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UPPER METHOW RIVER VALLEY

GROUND WATER MANAGEMENT AREA

AQUIFER TEST REPORT

Prepared for

Okanogan County Public Works

February 5, 1992

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Project S8902.08

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1 INTRODUCTION

1.1 Purpose

The purpose of this report is to document the aquifer test set up, procedures, and findings from two aquifer pumping tests performed on a 12-inch aquifer pumping test well in the Mazama Bridge area of the Methow River valley (see Figure 1-1). The pumping tests were performed to determine hydrologic parameters for the upper Methow River Valley aquifer, and, to the extent possible, to draw preliminary conclusions regarding aquifer behavior in response to pumping stress in this area. The test design and data evaluation procedures were also established in order to identify general relationships between the aquifer and the Methow River. The pumping test was not designed, nor is this report intended, to provide a detailed hydrogeologic evaluation of the shallow aquifer underlying the upper Methow River Valley. Conclusions are limited to technical aspects of the pumping test, limitations on interpretation, and additional data needs necessary for further interpretation.

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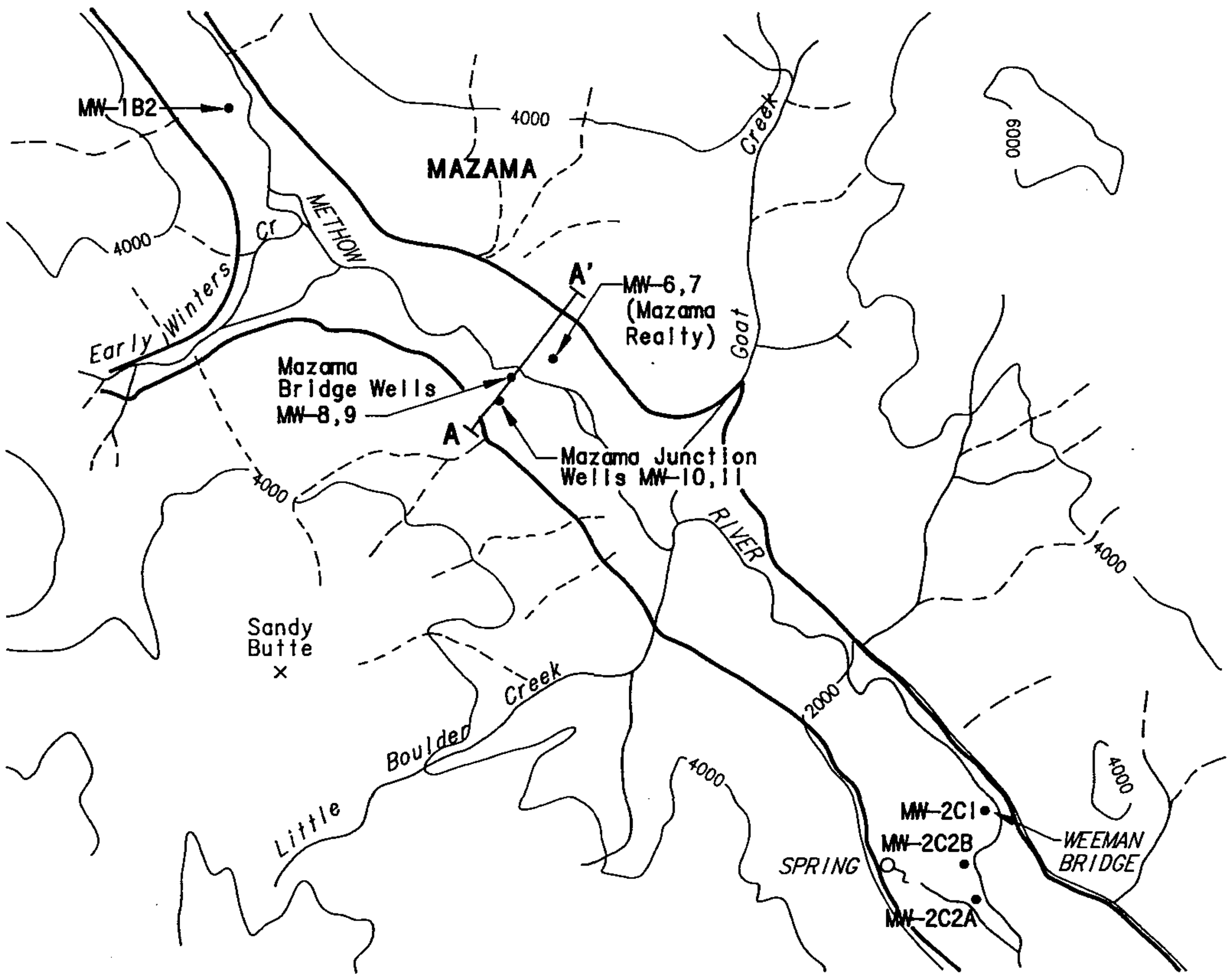

