Project Report C-7651

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INTERACTIONS BETWEEN OPEN MINING AND GROUNDWATER FLOW SYSTEMS AT THE EAST AREA OF THE GAY MINE, IDAHO

by
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Moscow, Idaho

March, 1980

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A Thesis
Presented in Partial Fulfillment of the Requirement for the
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in the
UNIVERSITY OF IDAHO GRADUATE SCHOOL
by

THOMAS F. CORBET, JR.
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ABSTRACT

Phosphate ore is mined from open pits at the Gay Mine, located 30 miles northeast of Pocatello, Idaho. Mining activity interacts with groundwater flow systems that are controlled primarily by complex fault block structure. Flooding of the pits by groundwater discharging from the Wells formation has seriously hindered mining operations. This report presents a conceptual model of groundwater flow systems to aid in the reduction of detrimental interactions between mining and water resource systems.

Folds and faults act as hydrogeologic boundaries in the Gay Mine area by placing rock units of low hydraulic conductivity (Phosphoria formation) adjacent to units of high or moderate hydraulic conductivity (Wells, Dinwoody, and Thaynes formations). A major groundwater flow system confined to a "block" of Wells formation is continuous throughout the portion of the mine studied. Less extensive flow systems occur at higher elevations in the Dinwoody and Thaynes formations and are separated from the major flow system by the Phosphoria formation. Recharge to both major and minor systems is by precipitation falling directly on the mine area. Discharge is by subsurface flow to the northwest.

The conceptual model was used to predict and evaluate potential interactions at a proposed Group 1 pit site. Mining at this site will intersect the major flow system in the Wells formation and a smaller flow system in the Dinwoody formation. Calculations show that dewatering wells are a practicable solution to these problems.

Limited studies involving leaching of mine waste material indicate that degradation of water quality is not a problem. The overall impact of mining on water resources is minimal.

CHAPTER I

INTRODUCTION

Statement of the Problem

In 1976 a research program directed by Dr. Dale Ralston of the University of Idaho was initiated to study the water resource systems of the Western Phosphate Field of southeastern Idaho. The goal of these studies was to gain an understanding of ground and surface water flow systems. This information can be used to develop mining procedures that will allow mining to continue with minimal negative interactions between mining and water resource systems. This report is presented as part of that program of study.

This report presents the geohydrology of the Gay Mine which is jointly operated by the J. R. Simplot Company and the FMC Corporation. The mine is located about 30 miles northeast of Pocatello, Idaho as is shown in figure I-1.

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) groundwater flow systems of the study area are controlled primarily by fault block structure, 2) the flooding of mine pits by groundwater has seriously hindered mining operations.

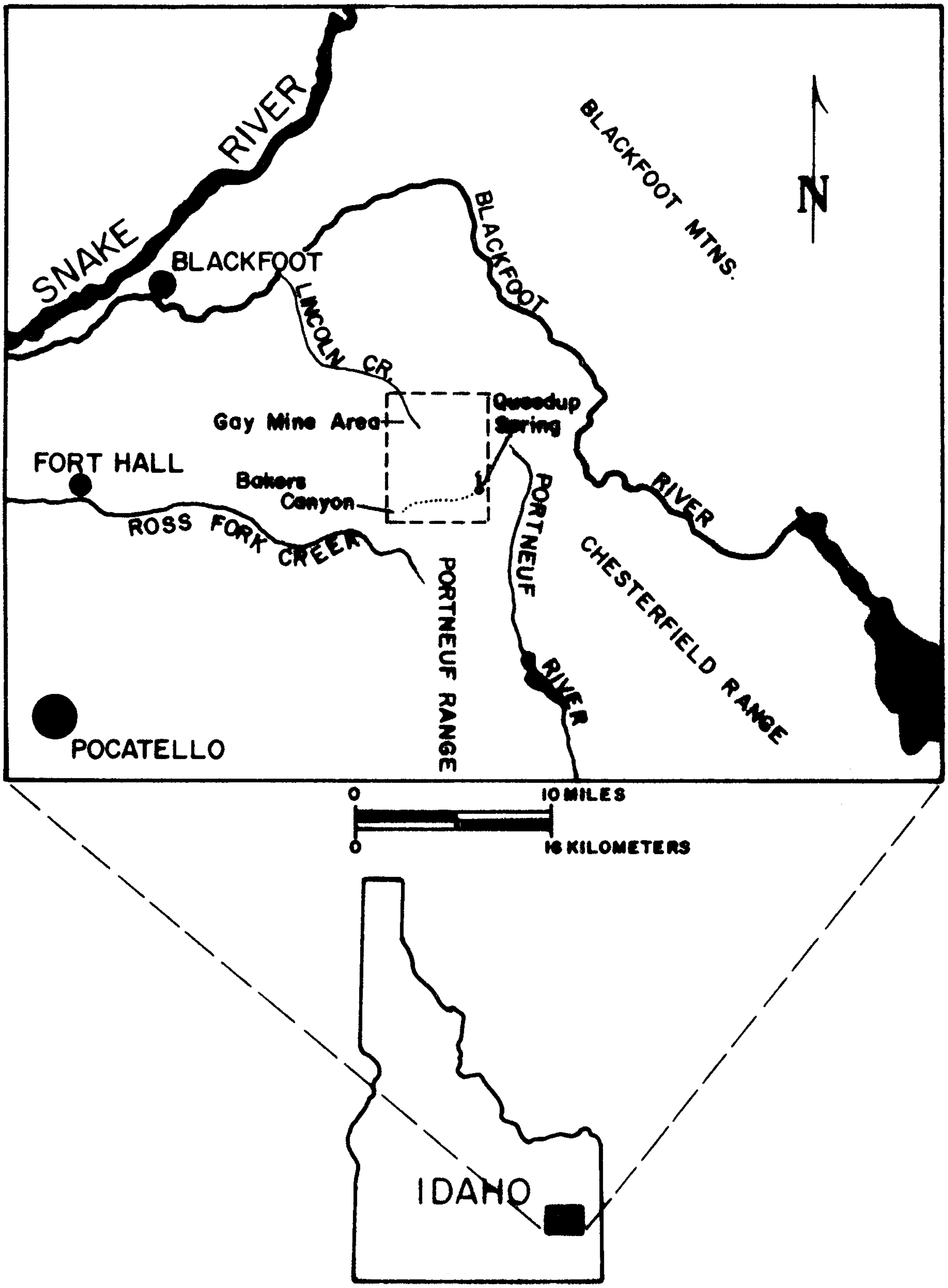


Figure I-1. Location of the Gay Mine area.

Purpose and Objectives

The purpose of this study is to:

a. Develop an understanding of the hydrogeology of the Gay Mine East Area to allow a reduction of possible detrimental interactions between mining and water resource systems.

b. Generate data for a regional hydrologic study of the "phosphate sequence".

The general objective of this study was to develop a conceptual model of groundwater flow systems for delineating water resource impacts on and impacts from mining in the Gay Mine East Area.

The specific objectives of the study are:

1) Describe in general the groundwater flow systems present in the vicinity of the Gay Mine.
2) Describe in detail the groundwater flow systems in a proposed mine area (Group 1 - pits 4, 5, and 6). Group 1 is a portion of the Gay Mine East Area.
3) Describe present and potential interactions between mining and groundwater flow systems.
4) Describe techniques to minimize detrimental interactions between mining and groundwater flow systems for the Gay Mine in general, and specifically for the Group 1 area.

Method of Study

1) Review existing information on geology. Information is given in the form of:
    a. Maps
    b. Driller's logs.
2) Obtain additional information on geology where needed.
3) Outline the hydrogeologic framework of the mine area.
4) Monitor the discharge from selected springs.
5) Monitor water levels in existing and new drill holes.
6) Identify the groundwater flow systems present in the mine area.
7) Evaluate the mine plan for Group 1 with respect to the groundwater flow systems.
8) State conclusions and recommendations in a report of findings.

Previous Investigations

Several excellent investigations concerning the geology of the study area have been utilized in this study. Mansfield's classic report (1920) constitutes the most comprehensive investigation of the general Gay Mine area. Lehman (1966) refined Mansfield's work for the immediate mine area. Since that time, Gay Mine personnel have improved the geologic mapping 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 groundwater flow systems in the mine area and the dewatering of perched zones. In a report to mine personnel, Geraghty and Miller Inc. (1971) discussed flow systems within the Wells formation.

In a joint effort, the U. S. Department of the Interior and the U. S. Department of Agriculture (1977) prepared an environmental impact statement concerning phosphate mining in southeastern Idaho.

Ralston and others (1977) summarized several years of hydrologic study done in the southeastern Idaho phosphate field by the University of Idaho.

Winter (1979) investigated the hydrologic characteristics of the "phosphate sequence" in Caribou County. A hydrogeologic investigation is being carried out by Brooks (1979) at the Henry Mine. Cannon (1979) developed a conceptual model that can be used to evaluate interactions between water resources and open pit mining. The work of Winter, Brooks, Cannon and this study have been summarized by Ralston and others (1979).

General Description of the Study Area

Physical Geography

The study area lies within the Basin and Range physiographic province and is characterized by nearly parallel mountain ranges formed by block faulting. More specifically, it lies in the northern most part of the Portneuf Range.

The northwest trending ridges in the study area are cut by Baker's Canyon. The elevation at the bottom of Baker's Canyon is approximately 5740 feet (1750 meters) above mean sea level as compared to elevations of approximately 6200 feet (1890 m) on the ridge tops. To the east, the study area is bounded by the Portneuf River Valley.

Warm to hot days and cool nights characterize summer months in the study area. Winter weather is severe; most of the annual precipitation received at the study area is in the form of snow fall. A storage precipitation gage is maintained by the U. S. Weather Bureau six miles (11.5 kilometers) to the southeast on Putnam Mountain. The elevation of this gage is 6300 feet (1920 m), or about 100 feet (30 m) higher than the ridge tops in the study area. The average annual precipitation at this station is 15 inches (381 mm), with most of the precipitation occuring in January, February and March. This value should be representative of ridge tops in the study area. Precipitation during summer months is usually in the form of localized thundershowers. Potential evapotranspiration exceeds rainfall during summer months (U. S. Department of the Interior, U. S. Department of Agriculture, 1977).

All streams draining the study area are tributary to the Snake River. The Portneuf River, Ross Fork Creek, and Lincoln Creek are of most importance (Fig. I-1). Perennial and ephemeral springs exist in the study area. The largest perennial spring is Queedup Spring. Numerous smaller springs exist in the study area; discharge from many of these is diverted to cattle troughs.

Geologic Setting

The geology of the Gay Mine area has been described by Lehman (1966); much of the following is based on his report.

Since the late Cambrian, a layer of sediments 6200 feet (1890 m) thick has been deposited in this area. The Phosphoria formation, which contains the phosphate ore (phosphorite) is part of this layer and was deposited under reducing conditions in a large, restricted, shallow sea.

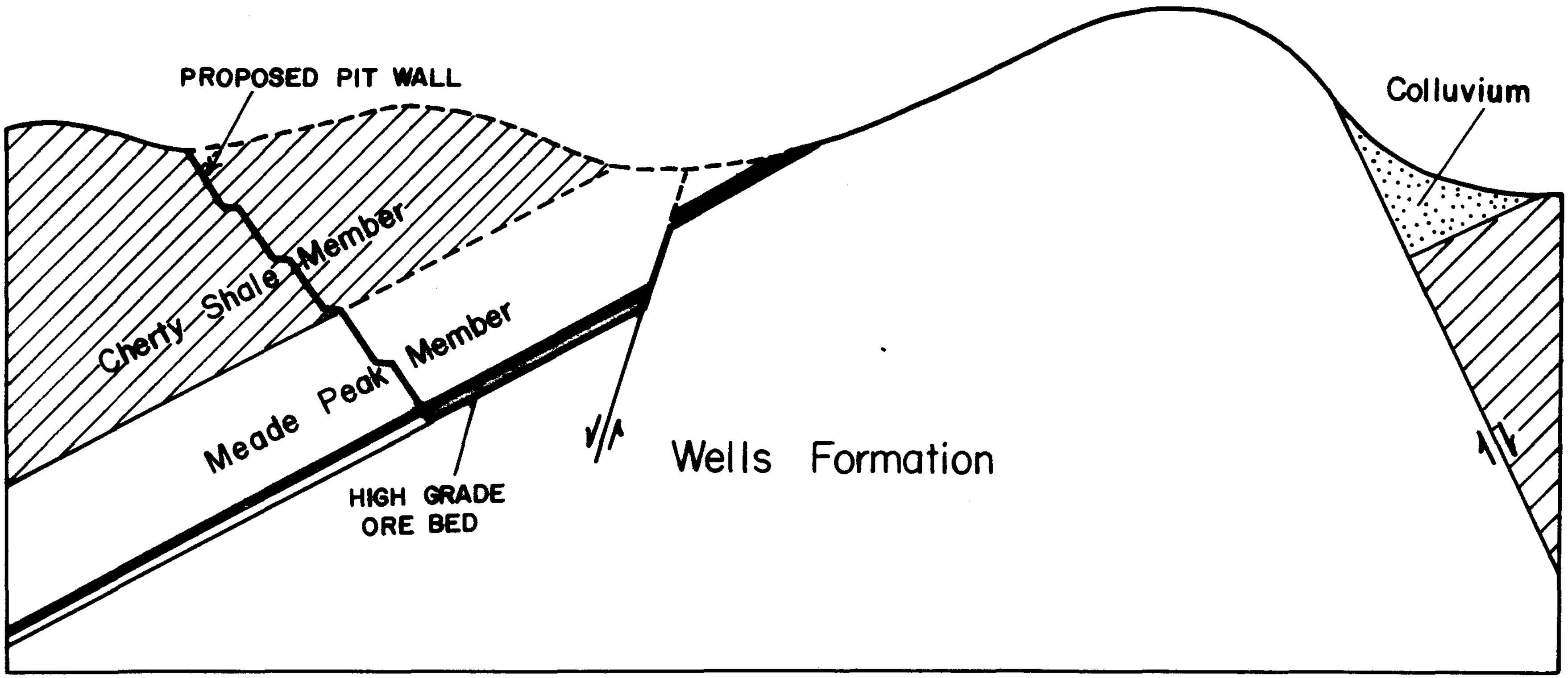
Compressional forces associated with the Laramide orogeny folded the region into a series of anticlines and synclines. Reverse and tear faults also were associated with this period. Later, as the compressional forces were released, widespread normal faulting occurred and was largely responsible for the area's present topography.

Only rock units of Pennsylvanian age and younger are thought to be of importance to this study. These units are described briefly in table I-1.

The outcrop pattern of the Phosphoria formation is largely controlled by normal faulting. Figure I-2 is a hypothetical cross section (drawn perpendicular to the strike of the beds) of a typical Gay Mine pit. The ridge forming capability of the Wells formation and faulting influence the topography. The Meade Peak member commonly forms a swale between the more resistant Wells formation and the Cherty Shale member of the

Table I-1. Description of the rock units.

Formation	Unit	Average Thickness in the Study Area		Description
		feet	meters	
		variable		alluvium and colluvium
Thaynes	Sandstone and Limestone Member	800	240	thin-bedded limestone with chert nodules, interbeds of tan siltstone and brown sandstone.
	Tan and Silty Limestone Member	850	260	slabby, thin-bedded gray and tan silty limestone.
	Black Limestone Member	300	90	non-resistant black limestone.
	Lower Limestone Member	250	75	massive gray to tan limestone with interbedded olive-brown calcareous shales in the upper part.
Dinwoody		1100	335	olive-drab shales with interbedded brown siltstone and fossilferous maroon and gray limestone in the lower portion
Phosphoria	Cherty Shale Member	350	105	thin-bedded black cherty mudstone, should not be confused with its time-rock correlary, the Rex Chert member
	Meade Peak Member	150	45	phosphorite, phosphatic mudstone, siltstones, and carbonate rocks
Wells	Upper Unit	40 to 50	12 to 15	This unit is actually the Grandeur member of the Park City formation, but is mapped as part of the Wells formation. It is a thick-bedded gray, siliceous limestone. Drilling has shown this unit to contain layers of poorly cemented calcareous sandstones
	Middle Sandstone	1700 to 1800	520 to 550	brownish to tan cross-bedded sandstone, predominent ridge forming unit in the study area
	Lower Unit	2100+	640+	thick bedded limestone, containing cherty limestones, bioclastic sandy limestones and sandstones, is not exposed in the study area



HORIZONTAL AND VERTICAL SCALE 1 INCH = 200 FEET (61 METERS)

Figure I-2. Cross section of a typical Gay Mine pit.

Phosphoria formation. One wall of a mine pit typically is an exposed dip slope of the Wells formation, while the other is a "high wall" benched into the Phosphoria formation.

CHAPTER II

DATA COLLECTION

Introduction

Data for this study were collected between May 1978 and April 1979 by University of Idaho and Gay Mine personnel. The most active period of data collection was the summer season of 1978. Geologic, hydrologic, and to a limited extent, water chemistry data were collected. Data collection was designed to give information on both the natural geohydrologic system and on the effects of pumpage from mine pits on the natural system.

Geologic Data

Geologic data consist largely of information compiled from previous mapping, and of drill and gamma logs of Simplot exploration holes. The geologic interpretation of the Group 1 area in particular is based on hundreds of logs of exploration holes. Gay Mine personnel constantly increase and modify the knowledge about the geology of the Gay Mine area; this study tapped this supply of information.

An additional six drill holes were completed specifically for this study. The purpose of these holes was to obtain both geologic and hydrologic data. These holes were located to provide information about the Wells formation. Figure II-1

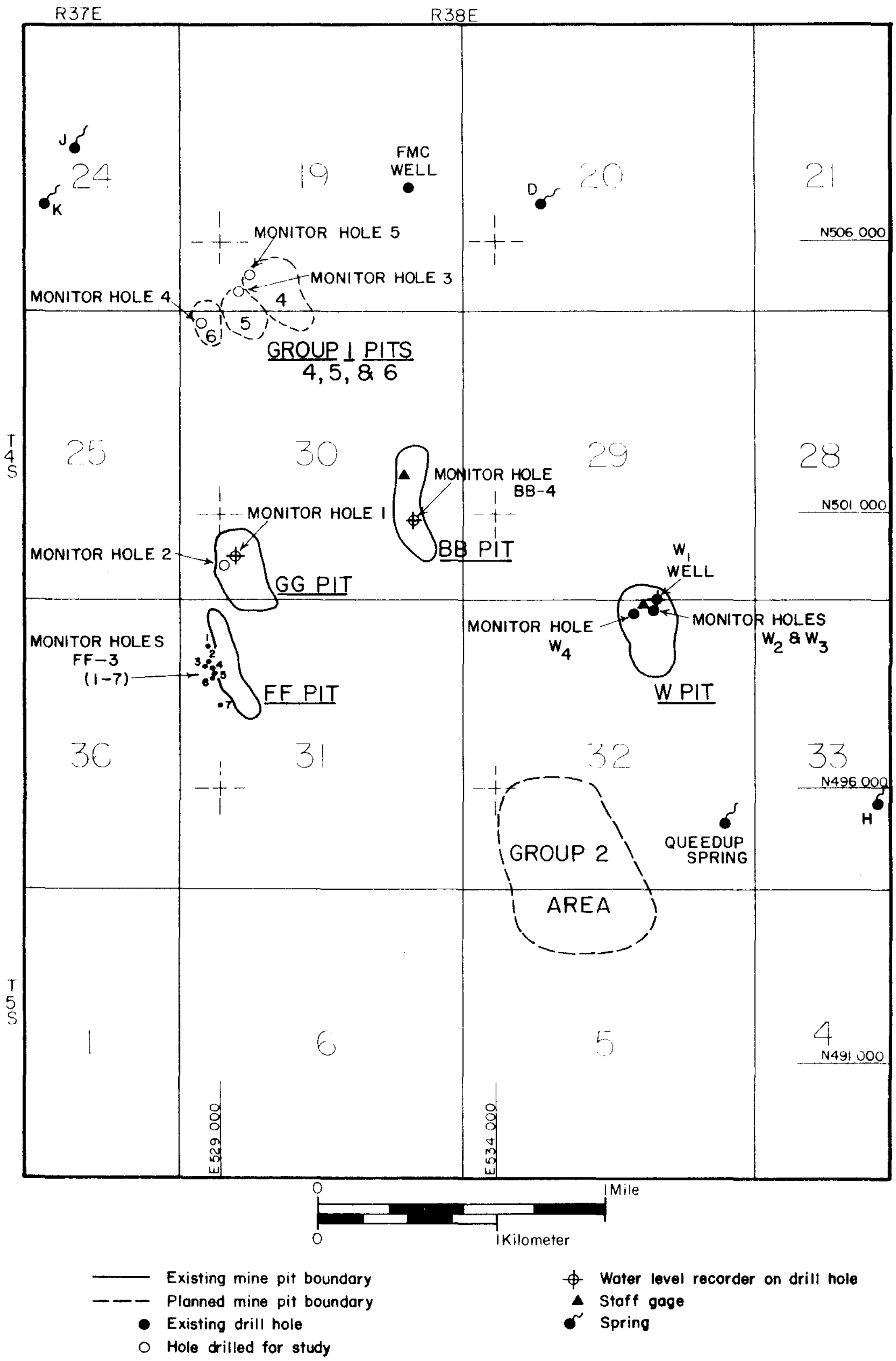


Figure II-1. Location of the mine pits, monitor holes, water level recorders, staff gages, Gay Mine East Area.

gives the location of these holes and table II-1 presents information about them.

