Research Technical Completion Report
Project C-7651

# INTERACTIONS OF MINING AND WATER RESOURCE SYSTEMS IN THE SOUTHEASTERN IDAHO PHOSPHATE FIELD

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# ABSTRACT

The early identification of water resource problems related to mining activities in a largely unmined area is necessary for resource development balanced with environmental management. The Western Phosphate Field, most of which is located in southeastern Idaho, offers an opportunity for effective conflict identification and for problem resolution prior to extensive mining developments. The general objective of this study was to analyze water resource impacts from the interaction of hydrologic and mining variables within the Western Phosphate Field. One of the outputs of the study is a model which may be used to predict water resource impacts based upon key mining and hydrologic variables. This report summarizes the results presented in four theses and one dissertation by graduate students of the College of Mines and Earth Resources and the College of Engineering at the University of Idaho.

The water resource systems in the Western Phosphate Field are the result of the interaction of a number of environmental factors. These may be classified under the following general headings: geologic, topographic, hydrologic, climatic, chemical and biotic factors. The mining activities which have the largest potential to affect water resource systems are the development of open pits and waste piles. Prediction of water resource impacts on and from mining can only be accomplished if it is known how changes in environmental conditions affect flow systems, because mining necessarily alters the environment of a mine site.

Past hydrogeologic research efforts have indicated that a regional pattern of ground water flow exists in the "phosphate sequence" of geologic units (Dinwoody, Phosphoria and Wells formations). This hypothesis of regional flow continuity was examined through a study of stream gains and losses and the locations of springs. The study confirmed that the following pattern of hydrogeologic characteristics occurs throughout the Idaho phosphate area: the Dinwoody and Thaynes formations support ground water flow systems, none of the members of the Phosphoria formation support significant ground water flow, and the Wells formation has sufficient hydraulic conductivity to support major ground water flow systems.

Detailed studies of two mine areas were conducted to obtain additional hydrogeologic insight on flow patterns in the "phosphate sequence" of geologic units. The Gay Mine of J.R. Simplot is located in a complexly faulted and folded area north and west of most of the existing phosphate development. The study of this mine provides information on a complex structural setting plus existing pit dewatering problems. The northern continuation of Monsanto Company's Henry mine extends across a portion of the valley of the Little Blackfoot River that is underlain by a considerable thickness of basalt. The formational pattern of hydraulic conductivity found throughout the region was common to the "phosphate sequence" in both mine areas. However, the flow systems at the Gay Mine are dominantly controlled by a pattern of folding and faulting that causes a block of Wells formation to be hydrologically isolated. Ground water levels in this block provide a lower limit to mining without a significant dewatering program. Only discontinuous ground water flow systems occur in the overlying Dinwoody and Thaynes formations.

Ground water in the basalt is the most important of the three flow systems identified at the North Henry Mine site. The Little Blackfoot River loses flow into the basalt through what is believed to be a

partially collapsed lava tube. Water level records show that the basalt aquifer is hydrologically connected with higher hydraulic conductivity zones in the Rex Chert Member of the Phosphoria formation. However, the total volume of water moving from the basalt into the Phosphoria formation is believed to be small.

A limited study of phosphate waste piles showed that chemical leaching and associated acid production is not a problem. The pH of leachate was above 7 because of the high carbonate content of the units disturbed by mining.

Theoretical patterns of ground water flow were utilized in the formulation of conceptual models of water resource systems for the southeastern Idaho phosphate field. The regional continuity of hydraulic conductivity distribution between formations of the "phosphate sequence" was also used as a basis for the models. Potential mine sites were classified based upon the dip of the units with respect to topography, the topographic pattern and location of the mine sites and the orientation of sites with respect to prevailing storm patterns and associated snow accumulation. For example, a mine that is located on a northeast facing slope near the top of a smooth ridge where the dip of the units is parallel to slope will have a different pattern of ground water flow than a site near the bottom of a southwest facing broken ridge where the units dip contrary to slope. The models that have been constructed may be used to evaluate both the mining impacts on the water resource systems and the hydrologic limitations to mining. The delineation of impacts is based on the size and types of flow systems which occur at the mine site.

A water quality model of the upper Blackfoot River basin was constructed to provide a basis for the projection of stream water quality impacts from various levels of mining activities. The steady state model is operated by inputting the possible waste loads and simulating the downstream effects.

# CHAPTER I

# INTRODUCTION

## Statement of the Problem

The early identification of water resource problems related to mining activities in a largely unmined area is necessary for effective resource development balanced with conservation management. The Western Phosphate Field, 85 percent of which is located in the southeastern Idaho area, offers an opportunity for effective conflict identification and for problem resolution prior to extensive mine developments (figure I-1). The hydrologic and mining related variables must be identified and their interaction evaluated in a systematic manner for problem identification. The presentation of variable interaction in a model format permits useful applications by administrative and regulatory personnel. The importance of the Western Phosphate Field in Idaho, Utah, Wyoming, and Montana, in terms of national needs for phosphate fertilizer and other phosphate utilization, underscores the significance of the prototype hydrologic research in this area.

Regionalized mineral resource development, such as the phosphate area of eastern Idaho, occur within a geologic framework that has regionally common characteristics. As a result, ground water flow characteristics also have regionally common characteristics. The analysis of the hydrologic variables of regional ground water flow in the phosphate mining area as related to mining activities serves as a prototype for similar investigations in other regions.

This research is the out-growth of a number of events that occurred

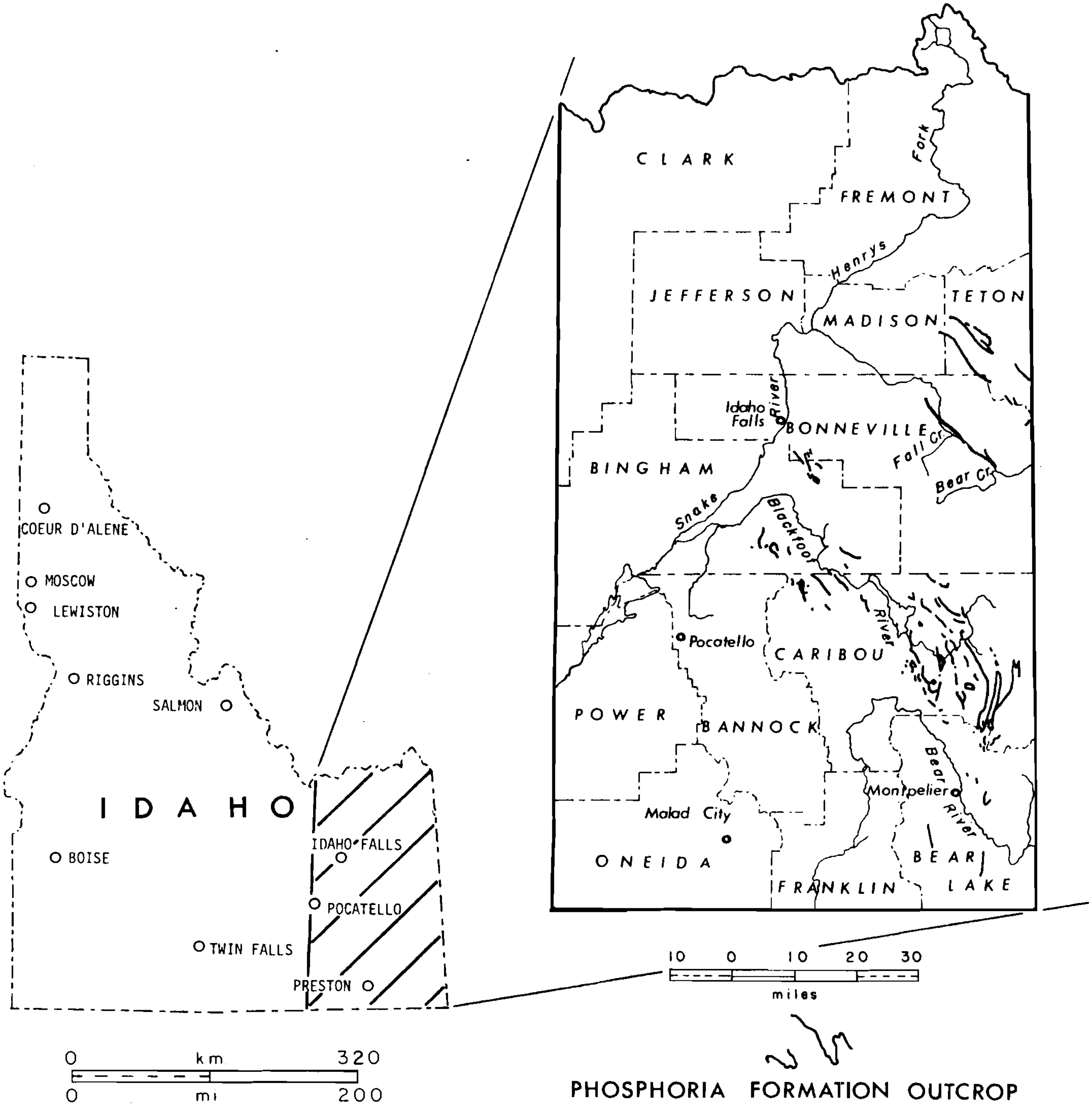


Figure I-1. Location of Phosphoria Formation outcrops in the southeastern Idaho phosphate field (after Ralston, et al., 1977).

both within the State of Idaho and across the nation in the early 1970's. The increased need for particular minerals and the associated increase push for mineral resource development generally conflicted with an increased awareness of the need for environmental protection during mineral resource development. The assessment procedure known as the Environmental Impact Statement grew into full bloom in the 1970's. An example of this was the environmental impact statement entitled "Development of Phosphate Resources in Southeastern Idaho" published in 1977. One of the main criticisms of this statement was the lack of a sound understanding of the interaction of hydrologic and mining variables upon which to base an assessment of potential impacts. At the same time, a University of Idaho study of ground water flow systems in the phosphate area supported by the U.S.D.A. Forest Service delineated a complex pattern of ground water-surface water systems in the areas to be mined. The Forest Service supported research, conducted from 1974-1977, resulted in the collection of water resource data at several potential mine sites. Preliminary hypotheses of regional patterns of ground water-surface water flow systems were formulated as a part of this study. Numerous research constraints, however, prevented the testing of these hypotheses or the formulation of a model of variable interaction that would be understandable to lay and technical people alike. The strong public interest in the Western Phosphate Field and in the regionalized analysis of hydrologic and mining variables resulted in the funding of this project by O.W.R.T. under Title II in 1976.

## Purpose and Objectives

The general objective of this research was to formulate a management analysis of water resource impacts from the interaction of key hydrologic and mining variables within the Western Phosphate Field. Specific objectives are noted below.

1. To delineate the climatological, hydrologic and hydrogeologic variables important in the Western Phosphate Field.
2. To delineate the mining related variables that would interact with the water resource systems including both surface and ground water.
3. To integrate these variables and analyze the combined effects on the total water resource systems.
4. To construct a management alternative model for use in administrative and regulatory functions.

## Method of Study

The project was divided into several phases. The first phase was the delineation of hydrologic and mining related variables that would be important in the analysis of potential water resource impacts from mining. The second phase involved the collection and analysis of additional water resource and mining data at selected sites in southeastern Idaho. This phase was divided into several subprojects. The first of these was an analysis of regional ground water flow systems. This involved the testing of two major hypotheses. The first hypothesis was that ground water flow systems occurred in a systematic manner related to the stratigraphic and structural features of the area. The second hypothesis was that there was areally consistent ground water control by specific lithologic units in the "phosphate sequence" (Dinwoody, Phosphoria and Wells formations) of geologic units within the phosphate mining area. A second subproject dealt with the hydrology of mine pits. Several mine sites were investigated to provide additional information on the interaction of hydrologic and mining variables in the construction and abandonment of open-pits. The mining sites were selected to compliment the information collected as part of previous University of Idaho research in the phosphate area. A third subproject dealt with the hydrology and hydrochemistry of waste piles. This hydrochemistry was completed by both laboratory leaching experiments and field water quality data collection and analysis. The research efforts dealing with the hydrology of mine waste piles were reduced because of concurrent investigations being conducted by the Intermountain Research Station of the U.S.D.A. Forest Service and the Department of Agricultural Engineering at the University of Idaho. Limited drilling and study of waste piles was done at several mine sites to gain a better understanding of the important variables for management analysis.

The third major phase of the project included the construction of a model showing variable interaction. This phase of the study was completed based upon inputs from other phases and results from previous research. The third phase also included construction of a water quality model for the Upper Blackfoot River basin. The final phase of the project was the preparation of papers, theses and this final report.

The overall research project had input from six individuals. The regional ground water flow systems subproject was completed by two graduate students. Gerry Winter prepared his Master's thesis in Hydrology dealing with the testing of hypotheses of regional ground water flow and regionalized control of flow patterns by specific lithologic units. Harb Singh worked on the construction, verification and analysis of a water quality-quantity model for the Upper Blackfoot River basin as his Ph.D. dissertation in Civil Engineering. Tom Brooks and Tom Corbet completed their Master's theses in Hydrology on the pits and waste piles subproject. Tom Corbet worked cooperatively with the J.R. Simplot Company in analyzing ground water flow systems in and around existing and potential pits and waste piles at the Gay Mine. This mine provided a unique opportunity to look at an area more complexly faulted and folded than most of the mining region. Tom Brooks studied water resource systems near potential pit and waste pile sites for the northern extension of the Henry Mine of the Monsanto Company. The ground water flow patterns at this mine are complicated by the presence of basalt flows and the presence of a major stream in the mining area. Tom Brooks also spent a limited period of time looking at the proposed Sulphur Canyon Mine of the J.R. Simplot Company. This mine site is more geologically complex than most sites within the region and thus of particular interest.

Dr. Chein Wai, Associate Professor of Chemistry and Geology at the University of Idaho, did research on the hydrochemistry of mine wastes. His studies included laboratory leaching experiments of wastes from various sites plus limited field sampling of water from several test holes drilled in selected waste piles.

Mike Cannon completed his Master's thesis in Hydrology dealing with the construction of a model showing variable interactions in the phosphate region of southeastern Idaho. Finally, Dr. Dale R. Ralston supervised all of these student theses, provided the overall direction for the project and was primarily responsible for the final product.

A listing of papers and theses resulting from this study is presented below.

Cannon, M. R., 1979, Conceptual models of interactions of mining and water resource systems in the southeastern Idaho phosphate field: University of Idaho, M.S. Thesis, 106 p.

Brooks, T. D., 1979, Hydrogeology of the proposed North Henry Mine, southeastern Idaho: University of Idaho, M.S. Thesis in progress.

Corbet, T. F., 1979, Hydrology of the Gay Mine area, southeastern Idaho: University of Idaho, M.S. Thesis in progress.

Ralston, D. R.; Cannon, M. R. and Winter, G. V., 1979, Ground water flow systems in the Western Phosphate Field in Idaho: Symposium on Mine Hydrology, Denver, Colorado.

Singh, Harbhajan, 1979, Construction and application of a water quality model for the Upper Blackfoot River basin in Caribou National Forest, Idaho: University of Idaho, Ph.D. Dissertation in progress.

Winter, G. V., 1979, Ground water flow systems of the phosphate sequence, Caribou County, Idaho: M.S. Thesis, University of Idaho, 120 p.

Winter, G. V. and Ralston, D. R., 1979, Ground water flow systems in the "phosphate sequence" of southeastern Idaho: Seventeenth Annual Engineering Geology and Soils Engineering Symposium, Moscow, Idaho.

## Acknowledgements

It is important to acknowledge the major input from the mining industry in the phosphate region of southeastern Idaho. The J.R. Simplot Company and the Monsanto Company provided not only cooperation but support for this research effort. This involved time from company geologists and engineers and also drilling services. Other mining companies, including Stauffer Chemical, Beker Inc., Alumet Company and the F.M.C. Company, provided input and time to Mike Cannon in his overall survey and analysis of mining and hydrologic variables and their interaction.

The authors wish to acknowledge the input provided by a number of faculty members at the University of Idaho. Special thanks go to Dr. Myron Molnau and Dr. Muriel Robinette. The authors also wish to thank the secretarial and drafting input by Sue Line and Trudy Peak.

# CHAPTER II

# HYDROLOGIC AND MINING VARIABLES AND THEIR INTERACTION IN THE WESTERN PHOSPHATE FIELD

## 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 anticapated, 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 in the 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 quality where water percolates through fractured waste rock as in mine waste piles.

3. pH balance between 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. 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).

### Waste Dump Factors

Construction of waste piles involves several factors that may affect the occurrence, movement, and quality of flow systems. These include:

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).

## Potential Impacts of Phosphate Mining On Water Resource Systems

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.

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 II-1.

## Water Quality

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

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

| X Designates Variable Interaction<br>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 |

areas of heavy precipitation and rapid surface runoff. Waste dump areas are particularly vulnerable to erosion.

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 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 III

## REGIONAL ANALYSIS OF GROUND WATER FLOW PATTERNS

### Introduction

Past hydrogeologic research efforts have been site specific but the results of these studies are similar. Ground water flow systems exist in the Thaynes and Dinwoody formations that usually occur stratigraphically above the Phosphoria formation which contains the phosphatic ore beds (Ralston and others, 1977). The Phosphoria formation does not support any major ground water flow systems but the Wells formation that underlies it was found to support such a system (Ralston and others, 1977). These similarities were found even though the region has been extensively folded and faulted. This study will examine the ground water flow systems of the "phosphate sequence" in Caribou County, Idaho over a larger area than any previous hydrogeologic research effort.

The low precipitation received in this research area prior to the summer of 1977 was particularly advantageous to the type of study undertaken. Ground water flow systems receive their principle recharge from the spring snow melt. The low volume of recharge available in 1977 was rapidly discharged from those ground water flow systems with a short flow path or a low storage capability. Only those ground water flow systems of significant length or storage capability continued to discharge during this period. This extended discharge exists due to the capability of the ground water flow system to store and discharge water that was recharged over more than one recharge period.

Extensive ore reserves exist in the Western Phosphate Field of

Idaho where mining has not been initiated. Little information is available on the ground water flow systems in these areas. The potential impact of phosphate mining on the hydrogeology and hydrology of the area can only be evaluated if the capability of the formations to support ground water flow systems is understood. The purpose of this study is to evaluate the ground water flow systems present in the geologic units stratigraphically near the Phosphoria formation.

The general objective of this study is to test the hypothesis that similar ground water flow systems exist within the "phosphate sequence" of geologic units throughout a large area of the Western Phosphate Field of Caribou County, Idaho. These geologic units include the Dinwoody, Phosphoria and Wells formations.

The specific objectives of this study are:

1. Test the hypothesis that major ground water flow systems exist in the upper member of the Dinwoody formation.
2. Test the hypothesis that major ground water flow systems exist in the lower member of the Dinwoody formation.
3. Test the hypothesis that the cherty shale member of the Phosphoria formation does not support major ground water flow systems.
4. Test the hypothesis that the Rex Chert member of the Phosphoria formation does not support major ground water flow systems.
5. Test the hypothesis that the Meade Peak Phosphatic Shale member of the Phosphoria formation does not support major ground water flow systems.
6. Test the hypothesis that major ground water flow systems exist in the upper member of the Wells formation.
7. Test the hypothesis that major ground water flow systems exist in the lower member of the Wells formation.

## Geography and Hydrology

The study area is located in southeastern Idaho and is a part of the Western Phosphate Field. Research was conducted in the area that lies between Soda Springs, Idaho, and the Wyoming state line as shown on figure III-1. Areas that should be noted include the Aspen Range, Slug Creek valley, Schmid Ridge, Dry Valley, Dry Ridge, Webster Range, Wooley Range, and Rasmussen Ridge. Elevations in the valleys and ridges range from about 6,500 feet (1,980 meters) above mean sea level (M.S.L.) to nearly 10,000 feet (3,050 meters) above M.S.L. with the ridges and valleys having a predominantly northwest to southeast trend. The major drainages are the Salt River to the east of the Webster Range, the Blackfoot River between the Webster and Aspen ranges, and the Bear River to the west of the Aspen Range.

Precipitation occurs principally as snow in the study area. The prevailing westerly wind causes the greatest snow accumulation on the east side of the ridges while decreasing significantly on the west slopes and valley floors (Ralston and Trihey, 1975). Since snow melt forms the greatest source of ground water recharge in this area, the east slopes of the ridges have the greatest potential for significant recharge.

The summer of 1977 was of particular importance for a ground water flow system study because of the preceding recharge period in which little precipitation occurred. Annual precipitation for Conda, Idaho is plotted on figure III-2 as is the annual streamflow of the Blackfoot River above the Blackfoot Reservoir. The magnitude of the low precipitation period is more accurately shown by the streamflow graph. Precipitation for the 1977 water year was lower than any preceding water

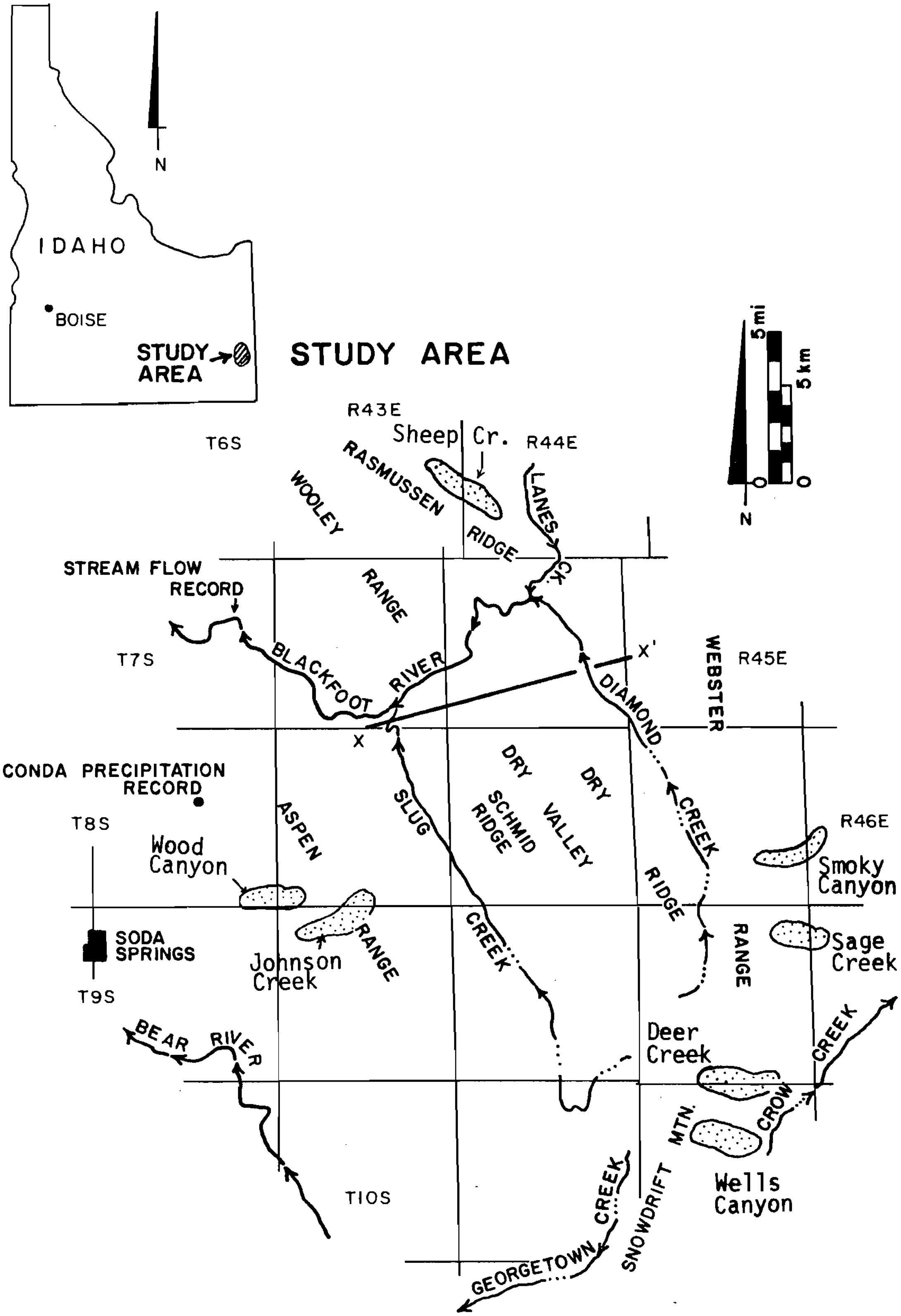
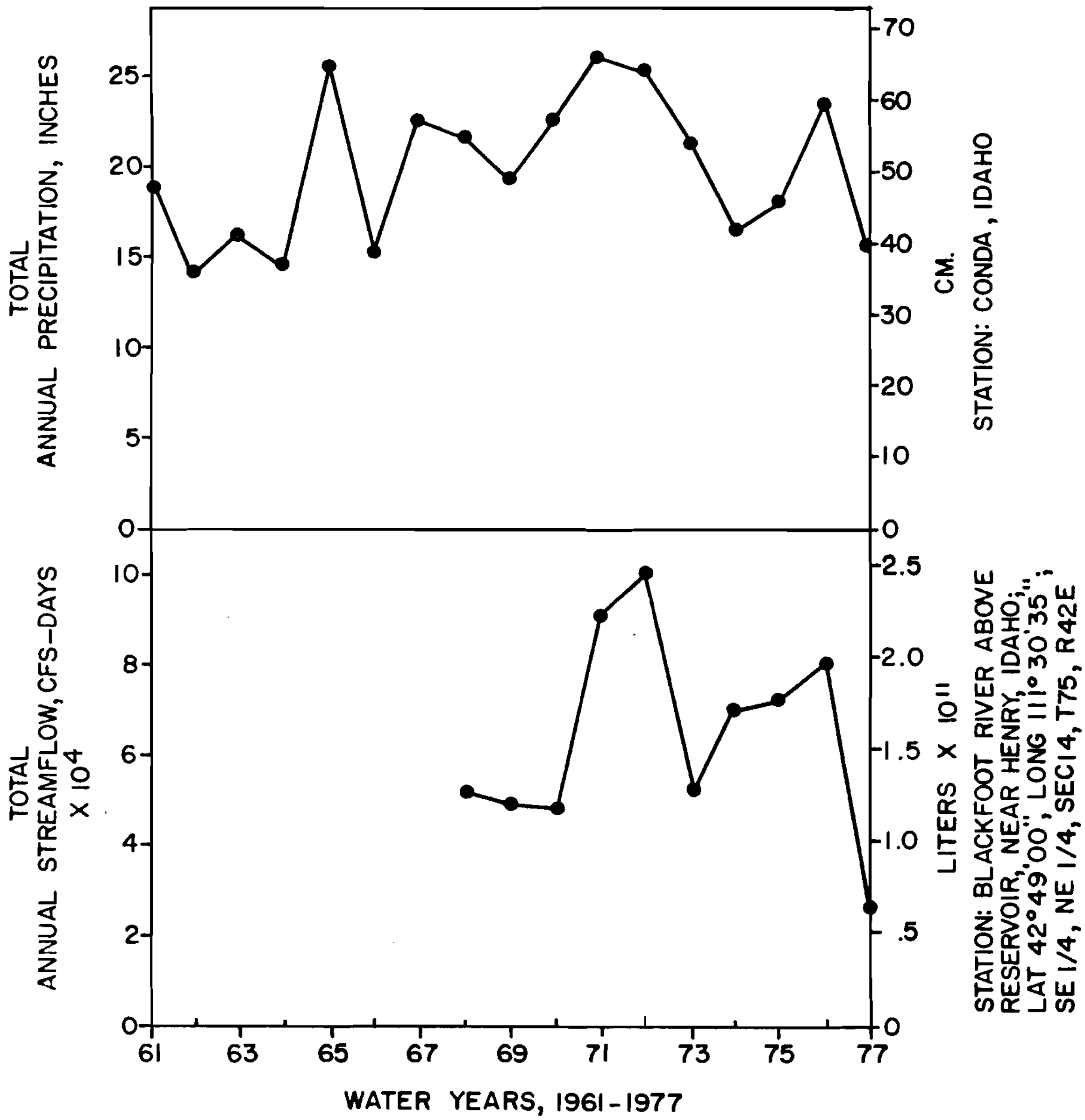


Figure III-1. Location map of study area showing stream gain-loss sites.



PRECIPITATION DATA SOURCE: U.S. DEPT. OF COMMERCE, NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

STREAM FLOW DATA SOURCE: U.S. DEPT. OF INTERIOR, GEOLOGIC SURVEY

Figure III-2. Annual precipitation and streamflow, Western Phosphate Field, Idaho.

year after 1966 while streamflow in the Blackfoot River was the lowest on record.

## Hydrogeology

The formations comprising the ground water flow systems that were encountered in this study are sedimentary in origin (table III-1). The Phosphoria formation is mined in the area for the phosphatic ore beds it contains. Mining operations would therefore affect any ground water flow systems that it might support. The potential impact of mining on other formations is significantly less due to the thickness of the stratigraphic section represented by the Dinwoody and Wells formations. The formations of primary interest are thus the Dinwoody, Phosphoria, and Wells. These formations comprise the "phosphate sequence".

The Dinwoody formation consists of an upper and lower member that are in some areas separated by a distinct tongue of the Woodside Shale. The distinction between the formations is not always evident and hence not mapped.

The Phosphoria formation consists of three members. Frequently the cherty shale member and the Rex Chert member are mapped as one unit although where possible the distinction between the members was maintained for this study. The third member is the Meade Peak Phosphatic Shale member which contains the phosphatic ore beds of economic interest in the area.

For the purpose of this study, the Grandeur Tongue of the Park City formation is considered to be a part of the upper member of the Wells formation. The lower member of the Wells formation is considered

Table III-1. Geologic section, Western Phosphate Field.

| Age | Formation Name | Unit Name | Symbol | Thickness | | Description |
|---|---|---|---|---|---|---|
| | | | | (ft) | (m) | |
| 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 III-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 III-1. cont'd

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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.

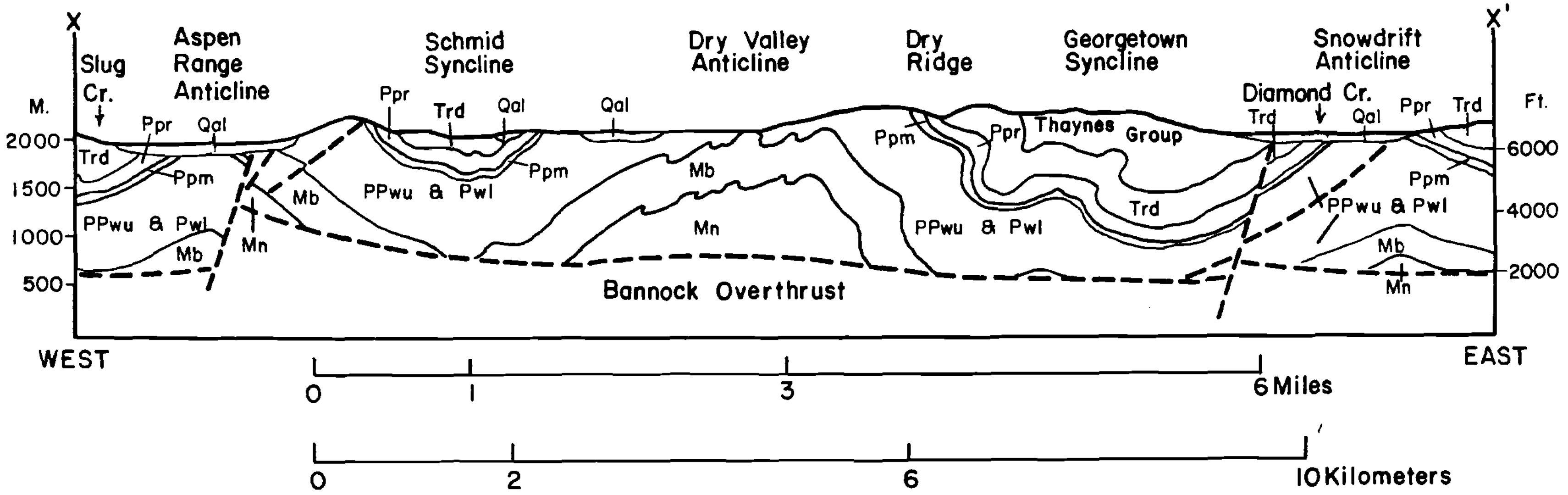
(Armstrong, F., 1969, 2 plates; Cressman, E., 1964, 105 p.; Cressman, E. and Gulbrandsen, R., 1955, 18 p.; Gulbrandsen, R., and others, 1956, 23 p.; Lowell, W., 1952, 53 p.; Montgomery, K. and Cheney, T., 1967, 63 p.; Rioux, R., and others, 1975, 6 p.)

as a separate unit in this study.

The geologic structure viewed today is the result of major overthrusting associated with the Bannock Thrust Zone. This thrusting resulted in synclinal-anticlinal folds and some faulting during the Upper Cretaceous and Paleocene periods. The plane of the overthrusting, at least in the Georgetown Canyon-Snowdrift Mountain area, is thought to be the base of the Madison limestone which lies below those formations of primary interest in this study. Additional faulting has occurred since the Oligocene with differential subsidence and uplift occurring mostly with normal faulting; these faulting and erosional processes have resulted in the current major valleys and ridges (Cressman, 1964, p. 62-91). The northward trending graben valleys seen today were produced at this time from extensive block faulting (Armstrong and Cressman, 1963, p. J20). The complex structure and formation sequence of the area are illustrated by the geologic section view of figure III-3.

The folding that occurred in the area results in the convex side of the fold being placed in tension while the concave side is placed in compression. Competent formations under this stress might rupture with tension fractures or small gravity faults on the convex side and small thrust faults on the concave side while incompetent formations will yield plastically (Billings, 1954, p. 89 and 90). Field investigations of the hydrogeologic properties of the "phosphate sequence" will therefore indicate the combined effects of both the primary hydraulic conductivity of the unaltered formations and the secondary hydraulic conductivity created by the stress induced fracturing and faulting.

Previous researchers found that the hydrogeologic characteristics



Note: Figure III-1 shows the location of X-X' in plan view

Figure III-3. Geologic section view, Lower Diamond Creek valley to Slug Creek valley (modified after Mansfield, 1927, Plates 4 and 11).

of the "phosphate sequence" are very similar even though their studies were conducted in different areas. Table III-2 summarizes the hydraulic conductivities determined by previous investigators. These values, besides indicating specific site values, indicate that anisotropic conditions exist in at least the Meade Peak Phosphatic Shale member of the Phosphoria formation.

Previous investigators concluded from this analysis of geology, ground water levels, spring discharges, stream gain-loss measurements, and pump tests that the formations comprising the "phosphate sequence" have distinct ground water flow system characteristics. The results of these analyses are summarized in table III-3. No major ground water flow system was found in the Phosphoria formation in any of the study areas (Ralston and others, 1977, p. 109).

The results of these investigators can be illustrated by the diagrammatical section view of Little Long Valley presented in figure III-4. Snow occurs mainly along the ridge tops and the eastern flanks of the ridges. Ground water recharge will also occur in these areas if the underlying formations have sufficient hydraulic conductivity. Some of the recharge will cross formation contacts while the rest follows the bedding plane of the formation to discharge at a lower elevation. The presence of a low hydraulic conductivity layer prevents any significant interchange of ground water flow between those formations above and below the layer. Different ground water flow systems can exist although formation displacement along faults may provide a means for ground water interchange.

Table III-2. 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).

| Formation | Unit | Symbol | Study Area | Test Procedure | Transmissivity T | | Hydraulic Conductivity K | | Storage S |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | ft$^2$/day | M$^2$/day | ft/day | M/day | |
| 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<br>2,300 | 1,100<br>210 | 75<br>28 | 23<br>8.5 | 0.0003<br>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<br>64<br>23<br>16<br>63<br>6.0 | 0.74<br>5.9<br>2.1<br>1.5<br>5.9<br>0.56 | 0.3<br>1.6<br>0.4<br>0.14<br>0.44<br>0.07 | 0.09<br>0.49<br>0.1<br>0.043<br>0.13<br>0.02 | --<br>--<br>--<br>--<br>--<br>-- |
| | 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 III-3. Flow system summary of previous studies, Western Phosphate Field.

| Formation | Member | Vandell's Conclusions | Robinette's Conclusions | Edwards' Conclusions | Mohammad's Conclusions |
|---|---|---|---|---|---|
| Thaynes | Upper | -- | -- | -- | Aquifer |
|  | Middle | -- | Intermediate flow system | -- | Aquifer |
|  | Lower | -- | Intermediate flow system | -- | Aquifer |
| Dinwoody | Upper | -- | Intermediate flow system | -- | Aquifer |
|  | Lower | -- | Intermediate flow system | Intermediate flow system | Aquitard |
| Phosphoria | Rex Chert | Aquifer - localized high transmissivity | Moderate hydraulic conductivity with confining beds | Intermediate flow system | Aquifer |
|  | Meade Peak | Aquiclude | Moderate hydraulic conductivity with confining beds | Intermediate flow system | Aquiclude |
| Wells |  | Regional ground water flow system | Regional ground water flow system | Postulated regional ground water flow system | Aquifer (all members) |
| Monroe Canyon Limestone (Brazer Limestone) | -- | -- | -- | -- | Aquifer (all members) |

(Vandell, 1978, IX, 93-95, 111-112; Robinette, 1977, p. 26-39, 43, 64, 67, 90; Edwards, 1977, p. 93-94; Mohammad, 1976, p. 31)

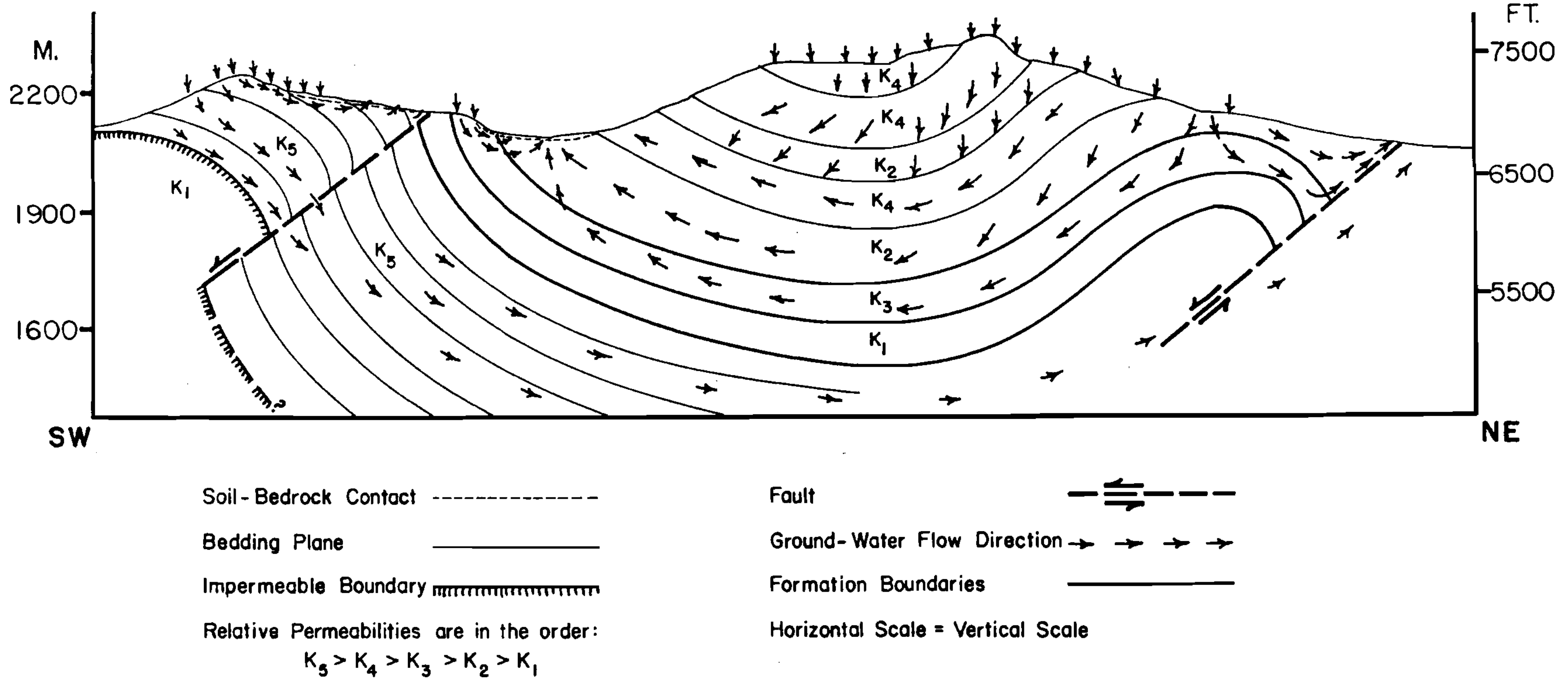


Figure III-4. Diagrammatical section view of the hydrogeologic characteristics of Little Long Valley.

## Method of Study

### Introduction

The hypothesis that the Dinwoody, Phosphoria and Wells formations exhibit similar hydrogeologic characteristics over a broad area was examined utilizing basic principles of hydrogeology. A ground water flow system consists of a recharge area and a discharge area connected by a continuous flow path. Several factors are necessary for the existence of a ground water flow system. First, the rock through which the water moves must have sufficient hydraulic conductivity to permit the significant movement of water. Second, the formation must be exposed to an area where recharge can occur and water must be available in that area. Third, a discharge area must exist. Fourth, there must be hydraulic continuity between the recharge area and the discharge area. Recharge or discharge can also occur via ground water movement to or from adjacent formations. This interformation movement can be due to the general hydrogeologic characteristics of the formations or to conditions found only at specific sites.

The existnece of ground water flow systems in the Dinwoody, Phosphoria or Wells formations would be indicated by the gain or loss of streamflow and by the presence of springs. The discharge of selected streams and springs were measured in order to determine the hydrogeologic properties of these three formations. A gain or loss of streamflow across a formation indicates that the formation supports a ground water flow system. Spring discharge indicates that the formation from which it issues also supports a ground water flow system. A lack of change in streamflow or the absence of springs does not necessarily indicate that the formation does not have significant hydraulic conductivity. A formation with a high hydraulic conductivity may not support a ground water flow system if the formation is structurally isolated. Streamflow and spring data were therefore analyzed in conjunction with local geologic conditions. This constitutes the bulk of the field data studies. Field data for this study were collected in June, July, and August of 1977.

### Site Selection

Stream gain-loss measurement sites were selected based on several criteria. The primary requirement was that there be streamflow across at least part of the "phosphate sequence" consisting of the Dinwoody, Phosphoria and Wells formations. It was desired that the stream channel be underlain by a minimum amount of alluvium and colluvium so that flow measurements would reflect as nearly as possible any flow change due to the exposed formation. Fault areas were avoided where possible so that the ground water flow system characteristics would represent the regional hydraulic properties of the given formations. These prerequisites combined with the desire to expand the current hydrogeologic knowledge outside the previously studied areas dictated that the eastern flank of the Webster Range be the primary study area. One main site was also selected in the Aspen Range to further extend the areal extent of this study. Information was also desired on the hydrogeologic characteristics of the members of the Thaynes formation which lie above the Dinwoody formation in the normal geologic sequence but only one site was possible, Sheep Creek on Rasmussen Ridge. Here the Dinwoody formation lies above the Thaynes formation. It was also required that all the selected sites have some means of reasonable access.

Areas were selected for spring reconnaissance based mainly on the desire to expand the areal extent of the study where stream gain-loss measurements were not possible. Particular emphasis was placed on the Sulphur Canyon area since no previous hydrogeologic research had been conducted in that area. The southern portions of Slug Creek valley and Schmid Ridge were also of interest since previous studies had only covered their northern portions. Those springs previously studied by Robinette (1977) were of interest due to the low precipitation received as snow prior to the summer of 1977. Spring reconnaissance along the base of the east flank of the Webster Range was desired since it was anticipated that large spring areas might exist there. This concept was based on the existence of a synclinal structure along that flank (Cressman, 1964, plate 1). Such a structure might allow the formation of long ground water flow systems from high on the range to Crow Creek valley where the formations are again exposed.

### Data Collection

Sites for stream gain-loss measurements were initially selected by locating the contacts between members of a formation or between formations using existing geologic maps and topographic maps. Formations were field verified where possible. A stream section suitable for a flow measurement was located or rebuilt at or near a contact and the flow was measured.

Streamflow was measured by one of three different methods. The primary method utilized a single, sixty degree, V-notch flume constructed of fiberglass with a sidewall head scale. Flume discharges were determined from a rating curve that shows a flow range from 0.05 to about

37 gpm (0.003 to 2.33 liter/sec). Twin flumes were also used in parallel to extend the range of these highly portable tools.

A second type of flume was also used but only to a limited extent due to its much greater size and weight. This was a forty-five degree trapezoidal flume with a two-inch throat constructed of fiberglass with sidewall head scale. A thin metal scale was used to measure vertical heads since the installed scale lacked divisions of a hundreth of a foot. The flow range of this flume is from 10.3 to 1,895 gpm (.65 to 119.5 liter/sec) based upon its rating chart. Field use was limited to locations close to a jeep trail since the flume was awkward to handle.

A pygmy current meter and topsetting rod were frequently used for measuring streamflow. The basic gear consisted of a converted flashlight for a power source and an earphone. The meter was used when the flow rate was too high for the flume or when channel or access conditions ruled out the use of a flume. All flow measurements are rounded off to two significant figures.

Comparison of measurements for determining gain-loss characteristics must be done with discretion as a number of variables affect the surface-ground water flow ratio. The primary variables are the width and depth of the valley alluvium and the hydraulic conductivity of the alluvium. An increase in the width or depth of the valley alluvium could cause more of the total down valley flow to occur as ground water resulting in a decreased surface water component. The same result would occur if the hydraulic conductivity of the alluvium increased. A decrease in the width, depth or hydraulic conductivity of the valley alluvium could cause an increase in the surface flow with a concurrent decrease in the ground water flow. These factors were recognized prior to conducting the field work; comments were noted while making the flow measurements so that a value judgement could be made during the data evaluation. The error of the methods used for measuring the rate of flow is estimated to be plus or minus ten percent.

Springs were located by either finding previously mapped springs or by hiking an area of interest and visually locating them. Once a spring was found, the site was located on a seven and one-half or fifteen minute quadrangle map. Locations were determined by a combination of techniques: pacing, compass bearings, vehicle odometer, topographic map orientation, and comparison with known geology. Once the spring was located, a site was selected where there was no apparent change in streamflow. The site was flagged and a flow measurement was made by one of the previously described methods.