EXPLANATION

Approximate Boundary of Valley Alluvium

Perenial Stream

Ephemeral Stream

4000 Elevation Contours

A A' Cross-section Location

MW-6,7 • Monitoring Well Location Cluster with Well Designations

Note: Map modified from USGS Mazama quadrangle.

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Figure 1-1
METHOW VALLEY GWMA

AQUIFER TEST LOCATION MAP

1.2 Pumping Test Background

Ecology guidelines for GWMA monitoring wells (Ecology, 1988) requires that aquifer testing be completed for a minimum of 24 hours. Prior to initiation of the monitoring well construction phase of the Methow Valley GWMA project, it was determined, based on a review of historic hydrologic data, domestic supply well drillers' logs, and surficial observations of aquifer materials that 2-inch diameter monitoring wells would not provide for adequate hydraulic aquifer testing. Ecology concurred with this conclusion.

Although monitoring wells were to be distributed throughout the upper Methow River Valley (from Wolf Creek to above the confluence of the Methow River and Lost River), the primary purpose of the monitoring wells is to provide water quality data for characterization and long term monitoring. It was intended that the hydrologic and physical characteristics of the aquifer would be determined for the intensely monitored area at Mazama and applied, as appropriate, to the remainder of the valley. Topographic and anticipated hydrostratigraphic conditions were expected to be the most nearly representative of the Methow Valley at this location, and proposed development density is greatest in the area immediately upstream from Mazama.

At Mazama, shallow and intermediate depth monitoring well pairs were constructed near the center and towards both sides of the valley, perpendicular to the trend of the valley. Well placement was intended to provide long term data on ground water quality below areas of potential development and surface water/ground water interaction. The six wells were constructed using 4-inch diameter casing and screen to allow for installation of submersible pumps that would provide for pumping capacities of up to approximately 50 gpm. It was anticipated that pumping tests completed on each of the six wells would provide data that could be applied to hydrologic conditions observed at the remainder of the monitoring well sites.

During well development and preliminary aquifer testing, it was found that pumping rates approaching 50 gpm had essentially no effect on the water levels in the pumping wells. The limited drawdown that was observed in the pumped wells was likely due to well effects rather than aquifer effects. Consequently, it was proposed to the County and Ecology that a high capacity well be constructed to allow aquifer tests to be conducted that would provide the required hydrologic data. Approval was granted and funding was provided for construction of the 12-inch diameter pumping well.

A deep borehole (528 ft below ground surface {bgs}) was drilled in the same area to provide hydrostratigraphic information and correlations with regional geophysical evaluations (GeoRecon, 1990). This borehole was modified to permit pumping test monitoring of the deeper aquifer units.

1.3 Relationship to Other Activities

The aquifer testing reported in this document is one element of a larger ground water monitoring and aquifer testing program undertaken by Okanogan County as part of the Okanogan County Ground Water Management Area (GWMA) investigation. Other activities included in the wider investigation of the Methow River Valley include:

- Installation and monitoring of monitoring wells for water quality and water level
- Monitoring of existing domestic supply wells for water levels
- Monitoring of surface waters for flow and water quality
- Geophysical testing to evaluate hydrogeostratigraphy
- Installation of a deep test boring to evaluate aquifer hydrogeology and stratigraphy
- Identification of data needs for regional hydrogeologic interpretations for both the upper Methow River Valley as well as other portions of the Methow River basin GWMA. Development of an aquifer and basin management plan for the upper Methow River Valley

Other documents produced to date as part of the GWMA program include:

- The Upper Methow River Basin Sampling and Analysis Plan (SAP), SE/E - Okanogan County, December 1991
- The Upper Methow River Basin Quality Assurance Project Plan (QAPP), SE/E - Okanogan County, November 1991
- Technical information and memos presented to the Methow River Valley Ground Water Areawide Advisory Committee (GWAAC) and submitted to the Washington Department of Ecology (Ecology).