Geologic relationships were field checked where the study required detail not included in previous mapping.

Hydrologic Data

Surface Water - Springs

Five springs were located (Fig. II-1) and their discharges and temperatures periodically measured. The geologic formation from which each spring emanated was noted from geologic maps and field checked. Table II-2 gives elevation and corresponding geologic formations.

Table II-2. Spring information Gay Mine area.

Spring	Elevation (meters)	(feet)	Formation From Which It Emanates
D	1768	5800	Dinwoody Formation?
J	1841	6040	Thaynes Formation
K	1853	6080	Thaynes Formation
H	1722	5645	Wells Formation (through alluvium)
Queedup	1743	5720	Wells Formation

Spring discharges were measured by one of three techniques: 1) portable fiberglass flumes, 2) pigmy current meter, and 3) timing the filling of a bottle with a stop watch. A sixty degree V-notch flume was used for flows less than 20 gallons per minute (GPM) (1.25 l/sec), while a forty-five degree trapezoidal flume with a two-inch throat was used to

Table II-1. Holes drilled for geohydrologic study, Gay Mine.

Monitor Hole	Location (mine grid)	Elevation Casing* (feet)	Depth (feet)	Casing	Perforations (feet)	Rock Units Encountered
BB-4	BB-4 Pit N 500 764 E 532 527	5737.40	175 (now 30)	6" steel to 64'	6 - 64	Wells Formation
1	GG-2 Pit N 500 107 E 529 270	5745.40	40	3" PVC to 37'	19½- 20½	Wells Formation
2	GG-2 Pit N 500 073 E 529 236	5745.32	129	6" steel to 58'	None	Wells Formation
3	Group 1 N 505 256 E 529 535	5973.18	280	3" PVC to 258'	255 -258	Cherty Shale Member Meade Peak Member Wells Formation (cased only to Meade Peak, caved)
4	Group 1 N 504 320 E 528 580	≈5953	175	6" steel to 20', 3/4" PVC from surface to 168' (not sealed)	165 -168	Dinwoody Formation Meade Peak Member
5	Group 1 N 504 969 E 529 368	5959.20	240	3/4" PVC to 231'	228 -231	Cherty Shale Member Meade Peak Member Wells Formation

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

measure flows up to 670 gpm (42 l/sec). Care was taken to install the flumes such that backwater effects would not introduce error into the measurements. One large spring (Queedup) was measured with a pigmy current meter. In several instances, spring discharges were collected by drain fields and piped into cattle troughs. The flow in these springs had to be measured using a bottle and stop watch.

Error in these measurements should not exceed ten percent; watch and bottle measurements should contain neglible error. The major source of error was changes in conditions at the measuring sites, such as growth of vegetation. Thick vegetation makes it difficult to measure springs at their source, and may cause significant stream loss due to evapotranspiration.

Surface Water in Mine Pits

Several mine pits intersect groundwater flow systems causing the formation of ponds in the pit floors (Fig. II-1). It is felt that these ponds are in equilibrium with groundwater; monitoring water levels of these ponds gave important information about groundwater conditions. The fluctuations of the water level of the pond in an active pit (BB-4) were of particular importance. Water was being pumped from this pit during most of the study period so that mining operations could continue. Comparing the water level changes in the pond to the rate of pumpage from the pond provided information about the rate of groundwater inflow into the pit. A record was maintained of pump "on-off" periods and of pumpage rate.

The water levels of the ponds were measured using staff gages mounted on posts driven into the bottoms of the ponds.

Groundwater

Much of the data collection concerning groundwater was derived from existing drill holes. The large majority of these holes were drilled for exploration of phosphate ore and thus usually yield information about conditions near pit sites. These holes are not cased and most have caved to some extent. Existing cased holes that were drilled for hydrologic reasons (i.e., water supply, aquifer testings, pit dewatering) were of great importance to this study. Information on these holes is given in table II-3.

Six holes were drilled by the air rotary technique specifically for this study. The water levels in these holes were measured periodically during the drilling process to collect water level data at different well depths. A chalked steel tape was used for these measurements. These holes were completed either by installing steel casing or by installing P.V.C. piezometers. The piezometers were hand perforated using a hack saw and "gravel packed" in the perforated zone with coarse sand. A bentonite layer was placed above the gravel pack and the hole backfilled to within 1½ feet of the surface. The surface was sealed with bentonite. When a water level recording device was to be installed on a hole, 3-inch P.V.C. pipe was used. Otherwise, 3/4-inch P.V.C. pipe was used for the piezometers. This technique for piezometer

Table II-3. Existing cased drill holes used for the geohydrologic study, Gay Mine.

Monitor Hole	Location (mine grid)	Elevation Casing* (feet)	Depth (feet)	Casing	Perforations (feet)	Rock Units Encountered
W_1	N 499 340 E 536 930	5746.89	60	18" steel to 59'	20-59	Meade Peak Member Wells Formation
W_2	N 499 276 E 536 878	5743.15	36	5" steel to 36'	0-36	Meade Peak Member Wells Formation
W_3	N 499 273 E 536 887	5741.29	65	5" steel to 60'	0-60	Meade Peak Member Wells Formation
W_4	N 499 148 E 536 544	5742.18	65	5" steel to 65'	0-65	Meade Peak Member Wells Formation
FMC Well	N 506 900 E 532 442	5840.1	210	10" steel to 75'	?	Dinwoody Formation
FF-3_1	N 498 520 E 528 815	6022.34	215	?	?	Phosphoria Formation Wells Formation
FF-3_2	N 498 210 E 528 835	6017.15	56	?	?	Phosphoria Formation
FF-3_3	N 498 175 E 528 778	6019.96	245	?	?	Phosphoria Formation Wells Formation
FF-3_4	N 498 118 E 528 861	6016.27	205	?	?	Phosphoria Formation Wells Formation
FF-3_5	N 498 025 E 528 888	6015.09	227	?	?	Phosphoria Formation Wells Formation
FF-3_6	N 497 926 E 528 910	6008.72	225	?	?	Phosphoria Formation Wells Formation
FF-3_7	N 497 435 E 529 053	6038.58	?	?	?	Phosphoria Formation

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

installation was also used in several of the existing and uncased drill holes. The locations of drill holes used in the study are shown in figure II-1; information on holes drilled for the study is given in table II-1.

Water levels were measured periodically with a chalked steel tape in holes that were cased or contained piezometers. In addition, Stevens Type F water level recorders provided continuous water level data at three holes.

Slug tests were conducted in fourteen open exploration holes in the Group 1 area that initially contained water. A water truck was used to raise the water levels in these holes. The following drop of water in these holes was monitored using a watch and electric probe.

Elevations of Measuring Points

Elevations of monitor holes and staff gages were determined by Gay Mine personnel using standard surveying techniques. The elevations are accurate to ± 0.02 feet (0.06 m).

Water Quality Data

Previous studies (Ralston and others, 1977) have indicated that poor quality water may discharge from the base of phosphate mine waste dumps. Two waste dump samples thought to be representative of Gay Mine waste rock were collected and used in pH and leaching experiments. Waste material was oven dried, ground, and sifted through a U. S. No. 80 standard testing sieve. The less than 80 mesh size fraction of the sample was leached in distilled water for 117 hours. Water samples were taken from the leaching experiment at various times and analyzed by atomic absorption spectrophotometry for calcium, magnesium, cadmium, lead, and zinc. The analysis was done by personnel of the Chemistry Department from the University of Idaho (Wai, 1979).

CHAPTER III

HYDROGEOLOGY OF THE STUDY AREA

Introduction

It has been shown that the groundwater flow system within a basin can be completely determined if three factors are known:

1) The spatial distribution of hydraulic conductivity within the basin.
2) The boundaries of the basin.
3) The water table configuration (Freeze and Witherspoon, 1968).

It is rarely economically feasible to collect the amount of data required to describe precisely a flow system. However, a general understanding of the above factors combined with field observations of natural discharges and the effects of pumpage can be used to construct a very useful "conceptual model" of flow systems. This technique is used in this report.

Part 1 of this chapter deals with the hydrogeologic framework including the distribution of hydraulic conductivity and the geologic evidence of boundary conditions. Analysis of hydrologic data used in constructing the model is covered in Part 2. Parts 1 and 2 were combined to formulate the conceptual model of groundwater flow systems within the East Area as presented in Part 3. Outcrops of the Phosphoria formation located southeast of the Gay Mine syncline (Fig. III-1) are referred to as the East Area; those to the northwest are referred to as the West Area. Most mining that will take place in the forseeable future will occur in the East Area.

Part 1: Geologic Framework

For the purposes of this study, the object of the geologic study is to examine the spatial distribution of hydraulic conductivity so that this information can be used to analyze the flow of groundwater. Hydraulic conductivity is a measure of the ability of a material to transmit water. Three factors determine the distribution of hydraulic conductivity in the immediate vicinity of the mine: 1) lithology 2) folding and 3) fracturing.

Lithology determines primary hydraulic conductivity, or the ability of the rock in an unaltered state to transmit water. This is in contrast to secondary hydraulic conductivity, which deals with the passage of water through fractures or solution cavities. Rock properties most important in controlling primary hydraulic conductivity are pore size, shape, and degree of connectedness. The bedding plane structure in sedimentary rocks also influences primary hydraulic conductivity. Hydraulic conductivity normally is greater in directions parallel to bedding planes than in directions at angle to them. This introduces a concept that will be used extensively in this report: the angle between the planes of relatively high hydraulic conductivity in sedimentary rocks and the direction in which gravity acts is an important determinant of groundwater flow patterns.

Folding and large displacement fracturing (faulting) affect the elevation and attitude of these planes of relatively high hydraulic conductivity. Fractures also offset rock units of high hydraulic conductivity, affect outcrop patterns (and thus exposure to atmospheric and surface waters) of rock units, and cause secondary hydraulic conductivity. Secondary hydraulic conductivity refers to localized zones of high hydraulic conductivity that occur where fractures allow water to pass more easily through a material with low primary hydraulic conductivity.

Primary Hydraulic Conductivity of the Rock Units

Discussion in this section is based on two sources: 1) a report by Winter (1979), and 2) field observations at the study site. Winter has shown that the rock units described in this study generally exhibit similar hydrogeologic properties over large areas. To reach this conclusion, he field checked 88 springs and 8 streams in the portion of the Western Phosphate Field that is located in Idaho.

The units that will be discussed herein are 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. The Cherty Shale member should not be confused with the Rex Chert member which does not occur in the study area. The evidence supporting the conclusions concerning the relative hydraulic conductivity of each of these units is listed below.

Thaynes formation:

1) Winter has shown that units that probably correlate to the Black Limestone and Tan Silty Limestone members present in the Gay Mine area (see table I-1) have sufficient hydraulic conductivity to support groundwater flow systems.
2) Three small springs issue from the Lower Limestone member (J, K, supply pond spring).
3) Groundwater flow to these springs flows through the Black Limestone and Tan Silty Limestone members.

Therefore at least the lowest three members of the Thaynes formation (Black Limestone, Tan Silty Limestone, and Lower Limestone) have moderate hydraulic conductivity.

Dinwoody formation:

1) Winter has shown that the Dinwoody formation supports flow systems.
2) A pump test has indicated that one well in the Dinwoody formation (FMC well) can yield 100 gpm.
3) A gaining perennial stream exists in the Dinwoody formation north of Group 1.

Therefore the Dinwoody formation has moderate hydraulic conductivity.

Cherty Shale member:

1) No springs issuing from this unit were found in the Gay Mine area.
2) There was no observed leakage into the pits from this unit.
3) There exists a major difference in water conditions across a fault that places the Cherty Shale member in contact with the Dinwoody formation; an 80-foot thickness of saturated Dinwoody formation lies against a section of "dry" Cherty Shale (see Fig. IV-2).

Therefore the Cherty Shale member of the Phosphoria formation has very low hydraulic conductivity.

Meade Peak member:

1) Winter has shown that this unit does not support flow systems.
2) No springs issuing from this unit were found in the Gay Mine area.
3) The Meade Peak member "confines" water below it in the pits.
4) No leakage into the pits from this unit was observed.
5) Several drill holes near the FF-3 pit site penetrated this unit and contained water. Pump test and water level data indicate that the flow system tapped by these holes probably occupies

a localized fracture zone.

Therefore the Meade Peak member of the Phosphoria formation generally has very low hydraulic conductivity. Localized zones of moderate hydraulic conductivity exist.

Upper Unit of the Wells formation:

1) Large quantities of water flow into the mine pits from this unit.
2) Much water was encountered when drilling in this unit.

Therefore the Upper Unit of the Wells formation has very high hydraulic conductivity.

Middle Sandstone Unit of the Wells formation:

1) Winter has shown that major flow systems occur in this unit.
2) Major springs issue from this unit and some are warm and mineralized (Queedup; H) indicating regional flow systems.

Therefore the Middle Sandstone Unit of the Wells formation has very high hydraulic conductivity.

Lower Unit of the Wells formation:

This formation is not exposed in the study area, however, Ralston and others (1977) show that this unit also has very high hydraulic conductivity.

The relative hydraulic conductivities of the rock units important to this study are summarized in table III-1.

Table III-1. Relative hydraulic conductivites of Gay Mine area rock units.

Unit	Hydraulic Conductivity
Thaynes formation	Moderate
Dinwoody formation	Moderate
Cherty Shale member	Very low
Meade Peak member	Very low
Wells formation	Very high

These hydraulic conductivity values represent each unit as a whole. On a small scale, intra-unit differences in hydraulic conductivity are probably significant. A consequence of this is that a fault must not offset the entire thickness of a permeable unit to hinder the flow of groundwater; only the more permeable zones within the unit must be offset. It is believed that the hydraulic conductivities presented in table III-1 accurately describe the units on a large scale. As previously mentioned, the hydraulic conductivity in each unit is at a maximum parallel to bedding planes.

When applying this information to later sections, the key will be the relationship of the most permeable unit (Wells formation) to the others, and especially to the Meade Peak member which is essentially a barrier to groundwater flow.

Folding and Fracturing

Two distinct periods of tectonic deformation were responsible for the geologic structures present in the study 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 III-1 and III-2.

The general fold pattern is a series of northwest-southeast striking synclines and anticlines. An important exception is the northeast striking Dry Hollow anticline in the northwest portion of figure III-1. Major faults break fold patterns.

The major folds affecting the hydrology of the study area are described below:

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

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.

Portneuf River Syncline - This is a wide, shallow, poorly defined northwest striking syncline. To the northwest (adjacent to the West Area) the syncline is highly fractured and tends to lose its identity. Much of this structure is covered

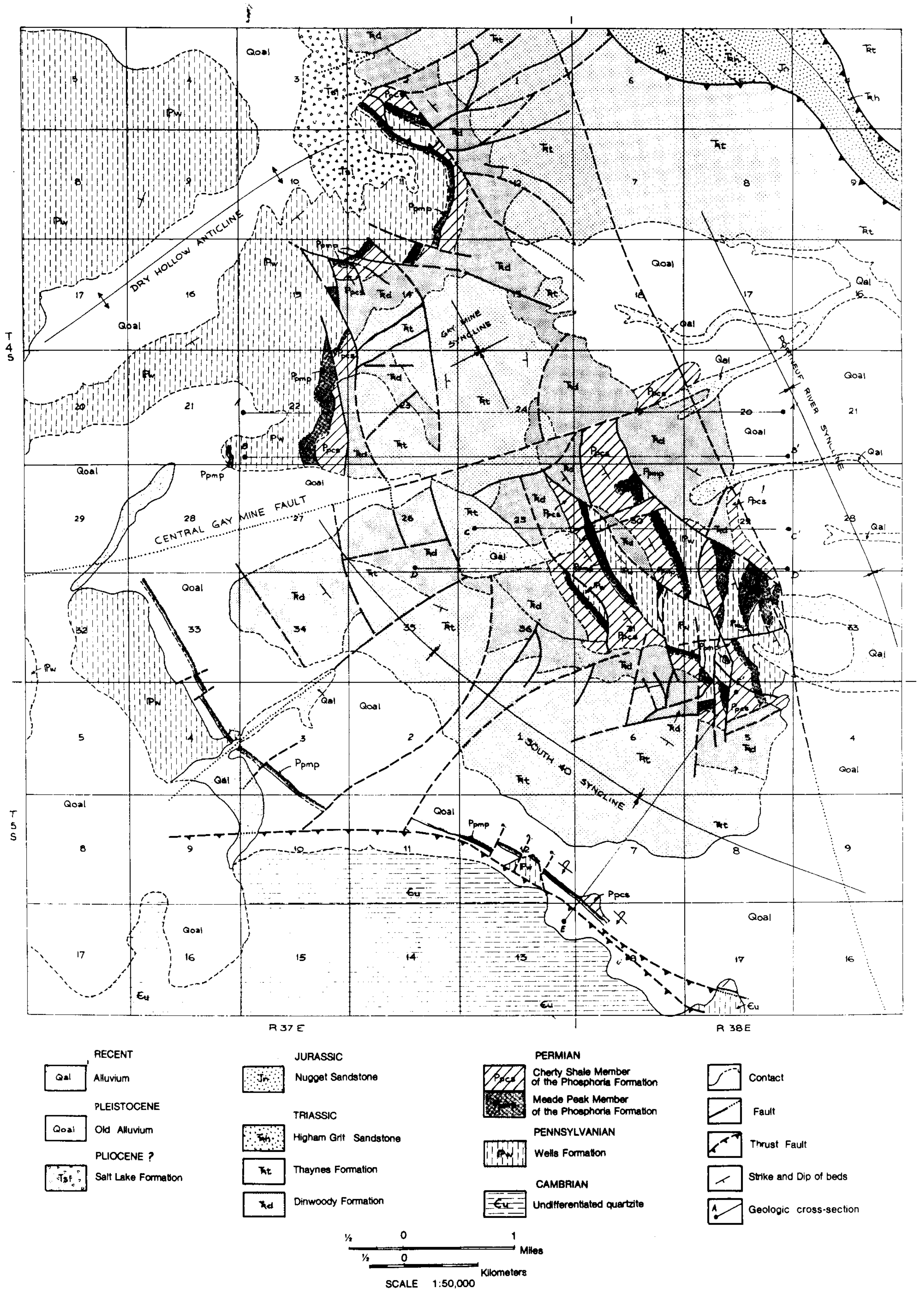
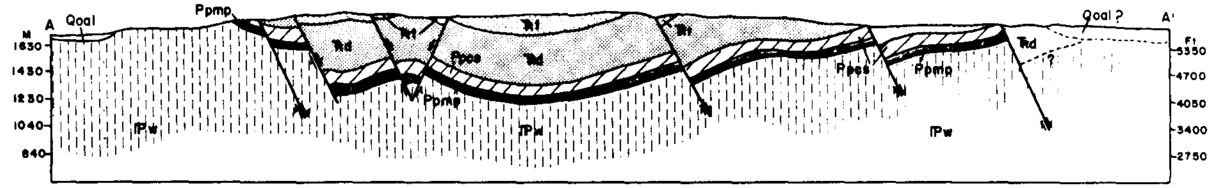