### Analysis Techniques

For the purposes of this study, hydraulic conductivity was defined to have one of two values, low or high. A low hydraulic conductivity indicates that a formation or geologic unit will transmit such a small volume of water under prevailing conditions that the volume can not be measured by the field measurement techniques used. Any measurable volume of stream gain or loss or spring discharge indicates that the formation has a high hydraulic conductivity.

A stream will gain flow as it crosses a formation if: (1) the formation has a high hydraulic conductivity and (2) there is a continuous flow path from a recharge area at a higher elevation to the formation exposure in the stream at a lower elevation. Figure III-5 illustrates

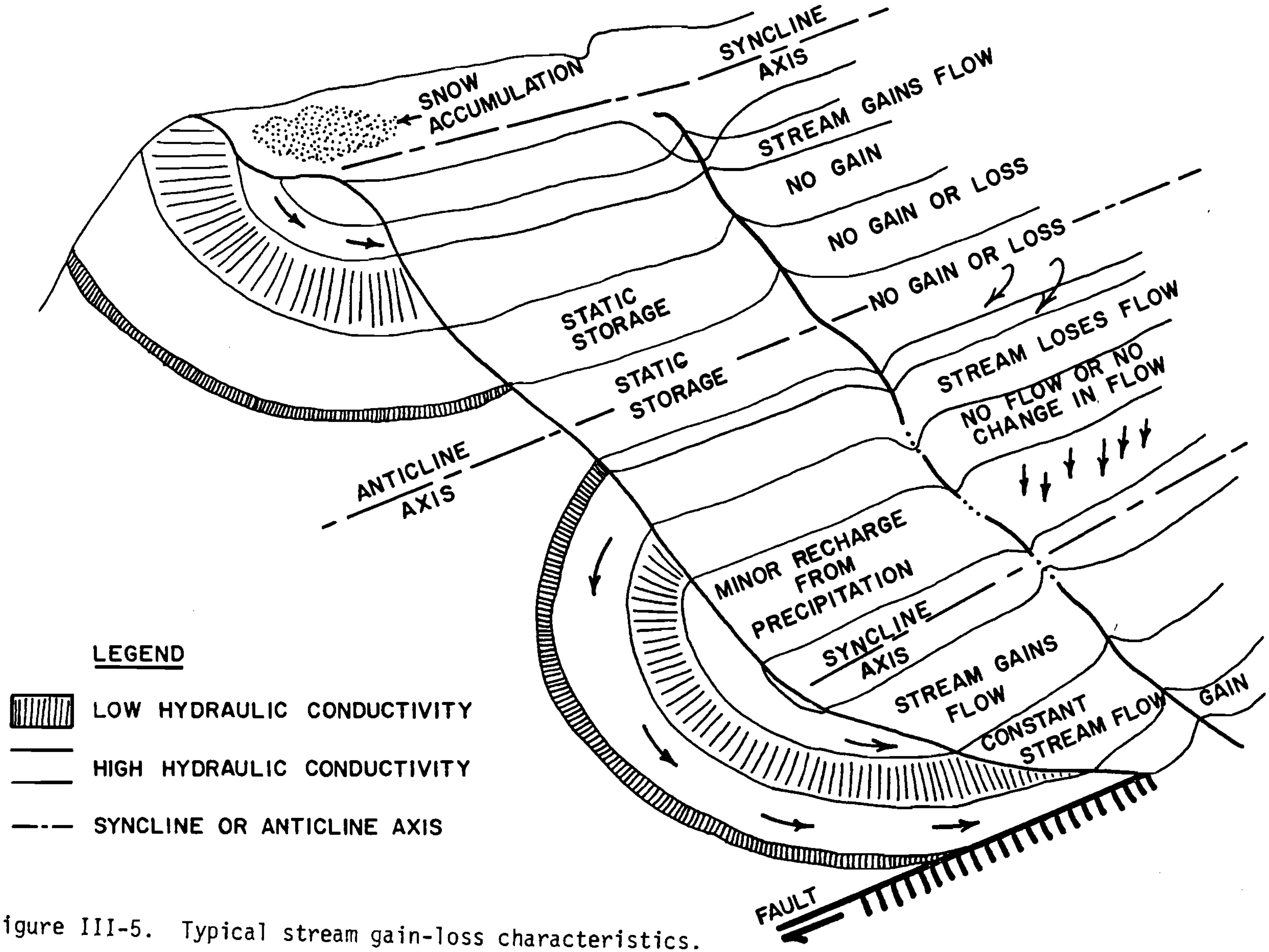


Figure III-5. Typical stream gain-loss characteristics.

the characteristics of gaining, losing, and no gain or loss sections of a stream.

The characteristics necessary for a stream to lose flow across a formation are basically the same as for a gaining stream. The formation must have a high hydraulic conductivity and a continuous flow path from the formation exposure at the stream to a formation exposure at a lower elevation. These characteristics are illustrated in figure III-5.

A stream can have a constant flow across an exposed formation for several reasons. The stream will not gain or lose flow if the formation has a low hydraulic conductivity, regardless of any other factors. Constant streamflow can also result if the formation has a high hydraulic conductivity and there is no difference between the elevation of the stream surface and the potentiometric surface of the ground water at that point. This can occur where there is no recharge at a higher elevation or where there is a flow path discontinuity between the recharge area and the formation exposure at the stream. The same result is achieved if the formation does not have an exposure at a lower elevation where discharge could occur. A flow path discontinuity could separate the formation exposure at the stream from an exposure at a lower elevation and prevent any ground water flow. The lack of a discharge site creates a static storage condition. Figure III-5 illustrates the basic no gain or no loss conditions that could exist.

A spring can exist only if the formation from which it issues has a high hydraulic conductivity. Recharge to the formation must occur at an elevation that is higher than the spring and there has to be flow path continuity from the recharge area to the spring. Spring discharge can only occur if the formation is capable of accepting recharge and yielding discharge from ground water storage. This discharge is determined by a number of factors as previously discussed in the hydrogeology section.

## Stream Gain-loss Characteristics

Eight stream segments were studied within the Western Phosphate Field in Idaho (figure III-1). Three of these site investigations, Wood Canyon, Sage Creek and Wells Canyon, are described in this section. Additional data are presented by Winter (1979).

### Wood Canyon

Streamflow in Wood Canyon began at spring #19 in section 32 in the black limestone member (Trtl) of the Thaynes formation and proceeded downstream across the sequence of formations until surface flow ceased in the upper member (PPwu) of the Wells formation at point I (figure III-6). Flow measurements for gain-loss characteristics began at the syncline axis in the Thaynes formation since any flow changes between the spring and the axis of the syncline would be difficult to interpret due to the fault. Stream gain-loss measurements are shown on table III-4.

Table III-4. Wood Canyon, stream gain-loss measurements.

| Measuring Point | Flow Measurement | |
|---|---|---|
| | gpm | liter/sec |
| A | 12 | 0.76 |
| B | 10 | 0.63 |
| C | 1.6 | 0.10 |
| D | 95 | 6.0 |
| E | 99 | 6.2 |
| G | 88 | 5.6 |
| H | 4.2 | 0.26 |
| I | 0 | 0 |

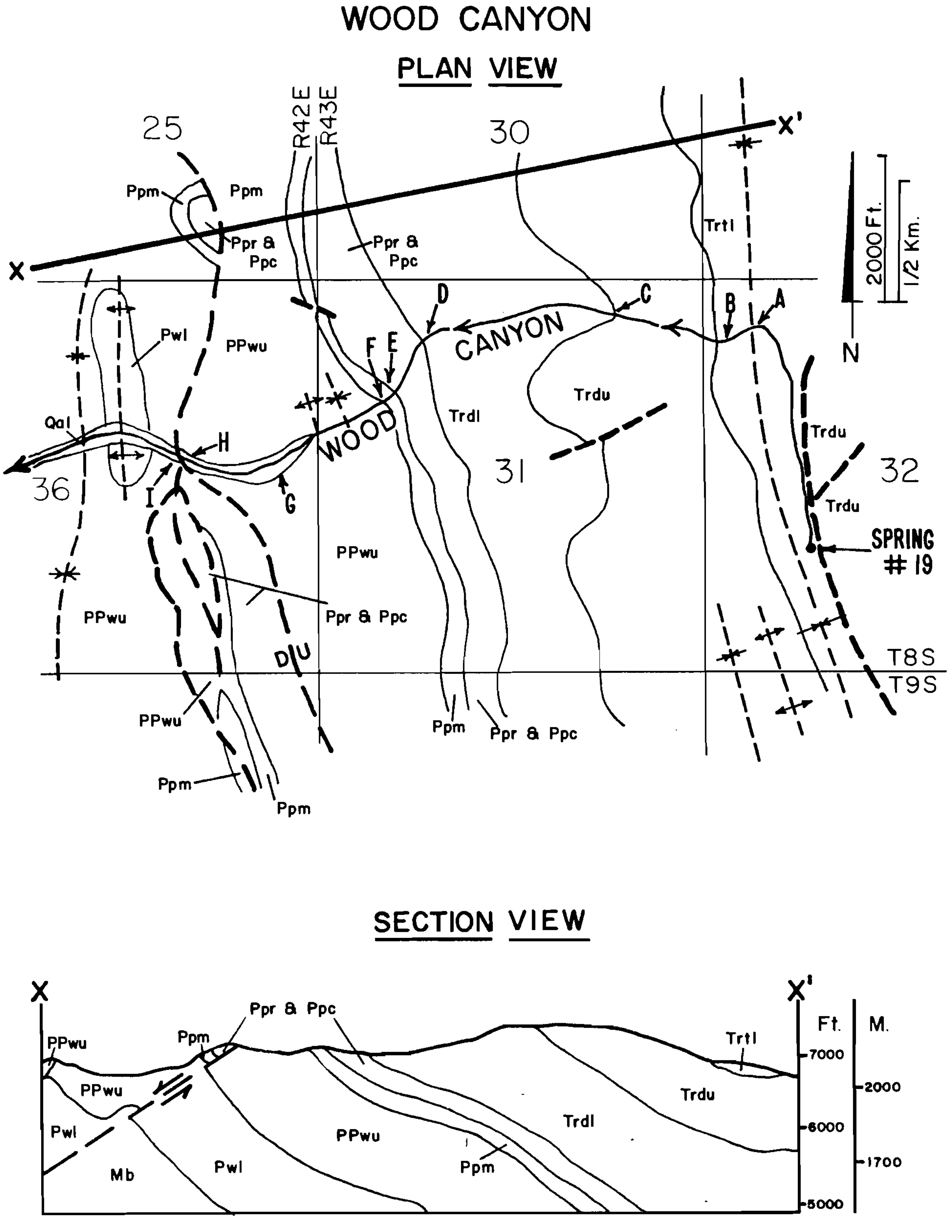


Figure III-6. Geologic plan and section views of Wood Canyon showing stream measurement sites and spring locations (modified after Gulbrandsen and others, 1956, Plate 1).

The black limestone member (Trtl) of the Thaynes formation between the synclinal axis at point A on figure III-6 and the contact with the upper member (Trdu) of the Dinwoody formation at point B does not appear to significantly affect the streamflow. An analysis of the geologic structure indicates that this lack of change in flow could be due to the synclinal structure creating a bathtub effect where the formation cannot accept any more water into storage. No categorization can be made as to the relative hydraulic conductivity of the formation or its potential as a ground water flow system.

The stream loses flow as it crosses the upper member (Trdu) of the Dinwoody formation between points B and C on figure III-6. Streamflow gains as the stream crosses the lower member (Trdl) of the Dinwoody formation between points C and D on figure III-6. Both members (Trdu and Trdl) have a high hydraulic conductivity as previously defined. Streamflow lost to the upper member (Trdu) probably enters a ground water flow path that connects the upper and lower members (Trdu and Trdl) through vertical leakage and possibly fault displacement. The upper member (Trdu) is a competent formation so the stresses induced by folding could be anticipated to create fracturing and faulting.

A distinction was not made between the two upper members (Ppc and Ppr) of the Phosphoria formation in Wood Canyon so these members will be referred to as the Rex Chert member (Ppr). There was no significant change in streamflow across the Rex Chert member (Ppr) or the Meade Peak Phosphatic Shale member (Ppm) between points D, E, and F on figure III-6. Cross bedding leakage from the lower member (Trdl) of the Dinwoody formation could have occurred or the formation could have been recharged directly by precipitation but neither process is apparent. Ground water flow in the Rex Chert member was not evident even though the formation is competent and would be expected to fracture and fault under strain. The incompetency of the Meade Peak Phosphatic Shale member (Ppm) would preclude the development of secondary hydraulic conductivity. The Phosphoria formation as a unit exhibits potential flow path continuity and a low hydraulic conductivity. This formation thus does not include a ground water flow system in this area.

Streamflow across the upper member (PPwu) of the Wells formation does not change significantly between the contact with the Phosphoria formation at point F and point G on figure III-6. All the streamflow is lost, however, between point G and points H and I. A major fault near points H and I is the apparent cause for the lost streamflow. Water movement is probably along zones of increased secondary hydraulic conductivity associated with the fault. The discharge point for this flow system is unknown.

### Sage Creek

Streamflow in Sage Creek was continuous from the initial measuring point at the Woodside formation (Trw) contact with the upper member (Trdu) of the Dinwoody formation to the final measuring point approximately 1,600 feet (488 meters) downstream of the contact between the Phosphoria formation and the Wells formation (figure III-7). The normal stratigraphic sequence of formations occurs at this site. Table III-5 lists the stream gain-loss measurements for this site.

Streamflow increased across the entire exposure of the upper member(Trdu) of the Dinwoody formation from point A to point D. This member

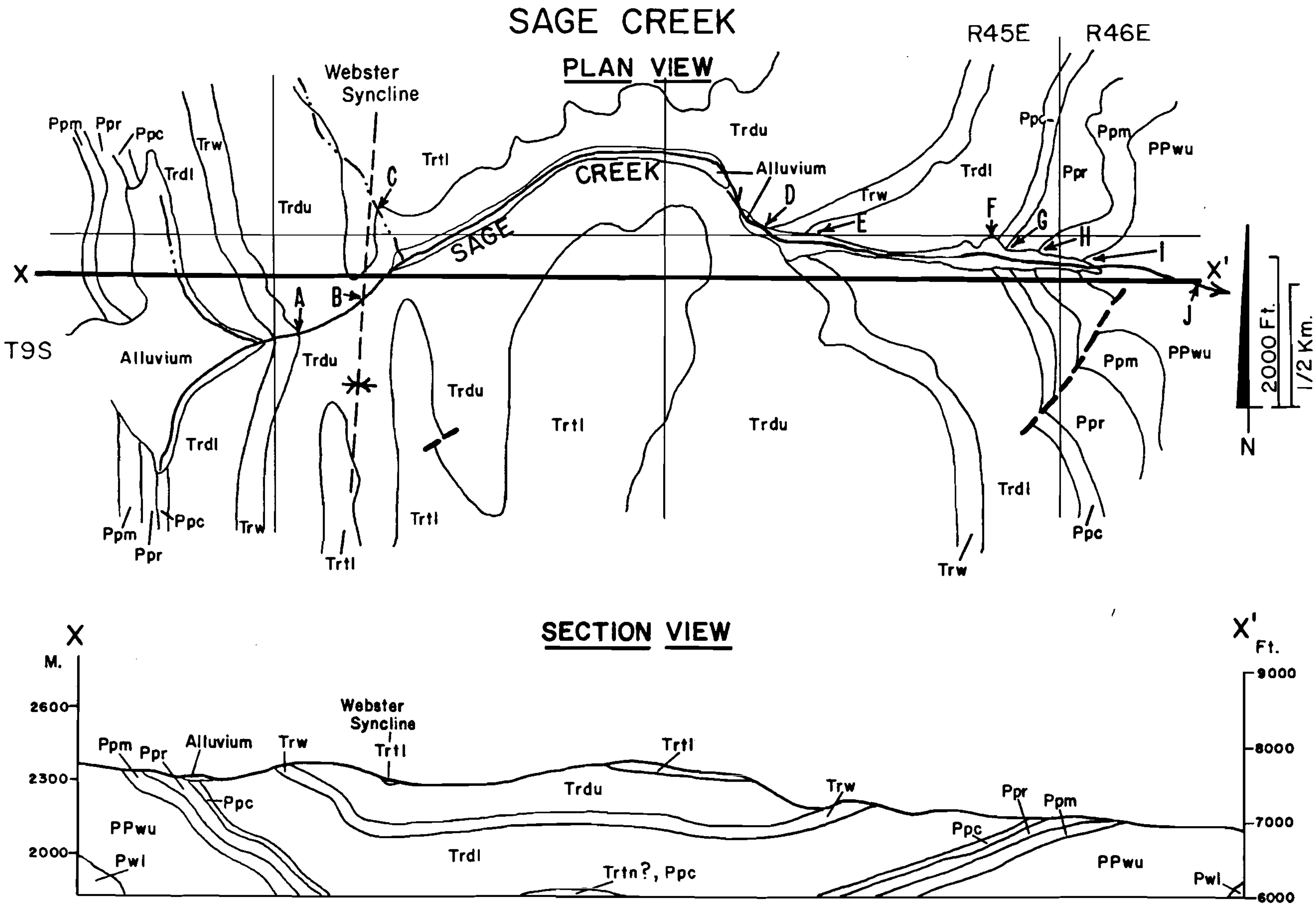


Figure III-7. Geologic plan and section views of Sage Creek showing stream measurement sites and spring locations (modified after Montgomery and others, 1967, Plate 2).

Table III-5. Sage Creek, stream gain-loss measurements.

| Measuring Point | Flow Measurement gpm | Flow Measurement liter/sec | Comments |
|---|---|---|---|
| A | 75 | 4.7 | |
| B | 340 | 21 | |
| C | 17 | 1.1 | |
| D | 950 | 60 | |
| E | | | Not measurable |
| F | 1200 | 76 | |
| G | 1200 | 76 | |
| H | 1100 | 69 | |
| I | 1100 | 69 | |
| J | 800 | 50 | |

has a high hydraulic conductivity. A continuous ground water flow path exists from the stream to higher elevations north and south of the stream where recharge occurs.

The Woodside formation (Trw) could not be checked for stream gain or loss since beaver dams at the contact, point E, with the lower member (Trdl) of the Dinwoody formation precluded measuring streamflow. Streamflow significantly increased across the combined Woodside formation (Trw) and the lower member (Trdl) of the Dinwoody formation. This increase is attributed primarily to the Dinwoody formation since it is much thicker. The Woodside formation (Trw) is about 150 feet (46 meters) thick whereas the lower member (Trdl) of the Dinwoody formation is about 900 feet (274 meters) thick in this area. This member (Trdl) of the Dinwoody formation has high hydraulic conductivity. A continuous flow path exists from the lower reach of the stream to higher elevations west of the Webster syncline where recharge occurs.

There is no significant change in the streamflow across the three members (Ppc, Ppr, and Ppm) of the Phosphoria formation from point F to point I. A continuous ground water flow path exists from their exposure in the stream channel to their outcrop west of the Webster syncline where recharge could occur at a higher elevation. These members (Ppc, Ppr, and Ppm) must have a low hydraulic conductivity since streamflow did not increase.

Streamflow decreased as Sage Creek flowed across the upper member (PPwu) of the Wells formation from point I at the contact with the Phosphoria formation to a point 1,600 feet (488 meters) downstream at point J. The upper member (PPwu) of the Wells formation has a high hydraulic conductivity. A continuous flow path must exist to some unknown discharge area.

## Wells Canyon

Streamflow began in the Rex Chert member (Ppr) of the Phosphoria formation in the NW¼ of the NE¼ of section 9 (figure III-8). All surface flow was lost across the upper member (PPwu) of the Wells formation also in section 9. Stream gain-loss measurements are shown on table III-6.

Table III-6. Wells Canyon, stream gain-loss measurements.

| Measuring Point | Flow Measurement gpm | liter/sec | Comments |
|---|---|---|---|
| A (Spring #82) | 3.1 | 0.20 | |
| B | 1.6 | 0.10 | May be low due to site conditions |
| C | 1.3 | 0.088 | |
| D | 6.0 | 0.38 | |
| E | 0 | 0 | 500 feet (150 meters) downstream of Fork |
| F (Spring #83) | 110 | 6.9 | |

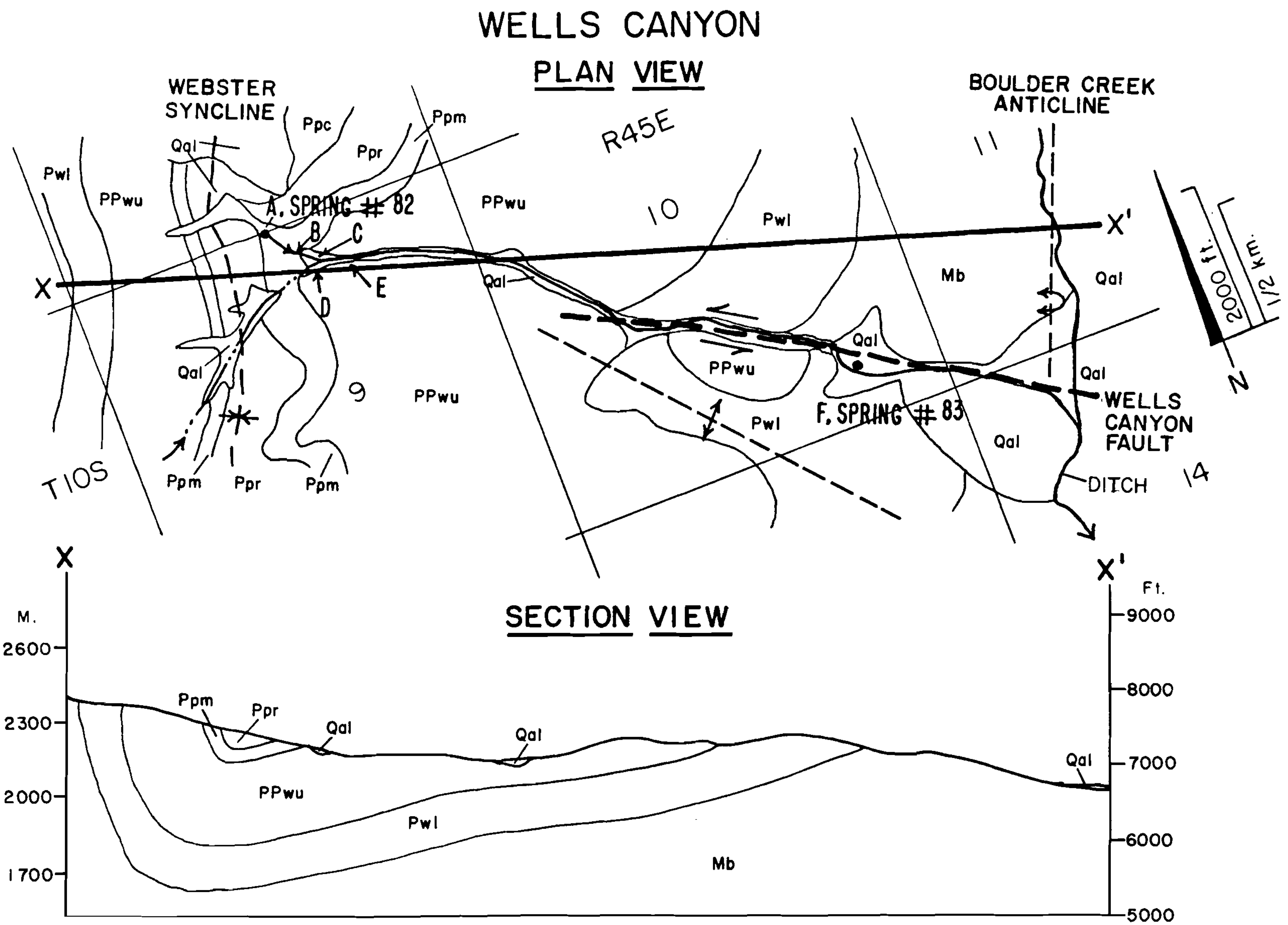


Figure III-8. Geologic plan and section views of Wells Canyon showing stream measurement sites and spring locations (modified after Cressman, 1964, Plates 1 and 2).

The initial streamflow measured in Wells Canyon was derived from a spring in the Rex Chert member (Ppr) of the Phosphoria formation at point A (figure III-8). This member has a high hydraulic conductivity with recharge occurring at a higher elevation. A potential flow path exists between the spring and the exposed member flanking the Webster syncline.

Streamflow did not significantly change across the Meade Peak Phosphatic Shale member (Ppm) from point A to point B (figure III-8). Streamflow may have been low at point B due to the presence of a considerable amount of alluvium at the site. A potential ground water flow path exists to higher exposures where recharge could occur on the east side of Snowdrift Mountain but streamflow did not increase. The member (Ppm) therefore has a low hydraulic conductivity.

All streamflow passing point B and from a side stream in the NW¼ of section 9 is lost to the upper member (PPwu) of the Wells formation. There was no streamflow at point E (figure III-8). The upper member (PPwu) of the Wells formation has a high hydraulic conductivity. A continuous ground water flow path must exist to a discharge area but the location is not known. Point F is the location of a large spring (110 gpm or 6.9 liter/sec) near the mouth of Wells Canyon which is a possible discharge area for recharge along the top of the ridge west of the Webster syncline.

## Summary of Stream Gain-loss Characteristics

A summary of the stream gain-loss characteristics is presented below. The hydrogeologic characteristics of the Thaynes formation are not well documented due to their limited exposure in stream channels. Both the black limestone member (Trtl) and the platy silstone member (Trts) may support ground water flow systems. The black shale member (Trtb) does not appear to be capable of supporting a flow system although the nodular siltstone member (Trtn) will, if intercepted by a fault.

Both members (Trdu and Trdl) of the Dinwoody formation support flow systems throughout the area. The cherty shale member (Ppc) and the Rex Chert member (Ppr) of the Phosphoria formation generally do not support ground water flow systems. The Meade Peak Phosphatic Shale member (Ppm) did not support a flow system in any of the areas. The upper member (PPwu) of the Wells formation supports flow systems throughout the area.

Table III-7 summarizes the gain-loss characteristics of these formations. The Dinwoody formation usually discharges ground water from its flow systems forming the perennial flow of those streams crossing this formation. Streamflow is usually lost to the upper member (PPwu) of the Wells formation to be discharged at some unknown location. The low hydraulic conductivity of the Meade Peak Phosphatic Shale member (Ppm) and of the Phosphoria formation in general at least partially restricts vertical flow from the Dinwoody formation to the Wells formation. Two major ground water flow systems are thus formed. One ground water flow system exists in the formations that stratigraphically lie above the Phosphoria formation, mainly the Dinwoody formation. The second ground water flow system consists of the formations that lie stratigraphically below the Phosphoria formation. The downward distribution of hydrologic potential indicates that this area is in the recharge portion of a regional ground water flow system.

Table III-7. Summary of geologic control of streamflow, Western Phosphate Field.

| Formation | Unit Name | Unit Symbol | Number of Sites With Given Stream Flow Characteristics: Gaining | Losing | No Change | Comments |
|---|---|---|---|---|---|---|
| Thaynes | Nodular Siltstone Member | Trtn | 1 | | | Fault intercepts stream and formation |
| | Black Shale Member | Trtb | | | 1 | |
| | Platy Siltstone Member | Trts | 1 | | | Validity of flow measurement questionable |
| | Black Limestone Member | Trtl | | 1 | | Validity of flow measurement questionable |
| Dinwoody | Upper Member | Trdu | 4 | 1 | | |
| Woodside | | Trw | No definitive data | | | |
| Dinwoody | Lower Member | Trdl | $4^{*a}$ | $1^{*a}$ | | |
| Phosphoria | Cherty Shale Member | Ppc | $1^{*a}$ | $1^{*a}$ | 4 | |
| | Rex Chert Member | Ppr | $2^{*a}$ | $2^{*a}$ | 3 | One gaining site is also noted as a spring |
| | Meade Peak Phosphatic Shale Member | Ppm | | | 5 | |
| Wells | Upper Member | PPwu | | 5 | | |

*a There was both a gain and loss across a single exposure

## Spring Characteristics

A total of 88 springs were located in the field during this study. Information on all the springs visited during this study is given by Winter (1979).

The principle information derived from an analysis of a spring is the formation that supports the ground water flow system discharging at that point. The Phosphoria formation supports very few springs while those formations that normally occur above the Phosphoria support the greatest number of springs. The largest concentration occurs from the lower member (Trdl) of the Dinwoody formation. This indicates that the Phosphoria formation acts as a barrier to ground water flow between those formations above the Phosphoria formation and those below it.

Most springs had a discharge of less than 10 gpm (0.63 liter/sec) although one spring had a measured discharge of 500 gpm (32 liter/sec). The majority of the springs issued from the Thaynes and Dinwoody formations but the discharges were small (figure III-9). The mean discharge was 25 gpm (91.6 liter/sec). The Phosphoria formation contains few ground water flow systems as only three springs were found discharging from this formation. Their mean discharge was only 2.0 gpm (0.12 liter/sec). Eight springs were found that discharge from the Wells formation with a mean discharge of 130 gpm (8.0 liter/sec). Several of these were small springs. Their occurrence is not believed to be indicative of the long ground water flow systems and large spring discharges anticipated from this formation.

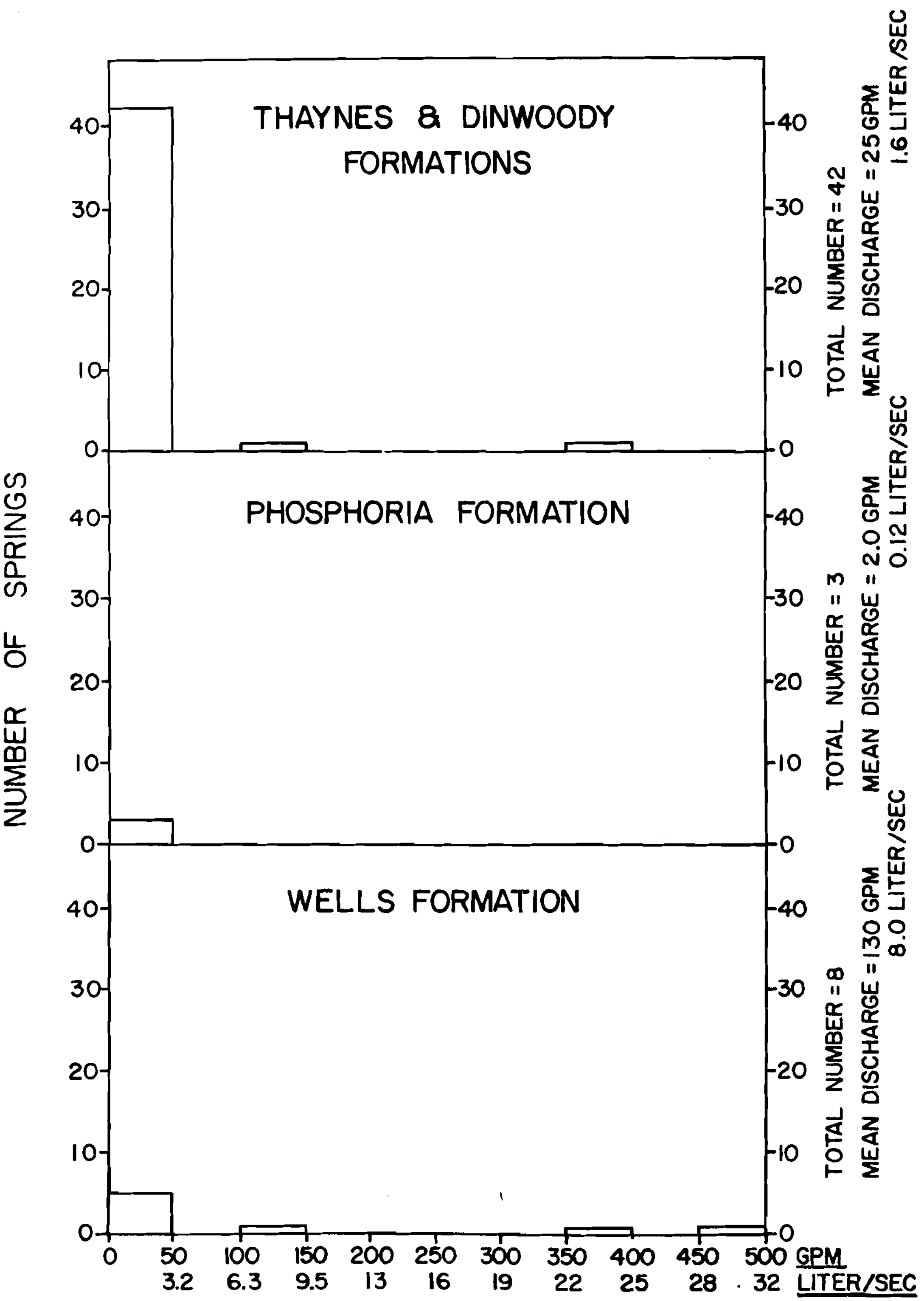


Figure III-9. Spring discharge histograms by formation.

## Discussion of Results

Streamflow data and spring data indicate that the formations constituting the "phosphate sequence" exhibit similar hydrogeologic characteristics throughout the study area. These characteristics are essentially identifiable by formation. Ground water flow systems can be delineated from these data.

Most members of the Thaynes formation have ground water flow systems supporting spring discharges. Streamflow data, though questionable, do support the spring data except for the black shale member (Trtb). Streamflow did not change across this member although the accuracy range of the measurement technique used may have prevented the detection of a flow change. The nodular siltstone member (Trtn) of the Thaynes formation can support a ground water flow system if faulted.

Ground water flow systems exist within the upper and lower members (Trdu and Trdl) of the Dinwoody formation at every site measured for their streamflow characteristics. Numerous springs occur in these members especially the lower member (Trdl). Streamflow data in Smoky Canyon indicate that the lower member (Trdl) has more than one ground water flow system characteristic. Reference to the member acting as a single hydrogeologic unit is only justified with that restriction in mind. Other formations may have similar complexities but the data are not of sufficient enough detail to analyze that aspect.

The Phosphoria formation supports very few ground water flow systems as indicated by both streamflow and spring data. Streamflow changed across the cherty shale member (Ppc) in one location. Here, the member (Ppc) discharges ground water to the stream while this streamflow is lost across the same exposure a short distance farther downstream. All this occurs on or near the axis of the Webster syncline where fracturing and faulting might have increased the hydraulic conductivity of this unit.

At least two springs were found to discharge from the Rex Chert member (Ppr) of the Phosphoria formation. A third spring may also discharge from this member (Ppr) but the specific member could not be identified in the field. Streamflow data indicate that this member (Ppr) may or may not support a ground water flow system. One site had both a stream gain and loss across the same exposure. This occurred near the axis of the Webster syncline where folding may have induced fracturing and faulting within this member (Ppr). The loss of streamflow to this member (Ppr) in Smoky Canyon can not be directly attributed to major secondary hydraulic conductivity. The formations are not folded to as great a degree at this location as at other sites.

The Meade Peak Phosphatic Shale member (Ppm) of the Phosphoria formation does not support any significant ground water flow systems at any of the sites studied. One spring discharges from this member (Ppm) from a complex geologic structure in North Sulphur Canyon. The primary hydraulic conductivity of this member (Ppm) is low. Secondary hydraulic conductivity is also low due, no doubt, to the incompetency of the member. The stresses imposed by folding generally do not cause extensive fracturing and faulting in an incompetent formation.

Streamflow was always lost to some degree if not entirely when the stream crossed the upper member (PPwu) of the Wells formation. A few springs were located that discharged from either the upper or lower (PPwu or Pwl) members of the Wells formation. One spring also appears to discharge from the Monroe Canyon limestone (Mb).

Ground water flow systems in the study area may be separated into two general categories by their relative position to the Meade Peak Phosphatic Shale member (Ppm) of the Phosphoria formation. Recharge to the Thaynes and Dinwoody formations from precipitation moves downward to discharge at sites stratigraphically above the Phosphoria formation. Further downward movement is virtually prevented by the low hydraulic conductivity of this unit. Numerous springs and areas where streams gain flow are thus located in the Thaynes and Dinwoody formations. Approximately 71 percent of the total stream gain and spring discharge occurred from the Thaynes and Dinwoody formations. The Wells formation supplied 27 percent of the total while the Phosphoria fromation supplied about 2 percent of the total stream gain and spring discharge.

The upper member (PPwu) of the Wells formation is recharged by precipitation where exposed but also through the vertical movement of ground water from those formations above the Phosphoria formation. This movement can only occur where the Phosphoria formation has been displaced or removed and a continuous flow path exists. The Wells formation and the Monroe Canyon limestone (Mb) normally occur, stratigraphically, below the rest of the formations exposed in the area. Their position and the recharge of the Wells formation by streamflow indicates that these formations form long ground water flow systems of regional extent.

## Conclusions

1. This study indicates that the formations comprising the "phosphate sequence" exhibit similar hydrogeologic characteristics throughout the study area.

2. The platy siltstone member (Trts) and the black limestone member (Trtl) of the Thaynes formation support ground water flow systems in the area.

3. Both the upper member (Trdu) and the lower member (Trdl) of the Dinwoody formation support major ground water flow systems.

4. The cherty shale member (Ppc), the Rex Chert member (Ppr) and the Meade Peak Phosphatic Shale member (Ppm) of the Phosphoria formation do not support any major ground water flow systems in the study area.

5. A major ground water flow system exists in the upper member (PPwu) of the Wells formation.

6. The flow system in the upper member (PPwu) of the Wells formation is separated from the flow systems in the Thaynes and Dinwoody formations by the low hydraulic conductivity of the Phosphoria formation and in particular the Meade Peak Phosphatic Shale member (Ppm).

7. A major ground water flow system exists in the lower member (Pwl) of the Wells formation.

8. Ground water flow systems above the Phosphoria formation are separated from those below the Phosphoria formation. This causes the upper flow systems to be local in extent while the lower flow system is regional in extent.

9. The ground water information derived from this study should be transferable to other areas where this "phosphate sequence" is present. Minor variations in the ground water flow system characteristics of the sequence may occur if the physical composition of the formations varies. Separation of the two flow systems by the Meade Peak Phosphatic Shale member (Ppm) of the Phosphoria formation should be consistent.

# CHAPTER IV

# HYDROLOGIC ANALYSIS OF MINING PITS

## Introduction

Ralston and others (1977) presented the results from site investigations of four existing or potential mine pit sites in the Upper Blackfoot River drainage (figure IV-1). This report provides information on the hydrologic conditions along outcrops of the Phosphoria formation that strike parallel to the ridges near the valley floors. A summary of these findings is presented in this chapter.

Detailed studies of two additional potential mine pit sites were completed as part of this research in order to provide detail on more complex geologic settings for mines. The Gay Mine of the J.R. Simplot Company is located in a complexly faulted and folded area north and west of most of the existing phosphate development. The study of this mine provides information on a complex structural setting plus existing pit dewatering problems. The northern continuation of the Monsanto Company's Henry Mine extends across the valley of the Little Blackfoot River. This valley not only contains the perennial Little Blackfoot River but also a considerable thickness of basalt. The detailed study of the North Henry Mine thus provides information on the ground water flow systems in a geologic setting made more complex by the stream and basalt. Detailed descriptions of these sites are presented following the review of previous studies.

## Review of Previous Mine Pit Studies

Ralston and others (1977) delineated two major ground water flow

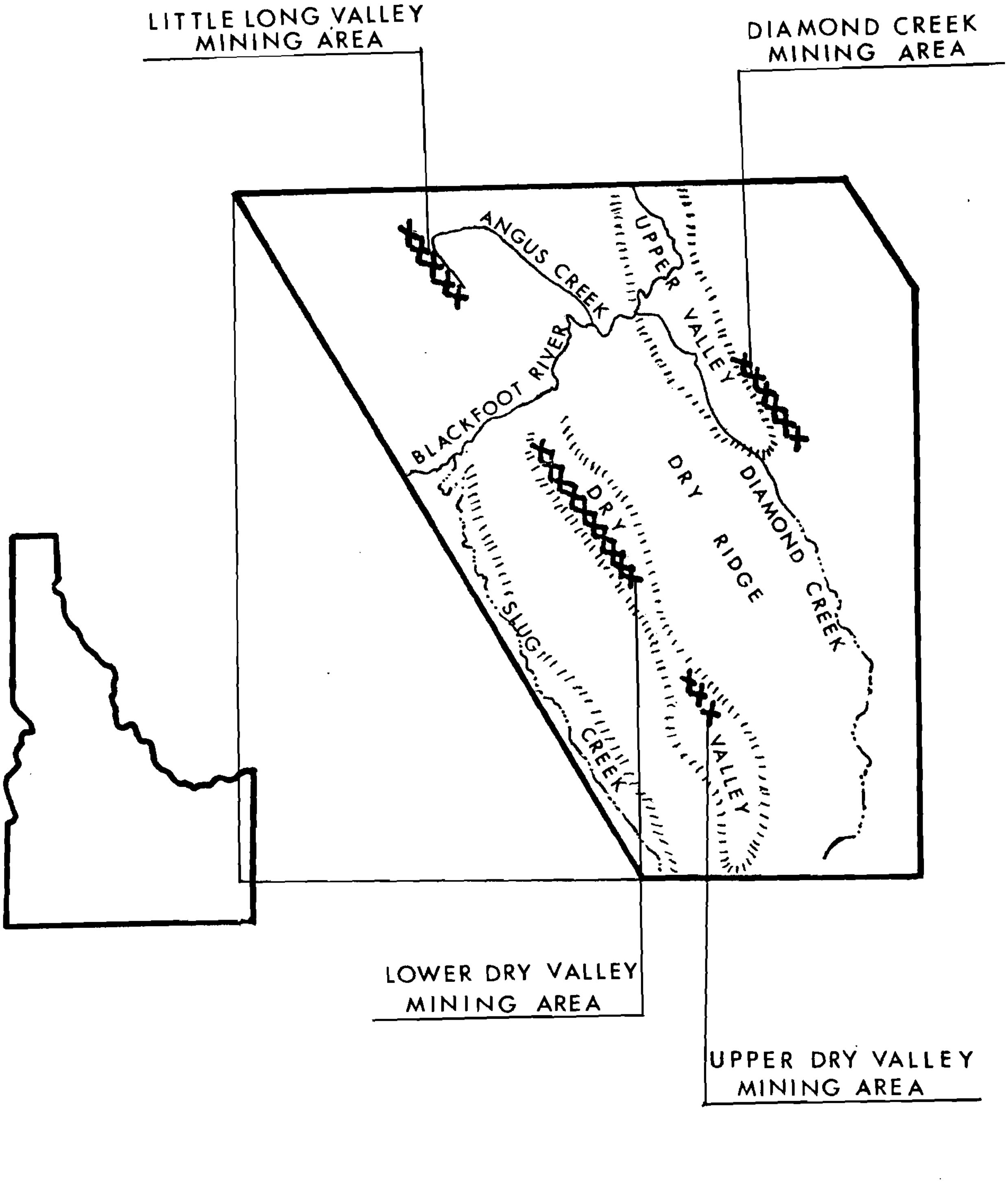


Figure IV-1. LOCATION OF MINING STUDY AREAS IN UPPER BLACKFOOT RIVER DRAINAGE systems in Little Long Valley, the site of an existing mine operated by the Stauffer Chemical Company (see figures III-4 and IV-2). One of these flow systems occurs in the Dinwoody formation associated with a syncline present along the east ridge of the valley. This flow system is important as it provides the baseflow for the Angus Creek. A second flow system is present in the shallow unconsolidated sediments and upper portion of the Wells formation on the western ridge. This flow system will be directly affected by mining but supplies only a relatively minor portion of the surface water system in the area. Ralston and others (1977, p. 35) concluded the following with respect to mining along the west side of Little Long Valley.

> "The proposed mining pit on the western ridge of Little Long Valley will intercept the local flow system on this ridge. If the pit is constructed to a depth below the valley floor, it may intercept a small portion of the discharge from the intermediate flow system in the Dinwoody Formation on the eastern ridge that is normally tributary to Angus Creek as subsurface flow. Ground-water movement from this flow system into the pit would have to follow a path across bedding through both the Lower Dinwoody Formation and the Rex Chert Member of the Phosphoria Formation. The total quantity of water that might be diverted from the Dinwoody flow system into the pit would be small because of the low across-bedding hydraulic conductivity of the sedimentary rock units."