The current report is intended as a technical report prepared prior to and in support of a more general hydrogeological evaluation report. The hydrogeological evaluation report will be prepared as a summary document for the ground and surface water investigations as part of the GWMA program.

All activities currently underway are being carried out with assistance from the Washington Department of Ecology (Ecology) via grant support from a Washington State Centennial Clean Water Fund (CCWF) grant to the Okanogan County Planning and Okanogan Public Works departments. All activities pursued under this investigation, including the current report, are detailed in the Grant Agreement dated ______________ between Ecology and Okanogan County. The lead local agency for this project is the Okanogan County Planning Department, with primary technical lead being delegated to the Okanogan County Public Works Department.

2 AQUIFER CONCEPTUAL MODEL

A conceptual aquifer model was developed based on a regional and site geomorphology and glacial history as an aid to developing aquifer test assumptions and interpreting pumping test data. The conceptual model was also used to guide set up of the numerical model and was, in turn, refined, based on interpretations of the pumping tests and numerical model.

2.1 Geology

2.1.1 Regional

The bedrock geology of the Methow Valley area was characterized by Barksdale (1975) as folded Mesozoic sediments and volcanic rocks that have been downfaulted between crystalline blocks. The stratigraphic sequence as outlined by Barksdale includes various sandstones, shales, siltstones, conglomerates, and andesitic flows, breccias, and tuffs. The crystalline rocks include various granitic type igneous intrusive rocks and high grade metamorphic types, including gneiss, marble, and schist.

Barksdale has also outlined the structural history of the valley. The dominant tectonic feature is the Tertiary Methow-Pasayten Graben, a 170-mile-long down thrown block extending into southern British Columbia, Canada. The northwest boundary of the graben in Washington is described as the Chewack-Pasayten Fault, which displays vertical displacement. The southwest boundary is attributed to the Foggy Dew Fault and the Twisp River Fault.

Folding occurred within the graben in at least four separate episodes. The most recent episode formed the asymmetrical Goat Peak syncline and the Midnight Peak syncline. The Boesel Fault (see Figure 1-1) truncates the southern side of the Midnight Peak syncline. Barksdale described several of the major faults in the valley, which are associated with the structural deformation of the area.

2.1.2 Methow Valley

Waitt (1972) described the geomorphology and glacial history of the Methow Valley including the events that lead to the formation of the thick sequence of unconsolidated sediments filling the valley floor. The glacial/ fluvial sequence provides the major ground water aquifers of the Methow Valley.

Waitt recognized that topographic features in and adjacent to the Methow Valley provided evidence of both alpine and continental ice-sheet types of glaciation. The most recent glacial event was the retreat of the Cordilleran Ice Sheet, correlating with the Fraser Glaciation of western Washington and British Columbia. Deglaciation of the Methow region was largely by downwasting and regional stagnation of the ice. This type of deglaciation is characterized by ice-contact channels, kame terraces, eskers, and other ice contact features. End moraines and other features typical of alpine glaciation are missing.

Waitt estimated the thickness of unconsolidated sediments by comparing the steepness of the Methow Valley sidewalls to the steepness and known depths of Yosemite valley and Chelan valley sidewalls. Both the Yosemite and Chelan valleys were formed by glacial conditions that were comparable to those that carved the Methow Valley. Waitt estimated the sediments in the Methow Valley to be between 500 and 1,200 feet thick.

2.1.3 Mazama Bridge Area

In the upper Methow Valley test area, formation materials encountered during drilling consisted of unconsolidated boulders, gravels, sands, and silts. The upper strata, to a depth of approximately 200 feet bgs, are primarily highly permeable, coarse sand through boulder size materials.