Figure III - 1 GEOLOGIC MAP OF THE GAY MINE AREA



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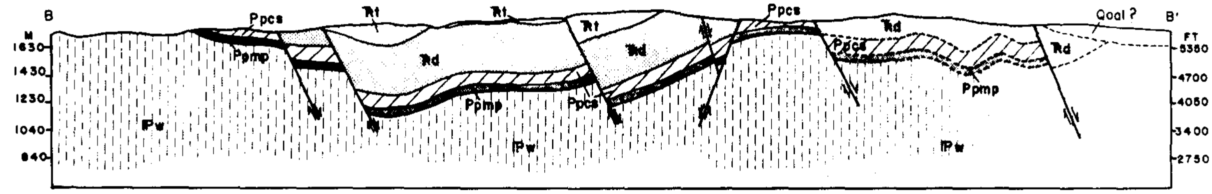

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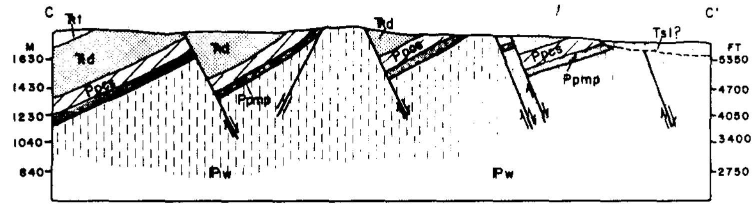

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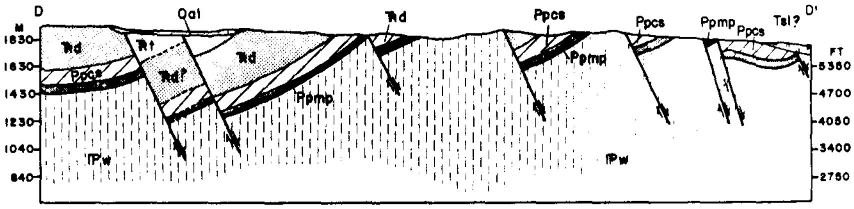

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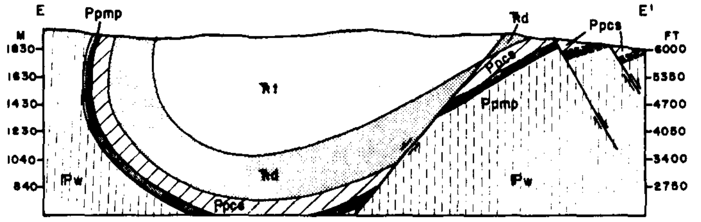

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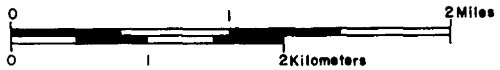
FIGURE III - 2 STRUCTURE SECTIONS OF THE GAY MINE AREA



by the Salt Lake formation and alluvium, and is poorly understood.

South 40 Syncline - This is a very deep, tightly folded, northwest trending syncline with an overturned to near vertical southwest limb.

Fracturing affects the hydraulic conductivity distribution and thus groundwater flow in four ways: 1) offsets zones of high hydraulic conductivity, 2) breaks fold trends, 3) changes the attitude of planes of high hydraulic conductivity, and 4) creates secondary hydraulic conductivity. Fracturing is also often responsible for exposing permeable units at the land surface.

There are two major types of faults in the Gay Mine area: north-west 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. Also this type of faulting is often associated with the formation of very impermeable fault gouge (Reid, personal communication, 1979).

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.

Fracturing on both the large and small scale creates secondary hydraulic conductivity. Examples of observed effects of secondary hydraulic conductivity in the Gay Mine area follow.

1) As part of this study, a borehole was drilled into the Wells formation to observe the hydrogeologic properties of this formation, and to observe the affects of faulting on groundwater flow. When a normal fault was encountered within the saturated zone, the rate of water movement into the hole increased greatly and the drilling operation was severely hindered.
2) In the pit walls, water can be seen seeping through the essentially impermeable Meade Peak member only where it is fractured.
3) It has been observed that ore is of higher grade (weathered to a greater extent) where the Meade Peak member is highly fractured (Lehman, 1966).

Summary of Hydraulic Conductivity Distribution and Hydrologic Boundaries - East Area

The overall effect on the East Area of the hydraulic conductivity considerations previously described is discussed in this section. An abrupt change from a zone of high hydraulic conductivity to one of relatively low hydraulic conductivity is condidered to be a groundwater boundary. This does not mean that groundwater cannot cross such a boundary; in fact a water table may be continuous across the boundary. The shape of the water table will be altered by the changes in hydraulic conductivity. This type of boundary condition does imply that, because of the difference in hydraulic conductivity, the amount and rate of flow through the less permeable material is insignificant relative to flow through material on a more permeable side of the boundary.

In summary, the East Area can be considered to be "a block" of highly permeable material exposed at land surface. The block is at high elevation relative to surrounding rocks which are less permeable. Hydraulic conductivity within the block is greatest in directions along lines trending northwest-southeast. The evidence supporting this summary is given in the following paragraphs.

The block is composed largely of the very permeable Wells formation (Fig. III-1, III-2). 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 parallel to the strike of and perpendicular to bedding planes are the most common faults within the block. These faults probably hinder groundwater flow down dip in this formation by offsetting the more permeable zones within the formation. The net effect is that hydraulic conductivity will be greatest parallel to both bedding planes and fault planes, or along lines trending norhtwest-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 (Figs. III-1, III-2). 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 area 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. Fault gouge along this fault may also help it to act as a boundary.

Part 2: Analysis of Hydrologic Data

The hydrologic data collected were analyzed with respect to water table configurations (and thus groundwater flow directions), hydraulic connection between measuring points, the effects of pumpage from the BB-4 pit, and seasonal recessions of water levels and of discharge rates from springs. This information will be combined with the geologic framework presented in Part 1 to formulate the conceptual model of flow systems.

The generally low hydraulic conductivity of the Phosphoria formation greatly reduces the rate of groundwater flow between the more permeable units located stratigraphically above and below it. Data concerning flow in the Wells formation are discussed separately from data concerning flow within the Thaynes and Dinwoody formations for this reason. The Phosphoria formation generally does not support flow systems in the study area; a case where the Cherty Shale member supports a flow system is presented as an exception to this generality. Data concerning the interaction between shallow and deep flow systems within the Wells formation are also discussed.

Wells Formation

Hydrologic data for flow systems within the Wells formation were taken from existing cased drill holes (monitor holes W_1, W_2, W_3, W_4), holes drilled for the study (monitor holes BB-4, 1, 2), ponded water in BB-4 and W pits and from springs issuing from this formation (Queedup and H). Locations are given in figure II-1 and information in tables II-1, II-2, and II-3.

Natural Water Table Gradient. Water elevations in four monitor holes, BB-4, W_1, 1 and 5, were used in an attempt to define the water table as it was 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. Water elevations at three points are required to define the direction of groundwater flow. Using any three of the four points indicates that the direction of groundwater flow in the Wells formation is to the north-northwest.

A report by Raymond and Williams (1973) indicated that a drill hole drilled to serve as an observation hole for a pump test in the FF-3 area (#1 obs.) penetrated the Wells formation to an elevation of 5697 feet (1737 m) and was dry. This hole, which has since been removed by mining operations, bottomed about 35 feet (10.7 m) below the elevation that water was encountered in other holes penetrating the Wells formation. A drilling report indicated that this hole caved to an elevation of 5760 feet (1766 m) shortly after the drilling was completed. Raymond (personal communication, 1979) has indicated that the hole probably was not checked for the presence of water until after the hole had caved. Information from this hole was disregarded in the hydrologic analysis.

Relationship: Mine Pit Ponds and Groundwater Flow Systems. Figure III-3 shows the relationship between W pit pond surface elevation changes and the water levels in nearby monitor holes. It shows that the W pit pond is connected to the groundwater flow systems tapped by these holes. The head in the monitor holes is greater than that of the pond indicating groundwater flow to the pond, from which evaporation removes water from the system. Monitor hole W_4 has been partially filled with sediment deposited when the pond covered this hole, and thus the water level in this hole does not represent the head at its original depth.

In order for mining to continue, water had to be pumped from BB-4 pit pond. Water was collected in a trench running the

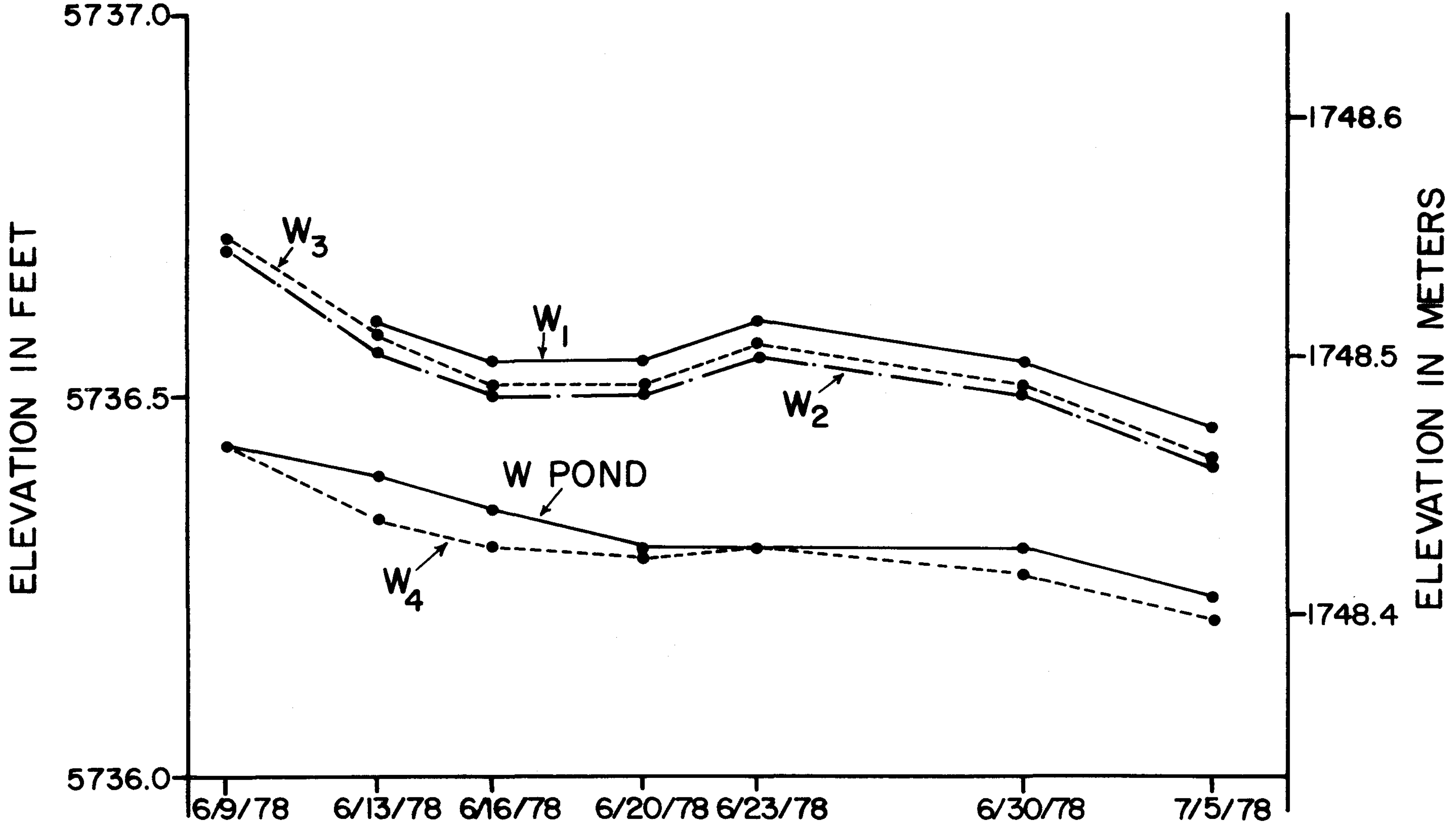


Figure III-3. Water levels in W pit pond and monitor holes, Gay Mine.

length of the pit on its west side, and channeled to sumps. The initial pump, which was put into operation on May 24, 1978, pumped from a sump in the north end at a rate of about 340-400 gpm (22-25 l/sec). At this time, this pumping rate was sufficient to drain the ditch. Later, as mining activity removed and disturbed more of the confining Meade Peak member, the rate of flow into the pit increased. On September 6, 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.

Monitor hole BB-4 is open to the Wells formation which is under artesian pressure 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 III-4 shows hydrographs of the BB-4 well and pond, and the pumping schedule for the same time period. The pumping rate was 350 to 400 gpm. 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.

Hydraulic Connectiveness of Measuring Points. Previous investigators have addressed the question of whether or not

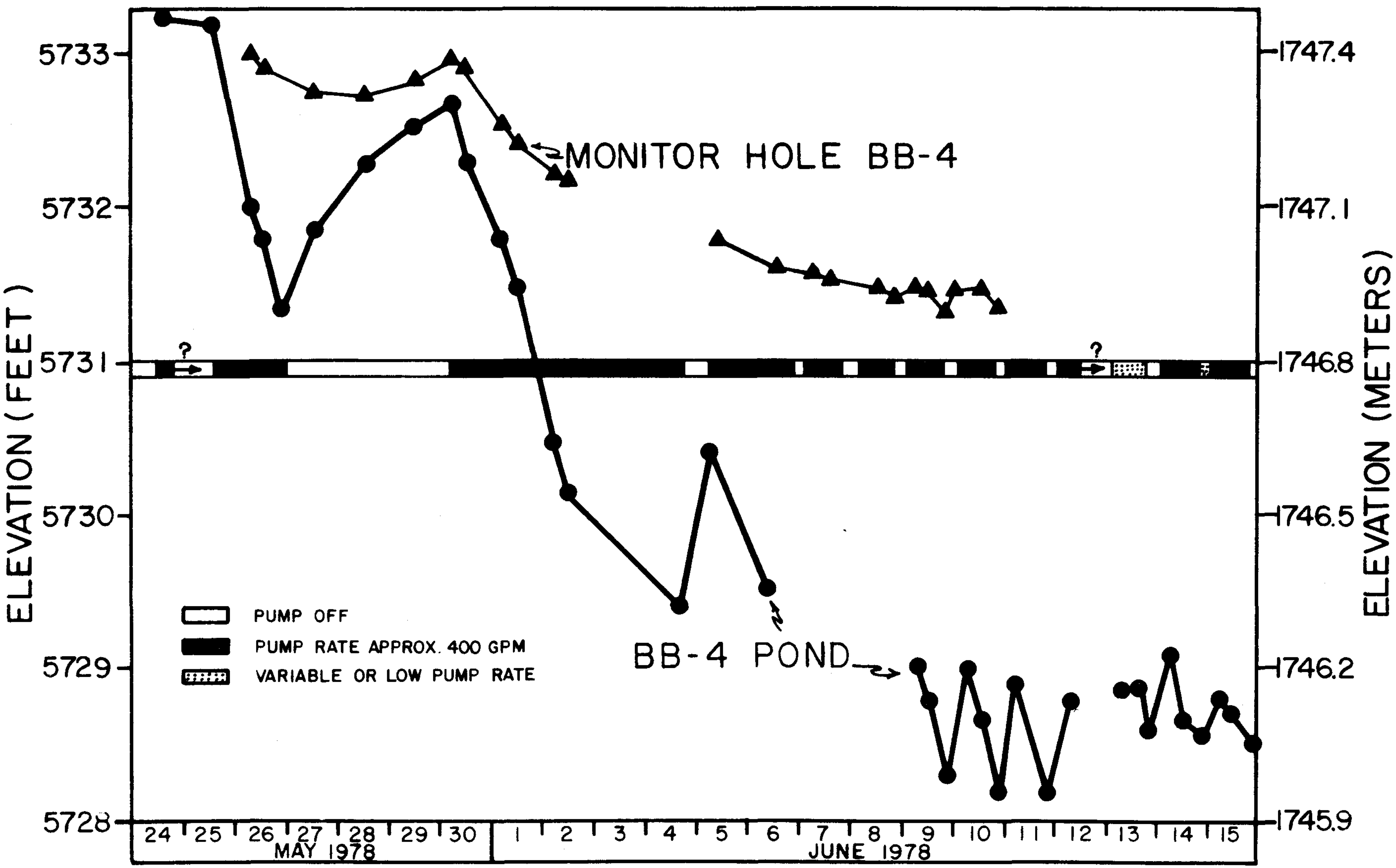


Figure III-4. Hydrographs of monitor hole BB-4 and the BB-4 pond in relationship to pumpage from the BB-4 pit, Gay Mine.

mine pits in the East Area are hydraulically connected (Raymond and Williams, 1973 and Combe, 1970). The first evidence that groundwater flow may be continuous between pits, and thus across major fault zones, was presented by Combe in his report concerning a pump test of monitor hole W_1. He reported that the water level in a 16-inch well located 5400 feet (1646 m) northwest of monitor hole W_1 (BB-II pit) was probably drawn down by the pumpage from monitor hole W_1. 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 affected.

In order to correlate pumpage to changes in water levels it is necessary to monitor pump rates and on-off periods. This information proved to be difficult to collect accurately over long periods of time. It was decided that the water level fluctuations in monitor hole BB-4 would be used as a record of pump operation.

