# Hydrologic Studies in the Umatilla Structural Basin

State of Oregon

Water Resources Department

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An Integration of Current Knowledge

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by

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# DEFINITIONS OF SELECTED GROUND WATER AND GEOLOGIC TERMS

| | |
|---|---|
| Alluvium: | Detrital deposits of sand, silt, gravel, or clay laid down in river beds, flood plains, lakes, and fans at the foot of mountain slopes. |
| Anticline: | An up-turned fold in which strata dip away in opposite directions from a common ridge or axis. |
| Aquifer: | A formation, group of formations, or part of a formation that contains sufficient saturated permeable material to yield significant quantities of water to wells or springs. |
| Aquitard: | A geologic unit that is capable of absorbing water slowly but will not transmit it fast enough to furnish an appreciable supply for a well. |
| Artesian: | Artesian is synonymous with confined. Artesian water and artesian aquifer are equivalent respectively to confined water and confined aquifer. The water level in an artesian well stands above the top of the aquifer. Under artesian conditions, water moves toward the well during pumping as a result of expansion of the water-rock matrix. |
| Borehole: | The uncased portion of a well where all aquifers are developed for maximum well yield. |
| Cone of Depression: | The conical depression in the potentiometric surface that forms around a well as a result of pumping. |
| Demand Overdraft: | A type of aquifer overdraft where water level declines are the result of appropriating water at rates greater than the aquifer can supply. |
| Dewatering: | Lowering of the potentiometric surface to less than atmospheric levels at the top of the aquifer. This drains the aquifer thus changing the hydraulic properties of flow. Dewatering increases the recoverable supply of water in artesian aquifers, but decreases flow rates to wells and usually damages aquifer for future water storage. |
| Geophysical Logging: | Collection of data of a geophysical nature from inside the well. Measurements are sequential for the entire depth of the well. The Water Resources Department collects temperature, caliper, gamma radiation, and borehole flow meter logs. |
| Fanglomerate: | A cemented heterogeneous mixture of uncemented materials originally deposited in an alluvial fan. |

Fault: A fracture or series of fractures in rock along which movement has taken place.

Fault Gouge: Clays that form between fault surfaces as a result of pulverization of the rock along the slippage face.

Ground Water Mining: Withdrawal of water from an aquifer in excess of the annual recharge rate. This produces a long term lowering of water levels.

Hydraulic Conductivity: The volume of water at the existing kinematic viscosity that will move in unit time under a unit hydraulic gradient through a unit area measured at right angles to the direction of flow.

Hydraulic Gradient: The change in static head per unit of distance in a given direction.

Meteoric Water: Water that occurs in or is derived from the atmosphere.

Monocline: A steplike bend in an otherwise horizontal or gently dipping geological unit.

Interference: The lowering of the water level in a well due to pumping of neighboring well(s).

Overdraft: Withdrawal of ground water at rates greater than the aquifer can supply to the area. Results in long term and consistent water level declines in the aquifer.

Permeability: The capacity of a rock or soil for transmitting fluid. The degree of permeability depends upon the size and shape of the pores as well as the size and shape of their interconnections.

Porosity: The ratio of the aggregate volume of voids in a rock or soil to its total volume, usually expressed as a decimal, fraction or as a percentage.

Porous: Containing voids, pores, interstices, or other openings that may or may not interconnect.

Potentiometric Head or Potentiometric Surface: The level to which water in an aquifer will rise by hydrostatic pressure.

Scoriaceous: Containing open voids in the rock. Applies usually to volcanic materials.

Storage Coefficient: The ratio of the volume of water an aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in head. In confined aquifers this is a measure of the expansion of the water and rock matrix, in unconfined aquifers this is essentially a measure of aquifer drainage.

Supply Overdraft: A type of aquifer overdraft where water level declines are the result of appropriating more water than the amount that is naturally recharging the aquifer.

Syncline: A concave upwards fold in rocks in which strata dip inward from both sides toward the axis of the fold.

Synoptic Measurements: A group of measurements taken at the same time over a broad area to give a simultaneous display of conditions.

Transmissivity: The rate at which water of the prevailing kinematic viscosity is transmitted through a unit width of the aquifer under a unit hydraulic gradient. This is usually expressed as gallons per day per foot, or square feet per day. A measure of how easily water will flow toward a well.

Unconfined Aquifer: An aquifer where the pressures at the upper surface of the aquifer are atmospheric. This is synonymous with water table aquifer.

Vesicular: Containing many small cavities.

Water Level: The distance from land surface to the top of the water column in the well. When the well is pumping, the water level is referred to as a pumping level. When the well is not pumping and well has recovered the water level is referred to as a static water level.

Well Density: The number of wells per unit area in a region.

Withdrawal Density: The amount of water that is withdrawn per unit area.

# INTRODUCTION

## PURPOSE

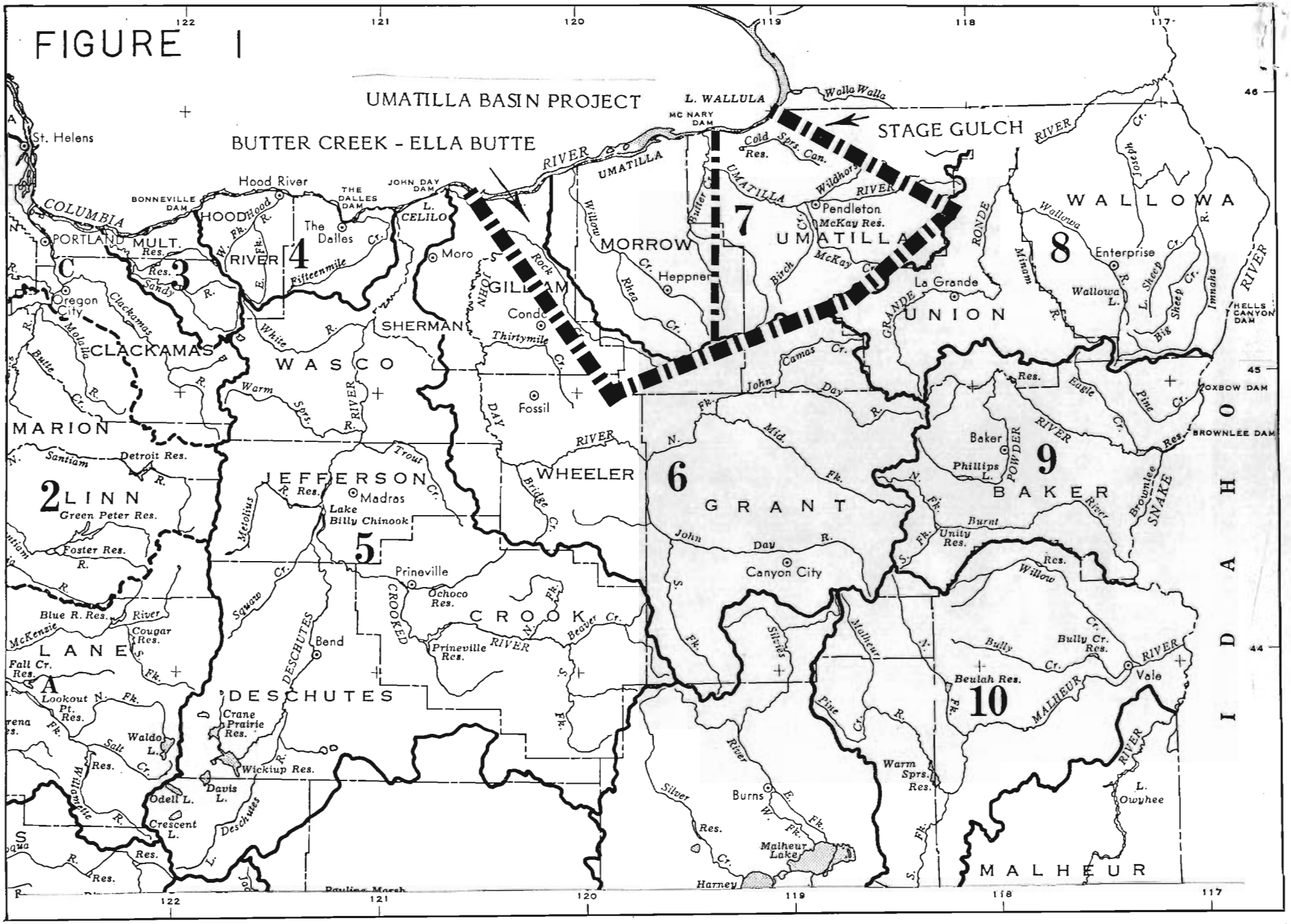
Water level declines in the Umatilla Basin, documented since the 1960's, have instigated three separate investigations by the Water Resources Department. (Two reports by the U.S. Geological Survey have been made in the study area.) The latest of these reports was published in October of 1975. The basic problem of declining water levels is still unresolved in the area and a large amount of new data has been collected over the last two years. The purposes of this paper are: combine and update information in previous studies and describe the hydrogeology of the region using the new data.

## LOCATION

The present study, known as the Umatilla Basin Project, encompasses 1500 square miles of intensive investigation and 1000 square miles of peripheral investigation. The study area is bordered by the Columbia River, the Horse Heaven Anticline, the Blue Mountain Uplift, and the Rock Creek Lineament. See Figure 1. For the purposes of this report the area is divided by a north-south line through the center of Range 28 East. This line coincides with the Service Anticline. The area to the west is known as Butter Creek--Ella Butte, and the area to the east as Stage Gulch.

The Milton-Freewater area has been included due to the availability of long term water well measurements. The area is not under intensive investigation at this time.

FIGURE 1


UMATILLA BASIN PROJECT
BUTTER CREEK - ELLA BUTTE
STAGE GULCH
L. WALLULA
MC NARY DAM
Walla Walla
St. Helens
COLUMBIA
BONNEVILLE DAM
Hood River
THE DALLES DAM
JOHN DAY DAM
L. CELILO
PORTLAND
MULT.
HOOD RIVER
The Dalles
Moro
GILLIAM
SHERMAN
Condo
Fossil
MORROW
Heppner
UMATILLA
Pendleton
McKay Res.
La Grande
UNION
WALLOWA
Enterprise
Wallowa L.
HELLS CANYON DAM
OXBOW DAM
BROWNLEE DAM
Oregon City
CLACKAMAS
WASCO
MARION
Detroit Res.
LINN
Green Peter Res.
Foster Res.
JEFFERSON
Madras
Lake Billy Chinook
WHEELER
GRANT
Canyon City
BAKER
Baker
Phillips L.
Unity Res.
Prineville
Ochoco Res.
CROOK
Prineville Res.
Bend
LANE
Blue R. Res.
Cougar Res.
Fall Cr. Res.
Lookout Pt. Res.
DESCHUTES
Crane Prairie Res.
Wickiup Res.
Davis L.
Odell L.
Crescent L.
Waldo L.
Burns
Malheur Lake
Harney
Warm Sprs. Res.
Beulah Res.
Bully Cr. Res.
Vale
MALHEUR
L. Owyhee
IDAHO
SNAKE RIVER
POWDER RIVER
GRANDE RONDE RIVER
UMATILLA RIVER
JOHN DAY RIVER
DESCHUTES RIVER
CROOKED RIVER
MALHEUR RIVER
Pauline Marsh
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## AQUIFER DEVELOPMENT

Extensive ground water development for irrigation began in the Hermiston area in the mid-1960's. Technological advances in hard rock well drilling coupled with new irrigation techniques encouraged rapid ground water development. Applications for water rights disclose that planned withdrawals from the basalt aquifer are 18 times greater in 1980 than in 1960. Figure 2 presents cumulative water right applications in the study area. Primary and supplemental water rights applied for presently total over 97,000 and 15,000 acres respectively. If these water rights were fully exercised, to the duty of water (3 acre-feet/acre), the withdrawal rate would exceed 300,000 acre-feet per year. This estimate is based on the 570 wells having water rights, and does not include aquifer use by approximately 3,000 domestic and stock wells. These exempt wells use an estimated 5000 acre-feet per year of additional withdrawals. All of the cities and towns in the study area depend on the basalt aquifer for municipal water supplies, and are included in the above estimate.

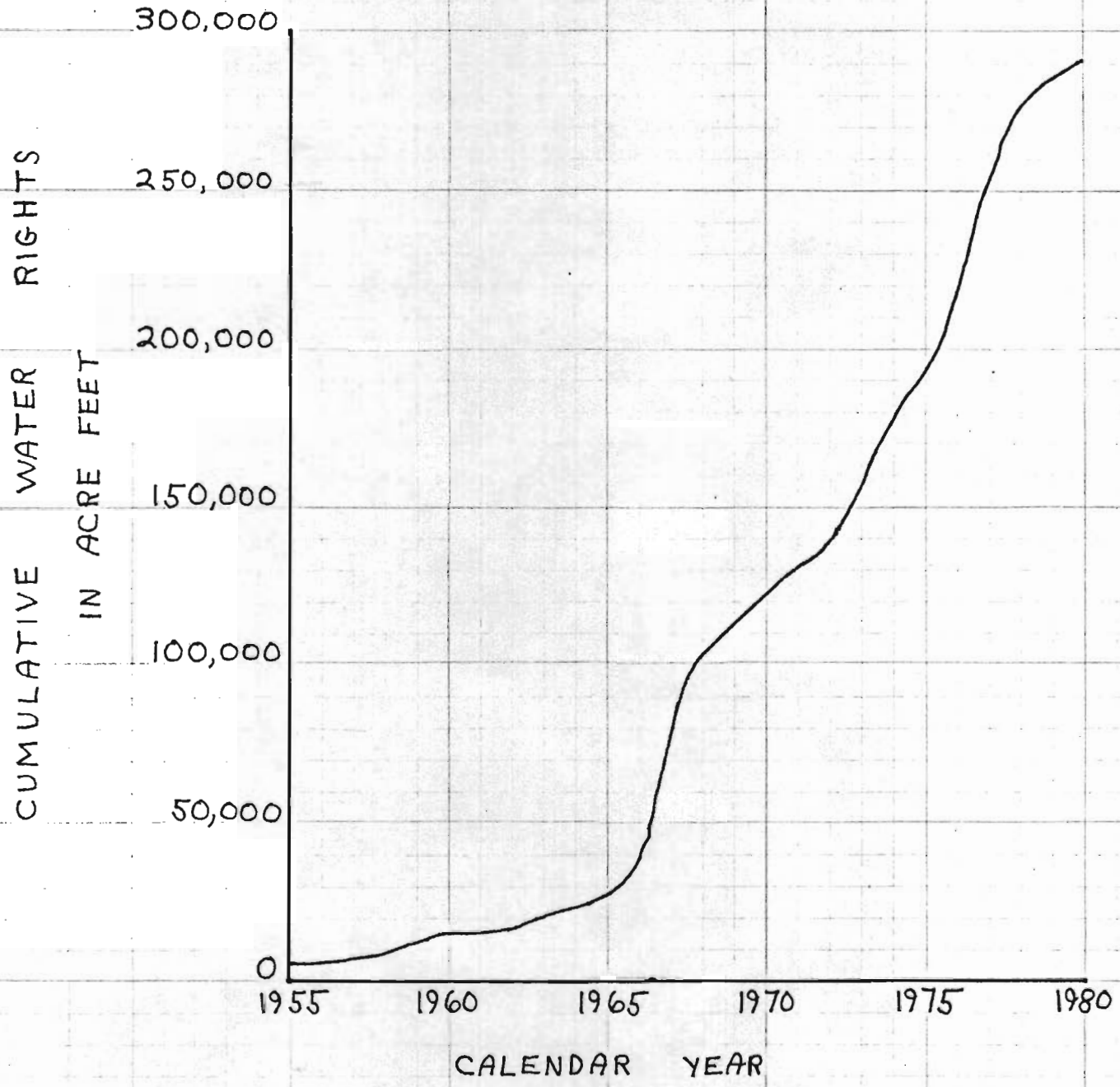
Water level declines in the region have occurred as irrigation development progressed. At the present time, almost the entire region has experienced some level of ground water decline in the basalt aquifer. The greatest water level declines are centered in areas where withdrawals for irrigation are the largest.

The Water Resources Department, the United States Geological Survey, local governments and local well owners have compiled over 3000 separate water level measurements documenting the water level changes of the basalt aquifer.

FIGURE 2

CUMULATIVE APPROPRIATIONS

BASALT AQUIFER



All information about wells in the study area that tap the basalt aquifer is now contained on computer tapes at the U.S. Geological Survey at Portland. The data includes: well location, owner's name, water rights data, horsepower pump setting, flowmeter readings, well depth, casing record, elevation, water temperature, airline length, and other data. This data base includes every recorded measurement for the entire study area. Machine processing will greatly speed data handling and public information requests.

## SUMMARY

1. The principal basalt aquifer is a regional confined ground water reservoir that can be represented by a potentiometric surface. Upper basalts in places contain a local flow system that can have a higher or lower head than the regional aquifer.
2. The basalt aquifer is nonhomogeneous and contains hydrologic boundaries. These boundaries are stratigraphic-petrological changes and structural changes. Folding and faulting is evident throughout the region. Some of these structures correlate with hydrologic boundaries. Variations in hydrologic properties of the basalt shape the potentiometric surface.
3. Aquifer testing has identified hydrologic boundaries and determined aquifer characteristics. To date the aquifer tests indicate the transmissivity ranges from 1000 $ft.^2$/day to 36,000 $ft.^2$/day. The weighted average transmissivity is 6,000 $ft.^2$/day. The confined storage coefficient varies less with location than does transmissivity and averages $5.2 \times 10^{-4}$ (dimensionless). The storage coefficient as computed from estimated withdrawals and volumetric overdraft calculations averages $3.2 \times 10^{-2}$ (dimensionless). The dual storage coefficients demonstrate that the aquifer is confined in mid-winter, short term tests and unconfined for actual long term use.

4. Ground water is recharged at the higher elevations where topography increases the rainfall and structural uplift exposes fractured interflow zones. The major flow component is from the Blue Mountains toward the north where the basalts are in hydraulic connection with the Columbia River. There is no significant flow of ground water from the State of Oregon into the State of Washington in the study area.

5. The rate of recharge under steady state conditions is reflected in the carbon 14 apparent age dates. Ground water now being withdrawn was last exposed to the atmosphere from 2,570 to 27,290 years ago. Most of the water being withdrawn from the aquifer is in excess of 10,000 years old. A significant proportion of the study area has water greater than 22,000 years old. The long period of time since emplacement of the water indicates that the recharge rate is very slow and is minor when compared to pumpage.

6. Water level declines are clearly evident in the major basalt aquifer. The water level decline from 1965 to 1980 have dewatered 13 cubic miles of basalt aquifer. The average decline rate for areas that have experienced a lowering of water levels equals 5.1 feet per year. The water level declines from 1965 to 1980 for the region are listed below.

| Decline in Feet | Area Affected in Square Miles |
|---|---|
| 20-50 | 262 (approximate) |
| 50-100 | 486.4 |
| 100-150 | 28.6 |
| 150-200 | 61.4 |
| 200-250 | 12.3 |
| 250-300 | 9.7 |
| 300-350 | 1.5 |
| 350 or greater | 0.1 |

Note: The total area of declining water levels greater than 20 feet equals 862 square miles.

7. Water level declines can be separated into two classifications depending on the transmissivity of the aquifer and pumping rate. Supply overdrafts result when the quantity of water withdrawn exceeds the recharge to the aquifer. This occurs throughout the study area. Demand overdrafts result when the rate of withdrawal exceeds the ability of the aquifer to move equivalent amounts of water toward the well. Overdrafts of this type occur in the areas of relatively low transmissivity. A well in an area of low transmissivity may have water level declines of both types with the demand overdraft responsible for the major part of the decline.

8. Wells in the northern portion of Sand Hollow (Township 2 North / Range 26 East) have a much lower rate of decline in the period 1975 to 1980 than in the period 1970 to 1975.

9. Water level decline rates are increasing in portions of Stage Gulch, at the City of Pendleton, and at the City of Milton-Freewater.