Finer grained sand with increased silt content was encountered below 200 feet. Gravelly zones were found below 200 feet but consisted of smaller gravels and a lower overall percentage of gravel. Cobbles and boulders that were relatively common at shallow depths were not generally found below 200 feet. The sediments were laid down in a glacial fluvial environment.

A low-permeability zone was encountered at a depth of 217 to 223 feet bgs during construction of the deep test boring. Observed potentiometric decreases in head with increasing depth through the low-permeability zone, imply a continuous downward hydraulic gradient. The lateral extent and continuity of the low permeability zone has not been directly identified. Geophysical survey results from seismic and resistivity traverses completed in the vicinity of Mazama Bridge indicated the thickness of glaciofluvial materials at approximately 1200 ft bgs, did not indicate the presence of laterally extensive low permeability strata. The geophysical studies are described in Geophysical Studies in Conjunction with Hydro-Geological Studies (GeoRecon, 1990) and were carried out as part of the GWMA program. A possible stratigraphic cross-section, based on these evaluations, is shown in Figure 2-1. The observed influences of the pumping test on the water levels monitoring in the deep test boring further indicate a degree of continuity of the shallow/intermediate aquifer(s) with the deeper

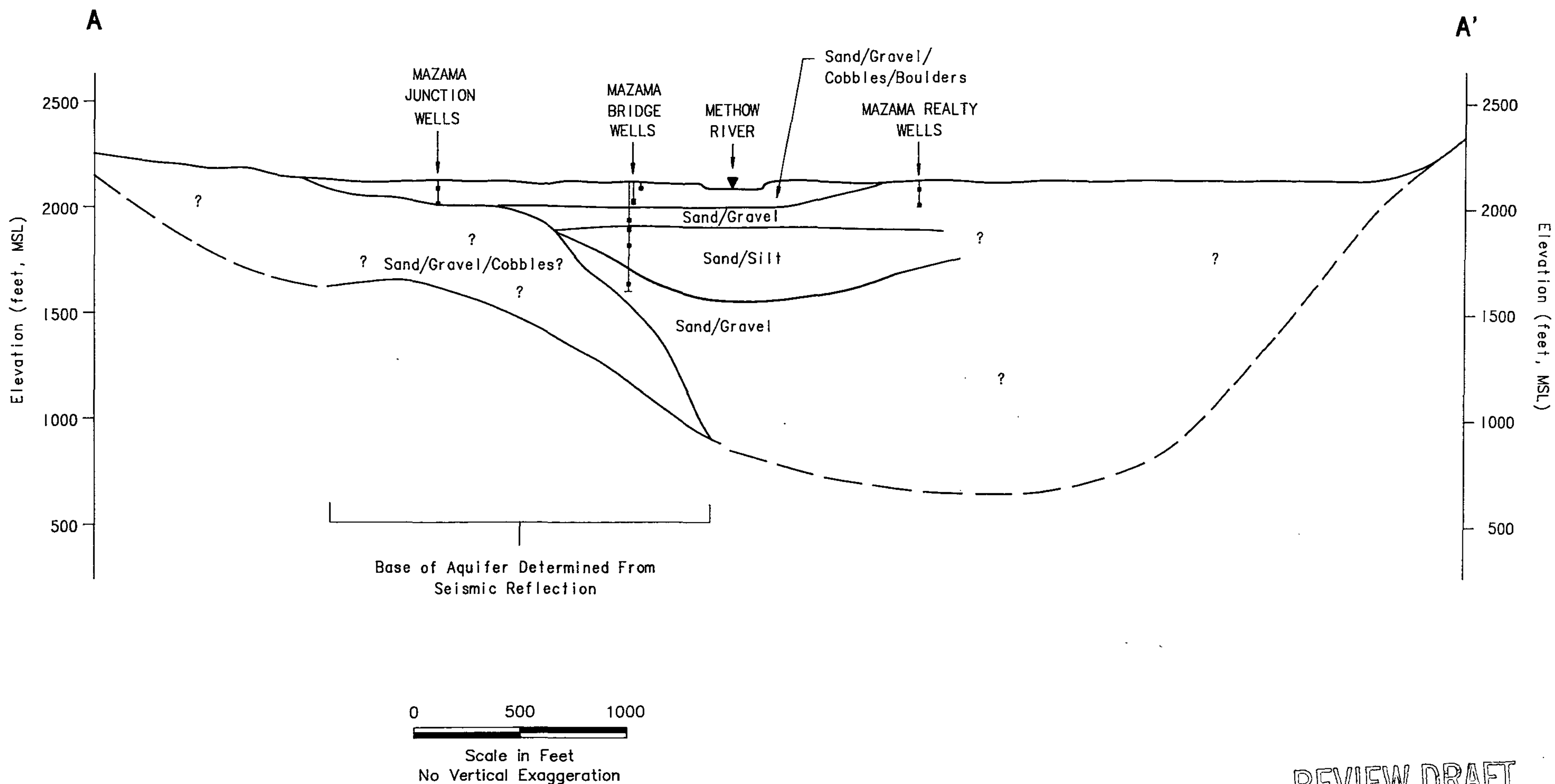

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Figure 2-1
METHOW VALLEY GWMA

STRATIGRAPHIC CROSS-SECTION

hydrostratigraphic zones.

2.2 Ground Water Hydrology

2.2.1 Recharge

Ground water flow in the upper Methow Valley is controlled largely by annual recharge from spring and early summer melt waters from the surrounding mountain streams. Annual precipitation on the valley floor at Mazama is approximately 26 inches, compared to approximately 15 inches at Winthrop. Approximately half of this annual precipitation falls in the form of snow during winter months. In the upland areas and tributary watersheds, total precipitation may average as high as 60 to 80 inches per year, predominantly as snow. Average annual precipitation may exceed this at the extreme upper end of the tributary stream headwaters near the crest of the Cascades. This large annual snow pack contributes to the large spring/early summer runoff from the major tributary watersheds including the upper Methow River (above Lost River), Lost River, and Early Winter Creek. Recharge contributions from other streams, including Goat Creek, McGee Creek, Goat Wall Creek, and Wolf Creek are more limited since these streams drain smaller and lower elevation watersheds.