F.M.C. holds mining leases along the west side of Lower Dry Valley. Rocks are exposed in a roughly north-south outcrop along the east limb of a syncline located along the alignment of Schmid Ridge (figure IV-3). Dry Valley is believed to be the recharge area for an inter-valley ground water flow system in the Wells formation. At least a portion of the water recharged in Lower Dry Valley moves downdip in the Wells formation to discharge in the adjacent Slug Creek Valley. Vandell (1978) conducted pumping tests in Lower Dry Valley to estimate the hydraulic conductivity

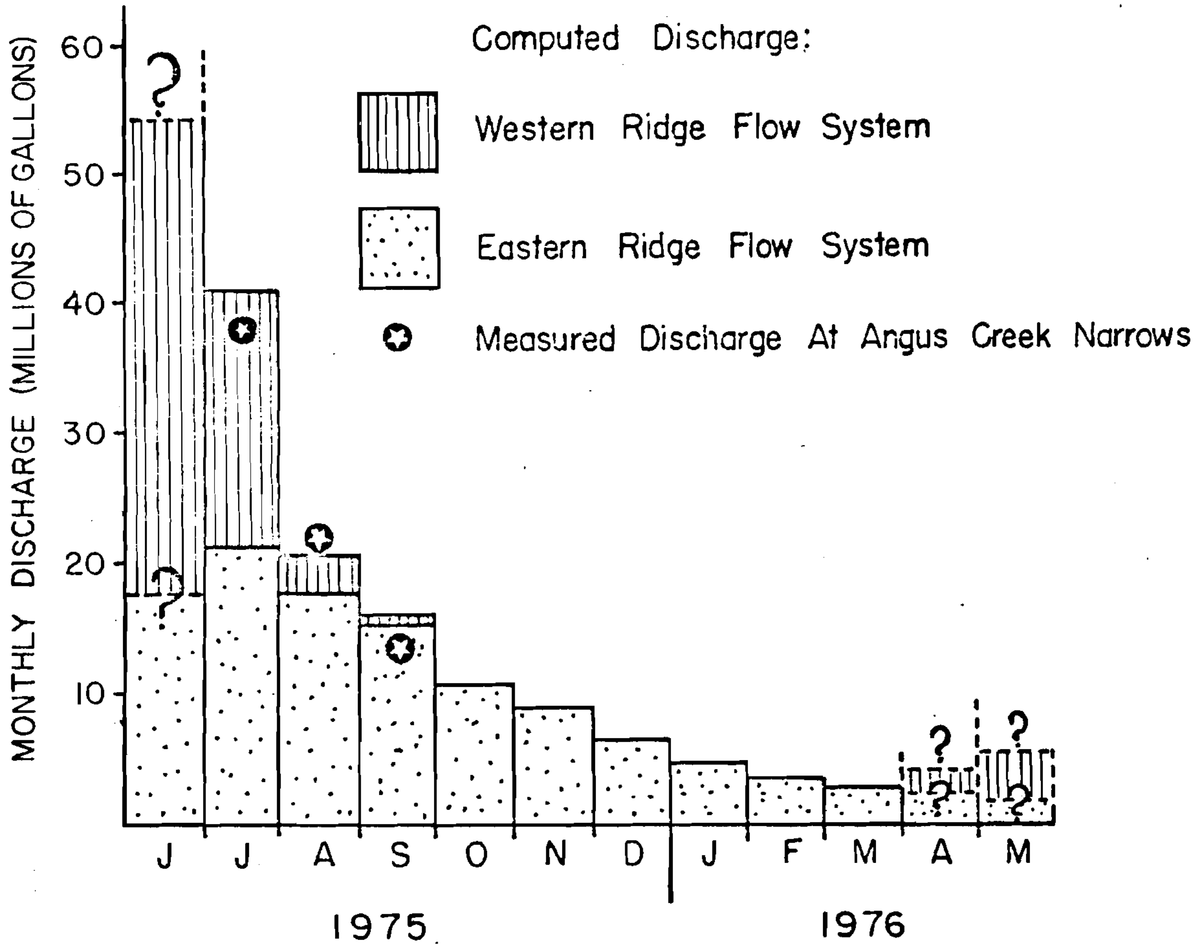
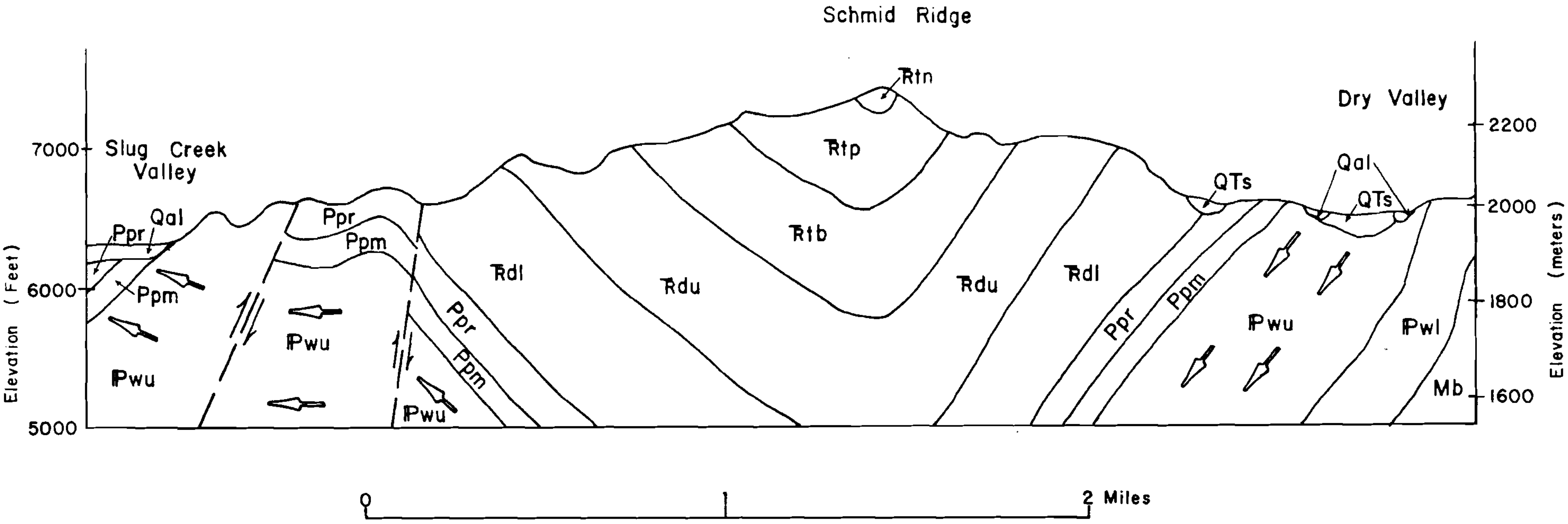


Figure IV-2. Computed and measured monthly discharge for Angus Creek at Narrows, Little Long Valley



| | | | |
|---|---|---|---|
| Mb | Brazer Limestone | TRdu | Upper Dinwoody Formation |
| ₱wl | Lower Wells Formation | TRtb | Lower Thaynes Formation |
| ₱wu | Upper Wells Formation | TRtp | Middle Thaynes Formation |
| Ppm | Meade Peak Member of the Phosphoria Formation | TRtn | Nodular Siltstone Member of the Thaynes Formation |
| Ppr | Rex Chert Member of the Phosphoria Formation | QTs | Sedimentary Deposits |
| TRdl | Lower Dinwoody Formation | Qal | Alluvium |
| | | ◁ | Postulated Flow Path |

Figure IV-3. Postulated Dry Valley-Slug Creek Valley ground water flow system.

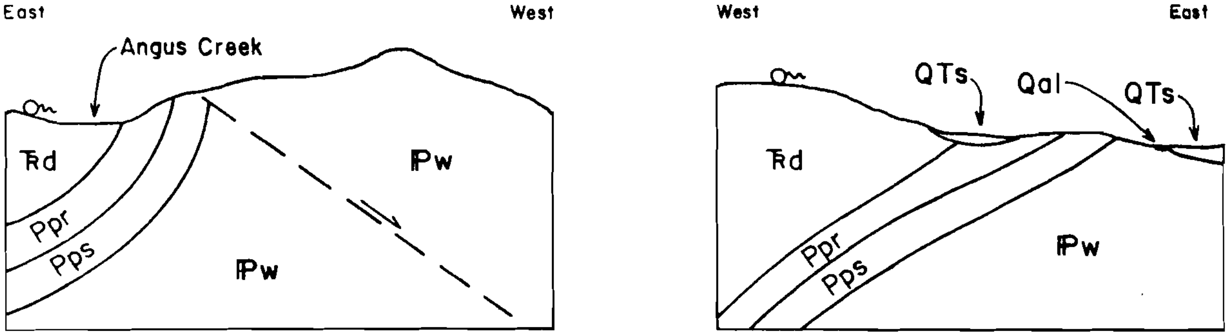
of the Phosphoria formation. She found that localized zones of high hydraulic conductivity were present in the Rex Chert member of the Phosphoria formation; however, the overall hydraulic conductivity of the formation was found to be low to very low.

A similar ground water flow system was found to exist in Upper Dry Valley along what is known as the Champ leases. Again water is believed to move downdip in the Wells formation through the Schmid syncline to discharge in the adjacent Slug Creek Valley.

The proposed development of the phosphate mine along the east side of the Diamond Creek Valley provided an opportunity to investigate the interrelationship of ground water flow in the consolidated sedimentary rocks with ground water flow in the unconsolidated valley alluvium. Ralston and others (1977) found that movement of ground water from the alluvium into the proposed pit was a greater potential problem than inflow from the Phosphoria formation or overlying Dinwoody formation.

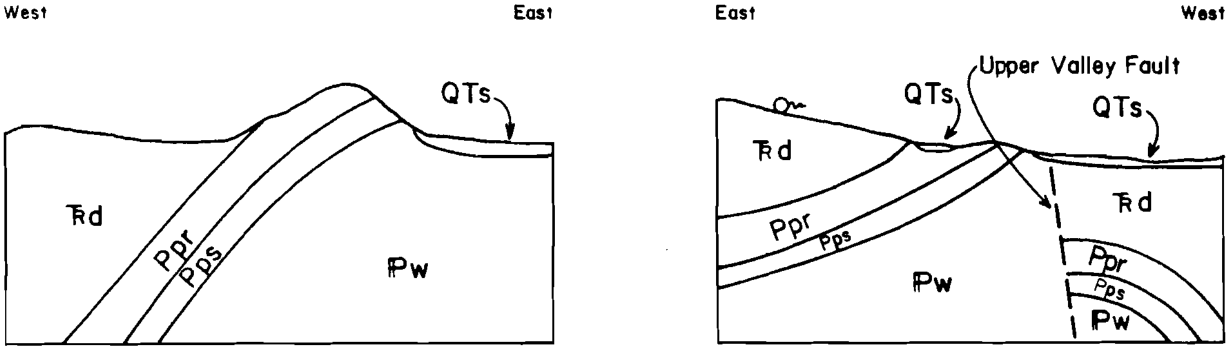
Ralston and others (1977, p. 123) found distinct similarities between the ground water flow systems at each of the proposed mine sites (figure IV-4). They concluded the following from their study of these sites.

> 1) "Each study area in the phosphate area has a unique water resource system dependent upon given geologic, topographic, hydrologic and hydrogeologic conditions. However, the areas have distinct hydrogeologic and hydrologic similarities in the geologic framework in the areas. The water resource system cannot be understood without an analysis of ground-water flow systems.
>
> 2) None of the proposed mining pits within the study area will intercept a major ground-water flow system in the sedimentary rock formations. The mining will cause a dewatering of the Phosphoria Formation in several areas with little impact on the total water resource system.



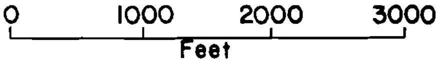
(a) Little Long Valley

(b) Lower Dry Valley



(c) Upper Dry Valley

(d) Diamond Creek Valley



Vertical Scale = Horizontal Scale

| | |
|---|---|
| Qal | Alluvium |
| QTs | Sedimentary Deposits |
| TRd | Dinwoody Formation |
| Ppr | Rex Chert Member of the Phosphoria Formation |
| Pps | Meade Peak Member of the Phosphoria Formation |
| IPw | Wells Formation |
| O⁓ | Spring |
| ---- | Fault |

Figure IV-4. Diagrammatic cross section of the Little Long Valley, Upper and Lower Dry Valley and Diamond Creek study areas.

3) Several of the mine pits may intercept ground-water flow systems in unconsolidated valley fill material. Any dewatering of the alluvial aquifer will affect the flow of Diamond Creek north of the mine area without mitagating measures.

4) Ground-water flow systems that are created in mine waste piles will probably discharge water that is poorer in quality than natural flow systems. Care must be taken to construct waste piles that will minimize groud-water flow."

## Hydrogeology of the East Gay Mine Area

### Introduction

A detailed study of the hydrology near an active phosphate mine was initiated at the Gay Mine near Pocatello. This mine is jointly operated by the J.R. Simplot Company and F.M.C. and is located about 30 miles (48 kilometers) northeast of Pocatello (figure IV-5). Important additional information was gained from this study because several conditions exist at the Gay Mine that were not encountered in previous University of Idaho studies: (1) ground water flow systems in the Gay Mine area are controlled primarily by fault block structure, and (2) flooding of mine pits by ground water has seriously hindered mining operations.

The purpose of this study was to develop an understanding of the hydrogeology of the East Gay Mine area. The general objective was to develop a conceptual model of ground water flow systems for delineating water resource impacts on and impacts from mining in the East Gay Mine area. The specific objectives are stated below:

1. Describe in general the ground water flow systems present in the vicinity of the Gay Mine.

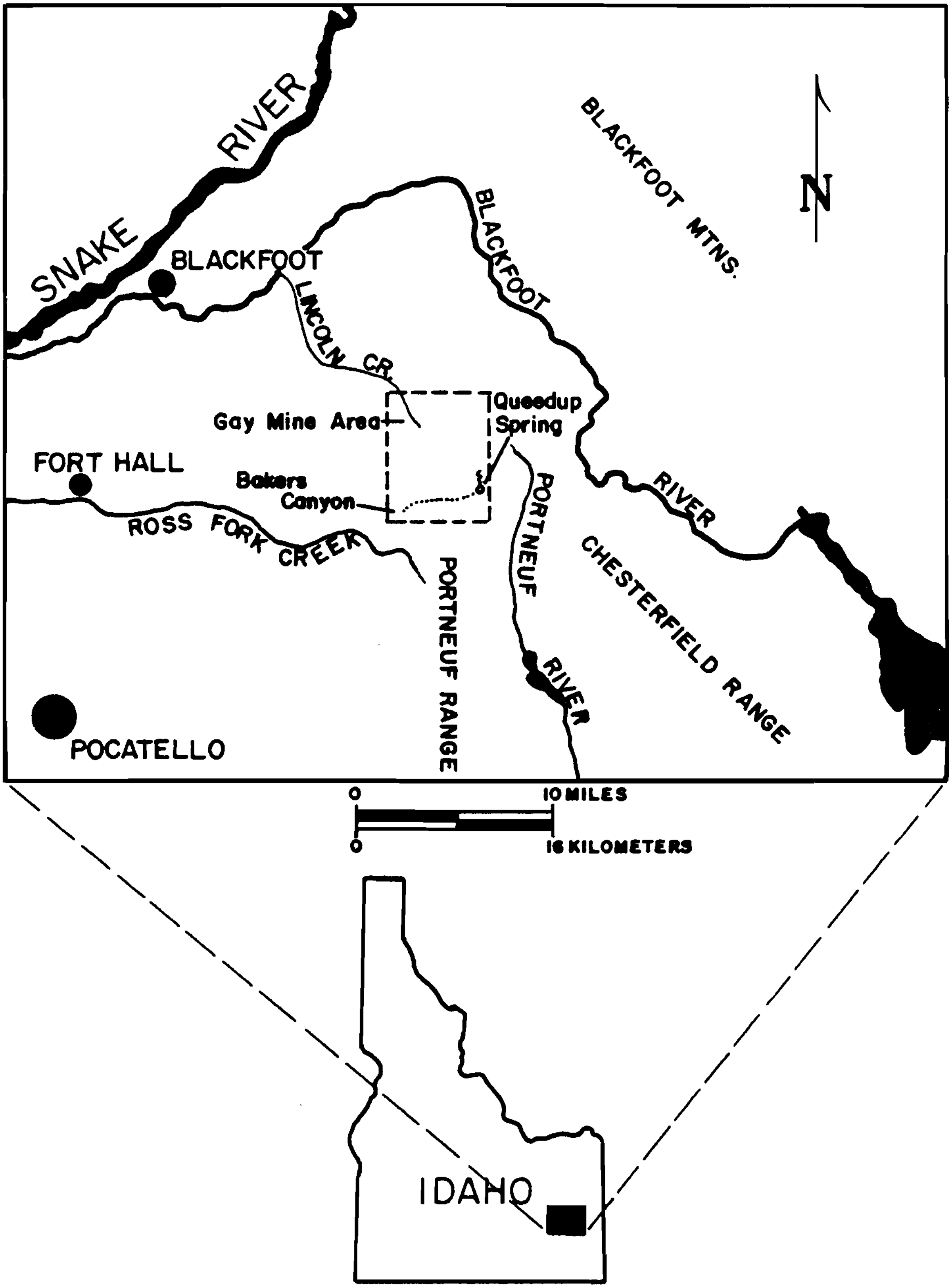


Figure IV-5. Location map of the Gay Mine area.

2. Describe in detail the ground water flow systems in the new proposed mine area (Group 1 - pits 4, 5, and 6) (figure IV-6).
3. Describe present and potential interactions between mining and ground water flow systems.
4. Describe techniques to minimize detrimental interactions between mining and ground water flow systems for the Gay Mine in general and specifically for the Group 1 area.

Several excellent investigations of the geology of the study area are available. The most comprehensive investigation of Fort Hall Reservation geology was Mansfield's classic report (1920). Lehman (1966) refined Mansfield's work for the immediate mine area. Since that time, Gay Mine personnel have improved the geologic map of the mine area as more information has become available.

Several unpublished J.R. Simplot Company reports have addressed the hydrology of the study area. Raymond and Williams (1973) discussed potential recharge to ground water flow systems in the mine area and the dewatering of perched water systems. In a report to mine personnel, Geraghty and Miller Inc. (1971) discussed flow systems within the Wells formation.

## Hydrogeologic Framework

The goal of the geologic portion of the study was to describe the spatial distribution of hydraulic conductivity so that this information could be used to analyze the flow of ground water. The hydraulic conductivity of the Thaynes and Dinwoody formations of Triassic age, the Cherty Shale and Meade Peak members of the Permian Phosphoria formation, and the Wells formation of Pennsylvanian age are discussed below. The Permian Granduer member of the Park City formation is included as part of the Wells formation. The Cherty Shale member should not be confused

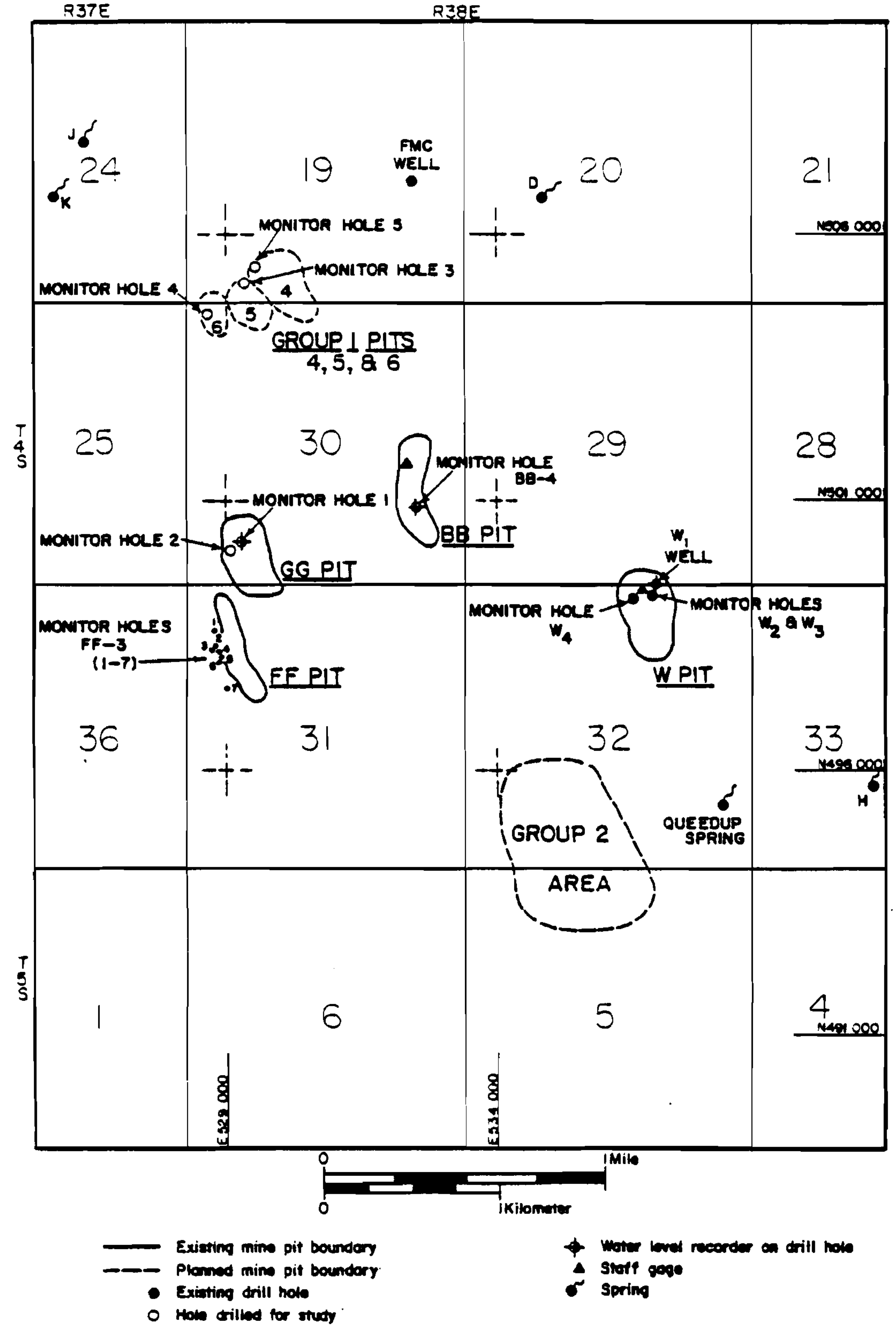


Figure IV-6. Location of mine pits, drill holes, water level recorders, staff gages, Gay Mine East Area.

with the Rex Chert member which does not occur in the Gay Mine area.

The Thaynes formation has moderate hydraulic conductivity based upon the following evidence: (1) Winter (1979) showed that most members of the Thaynes formation have sufficient hydraulic conductivity to support flow systems and (2) three small springs in the Gay Mine area issue from the Lower Limestone member of the Thaynes formation.

The Dinwoody formation has moderate hydraulic conductivity based upon the following evidence: (1) Winter (1979) showed that the Dinwoody formation supports flow systems, (2) a pump test in the Gay Mine area indicated that one well in the Dinwoody formation (F.M.C. well) can yield 100 gallons per minute (gpm), and (3) a gaining perennial stream is present in the Dinwoody formation north of Group 1.

The Cherty Shale member of the Phosphoria formation has low hydraulic conductivity based upon the evidence that there is no leakage into the north end of one of the mine pits through this member, even though water is ponded on the member near the highwall. The Meade Peak member of the Phosphoria formation also has low hydraulic conductivity based upon the following evidence: (1) Winter (1979) showed that this member does not support flow systems, (2) no springs were found issuing from this unit in the Gay Mine area, (3) the Meade Peak member "confines" water below it in the pits, and (4) there was no observed leakage into the pits from this unit.

The upper Wells formation and Granduer member have high hydraulic conductivity based upon the following evidence: (1) Winter (1979) showed that major flow systems occur in the upper Wells formation, (2) major springs issue from this unit in the Gay Mine area; some of these springs are warm and mineralized indicating regional flow systems, (3) large quantities of water flow into the pits from this unit, and (4) much water was encountered when drilling in this unit. The lower Wells formation is also assumed to have high hydraulic conductivity bases upon the results of Ralston and others (1977).

These hydraulic conductivity values represent each unit as a whole. On a small scale, intra-unit differences in hydraulic conductivity are probably as great as those between units. A consequence of this is that a fault must not offset the entire thickness of a particular unit to hinder the flow of ground water; only the zones of high hydraulic conductivity within the unit must be offset. When applying this information in later sections, the key will be the relationship of the unit with the highest hydraulic conductivity (Wells formation) to the others, and especially to the Meade Peak member which is essentially a barrier to ground water flow.

Two distinct periods of tectonic deformation were responsible for the geologic structures present in the Gay Mine area. A period of regional compression along a southwest-northeast axis caused most of the folding present, the northwest trending reverse faults, and the east-west trending tear faults. The northwest trending normal faults formed during a later period of regional tension. The major structural features are shown in figures IV-7 and IV-8.

The general fold pattern is a series of northwest-southeast striking synclines and anticlines. An important exception is the northeast striking Dry Hollow syncline in the northwest portion of figure IV-7. Major faults break the fold patterns. The major folds affecting the

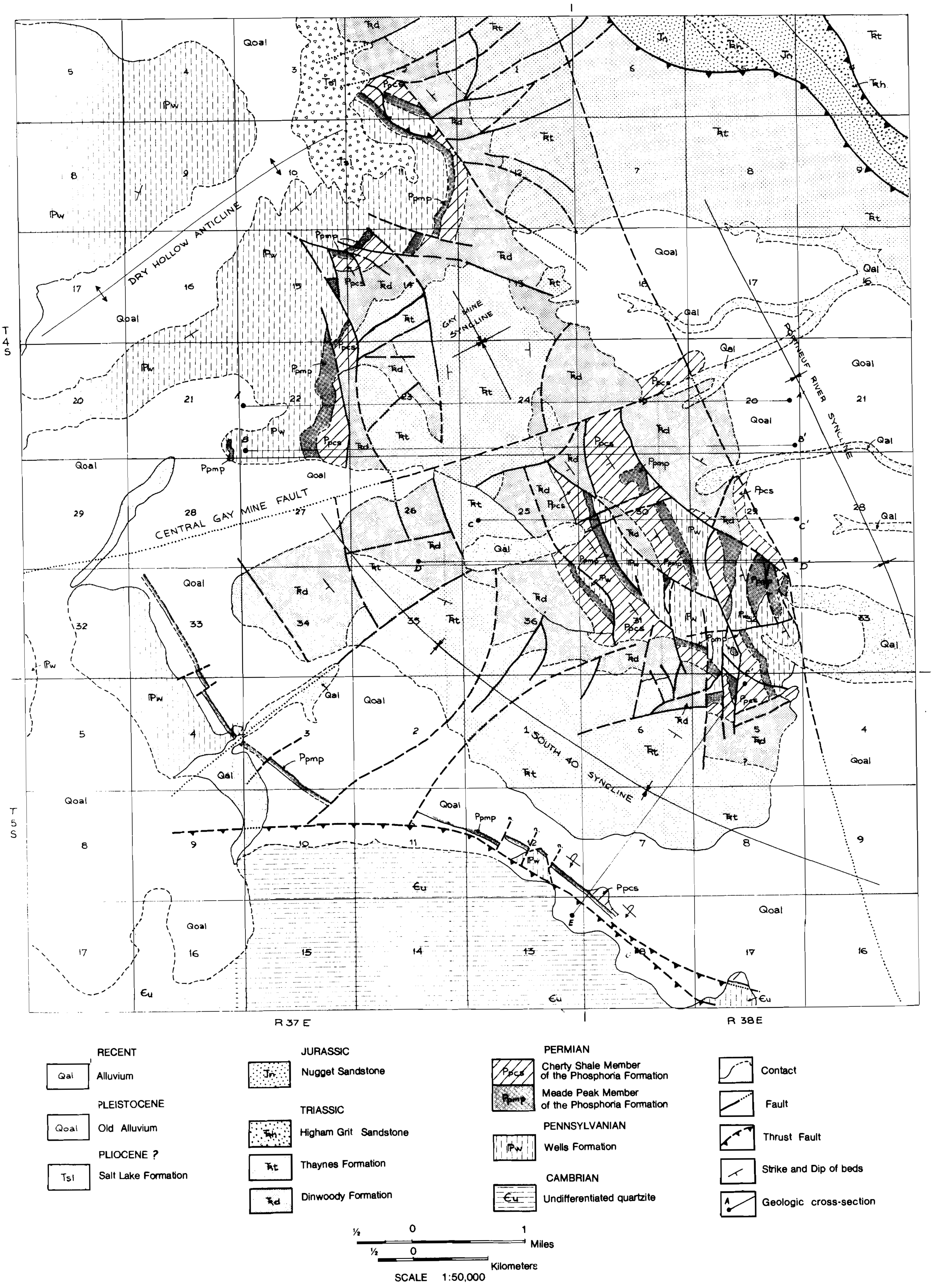


FIGURE IV-7. GEOLOGIC MAP OF THE GAY MINE AREA.

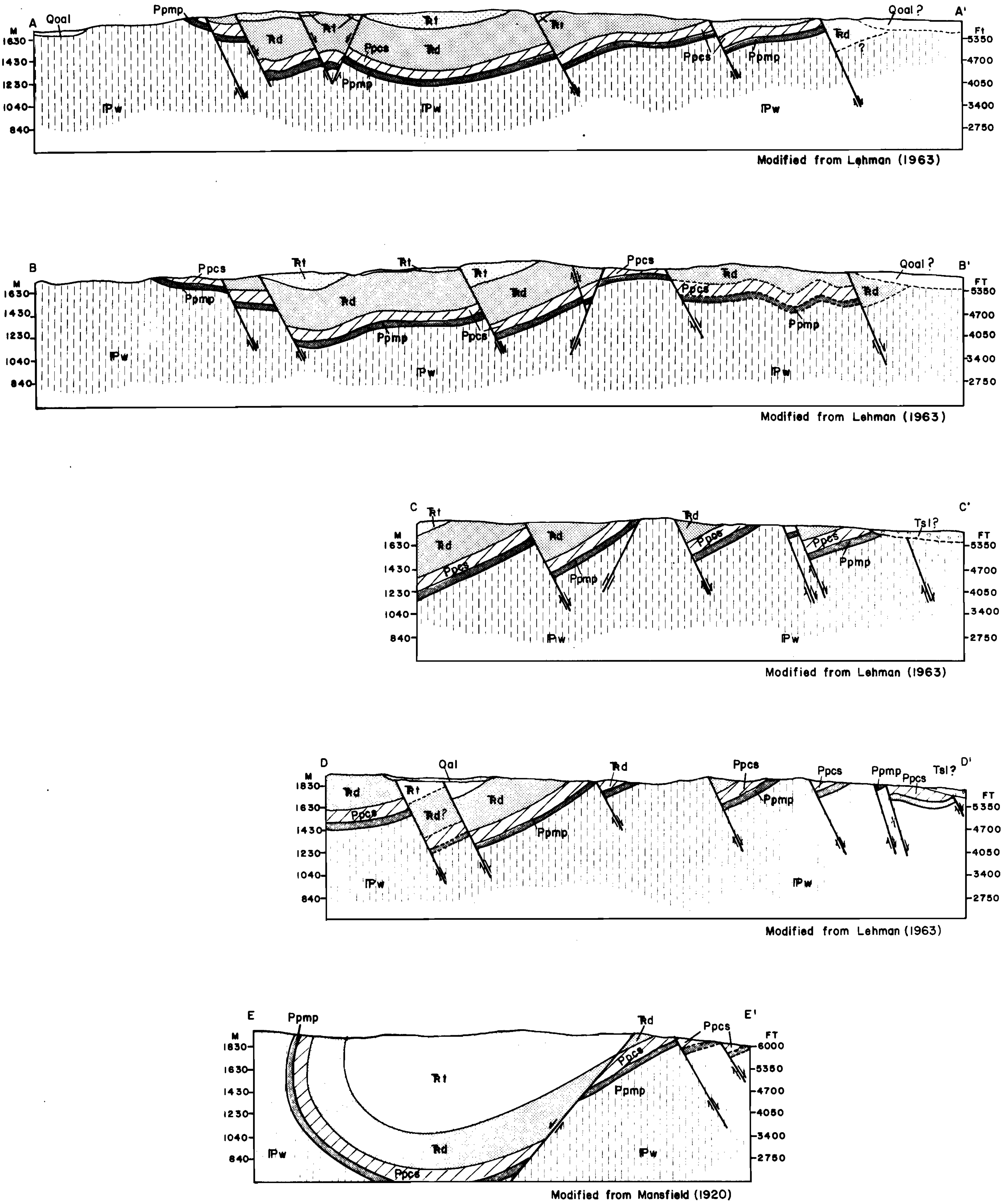
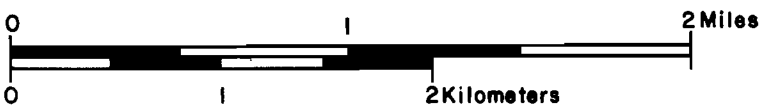


FIGURE IV-8. STRUCTURE SECTIONS OF THE GAY MINE AREA.



hydrology of the Gay Mine area are described below.

Portneuf River Syncline - This is a wide, shallow, poorly defined, northwest striking syncline. The syncline is highly fractured in the northwest portion of the mine area and tends to lose it's identity. Much of this structure is covered by the Salt Lake formation and is poorly understood.

Dry Hollow Anticline - This northeast trending anticline partially controls the outcrop pattern of the Phosphoria formation in the West Area, and is structurally related to the Gay Mine syncline.

Gay Mine Syncline - This is actually a bowl shaped structure formed by the Dry Hollow syncline and faulting. It is separated from the East Area by the Central Gay Mine fault.

South 40 Syncline - This is a very deep, tightly folded, northwest trending syncline with a near vertical southwest limb. The southwest limb has been turned under by a Cambrian thrust sheet.

There are two major types of faults in the Gay Mine area: northwest trending normal faults and east-west trending tear faults. The east-west faults tend to break regional fold trends and thus divide the area into sub-regions. The most important fault of this type is the Central Gay Mine fault. This fault separates the East Area from the Gay Mine syncline area by displacing the units north of the fault to the west and down relative to those on the south side. This type of faulting is often associated with the formation of very impermeable fault gouge. The northwest trending normal faults are generally perpendicular to bedding planes and are the most common fault type within the mine area. These faults separate the East Area from the Portneuf River syncline and largely control the outcrop of the ore zones.

The East Area can be considered to be "a block" of high hydraulic conductivity material exposed at land surface. The block is composed largely of the Wells formation (figures IV-7 and IV-8). Folding has placed the top of the Wells formation at a relatively high elevation in this area.

The beds generally strike northwest and dip about 30 degrees to the southwest. Normal faults perpendicular to bedding planes are the most common faults within the block. These faults probably hinder ground water flow downdip in this formation by offsetting the zones of higher hydraulic conductivity within the formation. The net effect is that hydraulic conductivity is greatest parallel to both bedding planes and to fault planes, or along lines trending northwest-southeast.

The area is bounded on the south and west by the South 40 syncline. The northeast limb of this syncline inclines the Phosphoria formation in such a way that it acts as a boundary in the horizontal direction. The area is bounded to the east and northeast by normal faults that drop the Portneuf River syncline area relative to the East Area. This places the Phosphoria formation of very low hydraulic conductivity against the Wells formation. The area is bounded to the north by the Central Gay Mine fault which separates the block from the Gay Mine syncline. This fault acts as a boundary primarily because it places the Phosphoria formation and lower Dinwoody formation against the Wells formation. The gouge along this fault may also limit flow.

## Analysis of Hydrologic Data

Data on ground water levels, spring discharge and pumpage from mining pits were collected and analyzed as part of the study of the Gay Mine area. The mining company installed several pumps in the BB pit to lower water levels so that mining could proceed. The pumpage from this site provided a unique opportunity to collect data on the hydraulic properties of the Wells formation.

### Wells Formation.

Hydrologic data for flow systems within the

Wells formation were taken from existing cased drill holes ($W_1$, $W_2$, $W_3$, and $W_4$), holes drilled for the study (BB-4, Mon 2, and Mon 5), ponded water in the BB-4 and W pits, and springs issuing from this formation (Queedup and H). Locations of these sites are given in figure IV-6; other information is presented in table IV-1.

Water elevations in four drill holes, BB-4, $W_1$, Mon 1 and Mon 5, were used in an attempt to define the water table as it existed prior to pumpage from the BB-4 pit. The analysis was hindered by the fact that two of these holes were not completed until after the pumping had started; elevations of water levels in these holes had to be extrapolated back to prepumping levels based upon water level data from the other holes. The water level data indicate that ground water in the Wells formation is moving in a north-northwest direction.

Several investigators have addressed the question of whether or not mine pits in the East Area are hydraulically connected (Raymond and Williams, 1973 and Combe, 1970). The first evidence that ground water flow may be continuous between mine pits, and thus across major fault zones, was presented by Combe in his report concerning a pump test of the $W_1$ well. He reported that the water level in a 16-inch well in the BBII pit was probably drawn down by the pumpage from the W pit well.

The long term pumpage from the BB-4 pit provided an excellent opportunity to see if water levels at distant points in the East Area were part of the same flow system. Water to be pumped from the BB-4 pit was collected in a trench running the length of the pit on its west side, and channeled to sumps. The initial pump, which was put into operation on May 24, 1978, discharged about 350-400 gpm (22-25 l/sec) from a sump

Table IV-1. Drill hole data for the geohydrologic study of the Gay Mine area, Western Phosphate Field, Idaho.

| Hole No. | Location (mine grid) | Elevation Casing* (feet) | Depth (feet) | Casing | Perforations (feet) | Rock Units Encountered |
|---|---|---|---|---|---|---|
| BB-4 | BB-4 Pit<br>N 500 764<br>E 532 527 | 5737.40 | 175<br>(now 30) | 6" steel to 64' | 6 - 64 | Wells Formation |
| Mon 1 | GG-2 Pit<br>N 500 107<br>E 529 270 | 5745.40 | 40 | 3" PVC to 37' | 19½- 20½ | Wells Formation |
| Mon 2 | GG-2 Pit<br>N 500 073<br>E 529 236 | 5745.32 | 129 | 6" steel to 58' | None | Wells Formation |
| Mon 3 | Group 1<br>N 505 256<br>E 529 535 | 5973.18 | 280 | 3" PVC to 258' | 255 -258 | Cherty Shale Member<br>Meade Peak Member<br>Wells Formation<br>(cased only to Meade Peak, caved) |
| Mon 4 | Group 1<br>N 504 320<br>E 528 580 | ≈5953 | 175 | 6" steel to 20', 3/4" PVC from surface to 168' (not sealed) | 165 -168 | Dinwoody Formation<br>Meade Peak Member |
| Mon 5 | Group 1<br>N 504 969<br>E 529 368 | 5959.20 | 240 | 3/4" PVC to 231' | 228 -231 | Cherty Shale Member<br>Meade Peak Member<br>Wells Formation |
| $W_1$ | N 499 340<br>E 536 930 | 5746.89 | 60 | 18" steel to 59' | 20 -59 | Meade Peak Member<br>Wells Formation |
| $W_2$ | N 499 276<br>E 536 878 | 5743.15 | 36 | 5" steel to 36' | 0 -36 | Meade Peak Member<br>Wells Formation |
| $W_3$ | N 499 273<br>E 536 877 | 5741.29 | 65 | 5" steel to 60' | 0 -60 | Meade Peak Member<br>Wells Formation |
| $W_4$ | N 499 148<br>E 536 544 | 5742.18 | 65 | 5" steel to 65' | 0 -65 | Meade Peak Member<br>Wells Formation |
| F.M.C. | N 506 900<br>E 532 442 | 5840.1 | 210 | 10" steel to 75' | ? | Dinwoody Formation |
| FF-$3_1$ | N 498 520<br>E 528 815 | 6022.34 | 215 | ? | ? | Phosphoria Formation<br>Wells Formation |
| FF-$3_2$ | N 498 210<br>E 528 835 | 6017.15 | 56 | ? | ? | Phosphoria Formation |
| FF-$3_3$ | N 498 175<br>E 528 778 | 6019.96 | 245 | ? | ? | Phosphoria Formation<br>Wells Formation |
| FF-$3_4$ | N 498 118<br>E 528 861 | 6016.27 | 205 | ? | ? | Phosphoria Formation<br>Wells Formation |
| FF-$3_5$ | N 498 025<br>E 528 888 | 6015.09 | 227 | ? | ? | Phosphoria Formation<br>Wells Formation |
| FF-$3_6$ | N 497 926<br>E 528 910 | 6008.72 | 225 | ? | ? | Phosphoria Formation<br>Wells Formation |
| FF-$3_7$ | N 497 435<br>E 529 053 | 6038.58 | ? | ? | ? | Phosphoria Formation |

* Elevations accurate to within ± 0.2 feet when compared to holes away from their immediate vicinity.

in the north end. At this time, this pumping rate was sufficient to drain the ditch. Later, as mining activity removed and disturbed increasing amounts of the confining Meade Peak member, the rate of flow into the pit increased. On September 19, 1978, a pump with a capacity of about 2300 gpm (145 l/sec) was installed in the south end of the pit. Both pumps operated until the pit was mined out on February 7, 1979.

It is necessary to monitor pump rates and on-off periods in order to correlate pumpage to changes in water levels. This information proved to be difficult to collect over long periods of time. It was thus decided that water level fluctuations in the BB-4 well would provide an adequate record of pump operation. The well is open to the Wells formation in the vicinity of the pit. Pumping water from the trench causes water to flow upward into the trench from the Wells formation and thus is essentially the same as pumping directly from the Wells formation. For this reason, it is expected that changes in the water level in the well would be proportional to changes in the pumping rate and would show the same pattern as water level changes in the trench. Figure IV-9 shows hydrographs of the BB-4 well and pond over a period that the pumping operation was closely monitored. The pumping rate was 350 to 400 gpm (22-25 l/sec). This figure indicates that water fluctuations in the BB-4 well do accurately reflect pumping rates. This relationship will be assumed throughout the hydrologic analysis.

Continuous water level data were collected at three well sites (BB-4, $W_1$, $GG_1$) by Stevens Type F water level recorders. Additional point measurements were taken with a steel tape at these points and at Group 1 Mon 5. A plot of these data is presented in figure IV-10.

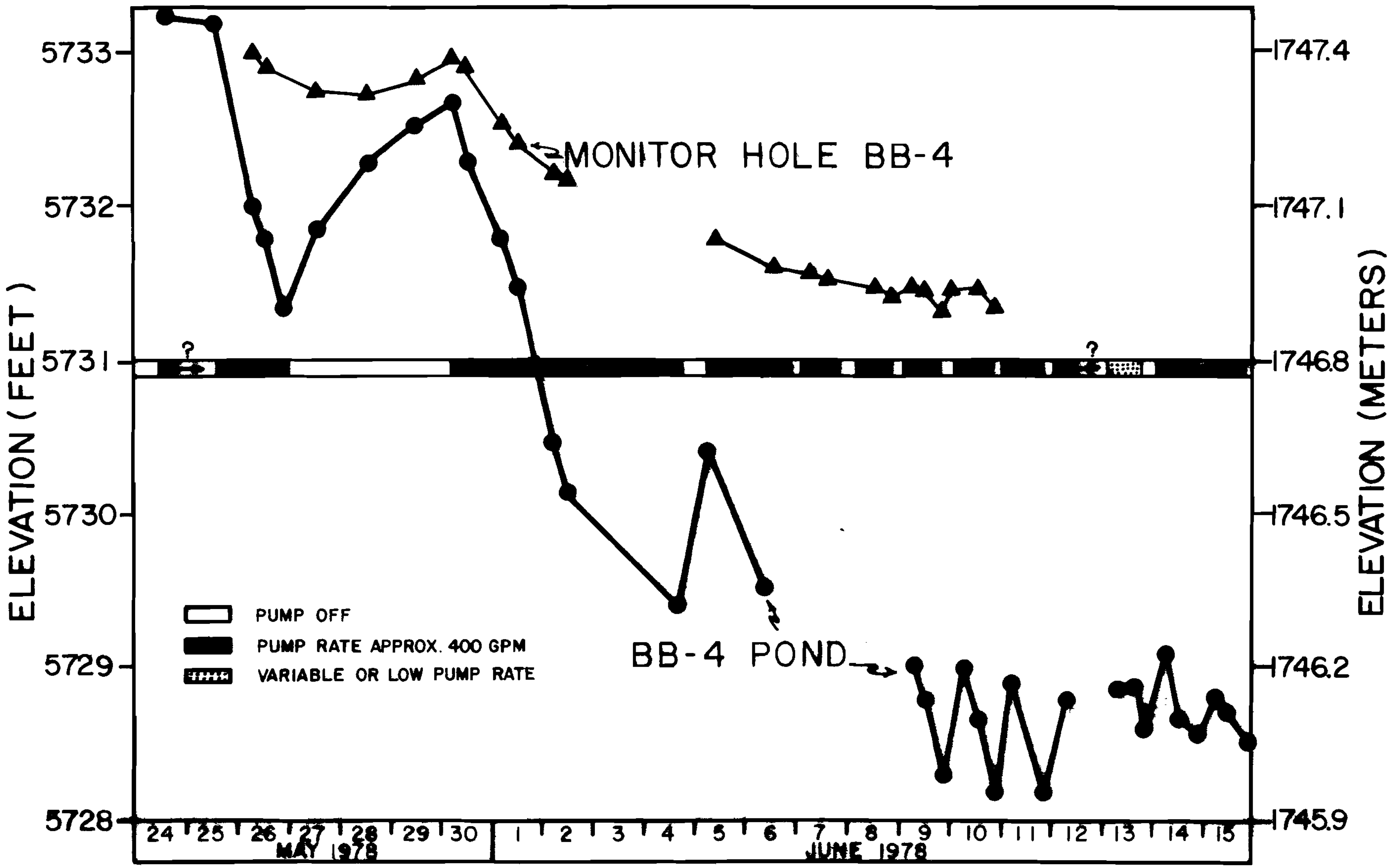


Figure IV-9. Hydrographs of monitor hole BB-4 and the BB-4 pond in relationship to pumpage from the BB-4 pit, Gay Mine.

Examination of figure IV-10 reveals that water levels in W and GG pit wells show a very similar trend and both correlate well with the BB-4 well. It is important to note that the W and GG pits are on opposite sides of the BB-4 pit. Both plots show a change of slope in response to the addition of the larger pump on September 19, 1978. Early parts of the $W_1$ plot correspond well to the early BB-4 record when the pumpage was irregular.

It is concluded that the wells monitored are hydraulically connected and that pumpage from the BB-4 pit affected an area at least as large as that represented by the data collection points. A corollary is that the major fault zones that separate the GG and W pits from the BB-4 pit are not complete barriers to ground water flow. Thus the fault blocks containing each of these mine pits does not have its own isolated flow system. Instead there is a regional water table inside the geologic boundaries described earlier.

Discharge from two springs (Queedup and H) that issue from the Wells formation remained very constant during the study period. Water from these springs is also warmer and more highly mineralized than water from any other part of the study area. These factors make it clear that these springs are discharging from a deep, long flow system that is different from the flow system represented by the other hydrologic data concerning the Wells formation. These two flow systems are both present in the W pit area.

