3AAB
	1BAA			1BBA		3BAB
	1ABB			1AAB		3ABA
	1BBB			1ABB		3BBA
	1AAB			1BAB		3ABB
	1BAB			1BBB		3BBB

location, topographic condition, geologic configuration, and slope aspect of the mine).

Reliability of Models

The models presented in this paper should predict ground water flow systems at proposed mine sites with a high level of reliability, when the mine sites are located within the specified environment. The models can only be used in areas where the "Phosphate Sequence" of sedimentary rocks occur in definite ridge and valley systems and the geologic structure must be dominated by folds and not by fault blocks. The models are based on ground water flow systems theory and on the observed relationships between flow systems and environmental factors of the study area. The models accurately represent the general ground water flow systems observed in six mine areas, which further insures their reliability. The predicted hydrologic limitations to mining and hydrologic impacts created by mining should be highly reliable as they are based on flow systems theory and on observed limitations and impacts. The predicted impacts from waste dumps will not be as reliable as those predicted for pits because many additional variables enter into the construction and location of waste dumps. These variables are discussed in Chapter V.

In some cases, the models may not accurately predict the ground water flow systems at mine sites due to the influence of variables not accounted for. These variables could be geologic factors such as faults, joints, or local folds, or they could be unknown local hydraulic conductivity changes in geologic formations. All models are simplifications of real systems. They portray the general characteristics of a real system but may not represent the system in certain areas due to the influence of unknown variables. The variables used in these models, which include geologic structure, topographic profile, hydraulic conductivity distribution, precipitation distribution, and ground water elevations, are felt to be the most representative variables for real systems and therefore they should give reliable results.

CHAPTER VII

CONCLUSIONS

The general conclusions from this study are as follows:

1. Ground water flow system theory provides the theoretical basis for the formulation of conceptual models of water resource systems of the southeastern Idaho phosphate field. Ground water flow system theory demonstrates how the environmental factors of geology, topography, hydraulic conductivity, and fluid potential control ground water flow.

2. Definite relationships between environmental factors and development of water resource systems have been observed in the study area. Past hydrogeologic studies have shown that relationships exist between geologic formation type and ground water flow systems. This study demonstrates that additional relationships exist between topographic, geologic, and climatic factors and flow system development.

3. Relationships between existing water resource systems, mining activities, and water resource impacts have been observed. The degree of hydrologic impacts from mining is related to the size (local, intermediate, or regional) and types (ground water or surface water) of flow systems encountered at the mine site. Hydrologic limitations to mining are dependent primarily on the size and types of flow systems intercepted by mine pits.

4. Conceptual models have been developed which can be used to identify water resource systems at existing and proposed mine sites in the southeastern Idaho phosphate field. The models delineate ground water flow systems based on the geologic structure, topographic configuration, topographic location, and climatic conditions of the mine area.

5. The models evaluate potential mining impacts on the water resources and they predict potential hydrologic limitations to mining, based on the size and types of flow systems which occur at the mine site. The evaluation of mining impacts and potential mining limitations relies on the relationships which have been observed between existing water resource systems, mining activities, and impacts on water resource systems.

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16. Abstract

Complex water resource systems occur within the southeastern Idaho phosphate field. Environmental factors such as the geologic, topographic, hydrogeologic, chemical, and climatic characteristics of the area largely control the occurrence, movement and quality of these water resource systems. Mining operations have the potential to impact the water resource systems through alteration of the existing environmental characteristics. At certain mine sites the water resource systems have the potential to interfere with mining operations through mine pit flooding and through pit and waste dump stability problems. Potential hydrogeologic impacts from mining and potential hydrologic limitations to mining are often difficult to predict because of the many variables involved.

Hydrogeologic studies in the southeastern Idaho phosphate field show that there are definite relationships between geologic, topographic, hydrogeologic, and climatic factors and existing ground water flow systems. Analysis of existing mine sites shows that relationships exist between the water resource systems which occur at a mine site and the potential hydrologic impacts from mining. Hydrologic limitations to mining are also related to the water resource systems which occur at the mine site.

Ground water flow system theory and observed water resource systems relationships were used to develop conceptual models that identify water resource systems at mine sites and evaluate mine sites for potential hydrologic impacts and mining limitations. The conceptual models can be used for existing or proposed mine sites. The models are expected to yield highly reliable results when used as specified.

17a. Descriptors Mine drainage

17b. Identifiers Southeastern Idaho

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