An evaluation of annual water budgets for the valley indicates that of the approximately 8 inches of precipitation reaches the valley floor as rainfall during the period of May through September. Of the 8 inches of spring and summer precipitation, less than 2.0 inch is available for aquifer recharge percolation due to the generally dry atmospheric conditions and the high evapotranspiration potential estimated at over 32 inches per year.

2.2.2 Low Flow

Historic records and observations by valley residents indicate that the low stream flow and low-ground water table elevations occur during two distinct periods of the year: late summer/early fall (September/October); and midwinter (January/February). These observations support the general hydrologic assumption that aquifer recharge is primarily from infiltration of stream surface waters. This implies that during periods of either low rainfall and diminishing river flow, (late summer/fall), or during periods of extremely cold temperatures (midwinter) when melting is greatly reduced and precipitation is in the form of snow, the aquifer and stream levels decline to their yearly lows due to lack of recharge. The late fall/early winter period may experience rising water tables, but this phenomenon is highly dependent on the pattern of precipitation and temperature during the fall season, i.e., if cold weather sets in before significant precipitation has occurred, the low aquifer period may stretch relatively uninterrupted from October through January or February.

2.2.3 Hydrologic Assumptions

A second major factor in controlling hydrology for the valley, in addition to meteorology and stream flow, is the geologic nature of the aquifer materials. Documented historical records, supported by the current aquifer testing, indicate that at least the shallower portions (approximately top 100 to 200 feet) of the aquifer zone are generally very permeable and highly conductive to water. As a result, the operating aquifer model assumes that the ground and surface waters are in close interconnection, and that water flows through the aquifer relatively rapidly and in large quantities. Based on these factors, and historical and recent observations that portions of the upper Methow River, as far down as Weeman Bridge (approximately 5 miles below the pumping test location), periodically go dry in both late Summer/early fall and midwinter, the aquifer hydrology model views the Methow River primarily as an expression of ground water, and not as a significant independent feature.

Based on this model, aquifer gradients in the shallow Methow Valley aquifer (or shallow portion of the aquifer) would be expected to be roughly parallel to the axis of the valley. It is also projected that the gradients and flow directions are influenced primarily by the recharge mounds of perennial streams draining the adjacent uplands. The principal recharge areas are Lost River, the Upper Methow River, and Early Winters Creek.

