BLACK ROCK - MOXEE VALLEY GROUNDWATER STUDY

by

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and
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January 1993
OFTR 93-1

This Open File Technical Report presents the results of a hydrologic investigation by the Water Resources Program, Department of Ecology. It is intended a working document and has received internal review. This report may be circulated to other Agencies and the Public, but is not a formal Ecology Publication.

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ACKNOWLEDGEMENTS

The authors would like to acknowledge the past project leaders on this study for their hard work and useful ideas: Bill Myers 1983 - 1985, Kirk Cook 1986 - 1988, and Mark Ader 1989 - 1990. We owe our thanks to Howard Powell, Enforcement Section Supervisor, for assisting us with his well construction expertise and lending us his knowledge of the drilling history within the study area. Dr. Robert Bentley of Central Washington University and Newell Campbell of Yakima Valley Community College are acknowledged for their assistance and helpful suggestions throughout the course of the study. We acknowledge Linton Wildrick and Dr. Art Larson for their careful review of the manuscript. Finally, we are grateful to John Kieling, Intern Assistant, Hank Riddle, Cartographer, and Phil Crane, Data Management Specialist, for the many hours spent tabulating data and creating charts, graphs and figures. Many other Departmental staff have contributed through the collection of water level and pump test data, to you we say thank you.

This study would not have been possible without the constant support and guidance of Darlene Frye, Technical Unit Supervisor, and Doug Clausing, Water Resources Section Supervisor.

EXECUTIVE SUMMARY

The Washington State Department of Ecology began a focused study of the ground water in eastern Moxee Valley and Black Rock Valley in 1983 after the discovery of ground-water-level declines in the area. The study determined the nature and extent of the aquifers, how the aquifers are hydrogeologically separated, and, most importantly which aquifers are experiencing water-level declines.

Based on a variety of geologic and hydrogeologic data, four aquifers were identified. The four aquifers lie on top of one another. The lower three aquifers are composed almost entirely of basalt with some interspersed sedimentary layers. The uppermost aquifer is mostly sediment and contains only one thin basalt flow.

The deepest aquifer in the study area is the Grande Ronde Basalt Aquifer. Water levels are declining approximately 13 feet per year in the few wells completed into this aquifer. The Grande Ronde water levels east of the Bird Canyon Fault (Figure E-1) are of greatest concern due to a long history of decline.

The Wanapum Aquifer overlies the Grande Ronde Aquifer, and is separated from the Grande Ronde by the sedimentary Vantage Interbed. The Wanapum is divided along the Bird Canyon Fault into two separate bodies of ground water (Figure E-2). Water levels west of the fault appear stable. East of the fault, however, water levels have been declining for the last ten tears at a rate of approximately 12 feet per year.

The two uppermost aquifers in the study area are the Upper and Lower Saddle Mountains Aquifers. The Lower Saddle Mountains Aquifer is divided geographically into three areas. The Upper Saddle Mountains Aquifer contains two separate ground-water areas. Water levels in the central area of the Lower Saddle Mountains Aquifer are declining approximately 6 feet per year. In a small portion of the western area of the Upper Saddle Mountains Aquifer, water levels have been declining approximately 2.5 feet per year (Figures E-3 and E-4).

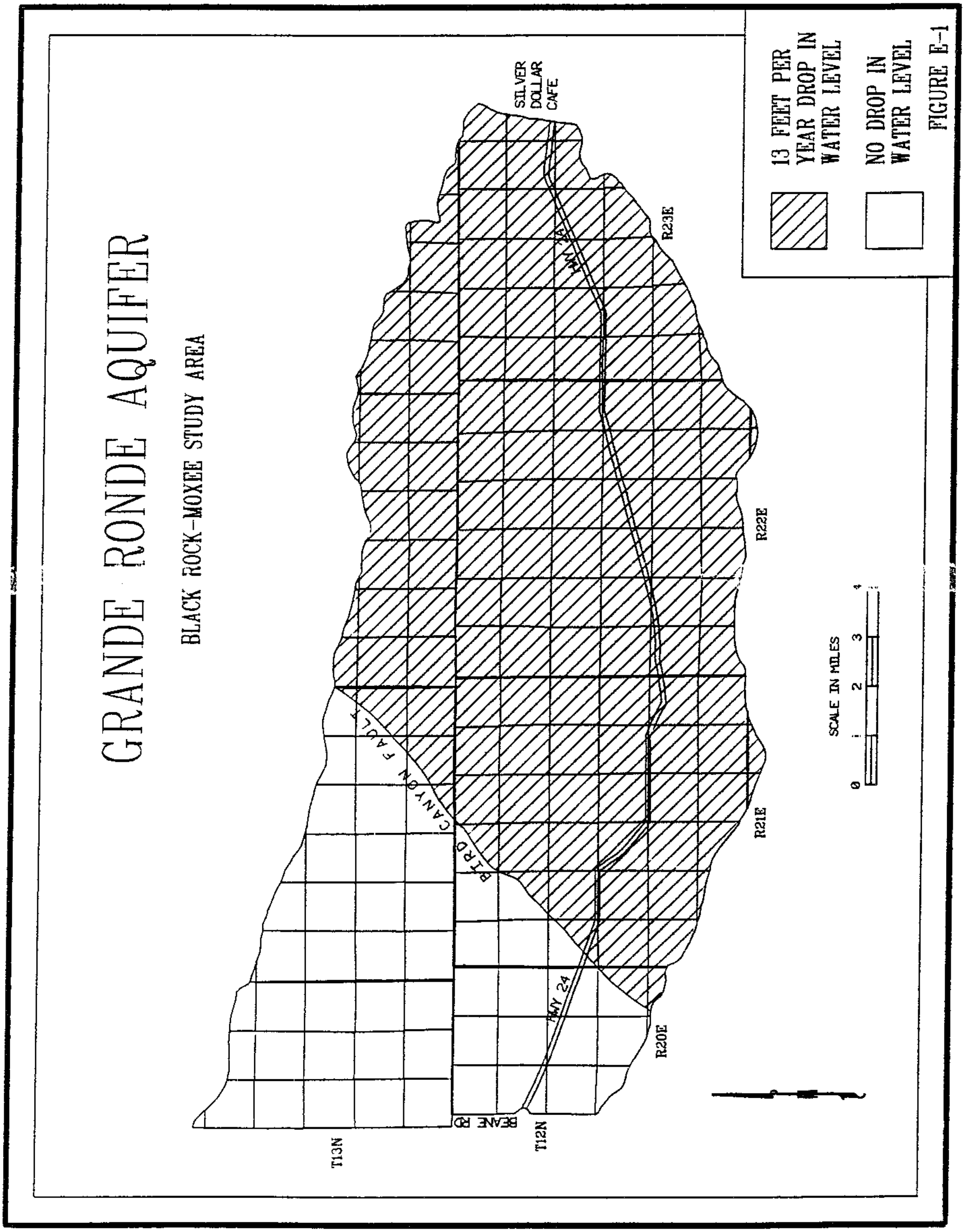
GRANDE RONDE AQUIFER
BLACK ROCK-MOXEE STUDY AREA
13 FEET PER YEAR DROP IN WATER LEVEL
NO DROP IN WATER LEVEL
SILVER DOLLAR CAFE
HWY 24
BIRD CANYON FAULT
BEANE RD
T13N
T12N
R20E
R21E
R22E
R23E
SCALE IN MILES
0
1
2
3
4

FIGURE E-1

WANAPUM AQUIFER

BLACK ROCK-MOXEE STUDY AREA

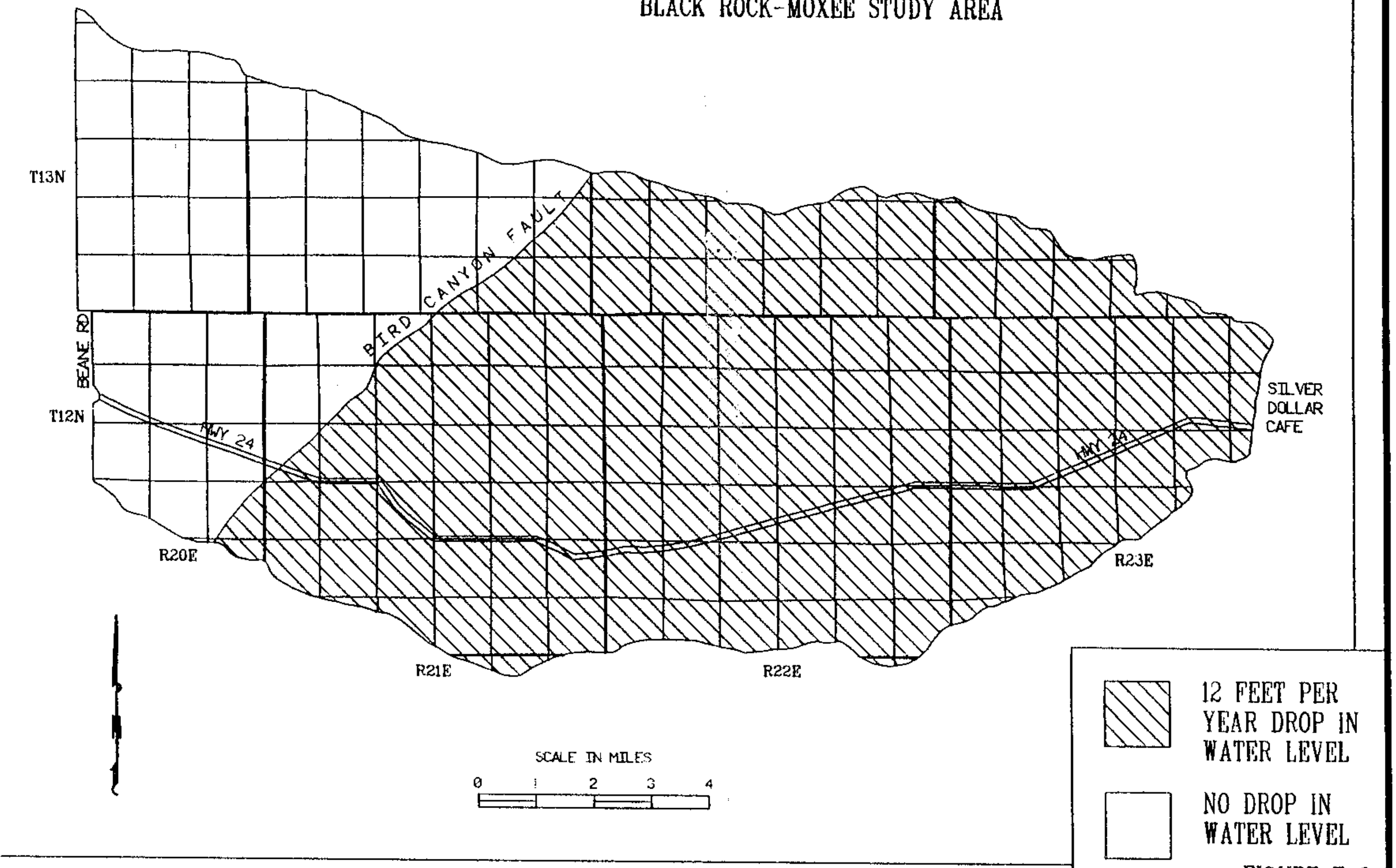

FIGURE E-2

LOWER SADDLE MTNS. AQUIFER

BLACK ROCK-MOXEE STUDY AREA

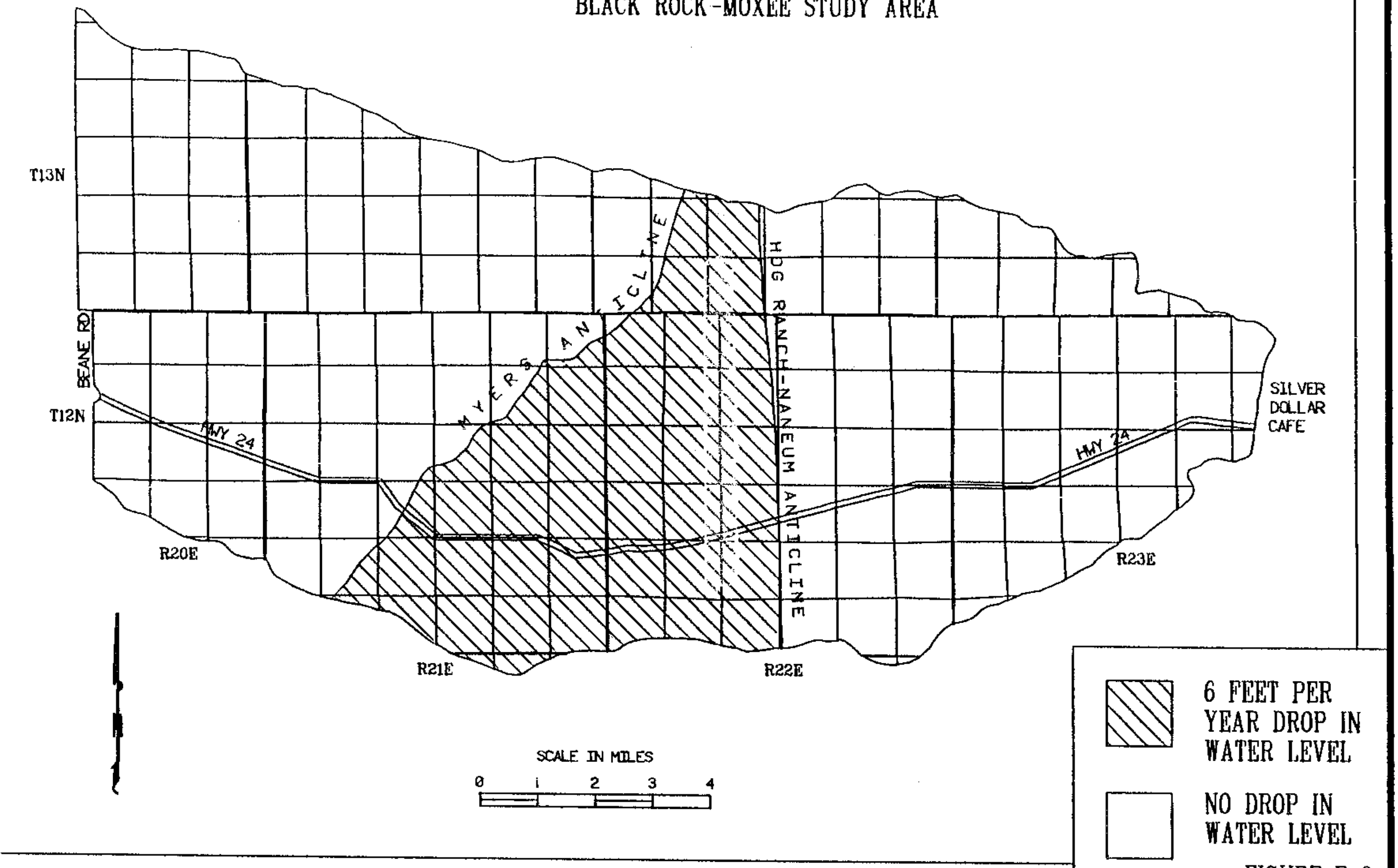

FIGURE E-3

UPPER SADDLE MTNS. AQUIFER

BLACK ROCK–MOXEE STUDY AREA

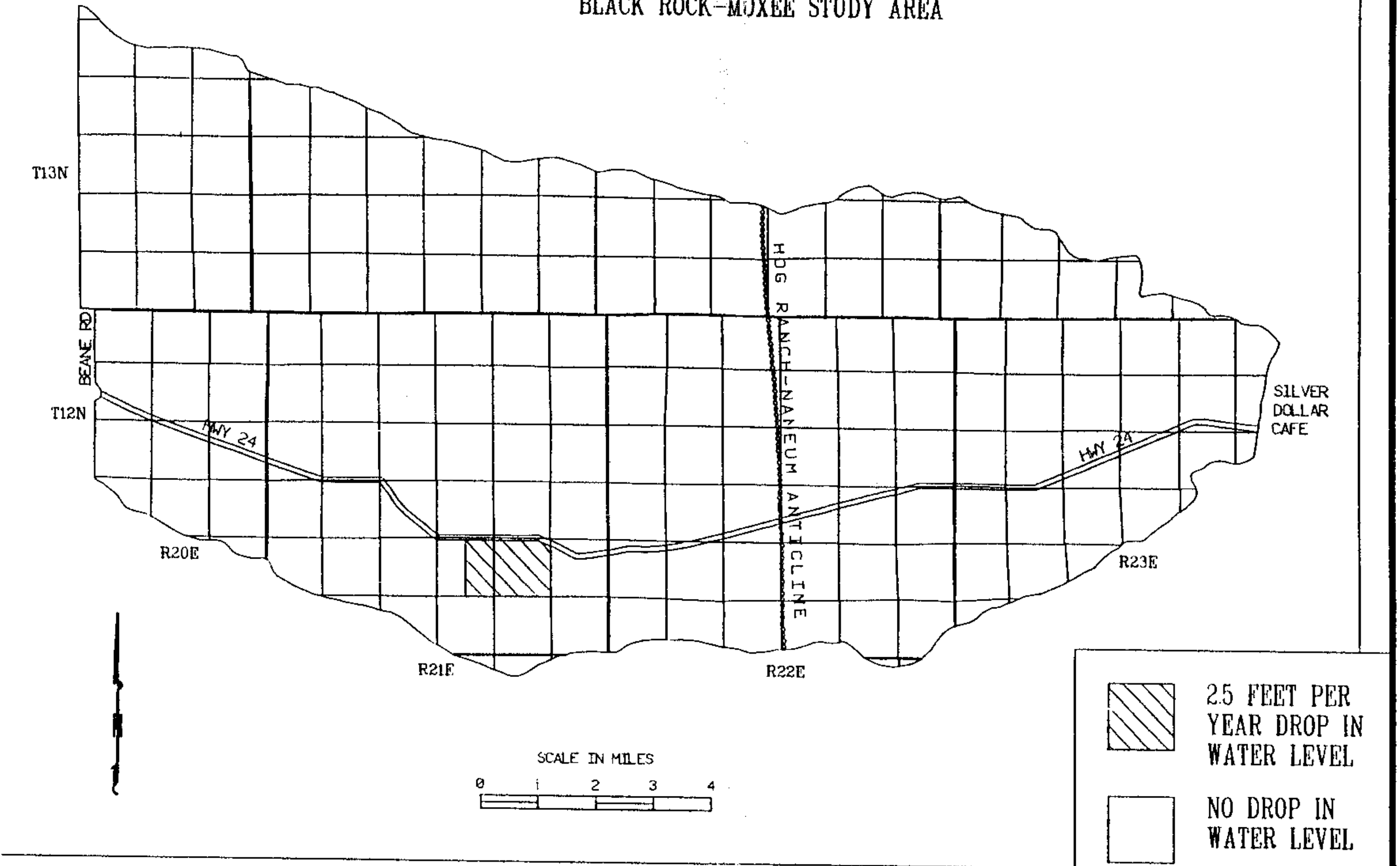

FIGURE E-4

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SECTION 1

INTRODUCTION

In the Spring of 1978, as part of a water-level-monitoring program, the Washington State Department of Ecology (hereafter referred to as the Department) began measuring certain wells in the eastern portion of the Moxee Valley and in the Black Rock Valley. Over the next several years, additional wells were selected for measurement. By 1981, the core of the present-day monitoring-well network was in place. In the spring of 1982, the Department noted significant annual water-level declines in a number of the monitoring wells. In 1983, the Department identified an area of concern and declined to make further permitting decisions until sufficient data was available. In 1983, a hydrogeological study of the area of concern was initiated.

Purpose and Objectives

The purpose of this study is to provide the water rights permitting section in the Department's Central Regional Office with the geologic and hydrogeologic information necessary to evaluate water right applications within the Blackrock-Moxee study area. The objectives are as follows:

1.) Determine the source aquifer for each well.

2.) Examine the spacial distribution of wells within each aquifer

3.) Determine if observed water-level declines are occurring throughout the study area or within discrete areas.

4.) Construct conceptual hydrogeologic models for each aquifer.

Location and Description of the Study Area

The study area covers approximately 153 square miles in the eastern portion of Yakima County, Washington, including the eastern portion of Moxee Valley and all of Black Rock

Valley (Figure 1). The western edge of the study area is about 8 miles east of Yakima, while the eastern edge is one half mile east of Horse Thief Point near the junction of Highways 24 and 241.

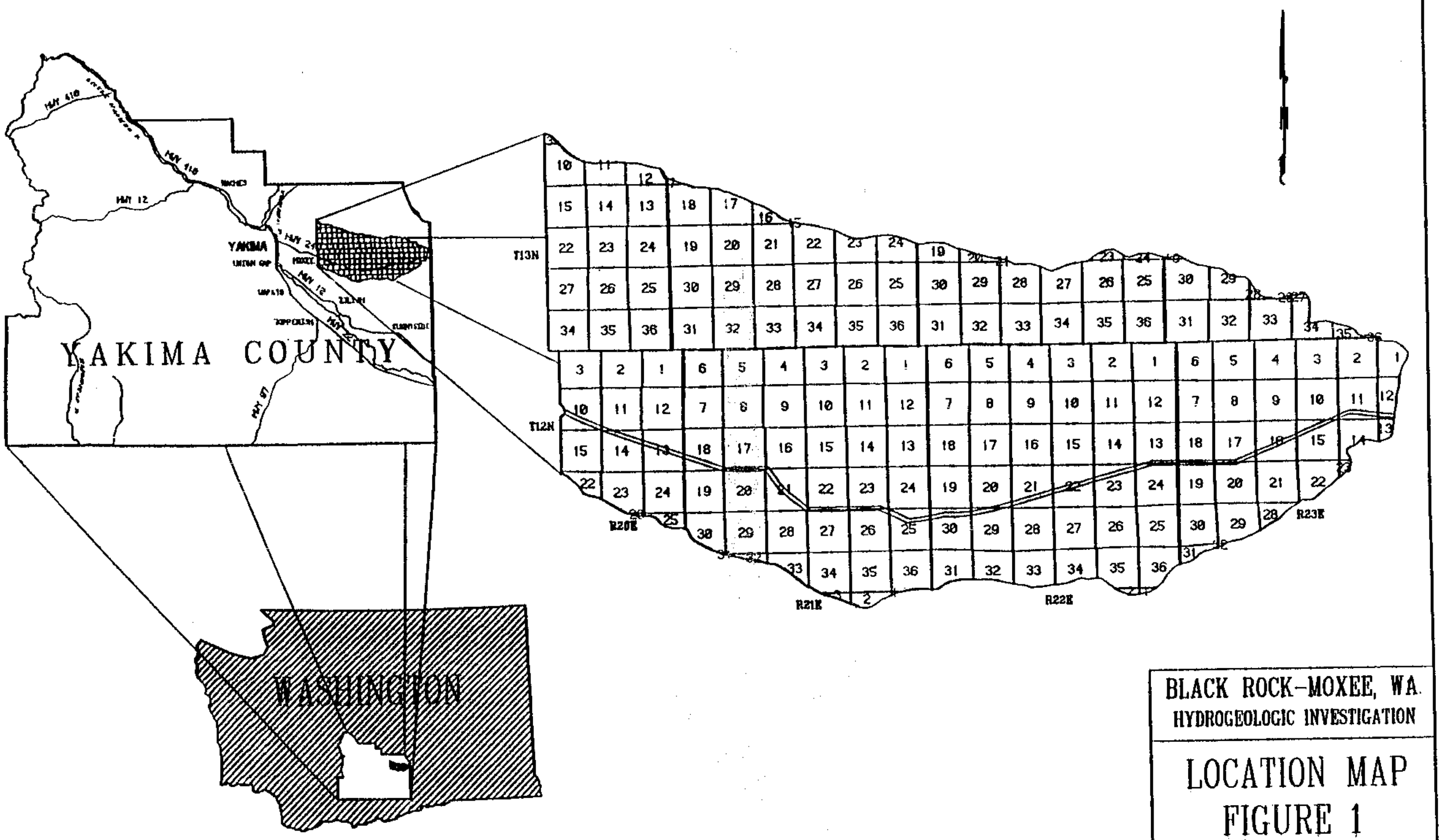
Physiography

The study area is located in the Yakima Fold Belt Subdivision of the Columbia Basin Physiographic Province (Figure 2) (Raisz, 1941). The Yakima Fold Belt is characterized by east-west trending ridges and intervening valleys. Canyons and draws that are eroded into the ridges generally trend northeast-southwest or northwest-southeast. The Blackrock-Moxee Valley is typical of the east-west tending valleys and is bounded on the north by Yakima Ridge and the Rattlesnake Hills on the south. The eastern margin of the study area is formed at a point east of Horse Thief Point where the Rattlesnake Hills and Yakima Ridge nearly converge. The western margin was chosen to fully incorporate the areas of observed ground water declines.

Climate

The climate is semi-arid and, on average, the area receives approximately 8 inches of precipitation annually (Donaldson, 1979). Average-annual precipitation collected from 1984 to 1990 is graphed in Figure 3. Approximately 70% of the area's precipitation occurs from October 1 through April 30, and by the end of June this figure increases to about 90% (Donaldson, 1979). The elevation of the study area is highest along Yakima Ridge which ranges in elevation from 3,000 to 4,100 feet above mean sea level (msl). Consequently, the average precipitation along Yakima Ridge from Range 20 through Range 22 is higher, being about 10 inches a year (USDA, 1965). With the exception of certain lands in the western end of the study area, ground-water withdrawals provide the only source of irrigation water.

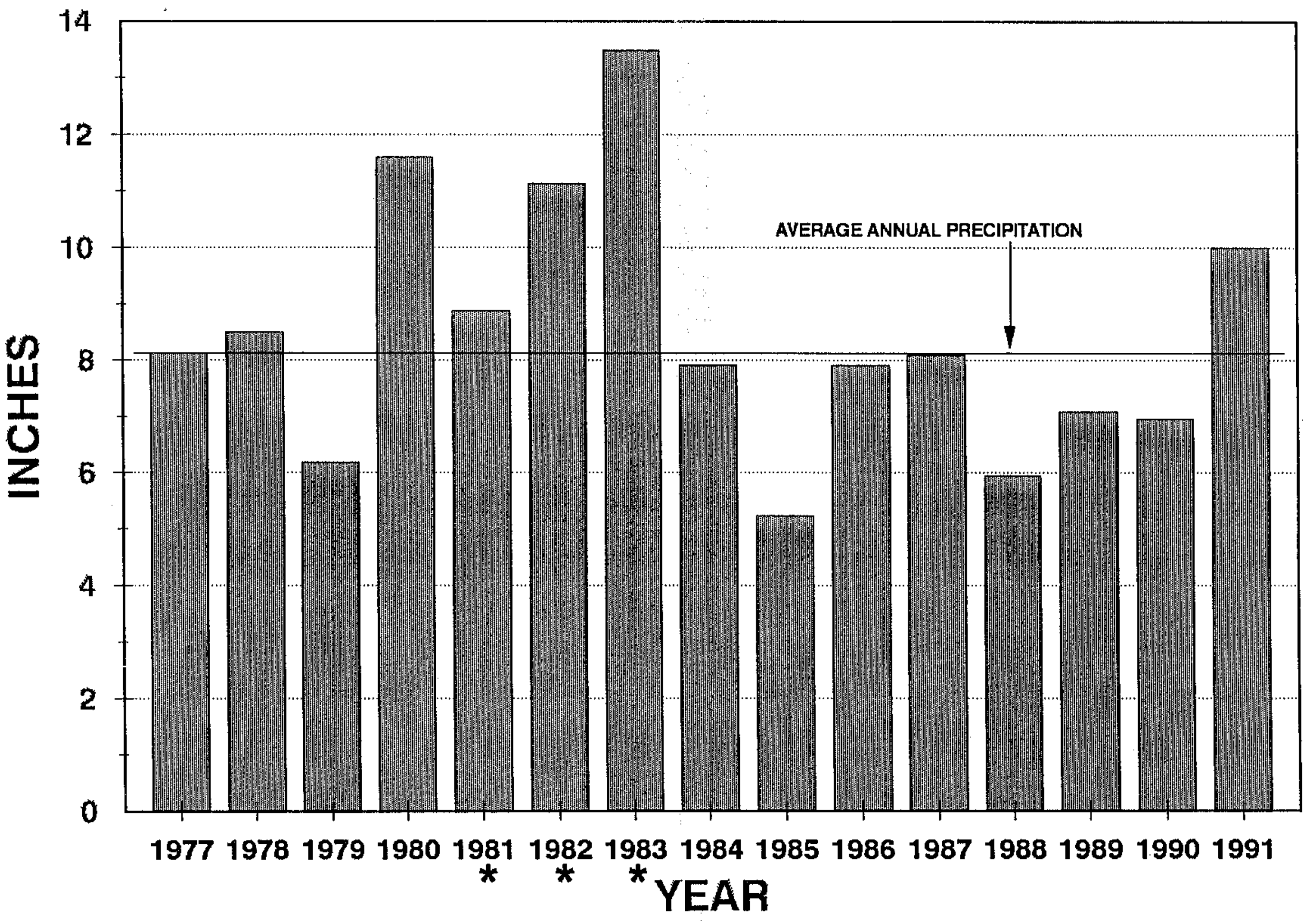
Approximately 8,000 acres within the study area are currently irrigated with ground water. The area does not have any perennial creeks or streams, but there are numerous springs and seeps that emerge from the south side of Yakima Ridge. The discharge from the springs usually does not coalesce and, in all cases, infiltrates back to the subsurface after a relatively short distance of travel from the source. Dry Creek has formed the most apparent channel in the study area and drains easterly within the Blackrock Valley. Dry Creek is ephemeral and, as such, flows infrequently and briefly in response to intense rainfall.