Phosphoria Formation. The Phosphoria formation in the Gay Mine area generally does not have sufficient hydraulic conductivity to support ground water flow systems. Data on this unit are available from

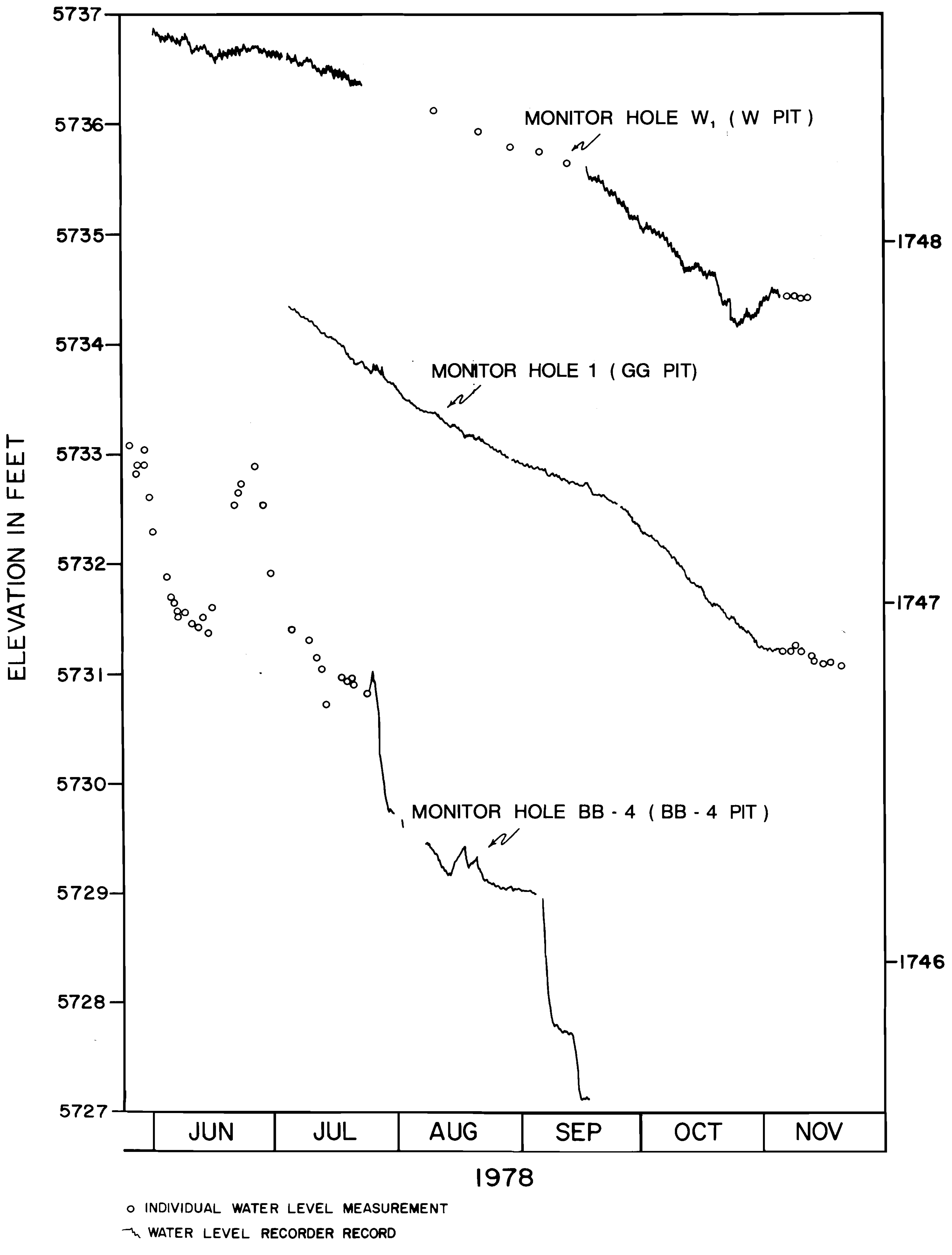


FIGURE IV-10. HYDROGRAPHS OF MONITOR HOLES BB-4, 1, AND $W_1$, GAY MINE.

seven drill holes constructed near the now back filled and reclaimed FF-3 pit. Two of these holes were used as observation wells for pump tests in December and February of 1972. Raymond and Williams (1973) concluded that the pump tests measured the hydraulic properties of the Meade Peak member only and that the hydraulic conductivity of this unit is on the order of 1.3 ft/day (.4 meter/day). They also report that water levels in several of the wells did not recover to pre-test elevations.

Dinwoody and Thaynes Formations. Hydrologic data for flow systems within the Dinwoody and Thaynes formations were taken from three springs (D, J, K) and one existing cased drill hole (F.M.C. well). Locations are given in figure IV-8 and information in table IV-1.

Water levels in the F.M.C. well were monitored from July 19, 1978 to November 6, 1978. The water level decline of almost seven feet (two meters) over this period is the result of natural recession in the absence of recharge. This magnitude of decline indicates that the flow system tapped by this well is not very extensive.

The recession trends and the relatively low flow rate of springs (J and K) from the Thaynes formation and spring (D) from the Dinwoody formation indicate that their flow systems are not extensive. The elevations of these springs and of water levels in the F.M.C. well are all higher than any water levels measured in the Wells formation.

## Ground Water Flow Systems

The information contained in the previous two sections are combined in this section to form the conceptual model of ground water flow systems in the East Area. The basic principles of the model are introduced using a schematic diagram (figure IV-11). Details of the actual

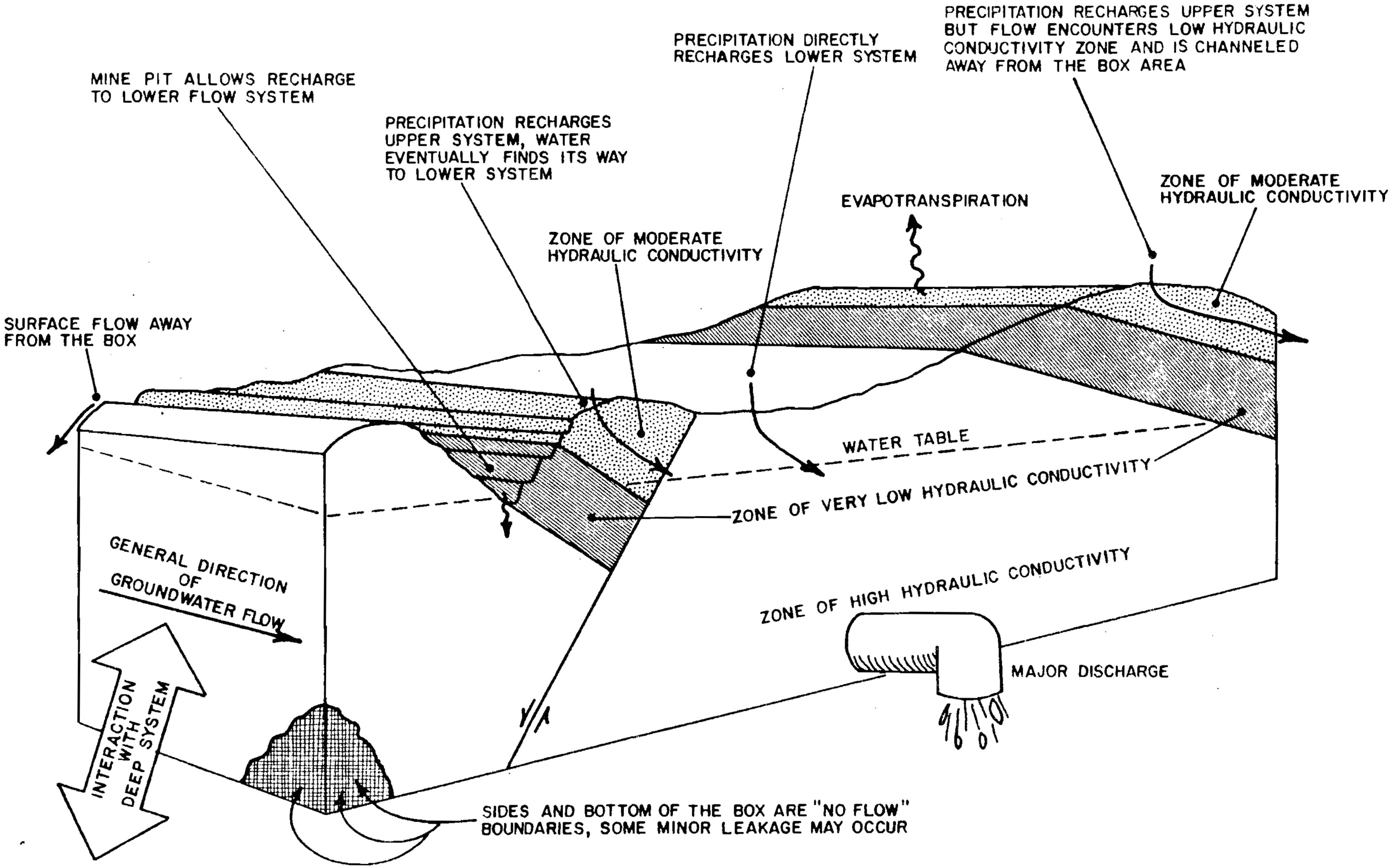


Figure IV-11. Schematic diagram of East Area ground water flow systems, Gay Mine.

flow system are then added to complete the model. Finally, generalities concerning the model and their implications are discussed.

General Principles. The following principles are illustrated in figure IV-11. (1) The East Area flow system can be considered to be contained within a box that is open at the top and is filled with high hydraulic conductivity material (Wells formation). The material in the box is partially saturated with water. (2) Layers with very low hydraulic conductivity material (Phosphoria formation) exist in the box and may extend below the zone of saturation. Above these layers are layers of moderate hydraulic conductivity (Dinwoody and Thaynes formations) that are also saturated with water. Flow above the low hydraulic conductivity layers is designated the "upper flow system"; flow beneath these layers (in the Wells formation) is designated the "lower flow system". The lower flow system is continuous within the box, whereas the upper flow system is discontinuous. (3) Recharge to flow systems within the box is from precipitation falling on the surface of the box. Components of the recharge are shown in the diagram. (4) Major discharge is from one end of the box. The location of the discharge point controls the direction of water movement in the lower flow system; the water table slopes toward the discharge point. Some discharge leaks through the bottom and sides of the box. (5) The system is in dynamic equilibrium; the inflow to the system is equal to the outflow plus changes in storage. Thus the location of the water table is determined by the relative magnitudes of the inflow and outflow rates. Artificial discharge (pumpage) removes water from storage and thus lowers the water table.

Details of the Real Flow System. The hydrogeologic boundaries of the East Area flow system are those described previously: South 40 syncline, normal faulting to the east, and the Central Gay Mine fault. Group 1, Group 2, and all active pits of the East Area are located within the boundaries. It must be remembered that a boundary has been defined as an abrupt change in hydraulic conductivity; the rate of flow across a boundary is usually insignificant. On a small scale however, hydraulic conductivity may change within a unit. For this reason, the boundaries may "leak" in places. Some flow may "leak out the bottom" of the system by flowing downdip in the Wells formation. The amount of water flowing out of the system in this way will be relatively small because normal faulting offsets zones of high hydraulic conductivity within the unit.

Analysis of the hydrologic data has shown that the direction of ground water flow in the lower system is to the north-northwest, or along lines of greatest hydraulic conductivity. It was also shown that flow in the lower system is continuous within the system boundaries. The piezometric surface of the lower flow system is about 5,730 feet (1,710 meters) above sea level.

Discharge from the system is by ground water flow to the north. The exact method of discharge is not known, although a study of the geology reveals a very probable explanation. The Central Gay Mine fault is the northern boundary to the system primarily because it drops the Phosphoria formation on the north to a position adjacent to the Wells formation on the south. However, the block on the north side of the fault is tilted to the west resulting in a 500-foot (150-meter) greater displacement on the west edge of the East Area flow system than on the east edge (Lehman, 1966). The top of the Phosphoria formation is adjacent to the top of the Wells formation to the east, but is 500 feet (150 meters) below it to the west. This results in a triangle of Dinwoody formation on the north side of the fault being exposed to the Wells formation to the south, thus providing an avenue of escape for ground water. Flow may also cross the fault at depths greater than 750 feet (210 meters) and flow into the Wells formation to the north.

Recharge is primarily from snowmelt in the spring. The pattern of snow accumulation within the mine area was not defined as part of the study. However, other studies in the Southeastern Idaho Phosphate field have shown that, because of wind patterns, snow tends to accumulate on northeast facing ridge slopes (Ralston and Trihey, 1975). The Wells formation is the main ridge forming unit in the Gay Mine area. This implies that much of the snowmelt will directly recharge the lower flow system. Mine pits remove the Phosphoria formation and thus create an avenue for water to move through to the Wells formation. Pits also tend to collect surface water and ground water intercepted from upper flow systems.

The upper flow system within the East Area is divided into two distinct parts, both in the Dinwoody formation. One of these flow systems is located to the east of the Group 1 area (figure IV-7). This flow system appears to be constrained to "a block" of Dinwoody formation with an area of about one square mile. Because of fault displacement, the low hydraulic conductivity Phosphoria formation bounds the block of Dinwoody laterally on the north, west, and south. The Phosphoria formation also lies below the Dinwoody formation in the normal stratigraphic relationship. Recharge to this flow system is primarily from snowmelt during spring runoff. Ground water probably moves to the east where the land surface is at a lower elevation. The elevation of the water table in this system is about 5,805 feet (1,740 meters). This is also the only direction not bounded by the Phosphoria formation. Discharge probably occurs as evapotranspiration in topographic low areas, or as subsurface flow into the Salt Lake formation. This system is recharged within the boundaries of the East Area flow system but discharges outside.

The second part of the upper flow system is located west of the BB-4 pit. Water in this system flows downdip to the west and eventually into the Wells formation where it is placed in contact with the Dinwoody formation by faulting. Discharge from this system thus recharges the lower flow system.

A third flow system was identified outside of the boundaries of the East Area. It is located in the topographically high Gay Mine syncline structure and occurs in the Thaynes formation. Recharge occurs on top of the knob and flow moves to the east and west. Discharge is from springs J and K on the east and from a spring that feeds a Simplot water pond on the west.

Implications of the Flow System Model. Implications of the flow system model are as follows:

1. The ground water levels in the upper flow system are higher than those of the lower system. Therefore, water from the upper system can be drained to the lower system by gravity.
2. The entire East Area flow system could be drained by gravity to a level that would allow underground mining of deep ore reserves. This could be accomplished by constructing a tunnel system that would drain the Wells formation to the Portneauf River valley.
3. Design of dewatering wells must take into consideration the location of the system boundaries and also the changes in the storage coefficient as the lower flow system changes from confined to unconfined conditions.

## Conclusions

1. The relative hydraulic conductivity of various formations within the "phosphate sequence" at the Gay Mine is similar to that found for other portions of the phosphate field in southeastern Idaho.

2. Ground water flow systems within the mine area are dominantly controlled by folding and faulting in the area. The pattern of folding and faulting in the Gay Mine area is markedly different than that found at most of the other phosphate mine sites in the phosphate field in southeastern Idaho.

3. Ground water flow systems in the East Gay Mine area may be depicted by a simple model showing a box of high hydraulic conductivity material draining out one end. In the actual field situation, the high hydraulic conductivity Wells formation is bounded by faults and folds on four sides and is located so that it can receive recharge directly from precipitation. Discharge from this block of material is believed to occur by ground water flow to the north across a fault structure.

4. Discontinuous upper ground water flow systems occur in the Thaynes and Dinwoody formations but are of limited significance in the mine area. These flow systems may easily be drained downward to the Wells formation due to a lower potential in the underlying flow system.

5. The entire block of high hydraulic conductivity material may be drained by a major tunnel into the Portneauf valley to the east. This would allow mining of most significant altered ore beds in the proposed mining area.

6. The warm springs (Queedup and H) found to the east of the mining area are believed to discharge from the Wells formation from a regional ground water flow system not directly associated with the mine area. Both flow systems are present in the vicinity of W pit.

## Hydrogeology of the North Henry Mine

### Introduction

Monsanto Company is operating an open-pit phosphate mine 18 miles (29 kilometers) north-northeast of Soda Springs, Idaho (figure IV-12). Mining will be extended northwestward to and beyond the Little Blackfoot River when present reserves south of the river are depleted. The mine extension will include construction of mine pits, a waste dump, loading tipple, and additional roads for ore removal.

Mining in the proposed area could impact and be impacted by local water resource systems. These systems include the Little Blackfoot River and ground water flow in volcanic and sedimentary aquifers. The North Henry Mine area represents a unique geologic-hydrologic situation. Mining is proposed to extend below the elevation of the perennial Little Blackfoot River in an area where basalt is an important aquifer.

The purpose of this study is to delineate potential water resource impacts on and from open-pit phosphate mining in the North Henry site. The general objective of this study is to describe the surface-ground water systems of the North Henry Mine area and their potential interconnection with future open-pit mining. The specific objectives of this study are to:

1. Describe the hydrogeologic framework of the North Henry Mine area.
2. Describe discharge and gain-loss characteristics of the Little Blackfoot River near the mine site.
3. Describe ground water flow systems within the basalt in the North Henry area.
4. Describe ground water flow systems within the sedimentary rock formations in the North Henry area.

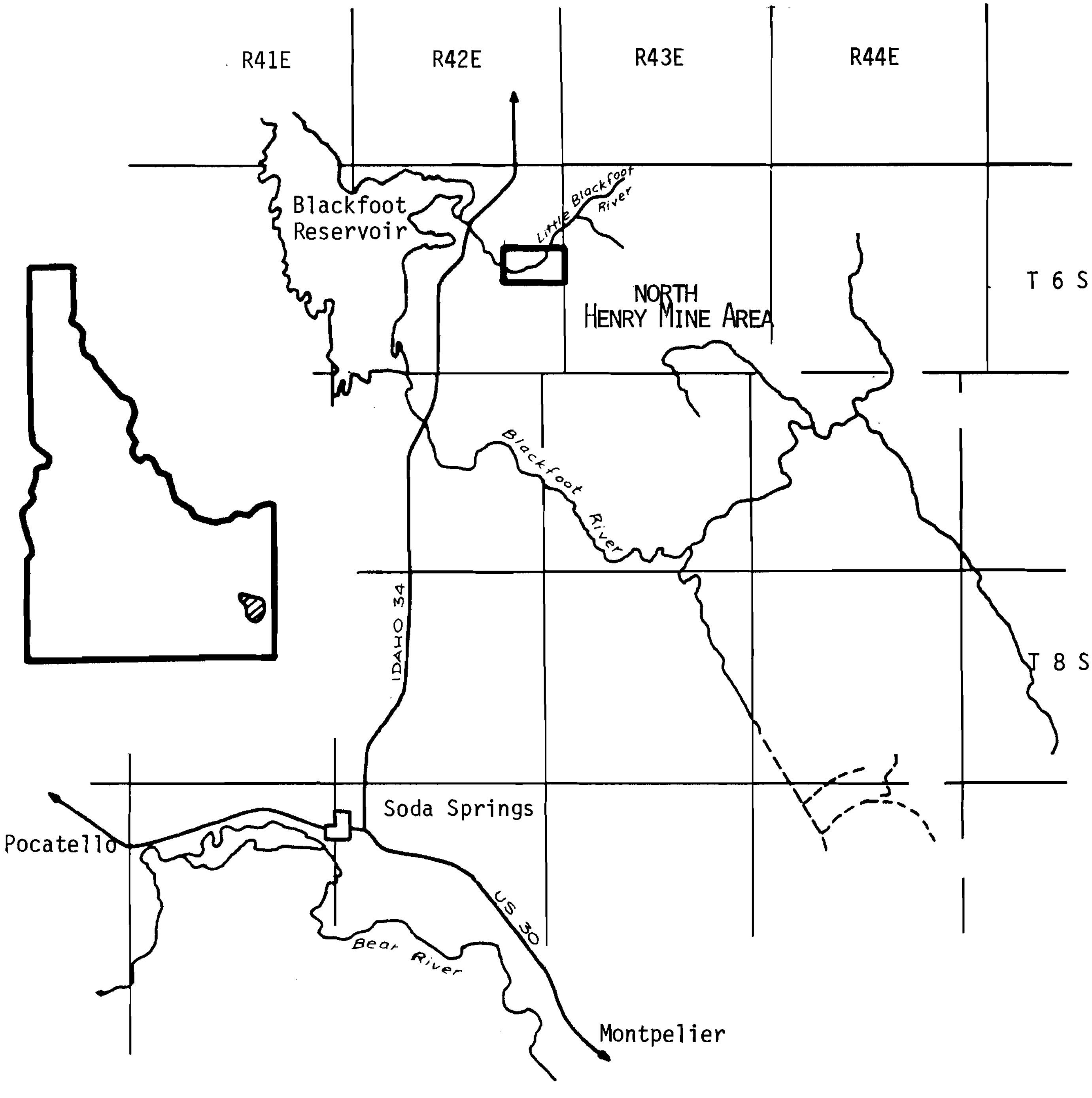


FIGURE 1V-12 LOCATION MAP OF THE NORTH HENRY MINE AREA

5. Describe the interrelationship between the Little Blackfoot River and the basalt and sedimentary ground water flow systems.

6. Delineate potential water resource impacts associated with the development of the North Henry Mine.

Field data were collected primarily during the summers of 1977 and 1978. The field data collection included: (1) installation of piezometers in existing and newly drilled test holes and subsequent monitoring of ground water levels, and (2) measurement of stream discharge at selected sites on the Little Blackfoot River.

The North Henry study area is within the Western Phosphate Field in southeastern Idaho, 18 miles (29 kilometers) north-northeast of Soda Springs and 2 miles (3 kilometers) east of Henry and the Blackfoot River Reservoir (figure IV-12). The proposed North Henry Mine will follow the ore strike northwest of the Little Blackfoot River along the "Henry Ridge". The general study area includes the "Henry Ridge", west of the ridge to Henry, east to Enoch Valley, north to Highway 34 and south to Monsanto's present South Henry Mine site. Most of the data collection occurred near where the strike of the ore crosses the Little Blackfoot River.

Ridges and valleys are generally aligned northwest-southeast parallel to the dominant geologic structure; elevations within the study area range from 6,200 to 7,000 feet (1,890 to 2,134 meters). The specific mine site would alter 480 acres (194 hectares) along the "Henry Ridge" and the adjacent eastern valley and be located on federal, state, and private lands.

Local climate varies with topography, but winters are generally cloudy with measurable precipitation on about one-third of the days with snow prevailing on the hills and mountains. Spring is the wettest and windiest season accompanied by gradually warmer weather but with continued night frost in the lower valleys until May. The summer consists of cool nights and warm to hot days with localized showers. Autumns are pleasant late into November when late summer showers evolve into unsettled weather and snow. Annual precipitation averages 20 inches (51 centimeters) per year with snowfall accumulation to depths as great as 10 feet (3 meters).

Mansfield (1927) produced the earliest investigation of the ore potential, geology, and hydrology in the Western Phosphate Field. The geology along the ore outcrop in the North Henry study area has been mapped in detail by Monsanto geologists. Hydrologic reports in the vicinity include: Dion (1974) on leakage from Blackfoot Reservoir to the Bear River Basin, Sylvester (1975) on the reconnaissance hydrogeology of Little Long Valley and Upper Dry Valley, Mohammad (1976) on potential impacts of open-pit mining in the Little Long Valley, Robinette (1977) on ground water flow systems in Lower Dry Valley, and Vandell (1978) on pump test results in Lower Dry Valley. The studies by Robinette and Mohammad are summarized in Ralston and others (1977).

## Hydrogeologic Framework

The locally important geologic units are the (1) Quaternary alluvium, (2) Quaternary basalt, (3) Triassic Dinwoody formation, (4) Permian Phosphoria formation which includes the Rex Chert and Meade Peak members, and (5) Pennsylvanian Wells formation. Figure IV-13 shows the surface geology and structural features. A geologic cross section from "Henry Ridge" to Rasmussen Ridge is shown in figure IV-14.

The primary regional and local structural features strike northwest-southeast in the vicinity of the Henry Mine. A series of parallel

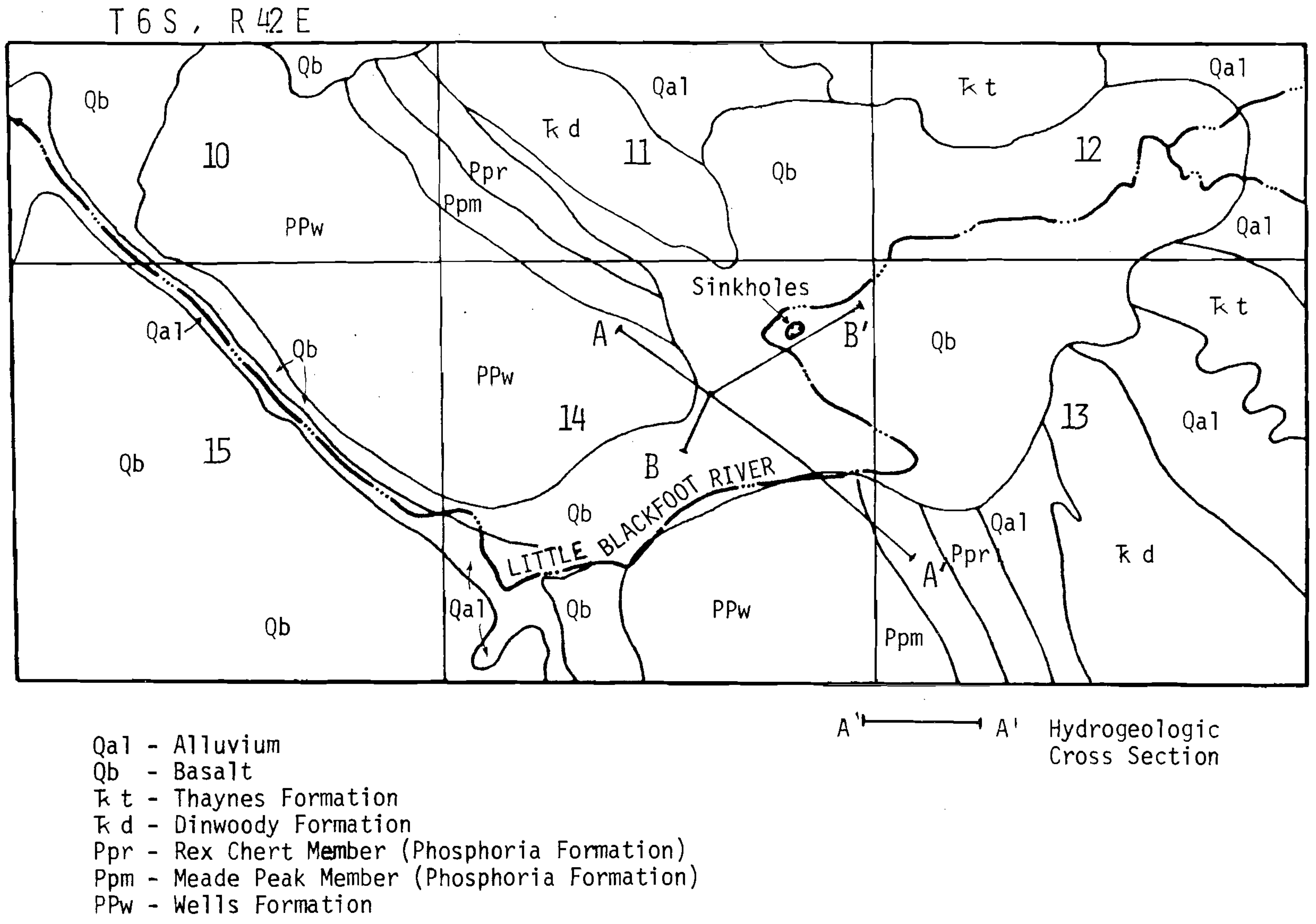
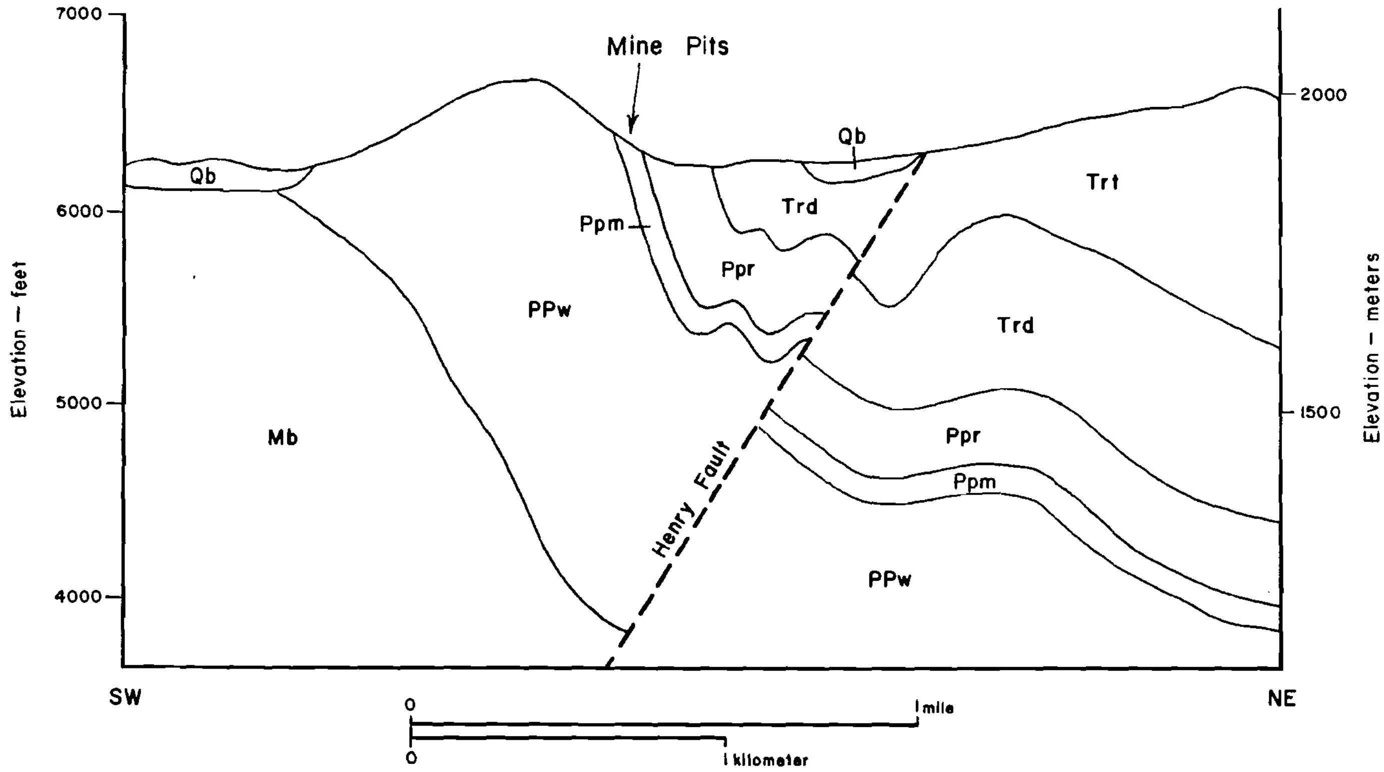


FIGURE IV-13 GEOLOGIC MAP OF THE NORTH HENRY MINE AREA



| | |
|---|---|
| Qb | Basalt |
| Trt | Thaynes Formation |
| Trd | 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 IV-14. Generalized geologic section through North Henry Mine site.

anticlines and synclines are topographically expressed as ridges or valleys, dependent upon the erodability of the exposed rock unit. Wooley Range and "Henry Ridge" were formed by the outcrop of the Wells formation along the east limb of the Wooley Valley anticline or west limb of the Georgetown syncline. Enoch Valley overlies the east limb of the Georgetown syncline (figure IV-14). Mansfield (1927) suggests that the valley east of the small Dinwoody ridge overlies a west trough of the Georgetown syncline. The phosphate ore outcrops continuously along the east slope of the Wooley and "Henry Ridge". In the study area the ore strikes about N. $40^{0}$ W. for about 6,500 feet (1981 meters) and dips $55^{0}$ to $70^{0}$ northeast.

The Henry fault and Enoch Valley faults are oriented northwest-southeast as is most structure in the region (figure IV-13). The Henry Thrust fault is concealed for nearly two-thirds of its 15-mile (24-kilometer) length and displaces a few hundred feet. The Enoch Valley normal fault is about 35 miles (56 kilometers) long and has a downthrow of several thousand feet. Several minor transverse faults have been determined by field observation and drilling along Wooley Valley Range.

Alluvium, basalt and the Dinwoody, Phosphoria and Wells formations comprise the surface geology in the immediate study area (figure IV-13). Alluvium thickness is as great as 60 feet (18 meters) in "Henry Valley" based upon drill log data. The basalt is widely found in the lower valleys. The olovine basalt thickness in the study area varies from about 60 feet (18 meters) or less in the lowlands to about 200 feet (61 meters) near the "narrows" where the basalt filled the ancestral valley of the Little Blackfoot River. The basalt thickness west of "Henry Ridge" is at least several hundred feet (Dion, 1974). Two lava flows are believed to make up the basalt in the study area.

Three sinkholes are present in "Henry Valley" near the Little Blackfoot River (figure IV-13). The sinkholes are expressions of weak zones in the basalt that have been overlain by alluvium. The alignment of the three structures suggests a partially collapsed lava tube. One drilling log indicated a void in the basalt up to 10 feet (3 meters) in depth. The largest sinkhole (S1) is about 15 feet (5 meters) long, 8 feet (2 meters) wide, and 10 feet (3 meters) deep. Soil failures along the perimeter suggests that the depression is getting larger. The second sinkhole (S2) is about 10 feet (3 meters) long, 3 feet (1 meter) wide and 3 feet (1 meter) deep and is located about 4 feet (1 meter) west of S1. This sinkhole is directly linked by a small 30-foot (9-meter) long channel to the Little Blackfoot River. Sinkhole three (S3) is a circular depression of about 5-foot (2-meter) diameter and 2 feet (1 meter) deep in the center. These sinkholes are of major hydrologic importance.

The alluvium is composed of weathered sediment from local topographic highs and fine clays and silts deposited by the Little Blackfoot River. The drillers log of a test hole in "Henry Valley" describes the composition of the nonindurated sediment as silt, clay, gravel, sand, and pebbles. Portions of the alluvium should act as aquifers. Ground water in basalt normally flows along zones of high hydraulic conductivity between individual flows such as the red cinder interbed zone found in the study area. Dion (1974) noted that the basalt is an excellent aquifer in the Blackfoot lava field, which is continuous with the basalt in "Henry Valley".

The Triassic Dinwoody formation consists of about 900 feet (274 meters) of interbedded limestone and siltstone with discontinuous shaly zones. Both the upper and lower members of the Dinwoody formation have been described by Ralston and others (1977) as aquifers. The lower member of the Dinwoody formation underlies the alluvium and basalt in "Henry Valley" and forms the ridge east of the valley. No data are available from the study area to document local hydraulic conductivity.

The Rex Chert member of the Phosphoria formation is about 250 feet (76 meters) thick and is composed of cherty mudstone, mudstone, siliceous shale, chert and argillaceous chert. It generally exhibits low hydraulic conductivity except when fractured and broken. Drilling records of one well in the study area note highly fractured zones within the Rex Chert member. Vandell (1978) concluded from studies in Dry Valley that the highly fractured zones within this member can support ground water flow, but the zones are localized features, not necessarily characteristic of the Rex Chert member over broad areas. The Meade Peak member which is stratigraphically under the Rex Chert member is about 180 feet (55 meters) thick and consists of phosphorite, mudstone and some limestone. This rock is dense and is considered an aquiclude (Ralston and others, 1977). Winter (1979) concluded that neither member of the Phosphoria formation supports major ground water flow systems in eastern Caribou County.

The upper unit of the Pennsylvanian Wells formation includes about 1500 feet (450 meters) of sandstone, limestones and dolomite. The lower unit is composed of sandy-cherty limestone. Winter (1979) found that both members support major ground water flow systems in the Western Phosphate Field. Several large springs located along the western face of "Henry Ridge" contribute significant flow to the Little Blackfoot

River. The springs issue from the upper member of the Wells formation along a possible fault.

### Data Collection Program

Ground water and surface water data were collected between June 1977 and November 1978. The data base consists of stream discharge at selected stations along the Little Blackfoot River and ground water elevations from piezometers installed in selected drill holes.

The criteria for selection of stream discharge measurement sites were: (1) locating sites near formation contacts to document stream gain-loss characteristics associated with individual units and (2) locating sections along the river suitable for current meter measurements. Discharge measurements were made with a pygmy current meter following the procedure described by Buchanan and Somers (1976). Five stations along the river were selected (figure IV-15).

Station A overlies basalt and was selected to document streamflow entering the immediate study area and proposed mine site. Station B is about 2,500 feet (762 meters) downstream of station A. The basalt is covered by less than 20 feet (6 meters) of alluvium at this site. Discharge differences between stations A and B represent gains or losses across "Henry Valley". Station C is near the contact between the Phosphoria formation and the Wells formation. The stream between B and C flows mostly on basalt underlain by the Dinwoody and Phosphoria formations. Discharge differences should represent gains or losses of the river associated with ground water flow in the lower portion of the Dinwoody formation, the Phosphoria formation or the basalt. Station D is located where the Wells formation is overlain by basalt. This station represents discharge leaving the immediate vicinity of the proposed mine area. Flow differences between sites C and D are associated with ground water flow in the Wells formation and basalt. The final station, E, is near the town of Henry and includes the discharge from several springs located less than one mile upstream from Henry.

Piezometers were installed in selected existing drill holes (holes drilled previous to this study for geologic purposes) and in new drill holes (holes drilled during this study for hydrogeologic purposes). The depth, formations encountered, and elevation of each piezometer and open hole are given in table IV-2. Piezometer locations are shown in figure IV-15.

Measurements of ground water levels were taken at least weekly during the summer field seasons and less frequently between summers. Hydrogeologic data were obtained during the construction of the new drill holes. Drill cuttings were examined and changes in ground water levels were measured. Finally, simple slug tests were used to check the validity of piezometer information. A detailed discussion of all field data is presented by Brooks (1979).

### Hydrology of the Little Blackfoot River

The Little Blackfoot River is formed by several springs located on the west slope of Rasmussen Ridge and in Enoch Valley. The stream meanders westward through "Henry Valley". Some streamflow is lost into the sinkholes in "Henry Valley" during the spring and summer. The stream flows west through a gap in "Henry Ridge" and continues along the west base of the ridge to where it discharges into the Blackfoot Reservoir. The Little Blackfoot River has low gradient in Enoch Valley and "Henry Valley" and

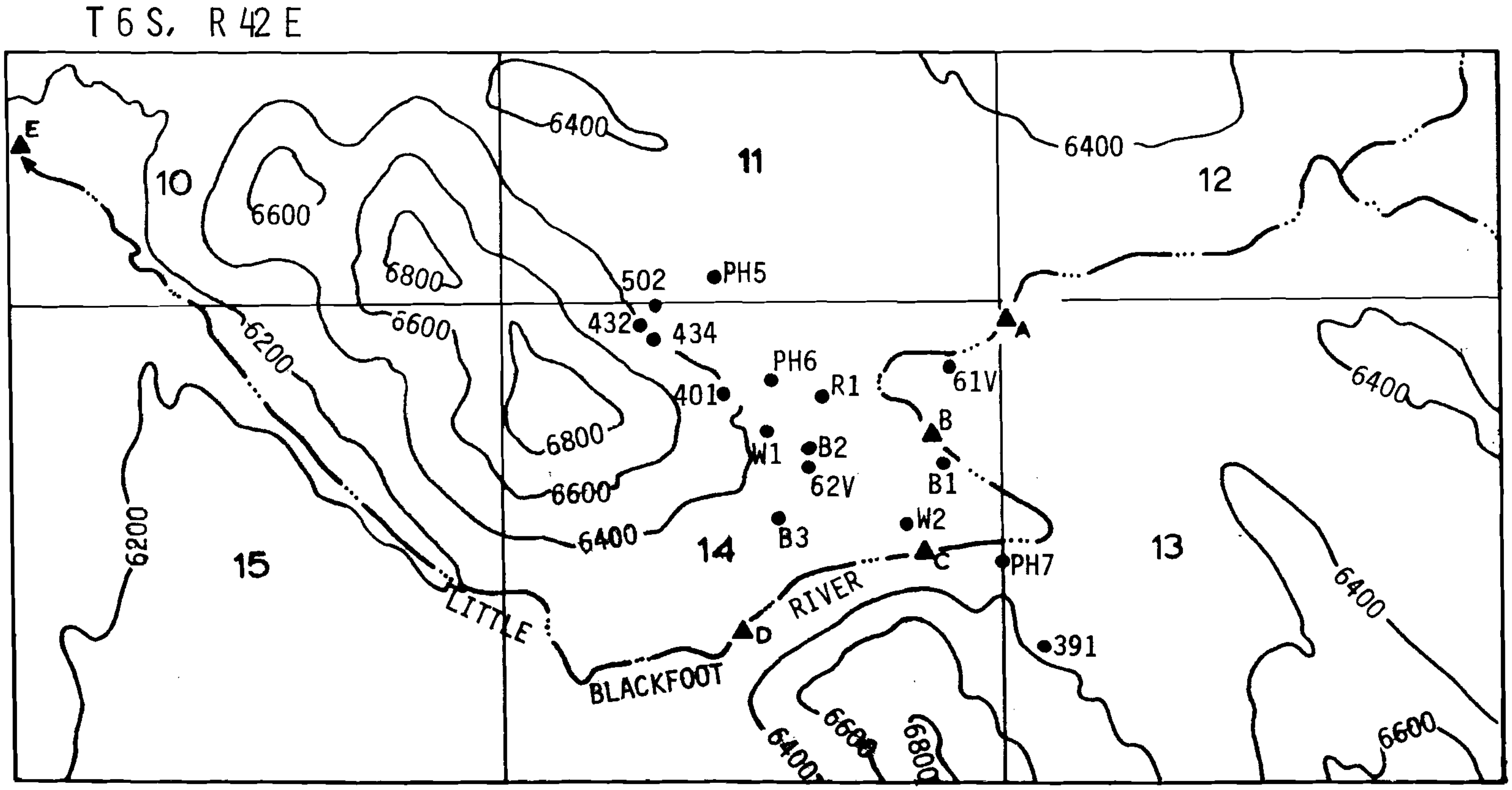


FIGURE IV-15 LOCATION OF GAGING STATIONS AND PIEZOMETERS

● PIEZOMETER
▲ GAGING STATION

Table IV-2. Test well data for the North Henry Mine area.

| Well No. | Depth (feet) | Elevation of Land Surface (feet) | Elevation of Water Surface (feet) | Depth Interval of Unit Penetrated (feet) | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | Alluvium | Basalt | Rex Chert | Meade Peak | Wells Formation |
| 61V | 59 | 6275 | 6227 | - | 0- 59 | - | - | - |
| 62V | 165 | 6351 | 6218 | - | 0-165 | - | - | - |
| PH5 | 56 | 6280 | 6236 | 0- 56 | - | - | - | - |
| PH6 | 70 | 6280 | 6228 | 0- 28 | 28- 70 | - | - | - |
| PH7 | 36 | 6253 | 6232 | 0- 36 | - | - | - | - |
| W1 | 190 | 6324 | 6192 | - | 0- 88 | - | 88-190 | - |
| W2 | 231 | 6348 | 6193 | - | 0- 74 | - | 74-218 | 218-231 |
| B1 | 100 | 6270 | @6220 | 0-100 | - | - | - | - |
| B2 | 273 | 6347 | 6220 | - | 0-246 | - | 246-273 | - |
| B3 | 265 | 6324 | 6202 | - | 0-260 | - | - | 260-265 |
| R1 | 380 | 6278 | 6229 (basalt)<br>6181 (chert) | - | 0-185 | 185-380 | - | - |
| 391* | 402 | 6351 | 6174 | - | - | - | 0-398 | 398-402 |
| 401* | 168 | 6319 | 6179 | - | - | - | 0-168 | - |

*Inclined drill hole

has a channel that is characteristic of a low energy system. The stream gradient increases west of "Henry Ridge" and the streambed composition is rock and gravel. Discharge of the Little Blackfoot River at station B in 1978 varied from 58 cfs (cubic feet per second) (1,640 liters/second) during peak flow in April to about 2 cfs (56 liters/second) in low flow.

Streamflow measurements for the Little Blackfoot River are given in figure IV-16 illustrating gains and losses from stations A to E. Losses were usually found between stations A and B, especially during peak flow through June. During this period water from the stream was continually flowing into the sinkholes. Consistent losses occurred between stations B and C. These losses suggest the basalt and possibly the underlying Rex Chert member of the Phosphoria formation are recharged by the Little Blackfoot River. Results are inconclusive between stations C and D. Both, gains and losses were measured on different dates during the summer of 1978. Distinct gains occur between stations D and E. The springs west of "Henry Ridge" near Henry significantly increase the streamflow in the Little Blackoot River.

## Ground Water Flow Systems

Three different ground water flow systems may be identified in the vicinity of the North Henry Mine: a local ground water flow system in the indurated and nonindurated sedimentary rocks along "Henry Ridge", a ground water flow system in the alluvium and basalt along "Henry Ridge" and the floodplain of the Little Blackfoot River, and a regional ground water flow system present in the Wells formation. All of these flow systems are of importance to the mining operation. The shallow flow system on the "Henry Ridge" will be directly intercepted by the

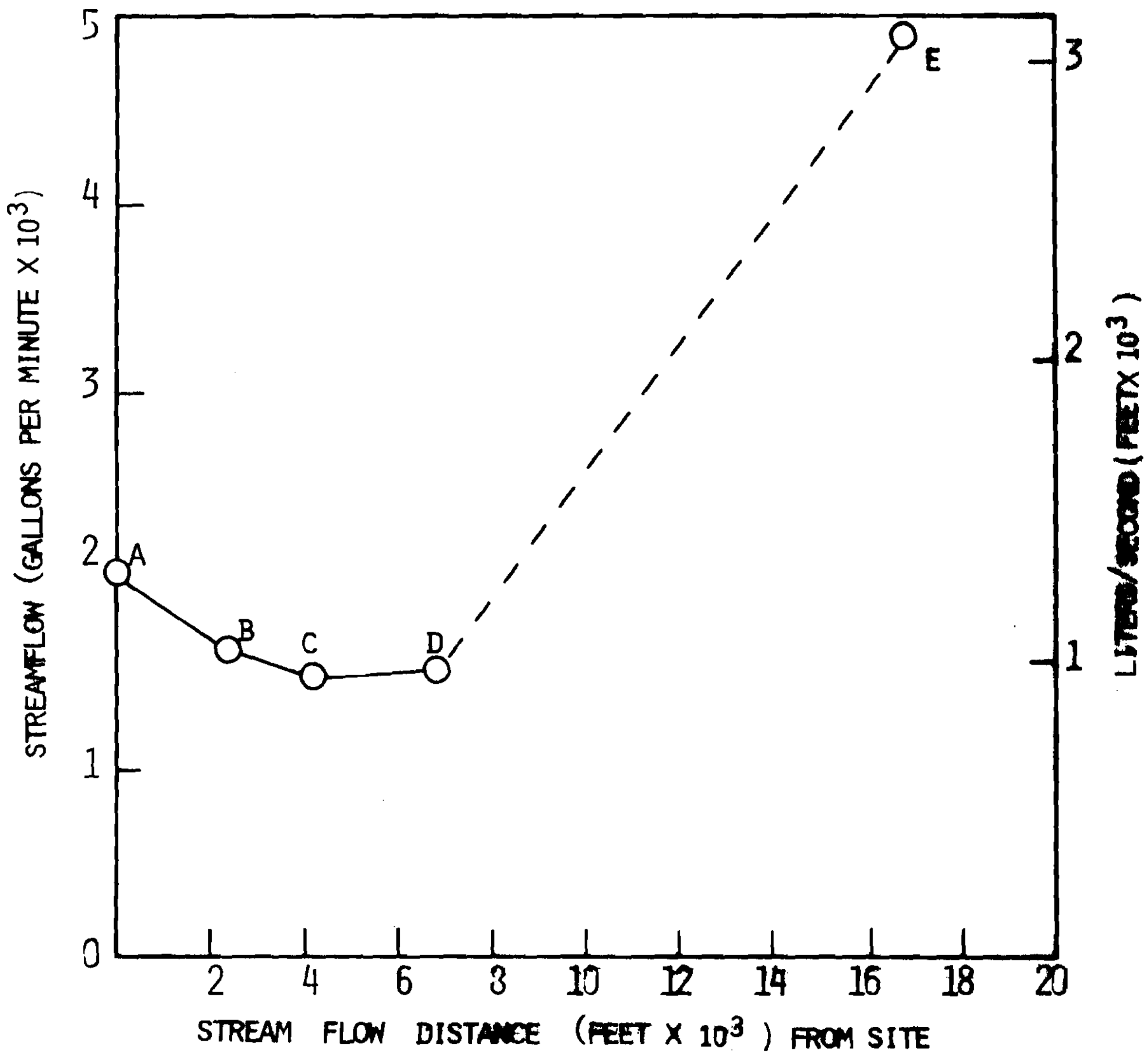


FIGURE IV-16 STREAMFLOW IN THE LITTLE BLACKFOOT RIVER AT GAGING SITES ON AUGUST 24, 1978 construction of the mining pits. The ground water flow in the alluvium and basalt is of special significance to mining because this is probably the primary source of water entering the Phosphoria formation and ultimately entering the portion of the pits that are constructed below stream level. The regional ground water flow system in the Wells formation is least likely to be affected by mining but is important in that it forms a significant portion of the baseflow of the Little Blackfoot River at Henry.