The model predicts that the impact of seasonal aquifer recharge would be largely coincident with seasonal stream discharge. The high conductivity of the aquifer materials should result in a general flattening of the water table both linearly and laterally across the valley.

For the purpose of pumping tests and numerical modeling, the closest aquifer boundaries are the valley sides and bottom at distances of 1,000 to 2,500 feet. These boundaries are "no-flow" boundaries. The Methow River, 350 feet from the pumping well, is not a boundary for the intermediate or deep aquifer zones and may be only a partial constant head boundary for the shallowest or upper units. Lateral (up and down valley) boundaries are more than 5 miles in either direction.

2.3 Ground and Surface Water Interactions

As noted in the previous section, the conceptual hydrologic model for the upper Methow River Valley aquifer assumes that the tributary streams are primarily important in terms of annual spring recharge to the aquifer. The conclusions regarding aquifer recharge are supported by the fact that, in some portions of the valley, the shallow ground water levels rise and fall by 15 to 30 feet per year. This spring recharge phenomenon is limited primarily to the period of significant streamflow. A probable interpretation is that once a stream discharge into the outwash fans enters the aquifer, the "identity" of that particular stream from a hydrologic standpoint is lost or subsumed by the general aquifer characteristics. This is felt to apply to the Upper Methow River, Lost River, Early Winters Creek, as well as the other minor tributary streams.

The Methow River is a significant physical feature in the valley, and plays a major role carrying excess spring melt water from the valley. However, during off-peak stream discharge situations, the current hydrologic model assumes that the Methow River is primarily an expression of the aquifer, and is, in fact, in a condition closely approximating equilibrium with the surrounding aquifer. During much of the year, aquifer discharge to the Methow River, except in the areas of perennial stream inflow, is quite limited. As noted, large portions of the river dry up historically.

The condition of general equilibrium between the aquifer and the river is expected to vary locally where depressions in the streambed may open "windows" into the aquifer for short periods of time or distance, or in areas of gravel mounding (low river gradient) that may cause the aquifer, and hence the stream, to disappear. For a perennial stream such as Early Winters Creek, aquifer levels in the vicinity of the "recharge fan" are likely to show only a slight mounding or a gradient flattening through much of the year.

The conditions described are felt to hold through much of the upper Methow River Valley, although they may only apply to the shallowest aquifer zone.

Below Weeman Bridge geophysical investigations (GeoRecon, 1990) identified the potential existence of a fault barrier. This barrier may substantially reduce both the depth of the aquifer sediments, as well as the pattern of flow at depth. Whereas the upper valley appears to be consistently 1,000 feet or more deep at its deepest central areas, the geophysical indications are that the depth of the valley may decrease to approximately 500 feet approximately 2 miles below Weeman Bridge. Although this geologic barrier may cause a constriction of aquifer flows, there are insufficient data to indicate whether this valley bottom change is, in fact, a significant feature affecting overall ground water flow. Incidental evidence related to the constancy of low season stream flow above the Winthrop area, and the existence of a large area of marshes formed by surface discharge of ground waters above Wolf Creek, support the tentative conclusion that a significant upwelling of flow due to depth constriction occurs in the mid to lower portion of the upper valley. However, neither the presence of a geologic constriction nor the assumptions regarding upwelling ground water flow have been verified by construction of monitoring wells in this area.

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Finally, it is important to note that the overall hydrologic regime as well as interaction of surface streams and ground water appears to change substantially in the vicinity of Winthrop. This area has not received adequate geologic mapping and additional correlative information is scarce, however, consideration of topography, geologic outcrops, general geologic characteristics, and well logs from several new wells near the U.S. National Fish Hatchery rearing ponds above Winthrop, would indicate that neither the geologic nor hydrologic model assumptions for the upper Methow River Valley are likely to be applicable below the Wolf Creek area.

Focus should be on interrelation to U. Methow

3 AQUIFER TEST DESCRIPTION

3.1 Department of Ecology Guidelines

The Washington State Department of Ecology Interim Guidelines for Data Collection from Wells Used in the GWMA Program (July 1988) were followed for the completion of both aquifer tests. The guidelines outline the minimum data collection requirements to participate in the GWMA Program. The data collection requirements address drilling, well construction, lithologic and geophysical logging, aquifer testing, and water quality analyses.