10. Well interference can cause low water levels at the end of the irrigation season in areas of large ground water withdrawals. Interference poses a greater problem to some irrigators than the annual aquifer overdraft. The well interference factor can be 10 to 20 times the value of the annual decline.

11. Improper well construction and deepening are draining some upper aquifers. This is lowering the potentiometric surface in upper aquifers, but will increase the water supply to lower aquifers.

## CONCLUSIONS

1. The basalt aquifer is being overdrafted in over a 600 square mile area as evidenced by water level declines of 50 feet or more in the last 15 years. See Plate 2.

2. The water level declines are continuing at the same rate or at an accelerated rate in nearly all of the study area. There is no evidence to suggest that water levels are reaching a point of equilibrium or that in the near future water level declines will cease.

3. Water level declines are due to: withdrawals that exceed natural recharge which depletes the limited supply of water in the aquifer, pumping rates that exceed the capacity of the aquifer to transmit water, and cross connection of high and low head zones within the aquifer. Supply overdrafts can be reduced only by limiting the total amount of water pumped each year from the aquifer. Demand overdrafts can be reduced by either a reduction in pumping rates or decreased withdrawal density.

4. The rate of recharge of meteoric water into the aquifer is unknown. Carbon 14 age dating tests and reasonable estimates based on hydrogeologic factors indicate that recharge is much less than present appropriations.

5. The amount of water that can be practicably recovered in aquifer storage to a depth of 500 feet below land surface is calculated to be 18.0 million acre-feet. Assuming that withdrawals remain constant, this represents approximately a 95 year supply of water for the 2,200 square mile region. However, centralized overdrafts of the aquifer are already restricting some appropriators' ability to withdraw water in intensely developed areas.

6. Interference between wells is common and contributes to the water supply problems of the area. The interference factor can be ten times the value of annual decline.

# GEOLOGY

## STRATIGRAPHY

### QUARTERNARY FORMATIONS

The Umatilla Basin contains two major aquifers, the unconsolidated deposits of sand and gravel of Pleistocene age, and Columbia River basalt of Miocene age. (See Figure 3.) The unconsolidated deposits consist of three distinct units and are of separate origin. Glaciofluvial deposits are found at elevations below 750 feet along the Columbia River. The glaciofluvial unit consists of lenticular, poorly sorted deposits of sand, gravel, silt and clay laid down by the ancestral Columbia River during various flood stages. Above 750 feet in elevation are found Pliocene fanglomerate and Pleistocene lacustrine sediments. The fanglomerate is composed of a heterogeneous mixture of tightly cemented sand, silt, and clay with embedded basaltic rock debris. Lacustrine deposits consist of clay and silt laid down in shallow lakes formed during periods of downstream ice damming of the Columbia River.

### TERTIARY FORMATIONS

Basalt of the Columbia River Group underlies all of the report area, and forms the major aquifer for domestic, stock, municipal, industrial and irrigation uses. See Figure 4. The Columbia River basalt consists of a series of individual lava flows 10 to 150 feet thick. The flows are a hard, dense, semi-porous olivine basalt near the base and grade upwards to softer, and scoriaceous zones near the top. The basalts locally comprising the Columbia River Group issued from fissure complexes located near LaGrande, Oregon. However, the United States Geological Survey has recently discovered an additional volcanic vent in Lone Rock Canyon four miles northwest of Lonerock, Oregon. Most of the basalt in the study area originated from the LaGrande complex. The lava was very fluid at the time of eruption and spread out for tens of miles to form broad lava plains.

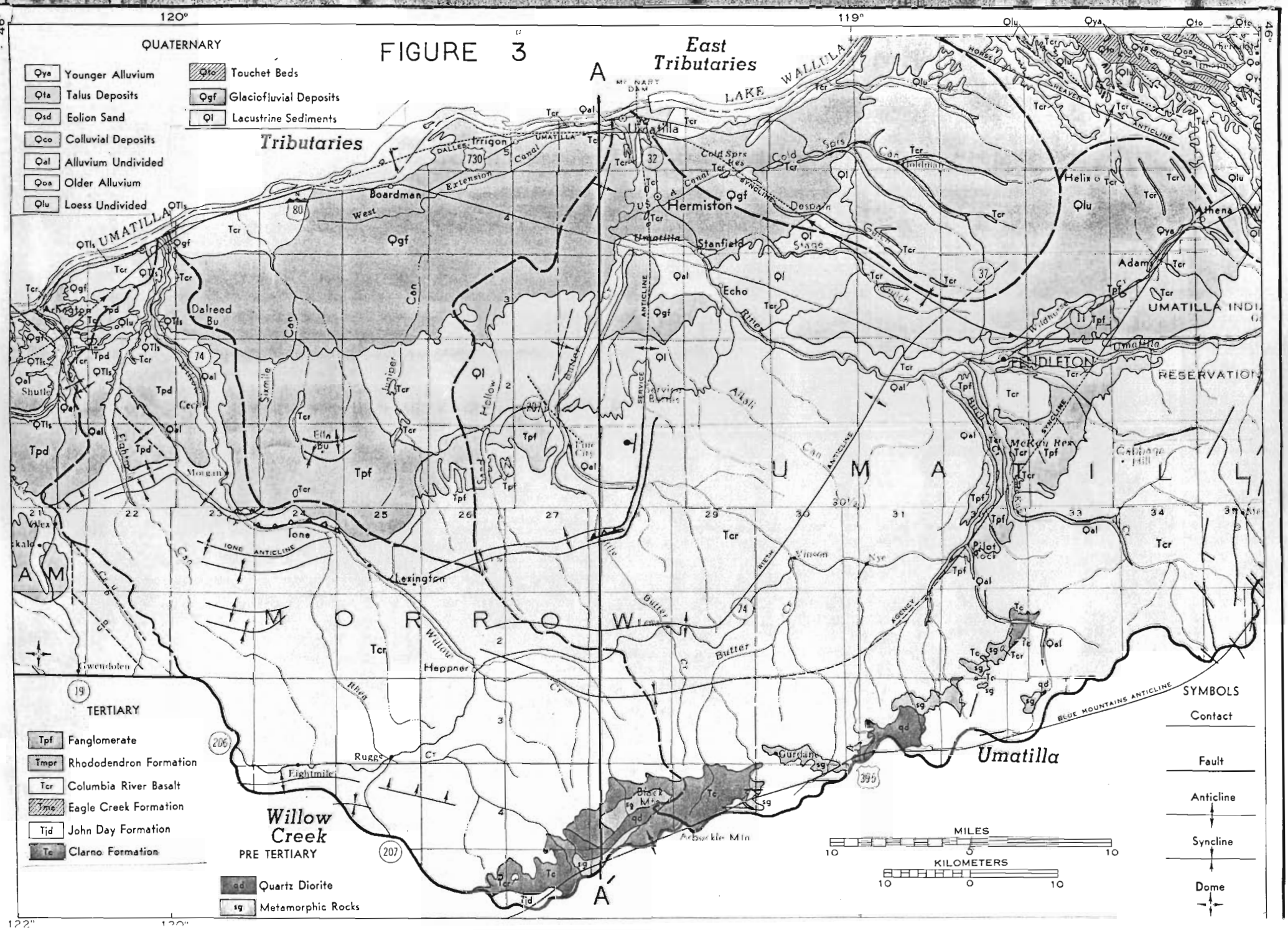


FIGURE 3
QUATERNARY
Qya Younger Alluvium
Qta Talus Deposits
Qsd Eolion Sand
Qco Colluvial Deposits
Qal Alluvium Undivided
Qoa Older Alluvium
Qlu Loess Undivided
Qto Touchet Beds
Qgf Glaciofluvial Deposits
Ql Lacustrine Sediments
TERTIARY
Tpf Fanglomerate
Tmpr Rhododendron Formation
Tcr Columbia River Basalt
Tme Eagle Creek Formation
Tjd John Day Formation
Tc Clarno Formation
PRE TERTIARY
qd Quartz Diorite
sg Metamorphic Rocks
SYMBOLS
Contact
Fault
Anticline
Syncline
Dome
MILES
KILOMETERS
East Tributaries
Tributaries
Willow Creek
Umatilla
Hermiston
Stanfield
Echo
Boardman
Irrigon
Arlington
Dalreed Bu
Ione
Lexington
Heppner
Ruggs
Eightmile
Gwendolen
Pilot Rock
Athena
Adams
Helix
Gurdane
Black Mtn
Arbuckle Mtn
UMATILLA INDIAN RESERVATION
LAKE WALLULA
UMATILLA
MORROW
UMATILLA
IONE ANTICLINE
BLUE MOUNTAINS ANTICLINE
SERVICE ANTICLINE
HORSE HEAVEN ANTICLINE
A
A'
120°
119°
122°
46°

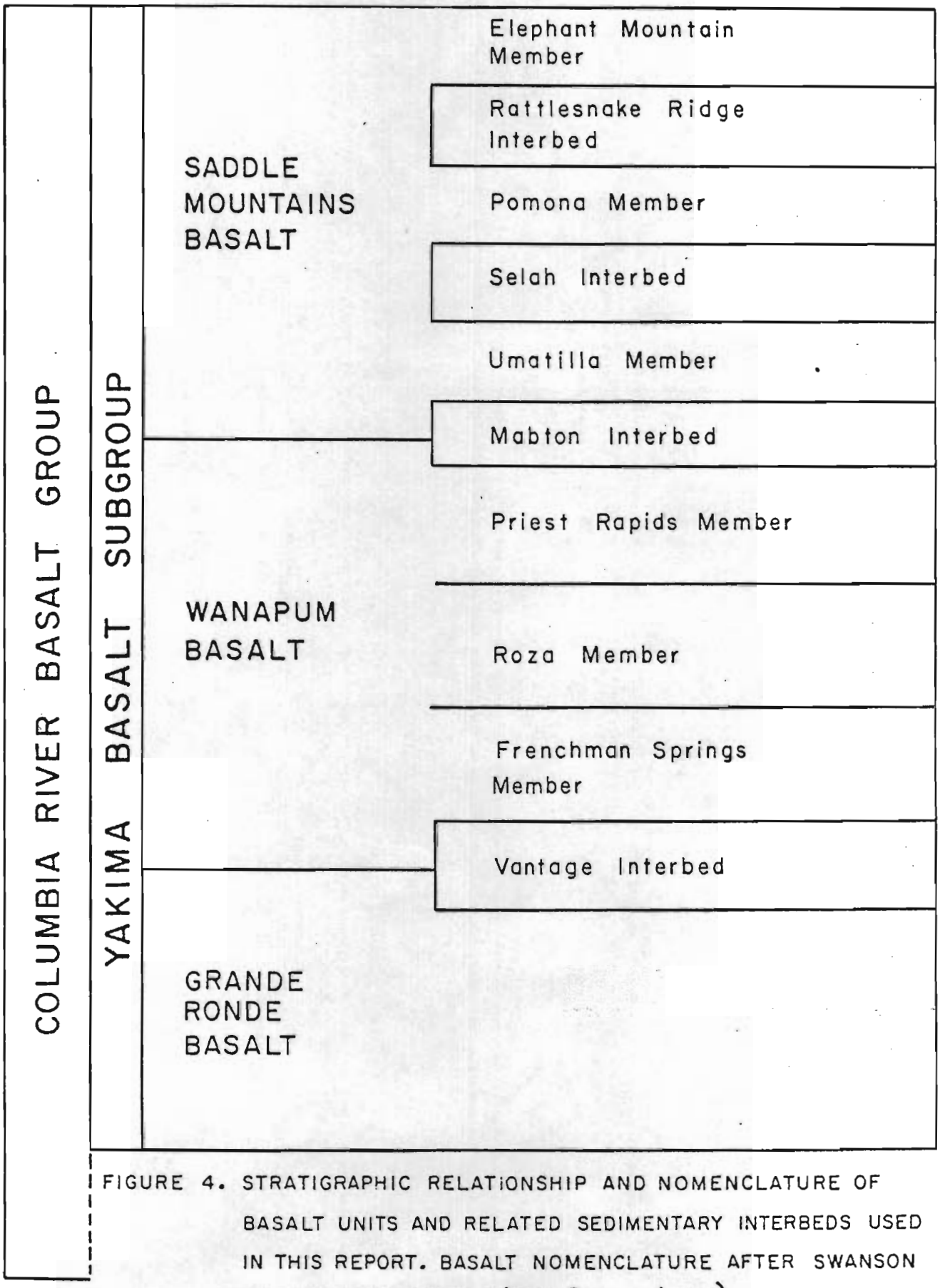



FIGURE 4. STRATIGRAPHIC RELATIONSHIP AND NOMENCLATURE OF BASALT UNITS AND RELATED SEDIMENTARY INTERBEDS USED IN THIS REPORT. BASALT NOMENCLATURE AFTER SWANSON AND OTHERS (1979) AND Brown (1979).

The Umatilla Basin study area has three separate formations of Columbia River Basalt. The Grande Ronde Basalt is the oldest formation and overlies Clarno Formation along the Blue Mountain Uplift. The Grande Ronde Basalt contains 34 separate flows in type section. The thickness of this formation varies considerably depending on prebasalt topography. In the Umatilla Basin study area it is estimated to be 1800 feet thick.

The middle formation is the Wanapum Basalt which is locally represented by the older Frenchman Springs Member and the younger Priest Rapids Member. The Frenchman Springs overlies the Grande Ronde throughout the study area. The thickness of the Frenchman Springs is uncertain in the region, but elsewhere it consists of at least nine flows totaling 600 feet in thickness at its greatest known exposure. In the Umatilla Basin study area it is estimated to be no more than 600 feet. Overlying this unit, the Priest Rapids Member occurs two miles south of Boardman to four miles south of Arlington in the northwest part of the study area. One or two flows may be present and are probably less than 200 feet thick.

The youngest formation of the Columbia River Basalt in the area is the Saddle Mountain Basalt, of which three members are present. The oldest unit, Umatilla Member, overlies the Frenchman Springs in the study area north of a line from Umatilla through Adams. The member consists of two flows with a thickness of about 300 feet near McNary Dam. The middle unit, Pomona Member, occurs in the area north of a line which is about eight miles south of the Columbia River across the entire northwest perimeter of the study area. Locally, it may consist of two flows, probably 100 feet or less in thickness, and directly overlies the Frenchman Springs, Priest Rapids or Umatilla Members. The Pomona forms the distinctive cap rock at Hat Rock State Park near Hermiston. The Elephant Mountain Basalt is the youngest member in the area and occurs in the area north of a line about four miles south of the Columbia River, overlying the Pomona Member. In the study area, the Elephant Mountain may be two flows which are less than 100 feet thick.

During long periods of volcanic inactivity, soil horizons, stream channels and lakes commonly formed on the basalt surface. These deposits belong to the Ellensburg formation and provide marker beds when present. Locally, Vantage sandstone and the Mabton member are important marker beds in the study area. The successive flows of lava buried sedimentary deposits mixed with air fall tuff in some locations. Preserved root systems remain in the Vantage, but most of these deposits have altered to clays and palagonite. In about 25 percent of the study area the interbeds are missing. The sedimentary interbeds and the weathered vesicular tops of the lava flows are known as interflow zones, and constitute 5 to 50 percent of the total rock thickness. In areas where the interflow-interbed zones are thick and comprised of coarser materials, they form excellent aquifers. The major interbed zones in the study area are composed of fine-grained volcanic and sedimentary materials and may constitute confining layers.

A detailed account of the physical characteristics of basalt flows is not given in this report. However, the reader is referred to Swanson and Wright (1978) for such an explanation. Figure 5 is derived from that report and reveals the bulk of the typical flow to have a highly varied macrostructure. The nature of basalt flow features is very important in determining the properties of the regional ground water flow system.

A detailed examination of the local geology is in progress by the Western Regional Office of the U.S. Geological Survey, Menlo Park, California. The results of the research will greatly aid in understanding the hydrogeology of the region.

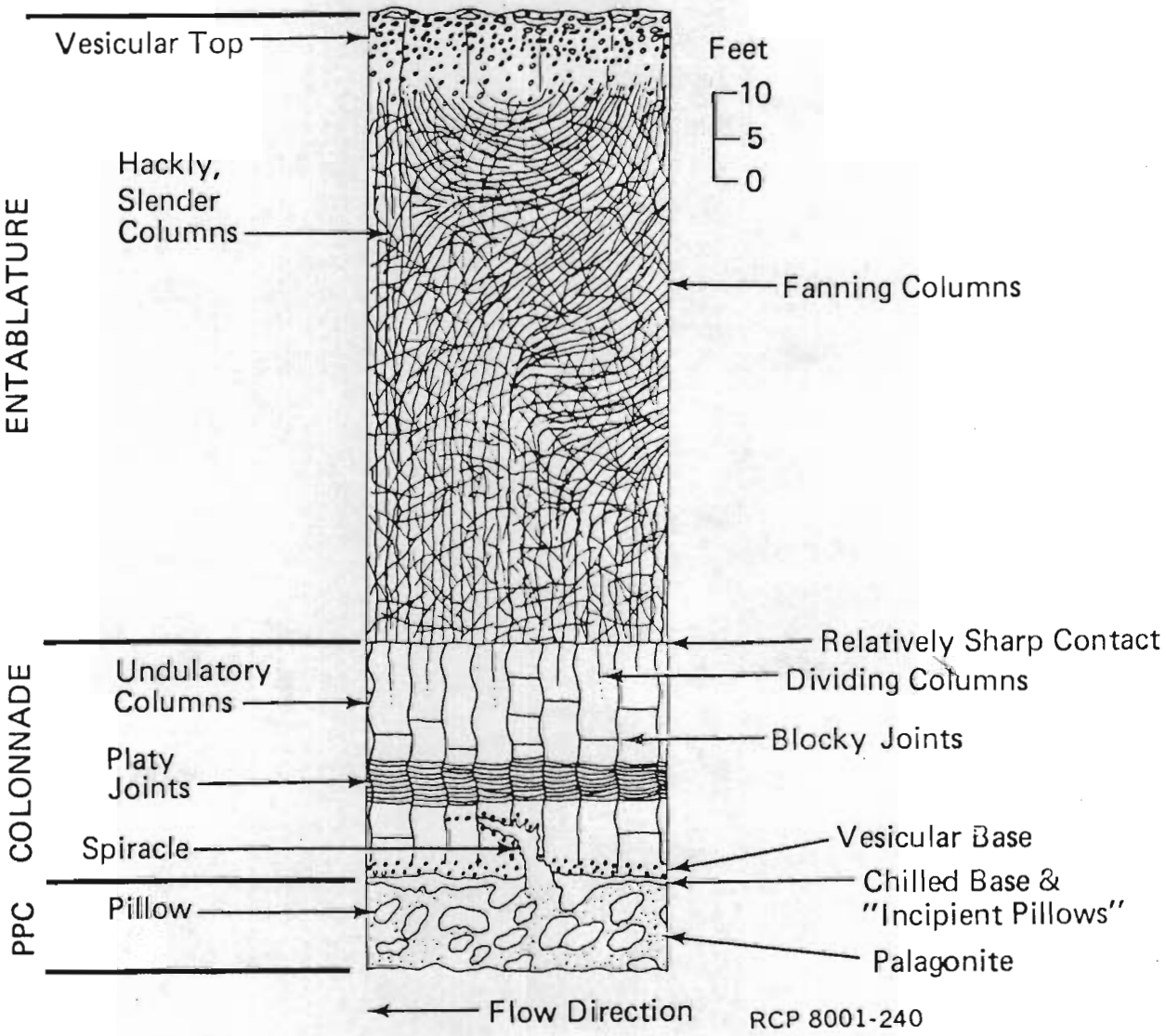



FIGURE . Typical Cross Section through a Columbia River Basalt Group Flow Showing Intraflow Structures.