BLACK ROCK-MOXEE, WA.
HYDROGEOLOGIC INVESTIGATION

LOCATION MAP
FIGURE 1

Figure 2. Columbia Basin Physiographic Province. Heavy lines = provinces; light lines = subdivisions. From Raisz, 1941.



* ESTIMATED FROM YAKIMA STATION

Figure 3. Annual Precipitation - Moxee Station, 1977-1991.

General Geology

Lying beneath the land surface in the Yakima area are about 4,900 feet (Campbell, 1989) of interbedded basaltic lava flows and sedimentary strata known as the Columbia River Basalt Group. Compositional and chemical differences in the lava flows allows geologists to stratigraphically divide the Columbia River Basalt Group into Formations and Members.

North-south compression of the earth's crust has caused the basalt and interbedded sedimentary strata to deform. Structures resulting from deformation in the Yakima Fold Belt are characterized by east-west trending anticlines and synclines that have been cut by northwest-southeast and northeast-southwest trending faults. The anticlines are now expressed at the surface as ridges, the synclines as valleys, and the faults as draws and canyons that dissect the ridges (Figure 4). Within the study area the stratigraphy and structural geology are the primary factors controlling ground water occurrence and movement.

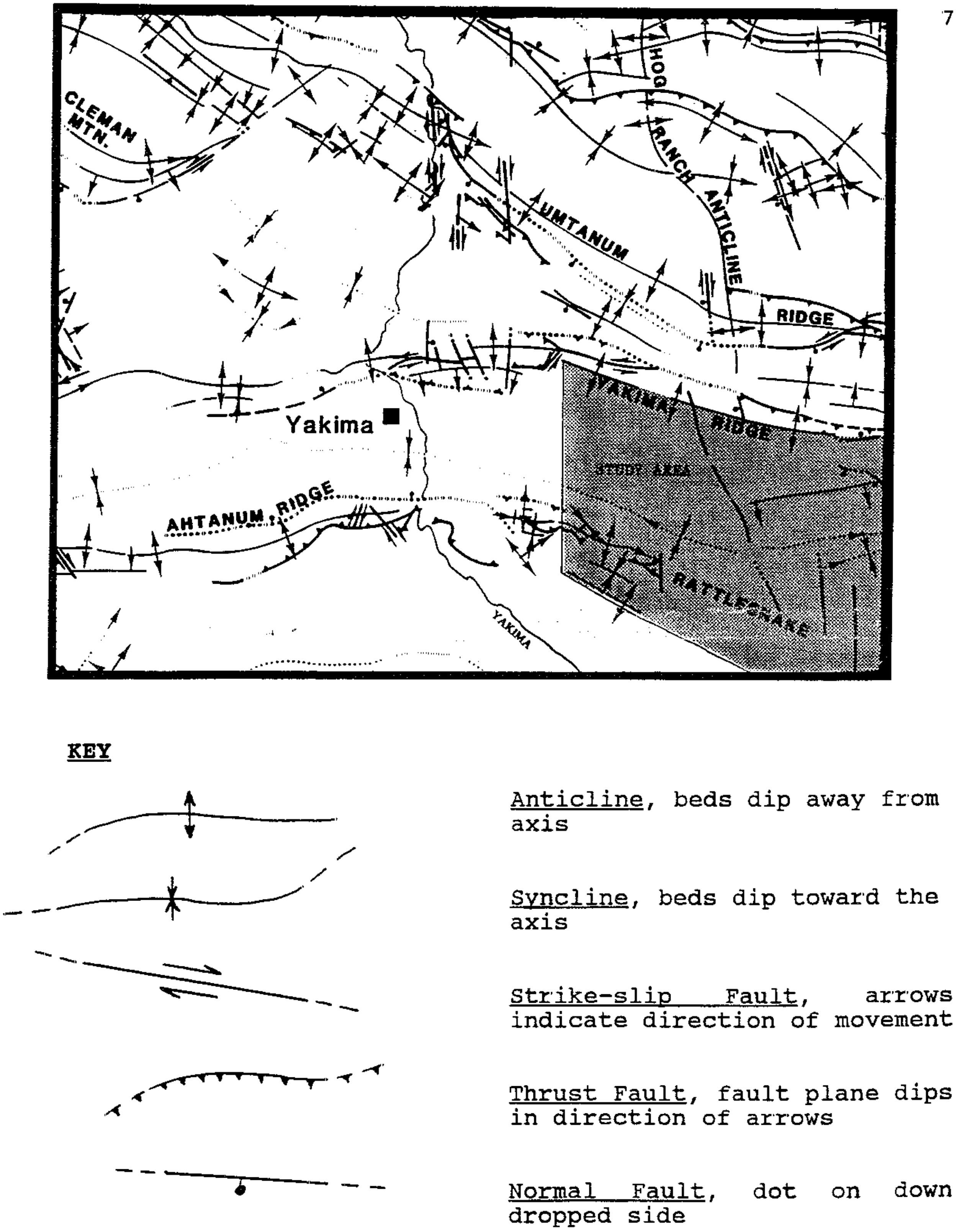
Methods of Investigation

To study the stratigraphy, the structural geology, and the hydrogeology of the study area, many different types of data from many sources were to be collected and analyzed. Much of the data pre-dates this investigation and some was collected primarily for this study. The data types include geophysics, geochemistry, hydrochemistry, water levels, hydraulic tests, well video scans, maps and aerial photographs, and well reports.

Description of Data

Borehole Geophysics - Borehole geophysics is useful in the correlation of strata between wells, determination of lithologies, bed thicknesses, and well construction. Several geophysical methods, referred to as suites, were run on 12 irrigation wells by Washington State University (Figure 5). A typical suite run on study area wells included a gamma-gamma (γ-γ) log, neutron log (N), natural gamma log (N-γ), caliper log (CALP), resistivity log (RES), self-potential log (SP), and fluid temperature log (TEMP). These twelve wells provide control points for the stratigraphic interpretation of the other well logs in the study area.

Geochemistry - In 1979 and 1980, the Department obtained rock-chip samples from the drilling operations of three irrigation



KEY

Anticline, beds dip away from axis

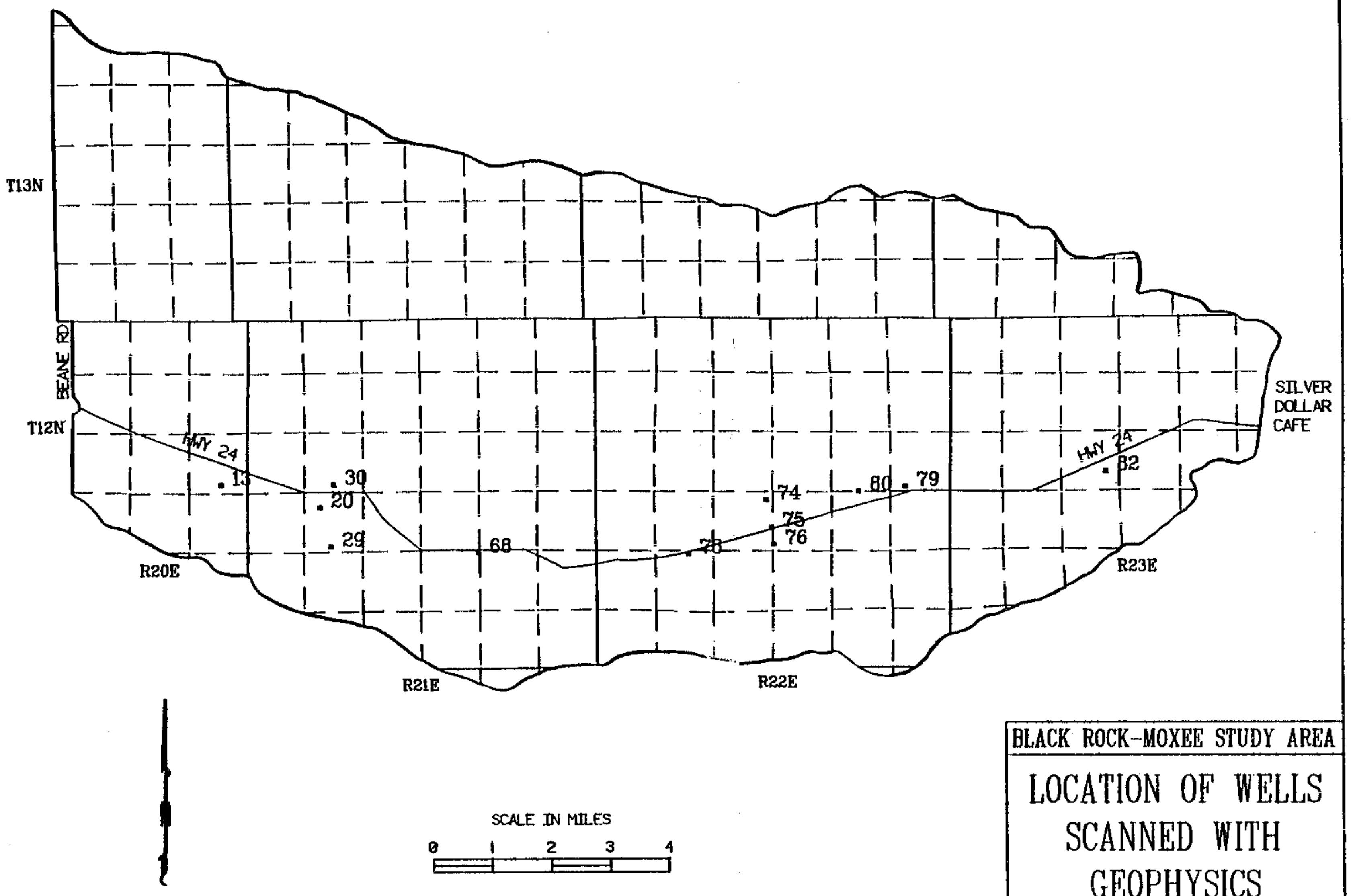
Syncline, beds dip toward the axis

Strike-slip Fault, arrows indicate direction of movement

Thrust Fault, fault plane dips in direction of arrows

Normal Fault, dot on down dropped side

Figure 4. Generalized Structural Geology (Modified from Tolan and Reidel, 1989).



BLACK ROCK-MOXEE STUDY AREA

LOCATION OF WELLS
SCANNED WITH
GEOPHYSICS

FIGURE 5

wells (Figure 6). These samples were sent to Washington State University in Pullman, Washington for X-ray fluorescence analysis. The analytical results were interpreted by Steve Reidel of Westinghouse Hanford Operations. Mr. Reidel provided the Department with a stratigraphic interpretation for each of the horizons from which samples were taken. This information was used for comparison with the geophysics and well log information on the three wells.

Water Quality - From 1979 to 1981, the Department collected water samples from 9 irrigation wells (Figure 7) and sent them to the Washington State University Soils Lab and the Yakima Testing Laboratory for elemental analysis. This information assisted in the definition of aquifers.

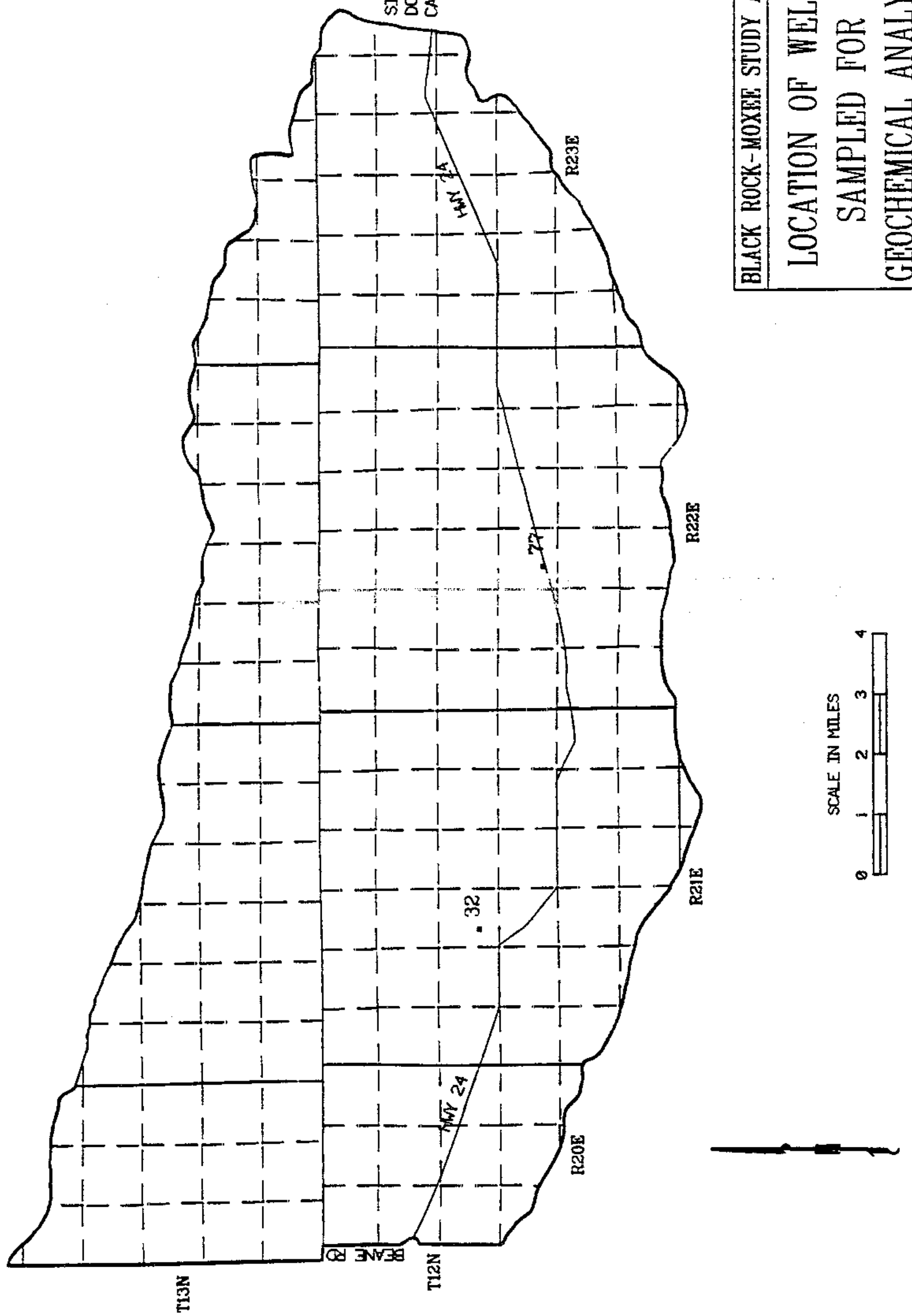
Water Levels - The Department has measured a network of wells within the study area since 1981. The wells are measured each spring before the start of irrigation season. However, not all wells have a full 10 years of data. Some wells have been added because they have been recently drilled. Other wells have been discontinued due to the discovery of well-construction problems, lack of well information, or of measurement problems. However, the network contains properly constructed wells in each of the four aquifers (Figure 8). Water-level measurements have been evaluated both temporally and spatially to reveal information about the aquifer.

Hydraulic Testing - Several aquifer tests were conducted to assist in characterizing aquifers and how they interrelate with one another. A typical aquifer test involved pumping a single well while monitoring the water levels in several observation wells. Aquifer test results helped the Department to understand the hydraulic relationships between aquifers and provided evidence as to the existence and location of vertical geologic structures.

Well Video Scans - In the summer of 1991, several well video scans were performed. These scans assisted in stratigraphic interpretation and understanding, as well as aquifer delineation and verification of well construction data.

Maps and Aerial Photographs - Several large-scale, regional mapping projects which include the study area have been published by the United States Geological Survey. These maps provided a rough guide to the structure and geology of the area. High-altitude aerial photographs were also used in structural interpretation and lower-elevation photographs were used for well location.

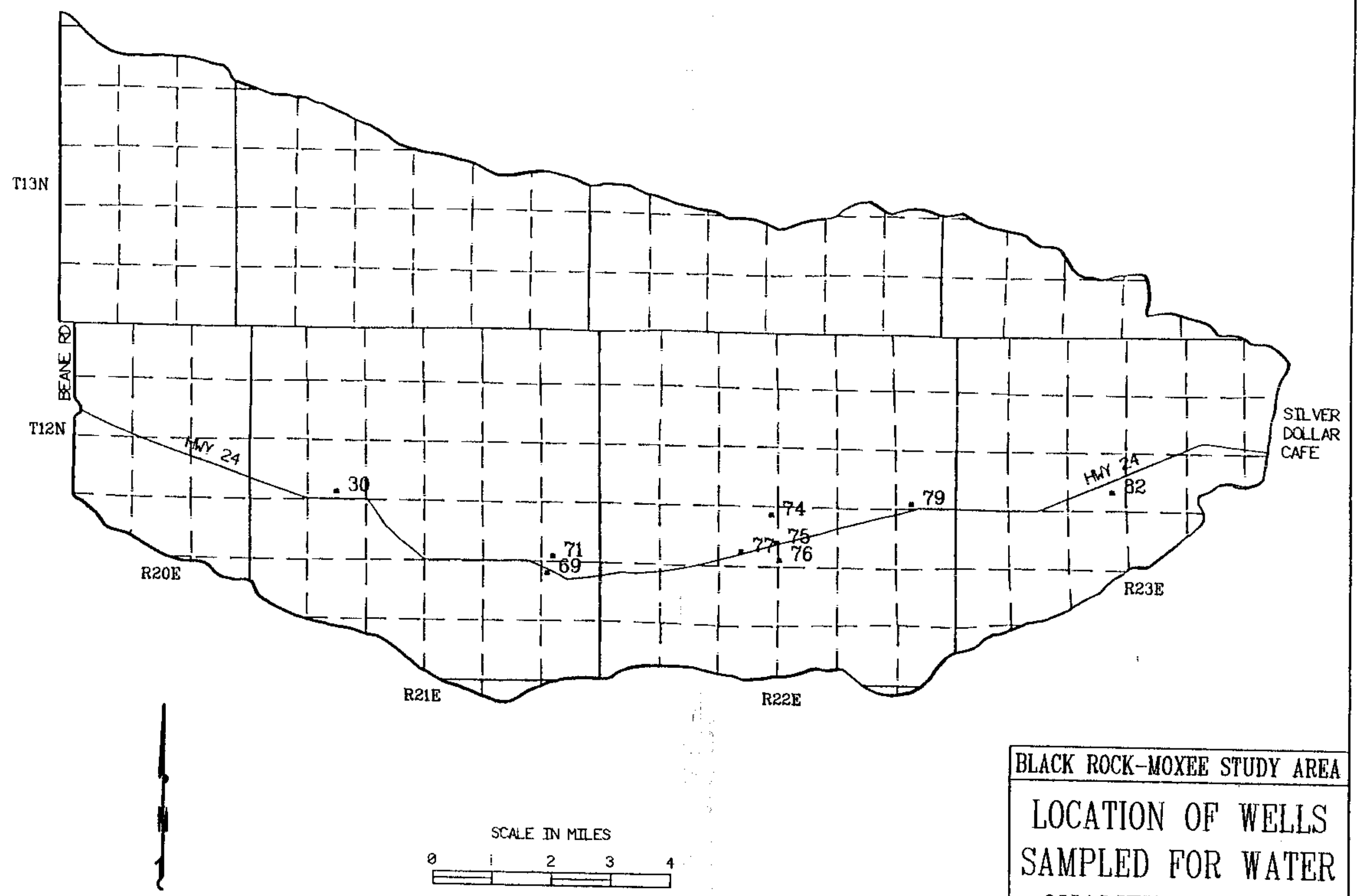
Well Reports - Well reports (well logs) contain the driller's record of rock types and sediment encountered during drilling, as well as water levels and well-construction information.



BLACK ROCK-MOXEE STUDY AREA

LOCATION OF WELLS SAMPLED FOR GEOCHEMICAL ANALYSIS

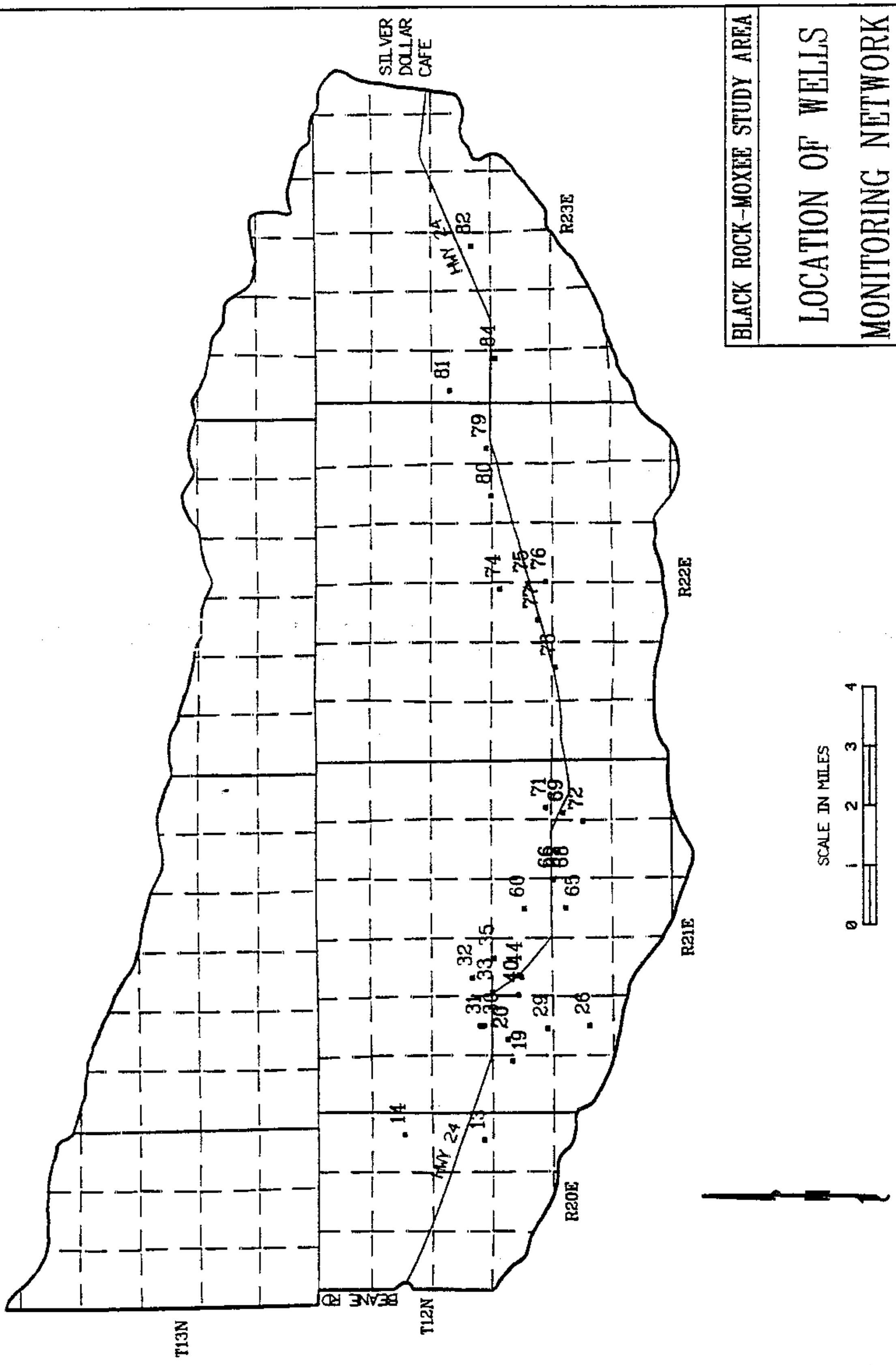
FIGURE 6



BLACK ROCK-MOXEE STUDY AREA

LOCATION OF WELLS SAMPLED FOR WATER QUALITY ANALYSIS

FIGURE 7



BLACK ROCK-MOXEE STUDY AREA

LOCATION OF WELLS MONITORING NETWORK

FIGURE 8

These reports were used to delineate the subsurface stratigraphy and to calculate aquifer thickness. All 150 of the well reports that the Department has on file for the study area were examined. Of these, 85 were selected as study wells and used in lithologic and hydrologic analysis. Wells were selected for study if they penetrated basalt, or if the well had an associated water-right certificate, permit, or application.

Well-Numbering Systems

The study wells are numbered and identified by two systems. The first system simply numbers the wells from 1 to 85. This system is used in conjunction with the owners name and personal well number and the prefix BSW. For example, the label BSW #75 - (Marley #3) should be interpreted as follows: BSW stands for Black Rock Study Well; #75 indicates it is number 75 of the 85 study wells; Marley is or was the well owner; #3 indicates the owners personal numbering system when he has more than one well. This was a convenient method for computer entry, data tracking, and quick recognition by those familiar with the area. The second is the standard locational system employed by the United States Geological Survey (Figure 9). The first number identifies the township in which the well is located. The second number indicates the range and the third the section. The third number is followed by a letter which designates in which 40 acre subdivision or quarter-quarter the well resides Any number following the letter indicates multiple wells in the 40 acre subdivision.

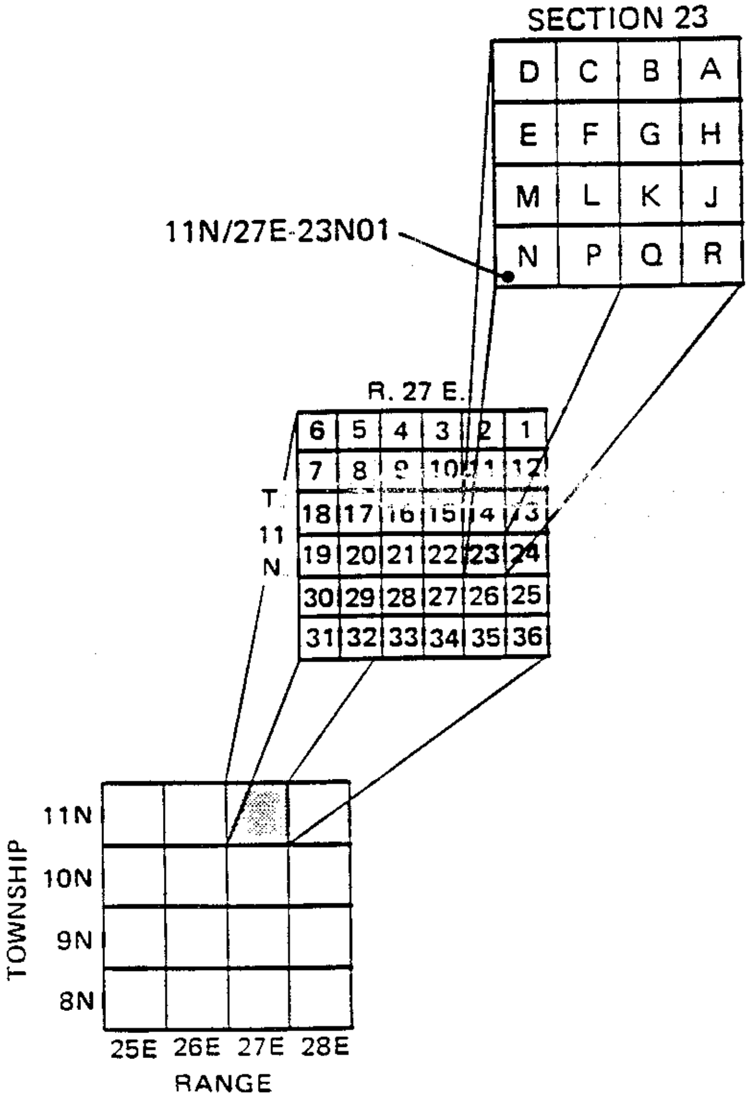


Figure 9. U.S.G.S. Well Numbering System.