The resource protection monitoring wells and test well were constructed to satisfy the specific guidelines identified above and to meet the standard outlined in Minimum Standards for the Construction and Maintenance of Wells (Chapter 173-160 WAC, May 5, 1988).

3.2 Test Site Description

The pumping test well was constructed on Okanogan County owned property adjacent to the Mazama County road off State Route 20 at Mazama, Washington (Okanogan County). Observation wells are located on the state highway right of way (Mazama Junction), on the county owned property adjacent to the pumping well (Mazama Bridge) and on county road right of way at the intersection of the Mazama Road and Lost River Road (see Figure 3-1). The wells are located in the SE¼ of Section 25, Township 36 North, Range 19 East. The pumping test well is approximately 340 feet southwest of the southwest bank of the Methow River.

3.2.1 Pumping and Observation Well Network

The pumping well used for both aquifer tests is a 12-inch diameter well constructed specifically as a high capacity pumping well for the purposes of aquifer tests as part of the Methow Valley GWMA project. This well was completed in what has been designated as the intermediate hydrostratigraphic unit (aquifer), with a screened interval from 89 to 114 feet bgs.

Three pairs of resource protection (monitoring) wells were used as observation wells during the pumping tests (see Figure 3-1). Well completion details are included in Table 3-1. These well pairs are located near the intersection of Lost River Road and the Mazama Road, approximately 1400 feet north-northeast of the pumping well (MW-6, MW-7); adjacent to the pumping well (MW-8, MW-9); and on the state highway right

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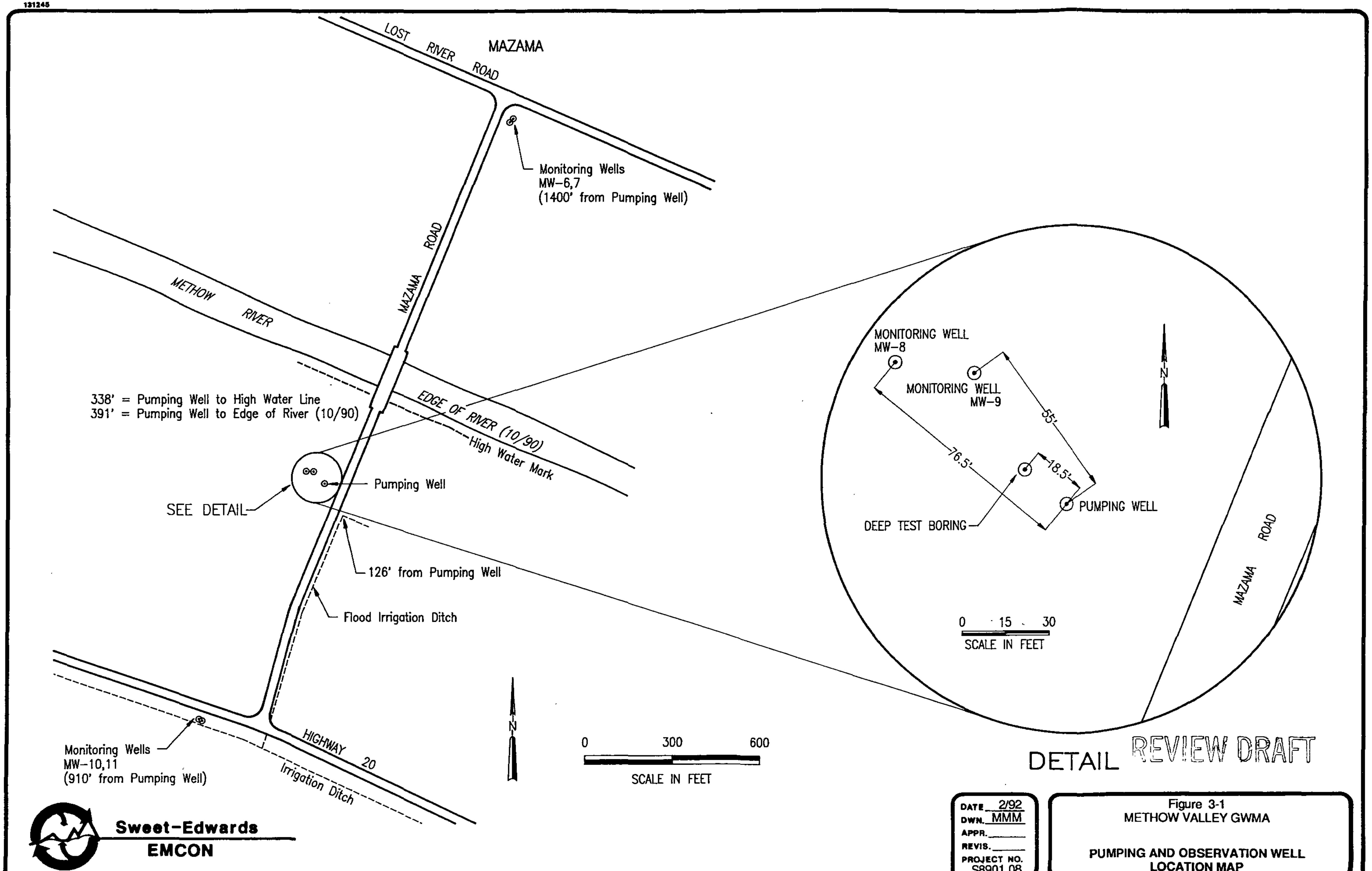