## STRUCTURES

The more obvious geologic structures within the study area are folds rather than faults. See Figure 3. The basalts have been warped into the 160-mile long Dalles-Umatilla Syncline upon whose axis the Columbia River follows from The Dalles to Umatilla. In the project area, the syncline axis forms the northern boundary of the study area from the mouth of Willow Creek to the town of Umatilla. From Umatilla the axis extends southeast to Pendleton and the Blue Mountain front. The western half of the study area lies on the south limb of this broad syncline where basalts dip in the southern part about 100 feet per mile to the north, flattening to 30 feet per mile in the northern half.

The Service Anticline is auxiliary to the Dalles-Umatilla Syncline and extends from Little Butter Creek northward across the Columbia River to Sillusi Buttes. The anticlinal nature of this structure is not apparent throughout its length. The structure shows reverse faulting along its western flank as well as normal faulting at 90° to the axis of the structure. The basalts generally dip away from the crest of the Blue Mountains in the south and east, away from and the Horse Heaven Hills in the northeast due to the Blue Mountain Anticline and Horse Heaven Anticline respectively.

The axis of the Reith Anticline is a northerly open arc extending from Reith to Heppner. This structure is a subtle feature with flanks dipping two degrees or less. About eight miles south and east of this anticline, the axis of the Agency Syncline trends parallel from Athena to Heppner. Other smaller east-west trending anticline-syncline sets are also identified at Ella Butte, Ione, southern Sand Hollow, Eight Mile Canyon and Shutler Flat. All of the preceeding folds are broad with flanks that average only about 1° of dip.

Faulting is also an important structural factor in the study area. In addition to the faulting associated with the Service Anticline previously cited, prior investigators have identified northwest trending faults near McDade Spring and Butter Creek Junction that have indeterminate direction and amount of movement. The presence of several buttes in the study area indicates a complex of sharp folds and/or faults. Lineations resulting from structural control are readily apparent in the area immediately west and north of the Reith Anticline. This is evidenced by the strong northwest orientation of the drainage pattern in the area including Cold Spring Canyon, Despain Gulch, Umatilla River and Alkali Canyon. In addition, abrupt water level elevation changes and transmissivity boundaries in the basalt aquifer result in compartmentalization from which faulting is inferred throughout the study area.

The major structurally controlled hydrologic boundaries are discussed in the hydrology section. Structural mapping indicates that a 700 square mile block comprising the area south of the Columbia Hills Anticline, west of the Service Anticline, north of Swaggart Butte, and north of Saddle Butte is being forced to the southeast. Evidence for this includes folds, thrust faults and other compressional features along the perimeter.

## HYDROLOGY

Basalt aquifers form complex flow regimes. Variations in permeability can separate layers of basalt into semi-discrete aquifers having different hydrologic characteristics. Wells drilled into the Columbia River Basalt in Oregon have typically cross-connected these units in order to produce a maximum amount of water. Water level measurements in wells, therefore, represent a composite level of all the separate zones encountered.

Water in the basalt aquifer exists under confined or artesian conditions. This means that the water is under pressure and water level changes are due to the expansion and contraction of the water and the aquifer. Therefore, water levels do not reflect a water table (unconfined conditions), but a pressure surface. The total hydrostatic head is known as a potentiometric surface and that term is used in this report.

## CONCEPTUAL MODEL

A conceptual model of an aquifer is a description of the flow system based on hydrogeologic principles and scientific measurements. At the present time, the authors have identified several main components of the regional aquifer system which are described later in the report. Correlation of these components with stratigraphic units is necessary in order to identify hydrostratigraphic zones for computer modeling the aquifer.

In brief, the Columbia River Basalts have formed a layered aquifer in the study area. Ground water movement is mainly in the broken interflow and interbed zones which are "sandwiched" between layers of massive basalt. The interflow zones are comprised of vesicular, scoriaceous basalt that contains open voids and interconnected fractures. These zones are excellent aquifers and supply most of the water to producing wells. In conjunction with the interflow zones there may be overlying sedimentary interbeds of sands and clays. When the interbeds are comprised of coarse material they also form aquifers. The numerous interflow zone aquifers in composite form the regional basalt aquifer. Massive basalt comprises most of the total rock thickness and separates the interflow - interbed zones. The massive basalts contain water in cooling joints in columnar zones, but generally do not allow rapid movement of water to wells. In some areas vertical fractures connect overlying interflow zones, and allow interaquifer communication. In such areas there is little or no change of potentiometric head with depth of the well.

However, in most of the study area aquitards of massive basalt and/or fine grained sedimentary interbeds isolate the aquifers which results in differing potentiometric heads with depth.

Where these areas have been identified, the major aquifers generally show less potentiometric head with depth. The potentiometric head drop between aquifers can be as high as 400 feet and is commonly over 200 feet. When an area has a thick sequence of highly transmissive interflow zones and contains aquitards, individual aquifers can be identified on the basis of bottom hole elevation and potentiometric head.

The basalt aquifer is recharged by rainfall and streamflow in limited areas of exposed interflow - interbed zones when the potentiometric surface is below land surface. In the study area these conditions are met mainly along the Blue Mountain front. Once the water has entered the aquifer the water moves in the direction of least potentiometric head by gravity flow.

In general, the resultant flow direction is down the structural dip of the basalt and produces confined aquifer conditions. The direction of flow is from topographically high areas to the Columbia River. The rate and direction of ground water flow is affected by structural features. These features (faults and folds) change the aquifer permeability and hence alter the potentiometric surface. The large regional flow system and the restrictive nature of basalt aquifers produce long travel times between recharge and discharge areas.

## HYDRAULIC CHARACTERISTICS

The hydraulic characteristics of the basalt aquifer have been evaluated by aquifer testing at nine locations to date. An aquifer test involves pumping a single well at a constant rate and observing the water level changes in surrounding wells. Measurements of water temperature, water chemistry, carbon 14 age date, and barometric air pressure are also taken. After 48 to 72 hours of pumping the well is shut off and the rebound of water level is observed. Interpretation of these data allows the aquifer to be described in terms of how easily water can move through the rock (transmissivity) and the amount of water released from storage in a unit volume of rock per unit decline in head (storage coefficient).

The aquifer tests also show areas of delayed yield from the aquifer, recharge responses, hydraulic boundaries and impermeable barriers. See Figure 4 for location of aquifer tests and representative parameters.

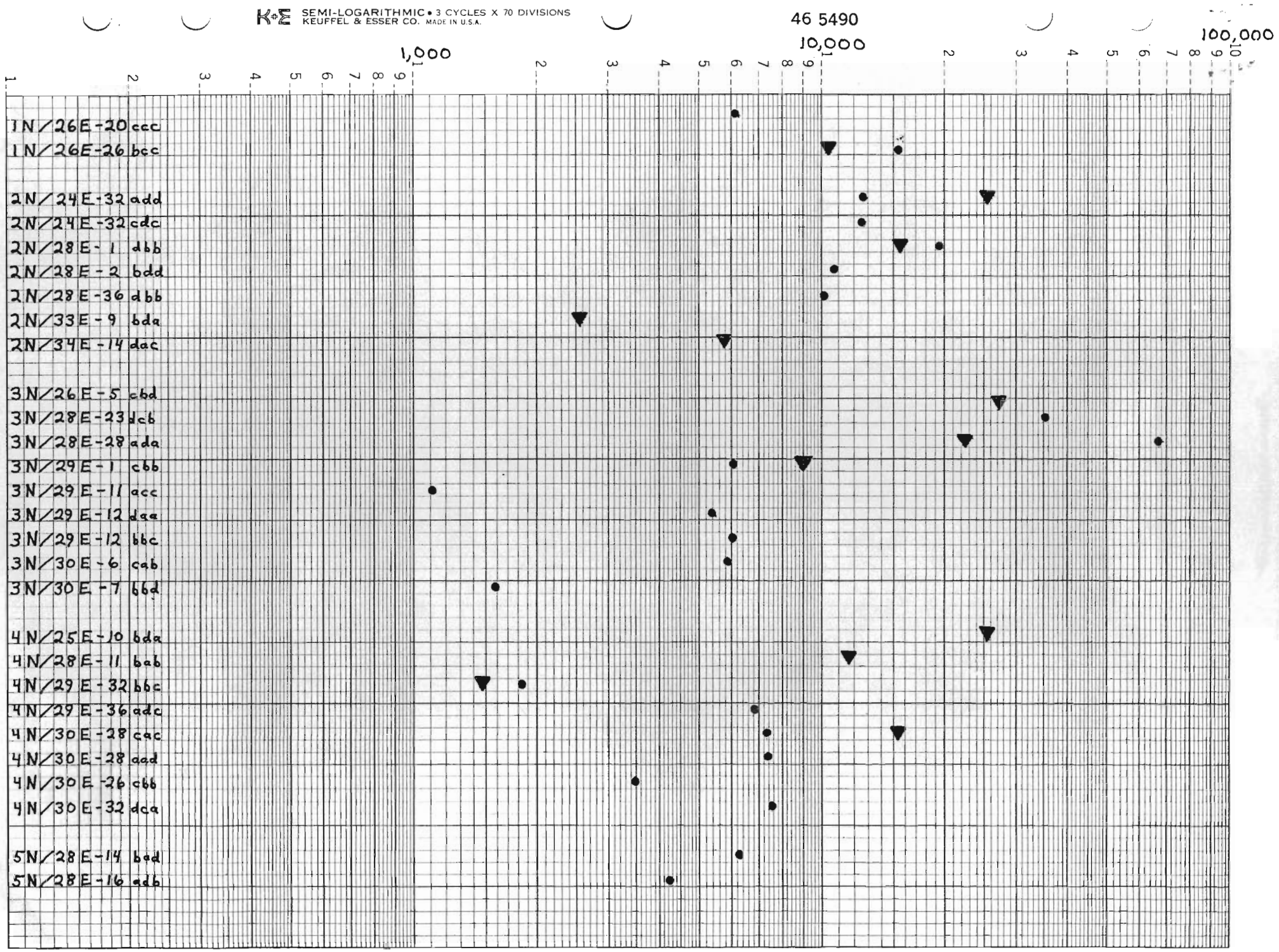
Table 1 lists all of the transmissivity and storage coefficient data calculated from aquifer tests. Figure 6 plots the aquifer test data and carbon 14 data by location on semi-log scale for examination.

TABLE I

Formation Constants
Computed from Aquifer Tests
Umatilla Plateau

| LOCATION | WELL NUMBER | DEPTH/SATURATED IN FEET | TRANSMISSIVITY 2 (FEET$^2$/DAY) | STORAGE COEFFICIENT |
|---|---|---|---|---|
| 1N/26E-20ccc | Turner 48 | 960/707 | 12,500 Early<br>6,150 Late | -<br>- |
| 1N/26E-26bcc | Turner 19 | 675/527 | 16,700 | $7.2 \times 10^{-4}$ |
| 2N/24E-32add | Lindstrom 2 | 945/600 | 12,750 | |
| 2N/24E-32cdc | Douglas 1 | 1,086/750 | 12,700 | $1.9 \times 10^{-3}$ |
| 2N/28E-1dbb | Eagle Ranch 4 | 650/528 | 19,650 | |
| 2N/28E-2bddd | Eagle Ranch 7 | 792/700 | 10,900 | $4.4 \times 10^{-4}$ |
| 2N/28E-36dbb | Eagle Ranch 3 | 640/588 | 10,200 | |
| 3N/28E-23dcb | L and L 1 | 1,012/690 | 36,650 | $2.1 \times 10^{-4}$ |
| 3N/28E-~~28ada~~ 26 | L and L 2 | 911/572 | 67,760 | |
| 3N/29E-1cbb | Circle C 4 | 1,065/? | 6,010 | |
| 3N/29E-11acc | Circle C 6 | 696/650 | 1,136 | |
| 3N/29E-12daa | Circle C 3 | 1,189/1,054 | 2,180 Early<br>5,390 Late | |
| 3N/29E-12bbc | Circle C 7 | 1,290/1,187 | 9,400 Early<br>6,060 Late | $1.1 \times 10^{-5}$ |
| 3N/30E-6cab | Circle C 2 | 1,455/1,321 | 5,930 | $3.1 \times 10^{-2}$ |
| 3N/30E-7bbd | Circle C 1 | 1,205/1,145 | 1,600 | $8.2 \times 10^{-5}$ |
| 4N/29E-32bbc | Stanfield 4 | 1,161/897 | 1,850 | - |
| 4N/29E-36adc | Zabransky 3 | 1,023/970 | 6,900 | $1.1 \times 10^{-5}$ |
| 4N/30E-28cac | Gehrke 3 | 665/665 | 40,000 Early<br>7,400 Late | |
| 4N/30E-28aad | Gehrke 4 | 950/887 | 7,400 Late | $9.2 \times 10^{-5}$ |
| 4N/30E-26cbb | Kilgore 1 | 750/570 | 3,500 Late | $5.3 \times 10^{-5}$ |
| 4N/30E-32dca | Gehrke 2 | 600/600 | 7,600 Late | |
| 5N/28E-14bad | Umatilla 3 | 989/489 | 6,330 | $1.2 \times 10^{-5}$ |
| 5N/28E-16adb | Umatilla 4 | 1,134/634 | 4,280 | - |

NOTE: The "Early - Late" notations under transmissivity indicate where in the time drawdown curve the calculations were made.




Transmissivity, Carbon 14 Age Plot
(▼, ft²/day) (● years before 1950)

Figure 6

The transmissivity in the Stage Gulch area ranges from 1,000 to 7,600 ft.$^2$/day. The mean value is about 6,000 ft.$^2$/day. Along hydrologic boundaries the transmissivity drops to an average of 1,000 ft.$^2$/day. Aquifer testing in the Butter Creek-Ella Butte area is incomplete, but data from their tests indicate a higher average transmissivity of 36,000 ft.$^2$/day to 1,980 ft.$^2$/day. The higher values of transmissivity are found mainly in the north west portion of the study area. The area of high transmissivity lies in the north central portion of the study area. (See Figure 7). In this area, pumping drawdown is less and minor interference between wells takes place over several miles. The confined storage coefficient changes little in the study area. The basalt aquifer has an average storage coefficient of $5.2 \times 10^{-4}$. The lowest value is $1.1 \times 10^{-5}$ at Circle C Farms. The values for confined storage coefficient are normal for Columbia River Basalt, but low compared to other aquifers. As an example, lowering the potentiometric surface one foot uniformly under one acre of land yields 170 gallons of water at the average confined storage coefficient. The values of transmissivity and storage coefficient are used as variables in ground water equations that allow prediction of drawdown at any distance from the well, at any time, and at any pumping rate.

The value of the storage coefficient computed from aquifer tests is valid for short duration confined events where there is no significant dewatering of the aquifer. Storage coefficients can be 100 times greater when dewatering takes place.

Evaluation of 15-year withdrawal and decline data supports the concept of aquifer dewatering. The storage coefficient determined from volumetric overdraft analysis yields an average storage coefficient of $3.2 \times 10^{-2}$. (A complete description of computation of regional storage coefficients is given later in the section "Ground Water in Aquifer

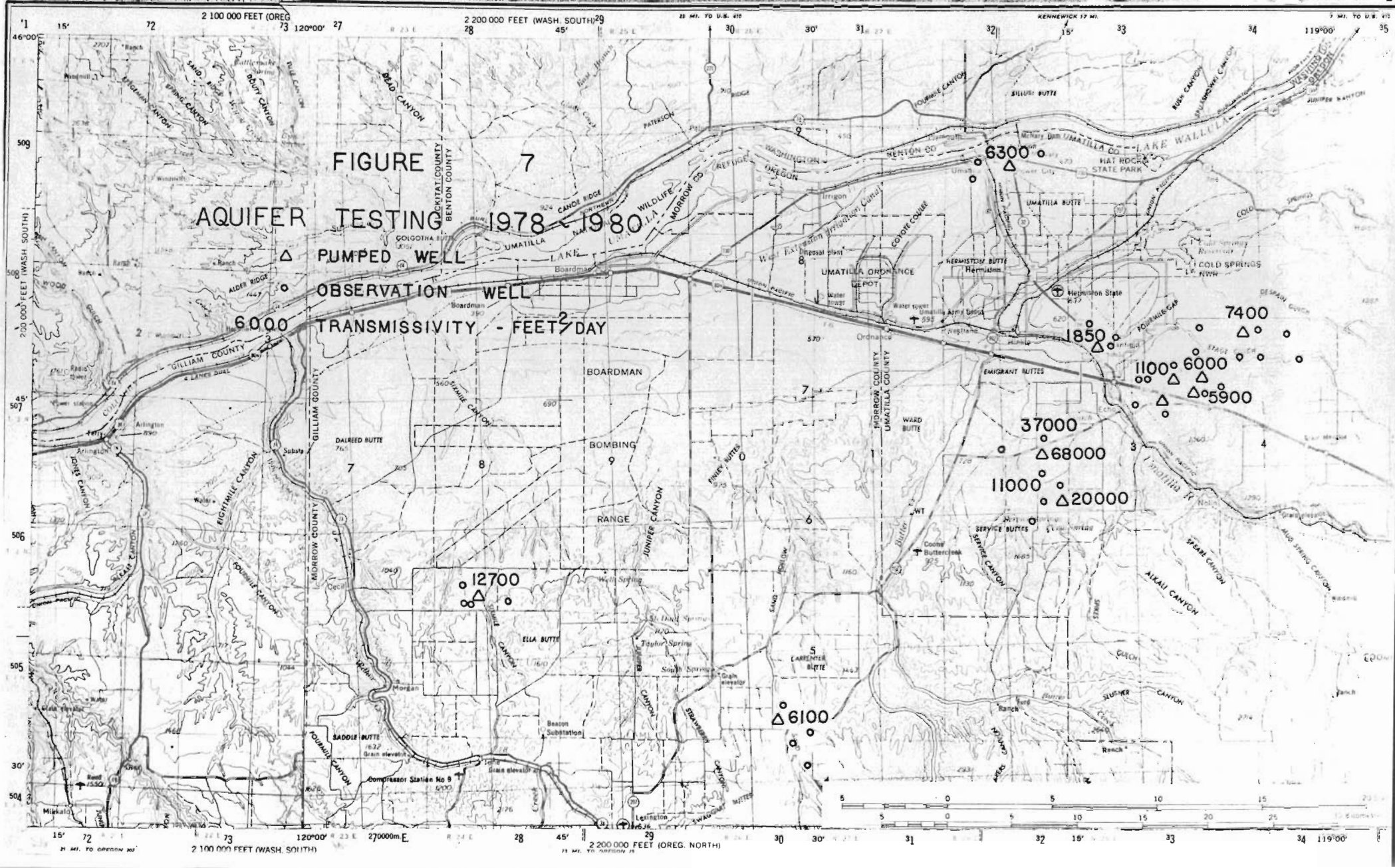


FIGURE 7
AQUIFER TESTING 1978 - 1980
△ PUMPED WELL
OBSERVATION WELL
6000 TRANSMISSIVITY - FEET²/DAY
6300
7400
1850
1100
6000
5900
37000
68000
11000
20000
12700
6100
BOARDMAN
BOMBING
RANGE
UMATILLA ORDNANCE DEPOT
HERMISTON BUTTE
HAT ROCK STATE PARK
LAKE WALLULA
UMATILLA BUTTE
EMIGRANT BUTTES
WARD BUTTE
ELLA BUTTE
SADDLE BUTTE
CARPENTER BUTTE
SERVICE BUTTES
GILLIAM COUNTY
MORROW COUNTY
UMATILLA COUNTY
BENTON COUNTY
2 100 000 FEET (OREG
2 200 000 FEET (WASH. SOUTH)
2 100 000 FEET (WASH. SOUTH)
2 200 000 FEET (OREG. NORTH)