Winter snowpack and additional precipitation throughout the year recharge the surficial flow system along the eastern slope of "Henry Ridge". This system is comparable to Mohammad's (1977) description of a similar ridge area in Little Long Valley (see figure III-4). The recharge area is small and resulting discharge in the immediate study area is small. This flow system would appear as small seeps and wet spots along the contact of the Wells formation and the slope wash material along the high wall of the mine pit. This flow system would be no more significant in the North Henry Mine area than it is in existing Henry Mine pits.

The ground water flow system in the alluvium and basalt receives most of its recharge in "Henry Valley" in the spring and summer (April through September) when a portion of the Little Blackfoot River flows into the alluvium/basalt sinkholes (S1, S2, S3). Additional recharge is contributed by surficial flow along "Henry Ridge" and infiltration of water (snowmelt, precipitation and streamloss) downward through the alluvium into the underlying basalt.

The ground water flow pattern in the alluvial/basalt aquifer system is shown on figures IV-17, IV-18, and IV-19. Figure IV-17 is a contour

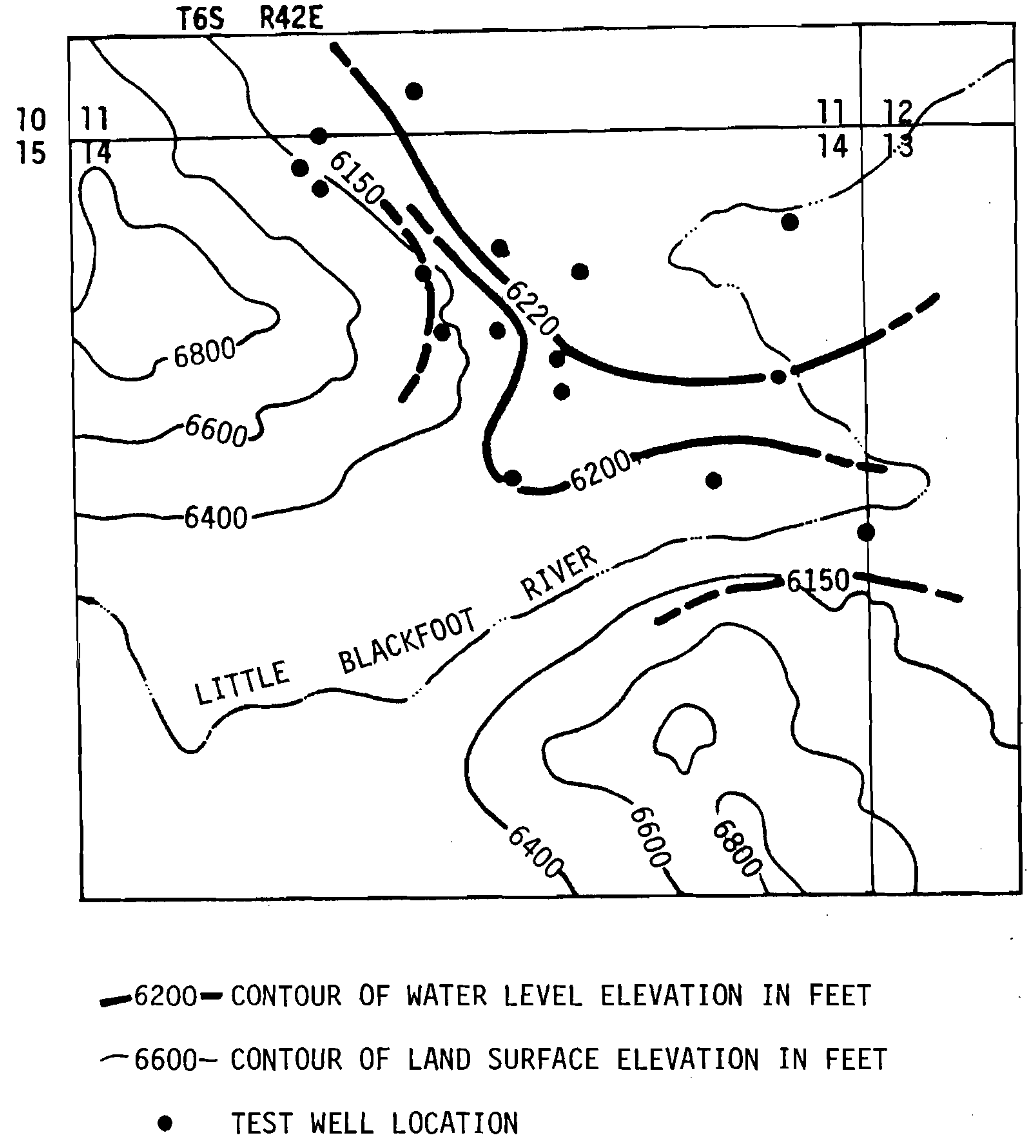


FIGURE IV-17 CONTOURS OF WATER LEVEL ELEVATION NEAR THE LITTLE BLACKFOOT RIVER, NORTH HENRY MINE AREA

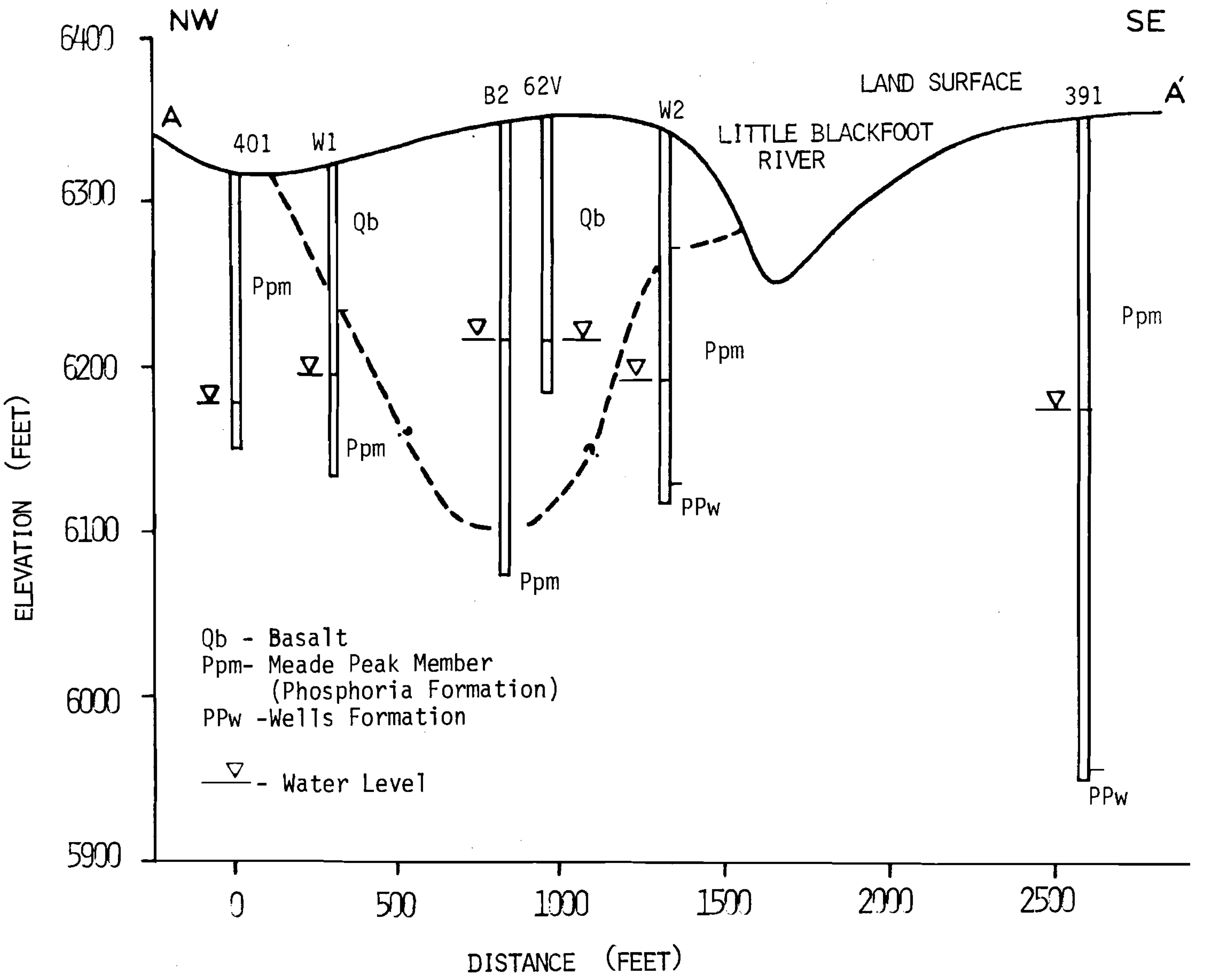


FIGURE IV-18 HYDROGEOLOGIC CROSS SECTION A-A′ NORTH HENRY MINE AREA

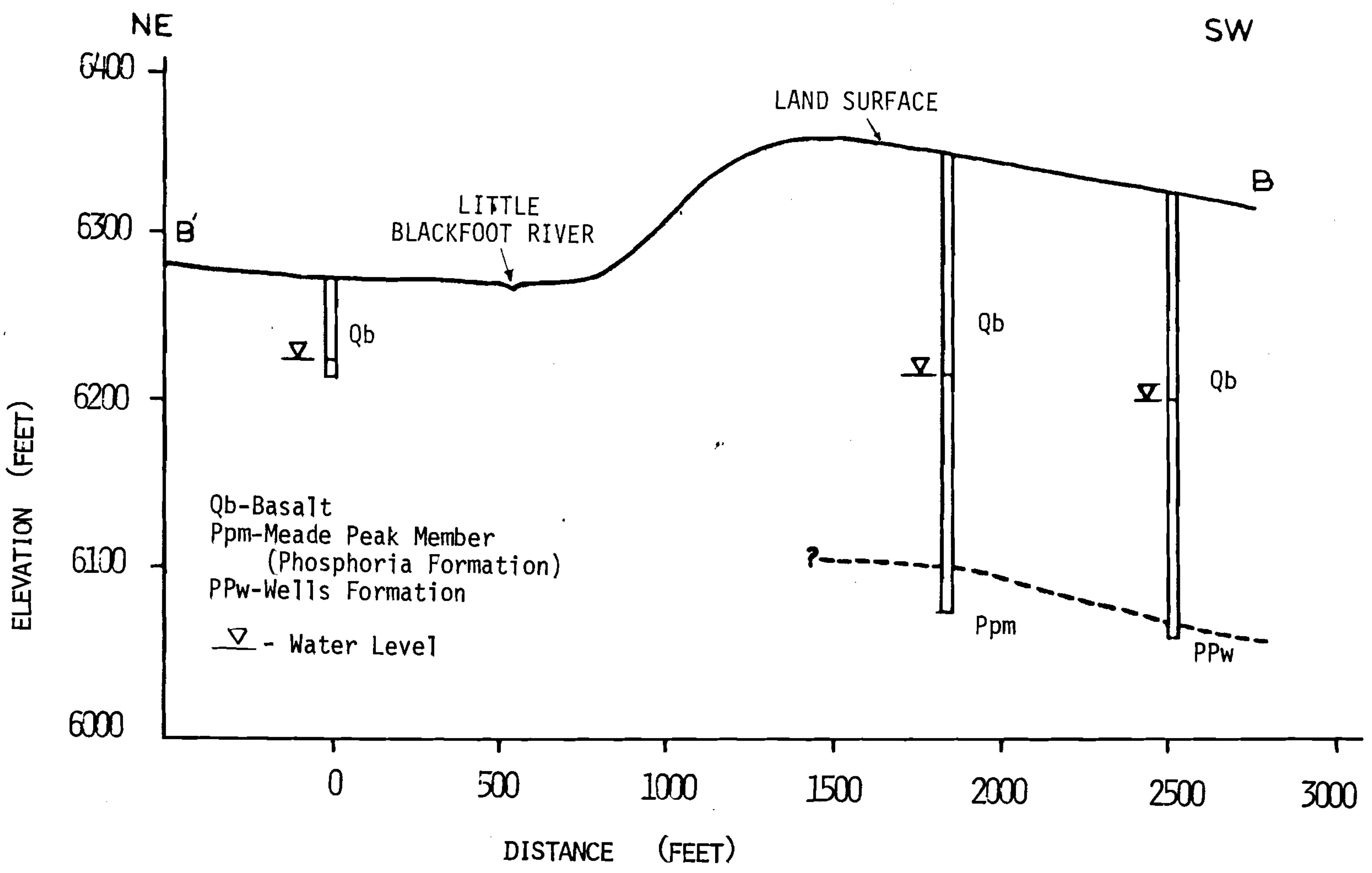


FIGURE IV-19 HYDROGEOLOGIC CROSS SECTION B-B' NORTH HENRY MINE AREA map of water level elevations obtained from piezometers in the alluvial/ basalt system. Figures IV-18 and IV-19 show the relationship between the geology and the ground water levels in the various units by means of two cross sections roughly parallel and at right angle with "Henry Ridge". Figure IV-17 shows that ground water flows westward in the basalt, through the narrows and into the Blackfoot lava field (figure IV-19). Dion (1974) found that ground water within the Blackfoot lava field flows southward toward Soda Springs. Water recharging the basalt aquifer in Enoch Valley and "Henry Valley" may discharge into the Little Blackfoot River near Henry, the Blackfoot Reservoir, or flow further south to discharge near Soda Springs. The basalt, though continuous through the "narrows", does thin. This condition may result in some stream gain from the basalt ground water flow system.

Dion (1974) also stated that the basalt composing the Blackfoot lava field contained fair to very productive aquifers with yields up to 3,500 gpm (220 l/sec) and specific capacities as much as 3,500 gpm per foot (67 l/sec per meter) of drawdown. Hydrographs of basalt piezometers 61V and 62V show that the aquifer responds rapidly to major recharge events suggesting that transmissivity rates for basalt are high within the immediate study area.

The alluvial/basalt flow system is under weak artesian conditions. Small increases in piezometric head (less than 5 feet) (1.5 meters) were measured during the drilling of basalt holes R1, B1, B2 and R2. The ground water levels dropped after the drill holes intercepted the Rex Chert member of the Phosphoria formation.

The alluvial/basalt ground water flow system provides a potential path for water to move from the Little Blackfoot River into the Rex Chert member of the Phosphoria formation and ultimately into any mining pits that may be constructed near the river below the channel elevation. It is thus very important to describe the hydrolgic pattern of flow near where the basalt intercepts the Rex Chert member. The hydrogeologic cross sections as presented in figure IV-18 and IV-19 show that the basalt filled the ancestral canyon which was cut deeply into the consolidated sedimentary units. Measurements of potential in piezometers show a steep ground water gradient in both the vertical and horizontal directions near the contact of the basalt with the sedimentary rock. This gradient reflects the sharp difference in transmissivity between the two rock types. In each observation well drilled, the water levels dropped as drilling preceded from the basalt into the Rex Chert member. The ground water levels decrease both northward and southward within the Rex Chert member from the Little Blackfoot River indicating that ground water flows down the strike in both directions (figure IV-17).

Several factors indicate that the total quantity of water moving northward and southward in the Rex Chert member is small: (1) the overall hydraulic conductivity of the Rex Chert member is low and (2) the lack of logical northward, southward, or downdip discharge areas indicate that the total quantity of ground water flow must in fact be small. These two points are discussed in detail in the following paragraphs.

Vandell (1978) provides what is believed to be maximum values of hydraulic conductivity for the Rex Chert member of the Phosphoria formation. Her results are based upon a series of pump tests that were conducted in Lower Dry Valley in a structural configuration similar to that found in the North Henry area. Vandell's pump test results gave maximum values for hydraulic conductivity of 30 to 70 feet per day (9-20 meters/day) for fractured Rex Chert. She did indicate that these values represent only very localized fracture zones and do not represent the Rex Chert member over a large area. Winter's study (1979) of stream gain and losses in springs indicate that the Rex Chert member conducts little water. Other investigators have classified the Rex Chert member as an aquiclude. The fracture areas in the chert found in the North Henry area are believed to be very localized. The overall hydraulic conductivity is believed to be low. The steep hydraulic gradient evident from the basalt into the Rex Chert member demonstrates the large difference in hydraulic conductivity between these units.

Ground water levels in the Rex Chert, both north and south of the Little Blackfoot River, are lower than water levels in the basalt along the river valley. The hydraulic gradient from the basalt into the Rex Chert indicates that some flow does occur along the strike in both a north and south direction. It is important to examine the potential discharge areas for such flow in order to estimate the total quantity of water movement involved. Mining has been preceding along in the Middle Henry Mine and South Henry Mine for a considerable period of time. Pits to the south of the North Henry along strike extend to elevations as low as the elevation of water surface found in observation wells in the study area. These pits are generally dry. Any significant water movement in the Rex Chert member down the strike to the south would be evident in existing mining pits. A discharge area for any water movement to the north along strike in the Rex Chert is not readily apparent. The land surface north of "Henry Ridge" is below the elevation of water surface in the observation well in the Rex Chert in the immediate study area. No springs are evident along the north end of "Henry Ridge". It is thus assumed that little water moves to the north along strike in the Rex Chert member. Flow downdip through the sedimentary rock units has been documented with major inter-valley flow systems occurring at several locations in the Western Phosphate Field. However, it is not reasonable to assume that water moves downdip to the east in the Rex Chert member to discharge at some distant point because of two major factors: (1) the hydraulic continuity of the formation is interrupted by a major fault located east of the study area; (2) the outcrop of the Phosphoria formation on the east arm of the syncline is at a higher elevation to that at the Henry Mine. All of these factors support the conclusion that there is little water movement from the basalt into the Rex Chert member in the immediate vicinity of the Little Blackfoot River.

The Meade Peak member of the Phosphoria formation generally has been classified as an aquiclude throughout the Western Phosphate Field. Site specific data from the North Henry area support this conclusion. Test hole W1 was completed in the Meade Peak member and below the expected water level but water didn't enter the hole until the day after drilling was completed. The delay period is characteristic of a low transmissivity material. Vandell estimated the hydraulic conductivity of fractured Meade Peak member to be less than 25 ft/day (7.6 meters/day) and less than 1.6 ft/day (0.5 meter/day) when unfractured. Mohammad (1977) determined by slug test values of hydraulic conductivity of 0.3 to 2.2 ft/day (0.1 to 0.7 meter/day). Winter (1979) found no stream gains or losses across the Meade Peak member and only one small spring in the entire Western Phosphate Field. All of these data overwhelmingly suggest that the Meade Peak member of the Phosphoria formation has extremely low hydraulic conductivity not only in the vicinity of the North Henry Mine but throughout the Western Phosphate Field.

The third ground water flow system in the vicinity of the North Henry Mine is a postulated regional flow pattern in the Wells formation. A number of authors have indicated that both the upper and lower members of the Wells formation have high hydraulic conductivity. Data from test wells in the North Henry area indicate that the upper portion of the Wells formation has a lower ground water potential than the overlying Phosphoria formation or the basalt. Ground water can move downward within the immediate vicinity of the proposed mine from the basalt and Phosphoria formation into the Wells formation.

There are several major springs discharging from the Wells formation about 1.5 miles (2.5 kilometers) downstream of the Narrows where the Little Blackfoot River flows through "Henry Ridge". The elevation of the springs range from about 6,130 to 6,150 feet (1,870 to 1,875 meters). The springs discharge about 2,000 gpm (125 l/sec) at or near the Little Blackfoot River and have signs of high mineralization. These springs also discharge water that is noticeably warmer than the streamflow. The large mineral deposits associated with the springs indicate that the Wells formation hosts a long or regional ground water flow system. Most of the recharge for this flow system probably occurs east of the study area. The marked difference in water quality and water temperature of the discharge from the Wells formation from that found in the basalt and

Phosphoria formation indicates that the regional flow system is hydrologically distinct from the other two flow systems described in the vicinity of the mine. The elevations of the springs may be indicative of the regional water table in the Wells formation and may pose a lower limit to mining without major dewatering.

### Relationship between the Little Blackfoot River and the Ground Water Flow Systems

A relationship was found between recharge to the basalt sinkholes from the Little Blackfoot River and the water levels in the basalt and the Phosphoria formation. Three separate high flow events occurred during the 1978 field season that resulted in recharge into the sinkholes. Ground water levels were closely monitored to record responses to changing surface water conditions.

Water in a stock pond in Enoch Valley was released on July 11, 1978, causing flow into the sinkholes and subsequent rise of ground water levels. Piezometer 61V (basalt) indicated the greatest water level rise with PH5 (alluvium), PH6 (basalt), and 62V (basalt) following suit within 24 hours. Piezometer 391 in the Meade Peak member south of the river had a barely distinguishable water level rise (0.01 ft. or 3 mm); the water level in piezometer 401 in the Meade Peak member north of the river remained the same (measured on July 9 and 12). All piezometers except 401 and 391 showed a definite relationship.

It rained about 0.9 inch (2 cm) on August 13, 1978, and water began to flow into the sinkholes. Ground water measurements were then taken daily from August 14th to August 17th (figure IV-20). Water levels in piezometers 61V, PH5, 62V, PH6, 391 and 401 all peaked on the 16th then

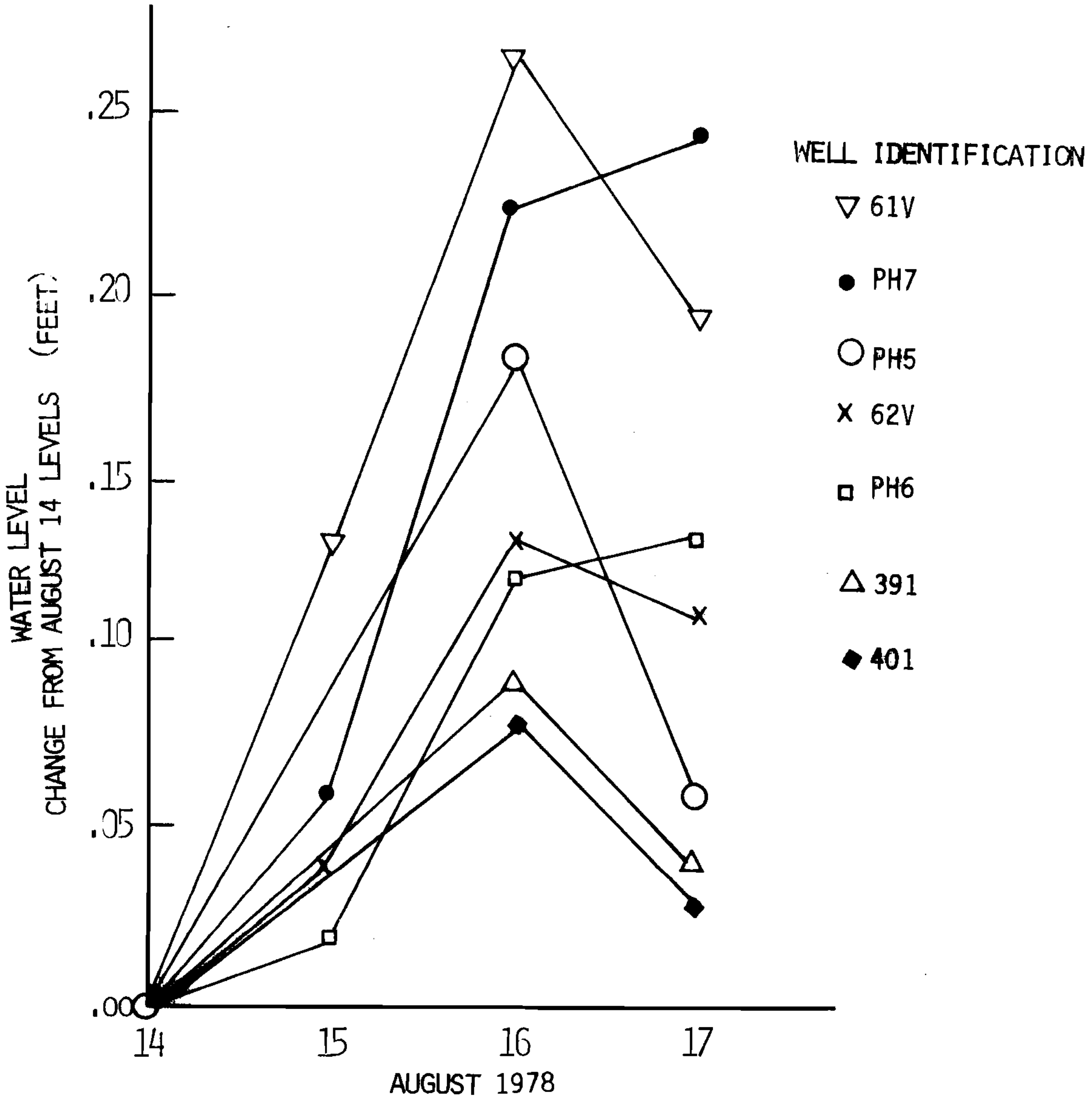


FIGURE IV-20 CHANGE IN WATER LEVELS IN THE WELLS IN RESPONCE TO STREAM FLOW INTO THE SINKHOLES, NORTH HENRY MINE AREA began to decline within 24 hours (excepth PH6). This event more convincingly indicated a relationship between the sinkholes and piezometers 401 (up 0.09 ft. or 27 mm) and 391 (up 0.08 ft. or 24 mm).

Beavers began damming the culvert near stream gage station B in early September and the result resembled spring flooding. All sinkholes were receiving water from the Little Blackfoot River. The dam was broken at noon, September 11 and water levels dropped in piezometers 61V, PH6, 62V, B2, and PH5 within about 24 hours. Water levels in piezometers 401 and 391 declined after about 3 days.

Ground water information from piezometers 401 and 391 represent the Meade Peak member of the Phosphoria formation. They respond more slowly than basalt and alluvium piezometers but 401 and 391 will react within 72 hours of a major recharge event into the sinkholes. Surface water from the Little Blackfoot River is therefore recharging the Meade Peak member, via the basalt aquifer.

## Conclusions

1. The distribution of hydraulic conductivity within the "phosphate sequence" of consolidated sedimentary formations is similar in the North Henry Mine area to that found elsewhere in the southeastern Idaho phosphate field. However, localized zones of higher hydraulic conductivity were found in the Rex Chert member in the North Henry area that are not characteristic of the unit throughout the region. These fracture zones were believed to be localized features similar to those found by Vandell (1978) in Lower Dry Valley.

2. A local ground water flow system was identified in the shallow alluvium and the upper portion of the sedimentary rock units on the eastern side of "Henry Ridge". This flow system is similar to that found on the west ridge of Little Long Valley by Mohammad (1976). The total volume of flow involved in this system is believed to be small and of little consequence with respect to mining.

3. An important ground water flow system was identified in the alluvium and basalt in Henry Valley and a floodplain of the Little Blackfoot River. This flow system is recharged from precipitation on the area,

from infiltration along the channel of the Blackfoot River and from streamflow directly into several sinkholes in "Henry Valley". Most of the water in this flow system moves to the west in the basalt through the Little Blackfoot River narrows and on into the Blackfoot lava field. Analysis of several small flood events confirmed the quick water level response in the basalt to recharge into the sinkholes.

4. A hydraulic interconnection has been shown between the aquifer system in the basalt and fracture zones in the Phosphoria formation both north and south along the strike of the unit. This interconnection has been confirmed by evaluation of water level fluctuations from short-term flood events. The total volume of water movement from the basalt into the Phosphoria formation is believed to be small based on two factors: (a) the overall hydraulic conductivity of the Phosphoria formation is low and (b) discharge areas for flow along strike in either north or south directions cannot be identified.

5. A regional ground water flow system occurs in the Wells formation in the vicinity of the mine. Springs discharging from this formation increase the flow of the Little Blackfoot River significantly downstream of the proposed mining area. The higher total dissolved solids and higher temperature of this discharge confirm that the flow is of regional extent with very limited interconnection with the shallower ground water flow systems in the vicinity of the mine. The elevation of springs (6,130 to 6,150 feet) (1,870 to 1,876 meters) may represent the regional water table in the Wells formation and thus pose a lower limit to mining without major dewatering.

# CHAPTER V

# HYDROLOGIC ANALYSIS OF MINE WASTE PILES

## Introduction

Mohammad (1976) presented the results of site investigations of more than twenty waste dumps in the southeastern Idaho phosphate mining area. His studies included measurement of spring discharges and quality and the identification of factors controlling flow systems. Eugene E. Farmer, hydrologist with the U.S.D.A. Forest Service at the Intermountain Forest and Range Experiment Station, initiated a detailed study of waste pile hydrology in 1976. His study at the Maybe Canyon Mine of Beker Corporation was still in progress at the time of writing of this report. The Farmer study should provide a very detailed analysis of water movement through saturated and unsaturated mine wastes. Dr. Myron Molnau of the Agricultural Engineering Department of the University of Idaho also initiated a hydrology study of phosphate mine wastes in 1976. Dr. Molnau investigated the snow accumulation and associated erosion on the same pile as the U.S.D.A. Forest Service study. The results of this study will be presented in a report entitled "Snow and Erosion in the Phosphate Mining Area of Idaho - Final Report", which will be published in December 1979 by Edward Chacho and Myron Molnau.

The scope of the waste pile portion of the present study was reduced because of the concurrent investigations by Farmer and Molnau. Two objectives were pursued.

1. Measurement of ground water levels in several piles to determine the degree to which the wastes were saturated.

2. Leaching experiments to determine the potential water quality changes associated with ground water movement through the wastes.

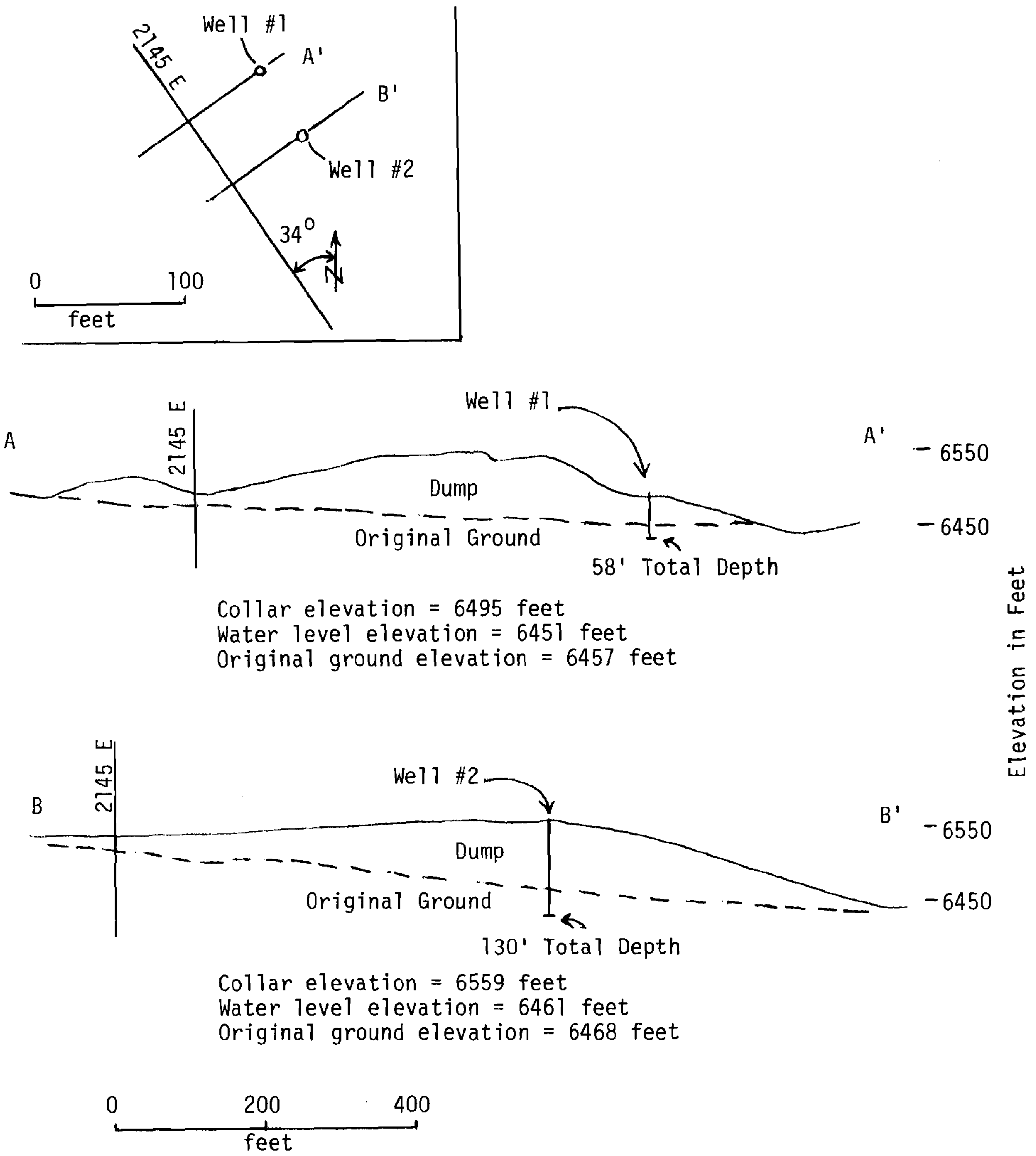
The leaching studies were conducted at the University of Idaho by Dr. Chien Wai of the Chemistry Department.

## Ground Water Levels in Mine Waste Piles

Test wells were constructed in the South Henry Mine waste pile by Monsanto Corporation and in a Gay Mine waste pile by the J.R. Simplot Company. The cross-section of the South Henry waste pile presented in figure V-1 shows the test well locations with respect to the original land surface and the wastes. Both wells fully penetrated the waste pile. Water levels were measured by Monsanto approximately weekly during the period of April-September, 1979. The water level hydrographs from both sites show a response to spring snow melt (figure V-2). The water levels in both wells are near the contact of the wastes with the original land surface.

The test wells in the Gay Mine waste piles showed similar results as the Henry Mine sites. The water level in one well was above the contact of the wastes and the original surface during the period of observation in June-July, 1978. The higher water levels were associated with the nearby discharge of water from pit dewatering. The test wells are believed to be nearly dry under more normal conditions.

The development of ground water flow systems in phosphate waste piles is dependent upon site specific factors. Mohammad (1976) noted that the factors which lead to the development of local flow systems within a waste pile include: (1) the availability of water for recharge, (2) suitable infiltration rates at the pile surface, and (3) favorable



Collar elevation = 6495 feet
Water level elevation = 6451 feet
Original ground elevation = 6457 feet

Collar elevation = 6559 feet
Water level elevation = 6461 feet
Original ground elevation = 6468 feet

Figure V-1. Cross sections of the South Henry Mine waste pile showing test wells.

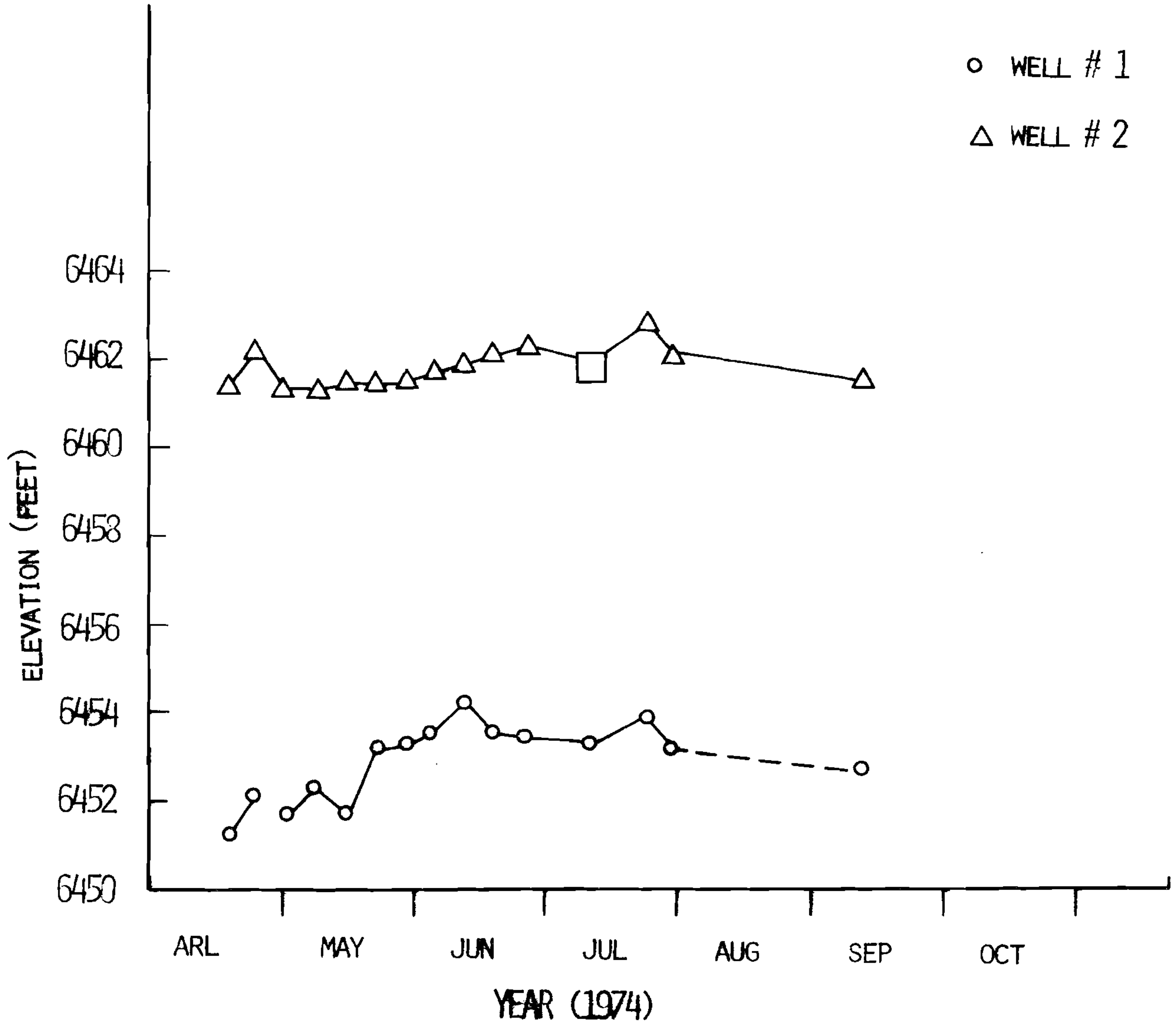


FIGURE V-2 HYDROGRAPHS OF WASTE PILE OBSERVATION WELLS 1 AND 2
SOUTH HENRY MINE

waste dump characteristics such as large catchment areas, low topographic slope of the underlying land surface, and a flat or very gentle waste pile surface. Cannon (1979) discussed the importance of pile location with respect to local geology and associated ground water flow systems. His comments are summarized in the next chapter.

Both waste piles that were investigated as part of this study were largely unsaturated. The water level pattern at the South Henry site is believed to be controlled by the flow system in the soil and underlying Dinwoody formation. A perennial spring discharges from the Dinwoody formation near the waste pile. The mine wastes at the Gay Mine site would be expected to be unsaturated because of the low level of precipitation in this area and the downward hydraulic gradient in the underlying Dinwoody formation.

## Leaching of Soils from Phosphate Mine Waste Piles

### Chemical and Mineralogical Composition of the Phosphate Mine Wastes

Four representative waste dump soils were collected from sites in the phosphate mining district for this leaching study. Soil samples were dried in an oven, ground with a mortar and pestle, and then sifted through a U.S. No. 80 standard testing sieve. The less-than-80-mesh size fraction of the samples were used for all leaching experiments. The concentrations of certain trace metals in the wastes are given in table V-1. The phosphate mine wastes contain significantly high levels of Cd, Cr, Zn, and U in comparison with continental crust average.

The principal rock types of the phosphate field are phosphate rock, carbonate rock, mudstone, and chert (U.S. Dept. of Interior, U.S. Dept. of

Table V-1. Concentrations of some trace elements (in ppm) in the phosphate mine wastes.

| | Cd | Cr | Cu | Mn | Pb | Zn | U |
|---|---|---|---|---|---|---|---|
| Henry Mine waste pile soil | 35 | 1950 | 185 | 130 | 34 | 1350 | 73 |
| Weathered waste pile soil from Gay Mine | 115 | 1280 | 115 | 180 | 45 | 2300 | 69 |
| Carbonaceous rich soil from Gay Mine waste pile | 102 | 1430 | 198 | 70 | 36 | 2350 | 64 |
| Ballard Mine waste pile soil | 17 | 530 | 67 | 140 | 27 | 600 | 27 |
| Continental Crust* | 0.2 | 100 | 55 | 950 | 30 | 70 | 2.7 |

*U.S. Dept. of Interior, U.S. Dept. of Agriculture, 1977

Agriculture, 1977). The phosphate rock of this area is composed mostly of carbonate fluorapatite. The carbonate rock contains primarily dolomite and calcite. The mudstone is a mixture of quartz, feldspar, muscovite, clay minerals, iron oxide minerals, and pyrite. The chert is primarily microcrystalline quartz. X-ray diffraction studies showed that the minerals present in the waste dump soils are apatite, quartz, dolomite, calcite, siderite, and in some cases fluorite, gypsum, and traces of clay minerals. Pyrite was not detected in these samples. The soil samples used in this leaching experiment appear to be a mixture of different rock types of this area. The Ca and Fe contents of the waste samples are given in table V-2. Average Ca and Fe in phosphate rock, carbonate rock and mudstone from the Meade Peak member of the Phosphoria formation are also given in the table for comparison. According to these data, carbonate rock and phosphate rock are high in Ca and low in Fe relative to mudstone. The waste dump soil samples have Ca and Fe contents intermediate between that of mudstone and that of phosphate rock or carbonate rock. Calcium in the mine wastes is probably a good measure of the amount of apatite and

Table V-2. Ca and Fe contents of the phosphate mine wastes

| | Ca (%) | Fe(%) |
|---|---|---|
| Henry Mine waste pile soil | 7.3 | 2.24 |
| Weathered waste pile soil from Gay Mine | 14.1 | 1.50 |
| Carbonaceous rich soil from Gay Mine waste pile | 9.6 | 1.55 |
| Ballard Mine waste pile soil | 4.3 | 2.35 |
| Mudstone* | 3.1 | 3.43 |
| Carbonate Rock* | 21.5 | 0.78 |
| Phosphate Rock* | 32.4 | 0.78 |

*From the Meade Peak member of the Phosphoria formation. U.S. Dept. of Interior, U.S. Dept. of Agriculture, 1977.

calcite in the system. Iron is likely in the form of siderite and iron oxides.

## Effects of Phosphate Mine Wastes on the pH of Water

When the phosphate mine wastes were mixed with distilled water, the pH of the resulting solutions was found to be either neutral or slightly basic. Figure V-3 shows the variation of pH of water as a function of time of contact with three different types of mine wastes. The experiment was carried out at room temperature under atmospheric pressure and the system was stirred using a magnetic stirrer.

The Henry Mine waste and the carbonaceous rich soil from the Gay Mine waste pile both gave near neutral solution in the beginning of the experiment and ended up at pH around 7.4 after 80 hours of mixing with distilled water. The weathered waste soil from the Gay Mine resulted in a more basic solution with a final pH around 8 after 80 hours of mixing. Apparently there is no significant amount of acid producing minerals

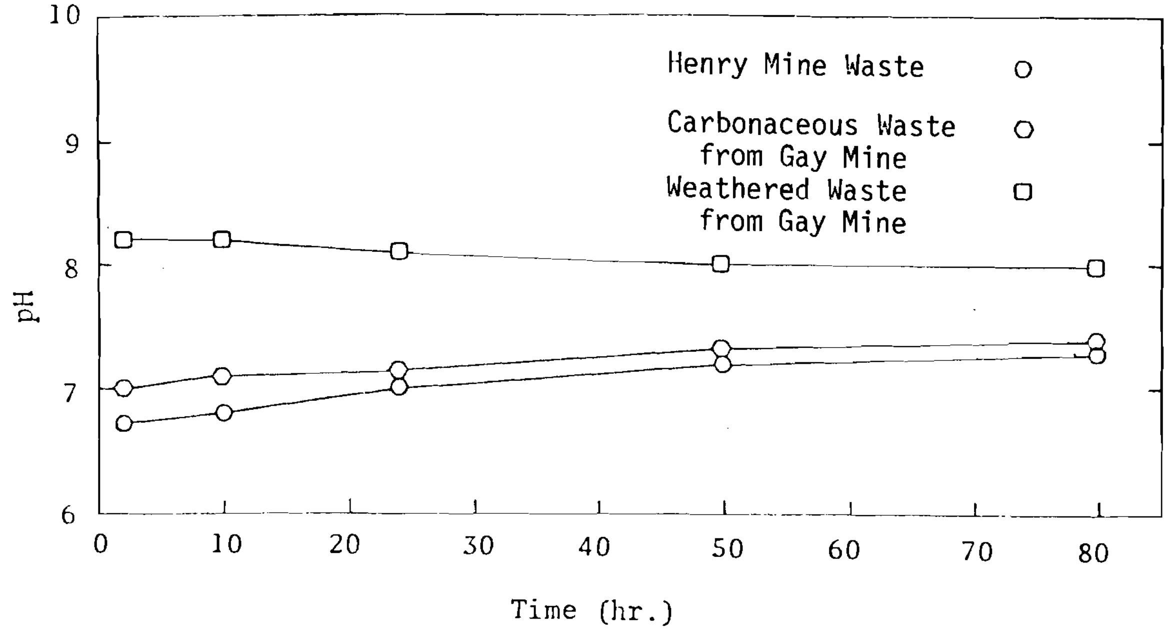


Figure V-3. pH of water with respect to time of contact with the phosphate mine wastes.

present in the phosphate mine wastes. The experimental observation is consistent with the dissolution of carbonate rocks in water. In a pure water-calcite system at room temperature and under atmospheric pressure, the final pH of the solution should be around 8.3 at equilibrium (Reece, 1975). The weathered waste dump soil obviously contained a significant amount of carbonate rock as indicated by its high Ca content. A basic solution is therefore expected to result from leaching of this soil as the result of dissolution of carbonate rock in water. Since all phosphate waste soils examined in this study contained varying amounts of carbonate rock, water in contact with such wastes is unlikely to become acidic.