Continuous water level data were collected at three well sites (monitor holes 1, BB-4, W_1) by Stevens Type F water level recorders. Additional point measurements were taken with a steel tape at these points and at monitor hole 5. The data were plotted by a Calcomp 936 plotting system to facilitate analysis (Fig. III-5). The continuous records were entered into the computer via a digitizer. Details of the digitizing program are given in Appendix 6. The plotting program was designed so that the vertical and horizontal scales

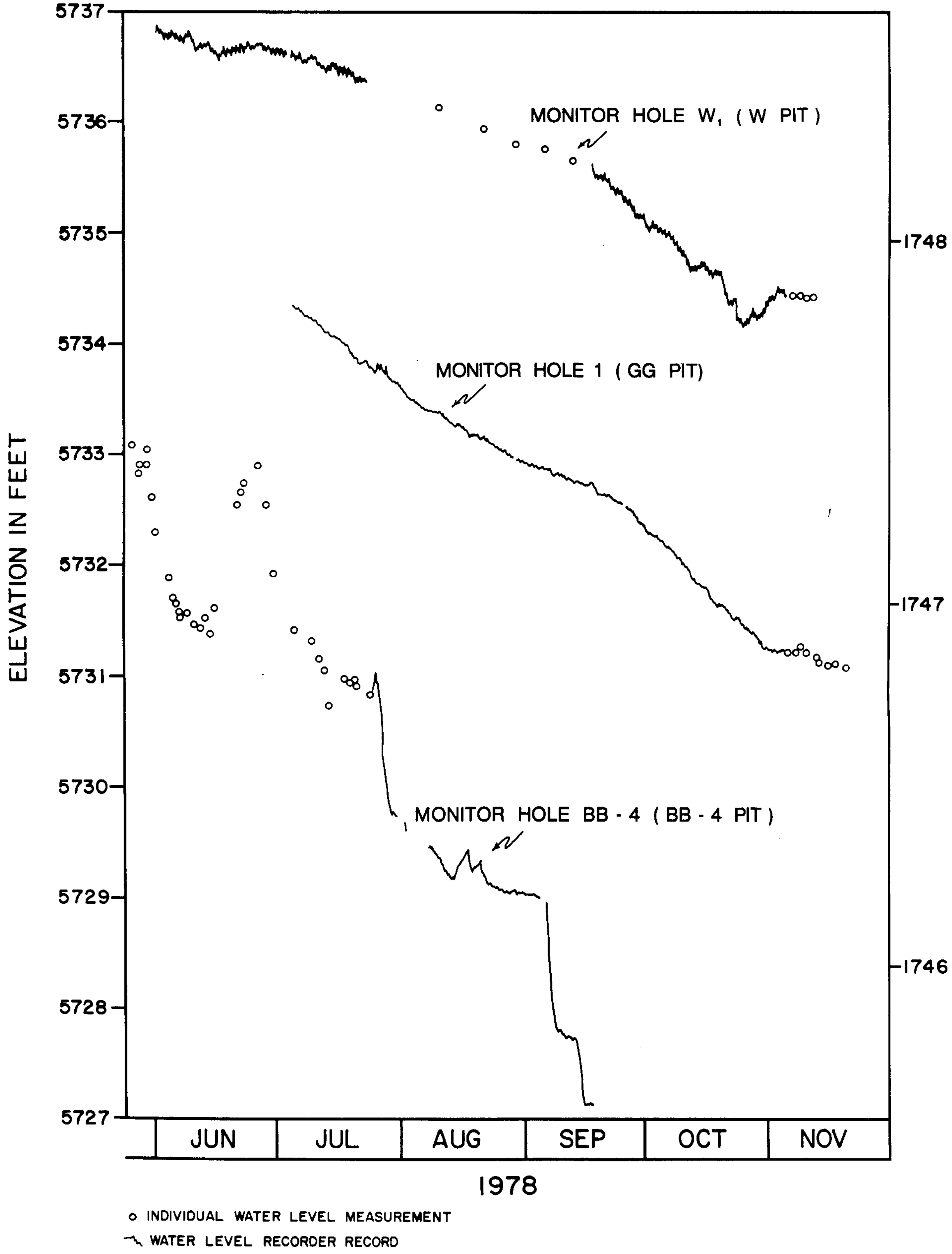


FIGURE III - 5. HYDROGRAPHS OF MONITOR HOLES BB - 4, 1, AND W_1, GAY MINE could be changed independently; this helped find the scale that would best show trends and correlations.

Examination of figure III-5 reveals that water levels in W and GG pit wells shows a very similar trend and both correlate well with monitor hole BB-4. 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. Early parts of the W_1 plot correspond well to the early BB-4 record when the pumpage was irregular.

Water levels in monitor hole 5 were periodically measured in the time period August 14, 1978 to September 19, 1978. During this period, the water level dropped from an elevation of 5732.2 feet to and elevation of 5731.8 feet, or about 0.1 feet (0.03 m) per week. This drop is comparable to that occurring at the other sites monitored during this period.

It is concluded that the points monitored are hydraulically connected and that pumpage from the BB-4 pit has 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 groundwater flow. Thus the fault blocks containing each of these mine pits do not have their own isolated flow system. Instead there is a regional water table inside the geologic boundaries described in Part 1 of this section.

Recovery of BB-4 Water Level. The water level in the BB-4 pond fully recovered to its original level within a week after the pumping stopped on February 7, 1979. The fact that the water level recovered to its original level in the absence of recharge (precipitation) indicates that a great amount of water is stored within the Wells formation. A large transmissivity value (measure of the ability of the unit to transmit water) is indicated by the rapid recovery.

Natural Groundwater Trends. Figure III-5 shows that the general decrease in water levels is at least partially, and probably largely due to pumpage from the BB-4 pit. In addition, groundwater flow theory requires there be a recession of the water level, at any point in a flow system, in the absence of recharge. Thus there must be a seasonal recession of water levels during the summer months. Unfortunately, data that would define this natural recession in the absence of artificial discharge are not available. This knowledge would be very useful in any attempt to evaluate the hydrologic properties (ability to transmit and store water) of the Wells formation. Natural recession data would also help evaluate quantitatively the natural seasonal recharge to the flow system.

Deep Flow System. Discharge from two springs (Queedup and H) that issue from the Wells formation was monitored (Table III-2). The flow of these springs remained constant during the summer season. Also, water from these springs is

Table III-2. Measured discharges of Queedup and H springs, Gay Mine area.

Date	Spring	Discharge (gpm)	Discharge (l/sec)	Measurement Technique
6/ 9/78	Queedup	670	42	45 degree trapezoidal flume
9/29/78	Queedup	600	38	Current meter
11/ 9/78	Queedup	600	38	Current meter
6/20/78	H	150	9	45 degree trapezoidal flume
9/17/78	H	110	7	45 degree trapezoidal flume
11/ 9/78	H	110	7	45 degree trapezoidal flume

Table III-3. Temperatures of groundwater at selected points, Gay Mine area.

Date	Location	Temperature (°F)	Temperature (°C)
11/19/70	Queedup Spring	65	18.5
7/10/78	Queedup Spring	64	18
7/20/78	Spring J	44	7
7/20/78	Spring K	46	8
7/26/78	Monitor Hole 1	50	10
7/ 1/78	Seepage into BB-4 Pit	48	9

warmer (Table III-3) 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.

The water temperature of monitor hole W_1 was measured to be 65° F (18.3° C) in August 1979. Combe (1970) reported that the temperature of the water in this hole increased to 82° F (27.8° C) when it was pumped. This indicates that this hole, like Queedup and H springs, is connected to a deep groundwater flow system.

Examination of the charts from the water level recorder on monitor hole W_1 reveal the affects of earth tides. Figure III-6 is a reproduction of one of these charts. The term earth tide refers to strain in the earth's crust due to the gravitational attractions of the moon and sun. Water levels in wells tapping confined aquifers show fluctuations twice daily in response to strain patterns caused primarily by the revolution of the moon (Todd, 1959, p. 168). The earth's crust strains toward the moon or sun releasing the load on the aquifer. This results in the lowering of the hydrostatic pressure in the aquifer and water level drop accordingly. The greatest daily water level drop occurs when the moon reaches upper culmination at the longitude of the well. A water level drop of lesser magnitude occurs at lower culmination. Because the gravitational attractions of the moon and sun act in the

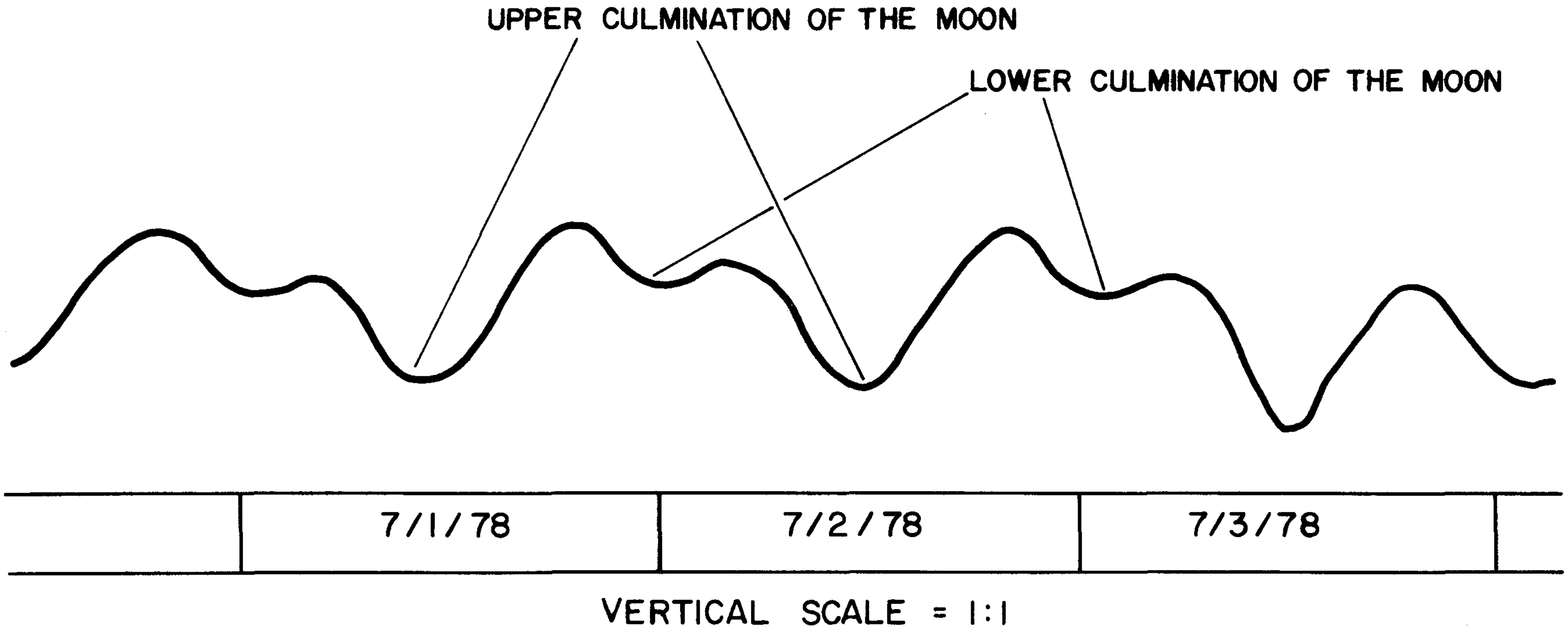


Figure III-6. Water level record showing the effects of earth tides, monitor hole W_1, Gay Mine.

same direction during new and full moons the water level fluctuations are of greater magnitude at these times; new and full moon events can be seen on the W_1 charts.

In order for an aquifer to show such a clear response to earth tides, it must be near perfectly confined. This degree of confinement is normally associated with very deep flow systems overlain by hundreds or thousands of feet of material. The clear response of water level in monitor hole W_1 provides further evidence that this well, although only 60 feet (18.3 m) deep, is in some way connected to a much deeper flow system. Monitor holes completed in the Wells formation in other parts of the study area show no response to earth tides.

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 (FMC well). Locations are given in figure III-1 and information in table II-2 and II-3.

Water levels in the FMC well were monitored from July 19, 1978 to November 6, 1978. The drop in water level of almost seven feet (2 m) over this period is the result of natural recession in the absence of recharge. This magnitude of drop indicates that the flow system tapped by this well is not very extensive.

Figures III-7, III-8 and III-9 are semi-log plots of discharge rates of the springs monitored. Springs J and K issue from the Lower Limestone member of the Thaynes formation.

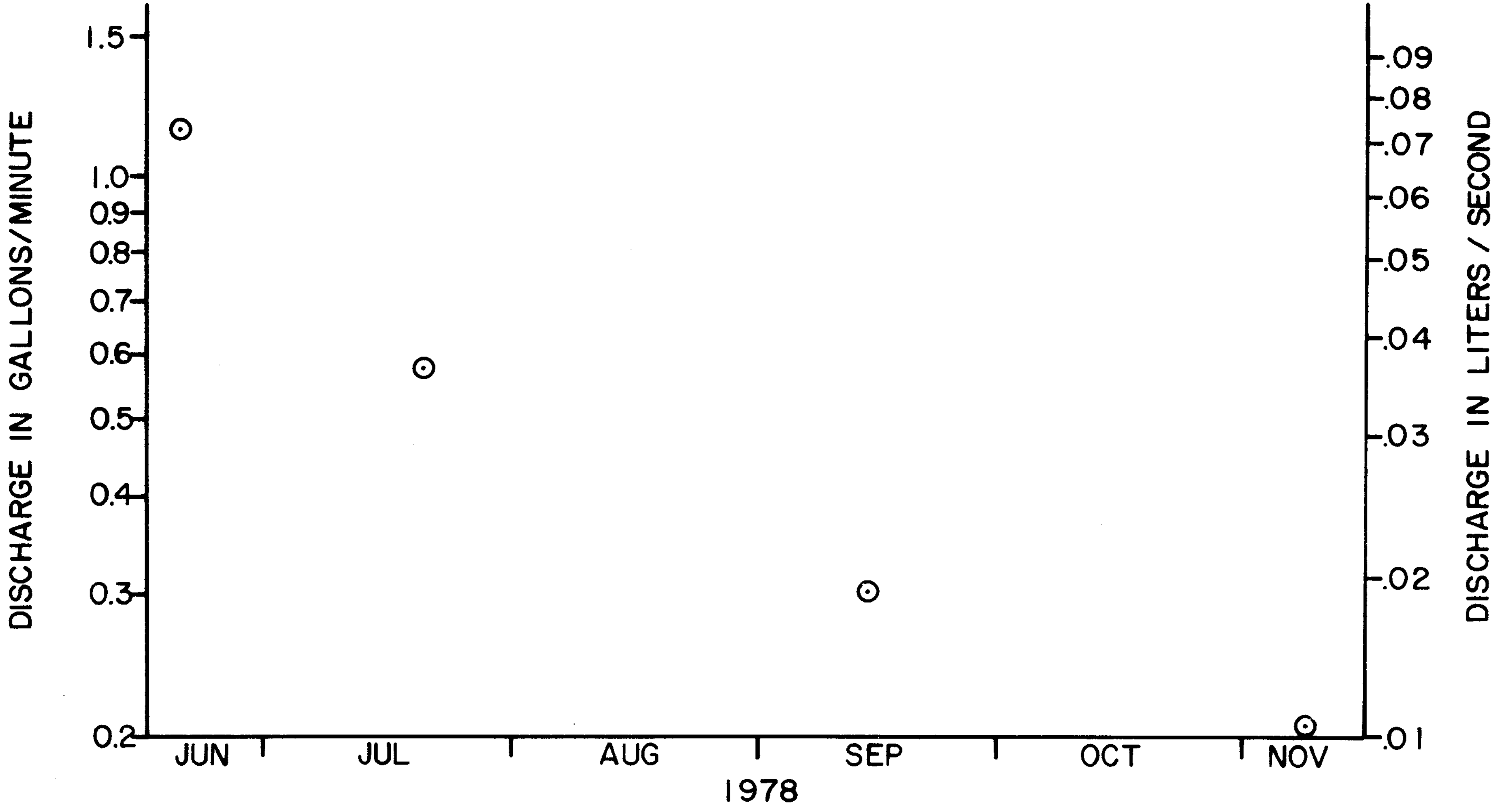


Figure III-7. Semi-log plot of discharge from Spring D, June 1978 to November 1978, Gay Mine.

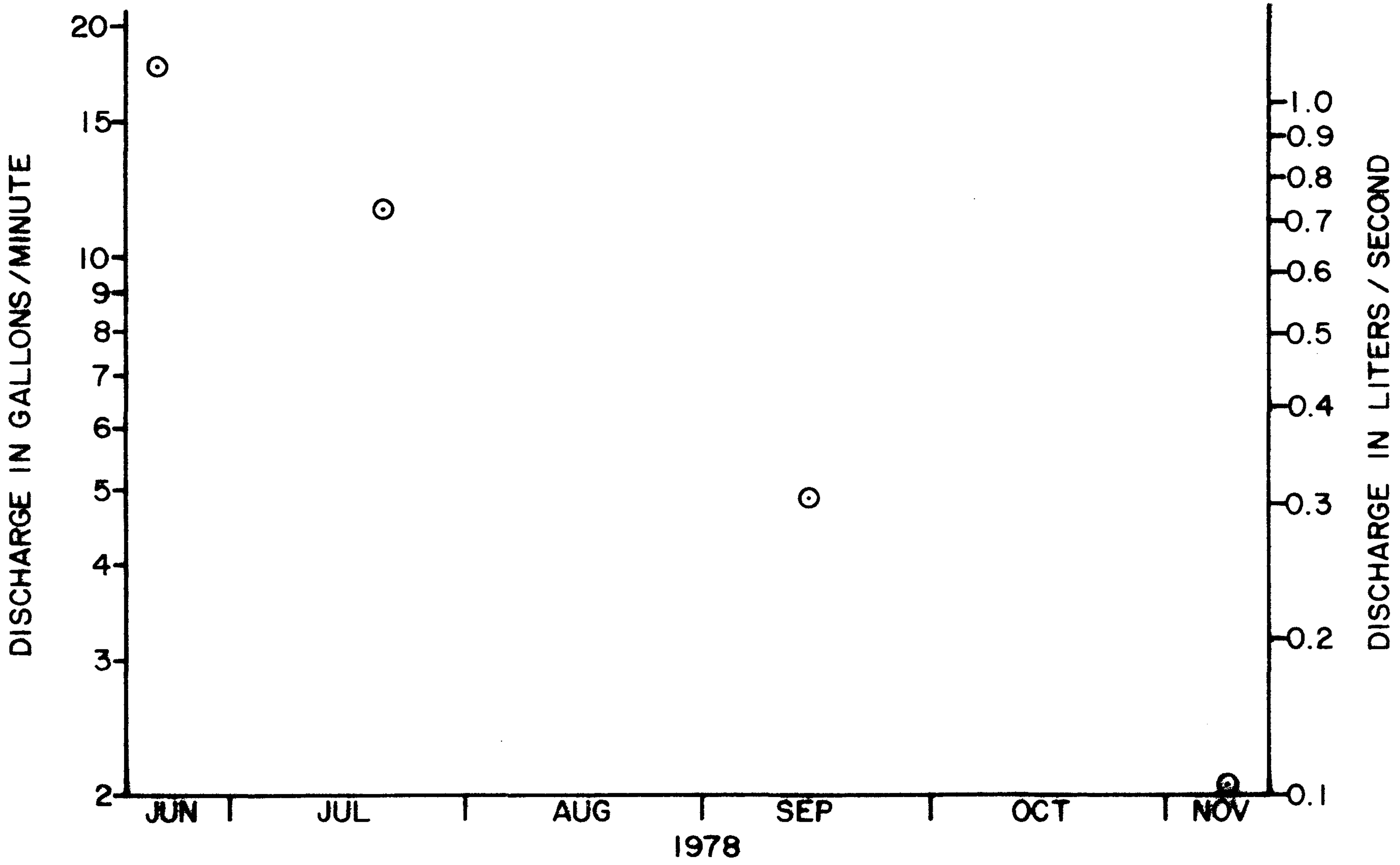


Figure III-8. Semi-log plot of discharge from Spring J, June 1978 to November 1978, Gay Mine.