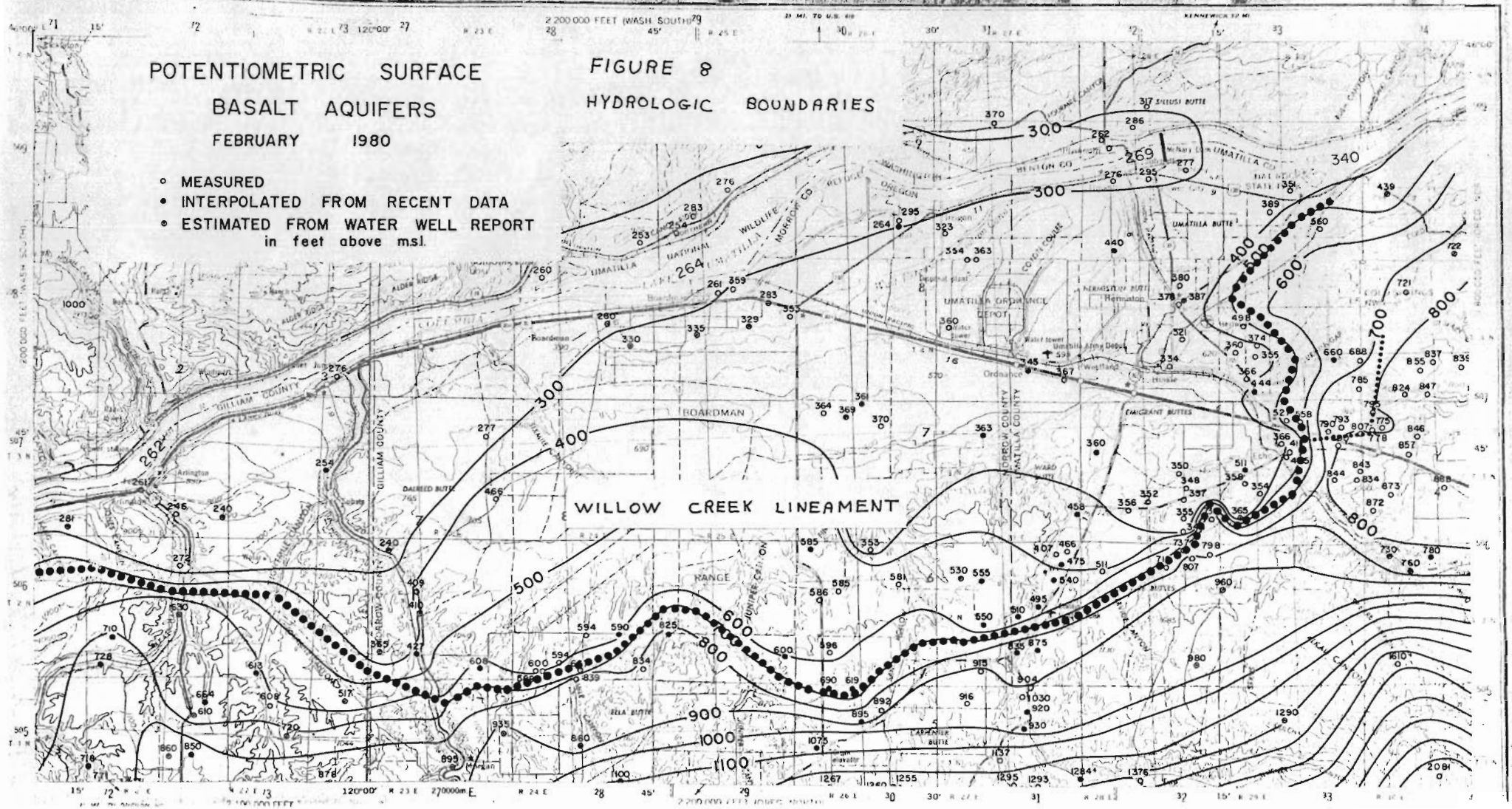
Storage"). As an example, lowering the potentiometric surface one foot uniformly under one acre of land yields 10,427 gallons of water at the regional storage coefficient. This value is typical of unconfined conditions. Therefore, it is possible to conclude that two sets of flow conditions exist in the study area. Confined flow exists: in areas of little or no development where long term decline is slight, during short term testing (2-3 days) in the winter when water level recovery is at its maximum (interflow zones refilled), at depth below the maximum pumping levels, and at depth below the developed zones. Unconfined flow conditions exist: in areas where water levels are lowered below major interflow zones, and in near surface basalt aquifers of the fracture permeability type.

## HYDROLOGIC BOUNDARIES

### LOCAL

Aquifer testing has shown the presence of numerous hydrologic boundaries in the study area. The boundaries are of two classifications. First are local hydrologic boundaries, usually semi-impermeable, that cause an increase in the drawdown rate of the pumping well or a lack of drawdown in an observation well.

Two of these boundaries have been located northeast of Echo. Impermeable hydrologic boundaries were detected during testing at Stage Gulch Ranch and Circle C Farms. They are each less than six miles in length and do not have a major effect on the regional potentiometric surface. Wells used for irrigation adjacent to the ground water barriers have experienced greater drawdown due to a limited area for expansion of the cones of depression. See Figure 8. When most of the well field is pumping in the area adjacent to, and north, of Highway 84 east of Echo the impermeable barriers restrict ground water movement to the wells. Therefore, static water levels of nonpumped wells measured in the winter and summer can fluctuate 500 feet.


POTENTIOMETRIC SURFACE
BASALT AQUIFERS
FEBRUARY 1980
FIGURE 8
HYDROLOGIC BOUNDARIES
MEASURED
INTERPOLATED FROM RECENT DATA
ESTIMATED FROM WATER WELL REPORT
in feet above m.s.l.
WILLOW CREEK LINEAMENT
BOARDMAN
GILLIAM COUNTY
MORROW COUNTY
UMATILLA COUNTY
UMATILLA ORDNANCE DEPOT
300
400
500
600
700
800
900
1000
1100

A shorter ground water barrier exists in the southern portion of Sand Hollow. An increase in the gradient of the potentiometric surface and aquifer testing show a barrier between the Turner Ranch wells and the Cutsforth Ranch wells. The hydrologic boundary trends east-west and extends for at least five miles. An eroded scarp coincides with the feature and extends to Butter Creek.

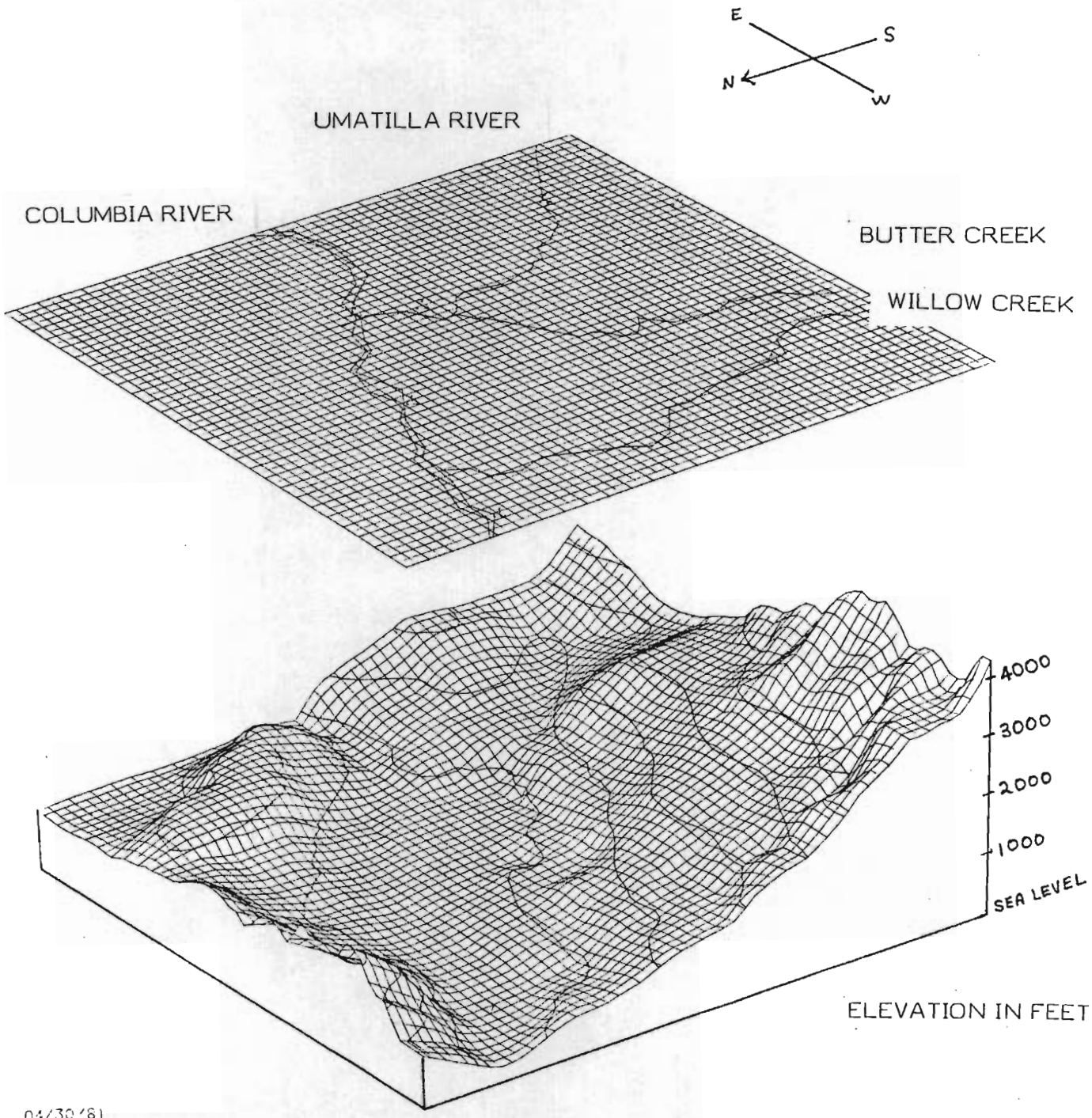
## REGIONAL

The second classification is regional hydrologic boundaries that affect the potentiometric surface and change the transmissivity by greater than one half of an order of magnitude. These features are seen on a map of the potentiometric surface. See Plate 1. Water level measurements of 140 wells were made in February 1980 when the irrigation wells were at maximum annual recovery from the previous season's pumpage. Additional data was interpolated from the Water Resources -- U.S. Geological Survey observation well net and recent water well reports. The depth to water was subtracted from the land surface elevation of each well and plotted as a surface above mean sea level. Major changes in the spacing of the contour lines indicate a hydrologic boundary.

The most significant of these hydrologic boundaries extends from Blalock to Ella Butte to Butter Creek Junction to Echo to near Hat Rock State Park. This feature has been tentatively named by the Water Resources Department as the Willow Creek Lineament. Along the lineament there is a steep gradient of the potentiometric surface. Water levels in the basalt aquifer indicate a gradient of 200 to 600 feet per mile across the structure. South of the Willow Creek lineament, the gradient averages 100 feet per mile. The potentiometric surface is much flatter north of the lineament with a gradient of about 25 feet per mile. See Plate 1. Figure 9 is a computer generated view of Plate 1 which is provided for easy visualization of the potentiometric surface.

FIGURE 9

1980 POTENTIOMETRIC SURFACE
UMATILLA BASIN




04/30/81
HOLLWAY

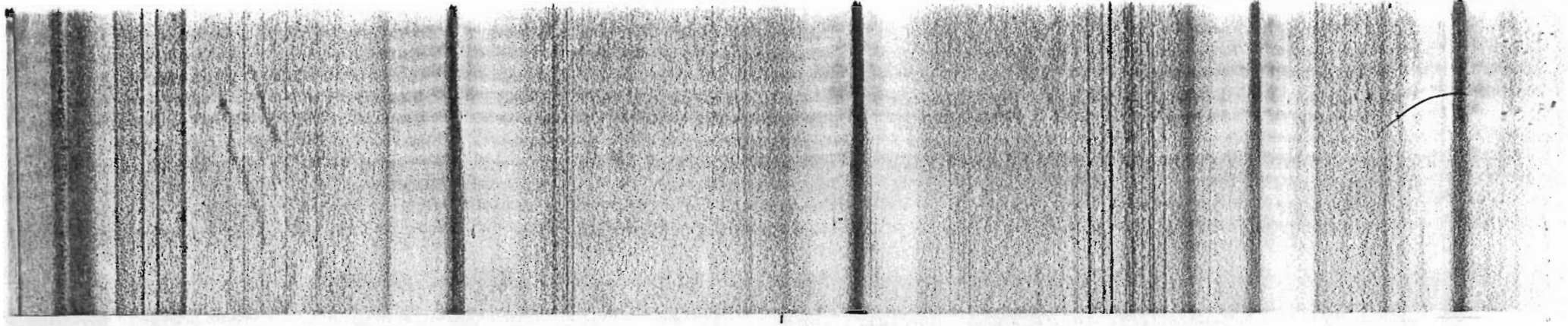
PERVUE
08/15/80

The Willow Creek Lineament is topographically expressed at its western extent as a line of steep hills south of Blalock trending east-southeast to Fourmile Canyon. To the east at Willow Creek, the lineament trends eastward and is expressed in a line of hills that form the northern extent of Ella Butte.

Along this section the lineament coincides with a monocline mapped by the consulting firm of Shannon and Wilson as a part of the Boardman plant site evaluation. See Figure 10 for a cross sectional view of the Willow Creek Lineament. The Willow Creek Lineament loses its topographic expression near McDade Springs to the east. For 15 miles to the east the lineament is evidenced only by the gradient of the potentiometric surface measured in the numerous irrigation wells along Butter Creek. Along this 15 mile section the Willow Creek Lineament is less distinctive due to the large water level declines in the area.

At Service Butte the Willow Creek Lineament truncates the Service Anticline as an east-west fault. The fault zone is a series of near parallel normal faults. The width of the fault zone is about 1.5 miles at this location and correlates well with the width of the steep portion of the potentiometric surface. To the east of Service Buttes the topographic expression is lost and the extension of the lineament is based on water level measurements and transmissivity changes.

The Willow Creek Lineament is probably a combination of folding and faulting along a line of structural weakness. The folding may be contemporaneous with the basalt flow emplacement producing stratigraphic pinchouts. This is evident in the Ella Butte area and may be common along the length of the lineament. In other locations post-flow folding and faulting may have offset the major producing zones or restricted water movement due to the formation of fault gouge. The structural expression is always higher on the south side of the lineament. In part of its length the lineament is clearly monoclinal



NORTH

SOUTH

A

A'

6000

4000

2000

COLUMBIA RIVER

WILLOW CREEK LINEAMENT

BUTTER CREEK

LITTLE BUTTER CREEK

RIETH ANTICLINE

AGENCY SYNCLINE

BLUE MOUNTAIN ANTICLINE

LAND SURFACE

POTENTIOMETRIC SURFACE

SEA LEVEL

SCALE IN MILES

0 5 10 15

ELEVATION IN FEET ABOVE MEAN SEA LEVEL

VERTICAL EXAGGERATION = 10.1

FIGURE 10

in nature. It is quite possible that the Willow Creek Lineament is a zone of adjustment between the Dalles-Umatilla syncline to the north and the Blue Mountain anticline to the south. The restrictive nature of the lineament forms a zone of low transmissivity/aquifer separation that can be considered as a "ground water dam."

Examination of Plate 1 also shows a "trough" in the potentiometric surface from the city of Pendleton to three miles southeast of the City of Stanfield. This feature lies along the axis of the Dalles-Umatilla syncline and is probably due to an increase of fracture permeability along the flexure.

## RECHARGE TO BASALT AQUIFER

The potentiometric surface also shows the location of sources of recharge to and discharge from the aquifer.

In general ground water enters the aquifer system along the Blue Mountain front and flows to the north. The Horse Heaven Anticline in the northeast section of the study area is also a recharge area. Precipitation is slight, about seven inches per year throughout much of the area. Snowpack and greater rainfall in the higher elevations contribute most of the water for surface streams and ground water recharge. The rate of water entering the aquifer is controlled by the amount and duration of precipitation and the vertical permeability of the basalt. The vertical flow component can be quite restrictive, as evidenced by the number of wells that flowed at land surface at the time of drilling. On a regional scale, the potentiometric surface map does not show any "ground water mounding" under rivers, lakes, or areas of heavy surface water irrigation. This again indicates a low vertical permeability. Only along the Blue Mountain front, where interflow zones of the basalt flows are upturned, may significant recharge be taking place.

At the present time, nearly all of the potentiometric surface is below land surface and further ground water declines will probably not induce additional recharge. The rate of recharge, as estimated by the U.S. Geological Survey for adjacent lands in Washington, may be 0.06 inches in dryland areas and 0.3 inches in upland areas. Calculations based on the above estimate indicate a maximum of 10,000 to 15,000 acre-feet of recharge per year for the 2,500 square mile region. This value is a tentative estimate only, future work and computer modeling will refine the value of annual recharge.

## POSITIVE PRESSURE AT DEPTH

The interconnection between ground water in the deep basalt aquifer and streamflows is assumed to be small. This assumption is based on the evidence that vertical permeability across basalt flows is low. Furthermore, the great age of the ground water in deep basalt wells suggests that once water enters
the aquifer it does not move out quickly. An examination of the regional potentials in the basalt aquifer reflects a subdued topography, indicating that land surface elevations do mirror ground water levels. Therefore, the movement of water from the basalts back to the surface does occur under natural conditions.

For the most part, water levels are shallowest in the more deeply incised valleys. Prior to development, basalt water levels were probably within a few tens of feet of land surface in these areas. Today, water levels in some of these areas have declined. This water level decline has increased the possibility that streamflows have been reduced due to the movement of water back into the ground. Again, it is emphasized that the probable impact on streamflows is minor.

In the Umatilla Basin, there are numerous areas where deep flowing wells have been drilled. In addition, a comparison of the 1980 potentiometric surface with land surface elevations offers other possible sites for flowing wells. Some of the known areas have experienced considerable head reductions such that water levels may currently be several hundred feet below land surface.

Areas where flowing wells have existed are as follows:

(1) Willow Creek near Morgan
(2) Willow Creek between Lexington and Heppner
(3) Rhea Creek near Ruggs
(4) Upper Juniper Canyon
(5) Central Sand Hollow
(6) Lower Butter Creek Valley north of Butter Creek Junction
(7) Butter Creek Valley south of Pine City
(8) Butter Creek Valley between Vinson and Pine City
(9) Umatilla River near Nolin
(10) Stage Gulch
(11) Northeast of Service Butte
(12) Speare Canyon
(13) Birch Creek at Pilot Rock
(14) Central Alkali Canyon
(15) Boardman
(16) McKay Creek
(17) Hermiston

Possible areas for flowing wells are as follows:

(1) Upper Eightmile Canyon
(2) Butter Creek Valley near Vinson
(3) Lower Despain Gulch
(4) Upper Alkali Canyon

It is evident from the listing that numerous areas exist where positive ground water pressure occurs at depth. Many of these have experienced little or no development.