SECTION 2

STRATIGRAPHY

The stratigraphic units that are of interest in the study area are the sedimentary Ellensburg Formation and the basalt formations of the Yakima Basalt Subgroup. Combined, the Ellensburg Formation and Yakima Basalt Subgroup comprise the Columbia River Basalt Group. Three basalt formations comprise the Yakima Basalt Subgroup including the Grande Ronde Basalt, Wanapum Basalt, and Saddle Mountains Basalt. Formation status has been assigned and formations distinguished from one another primarily on the basis of lithology and whole rock chemistry. A generalized stratigraphic column of the study area is provided in figure 10.

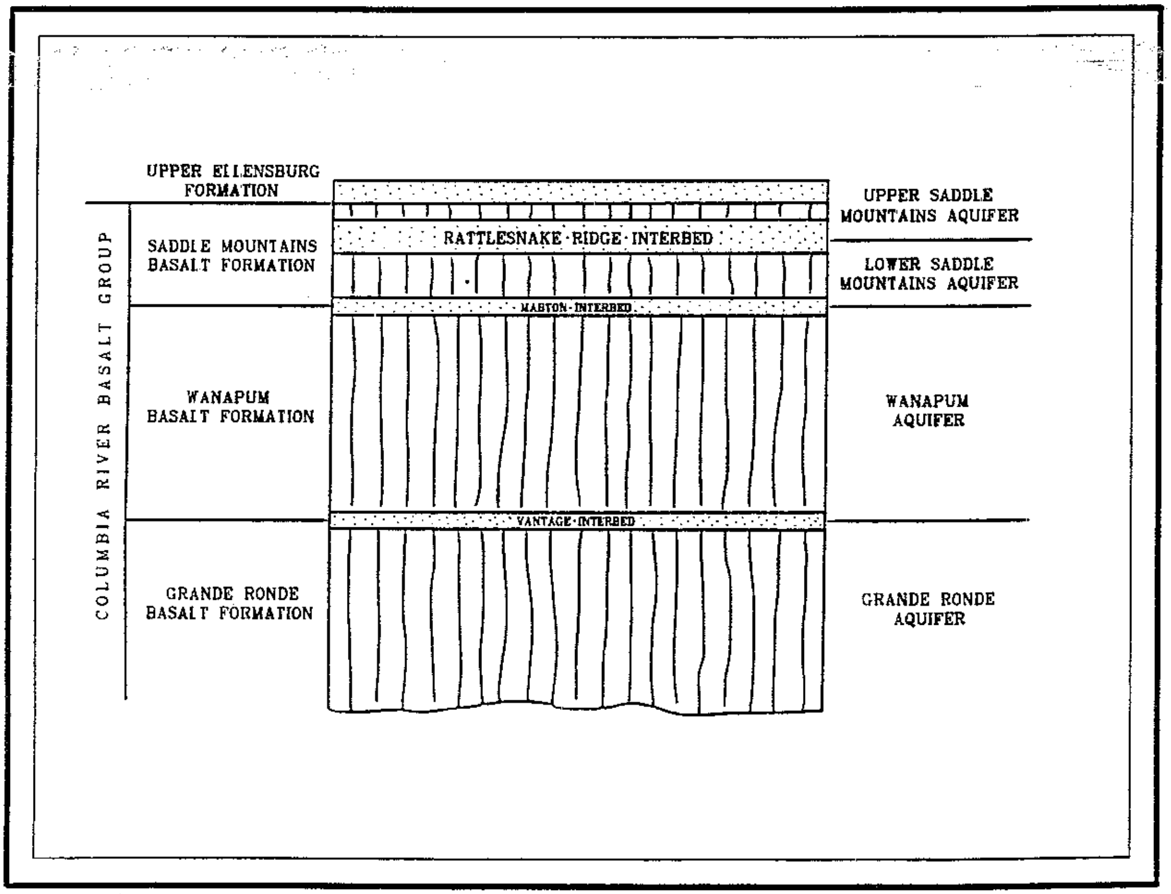


Figure 10. Generalized stratigraphy of the Columbia River Basalt Group

The basalt that makes up the Yakima Basalt Subgroup flowed from the east where it was extruded from fissures in what is now southeast Washington and northeast Oregon. Fissure eruptions began approximately 16.5 million years before present (MYBP) and continued for approximately 8 million years (Myers and Price, 1979). In many cases, several hundreds of thousands of years elapsed between eruptions. During the times between eruptions of Columbia River Basalt, ancestral Cascade volcanos discharged enormous volumes of volcanic debris that was typically deposited by debris flows, lahars, and sediment-laden rivers. The sediments, which are now preserved between basalt flows, are referred to as interbeds and belong to the Ellensburg Formation. The sedimentary interbeds exist within both the Wanapum and Saddle Mountains Formations but are most numerous and prominent within the Saddle Mountains Formation.

Grande Ronde Basalt

The Grande Ronde Basalt is the oldest and most voluminous of the formations. The formation is composed of numerous basalt lava flows that were extruded between 14 and 16.5 million years ago (Myers and Price, 1979). The Grande Ronde Basalt ranges in thickness from just a few feet along the western edge of the Columbia Plateau to 3,300 feet or more in the Pasco Basin which is east of the study area (Myers and Price, 1979).

Wanapum Basalt

Overlying the Grande Ronde Basalt is the Wanapum Basalt, the second most voluminous of the basalt formations (Myers and Price, 1979). The eruptive period of the Wanapum Basalt was between 14.5 and 13.5 million years ago (Reidel and Fecht, 1981). The formation is divided into three members, each of which is composed of several lava flows. From oldest to youngest they are the Frenchman Springs Member, Roza Member, and Priest Rapids Member (Figure 10). Known thicknesses of the Wanapum Basalt range from 988 feet in the western half, to 1,108 feet in the eastern half of the study area.

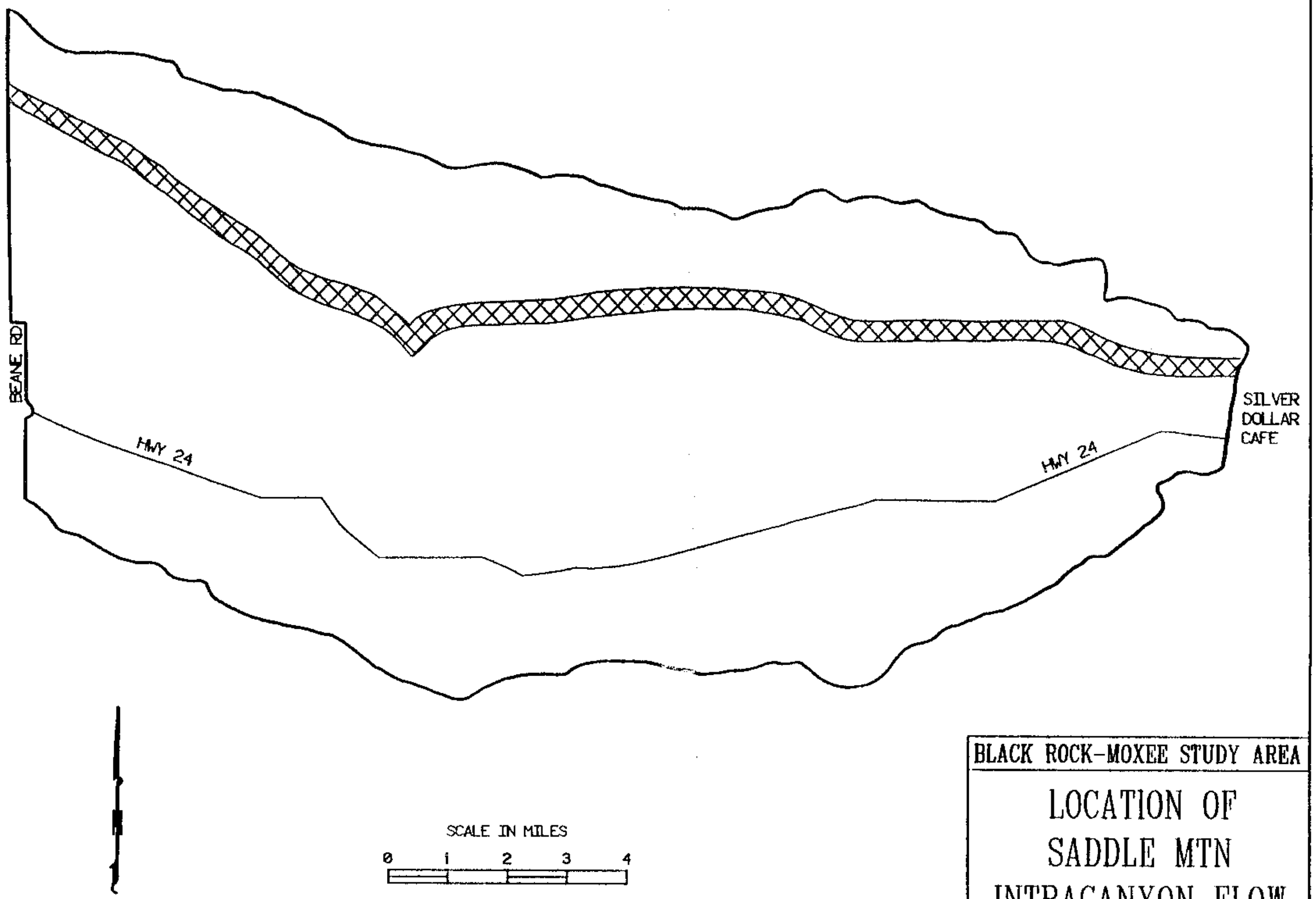
Saddle Mountains Basalt

The Saddle Mountains Basalt is the youngest and least voluminous of the three basalt formations. The Saddle Mountains Basalt was extruded over a long period of time, from about 13.5 to 6 million years ago. However, it represents less than 1 percent of the total volume of the Columbia River Basalt Group. (Myers and Price, 1979). The formation is divided into either 9 or 10 members. At some locations a member may contain only one lava flow. Only 4 or possibly 5 of the members are present in the study area. These members, from oldest to youngest, are the Umatilla Member, Wilbur Creek and/or Asotin Member, Pomona Member, and Elephant Mountain Member (Figure 10).

In contrast with the Wanapum and Grande Ronde Basalts, the distribution and thickness of the Saddle Mountains Basalt Formation appears to be much more variable. This contrast appears to have been a function of the topography that existed during Saddle Mountains time and the quantity of basalt extruded. In general, the Saddle Mountains Basalt formation thins to the west and north and includes intracanyon flows. Within the study area, the Saddle Mountains Basalt is thickest along the southern margin. A narrow intracanyon basalt flow, either part of the Wilbur Creek Member or the Asotin Member, runs roughly parallel to the crest of Yakima Ridge over most of the study area (Bentley, 1977). It is located high on the south side of Yakima Ridge and follows an east-west path that wanders just a mile or so south of the ridge crest (Figure 11). The variability in thickness and distribution of the Saddle Mountains Basalt results in notably different patterns of ground-water flow within it than either the Wanapum or Grande Ronde.

Ellensburg Formation

The Ellensburg Formation consists primarily of volcaniclastic sediments that were deposited during and between eruptions of the Columbia River Basalts. Sediments from the ancestral Columbia River are also included in the Ellensburg Formation. The sediments were typically deposited as mud flows, debris flows, lahars, or in fluvial systems that were transporting volcanic sediments. The Ellensburg sediments are thickest to the west and generally thin and inter-finger with basalt flows to the east. Some members of the Ellensburg Formation mark the geologic division between basalt formations. The deposition of these beds occurred between basaltic eruptions during periods of volcanic dormancy. The most notable of the interbeds in the study area are the Vantage, Mabton, Selah and Rattlesnake Ridge (Figure 10). The Vantage and Mabton interbeds are of particular stratigraphic interest. The Vantage is the marker bed which separates the older Grande Ronde Basalt Formation from the younger Wanapum Basalt Formation. Similarly, the Mabton Interbed is the marker bed which stratigraphically separates the Wanapum Basalt below from the Saddle Mountains Basalt immediately above it.



BLACK ROCK-MOXEE STUDY AREA

LOCATION OF
SADDLE MTN
INTRACANYON FLOW

FIGURE 11

At least two principal depositional systems have been described for the Ellensburg Formation (Schmincke, 1964). The first of these systems, known as the Ancient Cascade Volcano System, relied on a dominantly volcanic source area located to the west of the study area. This system erupted large volumes of volcanic debris which were carried eastward up to 100 miles. The principal mechanisms of transport and deposition that were acting in the Ancient Cascade Volcano System were debris flows, lahars, ash fall, and streams flowing easterly from the Ancestral Cascade Mountains. The other principle source area is referred to as the Ancestral Columbia system. The Ancestral Columbia River transported and deposited sediment eroded from the plutonic and metamorphic highlands of northern Washington and Idaho.

SECTION 3

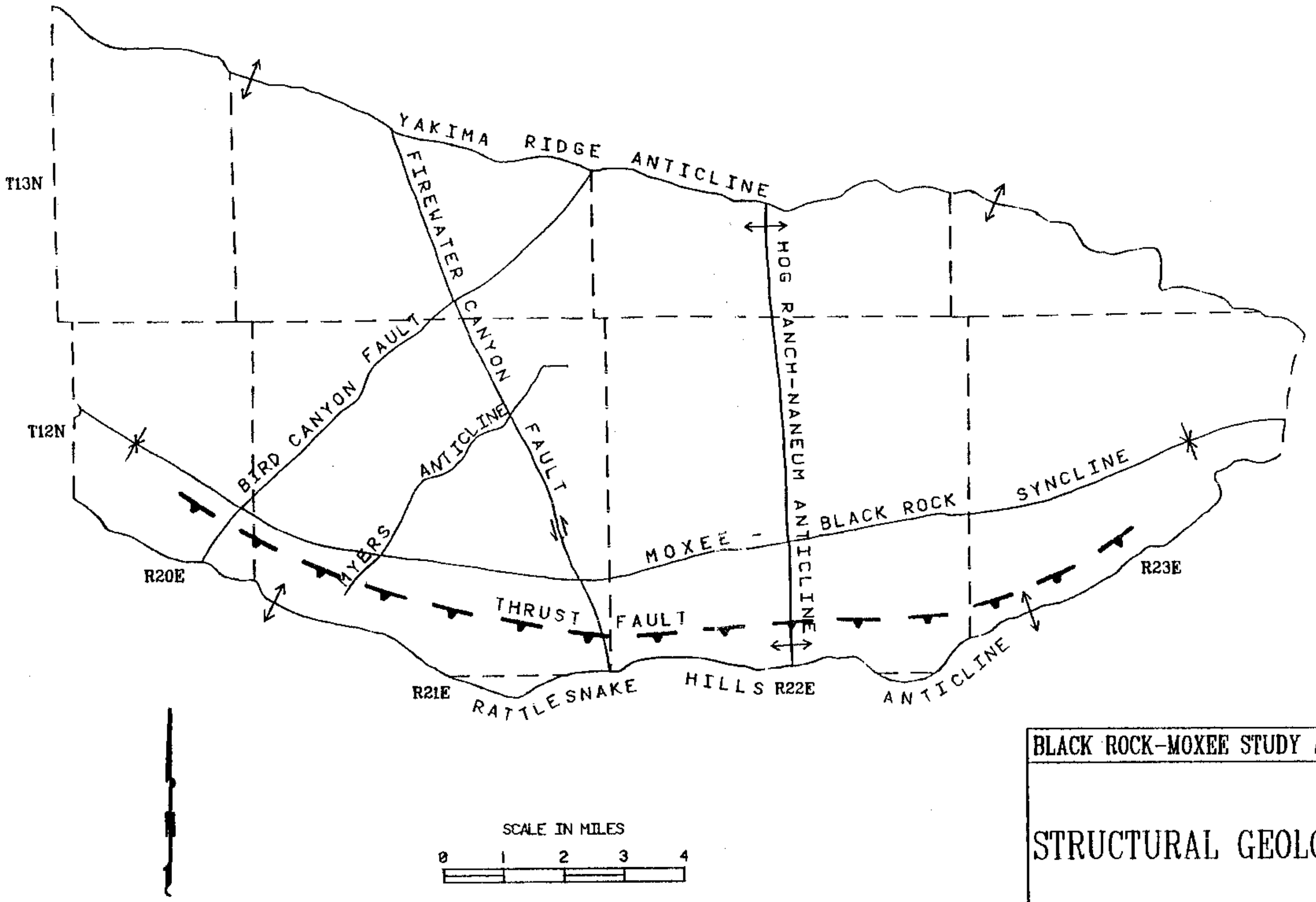
STRUCTURAL GEOLOGY

The boundaries of the study area encompass one of the more structurally complex areas within the Yakima Fold Belt. The Yakima Fold Belt resulted from north-south compression of the earth's crust that occurred contemporaneously with the eruptions of the basalts and deposition of the sediments. Known features include east-west trending synclines and anticlines, northwest-southeast and northeast-southwest trending strike-slip faults, and east-west trending thrust faults.

Folds

The study area is bounded to the north by the Yakima Ridge Anticline and on the south by the Rattlesnake Hills Anticline. The north-south trending Hog Ranch-Naneum Ridge Anticline separates the Moxee Valley from the Black Rock Valley (Figure 12). Both of the east-west trending ridges are asymmetrical, anticlinal folds with a relatively shallow angle of dip on their southern limbs and a steeper angle of dip on their northern limbs. The Rattlesnake Hills and Yakima Ridge are separated by a broad east-west trending asymmetrical syncline which forms the valley floor within the study area. West of this divide the syncline plunges westward toward the Yakima River and opens wide to form the Moxee Valley. East of the divide, the syncline plunges eastward toward the Hanford Reservation and forms the Black Rock Valley. The eastern portion of the syncline eventually narrows to a point of near closure at the east end of the study area.

A significant structural feature, herein referred to as the Myers Anticline, passes through Section 21, T.12N., R.21 E.W.M. on a diagonal northeast-southwest trend. The Myers Anticline appears to control ground-water movement in the Lower Saddle Mountains Aquifer.



BLACK ROCK-MOXEE STUDY AREA

STRUCTURAL GEOLOGY

FIGURE 12

Faults

The most prominent fault in the area is the Firewater Canyon Fault (Figure 12). The fault trends northwest-southeast and cuts through Section 25, T.12N., R.21 E.W.M. on a diagonal path. Drost and Whiteman (1986) mapped the fault as a right-lateral, strike-slip fault. Upon closer inspection in the field and from high-altitude aerial photographs, it appears that this is a left-lateral, strike-slip fault. The Fire Water Canyon Fault appears to be younger in age than the Wilbur Creek-Asotin Intracanyon flow. This assertion is supported by notable drag of the Intracanyon flow adjacent to the fault.

The Bird Canyon Fault is located near the western end of the study area. The fault trends northeast to southwest through Section 18, T.12N., R.21 E.W.M. This fault was first noted by Department geologist Bill Myers. Myers (1984) referred to this fault as a "buried feature". The term "buried" was used because the fault is apparently older than, and is therefore covered by, the Saddle Mountains Basalt. The surface expression of this fault trace is not apparent in the valley floor, but can be detected to the north on Yakima Ridge. Consequently, the presence and location of the fault are inferred as much by hydraulic conditions in the subsurface as by the physical expression of the fault at the land surface.

An east-west-trending thrust fault located along the northern limb of Rattlesnake Ridge has been suggested by Reidel and others, (1989). The approximate trace of this fault runs along the base of the northern limb and roughly parallel to the crest of the ridge (Figure 12). The thrust fault appears to be associated with the areas of greatest structural relief and dissipates with a reduction in relief (Reidel et al., 1989).

SECTION 4

BASALT HYDROGEOLOGY

The understanding of ground-water occurrence, movement and behavior in the Columbia River Basalt Group must begin with an examination of the hydrologic influence of basalt flow morphology, sedimentary interbeds, and geologic structures. The internal morphology of individual basalt flows are such that when multiple flows are stacked one on top of the other, the ground water tends to concentrate in interflow zones. Sedimentary interbeds can act as aquifers or as aquitards. Geologic structures such as folds and faults typically control the movement of ground water by either enhancing or restricting it's flow.

Basalt Flow Morphology

The internal character of each basalt flow plays an important role in controlling the movement and occurrence of ground water. In general, the flows are composed of a vesicular and often times rubbly, scoriaceous flow top, a relatively dense flow interior consisting of entablature and colonnade, and a flow base that may exhibit either a chilled margin or a pillow-palagonite complex (Figure 13). The flow tops, interiors, and flow bases each exhibit unique hydrogeologic properties.

Flow Tops

Ground water pumped from basalt aquifers primarily comes from the flow tops. A flow top is generally the most porous and permeable portion of a basalt flow. The high porosity and permeability is due to the vesicular, rubbly, and scoriaceous structure of the flow top. A flow top alone, or in conjunction with a permeable flow base, is referred to as an interflow zone (Brown, 1978). In hydraulic terms, this means an area of water flow between the more dense interiors of the basalt flows. Interflow zones can be thought of as porous, sheet-like reservoirs and conduits through which ground water can easily move. Burt (1989) suggests that the hydraulic conductivity within flow tops approaches isotropic conditions when considered over a large area (Figure 14).

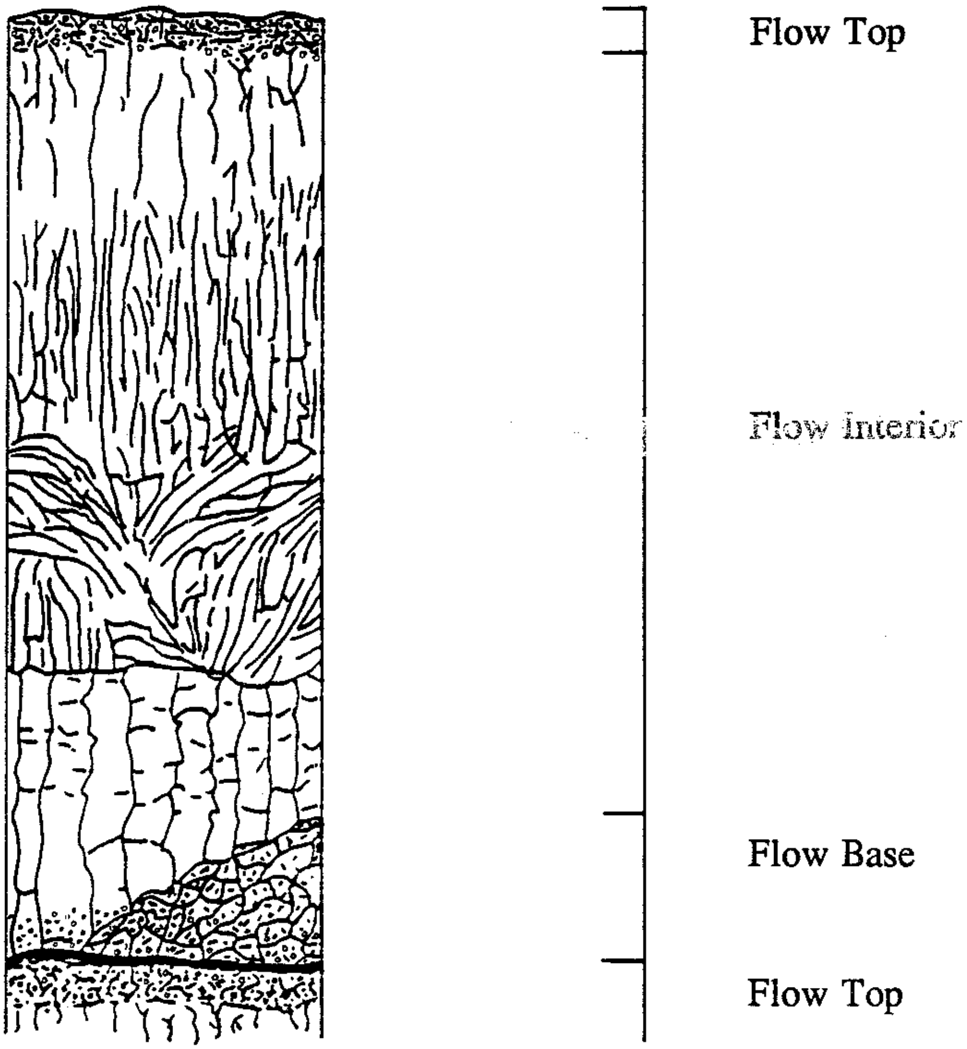


Figure 13. Typical basalt flow morphology, modified from Myers et al. 1981.

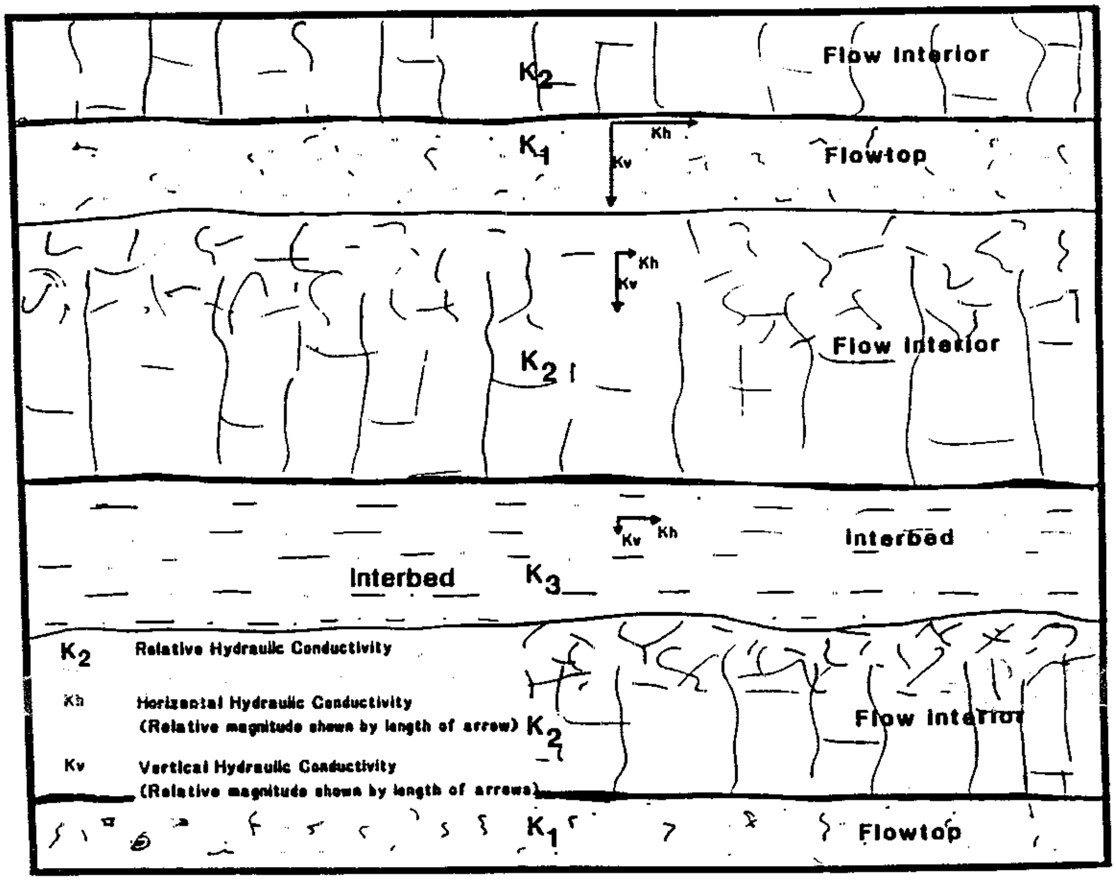


Figure 14. The distribution of hydraulic conductivity in a typical sequence of Columbia River Basalts (from Burt, 1989).