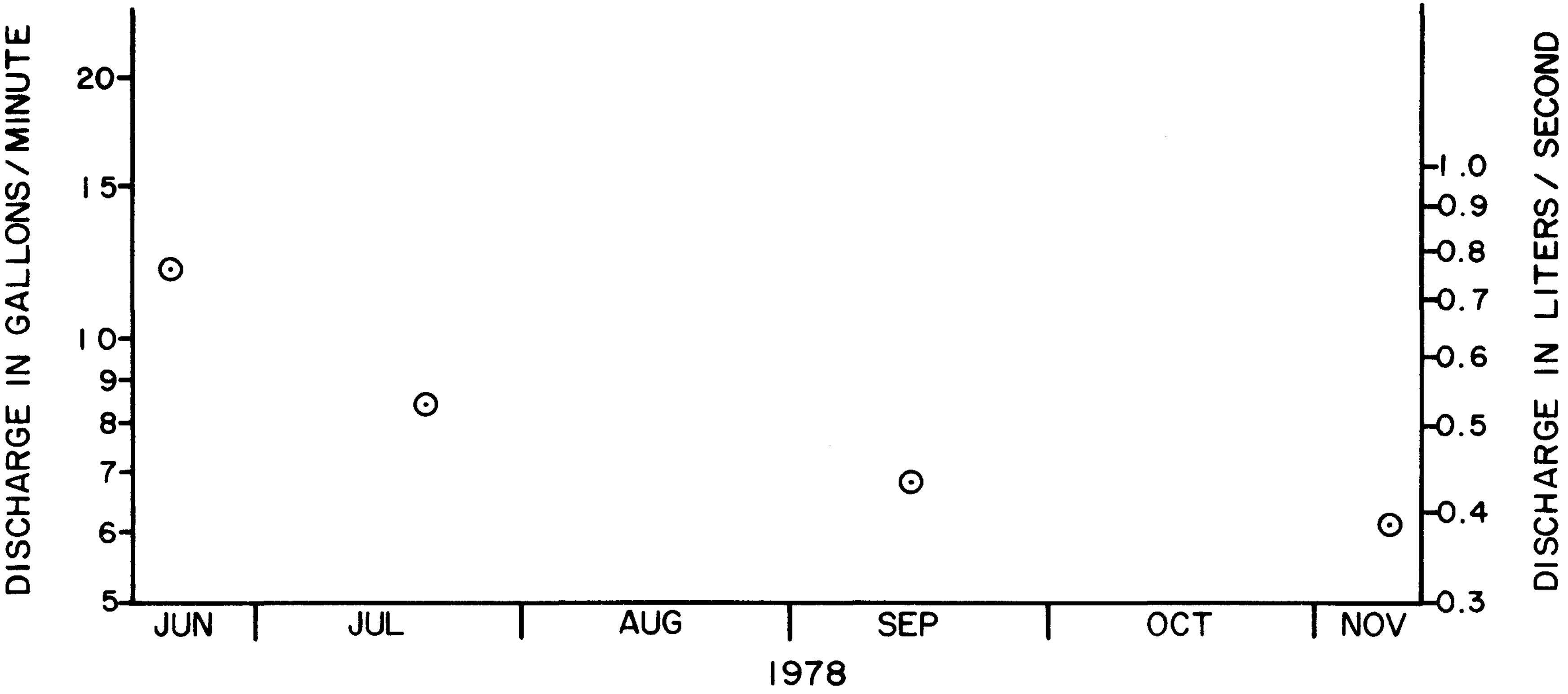


Figure III-9. Semi-log plot of discharge from Spring K, June 1978 to November 1978, Gay Mine.

Spring D probably issues from the Dinwoody formation where it comes in contact with the less permeable Cherty Shale member of the Phosphoria formation. The steep recession trends and the relatively low flow rate of these springs indicate that their flow systems are not very extensive. The elevations of these springs and of water levels in the FMC well are all higher than any water levels measured in the Wells formation.

Phosphoria Formation

The Phosphoria formation in the study area is, in general, not permeable enough to support groundwater flow systems. An exception to this generality occurs near the site of the now back-filled and reclaimed FF-3 pit.

Water levels in seven holes (Monitor Holes FF-3_{1-7}) that penetrate the Phosphoria formation were measured on May 29, 1978 and on July 14, 1978. These holes lie along a north-south line located about 80 feet (24 m) west of where the FF-3 pit highwall previously was located (Fig. II-1). Information concerning these holes is given in table II-3. Table III-4 gives water elevations measured. Water cascading down five of these holes made accurate measurement of water levels difficult.

Table III-4. Water level elevations in FF-3 monitor holes, Gay Mine.

Hole	5/29/78 Elevation of Water Level (feet)	5/29/78 Top of Cascading Water (feet)	7/14/78 Elevation of Water Level (feet)	7/14/78 Top of Cascading Water (feet)
$FF\text{-}3_1$	5873	5911?	5877	5920
$FF\text{-}3_2$	Dry	Dry	Dry	Dry
$FF\text{-}3_3$	5904	None	5909	None
$FF\text{-}3_4$	5885	5892	5891	5894
$FF\text{-}3_5$	5808	5884?	5834	None
$FF\text{-}3_6$	5842	Small Amount	5842	5881
$FF\text{-}3_7$	Not Measured	Not Measured	5914	5913?

Two of these holes ($FF\text{-}3_3$ and $FF\text{-}3_6$) were used as observation wells for pump tests in December and February of 1972 (Raymond and Williams, 1973). They report that water from hole $FF\text{-}3_6$ was draining into the Wells formation at an elevation of 5784 feet (1763 m) and that no water stood in the hole. In comparison, on July 14, 1978, the static water level in this hole was at 5842 feet (1780 m). Raymond and Williams concluded that the pump tests measured the hydraulic properties of the Meade Peak member only and that the hydraulic conductivity of this unit was on the order of 10 gal/day-ft^2. They also reported that water levels in several of the holes did not recover to pretest elevations.

The data show that this is not a continuous flow system with a simple water table or piezometric surface. Evidence supporting this conclusion is listed below:

1) Static water levels and elevations of the origin of cascading water show no consistency or trend.
2) Water levels in all five of the holes that were measured on both occassions went up, but the changes ranged from .2 feet to 26 feet (0.6 m to 8 m). This indicates that hydraulic connection between the holes is poor.
3) Hole FF-3_6 originally did not hold water but now has a static water level well above its bottom.

It is possible that some of these inconsistencies could be explained if more information about casing lengths and perforations were available. It is likely that these holes intersect a localized fracture zone containing water. The hydraulic connection between the holes is poor. Water levels in holes with cascading water are a function of rate of inflow versus rate of outflow at the hole bottom. Thus these water levels may be controlled by factors such as the caving of the hole or the plugging of a more permeable zone intersected by the hole. This is probably the case with hole FF-3_6.

Part 3: Groundwater Flow Systems

The information contained in the past two sections will now be combined to form the conceptual model of groundwater flow systems in the East Area. The basic principles of the model will be introduced using a schematic diagram (figure III-10).

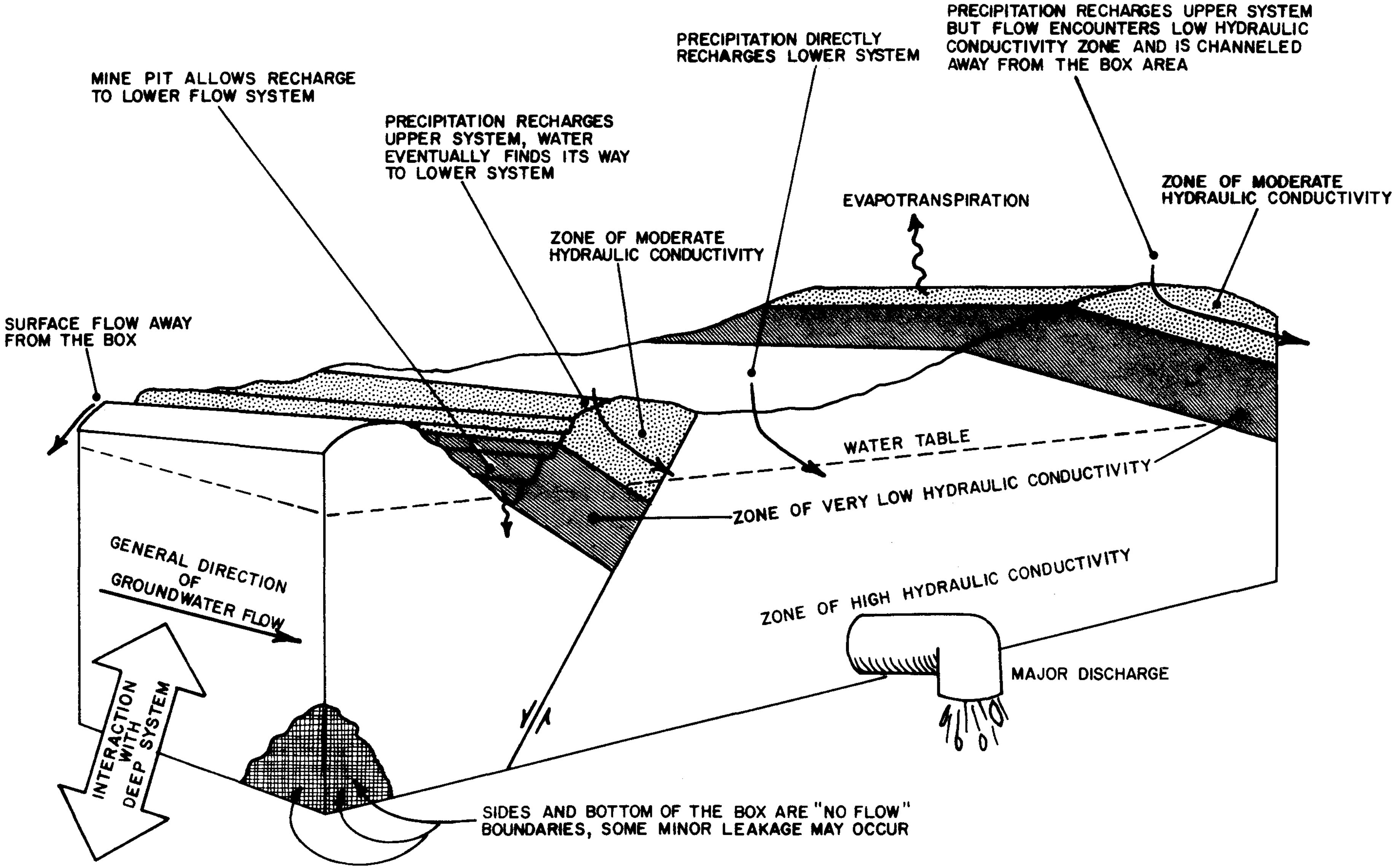


Figure III-10. Schematic diagram of East Area groundwater flow systems, Gay Mine.

Details of the actual flow system will then be added to complete the model. Finally, generalities concerning the model and their implications will be discussed.

General Principles

The following principles are illustrated in figure III-10.

1) The East Area flow systems can be considered to be contained within a box that is open at the top and is full of a permeable material (Wells formation). The material in the box is saturated with water to a certain level (the water table).
2) Layers of nearly impermeable material (Phosphoria formation) exist in the box and may extend below the level of saturation of the highly permeable material. Above the impermeable layers are layers of moderate permeability (Dinwoody and Thaynes formations) that contain groundwater flow systems. Flow above the impermeable 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 with its parts acting independently of each other.
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 water 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. 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.

6) The lower flow system can be dewatered (water table lowered) if the sum of artificial discharge (pumpage or drainage) and natural discharge exceed recharge to the system. The amount of artificial discharge required to achieve dewatering depends largely on the capacity of the system to store water.

7) The lower flow system interacts with a deep flow system located beneath the box.

Details of the Real Flow Systems

Lower Flow Systems. The hydrogeologic boundaries of the East Area flow systems are those described in Part 1: South 40 syncline, normal faulting to the east, the Central Gay Mine fault (Fig. III-1). 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 and that the rate of flow across a boundary is usually insignificant. On a small scale, however, hydraulic conductivity may change within a unit. An example of this was given for the FF-3 area where fracturing allowed a relatively small quantity of water to flow within the normally impermeable Phosphoria formation. For this reason, the boundaries may "leak" in places. Some flow may "leak out the bottom" of the system by flowing down dip 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 data in Part 2 has shown that the direction of groundwater 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 5735 feet (1748 m) above mean sea level.

Discharge from the system is by underground flow to the north. The exact method of discharge is somewhat hypothetical, 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 m) 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 m) 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 groundwater. Flow may also cross the fault at depths greater than 750 feet (230 m) and flow into the Wells formation to the north.

Recharge is primarily snowmelt in the spring. The distribution 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). Aspen trees tend to grow where snow accumulates; Aspen groves do tend to be located on northeast facing slopes in the study area. This implies that much of the snowmelt will directly recharge the lower flow system. Surface flow in the study area is generally toward the Portneuf River to the east. Some surface flow will move into the East Area and recharge groundwater flow systems, while some precipitation falling within the boundaries of the system will flow to the east, away from the East Area flow system, before it infiltrates.

Mine pits remove the Phosphoria formation and thus create an avenue for water to move directly into the Wells formation. Pits also tend to collect surface water and groundwater from upper flow systems intersected.

In the vicinity of mine pits water in the lower flow system is confined by the Phosphoria formation; water in drill holes penetrating the Wells formation rises above the top of this formation. This is why water flows upward through cracks in the pit bottoms. It is likely that the lower flow system is unconfined in areas where the Phosphoria formation does not extend below the saturation level of the Wells formation. No drill holes exist to confirm this.

Upper Flow System. The upper flow system within the East Area is divided into two distinct parts. Both are in the Dinwoody formation.

One of these flow systems is located to the east of the Group 1 area (Fig. III-1). This flow system appears to be constrained to "a block" of moderately permeable Dinwoody formation with an area of about one square mile. Because of fault displacement, the low permeability Phosphoria formation bounds the block of Dinwoody laterally on the north, west and south. The Phosphoria formation also lies below the Dinwoody formation in normal stratigraphic relationship.

Recharge to this flow system is primarily snowmelt during spring runoff. Groundwater 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 5805 feet (1769 m). This is also the only direction not bounded by the Phosphoria formation. Discharge probably occurs as evapotranspiration in topographically low spots, or as subsurface flow into the alluvium. 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. Thus flow from this system recharges the lower flow system.

A third flow system was identified outside of the boundaries of the East Area flow system. 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 away from the topographically highest point. Discharge on the east is from spring J and K, and from a spring that feeds a Simplot water pond to the west.

Deep Flow System. Combe (1970) cited evidence showing that a deep flow system containing warm water chemically similar to that issuing from Queedup spring is connected to the W pit pond and monitor hole W_1. This study has provided additional evidence indicating that monitor hole W_1 is connected to a deep, confined flow system, and that it is also hydraulically connected to monitor holes in GG and BB pits that contain cold water with relatively low total dissolved solids. Thus monitor hole W_1, although it is only 60 feet (18 m) deep, taps two distinct flow systems. The exact mechanism of this connection remains unknown.

It is likely that water from the deep flow system migrates upward along the large displacement normal fault located between Queedup spring and W pit.

When this study was initiated, understanding of this deep flow system was not given high priority. This study thus provides little additional information on the deep flow system. Further study of this system may become practical.

Implications of the Flow System Model.

1) The head in the upper is greater than that 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 Portneuf 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.

4) The quantity of water that would have to be removed to lower the water table in the lower system is largely determined by the capacity of the system to store water.

CHAPTER IV

HYDROLOGY OF MINE PLANNING (GROUP 1)

The conceptual hydrogeologic model formulated as part of this study is utilized in this chapter to evaluate the potential interactions between proposed mining operations and groundwater flow systems at a particular site. The site includes the area of proposed pits 4, 5 and 6 of Group 1. Figure II-1 gives the location.

The site covers about 10 acres at the head of a northeast trending drainage. There is no perennial streamflow in the drainage, although a definite grass covered channel exists in the northeast part. A small spring at the head of the drainage is diverted into a watering trough.

This area has been drilled on a 50-foot (15 m) grid for exploration purposes and thus the geology is well documented. The Cherty Shale member is exposed at the surface over the area of the proposed pits, with the beds dipping to the west-southwest. The pit area is uplifted relative to rocks to the north, east, and west, and is bounded on the north by the Central Gay Mine fault. Northwest trending normal faults that place the Dinwoody formation next to the Cherty Shale member bound the area to the east and west.

The area is broken by two sets of high-density small displacement normal faults. These faults strike approximately northwest and southwest and usually occur less than 50 feet

(15 m) apart. Figures IV-1 and IV-2 show the importance of these faults. The down-dropped blocks of the northwest striking faults are on the northeast sides; the down-dropped blocks of the southwest striking faults are on the northwest sides. The net effect is that the ore zone and thus pit bottoms will be at the lowest elevation in the north-northeast section of the pit area.

Hydrologic Data

All open drill holes in the area were checked for hole depth, presence of water, and depth of water if present. This was done to identify existing groundwater flow systems in the pit area. This information was compared to driller's logs and changes in hole depth or water conditions were noted. Figure IV-1 gives the locations and elevations of water where it was found.

Slug tests were performed in thirteen holes where water was found to determine if the water represented groundwater flow systems or just water standing in the drill holes. A water truck was used to raise water levels above their original levels and an electric tape was used to measure the decline in water level with time. Tabulated data from the slug tests are presented in appendix 4.

Because no existing holes remained open into the Wells formation below the 5730-foot (1747 m) elevation (the suspected level of water) three additional holes were drilled and piezometers placed in them. The specifications for these holes

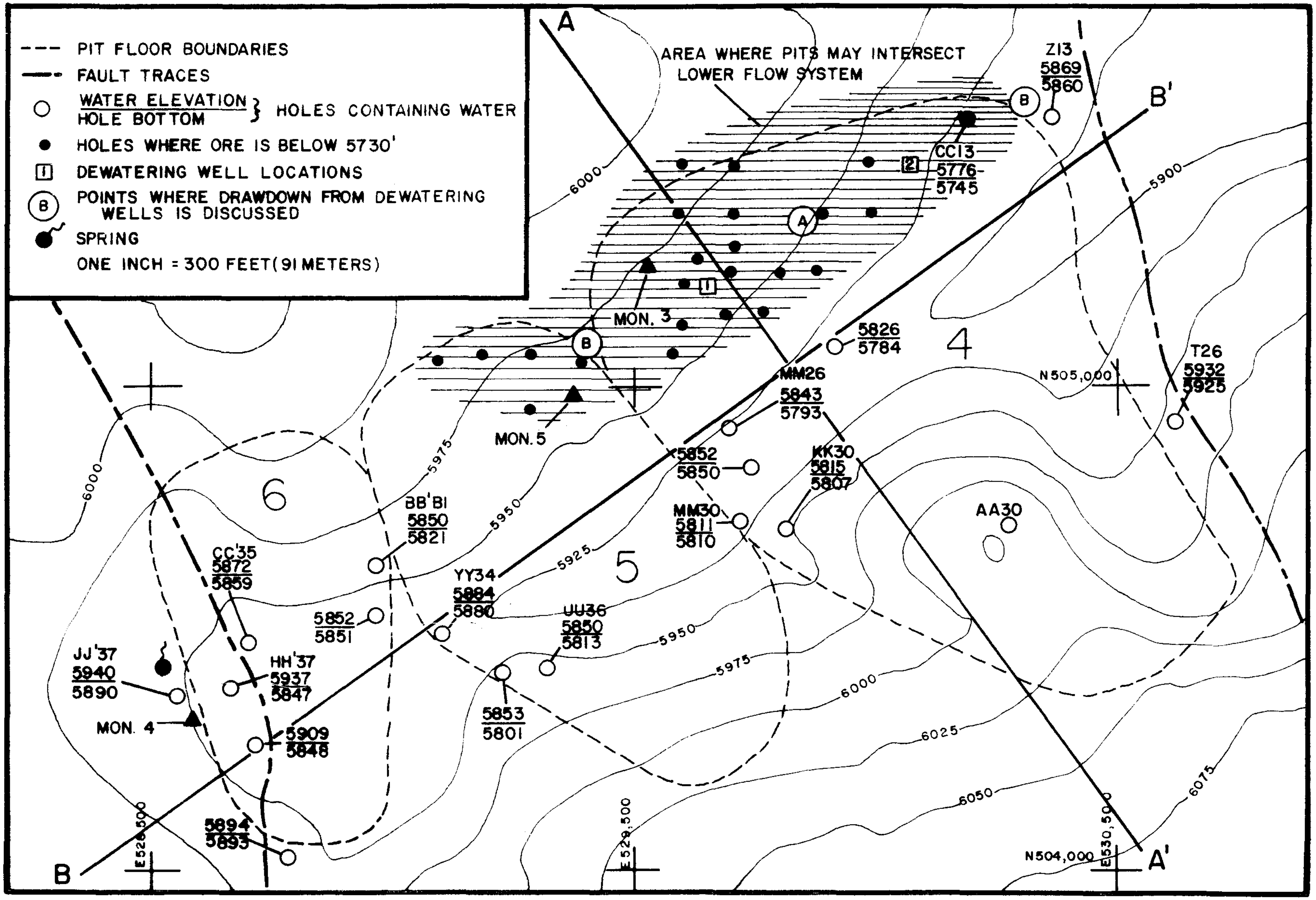


Figure IV-1. Plan map of pits 4, 5, and 6, Group 1, Gay Mine.