## DISCHARGE FROM BASALT AQUIFER

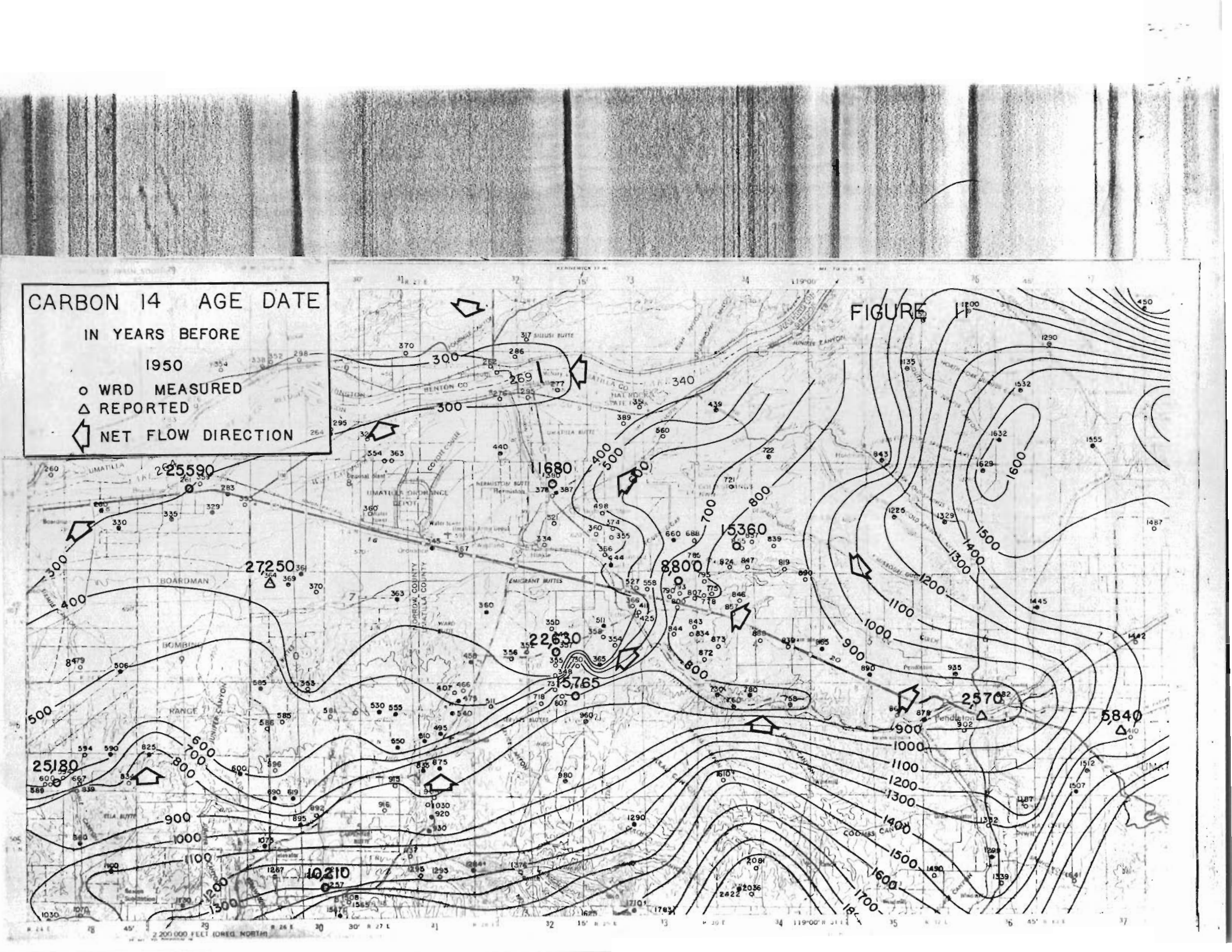
The discharge areas of the basalt aquifer are wells and springs. The total estimated pumping withdrawal from the basalt aquifer is 1.5 million acre-feet. The 1980 annual withdrawal rate was an estimated 175,000 acre-feet. Further discussion of historical basalt ground water pumping is found in the Volumetric Overdraft Analysis section.

A minor amount of water is discharged from shallow basalt aquifers through springs. South of the Umatilla River in canyon areas, there are numerous springs representing local flow systems. Plate 1 shows that the lowest heads on the potentiometric surface are along the Columbia River. The water level in deep basalt wells and the river level are nearly the same in a band up to three miles wide adjacent to the Columbia River. There are several springs that discharge directly into the Columbia River. The amount of water flowing from these springs has historically been minor (information source R.C. Newcomb).

Water levels collected by the Washington Department of Ecology and the U.S. Geological Survey at Tacoma, Washington demonstrate that ground water in Washington is also flowing toward the Columbia River. The river can be considered a regional line sink with no significant flow of ground water between the two states in the study area.

## AGE OF GROUND WATER

The Water Resources Department has sampled wells in the study area for carbon 14 age determination. The carbon 14 dates are reported in years before the present. The year 1950 is used as year 0 by international standard. The Carbon 14 age date indicates when the water was last exposed to the earth's atmosphere. Thus the length of time for the water to flow from the point of recharge to its present location is demonstrated by the carbon 14 age date. See Figures 6 and 11.


CARBON 14 AGE DATE
IN YEARS BEFORE
1950
o WRD MEASURED
△ REPORTED
NET FLOW DIRECTION
FIGURE 17
25590
11680
15360
8800
27250
22630
15765
25180
10210
2570
5840
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
BOARDMAN
UMATILLA
HERMISTON
PENDLETON
2,200,000 FEET (ORIEG. NORTH)

Two available carbon 14 analyses taken by the U.S. Geological Survey have been excluded from Figures 6 and 11. These are the 6,700 year old water from a 453 foot well at T4N/R27E-8dda and the "modern" age water from a 70 foot well at T1S/R26E-1dad. The former is not included since water level fluctuation and water chemistry evidence suggest that the well is mixing water from the basalt with alluvial aquifer water. Therefore, the apparent age would appear younger than would the basalt aquifer water alone. The latter well is excluded since it is quite shallow and situated next to the creek in Milk Canyon. It is believed that the shallow, perhaps eroded, basalts which yield water to this well contain water which is modern in age, but is not representative of the age of water which is extracted from deep basalt wells in the area. In recent years this well has been abandoned in favor of deeper more productive wells.

Ground water age dates show that ground water is youngest near the Blue Mountains in the south and oldest adjacent to the Columbia River to the north. This is in excellent agreement with the flow paths determined from the potentiometric surface map. Ground water north of the Willow Creek Lineament has tested to date in excess of 22,000 years old. Immediately south of the lineament ground water is 15,700 years old. Ground water in the southern part of Sand Hollow (the closest sample to the Blue Mountains) is only 10,200 years old. These data show that the effective flow rate for ground water is about five feet per year from the south to the Willow Creek Lineament. Effective flow rates are calculated at about two feet per year through the Willow Creek Lineament at Service Butte. The ground water north of the Willow Creek Lineament falls into a narrow age range which supports the theory of higher transmissivity in this area. In the Stage Gulch area, the northeastern most sample demonstrates that the water coming from the southeastern extent of the Horse Heaven Anticline is at least 15,360 years old.

Along the trough in the ground water between Stage Gulch and Pendleton the carbon 14 age dates show younger water. The two reported dates of 2,570 in Pendleton and 5,840 at

Mission are the youngest dates of deep basalt wells. At the northwestern extent of the trough the water is 8,800 years old. This indicates a water movement of approximately 15 feet per year along the Dalles Umatilla Syncline.

The relative carbon 14 age dates are a useful tool to understanding flow regimes. The actual flow rates will be determined by a combination of carbon 14 age dates, aquifer characteristics, and computer simulation. It is important to note that a ground water age of greater than 2000 years is considered to be recharged at a rate too low to prevent ground water mining. This would apply for all areas tested to date.

## GROUND WATER IN AQUIFER STORAGE

In 1968, James Robision of the United States Geological Survey authored an open-file report entitled Estimated Existing and Potential Ground Water Storage in Major Drainage Basins in Oregon. In this report, Robison estimates that 3.2 million acre-feet of practicably recoverable water are stored in the upper 500 feet of the basalt aquifer within the 2,666 square miles of the Umatilla River drainage. In addition, another 8.0 million acre-feet are estimated in storage below 500 feet and above 1,500 feet in the aquifer. Likewise, the report states that the 1,402 square-mile Willow Creek drainage stores 1.2 million acre-feet of recoverable water in the upper 500 feet and 3.2 million acre-feet between 500 and 1,500 feet. Further, the 486 square mile Walla Walla Valley in Oregon stores 1.2 million acre-feet of recoverable water in the upper 500 feet and 3.3 million acre-feet between 500 and 1,500 feet. These estimates considered the effective porosity to be one percent of total volume and an average saturated thickness of 400 feet in the upper 500 feet. These combined areas contain an estimated 5.6 million acre-feet of recoverable water in the upper 500 feet of rock and an estimated 14.3 million acre-feet below 500 feet.

Currently, permitted water rights for the basalt aquifer in the combined Willow Creek, Umatilla and Walla Walla River drainages are about 97,000 acres. At the legal duty of three acre-feet per acre, this translates into a theoretically permitted withdrawal of 290,000 acre-feet annually. Based upon the fact that some permitted acreage is not irrigated and some do not receive full duty, it is believed that the equivalent of about 60 percent of permitted acreage (175,000 acre-feet annually) is irrigated fully. Owing to the great age of water in deep basalt irrigation wells and companion water level declines with use, recharge within the area is believed quite small. Therefore, withdrawals can reasonably be viewed to represent releases from storage only.

Since 1968, when Robison's estimates were formulated, approximately 1.3 million acre-feet have been pumped from the basalt aquifer. Present day storage in the upper 500 feet is, therefore, lowered by that amount. Working under an idealized recovery scheme with the currently estimated withdrawal rate, the storage of the estimated 5.6 million acre-feet within the upper 500 feet will be totally depleted in 25 years (2005). The scheme is ideal for the following assumptions:

1. Future withdrawals will be constant at the estimated rates
2. Estimated storage is accurate and recharge is negligible
3. The upper 500 feet can be isolated as a storage unit
4. Withdrawals in the upper 500 feet are equalized over the entire area
5. Prior withdrawals, as calculated from water rights during the period, are accurate.

Again, assuming ideal recovery at the currently estimated withdrawal rate, the storage of the estimated 14.3 million acre-feet below 500 feet, but above 1,500 will be depleted in another 82 years (2087).

Actual water level declines will be larger in the areas of major use than elsewhere. This means that depletion will not be uniform within the upper 500 feet. The true depletion condition would show some areas which have water levels below 500 feet and others which show relatively minor declines. The aggregate effect in the previous analysis will be equivalent to an average decline over the entire area.

The volumetric overdraft analysis in this report indicates that the effective porosity of the basalt aquifer in the area is about 3.2 percent which stands in sharp contrast to Robison's estimate of 1 percent. This surprising discovery suggests that the ground water storage calculations are low by a factor of 3.2. On this basis a revised estimate of storage in the upper 500 feet is 18.0 million acre-feet instead of the 5.6 million acre-feet calculated for 1968. Considering the 1.3 million acre-feet of water withdrawn since 1968, the upper 500 feet will be totally depleted in 95 years (2075) under the currently estimated withdrawal rate. Likewise, the storage of an estimated 45.8 million acre-feet in the zone 500 to 1,500 feet will be totally depleted in 262 additional years (2337). Again, let it be understood that these figures represent an idealized recovery scheme. Actual withdrawals of ground water in the area will be controlled by what is economically recoverable.

According to Robison, the study area contains about 2,200 square miles under which there is recoverable ground water within the Willow Creek, Umatilla River and Walla Walla Valley subareas. The area of recoverable storage excludes areas where topographic relief or limited accessibility would seem to exclude practical ground water recovery. Using the estimated withdrawal of about 1.3 million acre-feet since 1968, and an effective porosity of 3.2 percent, the average water level decline for the period 1968 to 1980 is about 29 feet in the area of recoverable ground water. Robison's estimated effective porosity of 1 percent would show an average decline of 92 feet for the period.

By no means should these depletion figures be judged on anything but an average basis, since pumping centers will experience more acute changes in storage (water level) than lightly pumped areas. The real merit of these calculations is in providing a graphical instrument for the understanding of past and future trends.

## WATER LEVEL DECLINES

### REGIONAL - SUPPLY OVERDRAFT

Water level declines are clearly evident throughout the study area. The authors have identified three types of water level decline processes at work. First is a regional decline evidenced by lowering of potentiometric surfaces over a large area.

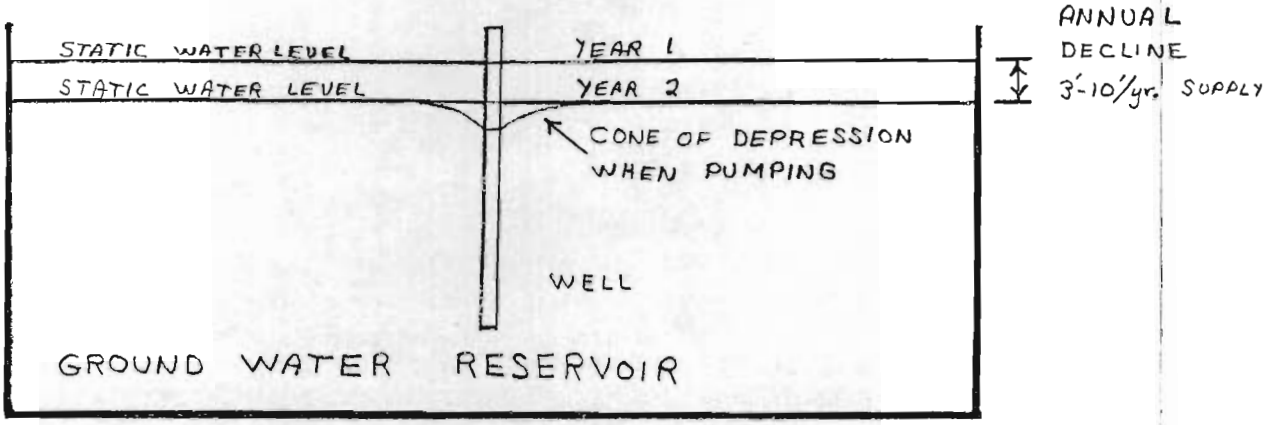
This occurs when withdrawals exceed recharge to the aquifer. This is most evident where the trasmissivities are high. The decline rates at wells under these conditions are similar and less than average for the region in relation to volume pumped. When withdrawals exceed recharge, a supply overdraft produces the decline of the aquifer.

### LOCAL - DEMAND OVERDRAFT

The second type of decline is a local decline that effects only nearby wells. This is evidenced by wells in areas where a combination of low transmissivity and/or local hydraulic barriers prevents complete water level recovery between seasonal pumpings. This is termed a demand overdraft of the aquifer. Support for this type of decline includes wells that have large declines and are located in areas of known low transmissivity, i.e. the Willow Creek Lineament. See Figure 12 for representations of supply and demand overdrafts. Wells that experience demand overdraft are pumping at rates that exceed the capacity of the aquifer to move equivalent quantities of water toward the well.

# OVERDRAFT EXAMPLES

## SUPPLY OVER DRAFT - HIGH TRANSMISSIVITY




## DEMAND OVERDRAFTS - LOW TRANSMISSIVITY

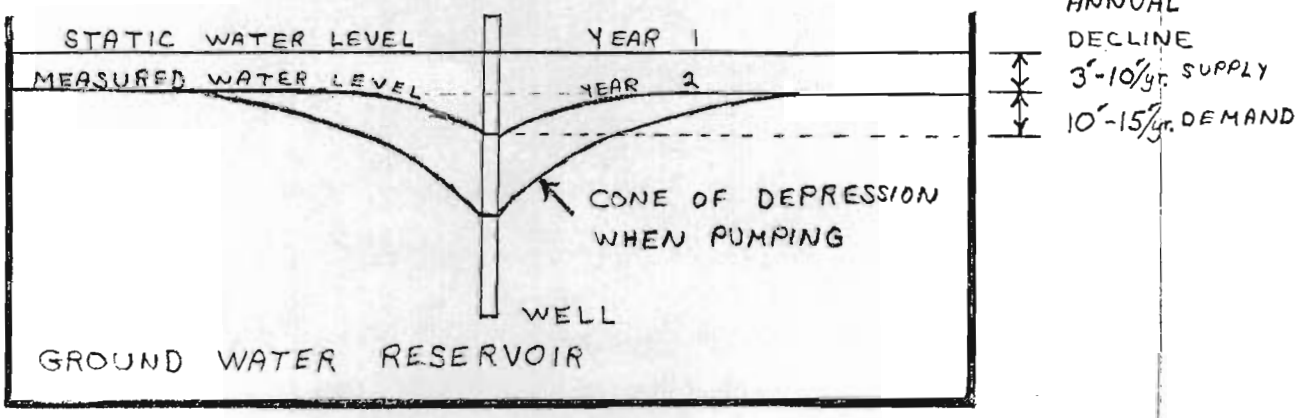



Figure 12

## WELL CONSTRUCTION INDUCED DECLINE

The third type of decline occurs when a well is deepened and the static water level drops. East of Service Butte, water levels have dropped 200 feet in at least two wells at the time of deepening. This drop is more common than a rise in water level when wells are deepened. Geophysical logging of wells has found that 50 percent of wells logged have down hole flow in the well bore. This indicates that a portion of the lower basalts have a lower hydrostatic head. Some wells have such high downhole flow rates that cascading water can be heard at land surface several feet from the well. Down hole flow acts as a constantly pumping well and increases the decline of upper aquifers.

To date potentiometric head drops with depth have occurred at the following locations:

| | |
|---|---|
| T1N, R30E, Section 33 | Head Drop of 400+ feet |
| T2N, R26E, Section 3 | Head Drop of 200+ feet |
| T3N, R28E, Section 35 | Head Drop of 180+ feet |

Wells near the above locations may also experience lower potentiometric head with depth if deepened.

Not all locations exhibit lower heads at depth, some wells have strong uphole flow in portions of the well bore.

A major part of this study is directed at separating documented declines into these types. Computer simulation analysis based on historical pumping withdrawals and hydraulic characteristics will yield much toward this problem.

## HYDROGRAPH EXAMPLES

Hundreds of hydrographs have been generated and analyzed in the preparation of the decline maps presented in this report. Several of these are included to demonstrate various features of water level declines in the region. Examples of these features are contained in the following hydrographs: high decline rate in Figure 13, low decline rate in Figure 14, average decline rate in Figure 15, increased decline rate in Figure 16, and reduced decline rate in Figure 17.

## WATER LEVEL DECLINE 1965 to 1980

To better understand the amount and extent of the ground water declines in the study area four maps have been made. These maps show the water level decline from 1965 to 1980 (Plate 2), 1970 to 1980 (Plate 3), 1975 to 1980 (Plate 4), and 1980 to 1981 (Plate 5). In order to evaluate the relative magnitudes of declines some data was interpolated between known values.

Examination of Plate 2 shows the amount of ground water decline from 1965 to 1980. The declines represented are cumulative, that is, declines that occurred from 1965 onward are plotted. Thus Plate 2 represents all documented ground water declines over the 15 year period. Areas that are lacking data points inside contour lines have declined after 1965. Only computed declines for individual wells of the period are plotted. The declines shown on Plate 2 show that the greatest amount of decline (350 feet plus) has taken place along Route 207 north of Butter Creek Junction.