## Leaching of Metals from the Phosphate Mine Wastes

Leaching experiments were carried out in beakers to study the rate of removal of metals from the phosphate mine wastes. Each experiment began with 20 grams of mine waste mixed with 100 ml of distilled water. Water samples (5 ml each) were taken from the system at various time intervals for chemical analysis. The samples were filtered through a 0.45 μm filter paper and acidified with nitric acid immediately after collection. Ca, Cd, Cr, Cu, Fe, Mn, Pb, and Zn in water were measured by atomic absorption spectrophotometry.

Calcium and magnesium can be leached out fairly rapidly from the mine wastes in the initial 24 hours of the experiment and then gradually approach equilibrium in the next few days. Figures V-4 and V-5 show typical leaching curves for Ca and Mg observed from Henry Mine waste soil and from the weathered waste soil from the Gay Mine. Depending on the nature of the mine waste, Ca concentration in solution would vary from several ppm to over 10 ppm after 3 to 4 days of leaching. Magnesium concentration would reach 1 to 2 ppm during the same period of leaching. Such levels of Ca and Mg are expected from the dissolution of carbonate rocks in water.

The concentrations of Cd, Pb, and Zn leached from the waste dump soils are given in table V-3. Only low levels of Zn were detected in the leaching solution. Cd and Pb were below our detection limits. None of these toxic trace metals in leaching solution exceeds the levels recommended by U.S. Public Health Service for drinking water standards (U.S.P.H.S., 1962). Besides these three metals, Cu and Mn concentrations in solution were found to be less than 0.05 ppm and 0.01 ppm, respectively. Iron was detectable in some samples at levels lower than 0.2 ppm. Chromium in the Henry Mine waste and in the carbonaceous rich soil from the Gay Mine were below our detection limit of 0.01 ppm but it was detectable in

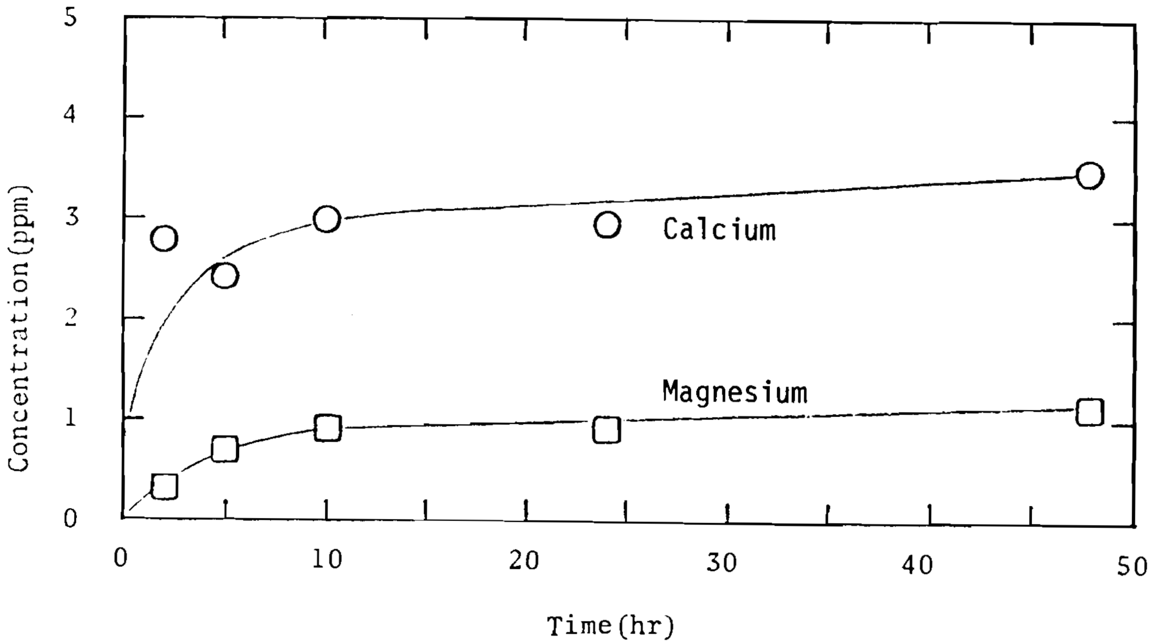


Figure V-4. Leaching of Ca and Mg from the Henry Mine waste as a function of time.

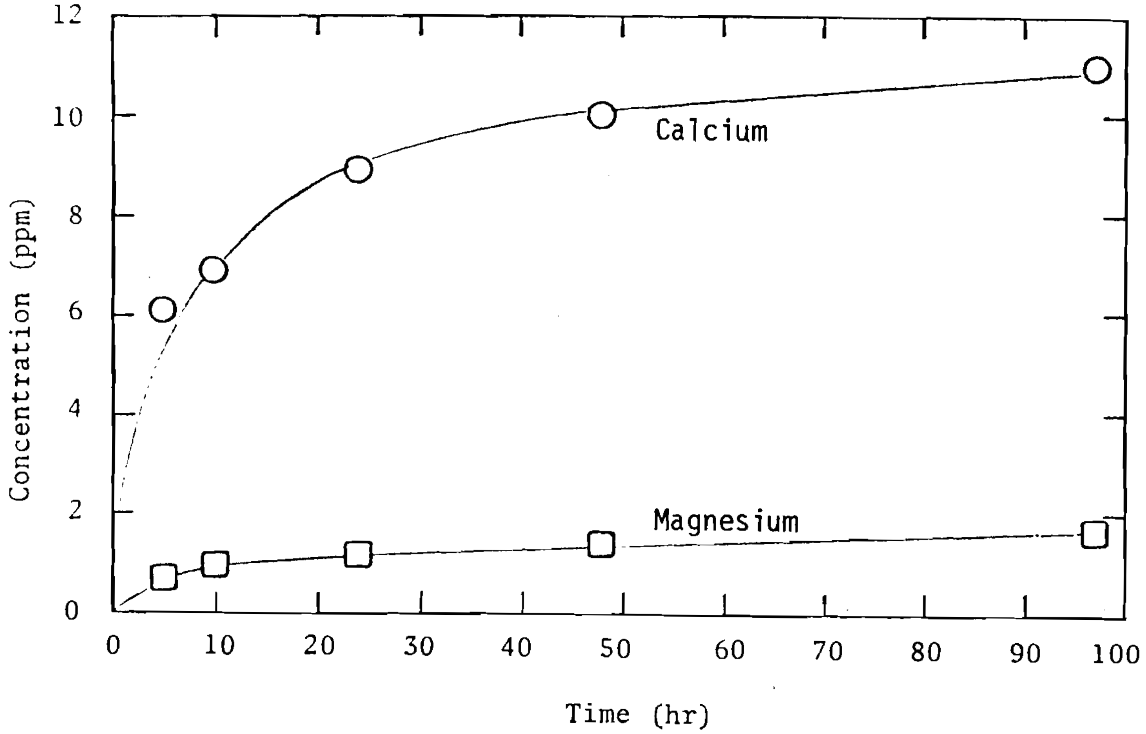


Figure V-5. Leaching of Ca and Mg from the weathered phosphate mine waste from the Gay Mine.

Table V-3. Cd, Pb, and Zn leached from the phosphate mine waste soils.

| | Metal Concentrations (Parts Per Million) in Solution | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 5 hours | | | 23 hours | | | 117 hours | | |
| | Cd | Pb | Zn | Cd | Pb | Zn | Cd | Pb | Zn |
| Henry Mine waste 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 pile | <0.01 | <0.05 | 0.09 | <0.01 | <0.05 | 0.12 | <0.01 | <0.05 | 0.17 |
| Weathered waste soil from Gay Mine | <0.01 | <0.05 | 0.09 | <0.01 | <0.05 | 0.12 | <0.01 | <0.05 | 0.16 |

the Gay Mine weathered waste solution at about 0.09 ppm after 117 hours of leaching.

One sample from leaching of Henry Mine waste dump soil was analyzed for uranium using neutron activation analysis. After one day of leaching, uranium is characteristic of phosphate mine waste in this area, this element may be a potential tracer for studying the effects of phosphate mine waste piles on ground water quality. Further experiment to test the feasibility of using uranium as a tracer for ground water study of this area is in progress.

# CHAPTER VI

# CONCEPTUAL MODELS OF INTERACTIONS OF MINING AND WATER RESOURCE SYSTEMS IN THE SOUTHEASTERN IDAHO PHOSPHATE FIELD

## Water Resource Systems of the Phosphate Area

Previous hydrogeologic investigations conducted in Little Long Valley, Lower Dry Valley, and Diamond Creek Valley have suggested that definite relationships exist between geologic formations in the "phosphate sequence" 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 and others, 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 (1979) concluded from his study that the "phosphate sequence" of sedimentary rock units (Dinwoody, Phosphoria and Wells formations) 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. Studies at the Gay Mine and North Henry Mine (Corbet, 1979 and Brooks, 1979) indicate that the relative hydraulic conductivity values of these units are consistent even in areas where the geologic structure is very complex or where the mine site hydrology is controlled by an unusual setting that includes major stream loss into a basalt aquifer.

Similarities in geologic, topographic, hydrogeologic, and climatic factors of the study area and their relationships with flow systems are discussed in this section. It will be shown that a distinctive pattern of surface water and ground water flow systems have developed in the Western Phosphate Field 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, for the most important geologic units of the study area, with respect to water resource systems at mine sites.

The Dinwoody formation of Triassic age consists of an upper member and a lower member. 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.

The Phosphoria formation of Permian age consists of the cherty shale member, the Rex Chert member and the Meade Peak Phosphatic Shale member. 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. Localized fractured zones within the Rex Chert have been found in Lower Dry Valley and at the North Henry site. The Meade Peak member of the Phosphoria formation does not support any major ground water flow systems at any site in the Western Phosphate Field.

The Wells formation of Pennsylvanian age is divided into an upper member and a lower member. 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.

Quaternary deposits of colluvium and alluvium support ground water flow systems at a number of sites in the phosphate 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 Geogetown Canyon, and many other smaller valleys, contain aquifers within alluvium which play important roles in ground water-surface water relationships.

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 vicinity of the Gay Mine 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 rock outcrops of high hydraulic conductivity on ridges may also follow fold structures and discharge in distant valleys. Fault structures affect the location of many springs.

## 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 (9 meters) 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. 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 (figure VI-1).

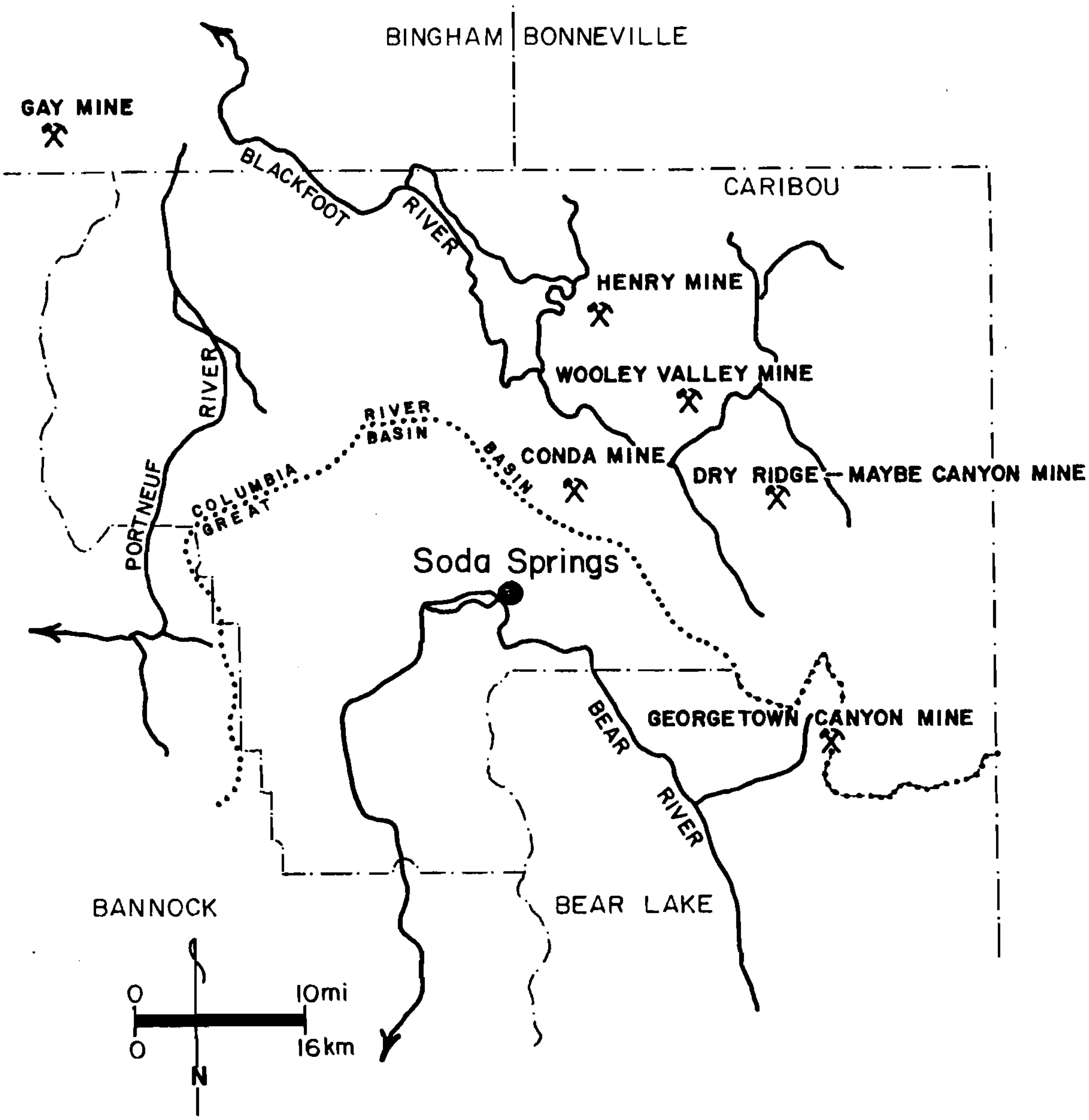


Figure VI-1. Location of drainage divide and mine sites, Western Phosphate Field in Idaho.

The largest portion of the phosphate 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. Maxium relief along this profile is about 5,400 feet (2,520 meters). 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 (1,200 meters).

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 (300 to 900 meters).

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 Sulphur Peak and other portions of the Aspen Range and in the hilly, broken topography of the Fort Hall Indian Reservation near the Gay Mine. 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 phosphate area was 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 VI-2. 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.

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 Sulphur Peak area in T.9S. R.43E. 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 ground water flow systems.

## General Flow Systems of the Phosphate Area

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

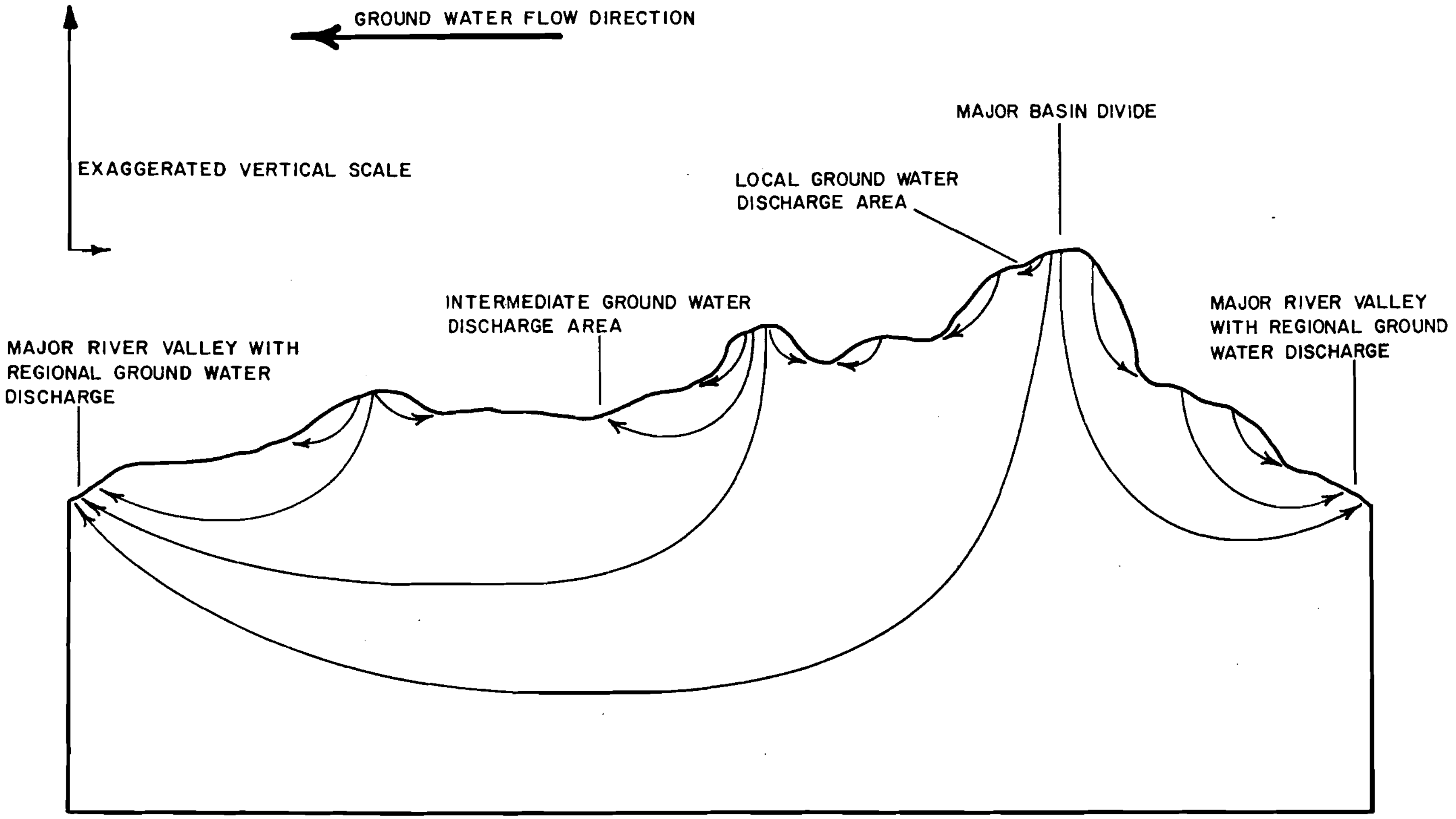


Figure VI-2. Hypothetical cross-section of ground water flow with local and intermediate systems superimposed on regional systems.

terrain than in terrain of constant slope.

Local flow systems are found on the side slopes of most ridges in the Western Phosphate Field. 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.

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 baseflows 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 act as conduits to flow. Discharge points often occur at the contact of two geologic units with large differences in hydraulic conductivity. Faults may intercept intermediate flow systems and create channels for surface discharge.

In the study area, intermediate ground water flow systems 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.

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 quantities 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 quantities 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, areally 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.

## 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 streamflow.

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.

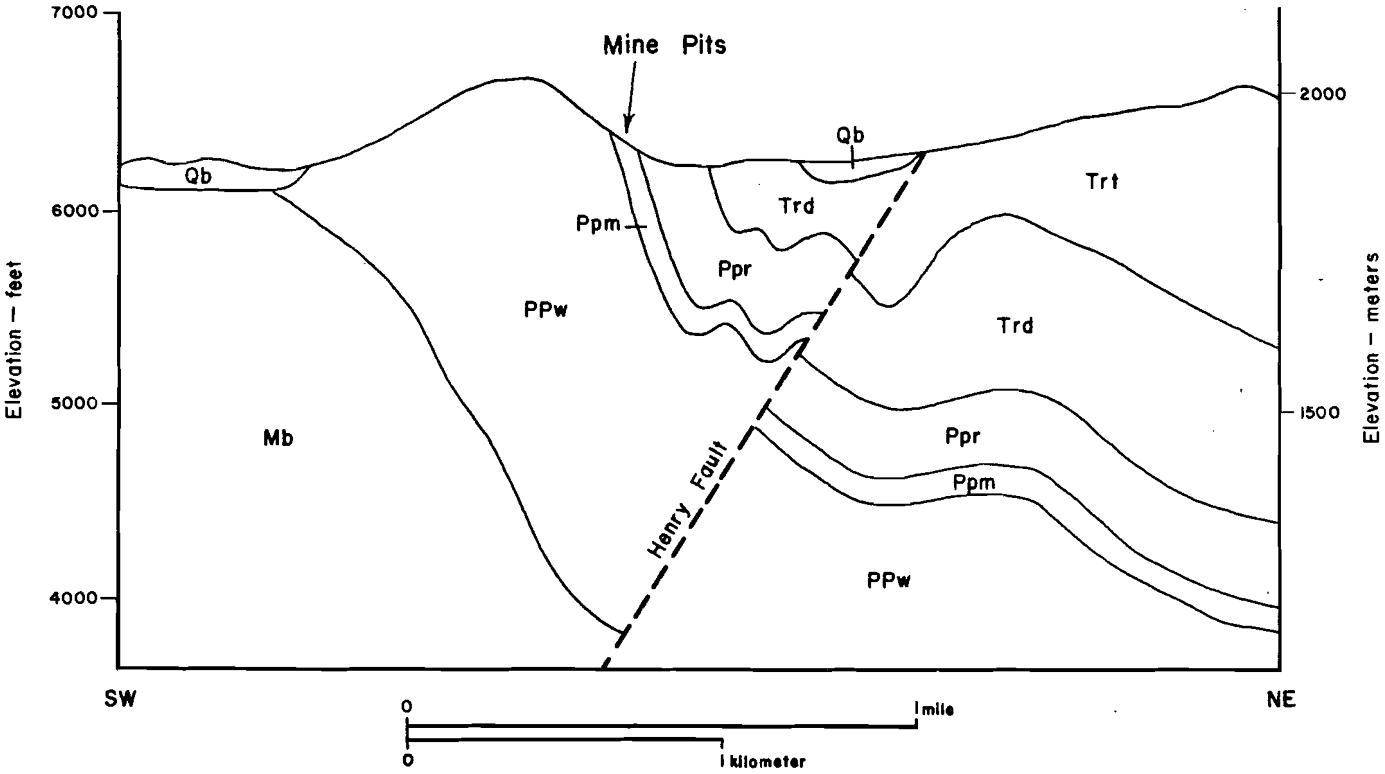
## Water Resource Systems at Selected Mine Sites

It has been demonstrated that surface water and ground water flow systems within the phosphate area exhibit many similar flow patterns and characteristics which are largely controlled by geology, hydrogeology, topography, and availability of recharge. The purpose of this section 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 system 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 figure VI-1). The first five mines listed are currently in operation; Georgetown Canyon Mine is not. Detailed investigations of the Henry Mine and Gay Mine are presented in the previous chapters. An investigation of the Wooley Valley Mine was reported by Ralston and others (1977).

### Relationships between Environmental Factors and Flow Systems of Mine Sites

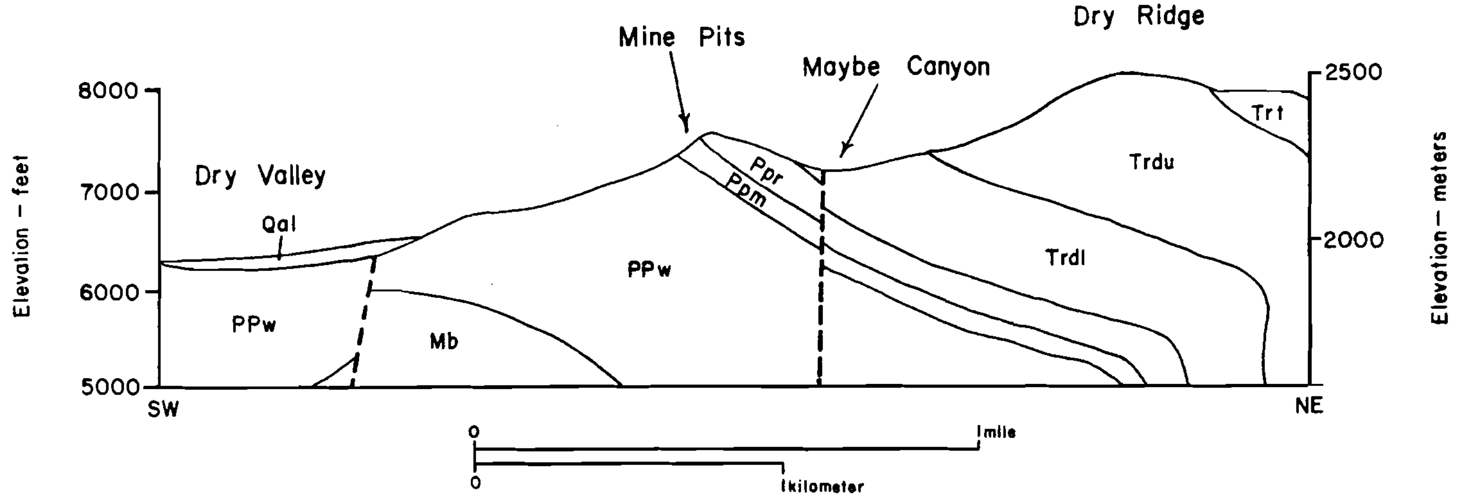
Hydrogeology. All mine sites studied contain the "phosphate sequence" of sedimentary rock units consisting of the Wells formation, Phosphoria fromation, and Dinwoody formation. The sedimentary rock units in each area, except the Gay Mine, are part of a steeply dipping syncline-anticline sequence. In the Gay Mine area, the sedimentary sequence occurs in a broad gently dipping syncline which has been extensively block faulted. A generalize geologic cross section of each mine area is presented in figures VI-3 through VI-8. 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,



| | |
|---|---|
| Qb | Basalt |
| Trt | Thaynes Formation |
| Trd | 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 VI-3. Generalized geologic section through North Henry Mine site (after Mansfield, 1927).



| | |
|---|---|
| Qal | Alluvium |
| Trt | Thaynes Formation |
| 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 |
| --- | Fault |

Figure VI-4. Generalized geologic section through Dry Ridge-Maybe Canyon Mine site (after Cressman and Gulbrandsen, 1955).

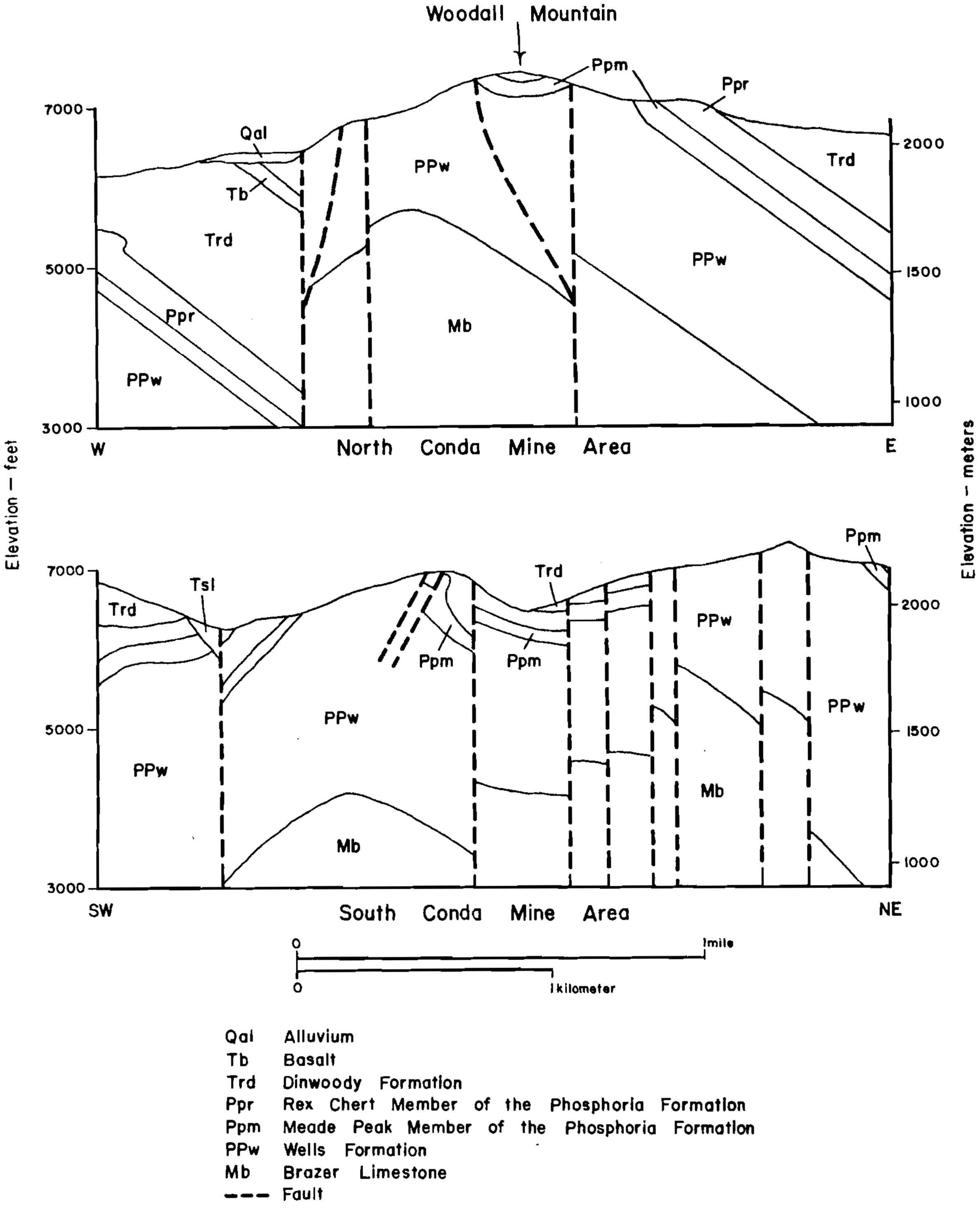


Figure VI-5. Geologic sections through north and south Conda Mine areas (after Armstrong, 1969).

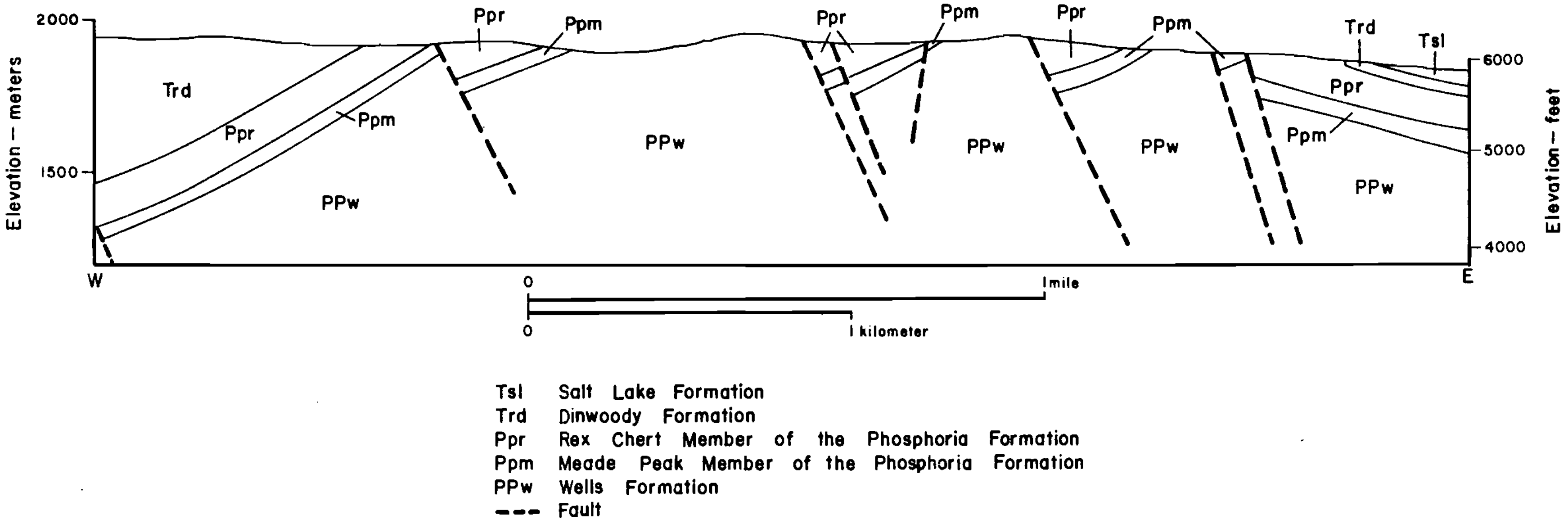


Figure VI-6. Generalized west-east geologic section through the Gay Mine (after Lehman, 1963, section J-J')

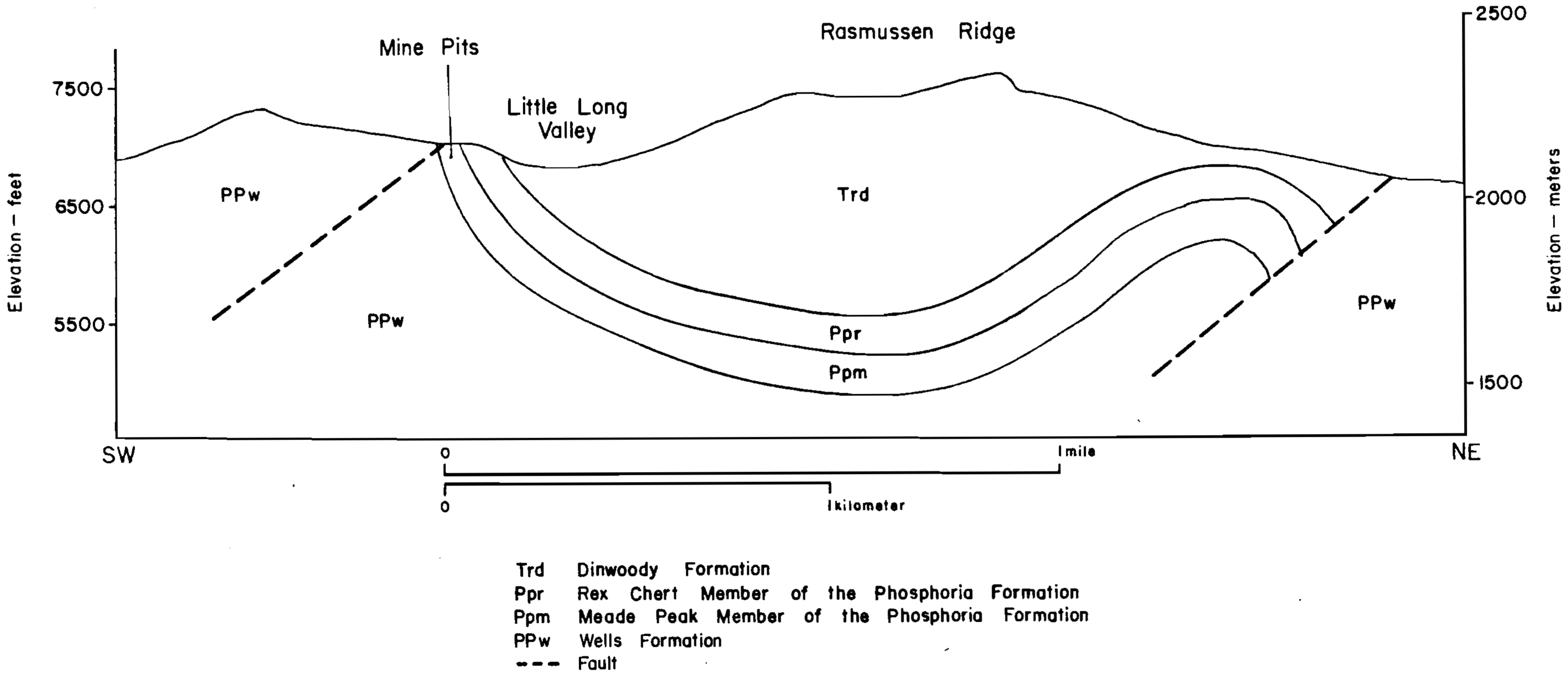


Figure VI-7. Generalized geologic section of the Wooley Valley Mine area (after Mohammad, 1977).

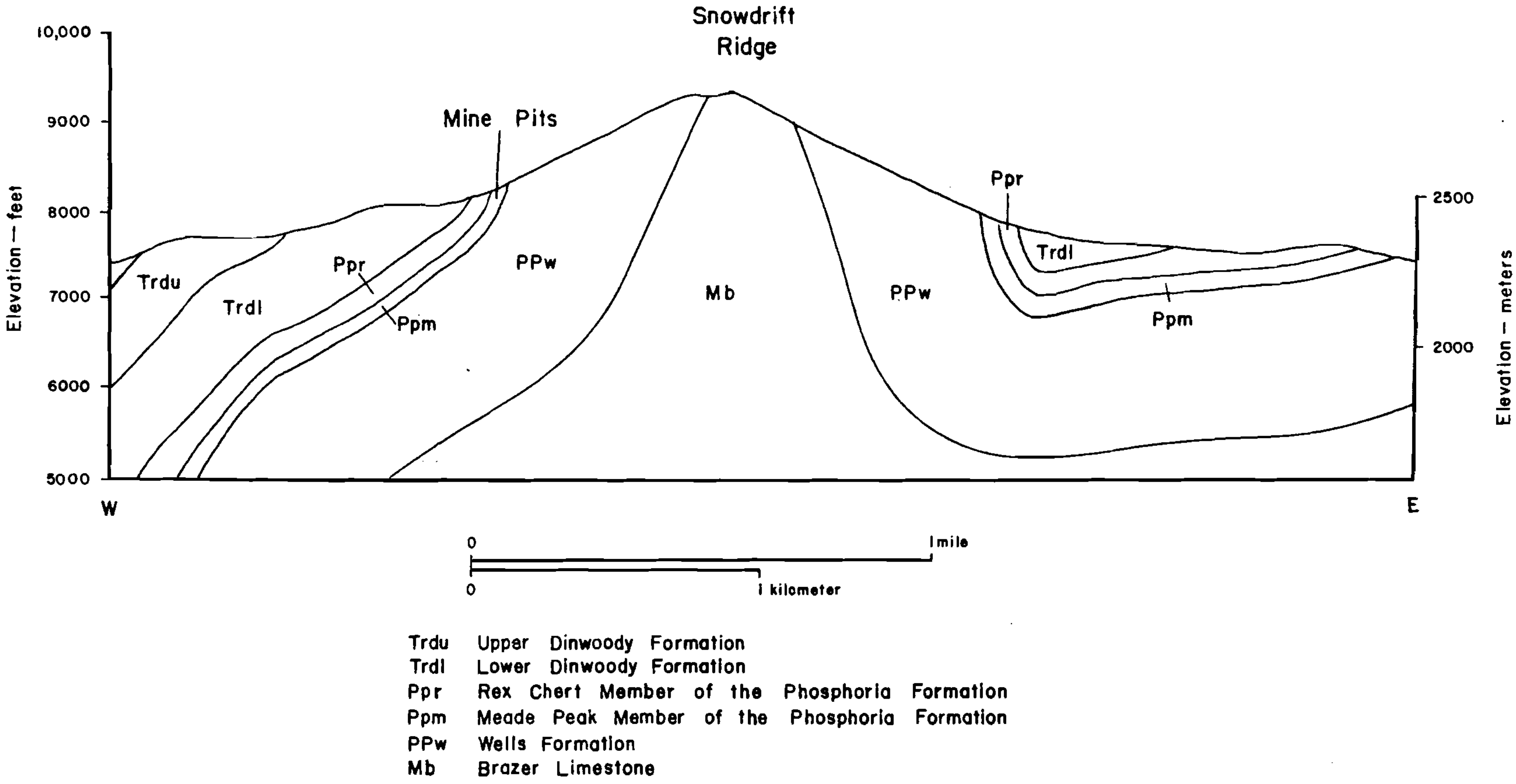


Figure VI-8. Geologic section through the Georgetown Canyon Mine site (after Cressman, 1964).

(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, 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 degrees to 40 degrees 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 both the Wells and Brazer 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 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 formation have such a high hydraulic conductivity 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. The 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. Definite relationships between geologic factors and ground water flow systems are difficult to identify.

Several small flow systems exist in the Dinwoody formation in the Gay Mine area controlled by local faulting. A larger flow system exists in a structurally isolated block of Wells formation rock. Recharge to these systems is primarily from direct precipitation. A thermal, mineralized spring indicates that some regional ground water flow occurs in the area, probably controlled by deep faulting.

Geologic structure appears to greatly affect ground water flow paths in fault block regions, based on the observations from the Gay Mine. 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 tortouous paths and ground water potentials may be greatly different than expected.

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 (1830 meters) 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 vicinity of the Blackfoot Reservoir.

-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.

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 large 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 (U.S. Environmental Protection Agency, 1973; 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 (1976) 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 quantities 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 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 southwestern 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. Southwestern 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 natural spring water; however, the concentrations measured were not determined to be harmful.

Laboratory studies show that water leaching through the waste material soon becomes basic due to the presence of large quantities of carbonate minerals. 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.

## 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 section 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 section are based on ground water flow systems theory and on the regional, intermediate, and local flow system relationships outlined previously. 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 study of ground water flow systems in the "phosphate sequence" conducted by Winter (1979) 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). If the answer is yes, continue.

-Step 2- From figure VI-9 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 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

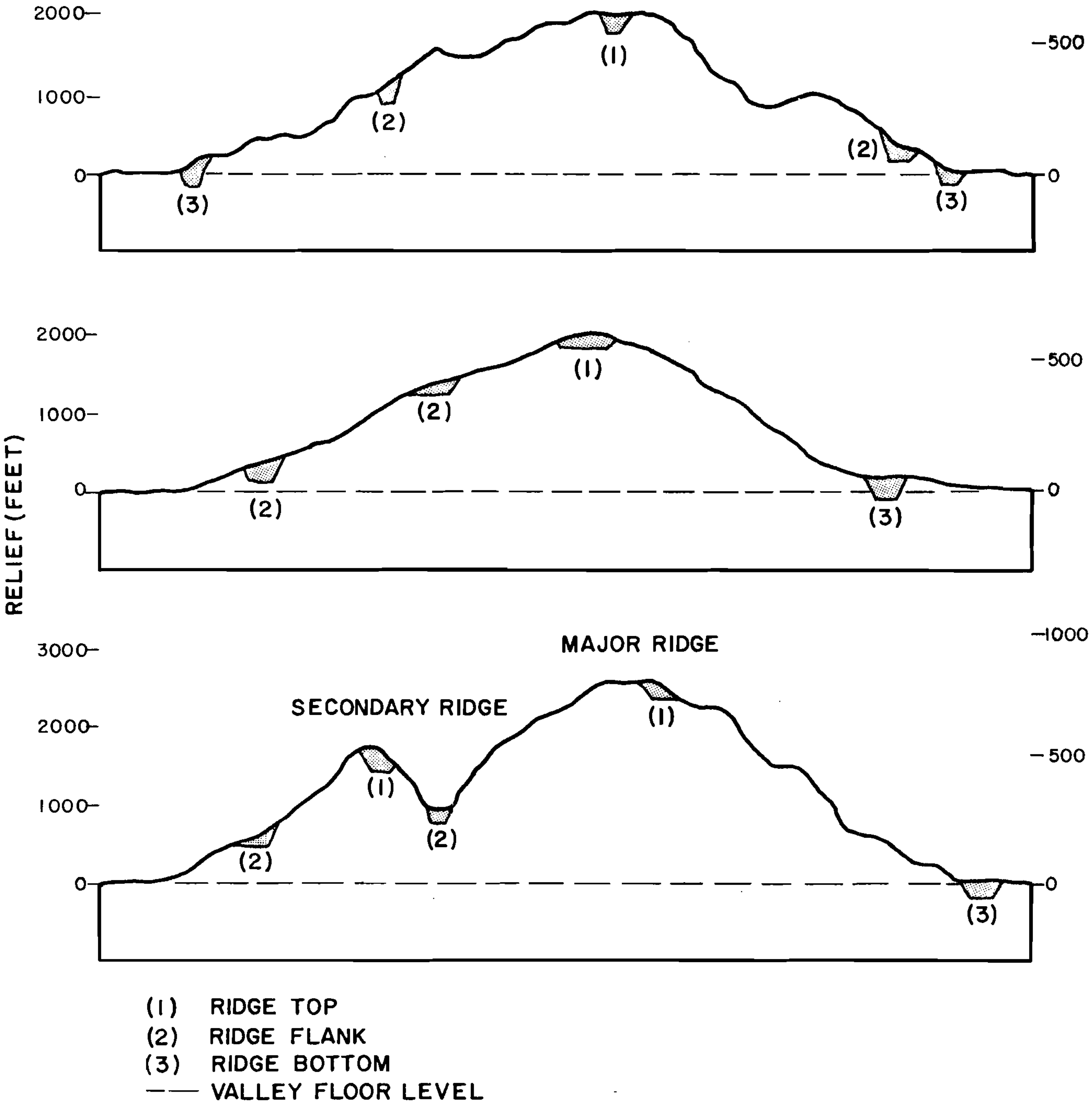


Figure VI-9. Diagrammatic sections showing possible topographic locations of mine sites.