Flow Interiors

Flow interiors, which consist of an entablature and collonade, are generally the thickest and most dense portion of a typical basalt flow. In the absence of sedimentary interbeds, the relatively dense nature of the flow interior generally does not prevent the vertical movement of ground water from one interflow zone to the next. Flow interiors are marked by mostly vertical cooling joints, as well as tectonic fractures. The vertical hydraulic conductivity of flow interiors is controlled by the extent, spacing, aperture, attitude, and the degree of filling of fractures and cooling joints (Burt, 1989). Brown (1979) postulates that the flow interiors have a relatively high degree of vertical hydraulic conductivity. His assertion is supported by the post-irrigation-season measurements of similar water levels within sets of nested piezometers. Each set of piezometers is open to a wide range of depths within an individual basalt formation. The predominance of vertically oriented fractures and cooling joints suggests that vertical hydraulic conductivity will be greater than horizontal hydraulic conductivity (Figure 14). Leakage between interflow zones is also supported by the fairly uniform decline rates exhibited in the Black Rock Study area by Wanapum Formation wells completed at varying depths.

Flow Bases

In cases where pillow basalts are absent, the flow bases tend to be rather dense and do not yield much water when compared to a typical flow top. Flow bases may be rubbly, fractured, or somewhat vesicular or may possess a combination of these characteristics. The contact with the underlying flow top or interbed is often marked by a thin glassy margin of chilled basalt. Generally, flow bases have considerably lower porosity and lateral permeability than do flow tops, yet higher than in flow interiors. The hydraulic properties of flow bases are generally more similar to those of flow interiors than to those of flow tops.

When the flow bases are composed of pillow basalts, their hydrologic properties are more variable, and their overall hydrologic contribution to an interflow zone is less clear. Pillow-basalt complexes commonly vary in structure, and, therefore, in hydraulic properties. Pillow complexes are composed of elongate, cylindrical basalt pillows set in a matrix of palagonite or volcanic clasts. The pillows may be either tightly packed one on another, or widely spaced and entirely supported by a prominent matrix around the pillows. In some cases, the matrix is composed of small, tightly packed shards of glass-like basalt with little palagonite. In other cases, the matrix may be composed primarily of loosely packed pebble-to-cobble sized fragments of scoria with no palagonite at all. A tightly packed palagonite matrix is one of the more common occurrences within pillow complexes. In general, as the amount of palagonite within a pillow complex increases, the ability of the flow base to store and transmit water decreases.

Sedimentary Interbeds

Within the study area, the sedimentary interbeds generally contain a sizable quantity of clay which allows them to function as aquitards. Samples of the Mabton Interbed from locations around the study area have been reported by Department staff as being clay rich. Drilling logs from within and around the study area also frequently report the Mabton as clay or "sticky clay" in colors from gray to blue-green. The Vantage Interbed has been encountered in only 3 wells within the study area but, in each case, the driller's report has recorded it as clay or having a clay component. Reports of sizable quantities of clay within the Rattlesnake Ridge Interbed exist as well. The presence of clay indicates that the vertical hydraulic conductivities within these interbeds are low enough to permit them to act as aquitards between the aquifers. This assertion is supported by drilling logs which frequently report marked changes in head upon drilling through the interbeds.

Structural Controls on Ground-water Movement

Geologic structures that have an effect on ground-water occurrence and movement include folds, faults, and fractures. The control that structures exhibit on ground-water movement is less predictable than that of interbeds and basalt-flow morphology. Folds, e.g. anticlines, can act either as lateral barriers to the migration of ground water or as areas of restricted lateral flow. Anticlinal folds can act as barriers when the lower-most interflow zones and confining layer are located above the water table or potentiometric surface for a particular basalt aquifer (Figure 15). In the Grande Ronde

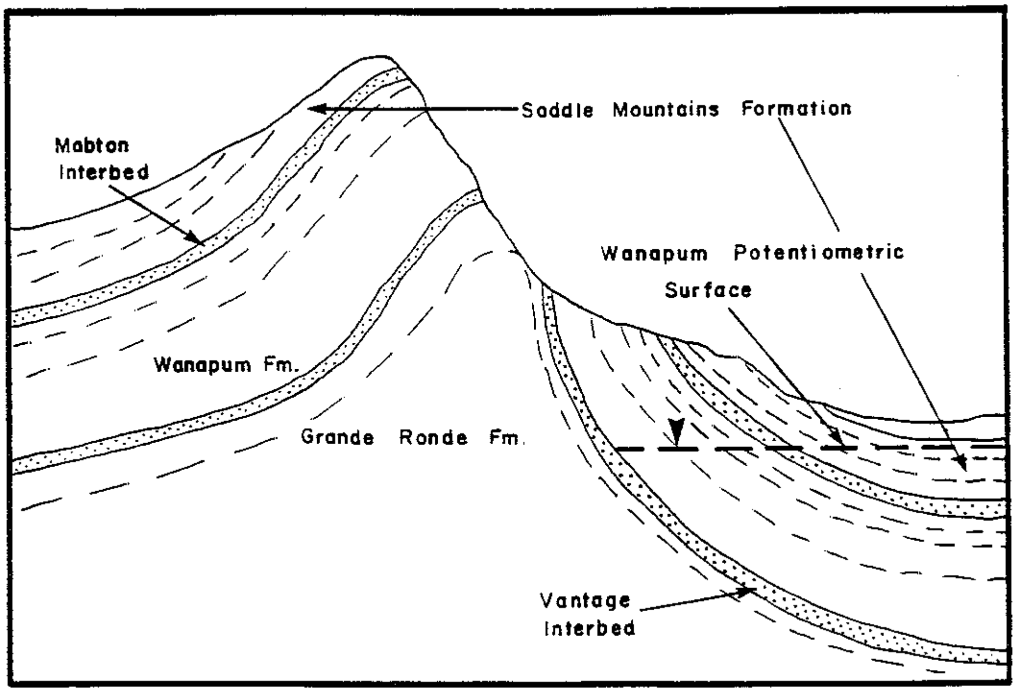


Figure 15. Diagrammatic cross-section illustrating how uplift and folding of basalt units can prevent movement of ground water through an anticline (Modified from Burt, 1989).

Aquifer, the above situation is not observed, and therefore, in this circumstance it is more likely that anticlinal folds act primarily as linear zones of hydraulic impedance rather than complete lateral barriers. Since ground water tends to follow the attitude of flow tops, fold geometry likely controls where significant recharge is occurring and accounts for the artesian heads encountered in many of the study area wells (Figure 16).

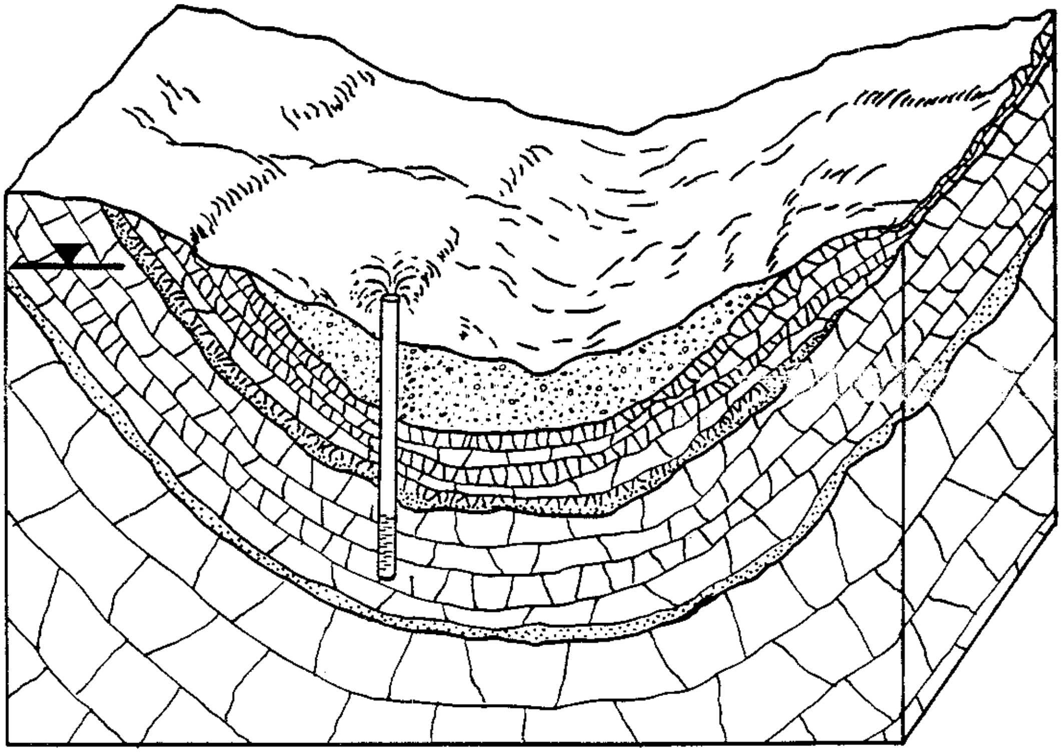


Figure 16. Diagrammatic Cross-section illustrating artesian potential of a confined aquifer.

Faults have been shown to act as both conduits <u>and</u> barriers to ground-water movement. If a fault is clear of obstructions, it may serve as a conduit for water and improve the vertical hydraulic connections between interflow zones. Conversely, if the fault has been subject to heavy secondary mineralization, or is filled with fine grained materials such as fault gouge or interbed sediment, it can act to limit or prevent the lateral movement of ground water. (Figure 17).

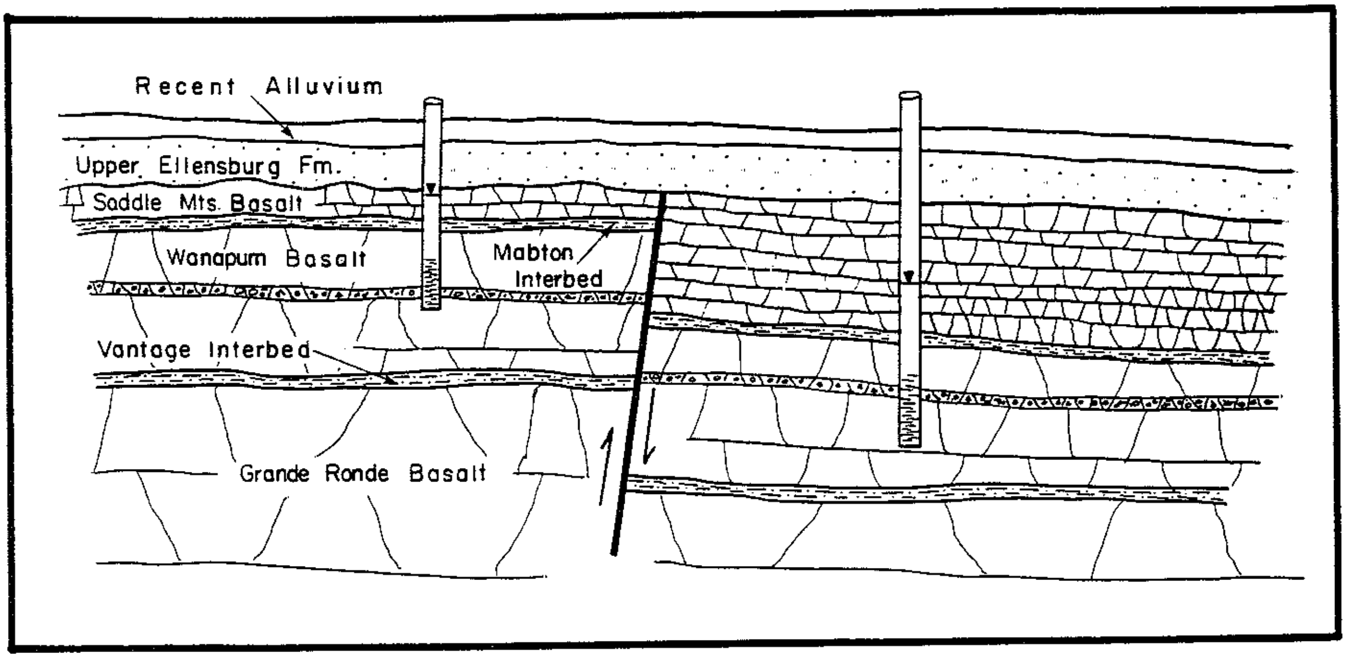


Figure 17. Decrease in horizontal flow due to vertical geologic structure, characterized by head differences on either side of the structure.

Tectonic fracturing generally increases the porosity and hydraulic conductivity of an aquifer. Fracturing often results in increased vertical movement of ground water between interflow zones (Brown, 1979). Hydraulic conductivity within fracture zones will vary depending on the spacial extent, fracture opening or width, and density of fractures (Burt, 1989). Gephart et al. (1979) note that the density of fracturing is greatest within the hinges of anticlinal folds, and therefore ridge tops are likely to represent areas of local recharge for certain basalt aquifers.

SECTION 5

GRANDE RONDE AQUIFER

In this section, and in the two following sections, conceptual models of each basalt aquifer will be developed. Data pertinent to each aquifer will be evaluated by data type. At the end of the section, all the elements of the conceptual model will be presented.

Wells

Only three wells in the study area are drilled into the Grande Ronde Aquifer (Figure 18). All three wells are cased and sealed into the Grande Ronde. They are listed in Table 1.

Owner name	USGS#	Study #	Depth ft	Spring 91 WL Elev ft
Martinez	12/20-12K1	BSW# 14	2703	1372
Marley #5	12/22-21A1	BSW# 74	2452	1427
Changala	12/22-13P1	BSW# 79	1703	1417

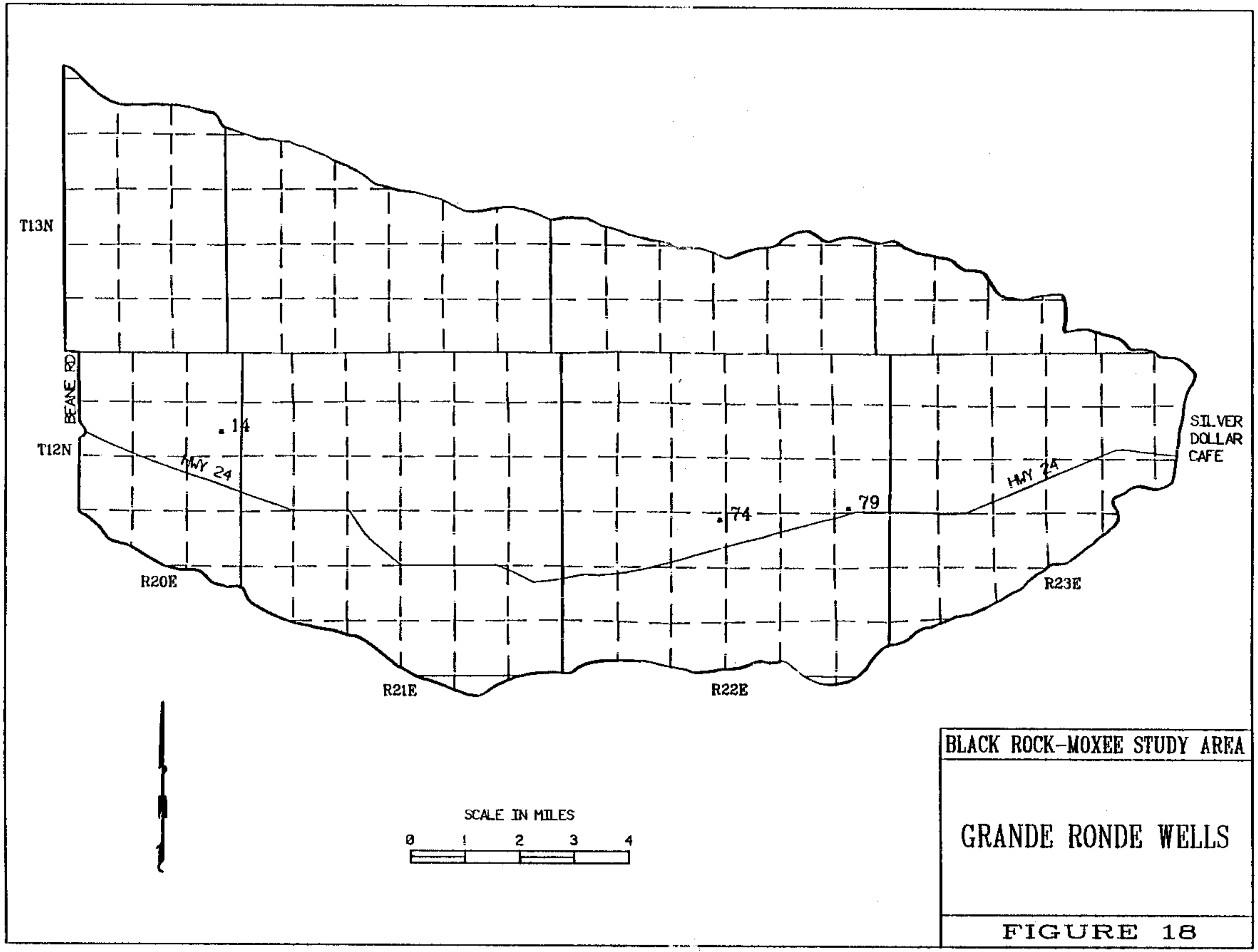
Table 1. Grande Ronde Wells.

Water Levels

Temporal Water-Level Analysis

A temporal water-level analysis is one in which static water levels are evaluated with respect to time. Static water-level measurements from the Grande Ronde Aquifer have been measured each spring over the last ten years and plotted verses time. Plotting water level measurements for wells over a sufficient time period has provided evidence of hydraulic barriers, and areas of the aquifer that are in decline.

Marked differences in decline rates for wells completed in the same aquifer may indicate the presence of a hydraulic barrier. In the absence of any such barrier, wells that are completed into the same aquifer should exhibit similar rates



BLACK ROCK-MOXEE STUDY AREA

GRANDE RONDE WELLS

FIGURE 18

of decline. This is due to the rapid hydraulic response within confined basalt aquifers, because theoretically, basalt aquifers are all subject to the same changes in hydraulic stress. Water level measurements show that decline rates among the three wells are similar. This suggests that structures such as the Hog Ranch-Naneum Ridge Anticline and north-south-trending faults, such as the Fire Water Canyon and Bird Canyon faults, may not represent significant lateral barriers to the east-west continuity of ground-water flow within the Grande Ronde Aquifer.

Spatial Water-Level Analysis

A spatial water-level analysis evaluates water levels measured from several wells located within a defined area during a single window of time. This kind of analysis yields evidence concerning the following:

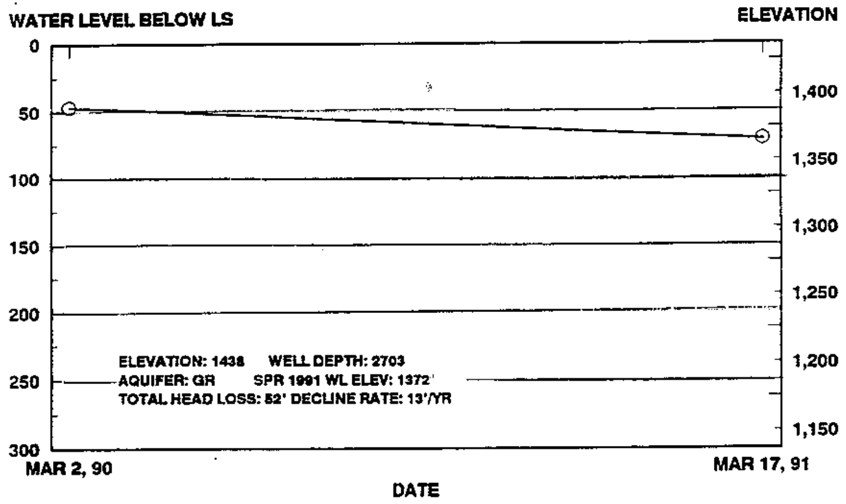
A. The presence of hydraulic barriers
B. Whether or not the Vantage interbed functions as an aquitard
C. Whether or not an aquifer is confined or unconfined
D. Head changes within an aquifer

Hydraulic Barriers - In the absence of hydraulic barriers, wells within close proximity of one another and completed into the same aquifer should reflect similar water-level elevations. In comparing the spring 1991 water-level elevations for the three Grande Ronde wells (Figure 19) it is evident that #79 (Changala) and BSW #74 (Marley #5) have similar water level elevations. This indicates that there are no vertical hydraulic boundaries between these two wells and that the lateral east-west continuity of ground-water flow within the Grande Ronde Aquifer is unbroken in this area. However, a comparison of the spring 1991 water levels in BSW #14 (Martinez) and BSW #74 (Marley 5) reveals that BSW #14 is 55 feet lower in head. This difference is notable, and may indicate the presence of a hydraulic boundary, or possibly a ground water gradient to the west.

Vantage Interbed - Based on a spatial water-level analysis, the Vantage interbed within the study area acts as an aquitard. A comparison of water-level elevations between Wanapum wells (above the Vantage Interbed) and Grande Ronde wells (below the Vantage Interbed) shows marked differences (Figure 19). In each case, the Grande Ronde well has a higher head than the Wanapum well. Such differences in head support the concept that Wanapum and Grande Ronde are distinct aquifers and that the Vantage Interbed is functioning as the aquitard between them. Further support of this concept is provided by the testimony of drillers who state that they

BSW #14 MARTINEZ (GRANDE RONDE)

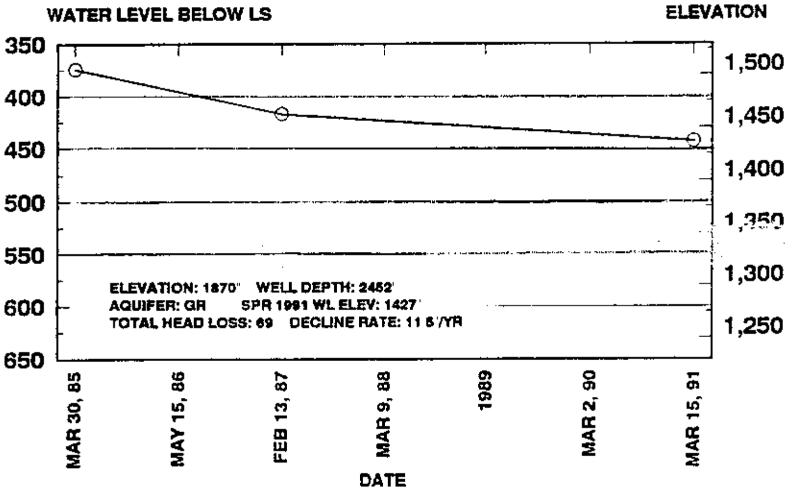
12/20-12K1



ELEVATION: 1438 WELL DEPTH: 2703
AQUIFER: GR SPR 1991 WL ELEV: 1372'
TOTAL HEAD LOSS: 52' DECLINE RATE: 13'/YR

BSW #74 MARLEY #5

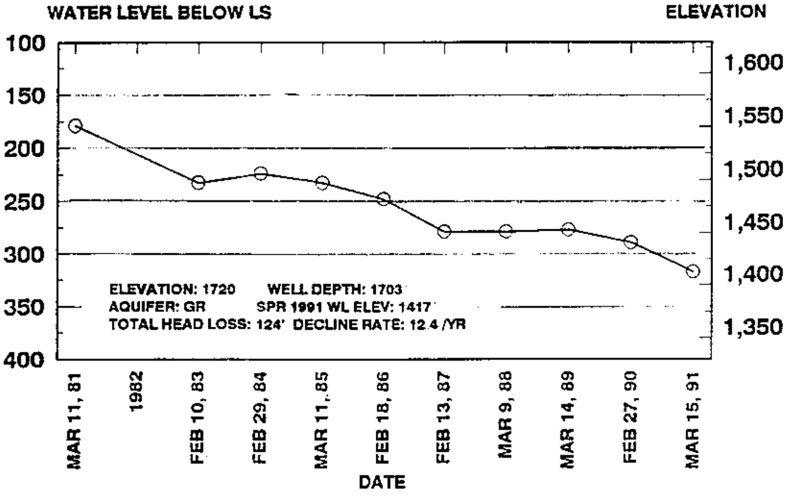
12/22-21A1



ELEVATION: 1870" WELL DEPTH: 2452'
AQUIFER: GR SPR 1991 WL ELEV: 1427'
TOTAL HEAD LOSS: 69 DECLINE RATE: 11 5'/YR

BSW #79 CHANGALA

12/22-13P1



ELEVATION: 1720 WELL DEPTH: 1703
AQUIFER: GR SPR 1991 WL ELEV: 1417'
TOTAL HEAD LOSS: 124' DECLINE RATE: 12.4 /YR

Figure 19. Grande Ronde hydrographs.

commonly experience a marked change in water levels upon penetration of the Vantage Interbed or shortly thereafter.

Confined vs. Unconfined - A confined aquifer is one in which the water is under pressure, such that when penetrated by a well the water-level lies above the top of the aquifer. A comparison of the water-level elevations of the three Grande Ronde wells versus the elevation of the upper Grande Ronde surface at each well shows that all water levels are above the top of the Grande Ronde Aquifer. This indicates that the Grande Ronde is a confined aquifer throughout the study area.

Head Changes - Within the study area, it is generally true that interflow zones within a given basalt aquifer are not hydraulically isolated from one another, and that flow interiors do not greatly restrict vertical movement of ground water. Consequently, head changes within a basalt aquifer do not vary much with depth (The Wanapum Aquifer is the classic case). This lack of head change, in fact, defines the aquifer. However, an apparent exception exists within the Grande Ronde Basalt Formation. The well log of BSW #14 (Martinez) shows an initial Grande Ronde water level of 109 feet below land surface upon penetration of the Vantage interbed. During drilling, this water level was unchanged until the flow interior of the McCoy Canyon flow was penetrated. The McCoy Canyon Flow is located 800 feet below the Vantage Interbed in BSW #14. Here the water level rose to 15 feet below land surface. This appears to be a circumstance where a flow interior, rather than an interbed, is acting as an aquitard. The head change that occurs across the McCoy Canyon Flow defines two aquifers within the Grand Ronde Basalt Formation.

The ability of the McCoy Canyon flow to act as an aquitard across the entire study area appears to be limited. A review of the well logs of BSW #74 (Marley #5), and BSW #79 (Changala) reveals that #74 is completed below the McCoy Canyon flow while #79 is completed above it. However, these two wells exhibit very similar water levels. Therefore, it seems that the hydraulic conductivity of this flow interior must increase to the east and that the two separate Grande Ronde heads encountered within well #14 are maintained by the presence of a vertical hydraulic barrier. A likely candidate for such a barrier is the Bird Canyon fault (Figure 12).

Since BSW #14 (Martinez) is open to two aquifers within the Grande Ronde, it is quite possible that the sharp decline measured in the well #14 is due in large part to an on going equalization of head between these two aquifers.

Water Quality

Analysis of ground-water quality can assist with the identification of aquifers and location of their recharge areas. Ground-water quality has been shown to be primarily a function of:

1. the chemical composition of the water before it enters the ground
2. the length of time the water has been in the ground
3. the geochemistry of the aquifer, and
4. temperature-pressure relationships within the aquifer which control rock-water interactions (Gephart et al., 1979).

Certain interpretive generalizations have also been derived:

1. the quantity of total dissolved solids increases with an increase in flow-path length and/or residence time
2. the concentration of the sodium cation (Na+) generally increases with increasing distance from the area of recharge
3. the concentration of calcium cations (Ca+) is greater in areas of recharge and declines as ground water moves away from the recharge area (Gephart et al., 1979).

Based on the above, it is reasonable to assume that ground-water samples taken within the study area from the same aquifer should exhibit similar ionic concentrations. Within a relatively small sampling area, such as the Black Rock Study Area, it is likely that the controls on ground water chemistry would be acting similarly on ground water to produce similar chemical compositions.