840 FOOT IRRIGATION WELL LOCATED IN BUTTER CREEK VALLEY DEVELOPING WATER FROM BASALT

2N/27E-1bdd
UMATILLA

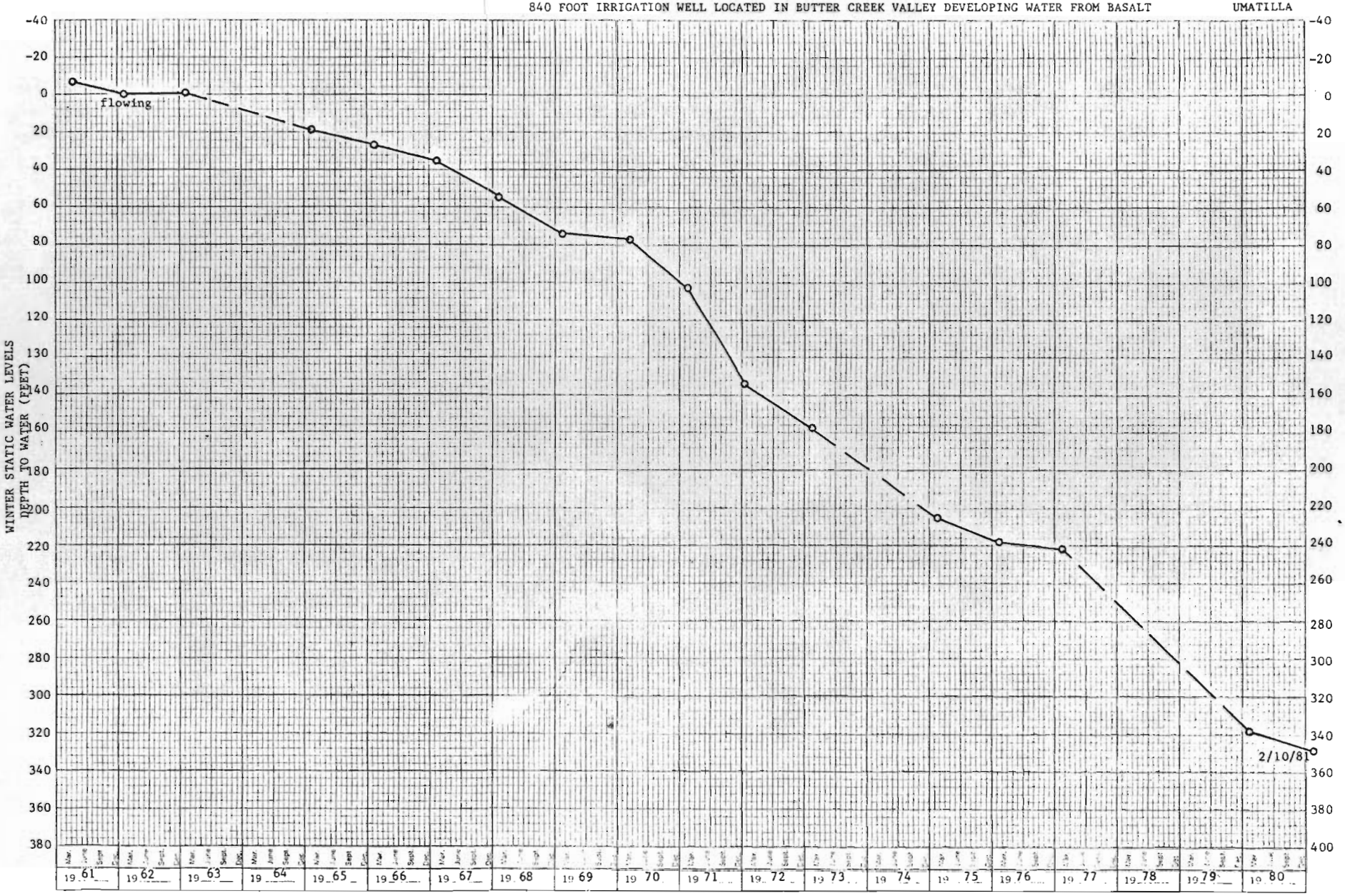



FIGURE 13

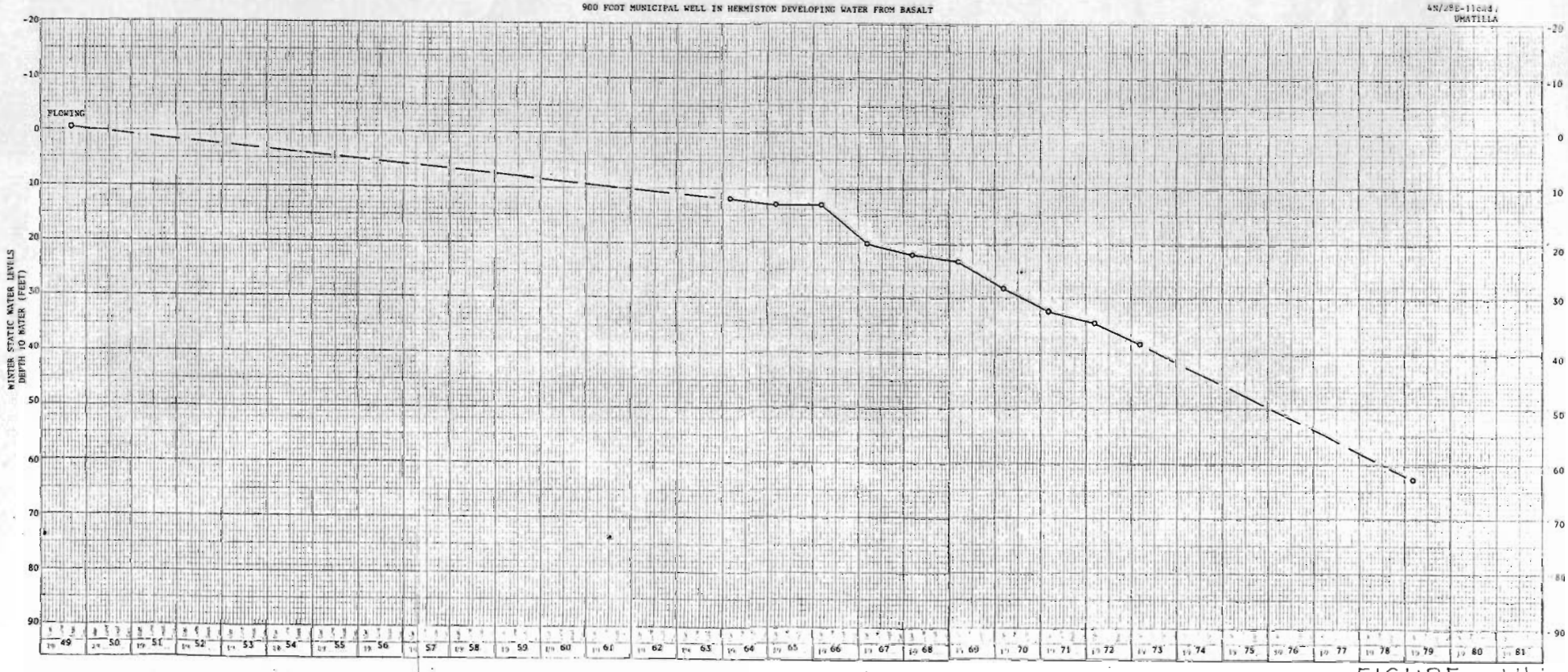

900 FOOT MUNICIPAL WELL IN HERMISTON DEVELOPING WATER FROM BASALT
4N/28E-11cdd,
UMATILLA
WINTER STATIC WATER LEVELS
DEPTH TO WATER (FEET)
FLOWING
-20
-10
0
10
20
30
40
50
60
70
80
90
49
50
51
52
53
54
55
56
57
58
59
60
61
62
63
64
65
66
67
68
69
70
71
72
73
74
75
76
77
78
79
80
81

FIGURE 14

945 FOOT IRRIGATION WELL AT ELLA BUTTE DEVELOPING WATER FROM BASALT

2N/24E-32add
MORROW

WINTER STATIC WATER LEVELS
DEPTH TO WATER (FEET)

260
270
280
290
300
310
320
330
340
350
360
370

19 69 | 19 70 | 19 71 | 19 72 | 19 73 | 19 74 | 19 75 | 19 76 | 19 77 | 19 78 | 19 79 | 19 80 | 19 81 | 19 82 | 19 83 | 19 84 | 19 85 | 19 86 | 19 87 | 19 88

47 3853
K+E 20 YEARS BY MONTHS X 10 DIVISIONS
KEUFFEL & ESSER CO. MADE IN U.S.A.

FIGURE 15

700 FOOT MUNICIPAL WELL IN PENDLETON DEVELOPING WATER FROM BASALT

2N/32E-2ccd
UMATILLA

WINTER STATIC WATER LEVELS
DEPTH TO WATER (FEET)

150
155
160
165
170
175
180
185
190
195
200
205

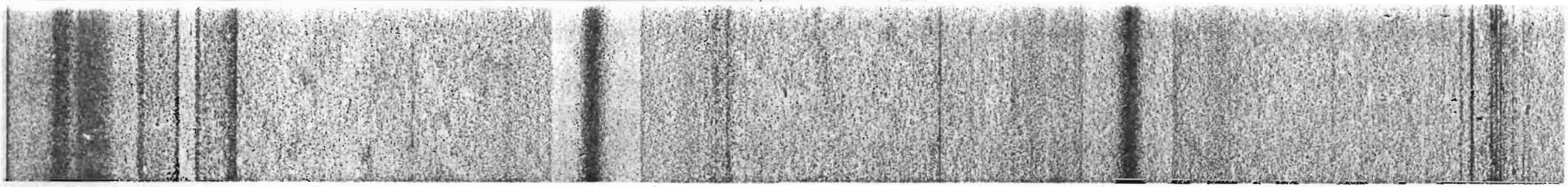
2/9/81

19_61_ 19_62_ 19_63_ 19_64_ 19_65_ 19_66_ 19_67 19_68_ 19_69 19_70 19_71_ 19_72_ 19_73_ 19_74_ 19_75_ 19_76 19_77_ 19_78_ 19_79 19_80_

K+E 20 YEARS BY MONTHS X 110 DIVISIONS
KEUFFEL & ESSER CO.

47 3853

FIGURE 16



1145 FOOT IRRIGATION WELL LOCATED ABOUT 15 MILES NE OF LEXINGTON DEVELOPING WATER FROM BASALT

2N/26E-18daa
MORROW

WINTER STATIC WATER LEVELS
DEPTH TO WATER (FEET)

140
160
180
200
220
240
260
280
300
320
340
360

19 71 | 19 72 | 19 73 | 19 74 | 19 75 | 19 76 | 19 77 | 19 78 | 19 79 | 19 80 | 19 81 | 19 82 | 19 83 | 19 84 | 19 85 | 19 86 | 19 87 | 19 88 | 19 89 | 19 90

47 3853

K+E 20 YEARS BY MONTHS X 119 DIVISIONS
KEUFFEL & ESSER CO

FIGURE 17

Additional noteworthy declines are evident: locally along Willow Creek, at Ella Butte, along "Bombing Range Road", east of Service Butte, Stage Gulch, and the Athena-Weston-Milton-Freewater area. The widespread extent of declines demonstrates the degree of aquifer interconnection. The greatest declines are concentrated in areas of the longest period of aquifer development. It is important to note that the declines are also concentrated along the Willow Creek Lineament.

Moderate decline of 50 feet in 15 years extends from Boardman, to Umatilla, to Hermiston, to three miles north of Stanfield, to the Rew Elevator, to two miles south of Echo, to north of Service Butte, to two miles north of the Willamette Base Line at Township 27 North, to Ella Butte, to Boardman. This area encompasses about 600 square miles.

The sharp break in decline south of the intersection of Route 207 and the Echo Highway is due to aquifer compartmentalization. Large differences in decline in adjacent wells are due to development of separate producing zones. On the other hand, the very similar declines centered around the Umatilla Ordnance Depot are evidence of a high degree of aquifer interconnection and lack of compartmentalization. The extension of the 50 feet decline line from Stanfield along Route 84 toward Pendleton coincides with the Dalles-Umatilla Syncline. This extension is probably due to an increase of fracture permeability along the axis of the syncline. The decline from 1965 to 1980 does not represent the total decline to date. In areas of long term withdrawals, an additional 20 to 70 feet of decline has occurred from 1953 to 1965. However, the 1965 to 1980 decline map represents nearly all of the water level decline from initial aquifer development to 1980.

At a few locations, water levels in wells have risen in the period 1965 to 1980. These wells are mainly along the Columbia River and rose in response to the filling of Lake Umatilla behind the John Day Dam. Water levels in these wells are at this time nearly identical to river level, indicating a strong hydraulic connection between the river and the basalt aquifer locally.

A computer generated view of the 1965 to 1980 decline surface is presented in Figure 18. This figure was made from the data used to make Plate 2 and graphically shows the depth and extent of long term ground water decline.

## WATER LEVEL DECLINES 1970 to 1980

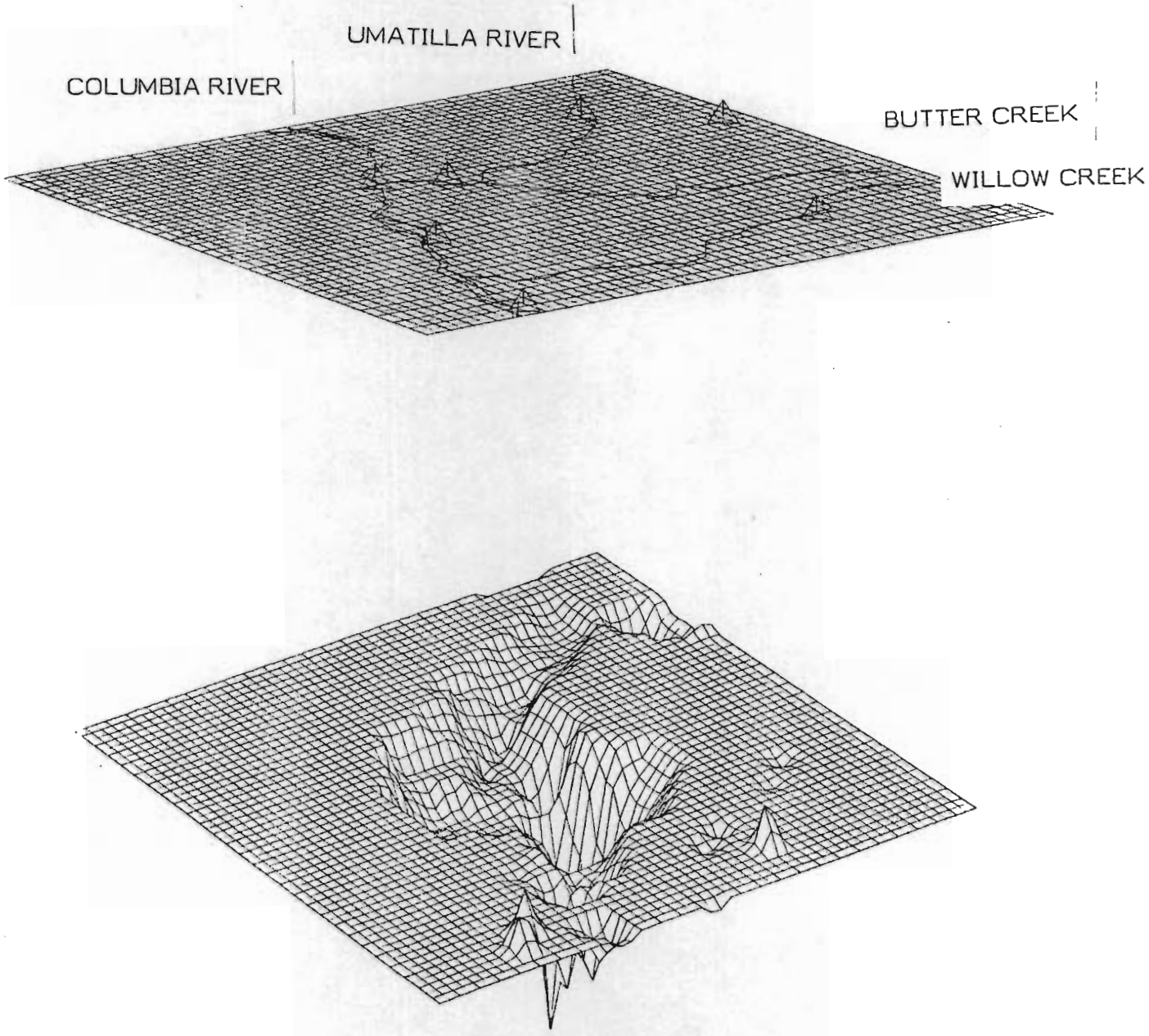
The water level declines from 1970 to 1980 are presented in Plate 3. The same trends and characteristics as seen in Plate 2 are evident. The maximum decline observed is 298 feet along Route 207. The greatest change from the 1965 to 1980 map is centered at the same location. Analysis of Plates 2 and 3 indicates that in general, most of the decline from 1965 to 1970 was centered along Butter Creek and ranged from 50 to 150 feet. The areas of the large withdrawals (pumping centers) averaged 50 to 75 feet of decline from 1965 to 1970. Outlying areas such as Hermiston declined about 15 feet over the same period. Water level declines of three feet or more are noted through the areas of aquifer use.

## WATER LEVEL DECLINES 1975 to 1980

The decline of water levels from 1975 to 1980 is given in Plate 4. The map shows that declines have continued at the same rate or increased for much of the study area. Analysis of Plates 3 and 4 demonstrates that from the period 1970 to 1975 substantial

FIGURE 18

15 YEAR HEAD DECLINE IN UMATILLA BASIN.




1965 TO 1980 GROUNDWATER DECLINES
UMATILLA BASIN

water level declines took place. The area along Butter Creek and north Sand Hollow had declined 50 to 100 feet in that period. Analysis of Plates 3 and 4 also shows that from 1970 to 1975 the Ella Butte and Stage Gulch areas had declined 25 to 50 feet. Declines of 2 to 25 feet are observed over all of the areas containing concentrations of irrigation wells.

Examination of Plate 4 by itself shows the most recent declines from 1975 to 1980. The area along Butter Creek had declined an additional 75 to 150 feet. The area from east of Service Buttes to Echo experienced similar declines of 50 to 150 feet. The Ella Butte area had declined locally over 100 feet. The Stage Gulch area declines were concentrated along the Dalles-Umatilla Syncline and averaged 25 to 50 feet. Wells in the Umatilla Ordnance Depot area continued to decline at the constant rate of about 30 feet per 5 years. North of Pilot Rock evidence shows the development of a localized decline of 25 to 75 feet in five years.

The above descriptions of water level declines have been purposely written to outline only the major features. A detailed year by year and well by well examination would fill countless pages of technical analysis. A computer generated progressive decline diagram is shown in Figure 19. This figure allows an easy visualization of the progressive water level declines over the last 15 years. The surfaces presented show the cumulative declines from Plates 2, 3, and 4. The major points concerning the water level declines are summarized below for the convenience of the reader.

1. Ground water declines in the basalt aquifer are concentrated in locations of major withdrawals.

# 1965 TO 1980 GROUNDWATER DECLINES
# UMATILLA BASIN

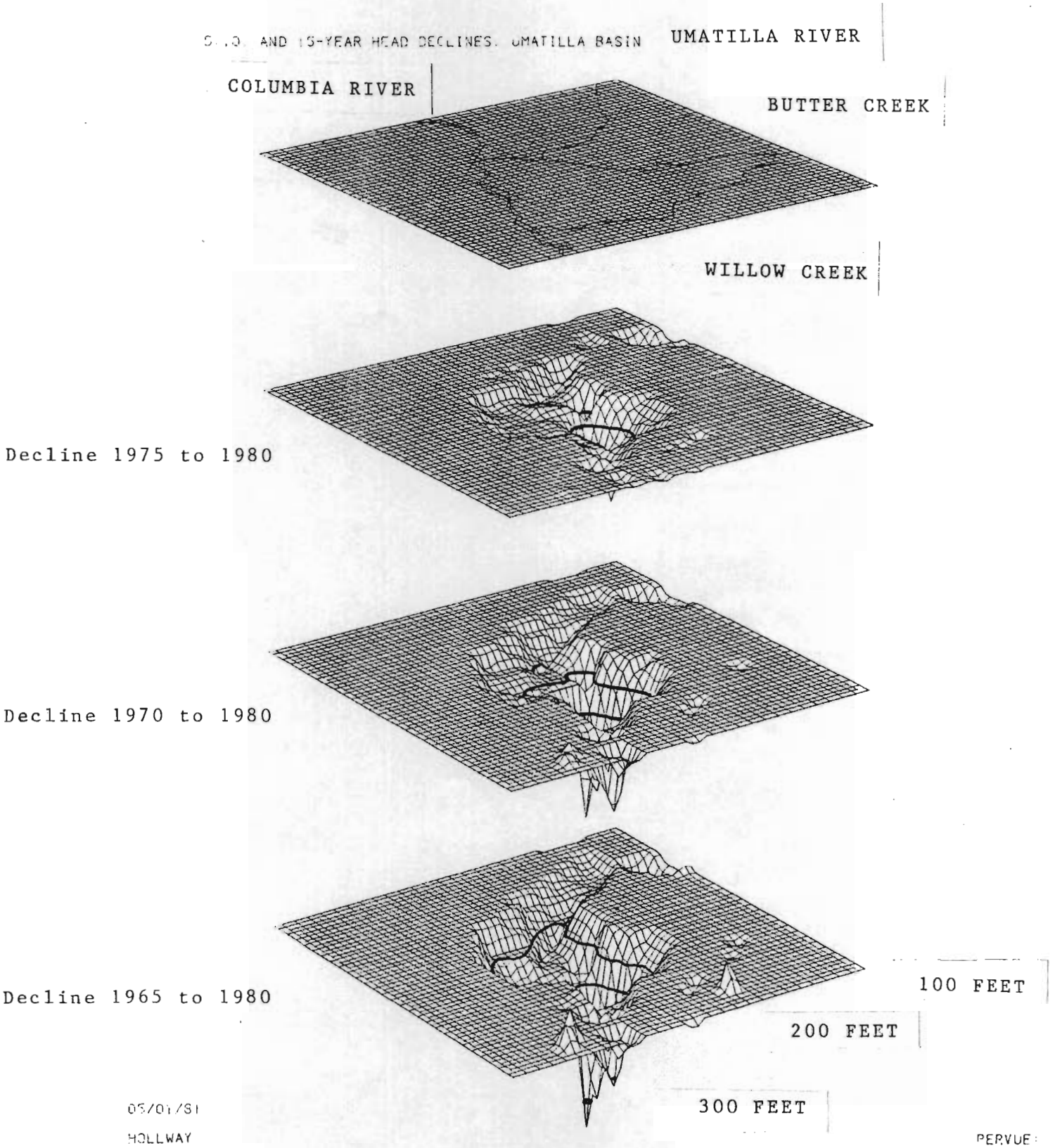



FIGURE 19

2. The development of additional withdrawals since 1975 in the areas of Stage Gulch and east of Service Butte has created new areas of extensive decline.