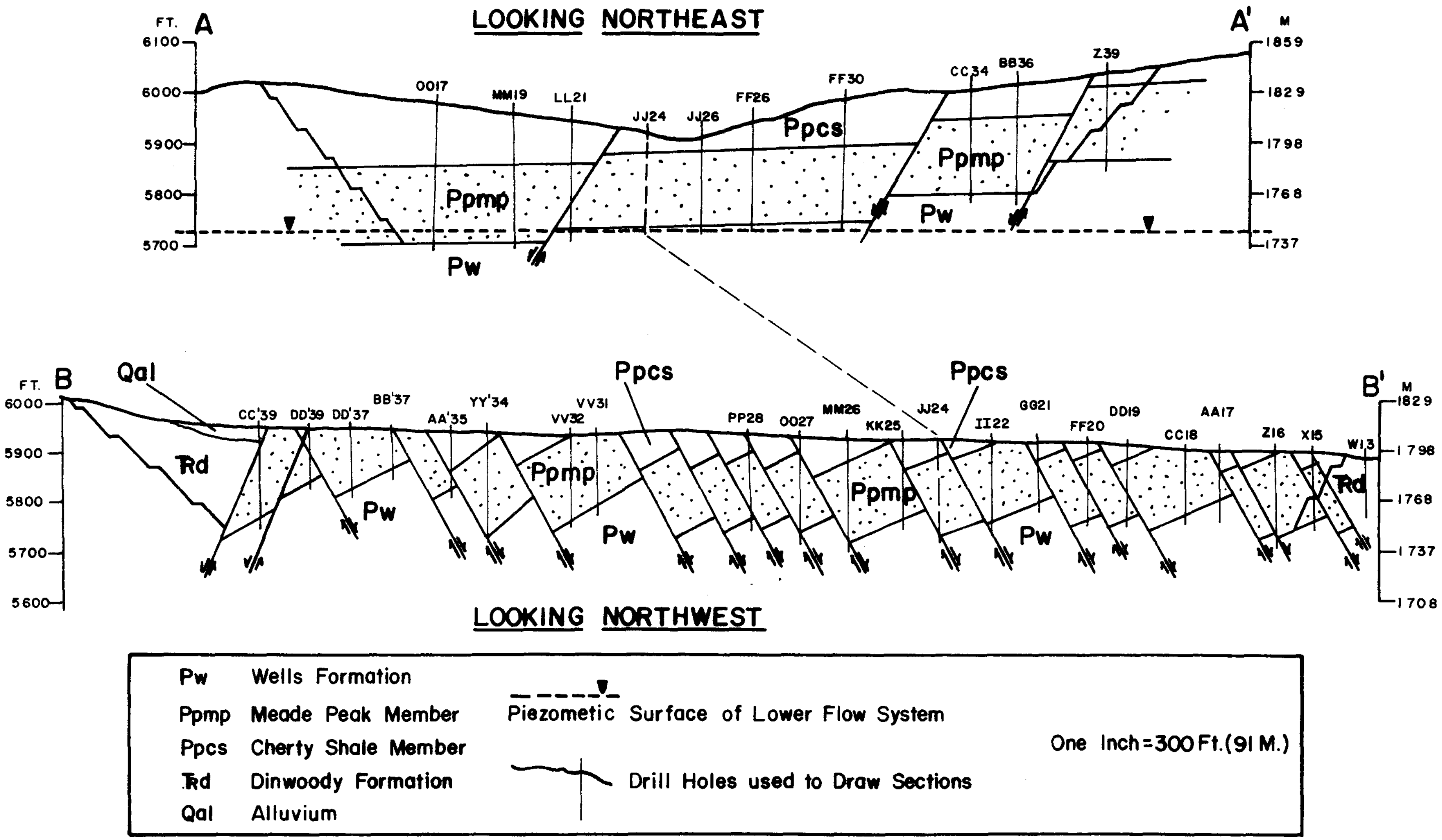


Figure IV-2. Structure sections, pits 4, 5, and 6, Group 1, Gay Mine.

(monitor holes 3, 4 and 5) are given in table II-1 and their locations in figure IV-1.

These holes were drilled with an air rotary drill that was unable to hold open holes in zones that tended to cave badly. No significant amount of water was encountered in monitor holes 3 and 5 until the Wells formation was penetrated, at which time the drill was unable to retain circulation. The Wells formation was encountered at 270 feet (82.3 m) (elevation = 5703 feet (1740 m)) in hole 3 and 225 feet (68.6 m) (elevation = 5734 feet (1748 m)) in hole 5. It is believed that the drill was unable to maintain high enough air pressure to blow the water out of the holes. Thus the cuttings could no longer be removed and the drilling was stopped.

An attempt to place a piezometer in the Wells formation in monitor hole 3 was unsuccessful because of severe caving. In monitor hole 5, a piezometer that penetrated 5 to 6 feet (1.5 m) of the Wells formation was successfully installed. The bottom elevation of this piezometer is 5727 feet (1745.6 m). Water levels in this piezometer are tabulated in appendix 1.

The third hole (monitor hole 4) penetrated the fault bounding the pit area on the east. The top fourteen feet (4.3 m) of the hole was in alluvium, below which the Dinwoody formation and Meade Peak member were encountered (Fig. IV-2). Water was present in the alluvium and is almost certainly the source of water for the watering trough. The underlying Dinwoody formation and Meade Peak member were unsaturated and water cascaded down the hole. The hole was abandoned because of caving. Cascading of water down the hole continued for several months and the flow in the cattle trough ceased.

A 160 foot (48.6 m) cased well is located 2600 feet (790 m) northeast of the pit area; the entire length of this hole is in the Dinwoody formation. This hole was drilled in the spring of 1970 by FMC Corporation to evaluate the water producing capacity of the Dinwoody formation. The water level in this hole is about 80 feet (24.4 m) above the 5730 foot (1747 m) level.

Groundwater Flow Systems

Shallow Water in the Pit Area

The existing exploration holes found to contain water all bottomed in the Phosphoria formation, although several of them had originally penetrated the Wells formation. Water found in these holes does not represent a continuous body of groundwater. Instead it represents small bodies of perched water and in some cases only rainwater standing in drill holes. Evidence supporting these conclusions is listed below.

1) Holes with water tend to be located in small groups; the groups are separated by numerous dry holes open to elevations below the water elevations in the groups.
2) Water levels within groups do not show any consistancy.

3) Slug test data indicate that water in the holes does not represent a "water table". In several of the holes water levels dropped below their original level during the slug test. In other tests water levels stabilized above original levels.

The spring located on the western edge of pit 6 issues from a thin layer of alluvium at the base of the ridge west of the pit area (Fig. IV-2). Monitor hole 4 showed this alluvium to be 14 feet (4.3 m) thick in the vicinity of the spring. Recharge to this small flow system is primarily snowmelt from the ridge slope. The quantity of water stored in this flow system is small; monitor hole 4 has drained enough water from this system to stop spring flow.

Flow Systems in the Dinwoody Formation East of Pit 6

This flow system has been described in Part 3 of Chapter III under the section title "Upper Flow System". A 54 hour pump test done by the Andrews Well Drilling Company on the FMC well indicated that a significant amount of groundwater is contained within this flow system (Larson, 1970). Using data from this pump test, Geraghty and Miller, Inc. (1970) concluded that this well could consistantly yield about 100 gpm (6 l/sec). The existence of this flow system is important because the water table of this system is at an elevation of 5805 feet (1770 m), well above the planned pit floor. The western edge of this system is adjacent to pit 4 (Fig. IV-1 and IV-2).

Flow System in the Wells Formation

The flow system in the Wells formation is part of the lower flow system that is described in Part 3 of Chapter III; all parts of that discussion can be applied to the Group 1 area. The piezometric surface (the elevation that water will rise to in a hole penetrating the aquifer) is at an elevation of about 5732 feet (1747.7 m) in the vicinity of pits 4, 5 and 6. Figure IV-1 shows the area where exploration hole logs have indicated that the bottoms of proposed pits 4 and 5 will be below the piezometric surface, thus allowing groundwater to enter these pits. A list of these drill holes is given in appendix 5. This flow system is confined by the Phosphoria formation where it dips below the piezometric surface.

Dewatering of Pits 4 and 5 by Wells

Gay Mine personnel have successfully dewatered mine pits by pumping from sumps in pit bottoms. However, wet pit bottoms have made the removal and transportation of the ore difficult. It may be economically beneficial to use wells to dewater future pits at the Gay Mine. Construction costs for dewatering wells may be offset by the savings made possible by the more efficient mining of "dry" pit bottoms. Dewatering by wells allows the option of dewatering the ore section before it is reached by pit excavation, thus allowing sufficient time for more complete drainage. The maintenance of a trench is also avoided. The purpose of this section is to give a rough idea of the number of wells, and pumping rates, that would be required to lower the piezometric surface of water in the Wells formation to an elevation below the bottoms of pits 4 and 5.

Any dewatering problem can be solved by multiple design options. Determination of the most cost effective locations, depths, and pumping rates of dewatering wells requires analysis of geohydrologic conditions, well construction and operation costs, and mining schedules. Wells dewater volumes that are approximately cone shaped; cone dimensions depend on the aquifer properties and the pumping rate. Hydrologically, the problem of dewatering an area becomes a matter of choosing the most effective way of positioning cones of various sizes to achieve the desired dewatered volume. Examples of possible trade-offs that may be encountered in this choice are:

1) A job might be accomplished by drilling one deep well or by drilling several shallower wells. The total quantity of pumpage required to dewater a given area generally decreases as the number of wells used increases.

2) A job may be accomplished by drilling deep wells outside the pit area or by shallower wells within the boundaries of a partially completed pit. The latter plan decreases drilling footage by taking advantage of mine excavation, but requires that the mine operation work around the wells. Dewatering wells placed inside the pit area will

generally do the job with less total pumpage. In the following example it has been arbitrarily assumed that the best option is locating two or three wells inside the pit area, and that 500 gpm (31.5 l/sec) is a reasonable pumping rate.

To successfully design a dewatering operation the hydraulic properties, storage coefficient (S) and transmissivity (T) must be reasonably well known. Values for these properties were estimated for the Wells formation by analyzing the drawdown, from July 1, 1978 to September 18, 1978, in monitor hole 1 (GG pit) in response to pumpage from the BB-4 pit. These data were chosen because they most nearly fit the logarithmic decline predicted by groundwater flow theory. The nonsteady radial flow equation (Lohman, 1972, p. 15) was used to calculate transmissivity and storage values of 20,000 gal/day-ft (250 m^2/day) and .02 respectively. The log-log plot of the data and the calculations are shown in figure IV-3.

The calculations of these T and S values may contain significant error because there was not sufficient information to determine how much of the drawdown in the observation well was actually due to pumpage from the BB-4 pit. Some portion of the decline in water level was undoubtedly due to natural seasonal recession. Also, the water elevation at the time pumping started was unknown because the observation well had not been drilled yet. It was assumed that the initial elevation of the water at this point was 5735.5 feet (1748.2 m). This

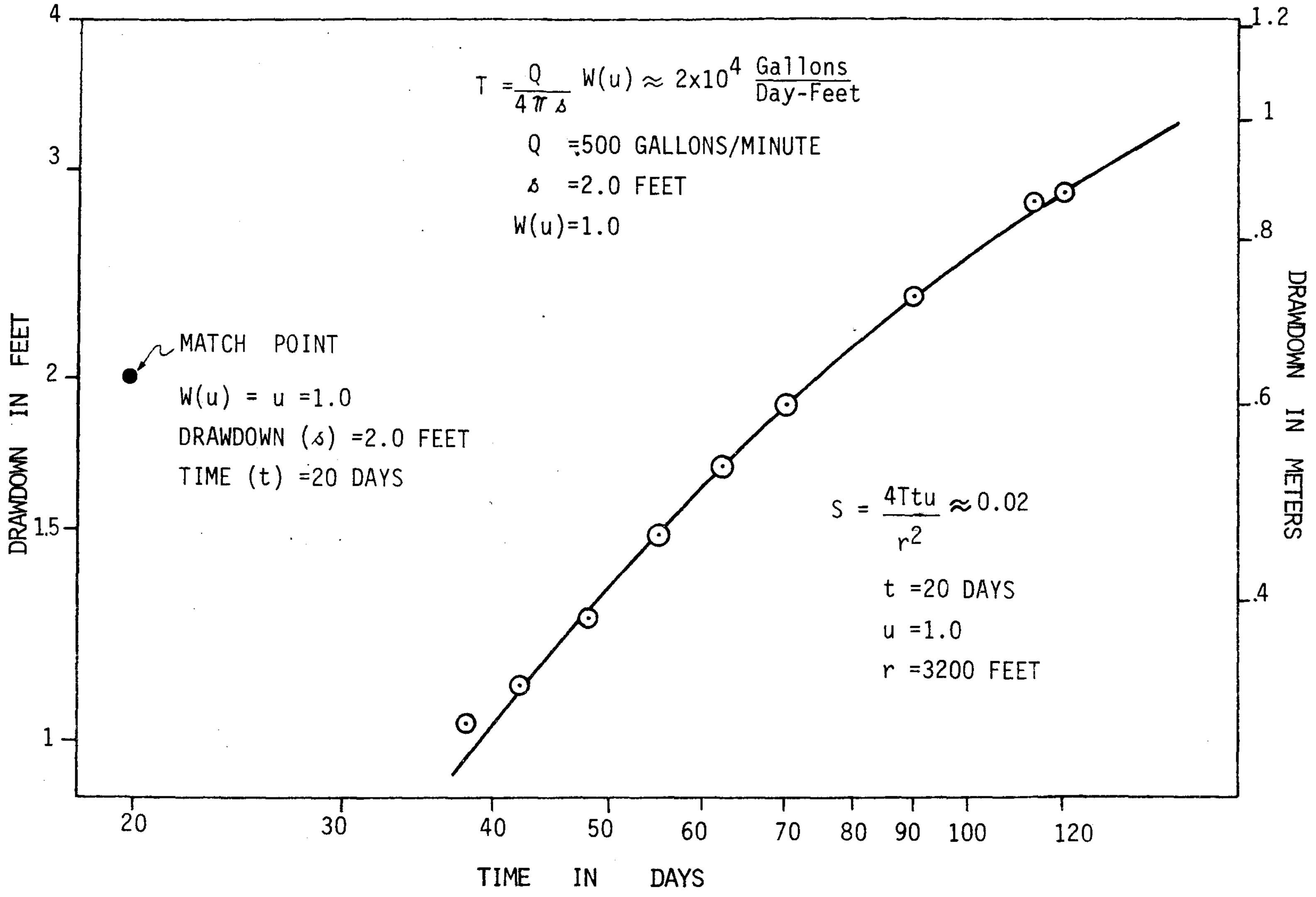


Figure IV-3. Log-log plot of drawdown in monitor hole 1 from July 1, 1978 to September 18, 1978, and calculations of transmissivity and storage coefficients, Gay Mine.

assumption results in the best log-log plot of the data. Extrapolation of known water elevations back to the time pumping started indicates that this value is reasonable.

These T and S values also may contian significant error because the test conditions violated the assumptions of the mathematical theory used in their calculation. The theory assumes that the aquifer tested is isotropic, homogenous, of infinite areal extent, and that T and S are constant spatially and with time. The discharge point is assumed to be a small diameter well that penetrates the full thickness of the aquifer (Lohman, 1972). It is felt that an inconsistant S is the most important assumption biolated. The part of the aquifer located in between the pumping site (BB-4 pit) and the observation site (GG pit) is most likely unconfined. Thus the S value will be larger between these pits than in the immediate vicininity of them.

The well locations and pumping rates were chosen to achieve drawdowns of at least 25 feet (7.6 m) in the area designated in figure IV-1. The actual drawdowns required would be somewhat less than this. Figure IV-4 gives time-drawdown response, at several points, to 12-inch wells 1 and 2 pumping concurrently at a rate of 500 gpm (31.5 l/sec). In constructing this figure, it was assumed that well interference (drawdown at any point due to the combined affect of pumpage of both wells) could be estimated by algebraically

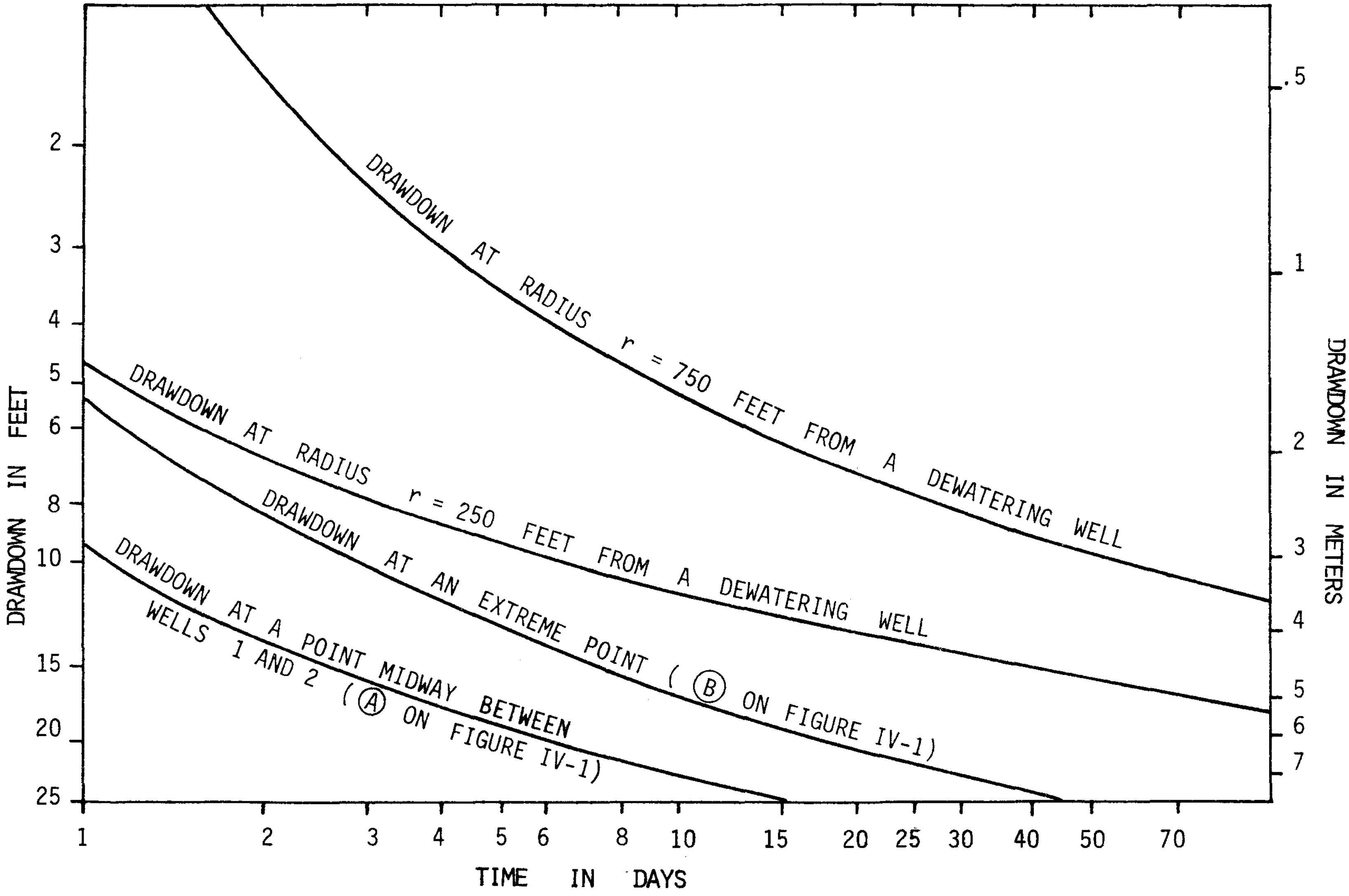


Figure IV-4. Theoretical drawdowns due to pumpage of proposed dewatering wells 1 and 2 at 500 gpm at selected points, Group 1 area, Gay Mine.

adding the drawdowns caused by each well acting alone. This assumption can be applied with little error in the case of two wells. The figure shows that the drawdown required to mine pit 4 would be achieved in about 10-20 days at a point midway between the wells (point A), and in about 50 days at the most extreme points (points B). Pumpage would continue until mining was completed.