In 1981, the Department sampled the waters of 7 wells-six from the Wanapum Aquifer and one from the Grande Ronde Aquifer. These samples were sent to the Yakima Testing Laboratory for analysis (Table 2). In 1986, an additional five wells were sampled (Burt, 1989), four from the Wanapum and one from the Grande Ronde. Both data sets have been evaluated with respect to whether or not the Grande Ronde is an distinct aquifer from the Wanapum, and if Grande Ronde ground water is recharged locally or from outside the study area. An examination of the two data sets supports the concept that the Grande Ronde and Wanapum are separate aquifers.

A comparison of the data from the two Grande Ronde wells (BSW No.s 74 and 79) within the study area, indicates uniform ionic concentrations within the Grande Ronde Aquifer. A comparison of the data among the Wanapum Wells (BSW No.s 30, 69, 71, 75, 76, 77, and 82) shows that ionic concentrations are uniform throughout the Wanapum Formation as well. The

TABLE 2
WATER QUALITY ANALYSIS

Water Chemistry - this paper

Study Well No.	Well Number	Owner	Date	K (mg/l)	Na (mg/l)	Ca (mg/l)	Mg (mg/l)	HCO_3 (mg/l)	SO_4 (mg/l)	NO_3 (mg/l)	Cond. (µmhos	pH	SAR*	Total dissolved solids (calculated) from cond. (mg/l)
#30	12/21-17P1	Martinez	5-29-81	-	29.6	14.1	7.6	-	-	-	300	7.8	1.6	195
			8-10-81	5.43	40.8	12.8	6.95	163.17	0.32	0.004	290	6.9	2.3	188
#71	12/21-24N1	Martinez	5-29-81	-	29.6	14.4	7.7	-	-	-	300	8.1	1.6	195
			8-17-81	4.50	38.6	14.1	0.81	169.39	0.20	0.036	287	8.0	2.7	186
#69	12/21-25D1	Opticar	5-29-81	-	29.3	14.8	7.7	-	-	-	295	8.1	1.5	192
#75	12/22-21H1	Marley 3	5-29-81	-	19.4	17.9	12.3	-	-	-	260	8.1	0.9	169
			7-23-81	5.12	22.9	18.2	11.0	157.3	0.40	0.004	270	6.9	1.0	176
#77	12/22-21L1	Marley 4	5-29-81	-	22.4	15.7	11.1	-	-	-	280	8.1	1.1	182
#76	12/22-22N1	Marley 2	5-29-81	-	20.6	16.0	11.3	-	-	-	265	8.0	1.0	172
#79	12/22-13P1	Changala	5-29-81	-	84.8	3.8	0.4	-	-	-	405	9.0	11.1	263
#82	12/23-16K1	WA DNR	8-12-80	5.83	26.0	16.9	10.3	160.5	0.28	0.03	280	7.6	1.5	182

*SAR - Sodium Absorption Ratio

Water Chemistry from Burt, 1989.

Study Well No.	Well Number	Owner	Ca (mg/l)	Cl (mg/l)	F (mg/l)	K (mg/l)	Mg (mg/l)	Na (mg/l)	No_3 (mg/l)	Si (mg/l)	So_4 (mg/l)	Total carbon	Organic carbon
#76	12N/22E-22N1	Marley #2	16.37	3.96	0.56	5.09	9.85	22.23	None	24.51	None	31.00	0.56
#75	12N/22E-21H1	Marley #3	17.32	4.10	0.53	5.00	10.56	19.86	None	24.91	0.89	38.68	8.38
#77	12N/22E-21L1	Marley #4	15.52	4.00	0.62	5.06	9.67	23.80	None	23.72	None	32.40	0.83
#74	12N/22E-21A1 (Grande Ronde)	Marley #5	1.50	4.06	1.83	5.98	0.14	70.68	None	35.46	0.67	35.10	0.82
#82	12N/23E-16K1	WA DNR	15.42	4.47	0.69	5.79	9.59	25.27	None	25.24	None	32.40	0.46

Study Well No.	Well Number	Water Temperature (°C)	pH	Alkalinity (mg/l)	Dissolved Oxygen (mg/l)	Redox Potential (millivolts)
#76	12N/22E-22N1	23.20	0.00	128.00	0.25	00.00
#75	12N/22E-21H1	24.00	8.10	129.00	0.10	-195.00
#77	12N/22E-21L1	23.00	8.86	126.00	0.10	45.00
#74	12N/22E-21A1 (Grande Ronde)	33.50	8.80	155.00	0.25	-305.00
#82	12N/23E-16K1	24.00	8.06	120.00	0.20	155.00

most revealing comparison is between the data for the Grande Ronde wells verses the data of the Wanapum wells. There is a dramatic difference in the concentrations of major ions and a notable difference in the concentrations of total dissolved solids. Such data strongly suggest that the two aquifers are separate from one another.

The water quality data also suggests that the Grande Ronde Aquifer receives little or no local recharge from sources within the study area. The data reveal that the calcium ion concentrations are much lower for the Grande Ronde than for the Wanapum. The sodium-ion concentration and total dissolved solids are markedly higher in the Grande Ronde. This suggests that the waters of the Grande Ronde are older and the recharge areas more distant than those of the Wanapum.

Hydraulic Testing

Properly conducted aquifer tests can yield valuable information about the presence and location of hydraulic boundaries, recharge areas, aquitard leakage, aquifer properties, aquifer identification, etc. Unfortunately, there is only one useful test that involves a Grande Ronde well. Burt (1989) cites a March, 1986 step drawdown test of Wanapum well BSW #77 (Marley #4) that was performed by CH2M-Hill. During this test the well was pumped at varying rates for a period of 24 hours. The three wells monitored during the test are presented in table 3.

WELL	FORMATION	DIST. FROM PUMPING
1). BSW #74 (Marley #5)	Grande Ronde	3,609 feet
2). BSW #75 (Marley #3)	Wanapum	2,953 feet
3). BSW #76 (Marley #2)	Wanapum	2,789 feet

Table 3. Observation wells for Marley 1986 aquifer test on BSW #77.

After 24 hours, over a meter of drawdown was recorded in both of the Wanapum wells and there was no response from the Grande Ronde well. This suggests that the Grande Ronde Formation and Wanapum Formation represent distinct aquifers.

Conceptual Model of Grande Ronde Aquifer

The following is the operating conceptual model which the Department will use to assist in making water right permitting decisions. To a large extent it is based on the foregoing data. Portions of this <u>conceptual</u> model are largely founded upon professional interpretation. The Department will continue with data collection in the study area for some time to come. As understanding increases this model will be updated.

A. The Vantage interbed is the aquitard that hydraulically separates the Grande Ronde Aquifer from the Wanapum Aquifer. The Vantage Interbed is laterally extensive throughout the study area.

B. Within the boundaries of the study area the Grande Ronde Aquifer is broken into two discrete hydrogeologic units, hereafter referred to as the western area and the eastern area (Figure 20). The Bird Canyon fault acts as the vertical hydraulic barrier that divides the ground water of the Grande Ronde Aquifer into two hydraulically separate areas, one east of the fault, and one to the west.

C. The area of the Grande Ronde Basalt Formation located <u>west</u> of the Bird Canyon fault may be horizontally divided into two aquifers. This division is accomplished by the dense and competent flow interior of the McCoy Canyon Flow. The two aquifers include a relatively low head upper aquifer and higher head in the lower aquifer. The McCoy Canyon flow acts as an aquitard throughout this portion of the aquifer.

D. In the area of the Grande Ronde Aquifer located <u>east</u> of the Bird Canyon Fault, the hydraulic conductivity of the McCoy Canyon flow increases and permits the existence of similar heads above and below it.

E. Within the Grande Ronde Basalt Formation east of Bird Canyon Fault, there are laterally continuous interflow zones that are stratigraphically separated by relatively dense flow interiors. However, the flow interiors (except portions of the McCoy Canyon flow) have sufficient vertical conductivity to maintain similar head values within all of the interflow zones during non-stressed conditions.

F. North-south-trending structures such as the Hog Ranch-Naneum Anticline and Fire Water Canyon Fault result in only modest reductions of east-west lateral transmissivity across these areas. Reduced transmissivity may result in small timing differences in the post-irrigation- season stabilization of head on either side of these structures.

G. The Myers Anticline has no effect on ground-water flow within the Grande Ronde.

GRANDE RONDE AQUIFER

BLACK ROCK-MOXEE STUDY AREA

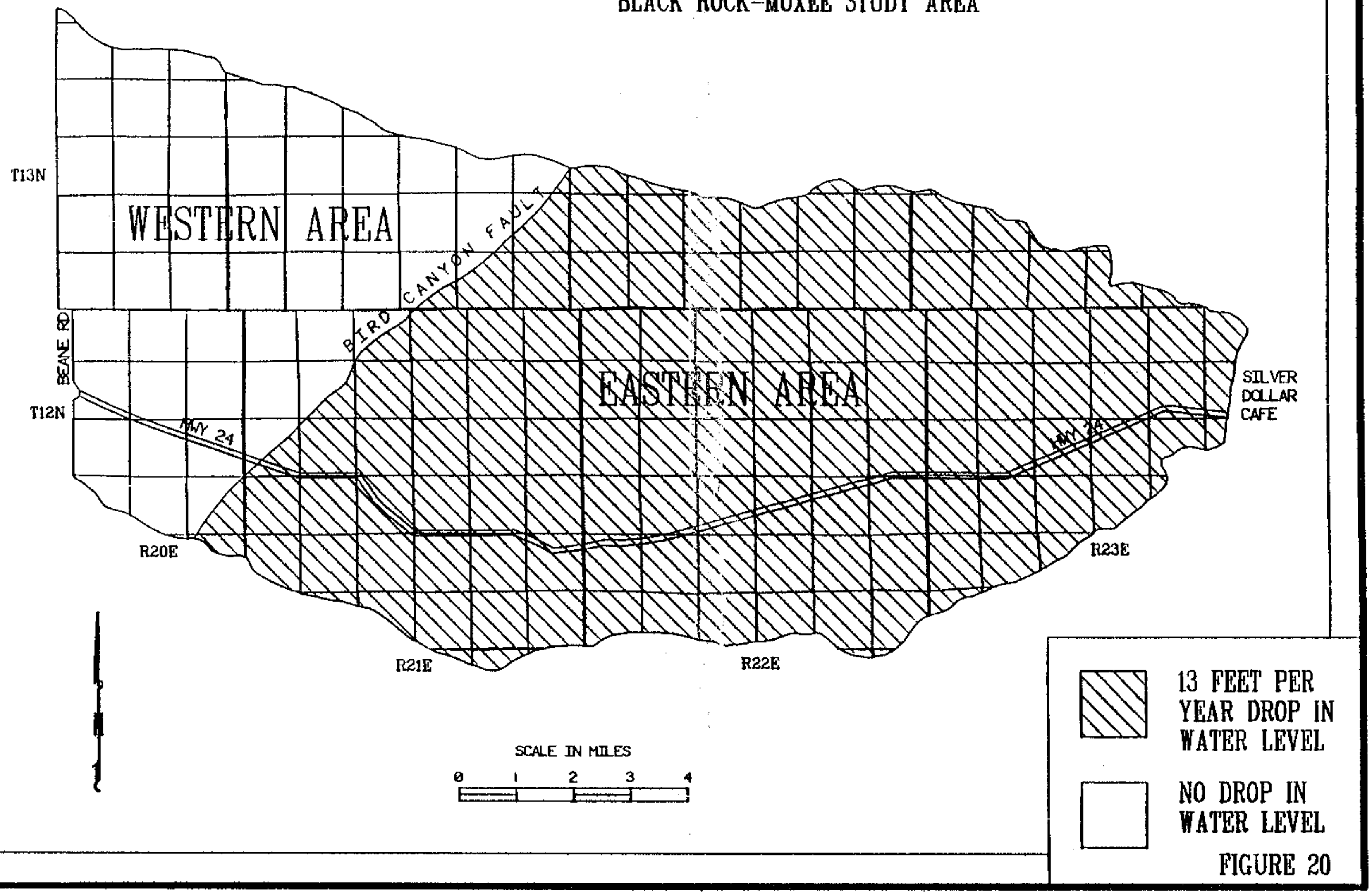


FIGURE 20

H. East-west-trending structures such as the Rattlesnake Hills and Yakima Ridge anticlines represent areas of markedly reduced lateral transmissivity within the Grande Ronde Aquifers. These ridges seriously limit, yet do not completely eliminate the north-south migration of ground water into and out of the study area.

I. Steeply dipping thrust faults mapped along the northern flanks of Yakima Ridge and the Rattlesnake Hills occur predominantly in areas of high relief. These faults form zones of reduced lateral transmissivity and retard the passage of ground water.

J. The thrust faults are not laterally continuous across the entire lengths of Yakima and Rattlesnake Ridges. They are present only along the areas of greatest structural relief (Figure 12).

K. The recharge areas for the Grande Ronde Aquifer are not located within the boundaries of the study area. Vertical leakage from above is not likely since head increases with depth from the Wanapum Aquifer to the Grande Ronde Aquifer. Recharge from below, on the other hand, via vertical leakage from pre-Columbia River Basalt strata is possible.

L. That portion of the Grande Ronde Aquifer located <u>east</u> of the Bird Canyon Fault probably receives small quantities of recharge water through Yakima Ridge. Most of this water comes through hydraulic windows in the ridge where the thrust fault is absent or relatively transmissive. The source of recharge water may be distant areas to the north, perhaps the Wenatchee Mountains.

M. That portion of the Grande Ronde Aquifer located <u>west</u> of the Bird Canyon Fault receives most of it's recharge water from the Cascade Mountains to the west of the study area.

N. The discharge area for that portion of the Grande Ronde Aquifer located <u>east</u> of the Bird Canyon Fault is the lower Dry Creek valley and eventually the Cold Creek Syncline. The Grande Ronde waters west of this fault are impounded against the Bird Canyon Fault.

O. The above model implies that pumping the three Grande Ronde wells can artificially increase, by a small amount, the quantity of ground water migrating southward into the study area. Similarly, pumping of the Grande Ronde on the south side of the Rattlesnake Hills may draw additional small quantities of ground water southward out of the study area.

P. The locations and water-level trends of the three Grande Ronde wells indicate that water levels are declining throughout the study area. The long-term water-level records of the two wells in the eastern area suggest that withdrawals are exceeding recharge. Well #14 (Martinez), which is located in the western area, has a short period of record. The declines in this well are due in part or in whole to an on going equalization of heads within the upper and lower head zones within this portion of the Grande Ronde Aquifer. Consequently, it is too early to conclude that withdrawals are exceeding recharge within the western portion of the Grande Ronde Aquifer.

SECTION 6

WANAPUM AQUIFER

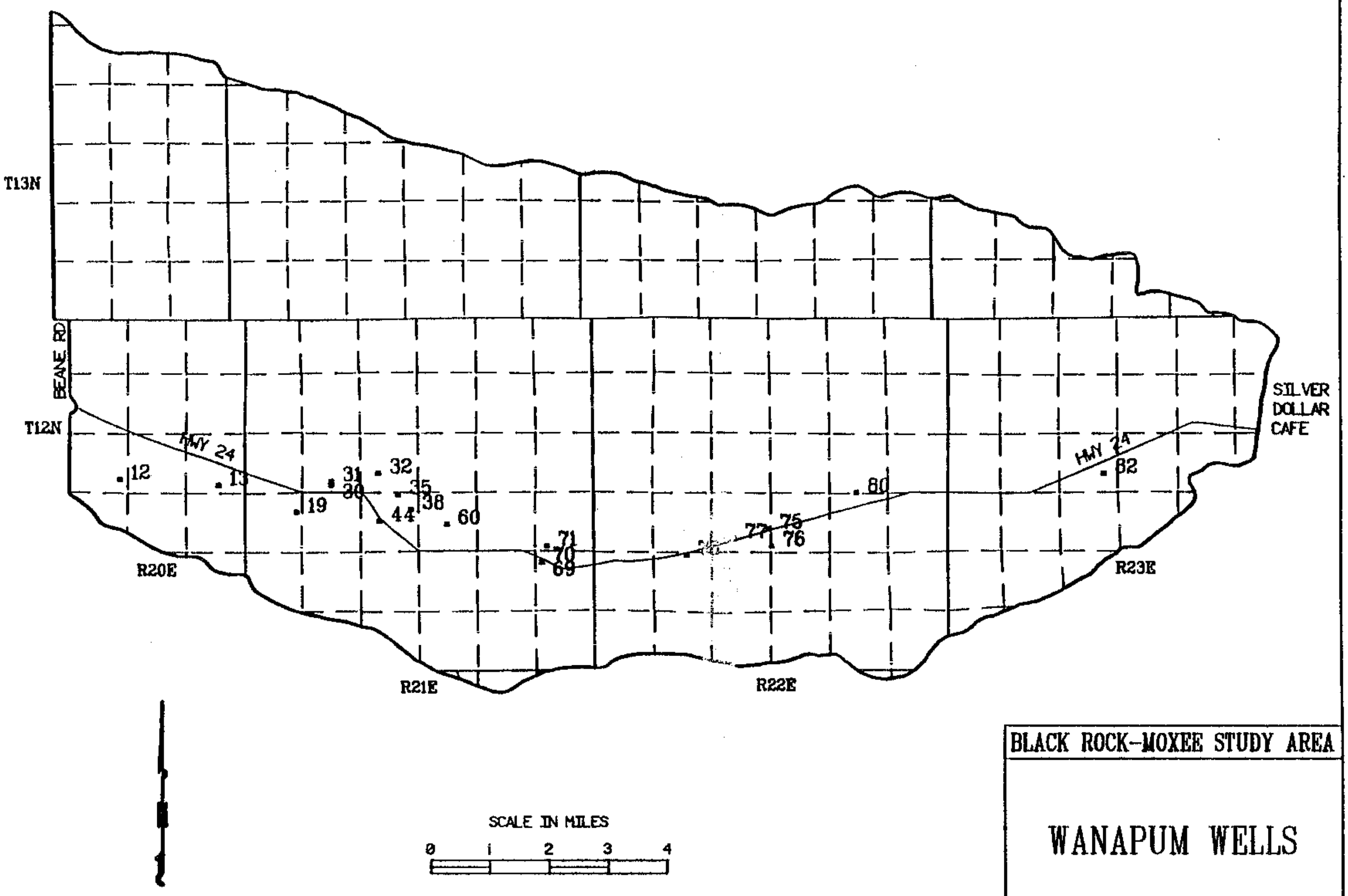
In this section, a conceptual model of the Wanapum Aquifer is developed. Data pertinent to the Wanapum is evaluated by data type. At the end of the section all the elements of the conceptual model are presented.

Wells

There are at least 18 wells within the study area which withdraw all or a part of their water from the Wanapum Aquifer (Figure 21). All wells except (BSW #70, Fines, 12/21-25D2), (BSW #12, Roy, 12/20-15J1), and (BSW #38, Fox, 12/21-21H2) have served as Department monitoring wells. Wanapum wells are listed in table 4.

Study #	Owner name	USGS #	Depth ft	Spring 91 WL Elev ft
BSW #12,	ROY,	12/20-15J1	1786	
BSW #13,	CHARRON,	12/20-13Q1	2213	1165
BSW #19,	LUDWIG,	12/21-19H1	1713	
BSW #30,	MARTINEZ,	12/21-17P1	1511	1377
BSW #31,	MARTINEZ,	12/21-17P2	803	
BSW #32,	DNR,	12/21-16N2	1565	1388
BSW #38,	Fox,	12/21-21H2	655	1351
BSW #44,	HART,	12/21-21L2	782	1368
BSW #60,	MARTINEZ,	12/21-22L1	662	1378
BSW #69,	FINES,	12/21-25D1	755	
BSW #70,	FINES,	12/21-25D2	?	
BSW #71,	MARTINEZ,	12/21-24N1	609	1364
BSW #75,	MARLEY #3,	12/22-21H1	1130	1379
BSW #76,	MARLEY #2,	12/22-22N1	904	1371
BSW #77,	MARLEY #4,	12/22-21L1	1430	
BSW #78,	MARLEY #1,	12/22-29B1	1600	1388
BSW #80,	TAYLOR,	12/22-14P1	801	
BSW #82,	DNR,	12/23-16K1	1145	901

Table 4. Wanapum Wells



BLACK ROCK-MOXEE STUDY AREA

WANAPUM WELLS

FIGURE 21

Well Construction and Data Control

The well reports have been reviewed for construction methods that may allow the withdrawal of ground water from multiple aquifers. Based on this review, it appears that several wells withdraw water from more than one aquifer. Two wells of concern are:

1. BSW #19, Ludwig, 12/21-19H1
2. BSW #31, Martinez, 12/21-17P2

The water-level data collected from these two wells have not been used in any analysis. Other wells in the study area may also be constructed such that they withdraw water from more than one aquifer, however, additional information needs to be either collected analyzed. Due to mechanical problems with air lines, the water-level data collected from wells #69 and #77 are considered to be unreliable and have not been used in this study.

Water Levels

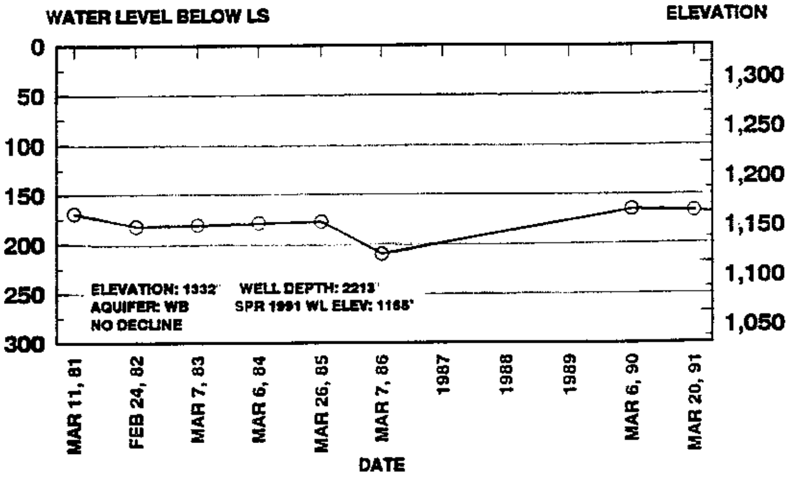
Water-level analysis follows a similar pattern to that of the previous section. Water levels are evaluated on a temporal and spacial basis. The analysis will look at water level declines, the presence or absence of hydraulic barriers and aquitards, internal head conditions, and the likelihood of north-south movement through anticlinal structures.

Temporal Water-Level Analysis

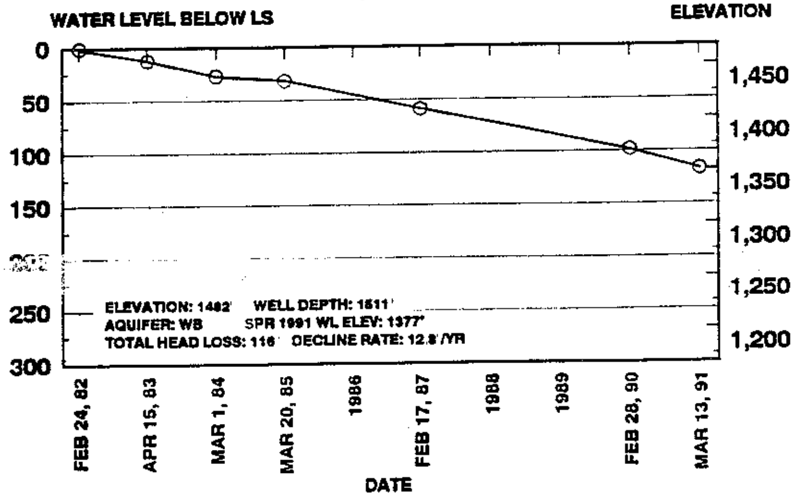
Annual spring water-level measurements for 11 Wanapum Basalt monitoring wells have been plotted verses time in order to evaluate the presence or absence of hydraulic barriers and the aerial extent of declines throughout the study area (Figures 22A - 22D).

A comparison of the Wanapum hydrographs reveals that two vertical hydraulic barriers traverse the Wanapum Aquifer. Except for BSW #82, all of the wells located east of the Bird Canyon Fault exhibit similar rates of water level decline. However, BSW #13, which is located west of the Bird Canyon Fault, shows no water-level decline. These data suggest that the Bird Canyon Fault acts as a hydraulic barrier. The presence of an additional hydraulic barrier located between BSW #82 and BSW #75 must also be considered. The decline rate measured in BSW #82 is about 3.5 feet/yr., markedly less than in the remainder of the Wanapum wells that are located east of the Bird Canyon Fault.

BSW #13 CHARRON
12/20-13Q1



BSW #30 S. MARTINEZ LIVESTOCK #6/#1
12/21-17P1



BSW #32 WA ST D N R
12/21-16L1

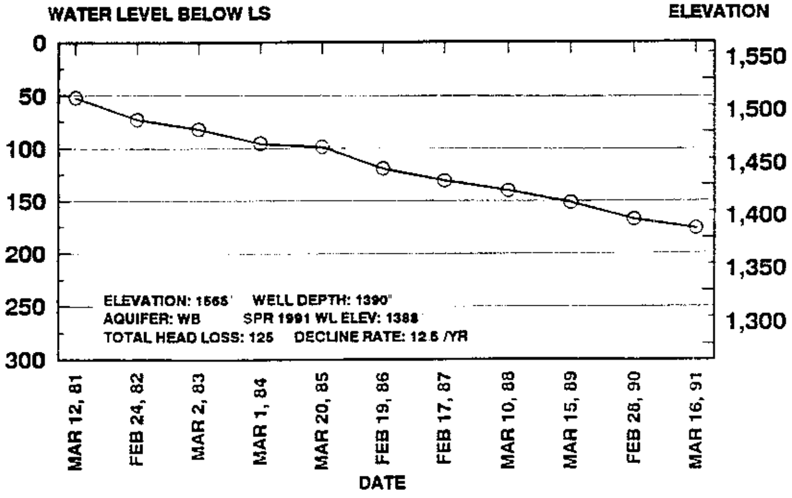
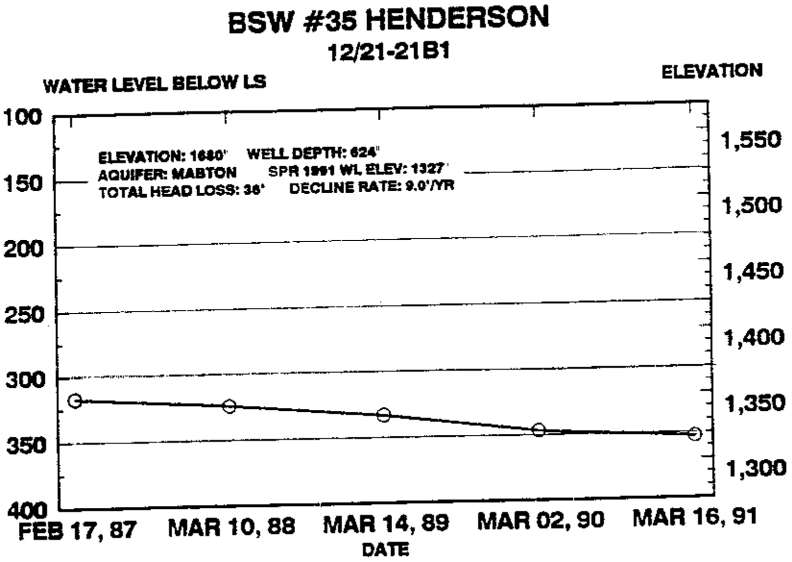
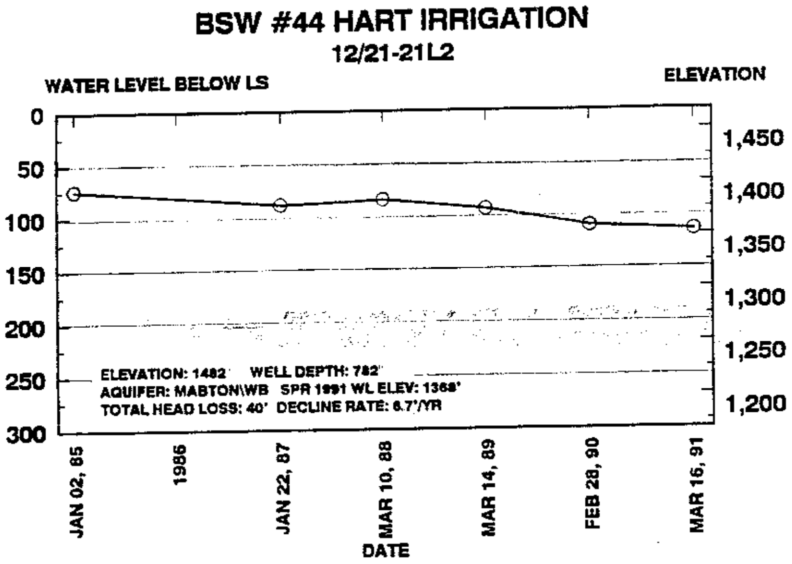


Figure 22A. Wanapum hydrographs.