3. The points that show the greatest decline are along the Willow Creek Lineament and are located in zones of compartmentalized aquifers. In these locations, the decline rate averages 20 to 30 feet per year.

4. The spread of decline is in the direction of greatest permeability. Examples of this include the area along Route 84 from Stanfield to Pendleton, and southward from the center of decline along Butter Creek.

5. Declines are widespread and show that the aquifer is interconnected on a regional scale. Most of the developed areas of the aquifer are declining at a rate of five feet per year or greater.

6. The Pendleton, Athena, Milton-Freewater, and Stage Gulch areas are experiencing an increase in decline rates in response to recent development.

7. No area has reached equilibrium (zero decline) as of 1981. The northern portion of the Sand Hollow area is unique because the decline rates have reduced from over 20 feet per year in 1975 to 3 feet per year in 1980. The area of greatest decline along Butter Creek has also experienced some reduction in the decline rate. This may be due to reduced withdrawals and/or variations in aquifer storage.

8. Wells adjacent to the Columbia River with shallow casing seals are in hydraulic connection with the river and have experienced an increase in water level.

9. The average decline rate for declining areas equals 5.1 feet per year. The water level declines from 1965 to 1980 have dewatered 13 cubic miles of aquifer.

Note: Additional information concerning water level declines is given in the section titled "Volumetric Overdraft Analysis".

## WATER LEVEL DECLINES 1980 to 1981

The decline in water level as measured from the second week of February 1980 to the same period 1981 is shown in Plate 5. The data can be expected to show more variation than the above mentioned decline maps due to the short time period. However, no data on Plate 5 refutes the summary listed above.

In brief, the observed declines are greatest in the areas of development since 1975. The wells around Hermiston and the Umatilla Ordnance Depot declined at the same rate as in the previous 10 year period. The greatest declines of 30 to 50 feet are noted east of Service Butte. In that area there is heavy development of a limited perched aquifer overlying the more regional aquifer. Declines of over 15 feet per year are noted in the Stage Gulch area.

It is also important to note that wells in remote areas can show fluctuations in the potentiometric surface. The small scale changes are effectively masked in developed areas by the annual decline.

## VOLUMETRIC OVERDRAFT ANALYSIS

The water level decline maps in this report offer an excellent opportunity to evaluate the specific yield of the basalt aquifer as well as to project the effects of future withdrawals. The specific yield analysis is a comparison of the estimated withdrawal volume to the dewatered aquifer volume. This is considered to be a valid methodology in the Umatilla Basin since both the aquifer and water volumes can be closely estimated. In addition, carbon 14 samples consistently reveal that basalt water ages are old enough that recharge can be considered negligible. Therefore, the basalt aquifer can be examined as an isolated unit to determine its storage property.

Ground water withdrawals from the basalt aquifer can be estimated from a review of water rights permitting tempered with a knowledge of local water application practices. It is believed that about 60 percent of theoretical water use from permitted water rights are realized as ground water withdrawals. Ground water permitting has approximated a linear function since about 1965, before which annual increases were small. Since 1965, the average annual permitted water use increase has been about 17,000 acre-feet. Prior to 1965, the increase was about 2,000 acre-feet annually. Withdrawals prior to 1965 represent only a few percent of total withdrawal from the basalt aquifer. On this basis, 1965 is considered to be the start of aquifer dewatering as used in subsequent figures. The following table shows estimated annual withdrawals from the basalt aquifer. Withdrawals between dates can be linearly interpolated.

ESTIMATED WITHDRAWALS FROM THE BASALT AQUIFER

| Year | Withdrawals (acre-feet/year) |
|---|---|
| 1940 | Negligible |
| 1955 | 4,000 |
| 1965 | 15,000 |
| 1970 | 70,000 |
| 1975 | 123,000 |
| 1980 | 175,000 |

The dewatered aquifer volume is calculated by a simple integration of the area under the water level decline vs. area plot (expressed in square mile feet or acre-feet). This information is presented in Figure 20. In order to determine the volumes for the periods 1965 to 1970 and 1965 to 1975, a difference method was used which subtracted the 1970 to 1980 decline volume from the 1965 to 1980 decline volume and the 1975 to 1980 decline volume from the 1965 to 1980 decline volume, respectively. The decline 'tails' which encircle large areas but outline small declines are conservatively extrapolated. The following table points out the calculations of dewatered volume, ground water withdrawal and specific yield.

VOLUMETRIC OVERDRAFT CALCULATIONS

| Time | Dewatered Volume (acre-feet) | Water Withdrawn (acre-feet) | Specific Yield (%) |
|---|---|---|---|
| 1965 to 1980 | $4.42 \times 10^7$ | $1.46 \times 10^6$ | 3.3 |
| 1970 to 1980 | $3.73 \times 10^7$ | $1.22 \times 10^6$ | 3.3 |
| 1975 to 1980 | $1.89 \times 10^7$ | $0.74 \times 10^6$ | 3.9 |
| 1965 to 1970 | $0.69 \times 10^7$ | $0.24 \times 10^6$ | 3.5 |
| 1965 to 1975 | $2.53 \times 10^7$ | $0.72 \times 10^6$ | 2.8 |

The values from the base year of 1965 were plotted in order to estimate the specific yield (regional storage coefficient) of the basalt aquifer. The regression gives a specific yield of 3.2 percent (Figure 21). Extensions of the regressed line display the possible effects of future withdrawals under two scenarios. The first shows the effects of withdrawals at the 1980 rate (about 175,000 acre-feet). The second shows the results of increased withdrawals at the trend established during the 1965 to 1980 period (actual withdrawal

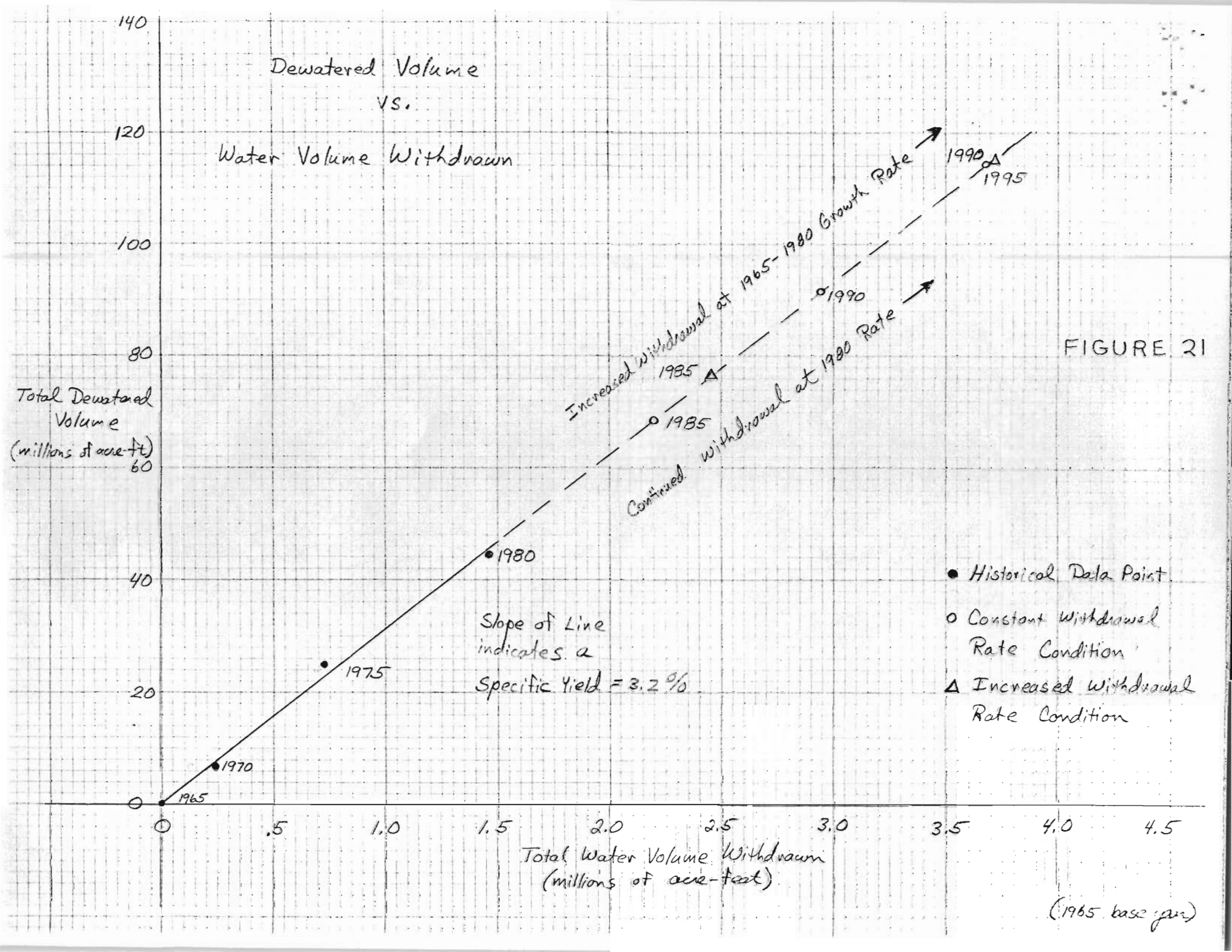

Dewatered Volume
vs.
Water Volume Withdrawn
Total Dewatered Volume (millions of acre-ft)
Total Water Volume Withdrawn (millions of acre-feet)
(1965 base year)
Increased withdrawal at 1965-1980 Growth Rate
Continued withdrawal at 1980 Rate
1965
1970
1975
1980
1985
1990
1995
Slope of Line indicates a Specific Yield = 3.2 %
● Historical Data Point
o Constant Withdrawal Rate Condition
Δ Increased Withdrawal Rate Condition

FIGURE 21

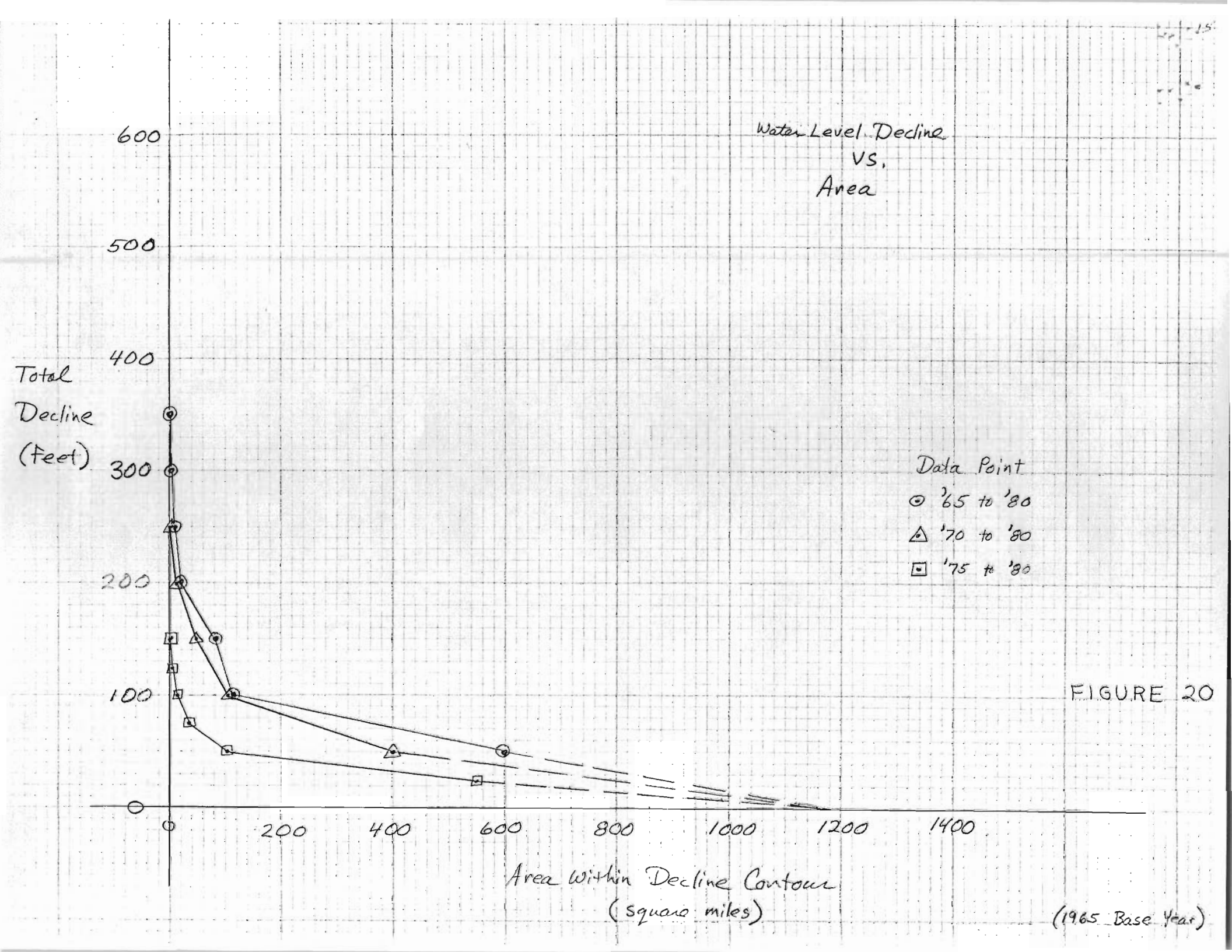

Water Level Decline
vs.
Area
600
500
400
300
200
100
0
Total
Decline
(feet)
Data Point
'65 to '80
'70 to '80
'75 to '80
0
200
400
600
800
1000
1200
1400
Area within Decline Contour
(square miles)
(1965 Base Year)

FIGURE 20

increases of about 10,000 acre-feet per year). Both cases disclose that greater declines will take place. The effects of reduced withdrawals are not shown but can be inferred to produce proportionally smaller declines.

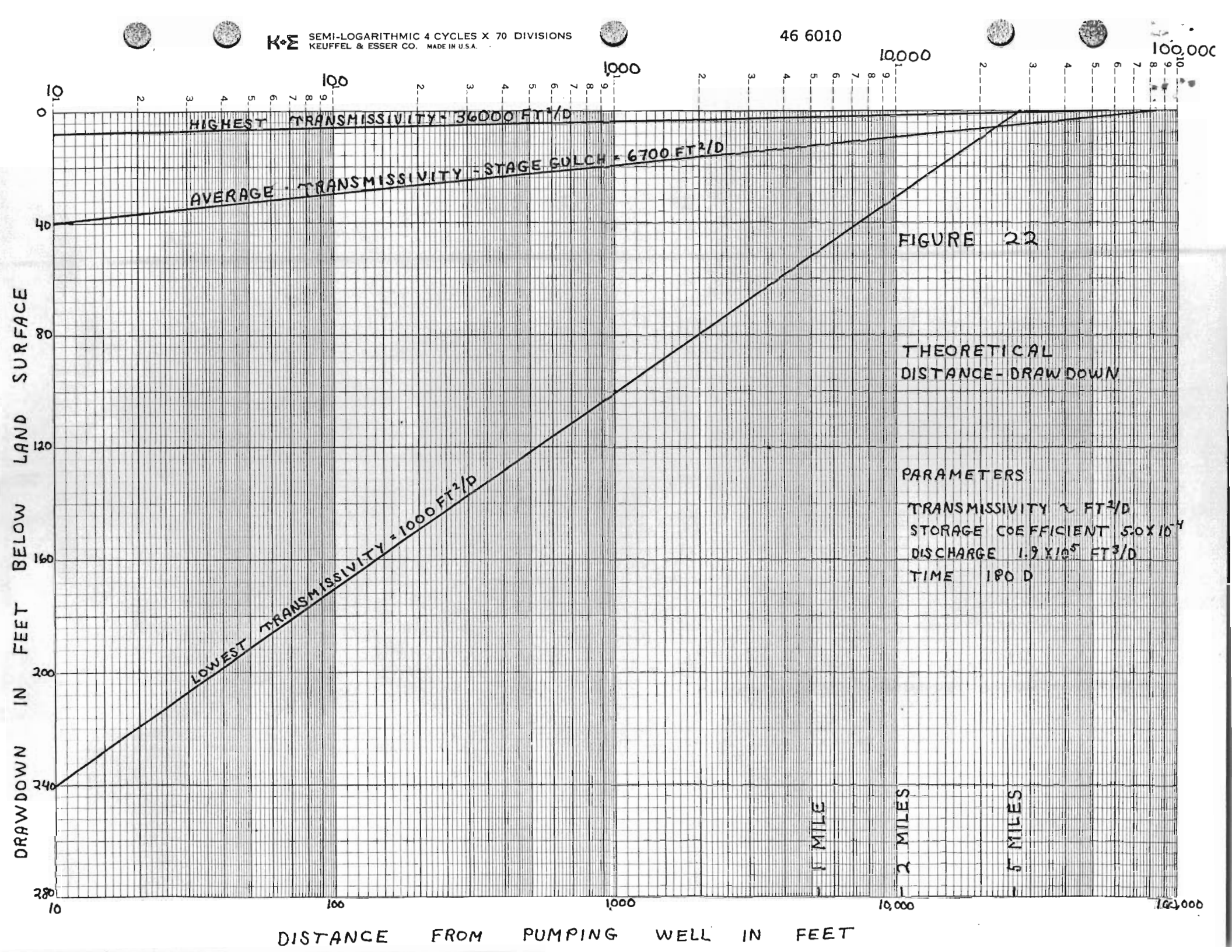
The specific yield determination suggests that no significant changes in storage can be detected during the dewatering process. The data points in the regression are surprisingly linear between 1970, 1975, and 1980. No changes are foreseen in specific yield over the next few years. However, as dewatering occurs in deeper zones it would appear that the specific yield might be lower since the lithostatic pressure of overlying rock may reduce the volume of interflow zones.

## THEORETICAL WELL INTERFERENCE

Varying degrees of pumping interference exist between wells in the area. In general, wells located in areas of low transmissivity produce greater interference over a short distance and wells in areas of high transmissivity produce a smaller degree of interference over a long distance. To illustrate this point, Figure 22 has been constructed to show the drawdown at increasing distance from an average irrigation well under the known range of aquifer characteristics. When wells are located close together, the drawdown effects due to interference are cumulative and can cause large yearly water level fluctuations. At Stage Gulch in 1980, one unpumped well experienced a 497 foot drop in water level as a result of well interference. Well spacing of approximately one mile between irrigation wells in areas of concentrated development has resulted in mutual well interference. Well density (the number of wells per square mile) and the associated withdrawal density (acre-feet withdrawn per year per square mile) can exceed the production capacity of the aquifer on a seasonal basis and cause low water levels in late summer.