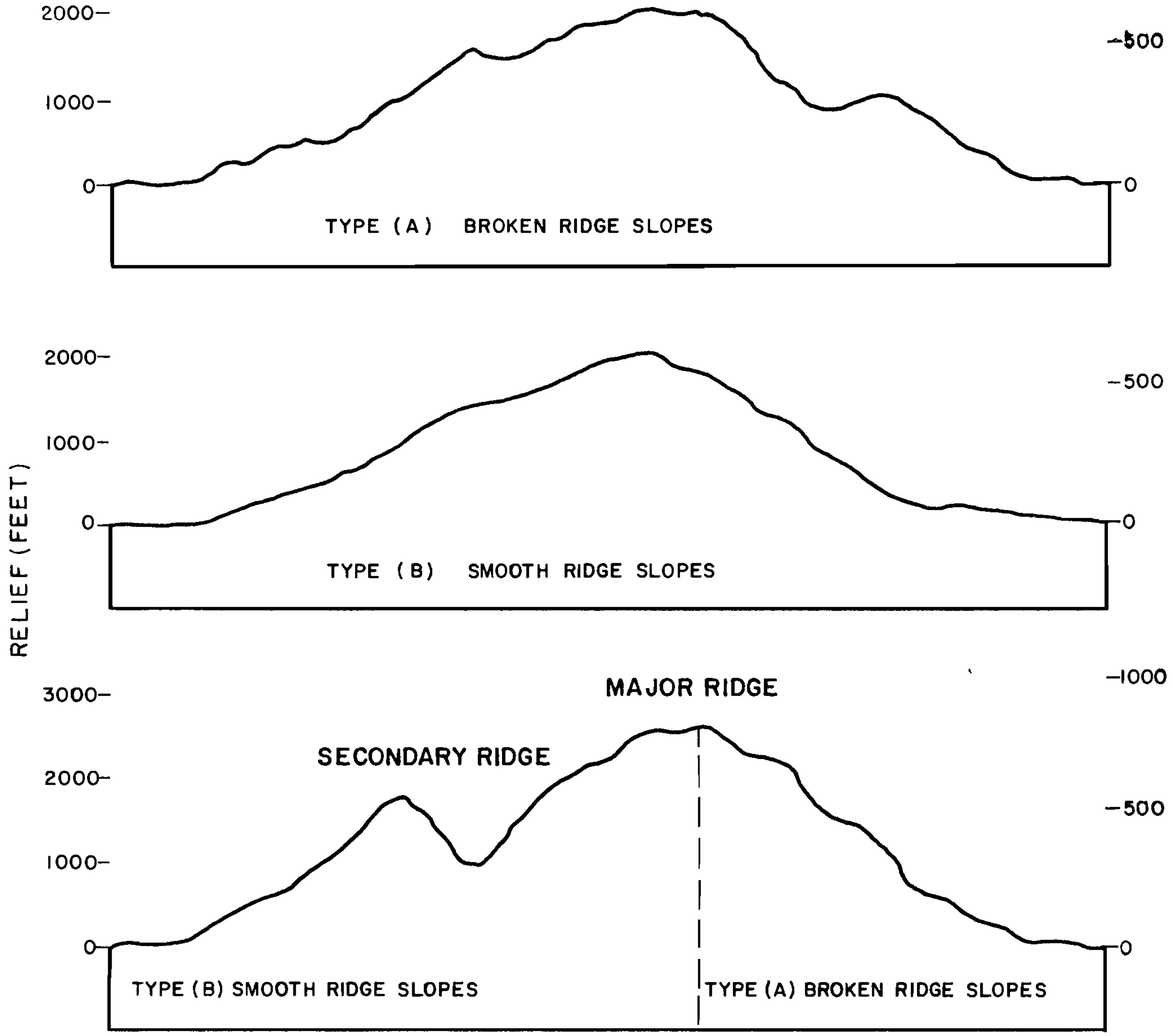


Figure VI-10. Diagrammatic sections showing possible topographic conditions of major ridge slopes.

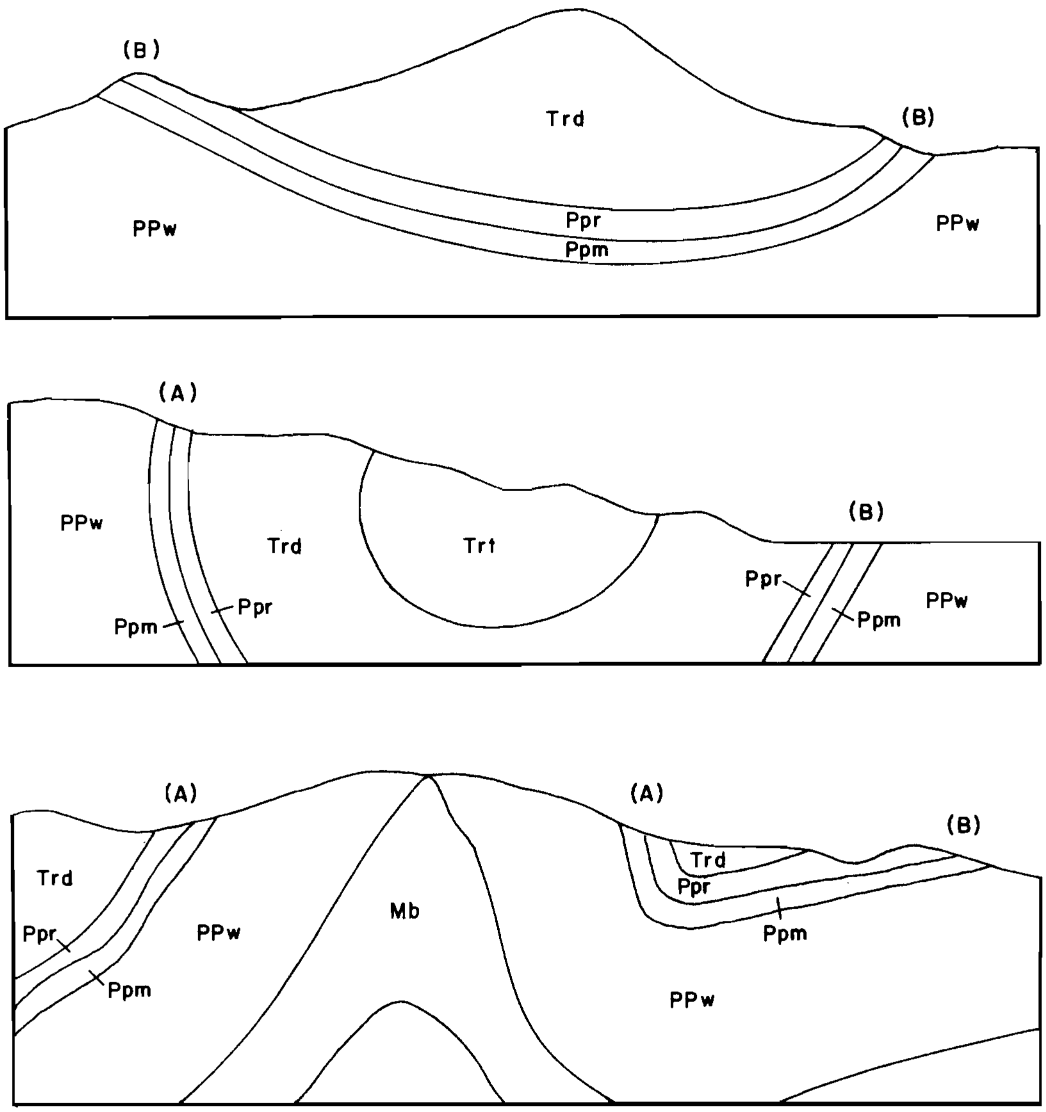
ridge or unless it occupies a secondary ridge and the bottom of the mine pits will be substantially above adjacent valley floors. Mines are classified as "ridge bottom" if mine pits will extend below the elevation of the adjacent valley floor. All mine sites located between ridge top or ridge bottom are classified as "ridge flank".

-Step 3- From figure VI-10, 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 figure VI-11, 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 configuration 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



| | |
|---|---|
| (A) | Dip with slope |
| (B) | Dip Contrary to slope |
| Trt | Thaynes Formation |
| Trd | 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 VI-11. Diagrammatic sections showing possible geologic configuration of mine sites.

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.

Flow Systems, Mining Limitations, and Hydrologic Impacts by Mine Type. A diagrammatic sketch of each mine type is presented in figure VI-12. 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

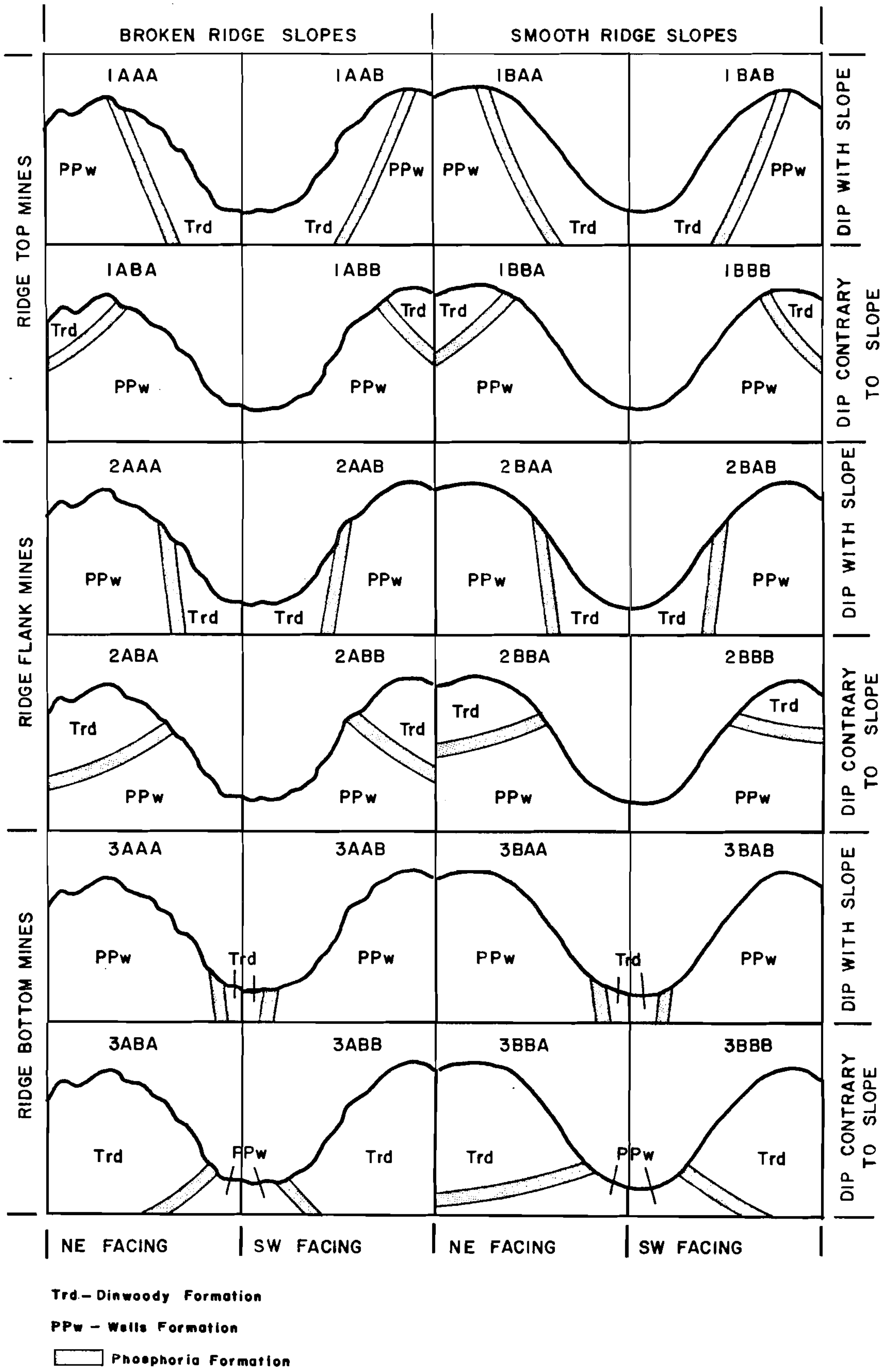


Figure VI-12. Diagrammatic section for each mine type.

hydrologic problems to mining may be stability problems in pit walls and in waste dumps during periods of rapid runoff. Waste dumps located on 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 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 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 baseflow 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.

-Mine Type 2AAB- 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.

-Mine Types 2BAA and 2BAB- 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.

-Mine Types 2ABA and 2BBA- 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 baseflow 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 be 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 baseflow 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 floodplain.

-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 baseflow 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 baseflow 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 floodplain.

Discussion of Model Predicitions. 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, streamflow, 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 prediced 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 baseflow 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).

## 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.

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 |

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.

In some cases, the models may not accurately predict the ground water flow systems at mine sites because of the influence of variables that were not included in model formulation. These variables could be geologic factors such as faults, joints, or local folds that would cause variations in local hydraulic conductivity. 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.

## Conclusions

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 Western Phosphate Field. 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.

6. The models are expected to delineate ground water flow systems at mine sites with a high degree of reliability, when the mine sites are located within the specified environment. Predicted hydrologic impacts from mining and hydrologic limitations to mining are also expected to be reliable.

# CHAPTER VII

# CONSTRUCTION AND APPLICATION OF A WATER QUALITY MODEL FOR THE UPPER BLACKFOOT RIVER BASIN

## Introduction

Activities involving exploration, mining and processing of phosphate can cause environmental impacts on natural and cultural environments. The natural environment involves land resources, water resources, air resources, vegetation, wildlife, and fisheries. The impacts may be short term or long term, reversible or irreversible, adverse or beneficial. With suitable management practices it is possible to completely avoid certain impacts while minimizing others. It is anticipated that the water quality of the streams in southeastern Idaho may deteriorate with the anticipated increase in phosphate mining activities. The purpose of this portion of the study is to provide a technique which can assist the management of furture phosphate mining operations so that adverse affects on the water quality of streams may be minimized.

The phosphate mining area in southeastern Idaho is drained by parts of four major drainages: the Portneuf, Blackfoot and Salt rivers all tributary to the Snake River and the Bear River which is tributary to the great Salt Lake. These stream basins include about 90 percent of the potential mining area. Quantitative predictions of water quality parameters resulting from various levels of mining and/or ore processing would aid in the formulation of management plans for these operations in these basins. A mathematical water quality model can be utilized as the basis for these predictions.

Construction and verification of such a model requires historic data on the water quality constituents, hydrologic parameters and meteorological elements and information on system coefficients and system geometry. The USDA Forest Service, Idaho Department of Health and Welfare, U.S. Geological Survey, and Alumet have collected these data for the Upper Blackfoot River basin. This area, therefore, was selected for development of a prototype water quality model.

The general objective of this portion of the study was to construct and verify a water quality model for the Upper Blackfoot River basin to aid in predicting the impacts of different levels of phosphate mining and processing. This model would then provide a basis for construction of similar models for other basins in the area. The specific objectives are:

1. To construct, calibrate, and verify a water quality model for the Upper Blackfoot River basin.
2. To apply the model to arbitrary point inputs of large dosages of expected pollutants and predict the water quality changes at certain points on the river.
3. To suggest procedures for application of the model to evolve suitable management practices for phosphate mining and processing.
4. To recommend improvement of data collection for improvement and better application of the model.

## Description of the Study Area

The Upper Blackfoot River basin comprises the catchment area above the weir just below the Narrows and near the Caribou National Forest Service boundary (figure VII-1). The basin covers an area of 157 square miles (407 square kilometers). The primary streams are Diamond Creek, Lanes Creek, and Angus Creek. The physical characteristics of the basin are two valleys called the Upper Valley and Rassmusen Valley surrounded

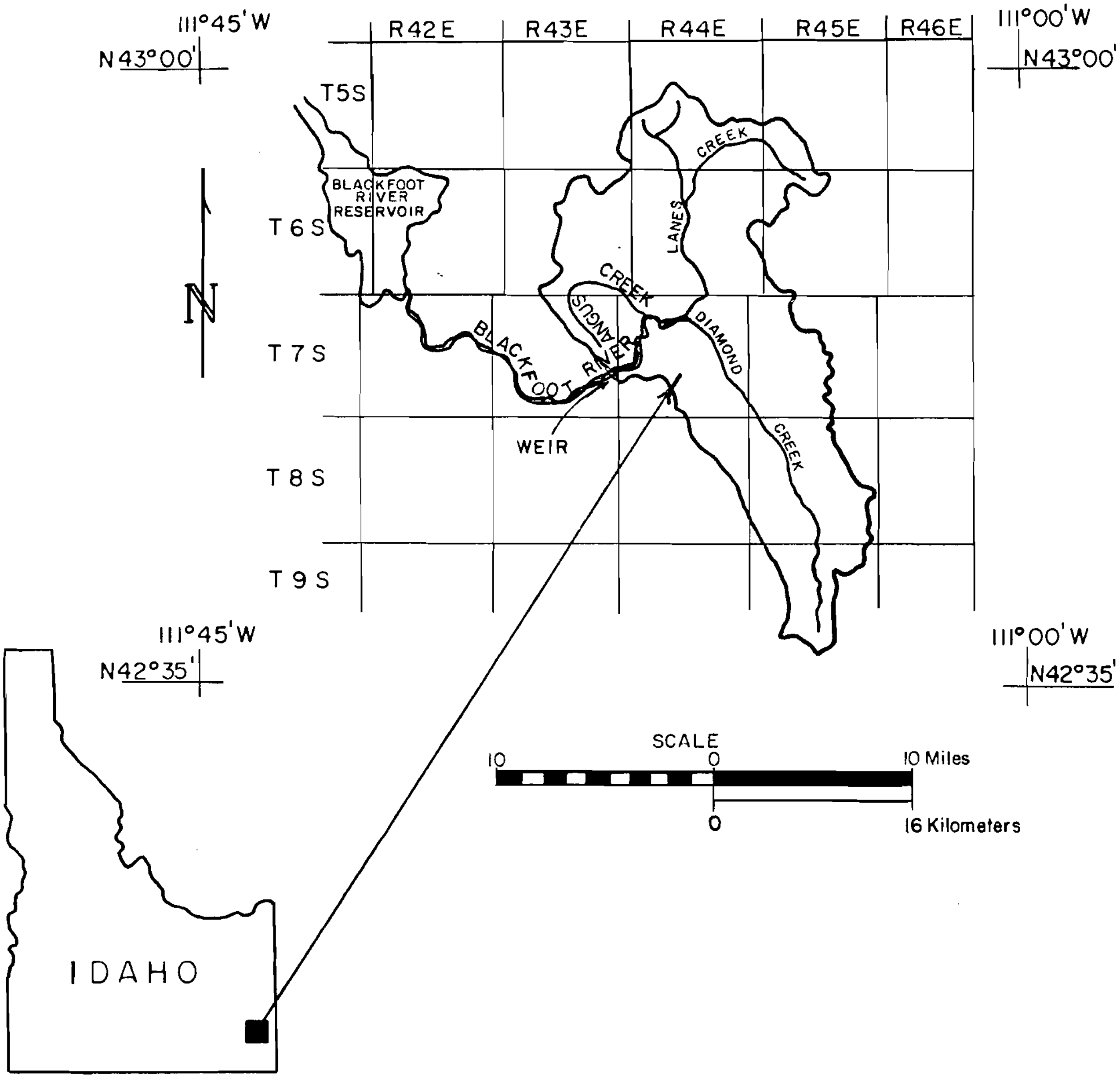


FIGURE VII-1. LOCATION MAP FOR UPPER BLACKFOOT RIVER BASIN, IDAHO by steep and high mountainous ranges.

Climate in the Upper Blackfoot River area is influenced by Pacific air current. The mountain ranges trend north and south and are nearly at right angles to the prevailing eastward air flow. The average annual precipitation varies from 20 to 35 inches (50 to 90 centimeters). An average of 54 percent of the annual precipitation falls from November to April which is mainly as snow. July is usually the driest month and June is the wettest. Temperatures over the study area range from $-49^{0}$F to $90^{0}$F.

Many of the small streams at higher elevations flow only during snow melt or high intensity rain storms but others are fed by large springs that are perennial. Large streams, such as Diamond Creek, Lanes Creek and Angus Creek and some of their larger tributaries, commonly have perennial flow. The complex ground water flow patterns described in previous chapters provide the baseflow for most of these streams.

The present study concerns itself with the impacts of phosphate mining on the water quality of streams in the Upper Blackfoot River basin. The other activities being carried on in the basin and having impacts on water quality include grazing, logging, irrigation, wildlife and recreation. The existing and proposed phosphate mines in the Upper Blackfoot River basin are shown on figure VII-1.

The primary factors controlling water quality degradation from a phosphate mining operation are noted below.

1. Forest clearing for exploration drilling, mining, mine waste and road construction.
2. Rail and road construction.
3. Ore removal.

4. Mine waste piles.
5. Ore stockpiles.
6. Oil, fuel and grease is used for mining and transportation machinery.
7. Ore processing, including beneficiation and calcination.
8. Possible failure of water and sediment control facilities as a result of inadequate design and/or unusual climatic events.
9. Leakage of ore slurry pipes, if used.

## Present Status of Water Quality

The present (1975) water quality conditions in the Upper Blackfoot River basin were established based upon data collected by various agencies during the period of September 1974 to August 1976. The data for eight sites in the basin for 27 water quality indices are given in tables VII-1, VII-2 and VII-3. The statistical values of the observed water quality data were evaluated against the water quality standards prescribed by the Idaho Department of Environmental and Community Services and the U.S. Environmental Protection Agency. The following conclusions may be stated with respect to the present water quality.

1. The water quality is good with respect to the following constituents: total and fecal coliform, dissolved oxygen, pH, total dissolved solids, ammonia ($NH_3$-N), nitrite ($NO_2$-N), conductivity, fluoride, arsenic, cadmium, chromium, copper, salinium, vanadium, and zinc. The concentrations of trace elements and fluoride are very low due to the basic nature of the water in the basin.
2. Water is generally alkaline and hard and below standards for some uses.
3. The water temperatures are low and good for cold water fish.
4. The turbidity is low except during peak flows when high values have been recorded.
5. The concentrations of suspended solids are satisfactory except during peak flow periods when they are high and below standards for certain uses.

Table VII-1. Statistical values of water quality constituents based on data from September, 1974 to August, 1976 for U.S. Forest Service stations in Upper Blackfoot River basin.

| Stream | Water Temperature (°F) | | | Turbidity (F.T.U.) | | | Suspended Solids (mg/l) | | | Dissolved Solids (mg/l) | | | Total Phosphorous (mg/l) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mean | Range | S.D. | Mean | Range | S.D. | Mean | Range | S.D. | Mean | Range | S.D. | Mean | Range | S.D. |
| Diamond Creek | 45.5 | 32-56 | 6.8 | 5.7 | .2-45 | 9.3 | 53 | 1-197 | 56 | 192 | 140-238 | 20 | .17 | .04- .44 | .08 |
| Stewart Creek | 41.6 | 32-51 | 4.6 | 3.0 | .2-30 | 6.1 | 44 | 0-856 | 114 | 205 | 181-425 | 31 | .12 | .02- .35 | .07 |
| Mill Creek | 44.4 | 37-59 | 4.5 | 1.1 | .2-11 | 1.3 | 12 | 0- 62 | 10 | 213 | 175-285 | 20 | .16 | .05- .88 | .12 |
| Kendell Creek | 39.3 | 32-45 | 3.2 | 3.2 | .3-63 | 12.2 | 12 | 0- 59 | 13 | 201 | 190-225 | 7 | .11 | .03- .71 | .13 |
| Sheep Creek | 47.6 | 32-62 | 8.1 | 2.3 | .3-15 | 2.8 | 26 | 0-260 | 44 | 213 | 130-525 | 41 | .12 | .01- .79 | .09 |
| Upper Angus Creek | 46.4 | 32-69 | 11.8 | 6.4 | .4-41 | 9.3 | 22 | 0-512 | 58 | 213 | 10-303 | 50 | .18 | 0 -1.06 | .17 |
| Lower Angus Creek | 43.8 | 32-61 | 8.9 | 3.2 | .4-32 | 4.9 | 16 | 0-206 | 27 | 205 | 120-266 | 21 | .14 | .05- .53 | .09 |
| Blackfoot River | 45.8 | 33-63 | 8.4 | 4.0 | .4-73 | 8.3 | 26 | 0-150 | 32 | 234 | 183-650 | 58 | .13 | 0 - .29 | .06 |

| | Dissolved Phosphorous $PO_4$ (mg/l) | | | Total Kjeldahl N (mg/l) | | | $NO_3$-N (mg/l) | | | Total Alkalinity $CaCO_3$ (mg/l) | | | Total Hardness $CaCO_3$ mg/l | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mean | Range | S.D. | Mean | Range | S.D. | Mean | Range | S.D. | Mean | Range | S.D. | Mean | Range | S.D. |
| Diamond Creek | .11 | .07-.17 | .03 | 2.08 | .09-21 | 2.89 | .16 | .06-.34 | .07 | 145 | 102-181 | 22 | 155 | 112-184 | 21 |
| Stewart Creek | .08 | .02-.12 | .03 | 1.69 | .08-11.2 | 1.41 | .16 | .09-.56 | .07 | 165 | 150-182 | 8 | 172 | 154-326 | 21 |
| Mill Creek | .05 | 0 -.2 | .11 | 1.62 | .45- 3.8 | .62 | .15 | .04-.25 | .04 | 170 | 138-190 | 11 | 174 | 154-198 | 9 |
| Kendell Creek | .06 | .02-.09 | .02 | 1.83 | .80- 2.9 | .54 | .14 | .05-.20 | .04 | 161 | 134-176 | 10 | 166 | 154-192 | 9 |
| Sheep Creek | .09 | .06-.11 | .01 | 1.70 | .60- 4.7 | .61 | .15 | .09-.21 | .03 | 168 | 86-326 | 35 | 172 | 106-248 | 29 |
| Upper Angus Creek | .16 | .07-.68 | .13 | 2.02 | .1 - 5.1 | .84 | .23 | .1 -.6 | .11 | 157 | 6-258 | 49 | 165 | 8-240 | 41 |
| Lower Angus Creek | .08 | .05-.11 | .02 | 1.64 | .38- 3.8 | .55 | .16 | .05-.38 | .05 | 155 | 58-194 | 32 | 159 | 64-198 | 29 |
| Blackfoot River | .11 | .04-.76 | .13 | 1.80 | .9 -16.8 | 1.70 | .13 | .04-.27 | .13 | 179 | 44-960 | 91 | 178 | 98-310 | 35 |

| | pH (field) | | | $NO_2$-N | | | Conductivity (µmhos) | | |
|---|---|---|---|---|---|---|---|---|---|
| | Mean | Range | S.D. | Mean | Range | S.D. | Mean | Range | S.D. |
| Diamond Creek | 7.3 | 6.6-8.0 | .5 | 0 | 0-0 | 0 | 295 | 215-366 | 30 |
| Stewart Creek | 7.3 | 7.0-8.1 | .4 | 0 | 0-0 | 0 | 311 | 270-616 | 44 |
| Mill Creek | 7.8 | 6.8-8.8 | .7 | 0 | 0- .01 | 0 | 232 | 269-438 | 31 |
| Kendell Creek | 8.0 | 6.9-8.8 | .7 | 0 | 0- .05 | .01 | 293 | 0-346 | 61 |
| Sheep Creek | 7.7 | 6.5-8.8 | .8 | 0 | 0- .01 | 0 | 323 | 200-761 | 58 |
| Upper Angus Creek | 7.1 | 6.4-7.6 | .4 | .02 | 0- .15 | .04 | 327 | 14-439 | 65 |
| Lower Angus Creek | 7.8 | 6.5-8.7 | .8 | .02 | 0-1.01 | .13 | 311 | 184-409 | 30 |
| Blackfoot River | 7.5 | 6.5-8.8 | .9 | 0 | 0- .01 | 0 | 355 | 281-942 | 83 |

S.D. = Standard Deviation

Table VII-2. Statistical concentrations values of trace elements based on two years data from September, 1974 to August, 1976 for U.S. Forest Service stations in Upper Blackfoot River basin.

| Stream | Arsenic (mg/l) | | Cadmium (mg/l) | | Chromium (mg/l) | | Copper (mg/l) | | Selenium (mg/l) | | Vanadium (mg/l) | | Zinc (mg/l) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mean | Range | Mean | Range | Mean | Range | Mean | Range | Mean | Range | Mean | Range | Mean | Range |
| Diamond Creek | 0 | 0-.001 | 0 | 0-.001 | .001 | 0 -.003 | .003 | .002-.004 | .004 | .001-.010 | .013 | .001-.031 | .019 | .008-.029 |
| Stewart Creek | 0 | 0-.001 | 0 | 0-.001 | .001 | 0 -.002 | .011 | .003-.021 | 0 | 0 -.001 | .210 | .001-.027 | .035 | .011-.068 |
| Mill Creek | 0 | 0-.001 | 0 | 0-.001 | .006 | .001-.014 | .008 | .003-.017 | 0 | 0 -.001 | .012 | 0 -.035 | .014 | .003-.024 |
| Sheep Creek | 0 | 0-.001 | 0 | 0-.001 | .001 | 0 -.001 | .006 | .004-.008 | 0 | 0 -.001 | .010 | .001-.022 | .017 | .014-.023 |
| Upper Angus Creek | 0 | 0-.001 | 0 | 0-.001 | .004 | 0 -.010 | .008 | .003-.016 | 0 | 0 -.001 | .010 | .001-.021 | .022 | .018-.025 |
| Lower Angus Creek | 0 | 0-.001 | 0 | 0-.001 | .001 | 0 -.002 | .004 | .002-.005 | 0 | 0 -.001 | .003 | .001-.071 | .020 | .019-.021 |
| Blackfoot River | 0 | 0-.001 | 0 | 0-.001 | .002 | 0 -.006 | .002 | 0 -.004 | 0 | 0 -.001 | .010 | 0 -.030 | .013 | .005-.021 |

Table VII-3. Water quality data from sources other than U.S. Forest Service for sites in Upper Blackfoot River basin.

| Site | Period | Dissolved Oxygen (mg/l) |  | BOD (mg/l) |  | COD (mg/l) |  | Total Coliform /100 ml |  | Fecal Coliform /100 ml |  | Ammonia $NH_3$-N (mg/l) |  | Fluoride (mg/l) |  |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  |  | Mean | Range | Mean | Range | Mean | Range | Mean | Range | Mean | Range | Mean | Range | Mean | Range |
| Diamond Creek 2 miles below Campbell Canyon | 2/1975 to 10/1976 | 11.1 | 9.2-13.9 | 1.6 | 0.1-2.4 | 3.8 | 0.3-11.8 | 22 | 4-34 | 3 | 2- 4 | .05 | .01-.12 | .11 | .01-.16 |
| Lanes Creek at mouth | 6/1977 to 10/1977 | 8.5 | 7.7- 9.4 | - | - | 11.0 | 0.4-20.1 | 5 | 2- 7 | 14 | 2-25 | .06 | .04-.06 | .11 | .07-.15 |
| Blackfoot River after confluence of Diamond Creek and Lanes Creek | 10/1975 to 10/1976 | 10.9 | 9.7-13.1 | 1.6 | 0.7-2.4 | 3.6 | 2.0- 4.7 | - | - | - | - | .06 | .01-.17 | .15 | .14-.15 |
| Blackfoot River above Angus Creek | 12/1974 | - | - | - | - | - | - | - | - | - | - | - | - | .10 | - |
| Blackfoot River below the Narrows | 7/1977 to 11/1977 | 9.7 | 7.1-13.0 | - | - | 10.7 | 0.8-31.2 | 39 | 2-70 | 4 | - | .08 | .02-.23 | .14 | .07-.16 |

6. According to studies by different workers, nitrogen below 0.1 mg/l and phosphorus below 0.01 mg/l may prevent algae growth. Concentrations of the two nutrients in the water of the Upper Blackfoot River can result in moderate algae growth, but according to the Idaho Department of Health and Welfare (McSorley, 1979) there is very little algae in the streams. This is probably due to the low temperatures of the water which inhibit its growth.

## Water Quality Model

### Mathematical Basis and Construction

A survey was conducted of the available mathematical models for simulation of water quality indices in streams. These models varied essentially in the indices simulated and their ability to simulate steady-state or dynamic inputs and outputs. The model which could be best applied to the Upper Blackfoot River basin considering the available data and the simulation needs, was the one used by Chen and Wells (1975) for the Boise River. This model was modified wherever necessary to suit the data and the needs of the study area.

The fundemental concept on which the water quality models are based is Law of Conservation of Mass which states that:

$$\text{Change} = \text{In} - \text{Out} + \text{Generation} - \text{Loss}.$$

Where the first two terms, In and Out, represent the outcome of physical processes and the last two terms, Generation and Loss, give the mass changes due to biological and chemical processes taking place in the aquatic ecosystem.

Certain simplifications and assumptions are necessary in mathematical representations of complicated and dynamic processes such as water quality changes. Without these simplifications and assumptions, the system would be unmanageable because of the large data requirement and large computer time required to solve the involved mathematical equations. Simplifications and assumptions entering the model for the study area are:

1. The concept of Continuously Stirred Tank Reactor (CSTR) as applied in chemical engineering has been used.
2. A steady-state condition is assumed.
3. The ecosystem is taken to be a single system.
4. The system is assumed linear.
5. Parameters of the functional relationships are assumed not to change with time and over a segment.
6. The system is taken to be one-dimensional.
7. Eddy dispersion is assumed insignificant and is ignored in streams.
8. Hydrodynamic characteristics are a function of the stream geometry only and can be expressed as a simple function of the flow in any segment.

The general mathematical equation for a water quality parameter which enters the model is:

$$\frac{\Delta C}{\Delta t} = \frac{Q \cdot C}{V} - \frac{(Q + \Delta Q)(C + \Delta C)}{V} \pm \Sigma_i \ K_i C + \frac{C_D \cdot \Delta Q_D}{V} \pm C_B + \Sigma_j \ \frac{C_{pj} \cdot \Delta Q_j}{V}$$

where:

$C$ = concentration of a water quality constituent ($M/L^3$).
$\Delta C$ = change in concentration of a water quality constituent over a river segment ($M/L^3$).
$\Delta t$ = small change in time ($T$).
$Q$ = discharge entering through upstream face of segment ($L^3/T$).
$V$ = volume of the segment ($L^3$).
$K_i$ = reaction coefficient for ith biochemical process resulting in generation or loss of the constituent ($1/T$).
$C_D$ = concentration of non-point or distributed source ($M/L^3$).
$\Delta Q$ = change in stream discharge across segment due to distributed and point sources ($L^3/T$).
$C_B$ = concentration added to or withdrawn from the stream per unit time by a distributed source or sink along the bottom ($M/L^3 \cdot T$).

$C_{pj}$ = concentration of jth point source ($M/L^3$).
$\Delta Q_j$ = discharge of jth point source ($L^3/T$).
$\Delta Q_D$ = discharge of distributed or non-point source ($L^3/T$).

The term $\Sigma_i K_i C$, representing the biochemical processes involved in loss or generation of a water quality constituent, was developed for each constituent from the processes involved. In certain cases like temperature and oxygen, there were exchanges at the interface of water and air. Equations representing these exchanges are included in the model.

A schematic diagram of the reactions taking place in the aquatic ecosystem under study is given in figure VII-2. As mentioned earlier algae is negligible which results in negligible zooplankton which feed on algae. These have, therefore, not been considered in the ecosystem and the model.

The Upper Blackfoot River basin was divided into 23 segments chosen such that residence time in each segment was about the same as the computational time interval $\Delta t$ which was 1 hour. These segments are shown in figure VII-3.

The solutions of the mathematical equations for the following water quality parameters were carried out for each segment node by a computer program. A multi-step method was used for these solutions due to each river segment being treated as a CSTR.

> Temperature, total suspended solids (TSS), coliform, Biochemical oxygen demand (BOD), dissolved oxygen (DO), pH, $CO_2$, total dissolved solids (TDS), $PO_4$-P, $NH_3$-N, $NO_2$-N, $NO_3$-N, total alkalinity, total hardness, turbidity, Cr, Zn, Cu, V, Cd, As.

The computer program comprised of a main program and seven sub-programs. Their operational steps are indicated in figure VII-4. Flow

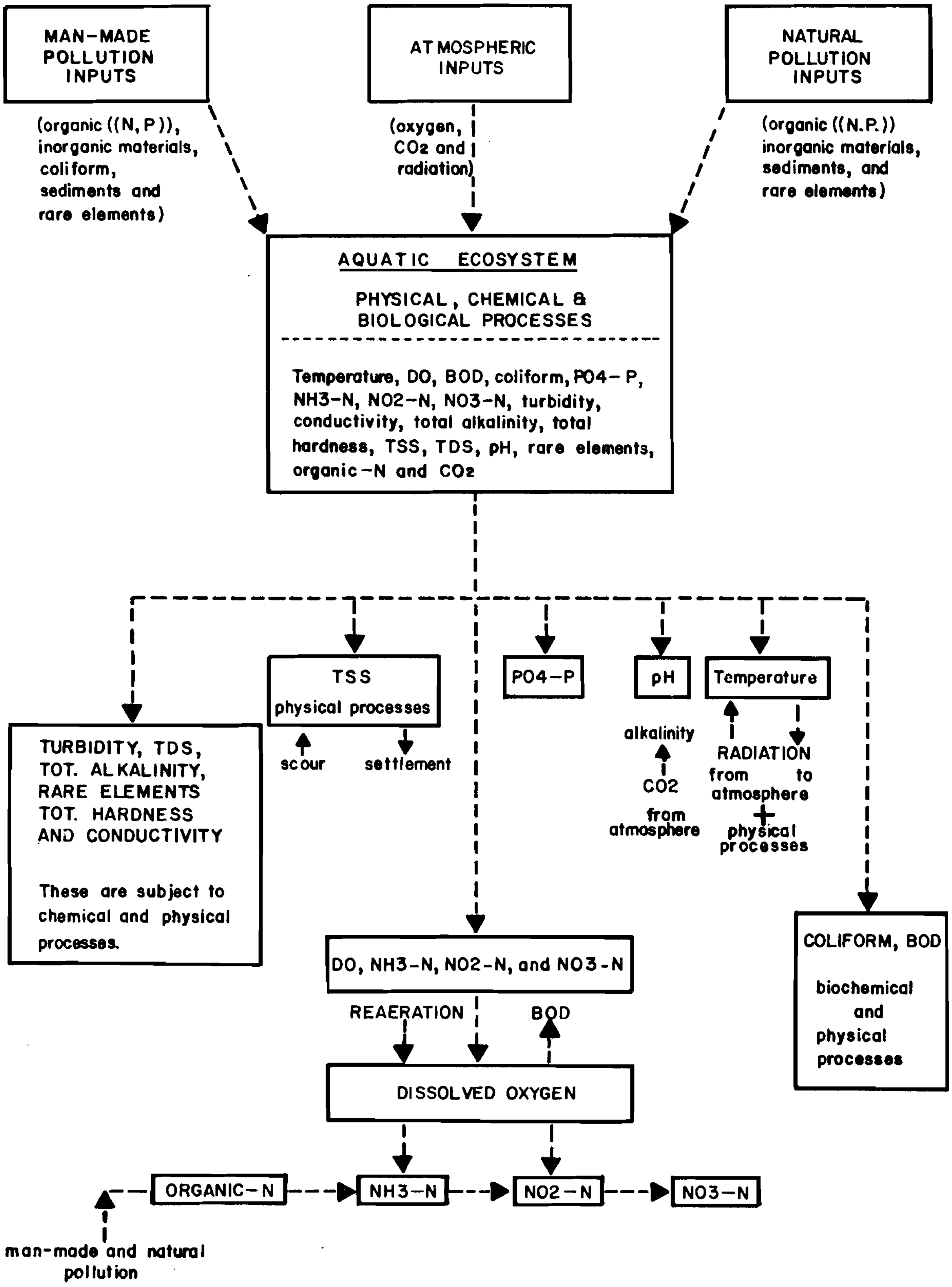


FIGURE VII-2. SCHEMATIC DIAGRAM OF THE UPPER BLACKFOOT RIVER ECOSYSTEM AND ITS ENVIRONMENT.

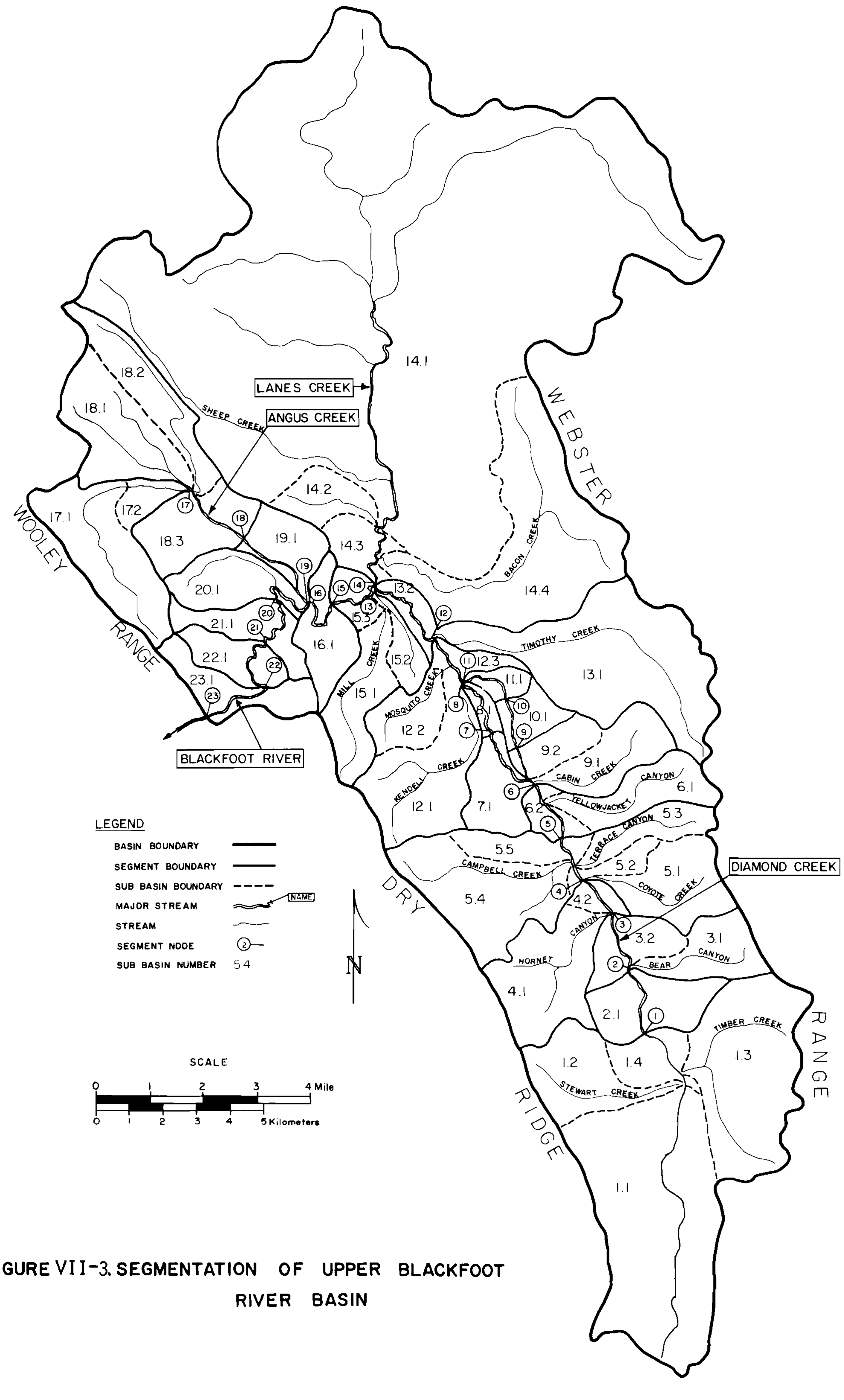


FIGURE VII-3. SEGMENTATION OF UPPER BLACKFOOT RIVER BASIN

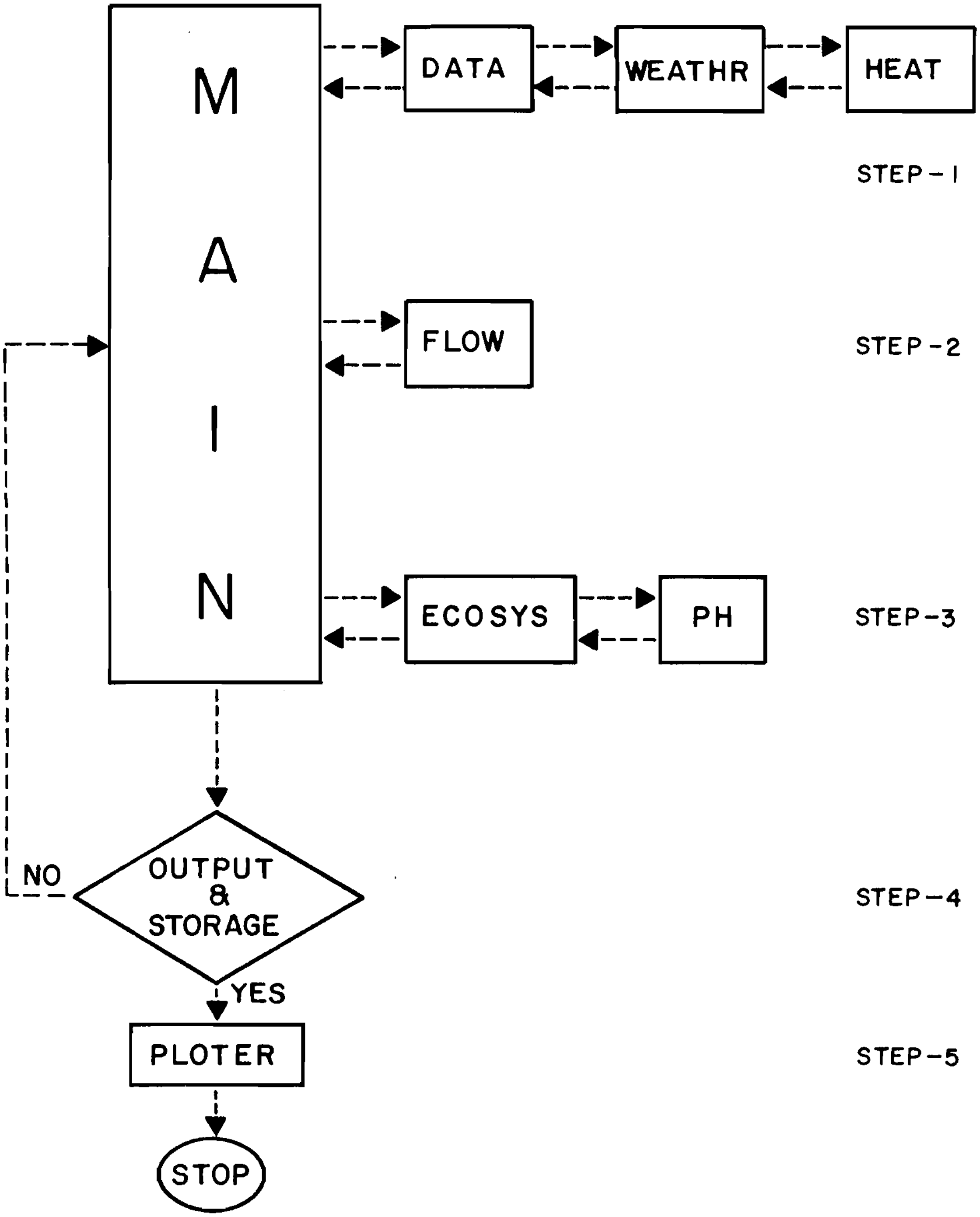


FIGURE VII-4. LAYOUT OF COMPUTER PROGRAM - MAIN AND SUBROUTINES diagram of the computational steps involved in the program is at figure VII-5.