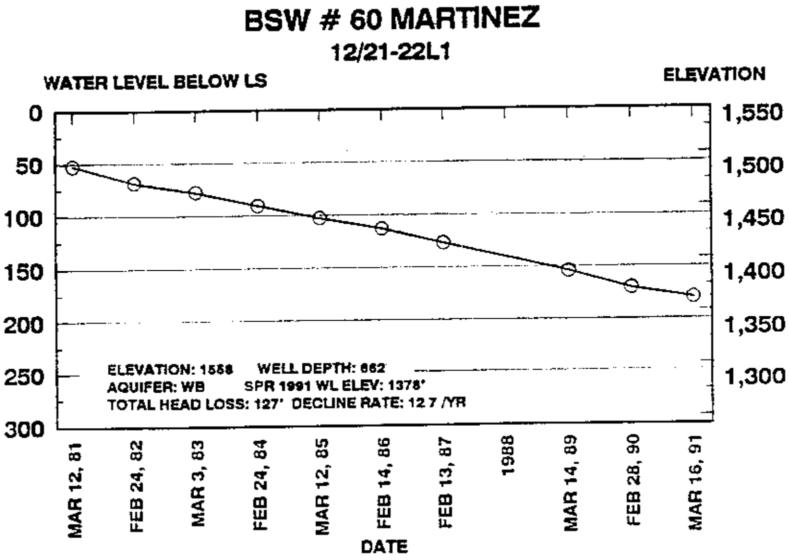
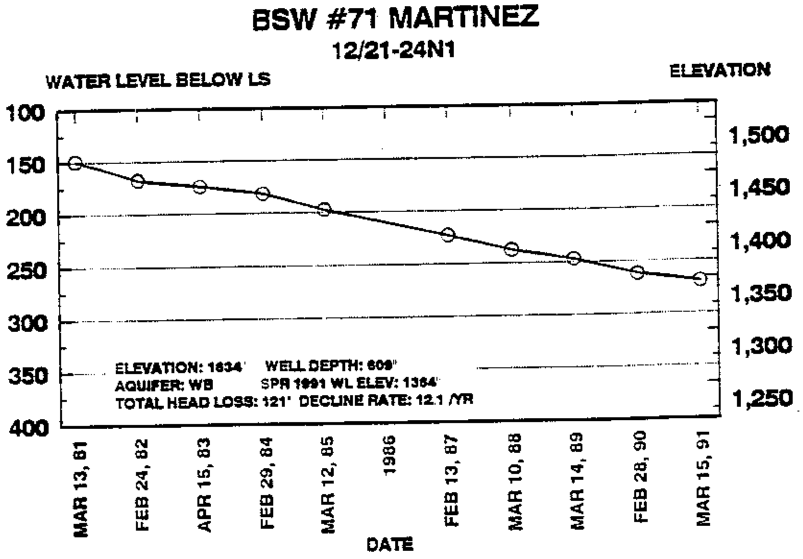
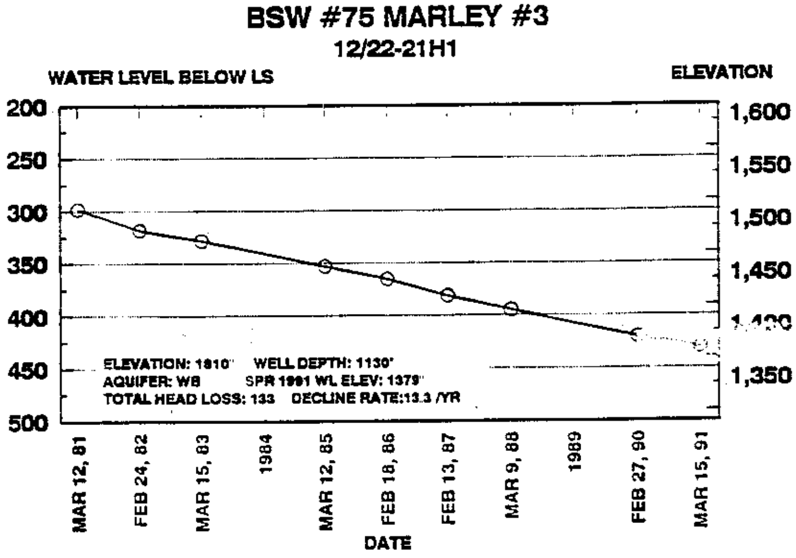


Figure 22B. Wanapum hydrographs.





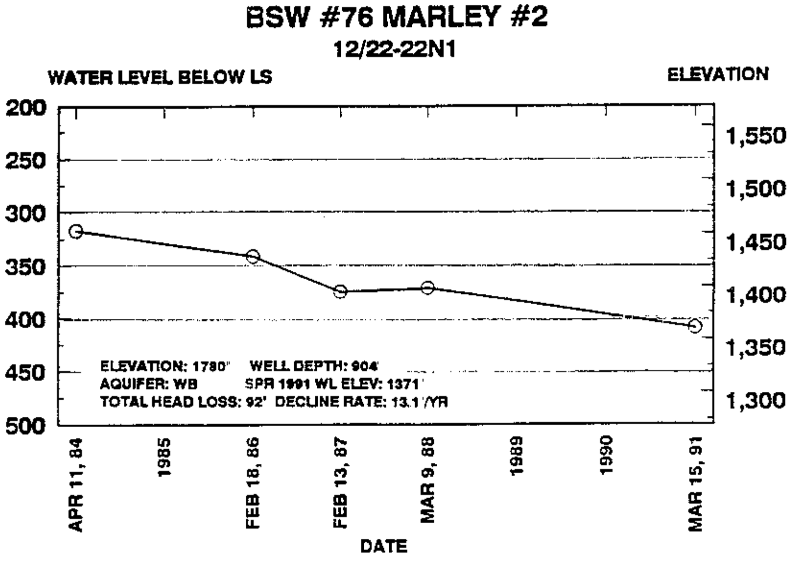


Figure 22C. Wanapum hydrographs.

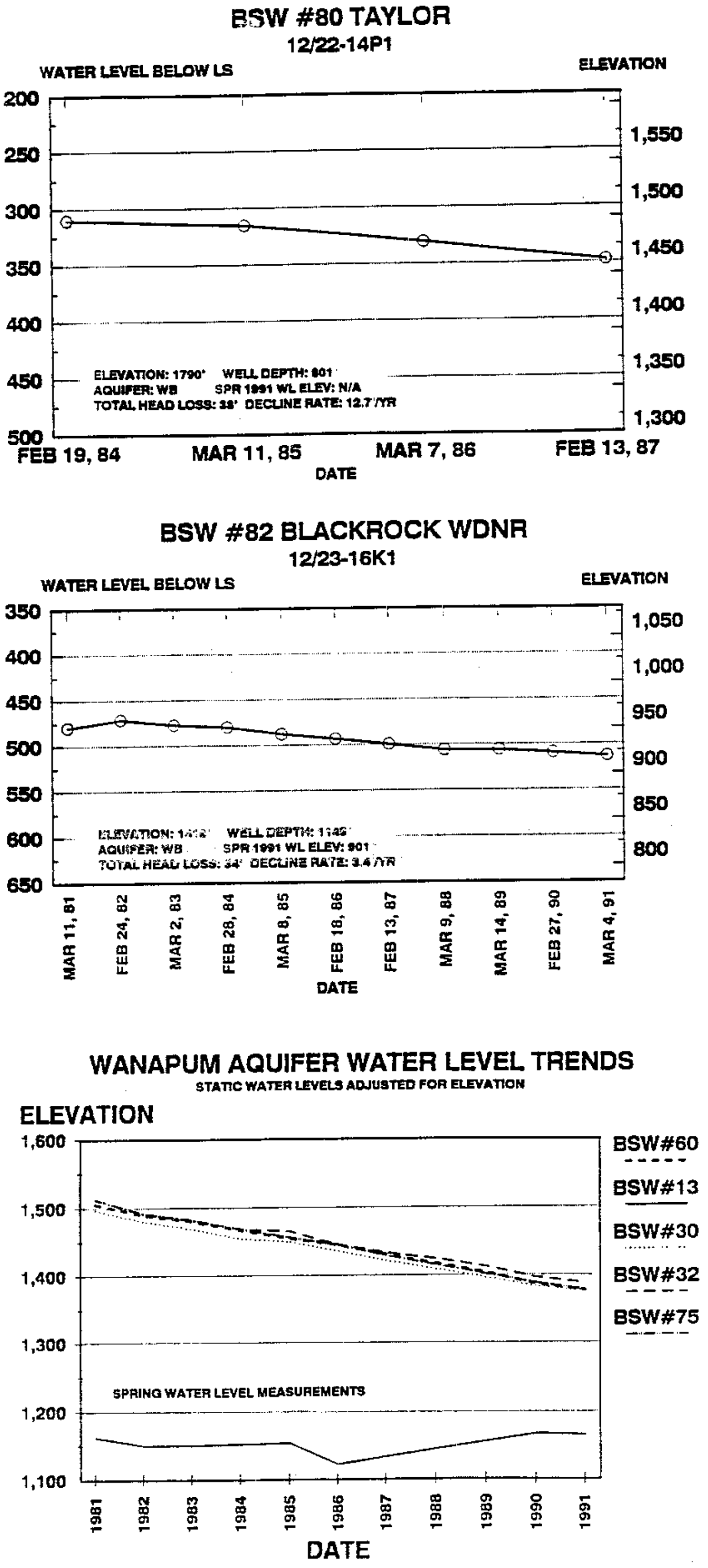


Figure 22D. Wanapum hydrographs.

Water-level declines within the Wanapum Aquifer are not occurring throughout the study area. At this time, there is no evidence of water-level declines in the Wanapum Aquifer west of the Bird Canyon Fault. However, east of this fault all but one well exhibit similar decline rates in excess of 11 feet per year.

Spatial Water-Level Analysis

Water levels for Wanapum wells were compared in order to determine:

A) Presence of hydraulic barriers
B) Whether or not the Mabton interbed functions as an aquitard
C) Whether or not the Wanapum is confined or unconfined
D) Head changes within the Wanapum
E) Water flow through the anticlines

Hydraulic Barriers - A comparison of the spring, 1991 water levels reveals that all of the wells east of the Bird Canyon Fault, except well #82, have similar heads. The water level in well #82 is about 475 feet lower than the water levels of the other Wanapum wells in this area. This information suggests the possibility of an unidentified hydraulic barrier. West of the Bird Canyon Fault, the water level within the Wanapum Aquifer, as measured in well #13, is about 212 feet lower than the water level on the east side of the fault in well #30. This adds further evidence that the Bird Canyon Fault is acting as a hydraulic barrier within the Wanapum Aquifer.

Mabton Interbed - Spring, 1991 water level data suggest that the Mabton may be functioning as an aquitard. Water levels from both Wanapum and Saddle Mountains Aquifers wells have been compared (BSW #33\BSW #30 and BSW #68\BSW #71). Wells completed into different basalt aquifers separated by interbeds will usually exhibit dissimilar heads because of the unique hydraulic stresses and physical attributes of each aquifer. The water levels from wells #33 and #30 reveal that, in this area, the Wanapum head is 167 feet higher than that of the lower Saddle Mountains Aquifer. In wells #68 and #71, we see a similar situation. The Wanapum water level in BSW #71 is 67 feet higher than in BSW #68 which is completed into the lower portion of the Saddle Mountains Aquifer.

Recent construction work on BSW #68 (USDA #2) also supports the concept of the Mabton being an aquitard. In June of 1986, BSW #68 was constructed "open-hole" across the Mabton Interbed open to the upper 20 feet below it. However, the water level was close to that of other near by Wanapum wells. In May of 1987, partially back-filled so that it was only open to the

Lower Saddle Mountains Aquifer. Though there are no near by wells in the Lower Saddle Mountains Aquifer, the head drop implies that the lower 65 feet of the Mabton Interbed is acting as an aquitard.

Confined vs. Unconfined - The Wanapum Aquifer is both confined and unconfined depending on location. West of the Hog Ranch-Naneum Anticline, the Wanapum is a confined aquifer. In the area of the anticlinal axis, and to the east of it, the Wanapum is not fully saturated and therefore ground water is not under confining pressure (Figure 23). East of the Hog Ranch-Naneum Anticline, the Wanapum water drains by gravity in an easterly direction and eventually discharges subsurface into the Wanapum Basalt of Cold Creek Syncline. Consequently, the dramatic difference in water levels between BSW #82 and BSW #75 is more likely due to the natural gravity drainage to the east, rather than resulting from a hydraulic barrier existing between them.

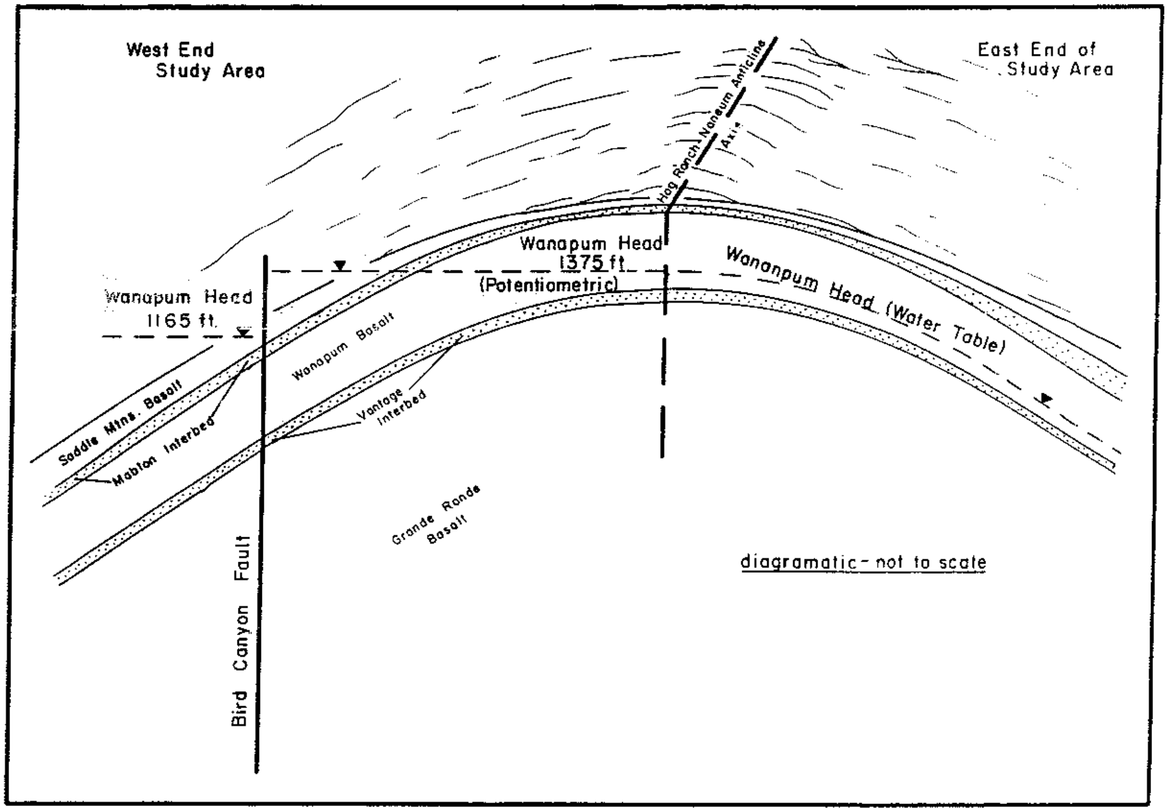


Figure 23. Head diagram for the Wanapum aquifer.

Head Changes - In the western portion of the study area, there are a number of wells completed within the Wanapum at varying depths. The water levels in these wells are very similar (Figures 21, 22 and Table 4). The uniformity of head within the Wanapum Aquifer indicate that it's interflow zones function as a collection of hydraulically interconnected water-bearing zones, rather than a set of markedly distinct aquifers.

Ground-Water Flow and Anticlines

1. Western Area - In the area of BSW #13 (Charron), the spring, 1991 water level within the Wanapum is at an elevation of 1,165 feet (msl). Due north of this well at the crest of Yakima Ridge, the estimated elevation of the Vantage Interbed is 2,400 feet (msl), and south of the well at the crest of Rattlesnake Ridge, the elevation of the Vantage Interbed is estimated to be 400 feet (msl). This information supports the concept that the northern ridge (Yakima Ridge) is a barrier to the north-south migration of ground water (Figure 15). The 400-foot (msl) elevation of the Vantage Interbed at Rattlesnake Ridge likely means there are several saturated Wanapum Interflow zones above the Vantage. Given this, it is possible that ground water within this area may be migrating southerly through Rattlesnake Ridge. However, the hydraulic connection is probably very weak. The reason is that even though the thrust fault is not likely present in this area, any faulting along the ridge has probably left the interflow zones broken and offset.

2. Eastern Area - In the eastern end of the study area at BSW #82 (DNR Black Rock), the head in the Wanapum Aquifer during the spring of 1991 was about 900 feet. The estimated elevation of the Vantage on the crest of Yakima Ridge due north of the well is 2,300 feet (msl). The estimated Vantage elevation on the crest of Rattlesnake Ridge due south of the well is 1,100 feet (msl). In this circumstance, the water level is below the elevation of the Vantage in each case. Therefore, it is not likely that there is any north-south movement of water through either of the ridges in this portion of the study area.

Water Quality

Two sets of water-chemistry data reveal information about the proximity of the Wanapum Aquifer recharge area relative to the Grande Ronde Aquifer recharge area. One data set was produced in 1981 by the Yakima Testing Laboratory and the other set was analyzed by the Basalt Waste Isolation Project Laboratory in 1986 and summarized by Burt, (1989). Each data set shows that the sodium concentrations within both the

Wanapum and Grande Ronde waters are higher than the calcium concentrations (Table 2). Yet the sodium concentrations within the Grande Ronde are nearly 3 times higher, and the calcium 10 times less, than in the Wanapum. This indicates that the Grande Ronde water has spent a longer period of time in the sub-surface. Therefore, the Wanapum recharge areas are more likely to be local and the Grande Ronde areas more likely to be distant.

Hydraulic Testing

On December 16, 1986 the Department conducted a 48 hour pumping test on BSW #44 (Hart) (Figure 24). The purpose of the test was to better delineate the extent of the aquifers in the area through monitoring the response of other wells. None of the other irrigation wells in the area were pumping. The Hart well pumped at a constant rate of 275 gallons per minute while 10 other wells in the area were monitored for water level response. The airlines of two wells (BSW #51 and #49) were considered to be malfunctioning, and consequently, the data from these wells were not used in any analysis.

Geology and Well Construction

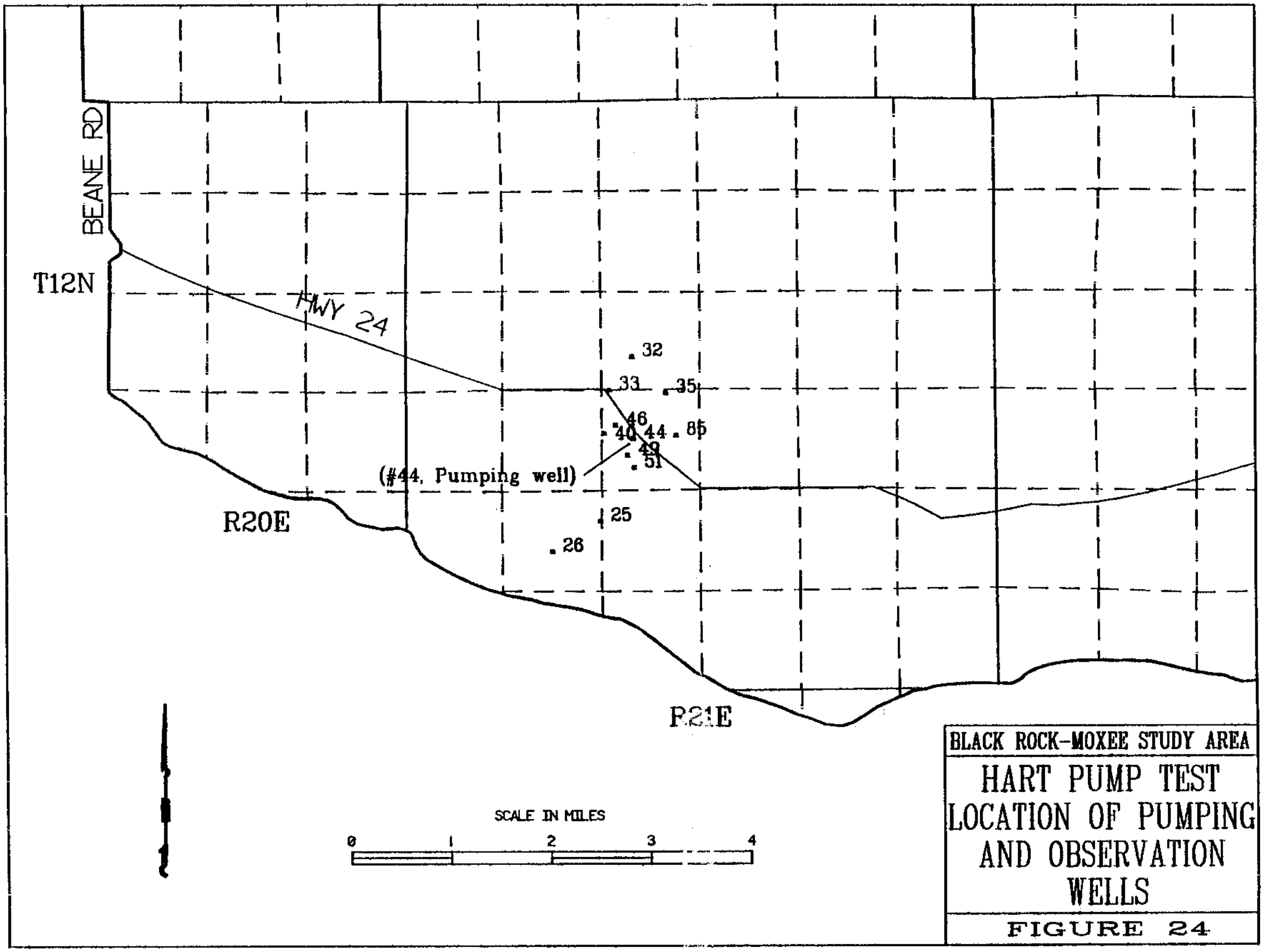
In the area of the BSW #44 (Hart well), the Mabton Interbed is approximately 53 feet thick. BSW #44 well report describes the upper 43 feet of the Mabton as a "blue, sandy, clay-shale" and the lower 8 feet of the Mabton as "blue sand & water". BSW #44 is screened through this lower 8 feet of sand as well as the uppermost 2 feet of the Wanapum. Therefore, much of the water withdrawn from this well is probably from the lower portion of the Mabton. The well report does not state that BSW #44 is sealed with grout across the Mabton.

Pre-test Expectations

Since the upper 43 feet of the Mabton is sandy clay, a likely aquitard, one would not expect a water-level drop, during the test, in the observation wells that were completed in the Saddle Mountains Aquifer located above the Mabton. Conversely, one should expect to see a marked reduction in water level in those observation wells completed in the lower Mabton/Upper Wanapum.

Test Results

Eight of the ten observation wells are completed within the Saddle Mountains Aquifer, one in the lower part of the Mabton and one in the deeper portion of the Wanapum. As expected, with only one exception (BSW #85, Harris), none of the Saddle Mountain observation wells showed any water level



BLACK ROCK-MOXEE STUDY AREA

HART PUMP TEST
LOCATION OF PUMPING
AND OBSERVATION
WELLS

FIGURE 24

drop that could be conclusively attributed to the pumping of the Hart well. The only Wanapum observation well (BSW #32, DNR), showed no response to pumping. The observation well completed into the lower part of the Mabton (BSW #35, Henderson) responded with a water level drop of 23 feet within the first 18 hours of pumping.

Analysis of Water-Level Response

The water-level drop in BSW #85 (Harris) was the only unexpected response of the test. BSW #85 began to decline after 300 minutes of pumping. A small decline in water level continued throughout the remainder test. Upon cessation of pumping, the level began to rise. The total amount of draw down within BSW #85 was 0.48 feet. This water level drop may be due to vertical leakage through the Mabton Interbed into the pumped aquifer or, it could represent downward leakage along the outside of a well casing from the Saddle Mountains Aquifer. Consequently, the interpretation of the BSW #85 response is inconclusive.

There are several reasons why Wanapum well BSW #32 did not show any response during the test. First, the pumping well (BSW #44) only penetrates 2 feet into the Wanapum Aquifer. Second, BSW #32 draws water from deep within the Wanapum. Third, BSW #32 is located 4,500 feet from the pumping well. Finally, the relatively low pumping rate of BSW #44 may account for a lack of response. At the relatively low pumping rate of 275 gpm, the well water is derived primarily from the uppermost portion of the Wanapum Aquifer and Mabton Interbed. Consequently, at only 275 gpm and a distance of 4,500 feet from the Hart pumping well, any pumping effect on BSW #32 would probably be to small to detect with an air-line and quickly erased by an up-hole supply from the lower interflow zones.

The twenty-three feet of draw down in the Henderson Well (BSW #35) represents the most dramatic test response. At a distance of about 3,000 feet from BSW #44 the initial reaction to this water level drop was one of surprise. Upon careful inspection of the BSW #35 well report, it is clear that the well is completed into the uppermost portion of the lower sand unit of the Mabton Interbed. The conclusion that can be drawn is that both BSW #35 and BSW #44 withdraw water from the lowest part of the Mabton.

Summary

The most valuable information gained from this test was that BSW #44 is in hydraulic connection with BSW #35. This response confirms that well #35 is completed into the Mabton.

Conceptual Model Of Wanapum Aquifer

A. The Mabton Interbed is the aquitard that hydraulically separates the Wanapum Aquifer from the Saddle Mountains Aquifer. The Mabton Interbed is laterally extensive throughout the study area. The Wanapum Aquifer is distinguished from the Grande Ronde Aquifer by the Vantage Interbed.

B. The Bird Canyon Fault acts as a vertical hydraulic barrier that divides the ground water of the Wanapum Aquifer into two hydraulically discrete areas within the study area.

C. Within the Wanapum Aquifer there are laterally-continuous, water-bearing interflow zones that are stratigraphically separated by relatively dense flow interiors. However, the flow interiors have sufficient vertical conductivity to maintain a similar head value within all of the interflow zones during non-stressed conditions.

D. North-south trending structures such as the Hog Ranch-Naneum Anticline, and Fire Water Canyon Fault are believed to result in modest reductions in east-west transmissivity across these areas. The reduced transmissivity may result in small timing differences in the post irrigation season stabilization of head on either side of these structures.

E. All the waters of the Wanapum Aquifer that are <u>west</u> of the Hog Ranch-Naneum Anticline are under confining pressure. However, the Wanapum waters over the Hog Ranch-Naneum Anticline and <u>east</u> of the anticline are not under confining pressure. East of the Bird Canyon Fault, all Wanapum waters are hydraulically interconnected and flow to the east. West of the Bird Canyon Fault, the Wanapum waters are thought to migrate eastward until they encounter the Bird Canyon Fault.