K·E SEMI-LOGARITHMIC 4 CYCLES X 70 DIVISIONS
KEUFFEL & ESSER CO. MADE IN U.S.A.



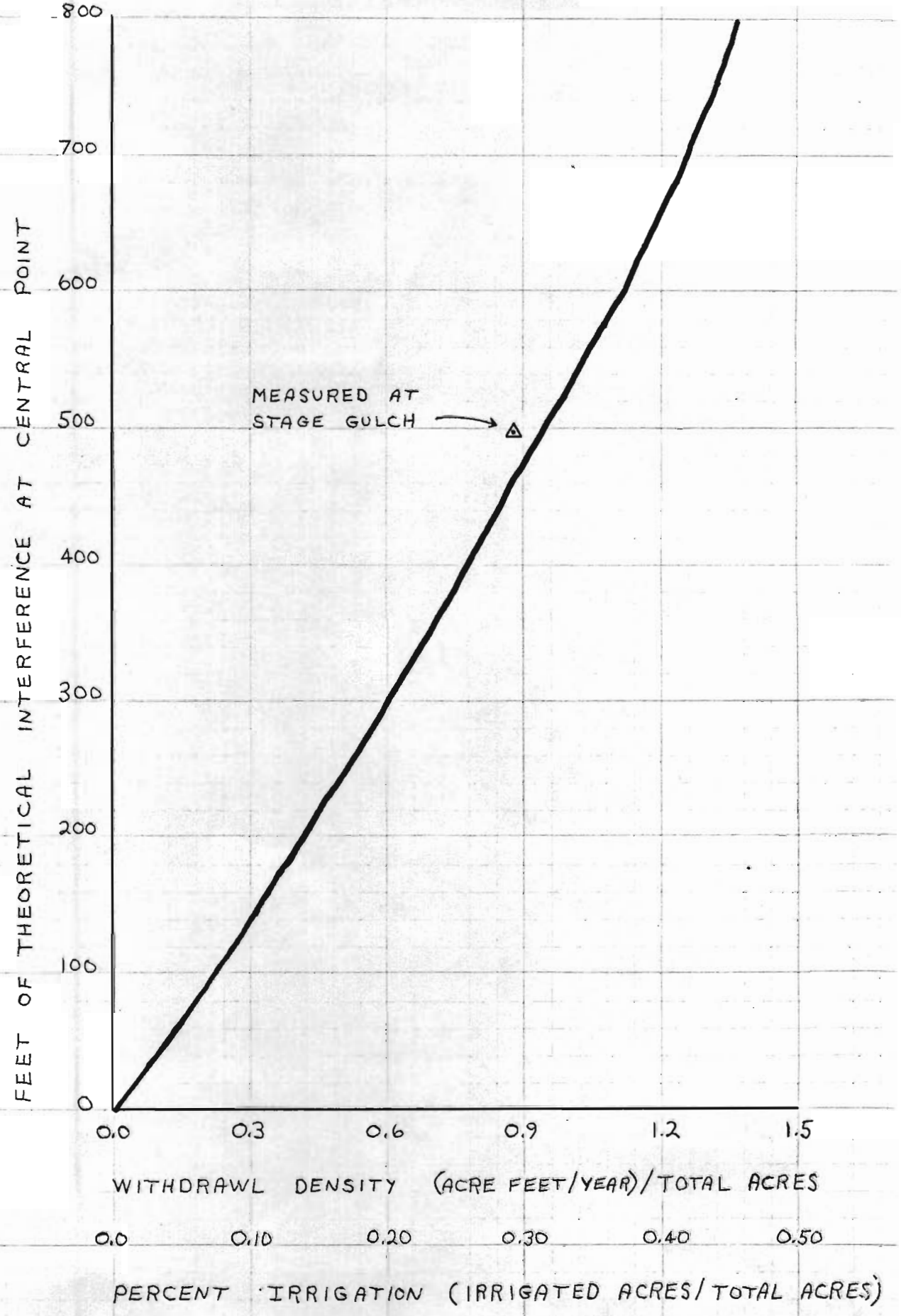


To examine the potential of mutual well interference in a developed area, a theoretical curve was produced that relates maximum interference and withdrawal density. See Figure 23. This curve assumes that an increased need for water in a 64 square mile area will be met by drilling additional wells capable of 1,000 gallons per minute. The wells are assumed to be equally spaced with one mile between wells as the minimum distance. The aquifer characteristics of the Stage Gulch well field are used in this example. The actual interference measured in the summer of 1980 is plotted for comparison to the theoretical value. This figure demonstrates that as aquifer development increases, so does the potential for well interference. It should be noted that the value for interference is the maximum amount experienced at the center of the well field. Well interference decreases toward the edge of the withdrawal area. From examination of Figures 22 and 23, it is apparent that for well interference to be reduced, the withdrawal density must be decreased. This does not necessitate reductions of withdrawals, but taking the water out of the aquifer over a broader area.

## FUTURE RESEARCH

A wide variety of research about the basalt aquifer is either planned or in progress. Most of this work will center around collecting information so that the aquifer can be simulated by a computer model. Computer modeling is being done as a cooperative project with the U.S. Geological Survey. Information concerning the pre-development potentiometric surface, total water level decline, rate and distribution of past withdrawals, areal extent of transmissivity and storage coefficients, well water temperature variations, and stratigraphic head relationships remain to be gathered. Final products of this work will include knowing the maximum amount of ground water that can flow to pumping centers at various levels of permitted decline and the amount of recharge.

FIGURE 23


800
700
600
500
400
300
200
100
0
FEET OF THEORETICAL INTERFERENCE AT CENTRAL POINT
MEASURED AT STAGE GULCH
0.0
0.3
0.6
0.9
1.2
1.5
WITHDRAWL DENSITY (ACRE FEET/YEAR)/TOTAL ACRES
0.0
0.10
0.20
0.30
0.40
0.50
PERCENT IRRIGATION (IRRIGATED ACRES/TOTAL ACRES)

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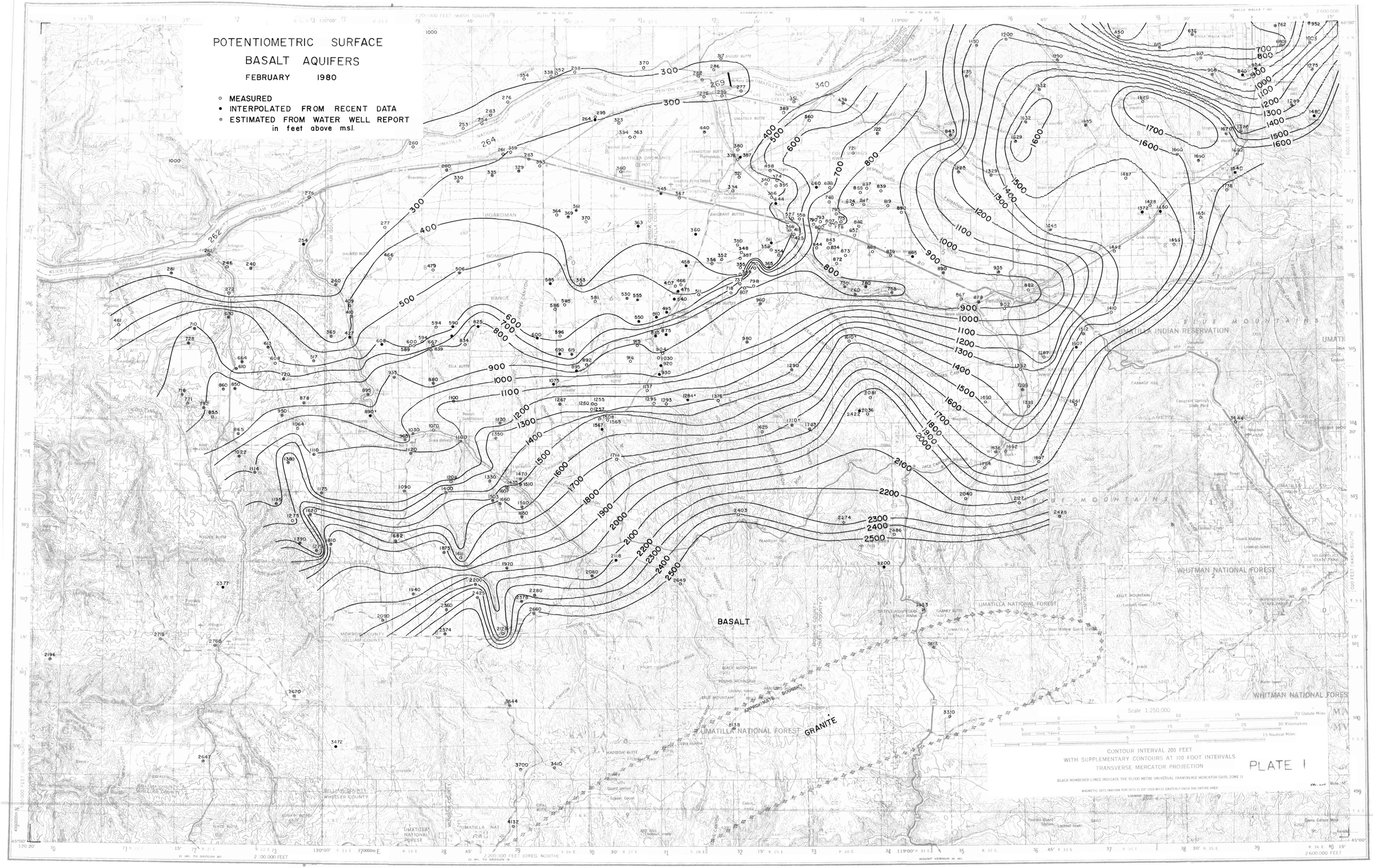
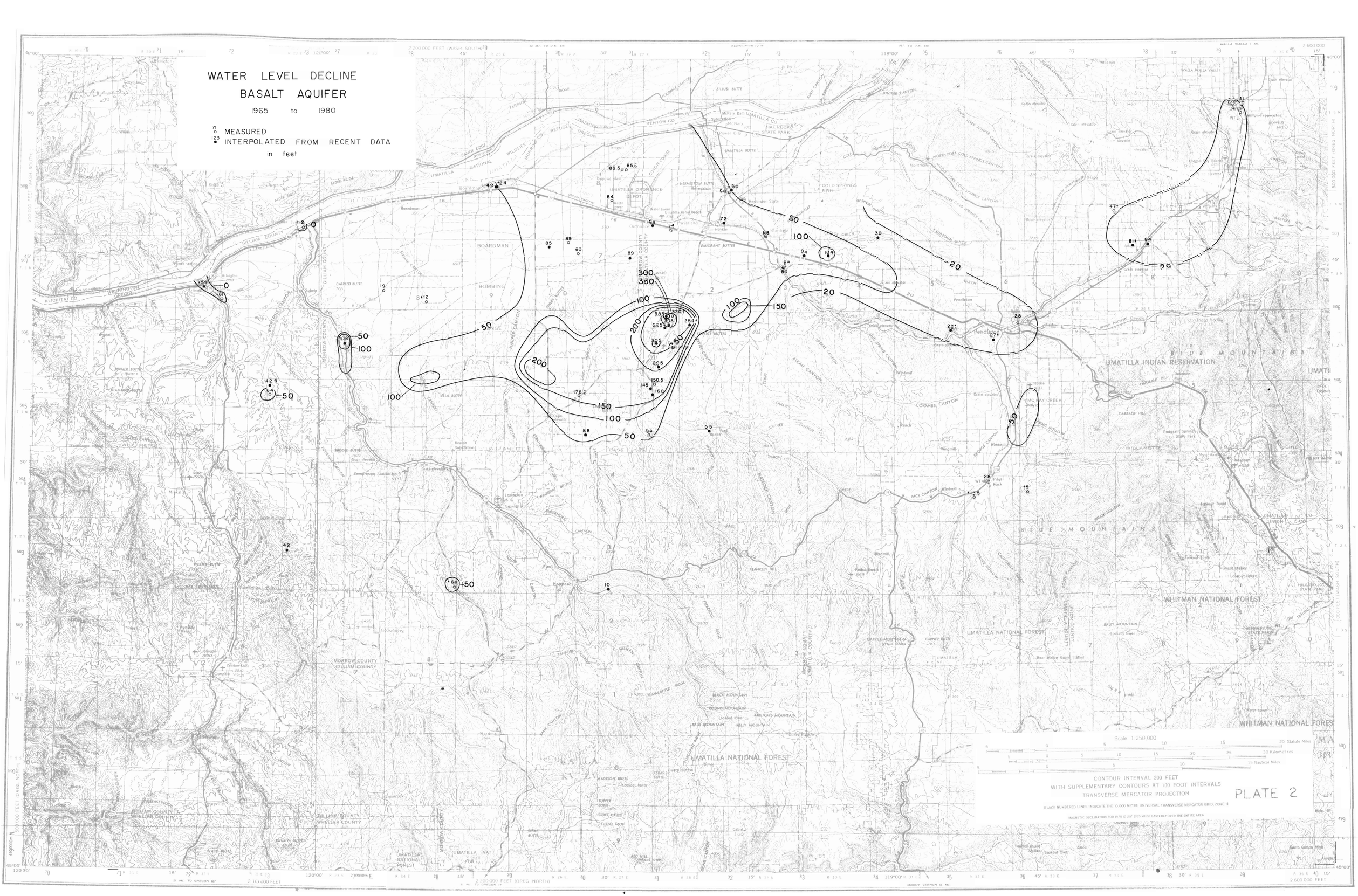

POTENTIOMETRIC SURFACE
BASALT AQUIFERS
FEBRUARY 1980
MEASURED
INTERPOLATED FROM RECENT DATA
ESTIMATED FROM WATER WELL REPORT
in feet above m.s.l.
BASALT
GRANITE
UMATILLA INDIAN RESERVATION
WHITMAN NATIONAL FOREST
UMATILLA NATIONAL FOREST
Scale 1:250,000
CONTOUR INTERVAL 200 FEET
WITH SUPPLEMENTARY CONTOURS AT 100 FOOT INTERVALS
TRANSVERSE MERCATOR PROJECTION
PLATE I

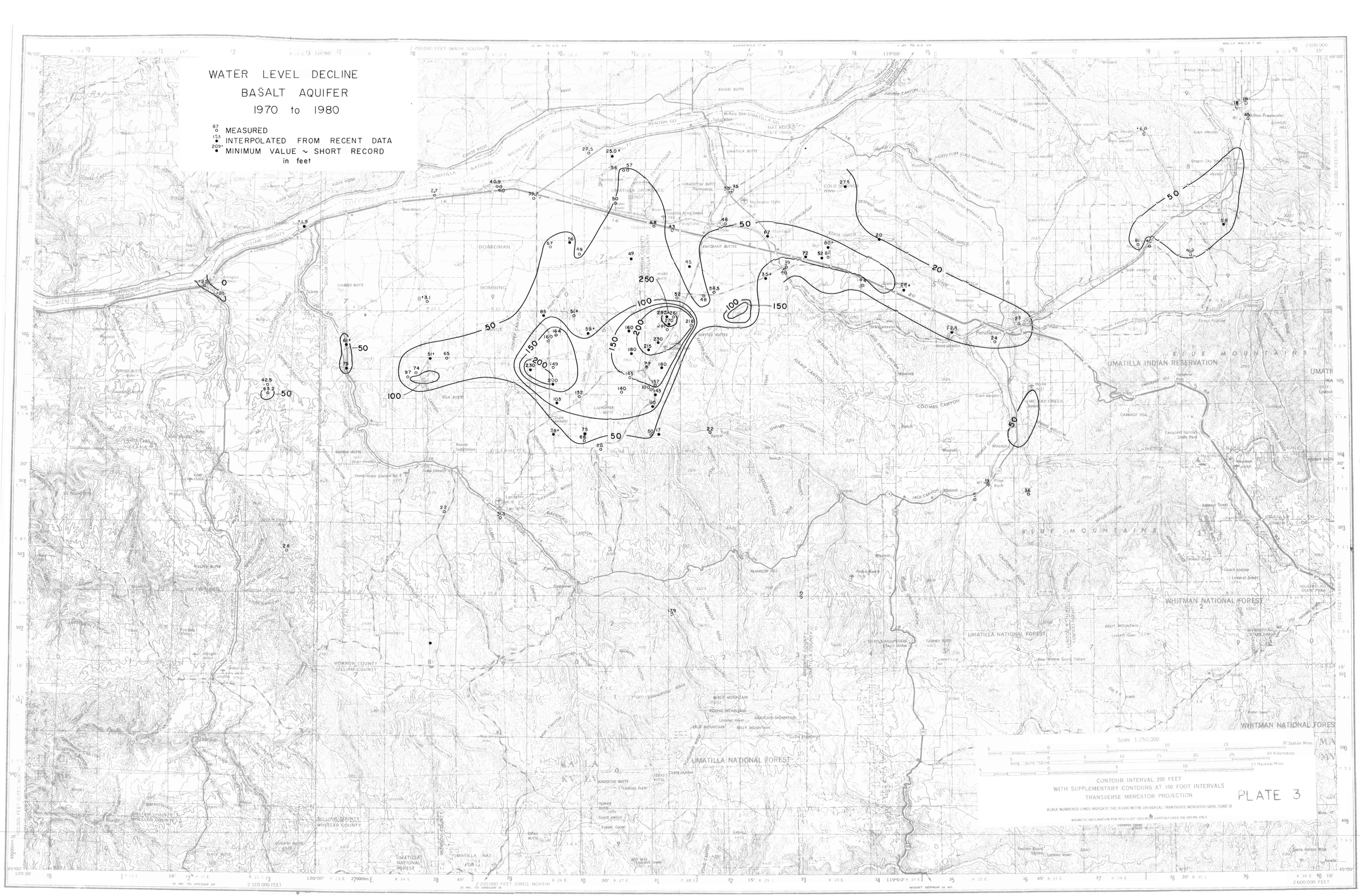
# WATER LEVEL DECLINE
## BASALT AQUIFER
### 1965 to 1980

71 MEASURED
123 INTERPOLATED FROM RECENT DATA
in feet



# WATER LEVEL DECLINE
# BASALT AQUIFER
# 1970 to 1980

87 MEASURED
153 INTERPOLATED FROM RECENT DATA
209+ MINIMUM VALUE ~ SHORT RECORD
in feet



# WATER LEVEL DECLINE
# BASALT AQUIFER
# 1975 to 1980

10 MEASURED
20 INTERPOLATED FROM RECENT DATA
30+ MINIMUM VALUE ~ SHORT RECORD
in feet

Scale 1:250,000

CONTOUR INTERVAL 200 FEET
WITH SUPPLEMENTARY CONTOURS AT 100 FOOT INTERVALS
TRANSVERSE MERCATOR PROJECTION

PLATE 4

BLACK NUMBERED LINES INDICATE THE 10 000 METRE UNIVERSAL TRANSVERSE MERCATOR GRID, ZONE 11

MAGNETIC DECLINATION FOR 1970 IS 20° (355 MILS) EASTERLY OVER THE ENTIRE AREA

# WATER LEVEL DECLINE
# BASALT AQUIFER

FEB. 1980 to FEB. 1981

- ○ MEASURED
- • INTERPOLATED FROM RECENT DATA

in feet

Scale 1:250,000

20 Statute Miles
30 Kilometres
15 Nautical Miles

CONTOUR INTERVAL 200 FEET
WITH SUPPLEMENTARY CONTOURS AT 100 FOOT INTERVALS
TRANSVERSE MERCATOR PROJECTION

PLATE 5

BLACK NUMBERED LINES INDICATE THE 10,000 METRE UNIVERSAL TRANSVERSE MERCATOR GRID, ZONE 11

MAGNETIC DECLINATION FOR 1970 IS 20° 13.5 MILS EASTERLY OVER THE ENTIRE AREA