The nonsteady radial flow equation was used to calculate drawdown (s) at the pumping wells:

$$u = \frac{r^2 S}{4Tt} = 9.4 \times 10^4$$

$$r = .5 \text{ feet}, \; S = .02, \; T = 2 \times 10^4 \frac{\text{gal}}{\text{day-ft.}},$$

$$t = 50 \text{ days}$$

$$\therefore \; W(u) = 17.905$$

$$s = \frac{Q}{4\pi T} W(u) \approx 50 \text{ feet } (15.2 \text{ m})$$

$$Q = 500 \frac{\text{gal}}{\text{min}}, \; T = 2 \times 10^4 \frac{\text{gal}}{\text{day-ft.}}, \; W(u) = 17.905$$

Using the same equations, it can be calculated that an additional 15 feet (4.6 m) drawdown would occur because of interference from the second well. The total drawdown at either dewatering well would be approximately 65 feet (15.2 m) after 50 days of continuous pumping.

Thus the dewatering wells would have to be deep enough to allow the top of the pump bowls to be placed at least 65 feet below the initial water level, or at an elevation of about 5670 feet (1728 m). The bowls would have to be placed deeper than this if it were suspected that well losses would cause significant additional drawdown.

Figure IV-4 gives drawdown analysis for pit 4 only. To dewater the portion of pit 5 that will extend below 5735 feet (1747 m) the pump from well 2 could be moved over to a well in pit 5. This well could then pump in conjunction with well 1 to achieve the required drawdown in pit 5. The time-drawdown curves would be very similar to those given for pit 4.

The fact that the T and S values used in the calculations are of questionable accuracy, and the fact that boundary conditions were not considered, makes it clear that figure IV-4 is a rough estimate of the drawdowns that would result from pumpage from dewatering wells. These calculations do indicate that the use of dewatering wells may be practical at this site. An aquifer test performed in the Group 1 area would be required to design a dewatering system with confidence.

Interactions Between Mining and Flow Systems

The interactions between mining and flow systems can be subdivided into two categories: those that impact mining, and those that impact flow systems.

Impacts on Mining

1) "Wet spots" may be encountered where water was found in exploration holes.
2) Water from the Wells formation will flood pits if they are taken below an elevation of about 5735 feet (1748.7 m). This is the most severe

potential impact on mining.

3) Water from the localized flow system in the Dinwoody formation may leak into pit number 4, and may cause highwall stability problems.

Impacts on Flow Systems

1) The spring near the west edge of pit number 6 will be removed by the mining operation.
2) Pumpage will be required if the pit floors are taken below an elevation of approximately 5735 feet. This will result in a lowering of the piezometric surface in this formation.
3) Pumpage from the Dinwoody formation east of pit number 4 will probably be required to prevent leakage into this pit. This action would lower the water table in this flow system.

Recommendations

1) Wet spots should be gravity drained to lower unsaturated zones (or to the Wells formation) by drilling vertical holes.
2) Water should be pumped from the FMC well, or from a new well located closer to the pit area, to prevent leakage through the pit wall.
3) A piezometer should be placed near the east wall of pit number 4 to check the effectiveness of recommendation 2.

4) Check the feasibility of redesigning the pits so that all of the area of potential flooding by water from the Wells formation will be contained within one pit.
5) Evaluate the feasibility of using wells to dewater the Wells formation where needed.
6) Be careful not to discharge water pumped from the Dinwoody or Wells formations where it will circulate rapidly back into one of these flow systems.

CHAPTER V

POTENTIAL IMPACTS OF MINING ACTIVITY ON WATER RESOURCES

Mining activity can impact groundwater flow systems in two ways: 1) change water quality, 2) change the flow patterns of groundwater. When evaluating the significance of a given impact, the use of the impacted resource must be considered. The primary use of water in the Gay Mine area is cattle watering. Springs are collected into troughs for this purpose. Because there are no perennial streams in the study area, this section will focus on impacts to groundwater and its discharge points.

Changes in Water Quality

A limited study of potential water quality impacts was done as part of this research effort. The work included analysis for pH and dissolved ions. Leaching experiments were performed on two Gay Mine waste dump samples: weathered waste and carbonaceous rich waste (Wai, 1979). A water sample taken from a seep at the toe of a waste dump was analyzed for dissolved ions by FMC Corporation personnel.

Leachate from the waste dump samples was found to be neutral or slightly basic in pH. This can be explained by the absence of pyrite (a common acid forming mineral) in the samples, and by the strong buffering effect of the carbonate material in the samples. Ions that commonly impair water quality generally have low solubilities in neutral pH water.

Leachate from the waste dump samples was also analyzed for calcium, magnesium, cadmium, lead, and zinc. These ions were all present in concentrations less than the maximum limits required by U. S. Public Health Service Drinking Water Standards.

Water pumped from the BB-4 pit was discharged at a location where it was able to infiltrate into a waste dump, causing seepage at the toe of the dump. A sample of the seepage was analyzed for fluorite, sulfate, iron, aluminum, silver, calcium, magnesium, copper, zinc, cadmium, and selenium by FMC Corporation personnel. Concentrations of these ions met U. S. Drinking Water Standards. The analysis of potential water quality degradation due to dissolved uranium or suspended solids was not evaluated as part of this study.

Changes in Distribution and Flow Patterns of Groundwater

Mining activity can impact groundwater flow patterns by locally increasing recharge to existing flow systems, by intersecting existing flow systems, or by creating new flow systems.

Increased Recharge

Mining operations usually remove the entire thickness of the nearly impermeable Meade Peak member. This allows the exposed Wells formation to interact with groundwater and meterological waters that were previously confined above the Meade Peak member. Mine pits tend to collect surface runoff from their catchment area and groundwater intersected from flow systems above the Meade Peak member. For these reasons, active mining tends to increase recharge to flow systems within the Wells formation.

Flow systems continue to be impacted after mine pits have been backfilled and reclaimed. The fill material probably has a high permeability and thus the site may act hydrologically much the same as when the pit was open. Water coming in contact with the fill material will percolate downward and recharge the Wells formation.

Intersected Flow Systems

The geological map of the area (Fig. III-1) shows that, over most of the East Area, mine pits do not or would not disturb the Dinwoody formation. In a few locations (in Group 1 and Group 2) faults place the Dinwoody in a position such that portions of it would be removed during pit contruction. In these cases, it is possible that flow systems in the Dinwoody formation would be intercepted. This situation was discussed in the previous section for pit number 4 of Group 1. Interception of a flow path may decrease or eliminate discharge from the system at natural discharge points. Natural discharge could occur at a point (a spring) or could occur over large areas as evapotranspiration. Water that would have been discharged from the Dinwoody formation under natural conditions would most likely become recharge to the Wells formation.

Creation of New Flow Systems

The construction of waste piles and the disposal of water pumped from active pits are two mining activities that can potentially create new groundwater flow systems. Saturation of waste piles may decrease their stability.

Waste piles are often large masses of permeable material, usually with steeply sloping sides. If sufficient recharge is available, flow systems will form within the waste pile. Recharge may occur as precipitation falling directly on the waste pile or as runoff from the catchment area of the waste pile. Discharge often occurs near the base of the pile. Variables affecting the formation of flow systems in waste piles have been listed by Ralston and others (1977) and are given below:

a) Catchment area (include intake area, and other areas contributing surface water runoff to the intake area)
b) Recharge area (include intake area only)
c) Surface topography
d) Vegetal cover
e) Texture and composition of the waste material on the surface of the pile
f) Annual precipitation
g) Occurrence of snow drifts on the pile surface or within its catchment area
h) Effect of secondary structures such as fracturing, piping and compaction
i) Location relative to existing flow systems.

The disposal of water pumped from mine pits can provide a relatively large amount of recharge over a small area. The characteristics of the resulting flow system would depend on the location of the discharge of this disposed water. In many cases the water would join existing surface water or groundwater flow systems.

Analysis of Impacts

The small amount of work done investigating changes in water quality indicates that mining activity does not significantly degrade the quality of water. Any negative impact on water resources would have to be related to changes in the flow paths of groundwater.

It has been shown that the net effect of changes in the flow paths of groundwater flow systems in the mine area will generally be an increase in recharge to the Wells formation. Although the Wells formation has excellent potential as a source of water, this resource is not presently being put to beneficial use. If water were to be recharged to this formation at the expense of flow systems being put to beneficial use, this could be viewed as a negative impact to the water resource system. In order for this to be the case, the impacted flow system would have to discharge as useable surface water. However, this situation will not usually occur in the East Area because rock units with permeability great enough to support flow systems (except the Wells formation) are generally not disturbed by mining activity. Because flow systems within the Dinwoody and Thaynes formations are of very discontinuous and localized nature, any impact to flow systems in these formations would be very localized.

In summary, the impacts on water resource systems by mining activity in the East Gay Mine area are presently and will continue to be minimal.

CHAPTER VI

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

1) The relative hydraulic conductivities of the geologic units at the Gay Mine are similar to those found in other portions of the southeastern Idaho phosphate field. The Thaynes and Dinwoody formations have moderate hydraulic conductivity, the Phosphoria formation has very low hydraulic conductivity, and the Wells formation has very high hydraulic conductivity.

2) Groundwater flow systems within the East Area can be depicted by a model consisting of a box filled with permeable material. In the actual field situation the very permeable Wells formation is bounded by faults and folds that place it in contact with less permeable formations.

3) Recharge to the East Area flow systems is by precipitation falling on the area. Groundwater flow is generally to the northwest; groundwater flow leaves the system north of the Group 1 area where it crosses a fault structure.

4) The source of water flooding the mine pits is the Wells formation. This flow system is continuous throughout the East Area; the mine pits are hydraulically connected.

5) Discontinuous groundwater flow systems occur in the Dinwoody and Thaynes formations at an elevation higher than that of the Wells formation flow system. These flow systems may easily be drained downward to the Wells formation due to a lower potential in the underlying flow system.

6) The entire East Area could be drained by a major tunnelling excavation into the Portneuf Valley to the east. A project of this scale may be practical if underground mining was ever attempted in this area.

7) The primary water problem in the Group 1 area will be flooding of the pits by groundwater flow from the Wells formation. Dewatering wells may be a practical solution to this problem.

8) Based on limited sampling, the water flowing from Gay Mine waste dumps is of good quality.

9) Impacts on water resources by mining activity at the Gay Mine have been, and should continue to be minimal.

Recommendations

1) This study was hindered by the lack of seasonal data on the Wells formation flow system. Useful quantative analysis of this system requires at least one full year of water level record. Water level recorders should be maintained on

several wells tapping the Wells formation.

2) Consolidate groundwater flow system data collection with exploration drilling. Piezometers can easily and inexpensively be installed in exploration holes when they are drilled. Periodic measurement of water levels in these piezometers will aid in the planning of mine operations. Careful recording of water conditions encountered during drilling is of great value to hydrologic studies.

3) Controlled pump tests are required to determine the amount of water stored within the Wells formation. This information is essential when designing efficient dewatering operations.

4) Make W pit into a recreation area.

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APPENDIX 1. Measured Water Level Elevations in Monitor Holes and of Ponded Water in Pits, Gay Mine Area.

BB-4 Pond

Elevation M. P.: 0.0 on staff gage = 5730.74

Date	Hour	Elevation of Water Level (feet)
5/22/78	14:00	5733.29
5/23/78	8:30	5733.29
5/24/78	10:30	5733.29
5/24/78	13:30	5733.29
5/24/78	13:50	5733.24
5/25/78	14:30	5733.19
5/26/78	8:30	5731.99
5/26/78	14:30	5731.79
5/26/78	23:30	5731.34
5/27/78	15:00	5731.84
5/28/78	15:48	5732.27
5/29/78	14:15	5732.51
5/30/78	7:30	5732.66
5/30/78	14:00	5732.28
5/31/78	7:30	5731.77
5/31/78	14:30	5731.47
6/ 1/78	8:00	5730.47
6/ 1/78	15:00	5730.14
6/ 3/78	19:30	5729.42
6/ 4/78	10:15	5730.42
6/ 5/78	13:15	5729.53
6/ 8/78	8:00	5729.00
6/ 8/78	13:50	5728.78
6/ 8/78	23:20	5728.29
6/ 9/78	7:25	5728.99
6/ 9/78	7:45	5728.98
6/ 9/78	15:10	5728.65
6/ 9/78	23:20	5728.19
6/10/78	6:00	5728.89
6/10/78	23:45	5728.19
6/11/78	9:00	5728.79
6/12/78	9:20	5728.86
6/12/78	16:00	5728.86
6/12/78	23:45	5728.59
6/13/78	7:30	5729.09
6/13/78	15:00	5728.65
6/13/78	16:30	5728.60
6/13/78	23:35	5728.55
6/14/78	7:45	5728.80
6/14/78	13:30	5728.72
6/14/78	17:00	5728.74
6/14/78	23:30	5728.51
6/15/78	7:30	5728.77
6/15/78	8:30	5728.75
6/15/78	9:50	5728.79
6/16/78	7:30	5729.65
6/19/78	8:15	5731.15
3/22/79	by stadia	5734 ± .5

Monitor BB-4

Elevation M. P.: 5737.40

Date	Hour	Elevation of Water Level (feet)
5/26/78	8:30	5732.99
5/26/78	14:30	5732.89
5/27/78	15:00	5732.73
5/28/78	15:50	5732.81
5/29/78	14:15	5732.81

Monitor BB-4 - cont'd

Date	Hour	Elevation of Water Level (feet)
5/30/78	7:30	5732.94
5/30/78	14:00	5732.89
5/31/78	7:30	5732.51
5/31/78	14:30	5732.40
6/ 1/78	8:00	5732.20
6/ 1/78	15:00	5732.165
6/ 4/78	10:15	5731.79
6/ 5/78	13:15	5731.605
6/ 6/78	7:45	5731.56
6/ 6/78	15:05	5731.53
6/ 7/78	14:00	5731.48
6/ 7/78	23:20	5731.4
6/ 8/78	8:00	5731.46
6/ 8/78	14:05	5731.44
6/ 8/78	23:20	5731.30
6/ 9/78	7:45	5731.47
6/ 9/78	15:10	5731.435
6/ 9/78	23:20	5731.32
6/11/78	9:00	5731.37
6/12/78	8:00	5731.34
6/13/78	8:00	5731.425
6/13/78	15:00	5731.35
6/15/78	7:30	5731.29
6/16/78	7:30	5731.52
6/19/78	8:15	5731.17
6/21/78	8:30	5732.45
6/22/78	7:45	5732.56
6/23/78	8:00	5732.64
6/26/78	9:00	5732.80
6/28/78	8:35	5732.45
6/30/78	8:35	5731.83
7/ 5/78	9:45	5731.33
7/10/78	10:30	5731.22
7/12/78	14:30	5731.06
7/13/78	15:10	5730.96
7/14/78	8:00	5730.635
7/18/78	8:30	5730.88
7/19/78	10:10	5730.86
7/20/78	14:20	5730.86
7/21/78	15:00	5730.82
7/24/78	14:50	5730.74
*7/25/78	10:30	5730.74
8/ 2/78	9:00	5729.58
8/22/78	13:45	5729.05
9/13/78	13:00	5727.72
9/18/78	12:45	5727.12

*Installed recorder

Monitor 1 GG Pit

Elevation M. P.: 5745.40

Date	Hour	Elevation of Water Level (feet)
6/28/78	9:00	5734.93
6/29/78	8:20	5734.67
6/29/78	9:45	5734.62
7/ 1/78	9:05	5734.46
+7/ 5/78	9:00	5734.38
7/11/78	14:30	5734.22
7/18/78	8:30	5734.01
7/25/78	14:30	5733.79

Monitor 1 GG Pit - cont'd

Date	Hour	Elevation of Water Level (feet)
8/ 2/78	8:20	5733.58
8/22/78	14:10	5733.13
9/13/78	14:30	5736.75
9/18/78	13:15	5732.71
3/ 3/79		5731.15
3/ 8/79		5730.06
3/21/79		5731.15

+Set up recorder

Monitor 2 GG Pit

Elevation M. P.: 5745.32

Date	Hour	Elevation of Water Level (feet)
7/28/78	7:30	5733.64
8/ 2/78	8:40	5733.44
8/ 8/78		5733.30
8/15/78		5733.17
8/22/78	13:15	5733.02
8/30/78		5732.84
9/18/78	13:15	5732.61

Monitor 3 Group 1

Elevation M. P.: 5973.18

Date	Hour	Elevation of Water Level (feet)
8/14/78		5731.83
8/16/78		5732.25
8/21/78	16:00	5732.21
8/22/78	10:20	5732.28
8/25/78	12:25	5732.13
8/28/78		5732.12
8/29/78		5732.04
8/30/78		5732.02
9/ 1/78		5732.00
9/ 5/78		5731.96
9/ 7/78		5731.93
9/12/78		5731.85
9/13/78	11:15	5731.85
9/14/78	14:15	5731.84

Monitor 5 Group 1

Elevation M. P.: 5959.20

Date	Hour	Elevation of Water Level (feet)
8/29/78		5731.81
8/30/78		5731.70
9/ 1/78		5731.85
9/ 5/78		5731.83
9/ 7/78		5731.77
9/12/78		5731.50
9/14/78	13:30	5731.48
9/18/78	14:00	5731.43
9/19/78		5731.38
3/22/79		5729.40

APPENDIX 1. cont'd

FMC Well

Elevation M. P.: 5840.1

Date	Hour	Elevation of Water Level (feet)
6/ 9/78		5805.86
6/20/78	13:15	5805.67
8/ 8/78		5802.47
8/17/78		5801.71
8/30/78		5801.8
9/ 7/78		5800.47
9/13/78		5800.86
9/19/78		5800.16
9/25/78		5800.43
10/ 3/78		5799.87
10/ 9/78		5799.75
10/16/78		5799.59
10/23/78		5799.43
10/30/78		5799.35
11/ 6/78		5799.25