F. Yakima Ridge represents a hydraulic barrier to the north-south flow of water within the Wanapum Aquifer.

G. Rattlesnake Ridge also represents a hydraulic barrier to the north-south flow of water within the Wanapum. However, in the extreme west end of the study area it is possible that there is a very small degree of north-south hydraulic communication through the Ridge during pumping.

H. The hydraulic gradient of Wanapum waters east of the Bird Canyon Fault along the Black Rock-Moxee Syncline axis slopes to the east.

I. The recharge areas for the Wanapum Aquifer west of the Bird Canyon Fault are thought to be the Cascade Mountains to the west, and those areas of Wanapum Basalt exposure on the southern side of Yakima Ridge west of the Bird Canyon Fault.

J. The recharge areas for the Wanapum Aquifer located east of the Bird Canyon Fault are only those areas of Wanapum Basalt exposure on the southern side of Yakima Ridge. This eastern area is recharged by precipitation falling on Yakima Ridge and entering the Wanapum Basalt to become ground water (local recharge). The discharge area east of the Bird Canyon Fault is the Cold Creek Syncline via Dry Creek Valley.

K. The Myers Anticline is not considered to be hydraulically significant within the Wanapum Basalt Aquifer.

L. Pumping the Wanapum Aquifer within the study area will not induce any southern migration of ground water through Yakima Ridge. Similarly, pumping the Wanapum on the south side of Rattlesnake Ridge would not draw ground water southward out of the study area. One exception within the study area may be along the western-most section of Rattlesnake Ridge where the thrust fault may not exist.

M. The long-term water-level data for the Wanapum wells located east of the Bird Canyon Fault, show marked decline rates within the Wanapum. This very likely means that withdrawals are exceeding recharge. However, west of the Bird Canyon Fault there is no evidence that waters of the Wanapum Aquifer are in decline (Figure 25).

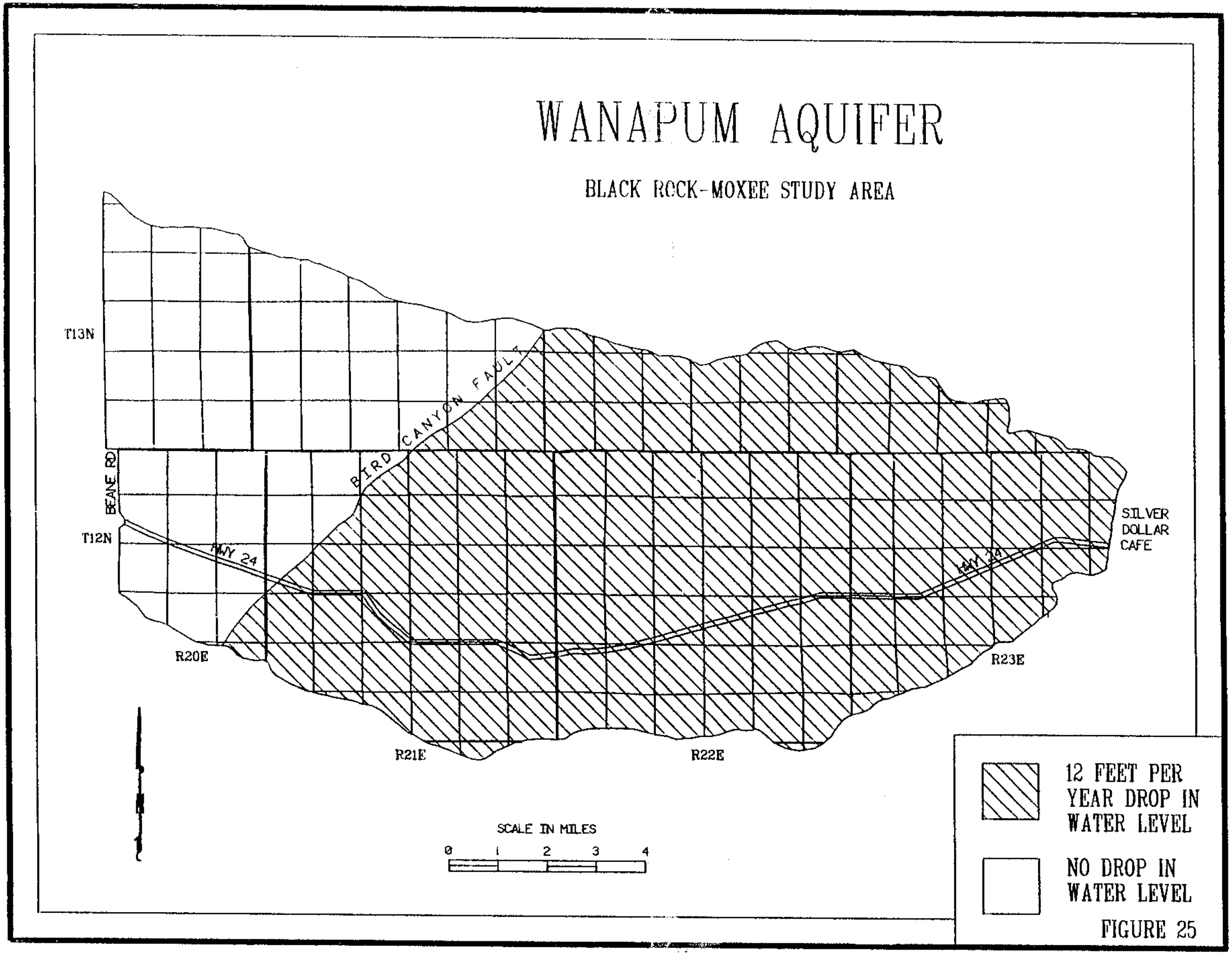

WANAPUM AQUIFER
BLACK ROCK-MOXEE STUDY AREA
T13N
T12N
BEANE RD
HWY 24
BIRD CANYON FAULT
SILVER DOLLAR CAFE
R20E
R21E
R22E
R23E
SCALE IN MILES
0
1
2
3
4
12 FEET PER YEAR DROP IN WATER LEVEL
NO DROP IN WATER LEVEL

FIGURE 25

SECTION 7

SADDLE MOUNTAINS AQUIFER

In this section, a conceptual model of Saddle Mountains Aquifer will be developed. Data pertinent to the Saddle Mountains aquifer will be evaluated by data type. At the end of the section, all the elements of the conceptual model will be presented and important points summarized.

Wells

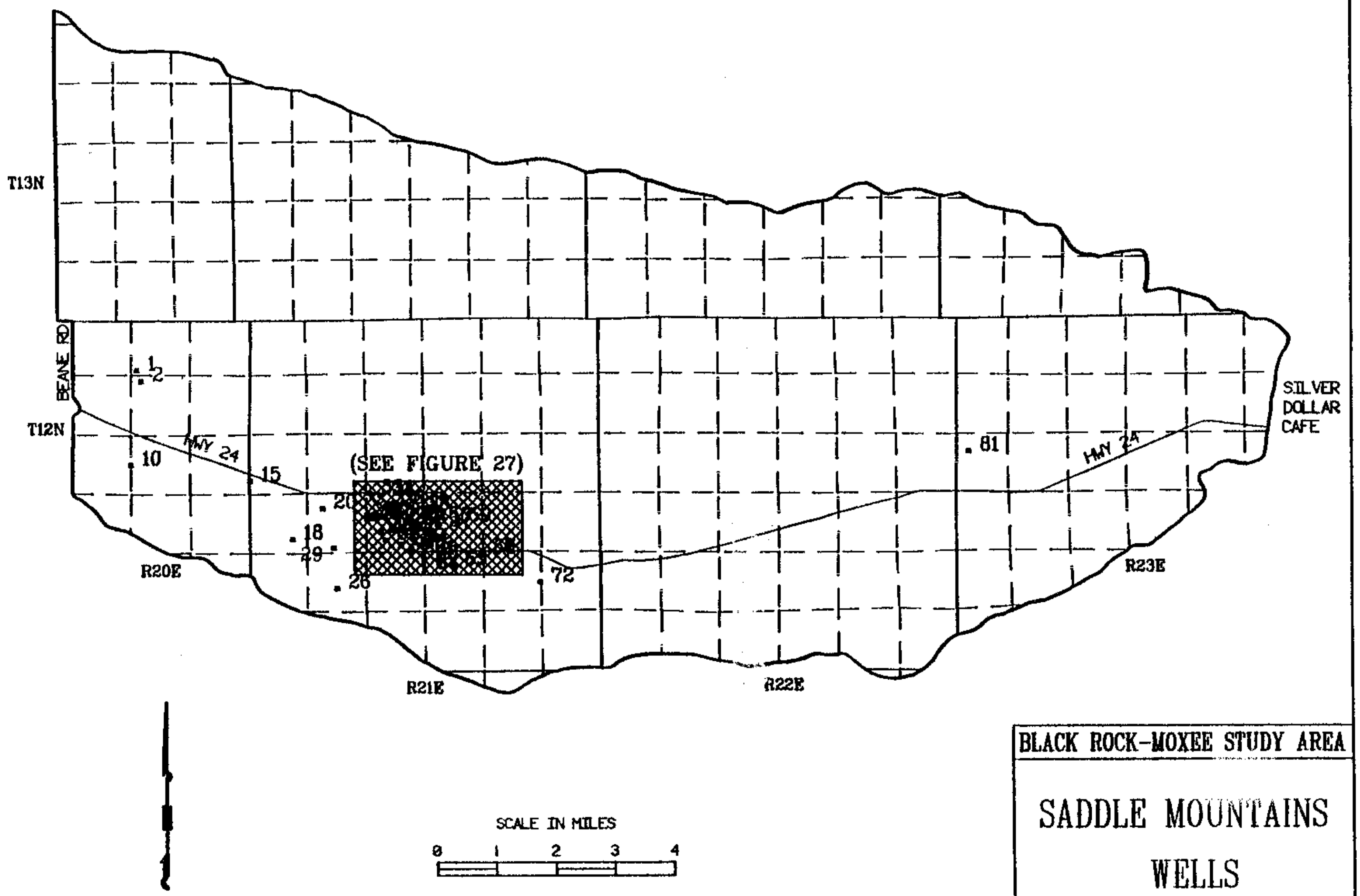
At least 42 of the study wells studied are open to the Saddle Mountains Basalt Formation (Figure 26). Of the 42 wells, 21 are located in Section 21 (Figure 27). The ten wells that have been underlined below are the wells that have served as Department monitoring wells for some period of time. The list of Saddle Mountains Basalt study wells is given in table 5.

Well Construction and Data Control

The well reports have been reviewed for construction methods that may allow the withdrawal of ground water from multiple aquifers. Based on this review the following wells have been identified for further study:

BSW #33, WDOE C-3
BSW #29, MARTINEZ
BSW #38, FOX
BSW #20, MARTINEZ
BSW#65, BENNINGFIELD
BSW #64, GRISWOLD

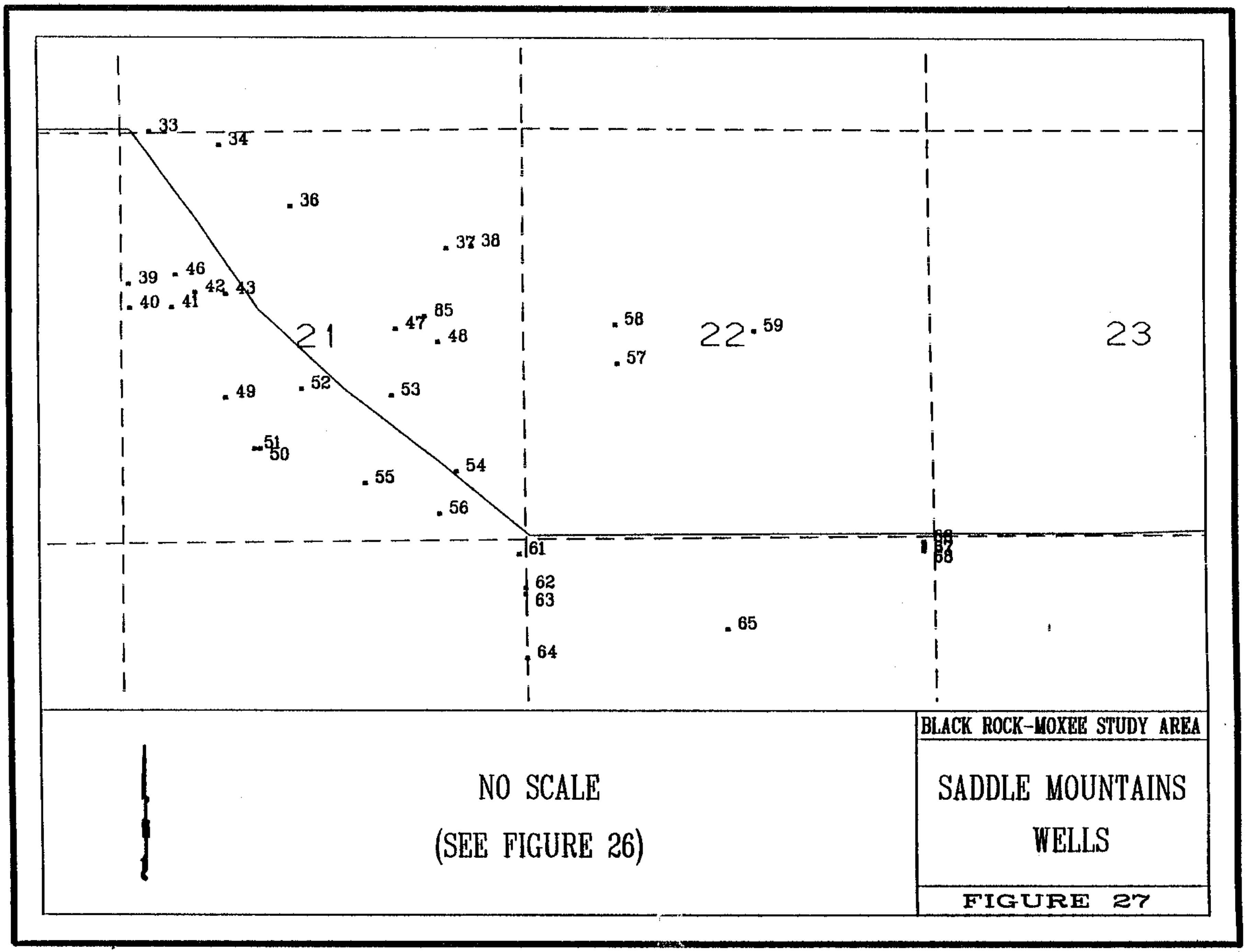
The water-level data from monitoring wells BSW #65, BSW #29, and BSW #20 were not used in the analysis. The data from BSW #65 are unreliable due to an uncertain air line length, and a questionable point of measurement access. The data from BSW #29 are suspect because of erratic measurements which are likely due to an excessive amount of oil on the water surface. The air line on BSW #20 broke only after a few years of measurements, and there is simply not enough data to plot a useful trend. Post-1987 data collected on BSW #72 (Decoto) will be considered with caution because of a sudden and anomalously steep drop in water levels.



BLACK ROCK-MOXEE STUDY AREA

SADDLE MOUNTAINS WELLS

FIGURE 26



NO SCALE
(SEE FIGURE 26)

BLACK ROCK-MOXEE STUDY AREA

SADDLE MOUNTAINS
WELLS

FIGURE 27

Study #	Owner name	USGS #	Depth(ft)	Spring 91 WL Elev (ft)
BSW #01,	NATIONAL FDS,	12/20-2N1	645	1168
BSW #02,	HARRIS FARMS,	12/20-11D1	566	
BSW #10,	COX (ROY),	12/20-15H2	302	
BSW #18,	MARTINEZ,	12/21-19?	946	
BSW #20,	MARTINEZ	12/21-20C1	862	----
BSW #26,	EKERICH,	12/21-29L1	850	1253
BSW #29,	MARTINEZ,	12/21-20P1	1061	----
BSW #33,	DOE-C3,	12/21-16N1	704	1210
BSW #34,	GUILLEMAUD,	12/21-21D1	732	
BSW #36,	THOMAS,	12/21-21C1	690	
BSW #37,	FOX,	12/21-21H1	503	
BSW #38,	FOX,	12/21-21H2	655	1351
BSW #39,	BERGER,	12/21-21E1	429	
BSW #40,	LDS,	12/21-21E2	384	1274
BSW #41,	BERGER,	12/21-21E3	402	1263
BSW #42,	BERGER,	12/21-21E4	352	
BSW #43,	HART,	12/21-21L3	602	
BSW #46,	LDS,	12/21-21E6	720	1220
BSW #47,	RUFF,	12/21-21G1	270	
BSW #48,	GOODRICH,	12/21-21H3	410	
BSW #49,	LDS,	12/21-21L3	448	
BSW #50,	LDS,	12/21-21P1	345	1338
BSW #51,	LDS,	12/21-21P2	385	1306
BSW #52,	SMITH,	12/21-21L1	365	
BSW #53,	NARDUZZI,	12/21-21K1	398	
BSW #54,	PAGH,	12/21-21R1	300	
BSW #55,	FITE,	12/21-21Q1	365	
BSW #56,	VAN EATON,	12/21-21R2	318	
BSW #57,	MOODY,	12/21-22M1	298	
BSW #58,	LABRANT,	12/21-22E1	440	
BSW #59,	STILES,	12/21-22G1	255	
BSW #61,	GRISWOLD,	12/21-28A2	295	
BSW #62,	GRISWOLD,	12/21-28A1	363	
BSW #63,	GRISWOLD,	12/21-28A3	286	1336
BSW #64,	GRISWOLD,	12/21-28H1	375	
BSW #65,	BENNINGFIELD,	12/21-27B1	560	----
BSW #66,	USDA #1	12/21-27A1	287	1294
BSW #67,	USDA #2	12/21-27A3	420	1297
BSW #68,	USDA #3	12/21-27A2	670	
BSW #72,	DECOTO	12/21-26J1	400	----
BSW #81,	STARK,	12/23-18E1	206	1706
BSW #85,	HARRIS,	12/21-21H3	350	

Table 5. Saddle Mountains Wells

Water Levels

The analysis will look at water-level declines, the presence or absence of hydraulic barriers and aquitards, internal head conditions, and the likelihood of north-south movement through either Yakima Ridge or the Rattlesnake Hills. Water-level data will be used to evaluate whether or not the Saddle Mountains Basalt Formation is essentially one aquifer like the Wanapum or is divided into upper and lower aquifers by an aquitard.

One hypothesis contends that when sufficiently stressed, the Saddle Mountains Basalt Formation functions as one hydraulic unit that is comprised of a package of highly interconnected individual aquifers. In other words, a single aquifer like that of the Wanapum. The other hypothesis contends that the Pomona and Umatilla basalt flows comprise one aquifer (Lower Saddle Mountains Aquifer), while the Rattlesnake Ridge Interbed, Elephant Mountain basalt flow and Upper Ellensburg Formationsediments form a separate one (Upper Saddle Mountains Aquifer).

Temporal Water-Level Analysis

Annual, spring water-level measurements from 7 Saddle Mountains Basalt monitoring wells have been plotted versus time (Figure 28). Analysis of well locations and hydrographs indicate that as many as three vertical hydraulic barriers traverse the Saddle Mountains Aquifers. The three barriers are the

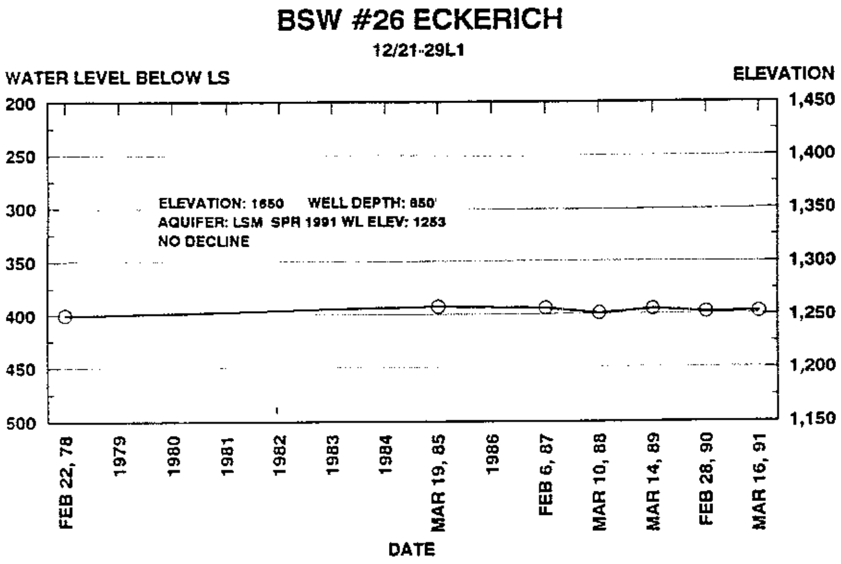
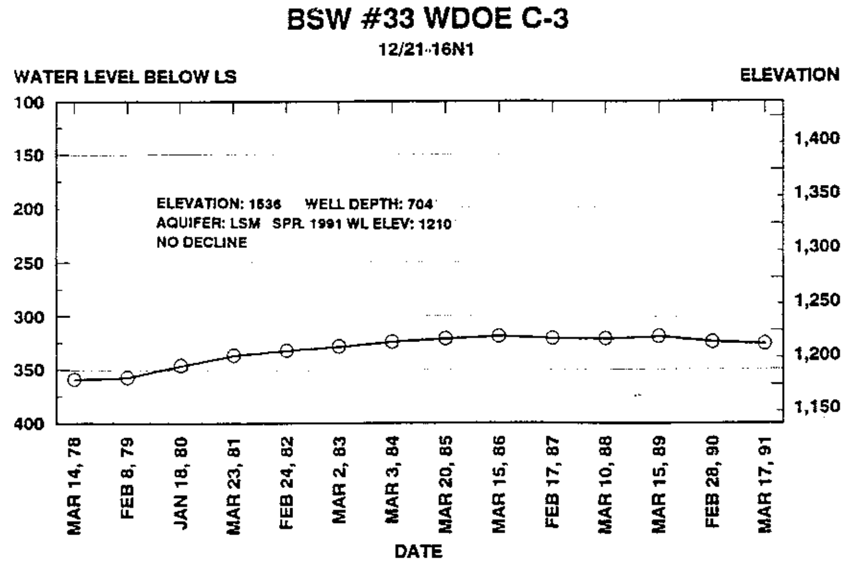
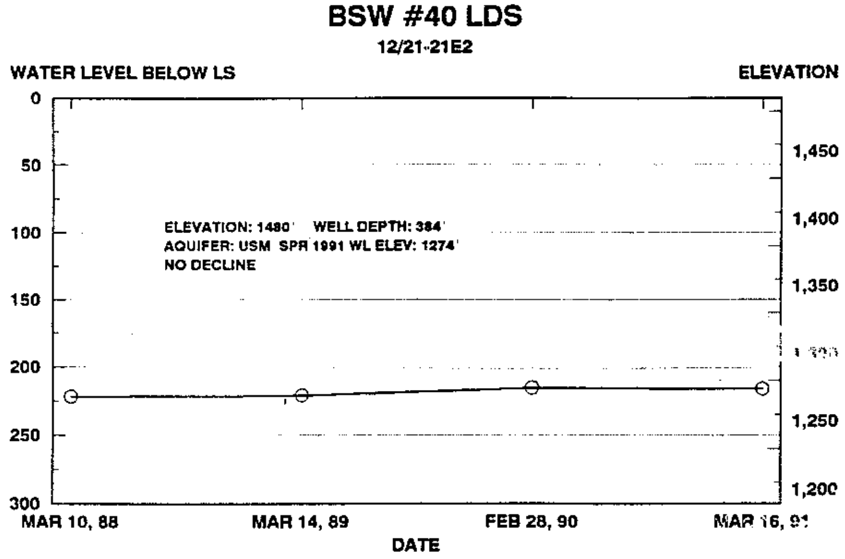


Figure 28A. Saddle Mountains hydrographs.





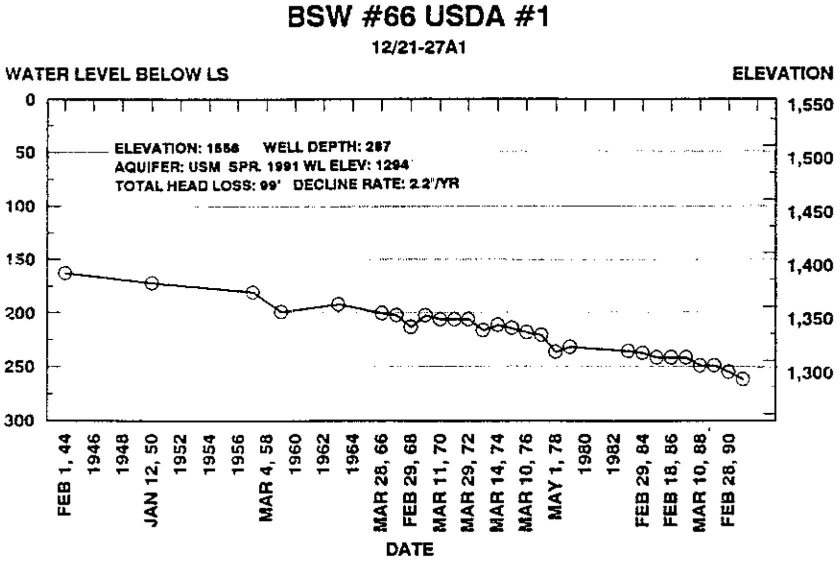
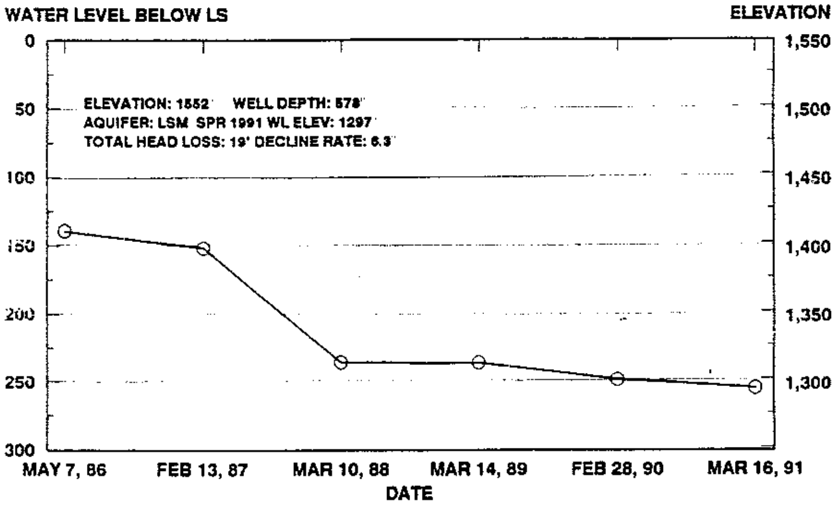


Figure 28B. Saddle Mountains hydrographs.