## Data for the Model

The following data were needed for the water quality model.

1. Systems geometry and connectivity data.
2. Weather data.
3. Hydrologic data.
4. Water quality data.
5. System coefficients.

System Geometry and Connectivity Data. The connectivity data were prepared from maps and from figure VII-3 showing the segmentation of the basin. The system geometry calculations were based on the work done by Leopold and Maddock (1953) on the relationships between discharge and width, mean depth and mean velocity in a stream. These relationships are of the forms:

$$w = aQ^b$$
$$d = cQ^f$$
$$v = kQ^m$$

where:

w = width
d = mean depth
v = mean velocity
Q = discharge
a, b, c, f, k, and m are numerical coefficients.

The numerical coefficients for various reaches of the main stem of the Upper Blackfoot River and Diamond Creek were determined from graphical relationships of data for w, d, v and Q obtained from the discharge

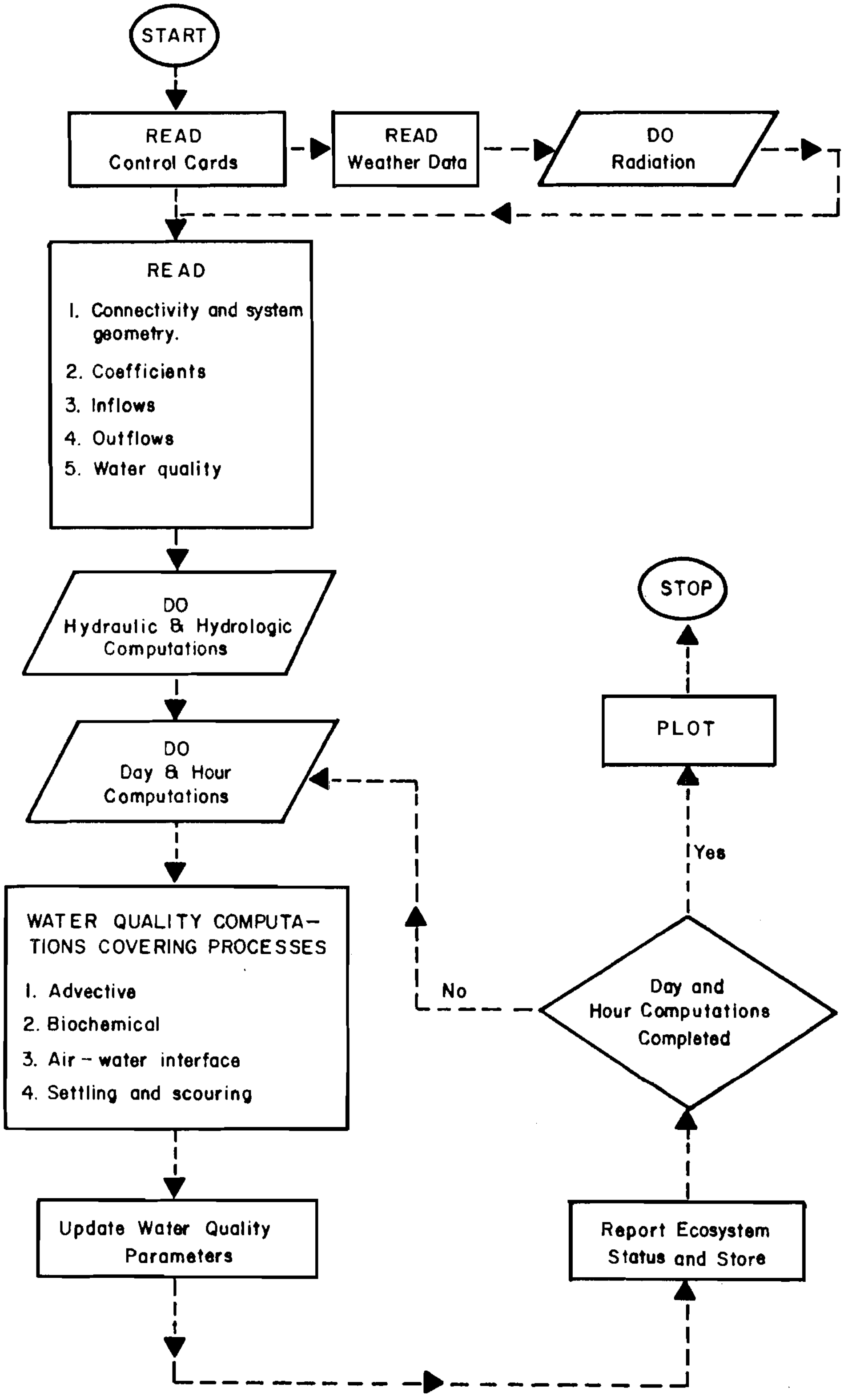


FIGURE VII-5. FLOW DIAGRAM, UPPER BLACKFOOT RIVER MODEL observations made by different agencies.

Weather Data. The weather data required for the model consisted of:

1. Dry Bulb temperature.
2. Dewpoint temperature.
3. Atmospheric pressure.
4. Cloud cover.
5. Wind speed.

These data were obtained or evaluated from the data collected by Greiner Environmental Sciences, Inc. at a weather monitoring station in Diamond Creek Valley near the proposed mine by Alumet, the data collected by U.S. Department of Commerce at the National Climatic Center in Pocatello, Idaho, and the data collected by USDA Forest Service during water quality and discharge measurements.

Dry bulb temperature, dewpoint temperature and wind speed data were obtained from correlation analyses between Pocatello and Diamond Creek data. Atmospheric pressure was evaluated by reduction of Pocatello pressures using suitable Laplace equation. The cloud cover data were based on information collected by USDA Forest Service.

Hydrologic Data. The sources of these data were the Forest Service, Greiner Environmental Sciences, Inc. and special project studies.

Water Quality Data. The Forest Service, Idaho Department of Health and Welfare, Greiner Environmental Sciences, Inc. and the University of Idaho have collected water quality data at various sites in the Upper Blackfoot River basin. These data were used to prepare the input data required for the calibration and verification of the model.

The locations of weather, hydrologic and water quality monitoring stations for which data were utilized in the model are shown in figure VII-6.

Systems Coefficients. The system coefficients can either be obtained from various sources in literature or can be obtained by actual measurements in the study area. Many of the coefficients are fundemental in nature and can be estimated with sufficient accuracy from the aggregate of available information. The coefficients used by Chen and Wells (1975) for Boise River model were checked with the coefficients listed in the model study of Chattahoochee-Flint-Apalachicola River basin (Alabama, Georgia and Florida) as reported by Yearsley (1975). Based upon this examination, it was considered that the coefficients used for Boise River model were also suitable for the Upper Blackfoot River model.

### Calibration of the Model

Two periods, May 1976 and September 1976, were selected for calibration and verification of the model. May was a high flow period while September was a low flow period. These periods had been selected considering the amount and quality of available meteorological, hydrologic and water quality data. The data for September 1976 was used for calibration.

### Verification of the Model

The data for May 1976 were utilized for model verification. A copy of the computer printout of inputs, outputs and weather, hydraulic and hydrologic calculations is presented by Singh (1979). The observed water quality data and that simulated by the model for four points on the main stem of the stream have been tabulated in table VII-4. Comparison of the two sets of data shows a satisfactory simulation for all the water quality indices except turbidity. Turbidity is dependent not only on the concentration

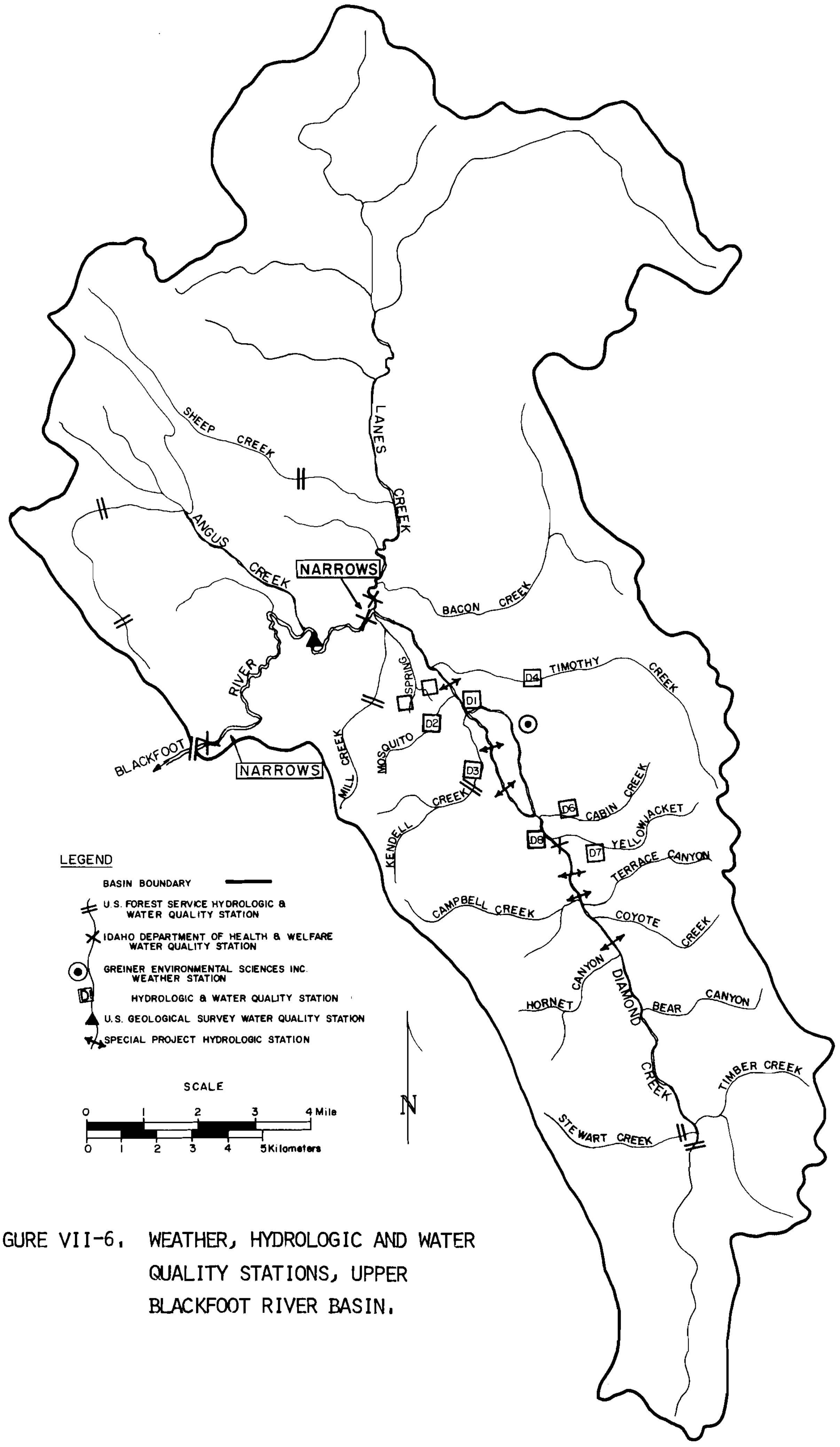


FIGURE VII-6. WEATHER, HYDROLOGIC AND WATER QUALITY STATIONS, UPPER BLACKFOOT RIVER BASIN.

Table VII-4. Comparison of observed and simulated water quality data - May, 1976, Upper Blackfoot River basin.

| Node | Kind of Data | Temp °C | TSS mg/l | Coliform MPN/100 ml | BOD mg/l | DO mg/l | $PO_4$-P mg/l | Alkalinity mg/l | pH | $NH_3$-N mg/l | $NO_3$-N mg/l |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 6 | observed | - | 143 | 4 | 0.8 | - | .03 | 161 | 8.3 | - | .08 |
|  | simulated | 8.1 | 70 | 2 | 0.6 | 10.0 | .06 | 149 | 7.4 | .08 | .15 |
| below 8 & 11 | observed | 8.0 | 56 | 4 | 0.8 | 9.0 | .03 | 162 | 8.2 | .04 | .06 |
|  | simulated | 9.8 | 68 | 2 | 0.6 | 10.5 | .05 | 149 | 7.9 | .08 | .14 |
| below 13 & 14 | observed | 9.0 | 5 | - | 1.6 | 9.0 | .06 | 172 | 8.5 | .07 | .10 |
|  | simulated | 11.6 | 44 | 2 | 1.2 | 9.6 | .05 | 156 | 8.0 | .08 | .14 |
| 23 | observed | 10.0 | 26 | 4 | 3.0 | 9.5 | .06 | 162 | 7.0 | .06 | .09 |
|  | simulated | 10.0 | 35 | 10 | 1.1 | 10.2 | .06 | 150 | 7.9 | .08 | .14 |

| Node | Kind of Data | TDS mg/l | Turbidity FTU | Total Hardness mg/l | Chromium mg/l | Zinc mg/l | Copper mg/l | Vanadium mg/l | Cadmium mg/l | Arsenic mg/l |
|---|---|---|---|---|---|---|---|---|---|---|
| 6 | observed | - | - | - | .001 | - | - | .001 | - | .002 |
|  | simulated | 206 | 13.8 | 149 | .001 | .013 | .004 | .001 | .001 | .001 |
| below 8 & 11 | observed | - | 1.5 | 160 | .010 | - | - | - | .001 | .010 |
|  | simulated | 206 | 13.3 | 149 | .001 | .013 | .004 | .001 | .001 | .001 |
| below 13 & 14 | observed | - | 3.0 | 176 | .010 | - | - | - | .001 | .010 |
|  | simulated | 202 | 8.8 | 157 | .001 | .010 | .007 | .001 | .001 | .001 |
| 23 | observed | 212 | 5.0 | 170 | .001 | .013 | .001 | .001 | .001 | .001 |
|  | simulated | 194 | 8.5 | 148 | .004 | .015 | .007 | .001 | .001 | .001 |

of suspended solids but also on the grain sizes which cannot be simulated by the model.

## Application of the Model

The mathematical model which has been developed can simulate the downstream effects of various levels of waste inputs into the stream system. Alternative management plans and associated levels of waste loading may thus be evaluated. The values of water quality parameters along the stream below the point or points of discharge are calculated based upon the input of anticipated waste loads in terms of the water quality indices included in the model. Utilization of the model allows efficient management of phosphate mining operations while meeting water quality requirements for downstream uses. The model also greatly reduces the required level of water quality monitoring.

The following example is presented to illustrate the technique of model application. Arbitrary waste inputs having constituent concentrations much higher than anticipated from mining were superimposed on the system and the effects of these inputs were simulated along the stream with the model. The water quality indices selected for this exercise were total suspended solids (TSS), total dissolved solids (TDS), biochemical oxygen demand (BOD), and zinc. The actual and arbitrary concentrations of these selected water quality parameters are presented in table VII-5. The points of inputs for the arbitrary wastes were selected at places where mining operations will be expanded or initiated. These input points were Diamond Creek, Stewart Creek, Diamond Creek between Yellowjacket Canyon and Mosquito Creek and Angus Creek. Different cases of waste inputs were tried to determine the effects resulting from different mines within the basin.

Table VII-5. Actual and arbitrary concentrations of selected water quality parameters, Upper Blackfoot River basin, for Case 1 and Case 2*.

| Segment No. | Stream | Actual/Arbitrary | Concentrations (mg/l) | | | |
|---|---|---|---|---|---|---|
| | | | TSS | TDS | BOD | Zinc |
| 1 | Diamond Creek | Actual | 109 | 207 | | |
| | | Arbitrary | 500 | 500 | | |
| 1 | Stewart Creek | Actual | 72 | 205 | | |
| | | Arbitrary | 500 | 500 | | |
| 7 | Unnamed Creek | Actual | 35 | 205 | 1.0 | .005 |
| | | Arbitrary | 500 | 500 | 10.0 | .200 |
| 9 | Cabin Creek | Actual | 12 | 205 | .50 | .005 |
| | | Arbitrary | 500 | 500 | 10.0 | .200 |
| 9 | Unnamed Creek | Actual | 50 | 205 | .80 | .005 |
| | | Arbitrary | 500 | 500 | 10.0 | .200 |
| 10 | Unnamed Creek | Actual | 50 | 205 | .80 | .005 |
| | | Arbitrary | 500 | 500 | 10.0 | .200 |
| 11 | Unnamed Creek | Actual | 71 | 210 | 1.0 | .005 |
| | | Arbitrary | 500 | 500 | 10.0 | .200 |
| 17 | Angus Creek | Actual | 19 | 190 | | |
| | | Arbitrary | 200 | 500 | | |

* Case 1 = arbitrary discharges in segments 1, 7, 9, 10, 11 and 17.
Case 2 = arbitrary discharges in segments 7, 9, 10 and 11.

The results of model simulations, under conditions of no input (present condition) and with arbitrary waste inputs at selected points are shown in figures VII-7, VII-8, VII-9, VII-10, VII-11, and VII-12. The simulations are for May 31, 1976, resulting from steady-state inputs starting on May 27, 1976.

## Conclusions

The model can be used to project the stream water quality impacts from various levels of mining activities on a steady-state basis by inputting the possible waste loads and simulating the downstream effects. The water quality model is state-of-the-art in 1979 and is limited by the assumptions listed previously. It should prove to be an asset in management of phosphate mining operations for water quality objectives.

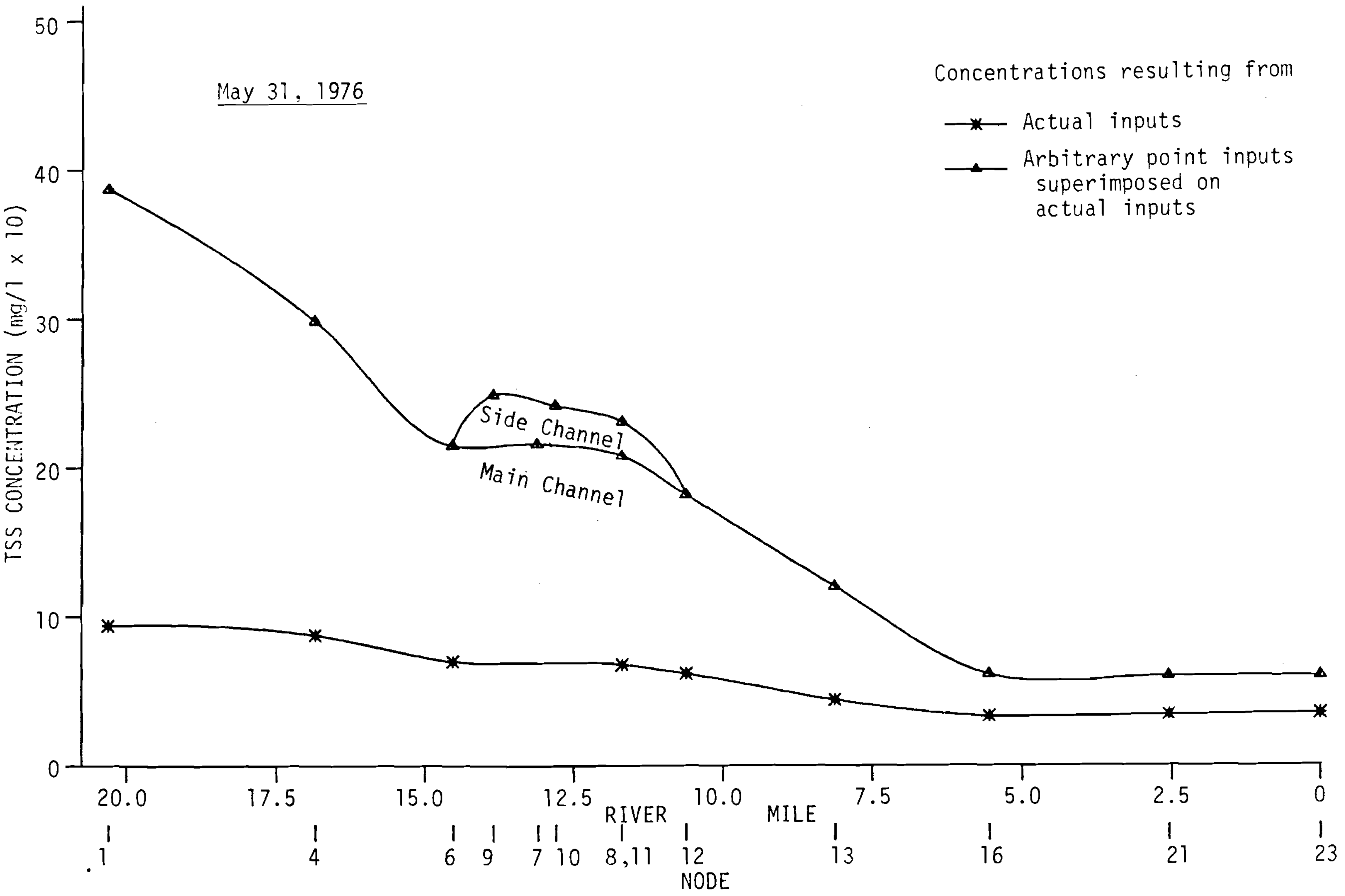


FIGURE VII-7. LONGITUDINAL PLOT OF TSS, UPPER BLACKFOOT RIVER BASIN - CASE 1

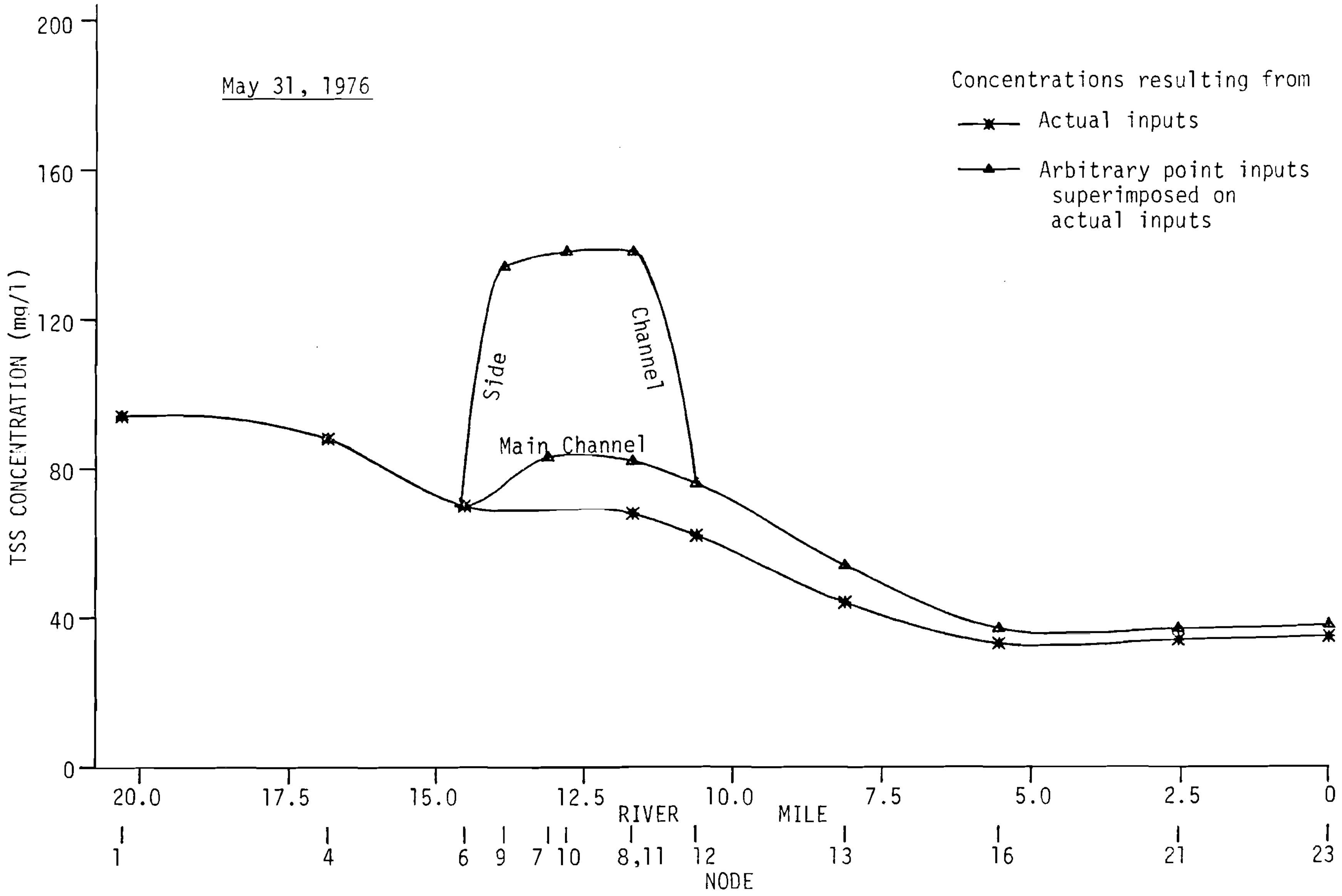


FIGURE VII-8. LONGITUDINAL PLOT OF TSS, UPPER BLACKFOOT RIVER BASIN - CASE 2

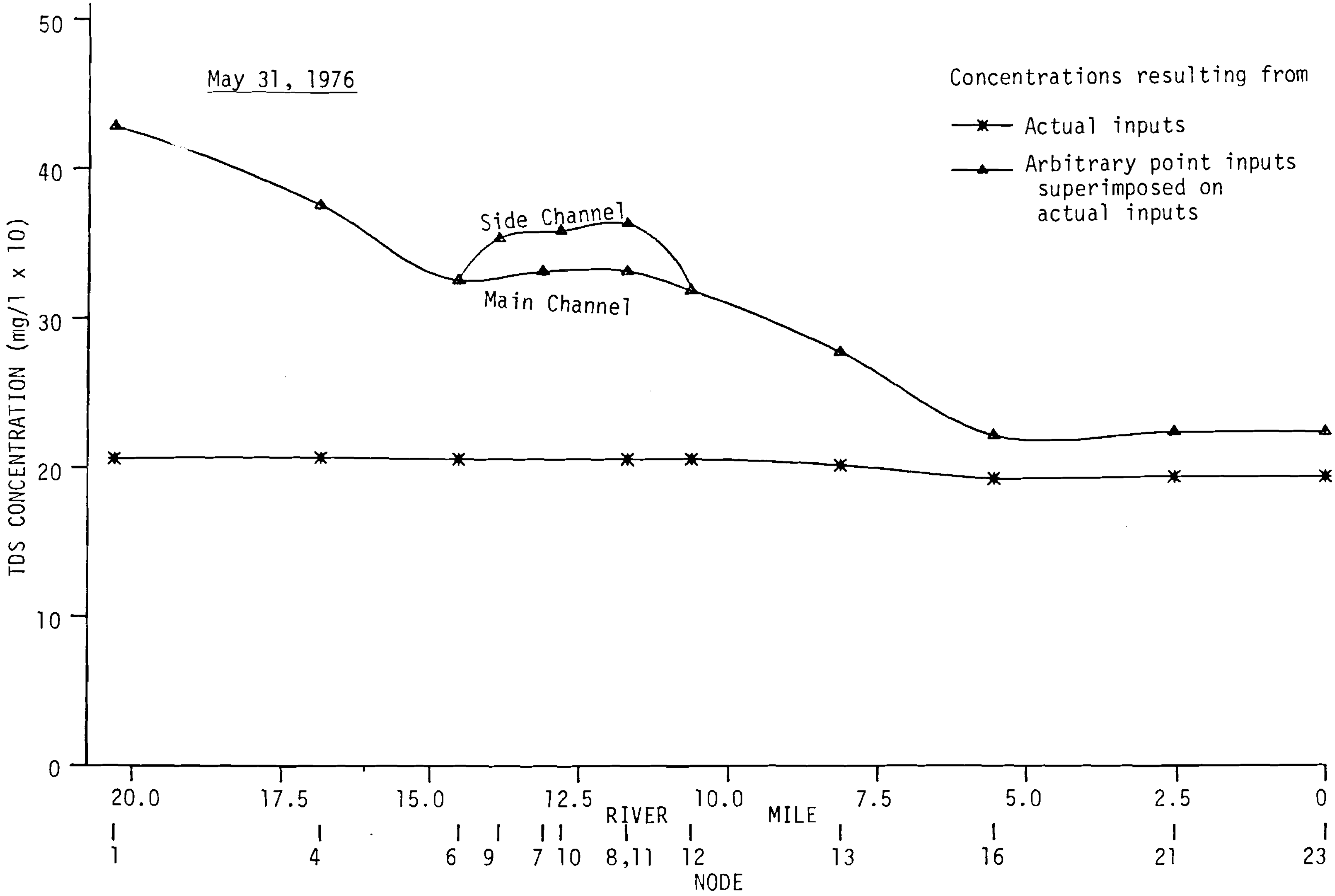


FIGURE VII-9. LONGITUDINAL PLOT OF TDS, UPPER BLACKFOOT RIVER BASIN - CASE 1

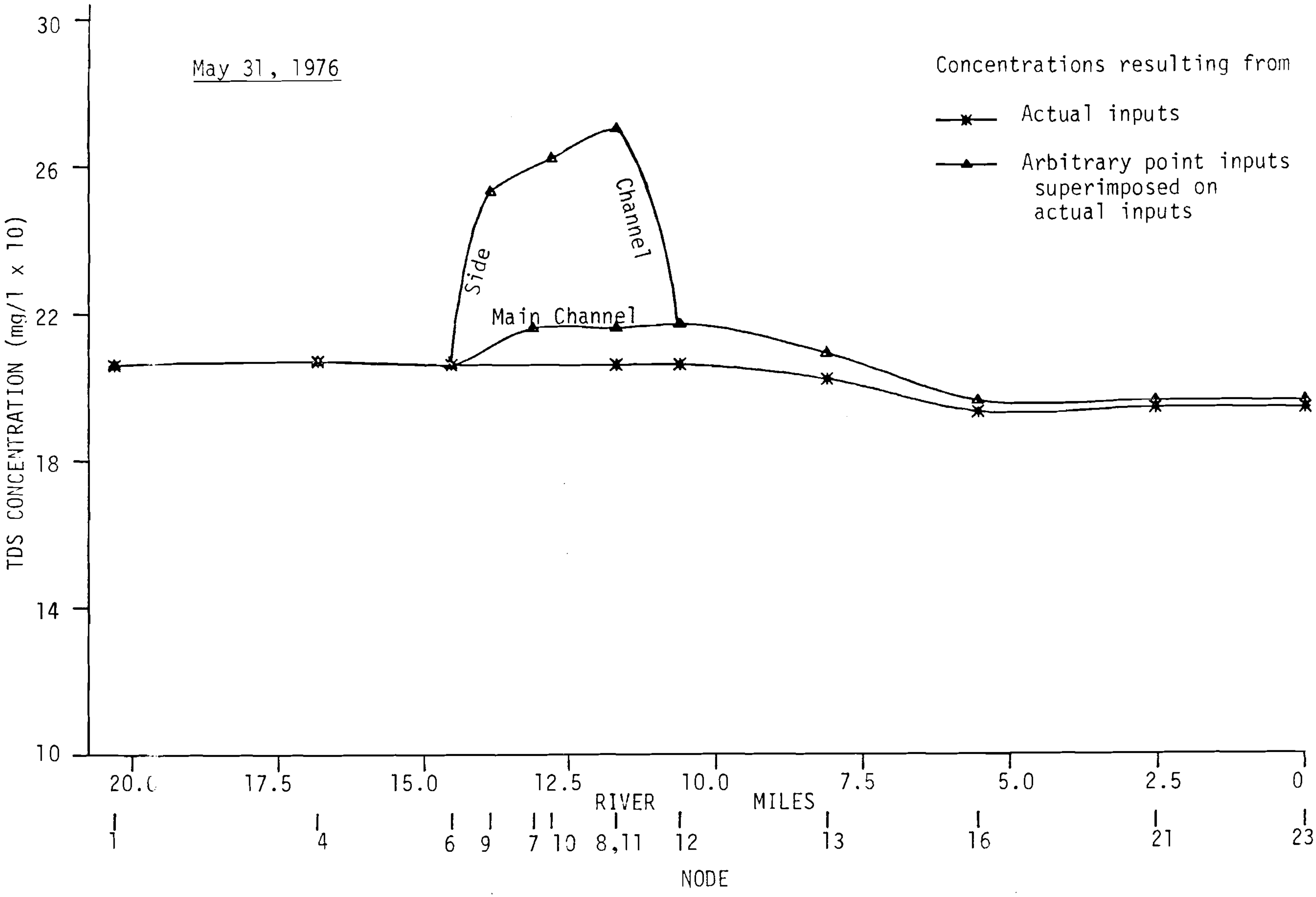
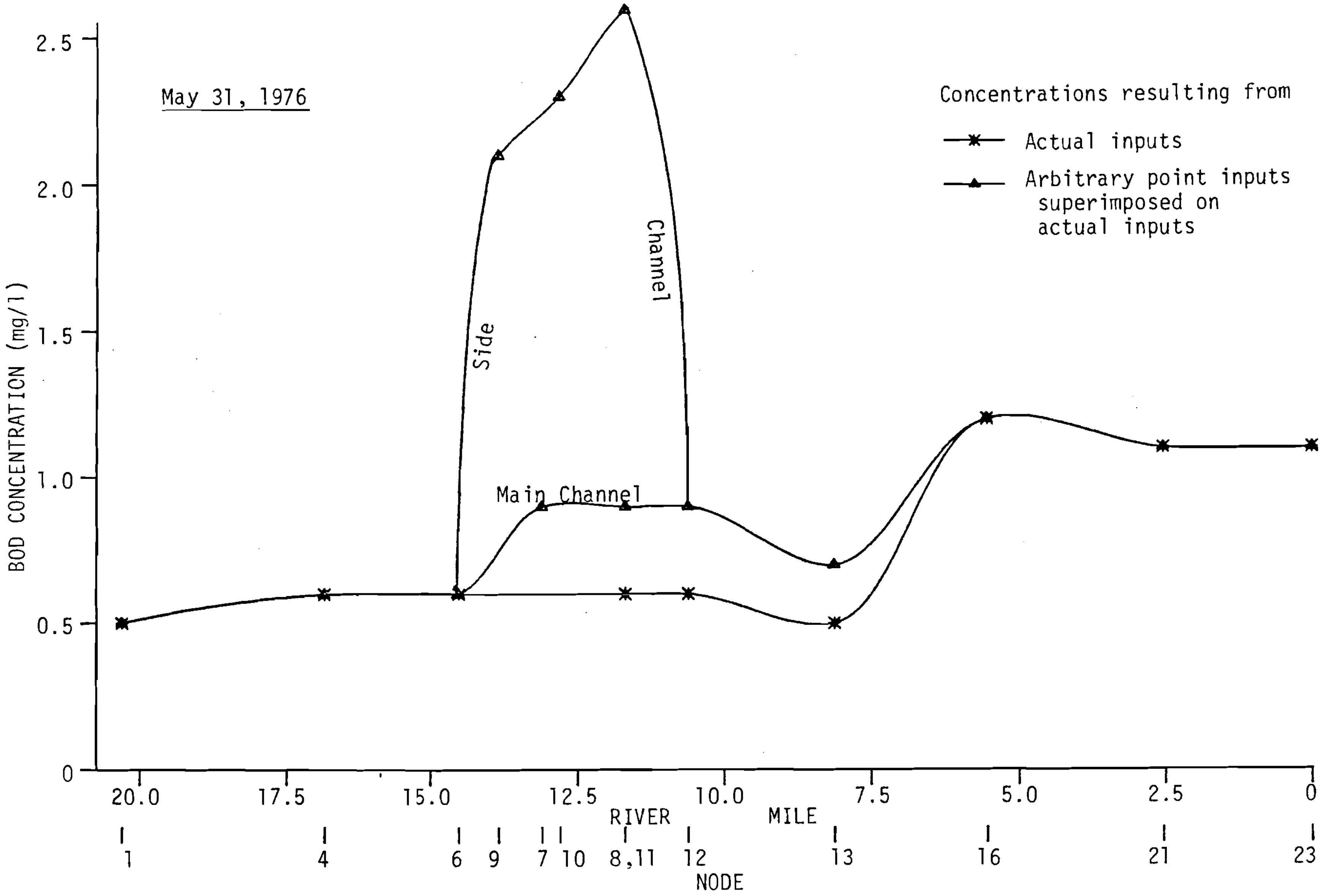


FIGURE VII-10. LONGITUDINAL PLOT OF TDS, UPPER BLACKFOOT RIVER BASIN - CASE 2



May 31, 1976

FIGURE VII-11. LONGITUDINAL PLOT OF BOD, UPPER BLACKFOOT RIVER BASIN - CASE 2

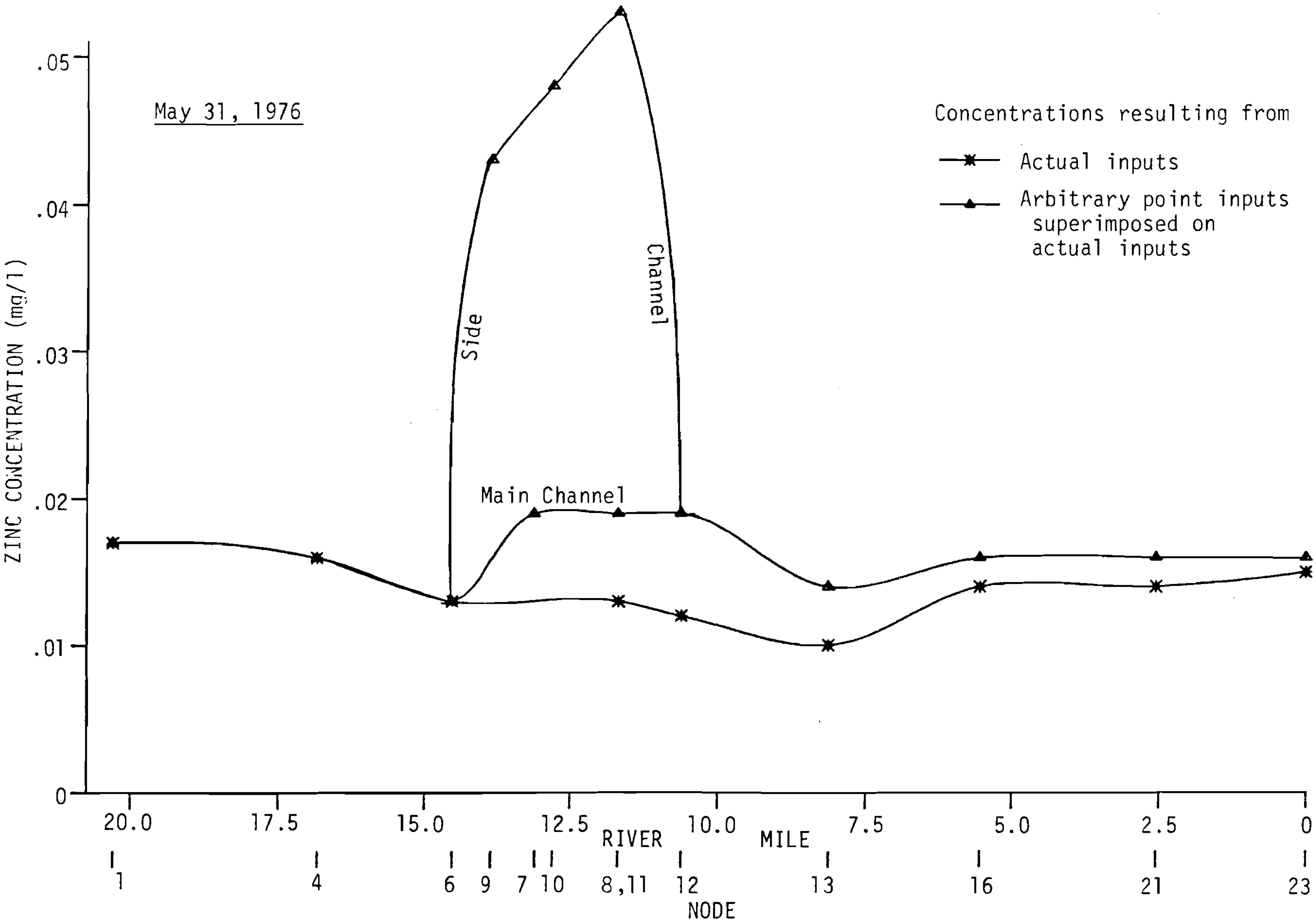


FIGURE VII-12. LONGITUDINAL PLOT OF ZINC, UPPER BLACKFOOT RIVER BASIN - CASE 2

## CHAPTER VIII

## CONCLUSIONS

1. The water resource impacts on and from phosphate mining occur from the interaction of specific hydrologic or environmental factors with mining factors. The environmental factors which affect water resource systems include the geologic setting, topography, hydrogeologic framework, climate, soil and water chemistry and biotic pattern. The mining factors are primarily the excavation of open pits and the construction of waste piles.

2. Previous studies indicated that a distinct pattern of ground water flow systems exist in the Western Phosphate Field based upon a regional similarity in the environmental factors listed above. A regional evaluation of stream gain-loss and spring locations confirmed that the formations comprising the "phosphate sequence" exhibit similar hydrogeologic characteristics through out the study area. The Thaynes and Dinwoody formations were found to have sufficient hydraulic conductivity to support ground water flow systems at a number of sites. The cherty shale member, Rex Chert member, and Meade Peak member of the Phosphoria formation were found to not support any major ground water flow systems in the phosphate mining area. Finally, the Wells formation was found to have sufficient hydraulic conductivity to support ground water flow at most sites. Ground water flow systems above the Phosphoria formation are separate from those below the Phosphoria formation. This causes the upper flow systems to be relatively local in extent while the lower flow system is more regional in extent.

3. Site investigations at the J.R. Simplot Company Gay Mine have provided important ground water information on the "phosphate sequence" in an unusual geologic setting. Ground water flow systems within the mine are dominantly controlled by faulting and folding in the area. However, the relative hydraulic conductivity of the various formations within the "phosphate sequence" at the Gay Mine is similar to that found for other portions of the phosphate mining area. Ground water flow systems in the east Gay Mine area may be depicted by a simple model consisting of a box filled with high hydraulic conductivity material with water draining out one end. In the actual field situation, the high hydraulic conductivity Wells formation is bounded by faults and folds on four sides and is located so it can receive recharge directly from precipitation. The water table in the Wells formation forms a lower limit to mining without major dewatering. Discontinuous upper ground water flow systems occur in the Thaynes and Dinwoody formations but are of limited significance to the mining operation.

4. Hydrologic investigations at the proposed North Henry Mine of Monsanto found a similar distribution of hydraulic conductivity within the "phosphate sequence" as found elsewhere in the phosphate field. However, localized zones of higher hydraulic conductivity were found in the Rex Chert member in the North Henry area that are not characteristic of the unit throughout the region. These fracture zones are believed to be localized features similar to those found in lower Dry Valley by previous investigators. Three ground water flow systems were delineated in the North Henry area: (a) a local flow system in

the shallow alluvial and upper portion of the sedimentary rock on the east side of "Henry Ridge", (b) a ground water flow system in the alluvium/basalt in Henry Valley and (c) a regional ground water flow system in the Wells formation. The alluvial/basalt flow system is of particular importance because water from the Little Blackfoot River may recharge the flow system and move from the basalt into the zones of higher hydraulic conductivity within the Phosphoria formation. This water may thus enter mine pits that are constructed below the stream level. However, the total volume of water movement from the basalt into the Phosphoria formation is believed to be small. A portion of the stream recharge to the basalt occurs from water movement directly into a series of sinkholes that probably represent the surface expression of a partially collapsed lava tube. Most of the ground water in the basalt aquifer discharges to the Blackfoot lava field west of the mine area. The regional ground water flow system in the Wells formation discharges west of the proposed mine area and is probably hydrologically separate from the mining activities. The elevation of the springs discharging from the Wells formation probably represent the regional water table and thus denote the lower limit to mining without a dewatering program.

5. Test wells in tailings and waste piles at two mine sites show that most of the mine wastes are unsaturated. Ground water flow systems within waste piles are dependent upon site specific characteristics.

6. Leaching experiments utilizing soil samples obtained from phosphate mine waste piles showed that acid drainage from these piles is not a

problem. The leaching experiments indicated that the effluent would have relatively low concentrations of most elements and be slightly basic.

7. Ground water flow system theory provides the basis for the formulation of conceptual models of water resource systems for the southeastern Idaho phosphate field. The theory of ground water flow systems demonstrates how the environmental factors of geology, topography, hydraulic conductivity and fluid potential control ground water flow. Definite relationships between environmental factors and the development of water resource systems have been observed in the Western Phosphate Field. Relationships between existing water resource systems, mining activities and water resource impacts have also been observed. The level of hydrologic impacts from mining is related to the size and types of ground water flow systems encountered at the mine site. Hydrologic limitations to mining are also dependent primarily on the size and types of flow systems intercepted by mine pits.

8. 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 upon geologic structure, topographic configuration, topographic location and climatic conditions of the mine area. The models evaluate potential water resource impacts on and from mining based on the size and types of flow systems that occur at a mine site. Ground water flow systems at the mine site are delineated with a high degree of reliability. Predicted hydrologic

impacts from mining and hydrologic limitations to mining are also expected to be reliable.

9. A water quality model has been constructed and calibrated for the stream system in the Upper Blackfoot River basin. The model can be used to project stream water quality impacts from various levels of mining activities on a steady-state basis by the input of possible waste loads and the simulation of the downstream affects. The water quality model is state-of-the-art in 1979 and should prove to be an asset in the management of phosphate mining operations for water quality objectives.

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*16. Abstract*

The water resource systems in the Western Phosphate Field are the result of the interaction of a number of environmental factors. These may be classified under the following general headings: geologic, topographic, hydrologic, climatic, chemical and biotic factors. The mining activities which have the largest potential to affect water resource systems are the development of open pits and waste piles. Prediction of water resource impacts on and from mining can only be accomplished if it is known how changes in environmental conditions affect flow systems, because mining necessarily alters the environment of a mine site.

Detailed studies of two mine areas were conducted to obtain additional hydrogeologic insight on flow patterns in the "phosphate sequence" of geologic units. A limited study of phosphate waste piles showed that chemical leaching and associated acid production is not a problem. Models of groundwater flow were constructed. These may be used to evaluate both the mining impacts on the water resource systems and the hydrologic limitations to mining. The delineation of impacts is based on the size and types of flow systems which occur at the mine site. A water quality model of the upper Blackfoot River basin was also constructed to provide a basis for the projection of stream water quality impacts from various levels of mining activities.

*17a. Descriptors* Idaho, groundwater, surface-groundwater relationships, water pollution, waste disposal, subsurface flow, aquifer characteristics, areal hydrogeology

*17b. Identifiers*
Southeastern Idaho, Western Phosphate field

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