W Pit Pond

Elevation M. P.: 0.0 on staff gage = 5733.32

Date	Hour	Elevation of Water Level (feet)
6/ 1/78	14:30	5736.45
6/ 2/78	11:40	5736.46
6/ 4/78	12:15	5736.47
6/ 5/78	13:45	5736.48
6/ 7/78	13:00	5736.46
6/ 9/78	8:20	5736.44
6/11/78	10:00	5736.42
6/13/78	10:30	5736.39
6/16/78	8:35	5736.355
6/20/78	8:45	5736.31
6/23/78	9:00	5736.30
6/27/78	8:25	5736.30
6/30/78	8:20	5736.29
7/ 5/78	10:35	5736.23
7/18/78	8:15	5736.05
8/22/78	13:20	5735.56
9/13/78	14:03	5735.35
9/18/78	12:00	5735.28

Monitor W_1

Elevation M. P.: 5746.89

Date	Hour	Elevation of Water Level (feet)
5/29/78	15:00	5736.75
6/ 1/78	11:00	5736.72
6/ 1/78	14:30	5736.76
6/ 2/78	11:40	5736.72
6/ 4/78	12:00	5736.67
6/ 7/78	14:15	5736.64
6/11/78	10:00	5736.60
6/13/78	10:15	5736.60
6/16/78	8:30	5736.545
6/20/78	8:30	5736.55
6/23/78	8:45	5736.60
6/30/78	8:00	5736.54
7/ 5/78	10:30	5736.46
7/11/78	10:45	5736.44
7/18/78	8:30	5736.29

Monitor W_1 - cont'd

Date	Hour	Elevation of Water Level (feet)
8/10/78		5735.97
8/11/78	13:00	5735.97
8/15/78		5735.88
8/18/78	11:30	5735.78
8/22/78	13:10	5735.77
9/13/78	13:30	5735.48
9/18/78	12:00	5735.46
3/22/79	10:30	5733.30

Monitor W_2

Elevation M. P.: 5743.153

Date	Hour	Elevation of Water Level (feet)
6/ 1/78	11:45	5736.693
6/ 4/78	12:15	5736.633
6/ 9/78	8:30	5736.688
6/13/78	10:30	5736.558
6/16/78	8:35	5736.513
6/20/78	8:40	5736.513
6/23/78	8:55	5736.558
6/27/78	8:15	5736.563
6/30/78	8:15	5736.503
7/ 5/78	10:35	5736.413

Monitor W_3

Elevation M. P.: 5741.293

Date	Hour	Elevation of Water Level (feet)
6/ 1/78	11:45	5736.753
6/ 4/78	12:15	5736.663
6/ 9/78	8:30	5736.708
6/13/78	10:30	5736.583
6/16/78	8:35	5736.523
6/20/78	8:45	5736.523
6/23/78	8:55	5736.573
6/27/78	8:15	5736.573
6/30/78	8:15	5736.513
7/ 5/78	10:45	5736.423

Monitor W_4

Elevation M. P.: 5742.183

Date	Hour	Elevation of Water Level (feet)
6/ 9/78	8:35	5736.443
6/13/78	10:35	5736.368
6/16/78	8:40	5736.313
6/20/78	8:50	5736.283
6/23/78	9:05	5736.303
6/30/78	8:25	5736.273
7/ 5/78	10:40	5736.203

APPENDIX 2. Logs of Holes Drilled for the Study, Gay Mine.

Monitor Hole	Depth in Feet	Geologic Unit
Monitor BB-4	0- 18	Meade Peak Member
	18-175	Wells Formation
Monitor 1	0- 18	Wells Formation
Monitor 2	0-129	Wells Formation
Monitor 3	0- 10	Alluvium
	10- 65	Cherty Shale Member
	65-270	Meade Peak Member
	270-280	Wells Formation
Monitor 4	0- 14	Alluvium
	14- 97	Dinwoody Formation
	97-115	Meade Peak Member
Monitor 5	0- 10	Alluvium
	14- 95	Cherty Shale Member
	95-225	Meade Peak Member
	225-240	Wells Formation

APPENDIX 3. Spring Discharge Data, Gay Mine Area

Date	Spring	Discharge		Measurement Technique
		gpm	l/min	
6/19/78	D	1.1	4.2	Bottle and watch
7/20/78	D	0.6	2.3	Bottle and watch
9/14/78	D	0.3	1.15	Bottle and watch
11/ 7/78	D	0.2	0.75	Bottle and watch
6/20/78	J	17.9	67.8	60^o V-notch flume
7/20/78	J	10.2	38.6	60^o V-notch flume
9/14/78	J	4.9	18.5	60^o V-notch flume
11/ 9/78	J	2.0	7.5	60^o V-notch flume
6/20/78	K	12.1	45.8	60^o V-notch flume
7/20/78	K	8.4	31.8	60^o V-notch flume
9/14/78	K	6.9	26.1	60^o V-notch flume
11/ 9/78	K	6.1	23.1	60^o V-notch flume

APPENDIX 4. Slug Test Data, Gay Mine Area

Drill Hole	Date	Depth of Water (feet)	Time Since Test Began (minutes)	Drill Hole	Date	Depth of Water (feet)	Time Since Test Began (minutes
GG'-35	8/23/78	70.7	original	KK-30	8/24/78	116.85	287
	8/23/78	50.8	0	cont'd	8/24/78	117.4	331
	8/23/78	54.18	13		8/25/78	124.4	1388
	8/23/78	61.71	61	JJ'-37	8/23/78	9.04	original
	8/23/78	65.04	151		8/23/78	4.05	0
	8/23/78	69.42	349		8/23/78	9.01	32
	8/24/78	70.22	1398		8/23/78	9.01	44
YY-34	8/23/78	41.82	original		8/23/78	9.02	65
	8/23/78	27.75	0		8/23/78	9.01	196
	8/23/78	29.7	13		8/23/78	9.02	380
	8/23/78	29.8	31		8/24/78	9.025	1385
	8/23/78	30.0	66	MM-30	8/23/78	108.1	original
	8/23/78	30.3	146		8/23/78	87.4	0
	8/23/78	30.55	223		8/23/78	89.3	25
	8/24/78	33.45	1416		8/23/78	90.95	55
UU-36	8/24/78	107.5	original		8/24/78	105.85	1269
	8/24/78	97.45	0	HH'-37	8/23/78	54.73	original
	8/24/78	76.6	23		8/23/78	15.7	0
	8/24/78	99.65	72		8/23/78	22.11	34
	8/24/78	102.3	112		8/23/78	24.28	47
	8/24/78	105.9	213		8/23/78	26.92	66
	8/24/78	106.8	260		8/23/78	32.34	115
	8/24/78	107.4	306		8/23/78	39.35	197
	8/25/78	107.5	1480		8/23/78	46.31	390
O-32	8/24/78	27.5	original		8/24/78	59.03	1494
	8/24/78	20.65	0	MM-26	8/23/78	97.4	original
	8/24/78	25.4	8		8/23/78	92.9	0
	8/24/78	26.55	48		8/23/78	96.4	11
	8/24/78	26.8	97		8/23/78	96.9	30
	8/24/78	27.8	217		8/24/78	97.45	1246
	8/24/78	27.05	348	BB'-31	8/23/78	107.1	original
AA-30	8/24/78	157.65	original		8/23/78	77.25	0
	8/24/78	127.9	0		8/23/78	78.79	11
	8/24/78	136.3	44		8/23/78	100.7	37
	8/24/78	138.1	57		8/23/78	108.3	119
	8/24/78	145.3	125		8/23/78	108.7	204
	8/24/78	148.4	171		8/24/78	108.35	1396
	8/24/78	152	268	CC-13	8/24/78	172.25	original
	8/24/78	153.5	315		8/24/78	145.9	0
	8/24/78	154.7	363		8/24/78	149.6	57
	8/24/78	157.5	1539		8/24/78	152.15	115
KK-30	8/24/78	125.55	original		8/24/78	156.15	240
	8/24/78	105.9	0		8/24/78	158.8	375
	8/24/78	106.75	12	2-13	8/24/78	34.85	original
	8/24/78	112.0	98		8/24/78	24.3	0
	8/24/78	113.4	139		8/24/78	34.4	9
	8/24/78	115.9	239		8/24/78	34.7	55

APPENDIX 4. cont'd

Drill Hole	Date	Depth of Water (feet)	Time Since Test Began (minutes)
2-13	8/24/78	34.8	115
cont'd	8/24/78	34.8	240
	8/24/78	34.8	372
T-26	8/24/78	24.05	original
	8/24/78	20.0	0
	8/24/78	21.75	7
	8/24/78	23.0	29
	8/24/78	23.55	61
	8/24/78	23.75	109
	8/24/78	23.8	209
	8/24/78	23.8	361

APPENDIX 5. Exploration Holes in Which the Ore is Located at an Elevation Lower than 5730 feet.

YY23
WW23
UU23
SS23
UU25
0023
0022
0020
NN19
MM21
LL21
MM19
MM18
MM17
MM15
0017
0015
KK19
JJ19
1117
GG17
GG15
CC13

APPENDIX 6. Description of the Digitizing Process.

This program was written to handle graphs that are recorded on multiple sheets. Each sheet can be placed on the digitizing table at any angle or location; the program normalizes all points to a common axis. The program handles discontinuities by commanding the plotter pen to be in the up position where these "spaces on the graph" are encountered. The digitizing was done by a PDP 11/03 computer.

A step by step description of the process, a flow chart, and the actual program are given below.

1) The "call plots" statement initiates an internal routine to activate the plotter and digitizer hardware.

2) The file name is entered by the user through the keyboard. The program opens a disk file with this name.

3) The first two points entered are any two points along a horizontal line on the graph. The program uses these two points to rotate all subsequent points to their proper location on a horizontal axis. This is necessary in case the graph is placed on the digitizer table at an angle to the horizontal.

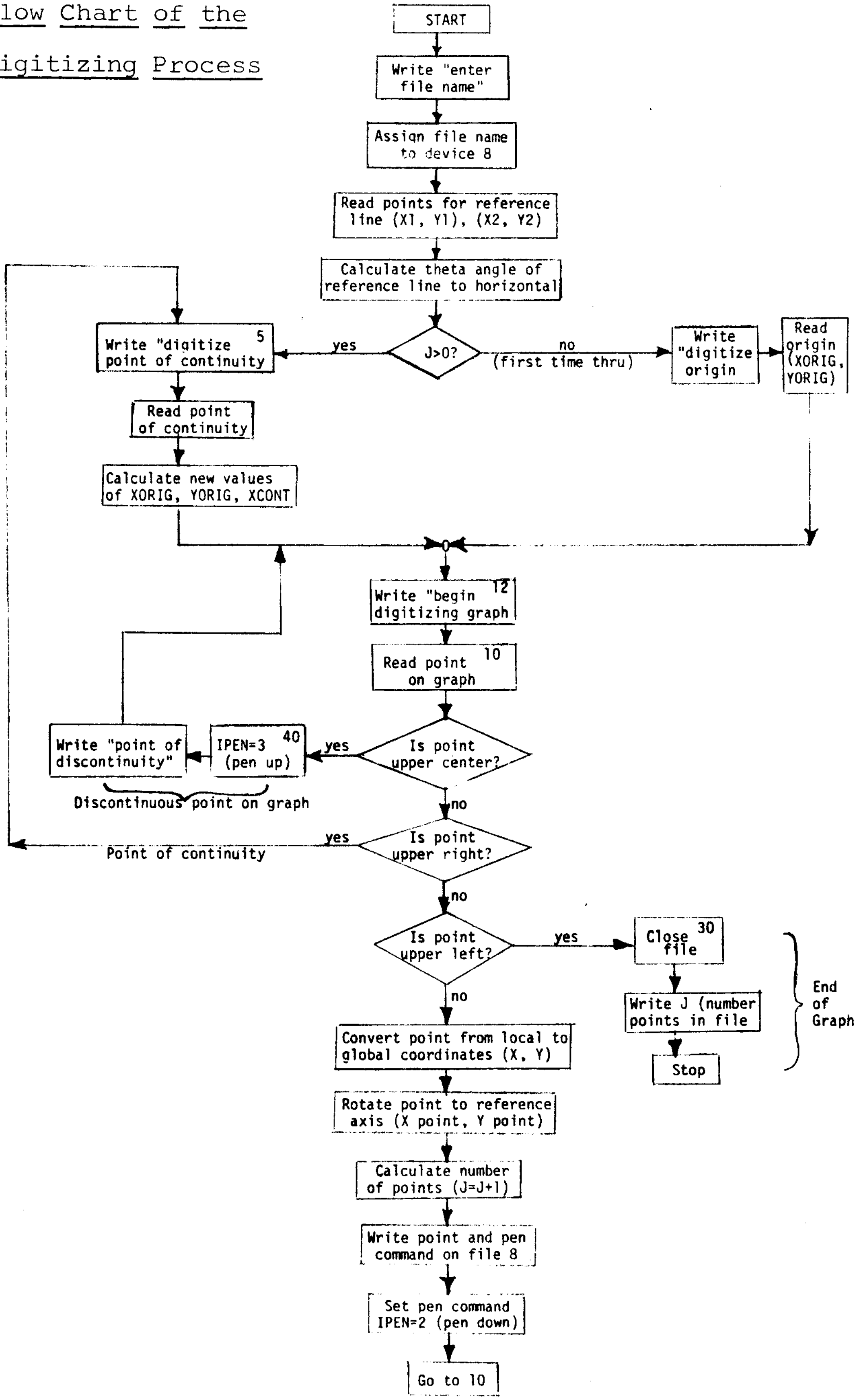
4) The next point digitized is the origin. All subsequent points are recorded in coordinates relative to this origin. Once an origin has been defined, this step is bypassed.

5) All subsequent points are checked to see if they are command points or graph points. Command points are located in defined areas away from the part of the digitizing table where the graphs are placed.

6) A point may indicate one of three commands:
    a) Point of continuation. This is used when swithcing from one sheet of a graph to the next when continuity is not broken. The program moves back to Step 3). The new origin is normalized with the previous one.
    b) Point of discontinuity. This command causes the pen to be in an up position when graphing between this point and the next.
    c) End of graph. This indicates that the previous point was the last on the graph. The file is closed and the points are counted.

7) If the point is not a command point, it is a graph point. Its coordinates are normalized to the origin and the horizontal axis, and are written on the file. The program then reads the next point.

Flow Chart of the Digitizing Process



Digitizing Program*

```
         CALL PLOTS(0,0,13)
      TAN(X)=SIN(X)/COS(X)
      J=0
      XCONT=0.
      IPEN=3
      WRITE(7,1)
    1 FORMAT(///,1X,'ENTER FILE NAME')
      CALL ASSIGN(8,,-1)
C  READ TWO REFERENCE POINTS
    5 WRITE(7,2)
    2 FORMAT(///,1X,'DIGITIZE TWO REFERENCE POINTS')
      CALL TCOCR(ICHAR,IX,IY)
      X1=IX/100.
      Y1=IY/100.
      CALL TCOCR(ICHAR,IX,IY)
      X2=IX/100.
      Y2=IY/100.
      THETA=ATAN2(Y2-Y1,X2-X1)
      IF(J.GT.0)GO TO 20
C   ESTABLISH AN ORIGIN
      WRITE(7,3)
    3 FORMAT(//,1X,'DIGITIZE THE ORIGIN')
      CALL TCOCR(ICHAR,IX,IY)
      XORIG=IX/100.
      YORIG=IY/100.
C  READ POINTS ON THE GRAPH
  12  WRITE(7,4)
    4 FORMAT(//,1X,'BEGIN DIGITIZING THE GRAPH')
   10 CALL TCOCR(ICHAR,IX,IY)
C  CHECKS UPPER, CENTER FOR DISCONTINUITY
      IF(IY.GE.2900.AND.IX.GE.1500.AND.IX.LE.2500)GOTO 40
C  CHECKS UPPER RIGHT CORNER---CONTINUATION
      IF(IY.GE.2900.AND.IX.GE.2500) GO TO 5
C   CHECKS UPPER LEFT CORNER---END OF FILE
      IF(IY.GE.2900.AND.IX.LE.1000)GO TO 30
      X=IX/100.-XORIG
      Y=IY/100.-YORIG
C   ROTATE POINT TO REFERENCE AXIS
      XPOINT=X/COS(THETA)+(Y-X*TAN(THETA))*SIN(THETA)+XCONT
      YPOINT=(Y-X*TAN(THETA))*COS(THETA)
      J=J+1
      WRITE(8,100)XPOINT,YPOINT,IPEN
      IPEN=2
  100 FORMAT(2F10.2,I1)
      GO TO 10
C NEW POINT FOR CONTINUATION, READ THE POINT FIRST
   20 WRITE(7,7)
    7 FORMAT(//,1X,'DIGITIZE POINT OF CONTINUITY AT NEW LOCATION')
      CALL TCOCR(ICHAR,IX,IY)
      XORIG=YPOINT*SIN(THETA)+IX/100.
      YORIG=-YPOINT*COS(THETA)+IY/100.
      XCONT=XPOINT
C  FIND NEW REFERENCE ANGLE
      GO TO 12
   30 CALL CLOSE(8)
      WRITE(7,6)J
   6  FORMAT(///,1X,'THIS FILE HAS ',I4,' POINTS')
      STOP
   40 IPEN=3
      WRITE(7,41)
   41 FORMAT(//,1X,'POINT OF DISCONTINUITY')
      GO TO 12
      STOP
      END
```

---

* Programming by Steve Elgar, University of Idaho, Engineering School

Definition of Variables and Subroutines

Variables

J	Number of points digitized
XCONT	Value added to X-coordinate to "extend" size of digitizing table
IPEN	=2, pen down; =3, pen up
ICHAR	Dummy variable (not used)
IX, IY	Points on digitizer, in inches * 100
(X1, Y1) (X2, Y2)	Coordinates of points on reference axis
Theta	Angle of reference axis with table's horizontal
(XORIG, YORIG)	Coordinates of an origin - all subsequent points are relative to this point
(X, Y)	Coordinates of point on graph relative to origin
(XPOINT, YPOINT)	Coordinates of point on graph relative to origin and rotated to align with a true horizontal axis

Subroutines

Plots	Initializes plotter hardware (system routine)
Assign	Reads name and assigns name to file on disk and opens file for input (system routine)
TCHOOR	Reads coordinate of point from digitizer (system routine) IX = X coordinate * 100 in. IY = Y coordinate * 100 in.
Close	Closes file opened by assign (system)
Tan (X)	Returns tangent of angle (radians) X

SELECTED WATER RESOURCES ABSTRACTS Input Transaction Form 1. Report No. 2.	3. Accession No. W
4 Title **Interactions between Open Mining and Groundwater Flow Systems at the East Area of the Gay Mine, Idaho**	5. Report Date 6.
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16. Abstract

Phosphate ore is mined from open pits at the Gay Mine, located 30 miles northeast of Pocatello, Idaho. Mining activity interacts with groundwater flow systems that are controlled primarily by complex fault block structure. Flooding of the pits by groundwater discharging from the Wells formation has seriously hindered mining operations. This report presents a conceptual model of groundwater flow systems to aid in the reduction of detrimental interactions between mining and water resource systems.

The conceptual model was used to predict and evaluate potential interactions at a proposed Group 1 pit site. Mining at this site will intersect the major flow system in the Wells formation and a smaller flow system in the Dinwoody formation. Calculations show that dewatering wells are a practicable solution to these problems.

Limited studies involving leaching of mine waste material indicate that degradation of water quality is not a problem. The overall impact of mining on water resources is minimal.

17a. Descriptors Mine wastes

17b Identifiers Pocatello, Idaho

17c COWRR Field & Group 08 D, 08 E

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