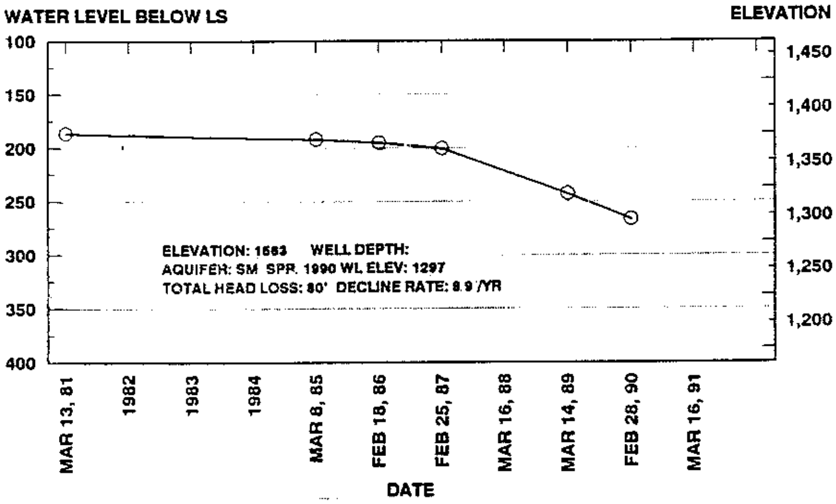
BSW #68 USDA #2

12/21-27A2



BSW #72 DECOTO

12/21-26J1



BSW #81 STARK

12/23-18E1

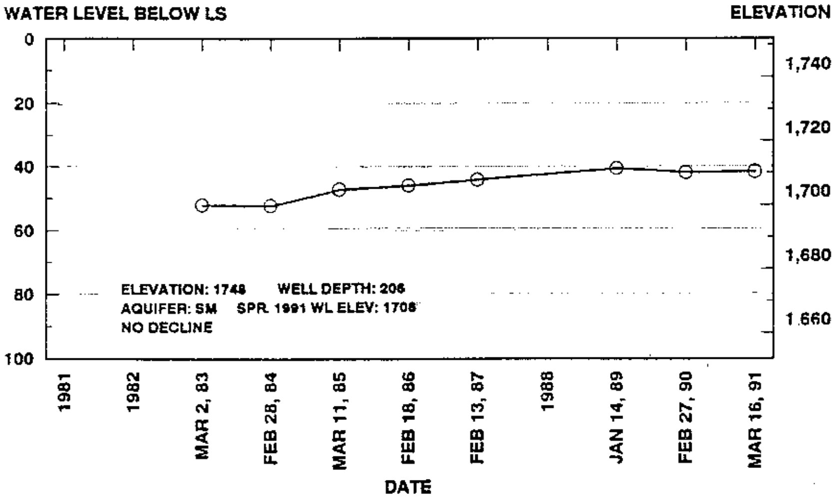


Figure 28C. Saddle Mountains hydrographs.

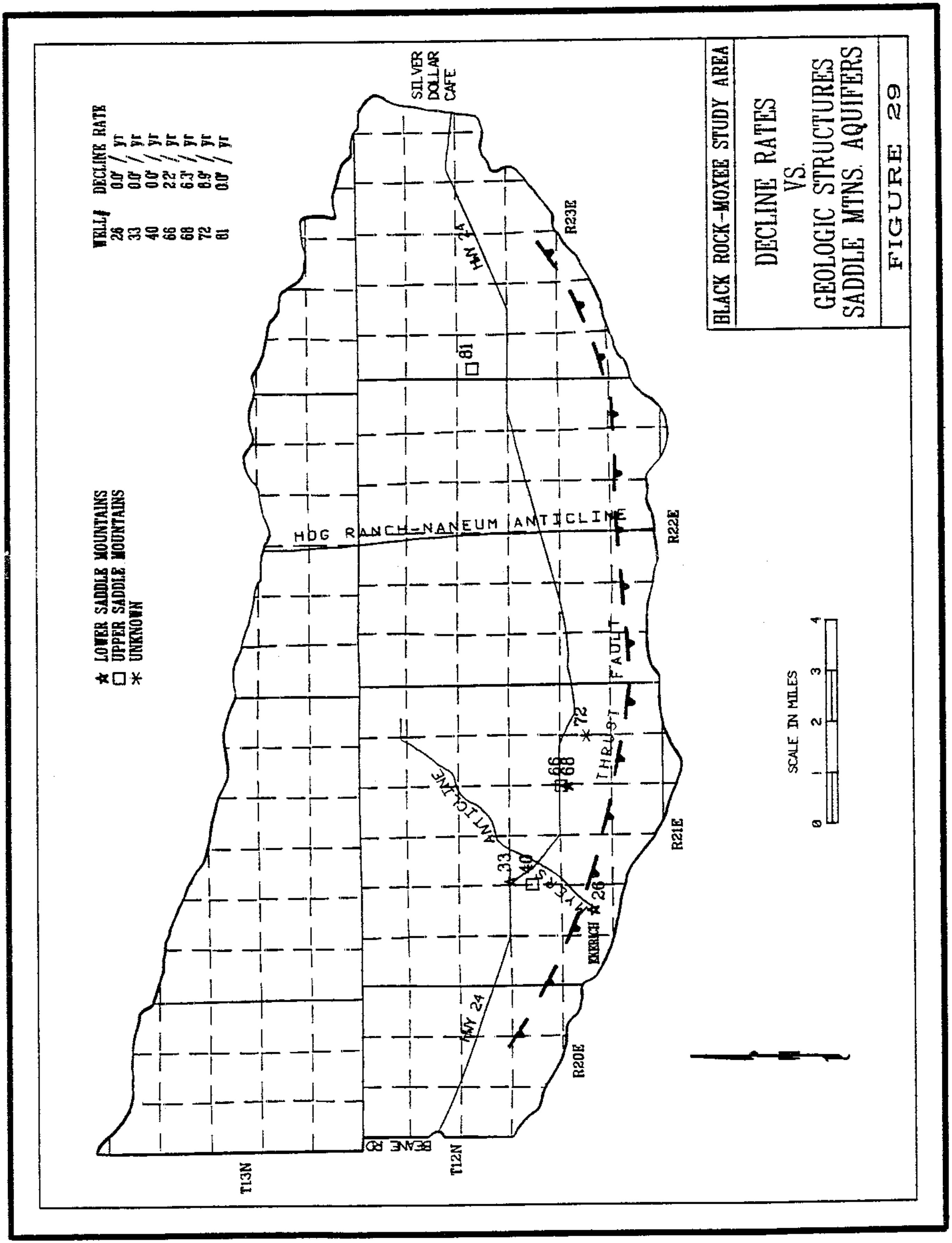
Myers Anticline, the Hog Ranch-Naneum Anticline, and the Rattlesnake Ridge Thrust Fault. The locations of the seven monitoring wells, their decline rates, and the three structural barriers have been plotted on a map of the study area (Figure 29). This information indicates that the Myers Anticline may be acting as a hydraulic barrier and separating BSW #40 and #33 from BSW #66, #68, and #72. The lower static water level in BSW #26 suggests that the thrust fault isolates this well from the rest of the Saddle Mountains Aquifer. Finally, BSW #81 does not show any evidence of water-level decline which suggests that the Hog Ranch-Naneum Anticline functions as a hydraulic barrier within the Saddle Mountains Aquifer.

The two Saddle Mountains Basalt Formation wells, BSW #66 (USDA #1) and BSW #68 (USDA #2), exhibit a notable difference in decline rate, even though they are approximately 100 feet apart. Well #66 is open to the Rattlesnake Ridge Interbed which lies stratigraphically above the Pomona Member of the Saddle Mountains Basalt Formation. Well #68, on the other hand, is open only to the Pomona Member. The notable difference in decline rate between wells of such close proximity supports the hypothesis that the Saddle Mountains Basalt Formation is divided into upper and lower aquifers as previously defined.

Declines within the Lower Saddle Mountains Aquifer appear to be limited to that portion of the study area which lies west of the Myers Structure, east of the Hog Ranch-Naneum Anticline, and north of the thrust fault on Rattlesnake Ridge (Figure 30).

Spatial Water-Level Analysis

In the spring of 1991, the Department measured the water levels of as many Saddle Mountains wells as possible. From Lower Saddle Mountain Aquifer well #68 to Lower Saddle Mountain Aquifer well #33, the water level decreases 87 feet over a distance of approximately 2.2 miles defining a gradient of about 40 feet per mile. From Lower Saddle Mountain Aquifer well #33 to Lower Saddle Mountain Aquifer well #01, the water level decreases 42 feet over a distance of about 4.5 miles, resulting in a gradient of 9 feet per mile. The abrupt change of hydraulic gradient across the Myers Anticline, located between wells #33 and #68, is a further indication that within the Lower Saddle Mountains Aquifer, this structure functions as a hydraulic barrier. If this is the case, then the water levels within the Lower Saddle Mountains Aquifer east and up gradient of the Myers Anticline should be pooled up and should exhibit a fairly uniform head. West of the Myers Anticline,



BLACK ROCK-MOXEE STUDY AREA

DECLINE RATES VS. GEOLOGIC STRUCTURES SADDLE MTNS. AQUIFERS

FIGURE 29

WELL#	DECLINE RATE
26	0.0' / yr
33	0.0' / yr
40	0.0' / yr
66	2.2' / yr
68	6.3' / yr
72	6.9' / yr
81	0.0' / yr

LOWER SADDLE MTNS. AQUIFER

BLACK ROCK-MOXEE STUDY AREA

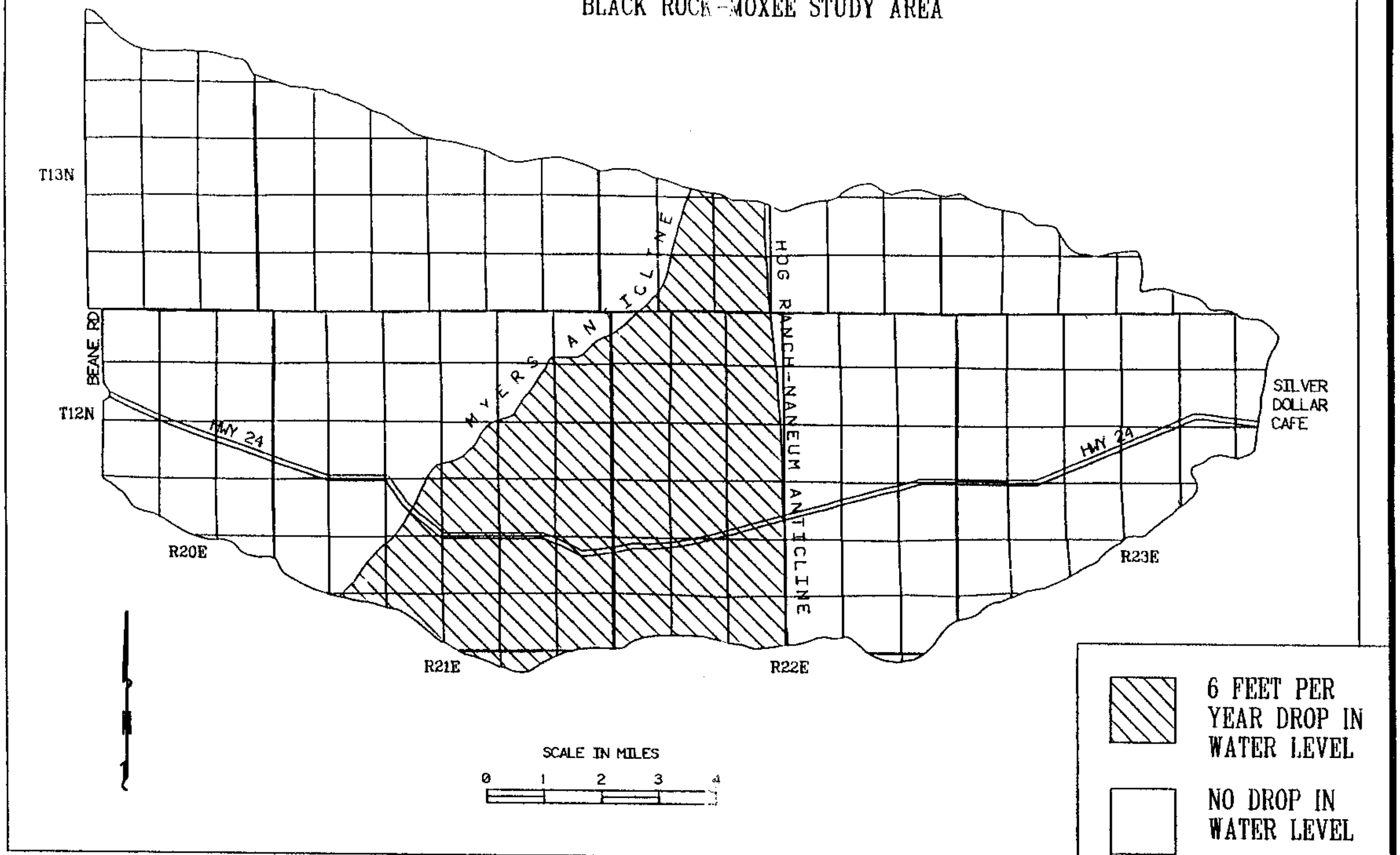


FIGURE 30

the Lower Saddle Mountain Aquifer waters drain west under a gradient of about 9 feet per mile.

A comparison of the water-level elevations of BSW #68 (USDA #2) and BSW #66 (USDA #1) supports the hypothesis that the formation acts as a single aquifer. Another possibility is that the formation is in fact divided into two aquifers, and that the similar heads in the two wells are a coincidence.

In the area of BSW #01 (National Foods), the spring 1991 water level within the Lower Saddle Mountain Aquifer has an elevation of 1,168 feet (msl). North of this well at the crest of Yakima Ridge, the Wanapum Formation is exposed and the Saddle Mountains Basalt Formation is not present. Consequently, there could be no ground-water migration through Yakima Ridge within the Saddle Mountains Basalt. South of BSW #01, at the crest of Rattlesnake Ridge, the elevation of the Mabton Interbed is estimated to be 1,300 feet (msl). Given that the water-level elevation at BSW #01 is 1,168 feet (msl), it would appear that there is no north-south migration of Saddle Mountain ground water through Rattlesnake Ridge.

In the eastern portion of the study area at BSW #81 (Stark), the water level in the Upper Saddle Mountains Aquifer (spring 1991) was about 1,706 feet. Due north of the well on the crest of Yakima Ridge, the Saddle Mountains Basalt Formation is not present, therefore, there is no north-south movement of Saddle Mountains ground water through Yakima Ridge. South of BSW #81, at the crest of Rattlesnake Ridge, the elevation of the Mabton Interbed is estimated to be at 2,700 feet (msl). In this circumstance, the water level is below the elevation of Mabton Interbed, and, therefore it is not likely that there is any north-south movement of water through Rattlesnake Ridge.

Only a relatively thin portion of the Saddle Mountains Basalt Formation remains across the Hog Ranch-Naneum Anticline. A review of the well report for BSW #75 and the geochemical results on BSW #77 (Table 6) indicate that only the Umatilla Member and perhaps a portion of the Pomona Member of the Saddle Mountains Basalt Formation are present. These members are in turn overlain by alluvium.

The elevation of the top of the Mabton Interbed near the crest of the Hog-Ranch Naneum Anticline is about 1,594 feet (msl) as evidenced by the well log of BSW #80. The spring, 1991 water-level elevation for BSW #68 (USDA #2, Lower Saddle Mountain Aquifer) is 1,297 feet (msl). This level was considerably below the elevation of the Mabton at the crest of the Hog Ranch-Naneum Anticline and suggests that the anticline serves as a ground-water divide within the Saddle Mountains Basalt Formation.

TABLE 6
GEOCHEMISTRY FOR ROCK CHIP SAMPLES (Weight %)

Well No.	Owner	Depth Feet	Rock Well Sample No.	SiO_2	Al_2O_3	TiO_2	FeO_3	FeO	MnO	CaO	MgO	K_2O	Na_2O	P_2O_5	Basalt Member Chemical Type
12/20-13O1	Charron:														
BSW #13		2079-2088	BM380	53.86	15.23	2.55	2.00	12.36	0.21	6.02	5.26	1.06	1.13	0.32	Frenchman Springs
12/21-16N2	DNR Martinez:														
BSW #32		1370-1380	C4616	51.01	14.41	3.07	2.00	12.79	0.27	8.09	4.36	1.10	2.32	0.59	Frenchman Springs
		1365-1370	C4617	50.80	14.13	3.20	2.00	13.00	0.25	8.39	4.32	1.00	2.48	0.60	Frenchman Springs
		1380-1390	C4618	50.85	14.53	3.08	2.00	13.29	0.22	7.70	4.65	1.01	2.13	0.54	Frenchman Springs
12/22-21L1	Marley #4:														
BSW #77		70-80	BM8231	52.45	15.15	2.74	2.00	10.53	0.20	8.35	4.52	1.25	2.26	0.54	Frenchman Springs type?
		190-200	BM8232	54.54	15.08	2.94	2.00	10.26	0.20	6.54	2.88	2.48	2.24	0.82	Umatilla
		300-310	BM8233	54.32	15.41	3.02	2.00	9.73	0.18	6.61	2.65	2.62	2.69	0.78	Umatilla
		330-340	BM8234	49.35	14.45	3.30	2.00	11.80	0.25	9.39	5.50	0.92	2.38	0.66	Priest Rapids Lolo
		480-490	BM8235	49.84	13.84	3.72	2.00	12.92	0.24	8.62	4.86	1.10	2.19	0.67	Priest Rapids Lolo
		560-570	BM8236A	50.54	14.71	3.25	2.00	11.83	0.20	8.71	4.71	0.99	2.46	0.59	Priest Rapids Rosalia
		600-610	BM8236B	50.61	14.61	3.31	2.00	12.01	0.21	8.47	4.51	1.15	2.54	0.58	Priest Rapids Rosalia
		690-700	BM8237	51.96	14.90	3.26	2.00	11.71	0.23	8.24	3.91	0.87	2.35	0.57	Frenchman Springs
		750-760	BM8238A	52.54	14.69	2.96	2.00	11.60	0.23	7.65	3.75	1.38	2.59	0.60	Frenchman Springs
		790-800	BM8238B	52.23	14.28	2.93	2.00	12.25	0.23	7.67	3.66	1.42	2.71	0.62	Frenchman Springs
		830-840	BM8239	51.99	14.44	2.99	2.00	12.24	0.21	7.60	4.12	1.36	2.43	0.60	Frenchman Springs
		1000-1010	BM8240	50.74	14.54	3.05	2.00	12.16	0.21	8.44	4.73	1.20	2.41	0.53	Frenchman Springs
		1300-1310	BM8241A	50.58	14.39	3.18	2.00	12.55	0.22	8.25	4.34	1.20	2.71	0.58	Frenchman Springs
		1370-1380	BM8241B	50.60	13.92	3.21	2.00	12.92	0.24	8.20	4.23	1.27	2.78	0.63	Frenchman Springs
		1436-1440	BM8242	54.02	15.73	1.80	2.00	9.30	0.19	8.55	4.69	1.03	2.40	0.29	Grande Ronde

Hydraulic Testing

On November 12, 1991, the Department conducted a six-day aquifer test on BSW #67 (USDA #3). The purpose of the test was to gain a better understanding of the Saddle Mountains Aquifers and its inter-relationship with the Wanapum. None of the other irrigation wells in the area were pumping. Wells in the area were in various stages of recovery following the irrigation season. The USDA #3 well was pumped at a constant rate of 250 gallons per minute while 8 other wells in the area were monitored for water-level response (Figure 31). The water-levels in these wells were monitored on a semi-regular basis for the first 3 days.

Geology and Well Construction

USDA well #3 is cased and sealed 360 feet into a 20-foot thick layer of "cemented sandstone" which is located in the lower part of the Rattlesnake Ridge Member of the Saddle Mountains Basalt Formation. The remainder of the well is screened and open to the lowest 10 feet of the Rattlesnake Ridge Member and a portion of the Pomona Basalt Member of the Saddle Mountains Basalt Formation. This construction indicates that USDA #3 is completed into the Lower Saddle Mountain Aquifer.

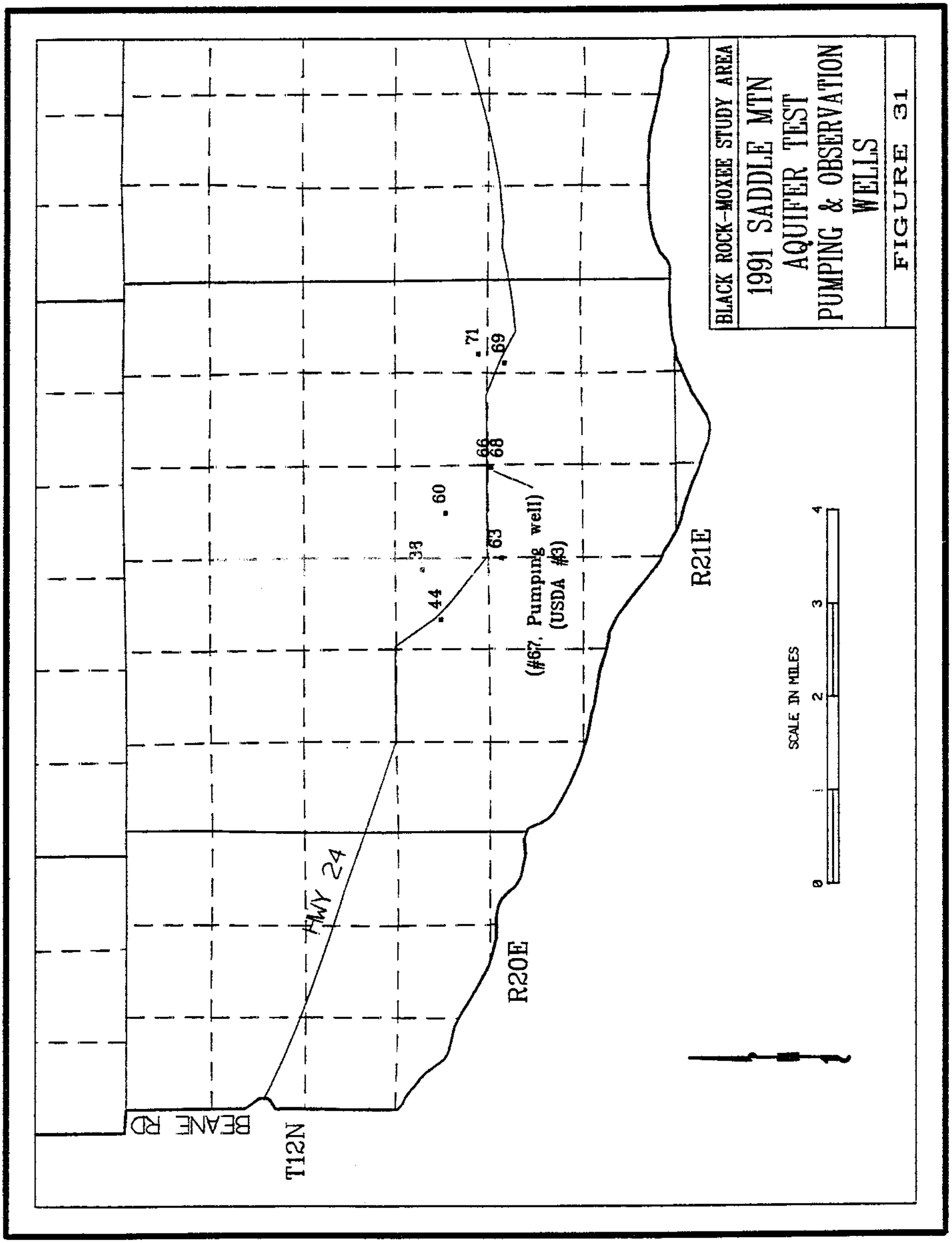
Pre-test Expectations

Four of the eight observation wells were Wanapum Aquifer wells, and therefore, no response or drop in water level was expected in these wells. Two of the wells are open to the Upper Saddle Mountains Aquifer, and consequently, if the Saddle Mountains Basalt Formation really contains two aquifers, then little or no response would be expected from these wells. One observation well is open to the Lower Saddle Mountain Aquifer from which a marked response was expected. Pre-test expectations for BSW #38 were uncertain because this well is suspected of being open to both the Lower Saddle Mountain Aquifer and the Wanapum.

Test Results

The response from the four Wanapum Aquifer wells was negative. In fact, the water levels in these wells rose slightly during the test. The negative response was expected because of the aquitard properties afforded by the Mabton Interbed.

The two Upper Saddle Mountains Aquifer wells were of particular interest. The response from BSW #63 (Griswold) was a water level rise of 0.5 feet, while BSW #66 (USDA #1) ended with the test with no change. These results support the



BLACK ROCK-MOXEE STUDY AREA

1991 SADDLE MTN AQUIFER TEST PUMPING & OBSERVATION WELLS

FIGURE 31

divided aquifer hypothesis within the Saddle Mountains Formation. The Lower Saddle Mountain Aquifer well BSW #68 (USDA #2) responded very positively as expected, the total drawdown over the six day test was about 19 feet. This confirms that BSW #67 (UDSA #3 - the pumping well) is completed into the same aquifer as BSW #68 (USDA #2).

The Fox well (BSW #38) did not respond with a decline in water level. The water level in this well rose during the test. This well is open to the Lower Saddle Mountain Aquifer and also may be open to the Wanapum Aquifer. In the four-day period prior to the start of the test, the water level rose 3.63 feet, while in this same time period the USDA #2 well rose only 0.25 feet. Furthermore, the water level in BSW #44 (the Hart Wanapum well) rose 4.62 feet during the six-day test period.

Eckerich Well Observations

Starting in March of 1988 and ending in October of 1988, the Department monitored water levels in BSW #26 (Ekerich) on a monthly basis. During this time period, the water levels in this Lower Saddle Mountain Aquifer well remained unchanged despite the pumping of many of the Saddle Mountain and other irrigation wells in the valley. Given the location of well #26 (Figure 29), the data supports the presence of a thrust fault which acts as a hydraulic barrier.

Conceptual Model Saddle Mountains Aquifers

A. Within the lower one third of the Rattlesnake Ridge Interbed, a cemented sand/gravel or clay aquitard hydraulically separates the Saddle Mountains Basalt Formation into two distinct aquifers, an upper and a lower. The aquitard is laterally extensive throughout the study area and maintains some measure of hydraulic separation at all points.

B. Portions of the basalt flows that comprise the Lower Saddle Mountains Aquifer are composed of pillow basalts. These pillow basalts are not aerially extensive and are less conductive than a typical interflow zone.

C. The flow interiors of the Lower Saddle Mountains Aquifer have sufficient vertical conductivity to maintain a similar head within the interflow zones during non-stressed conditions.

D. The Upper Saddle Mountains Aquifer consists of the Elephant Mountain Basalt and the stratified sediments of the Rattlesnake Ridge Interbed. The sediments in the Rattlesnake Ridge Interbed alternate from conductive to relatively nonconductive, the end result being a set of thin, semi-confined water-bearing zones that collectively act as an unconfined aquifer.

E. The Bird Canyon fault is not a vertical hydraulic barrier within either the Upper or Lower Saddle Mountains Aquifers.

F. The Fire Water Canyon Fault is not a vertical hydraulic barrier within either the Upper or Lower Saddle Mountains Aquifers.

G. The Hog Ranch-Naneum Anticline acts as a hydraulic divide within both of the Saddle Mountains Aquifers. Recharge from irrigation seepage and precipitation on the crest drains either to the west or the east.

H. Within the Lower Saddle Mountains Aquifer, the Myers Anticline acts as a hydraulic barrier. Ground water to the east of the structure is thought to be "pooled", while on the west side the water discharges to the west.

I. Yakima Ridge acts as a hydraulic barrier to the north-south flow of ground water within the Saddle Mountains Aquifers

J. Rattlesnake Ridge forms the southern boundary of the study area and also represents a hydraulic barrier to the north-south flow of ground water within the Saddle Mountains Aquifers.

K. The thrust fault along the north side of Rattlesnake Ridge also acts as a hydraulic barrier.

L. The recharge areas for the two Saddle Mountains Aquifers are considered to be the south side of Yakima Ridge and the irrigated areas within the study area.

M. Within the study area, the <u>Upper</u> Saddle Mountains Aquifer is broken into two separate hydrogeologic areas. One is that area located west of the Hog Ranch-Naneum Anticline and the other is the area east of this anticline.

N. The western area receives recharge from local precipitation and deep percolation of irrigation water. The ground water within the western area drains by geologic structure to the west. The eastern area of the upper aquifer also receives recharge from local precipitation and deep percolation of irrigation water and flows to the east.

O. Long-term records of water levels indicate declines only within the western area of the Upper Saddle Mountains Aquifer. The wells with records of declines are limited to wells BSW #66 (USDA #1) and possibly BSW #72 (Decoto) (Figure 30).

P. Pumping the Saddle Mountains Aquifers within the study area will not induce any migration of ground water through either Yakima Ridge or Rattlesnake Ridge.

Q. The Lower Saddle Mountains Aquifer is divided into three separate hydrogeologic areas. The western area lies west of the Myers Anticline. The central area lies between the Myers Structure and the Hog Ranch-Naneum Anticline. The eastern area lies east of the Hog Ranch-Naneum Anticline. Water-level declines in the central area are limited to BSW #68 (USDA #2), BSW #67 (USDA #3), and possibly BSW #65 (Benningfield) (Figure 31).

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