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Figure 3-1
METHOW VALLEY GWMA

PUMPING AND OBSERVATION WELL LOCATION MAP

Table 3-1

Methow Valley GWMA
Summary of Observation Well Construction Depths

Monitoring Well	Depth of Monitoring Zone (ft bgs)[1]	M.P Elevation[3] (ft amsl)[2]	Elevation of Monitoring Zone (ft amsl)	Well Depth (ft)
Mazama Realty				
Shallow (MW-6)	9 to 39	2,109.25	2,068 to 2,098	43
Intermediate (MW-7)	109 to 119	2,108.59	1,987 to 1,997	120
Mazama Bridge				
Shallow (MW-8)	14 to 44	2,114.92	2,069 to 2,099	47
Intermediate (MW-9)	108 to 118	2,114.01	1,994 to 2,004	123
Deep Test Boring				
Annulus (intermediate unit)	185 to 195	2,114.84	1,917 to 1,927	527
Middle Shallow (deep unit)	223 to 238	2,114.80	1,874 to 1,889	527
Middle Deep (deep unit)	305 to 315	2,114.78	1,797 to 1,807	527
Deep (deep unit)	475 to 485	2,114.78	1,627 to 1,637	527
Mazama Junction				
Shallow (MW-10)	19 to 49	2,122.53	2,072 to 2,102	49
Intermediate (MW-11)	108 to 118	2,122.12	2,003 to 2,013	120

Notes:

[1] ft bgs = feet below ground surface
[2] ft amsl = feet above mean sea level
[3] M.P. = measuring point

of way, approximately 900 feet south-southwest of the pumping well (MW-10, MW-11). At each location, one well is completed in what has been designated the shallow hydrostratigraphic unit (less than 50 feet) and a second in the intermediate hydrostratigraphic unit (50 to 200 feet) (see Table 3-1).

As indicated in Table 3-1, the observation and pumping well sites have been informally designated as the "(Mazama) Realty," "(Mazama) Bridge," and "(Mazama) Junction" sites. The monitoring wells used as observation wells are referred to by site name and completion depth (e.g., Realty-Shallow, Junction-Intermediate).

The deep test boring adjacent to the pumping well was also used as an observation well during both pumping tests. As indicated by Table 3-1, this boring was completed to a depth of 527 feet bgs to evaluate aquifer hydrogeologic and stratigraphic characteristics. Prior to the initial pumping test, the well casing was perforated from 185 to 195 feet bgs to provide for observation of pumping influences on the deeper portion of the intermediate hydrostratigraphic unit. Prior to the second pumping test, three additional zones were perforated and isolated to allow water level measurements to be taken at four levels within the deep boring (see Table 3-1). The three deeper zones (223 to 238 feet, 305 to 315 feet, and 425 to 485 feet bgs) allow measurement of water levels in deep stratigraphic units that appear to be distinctly different from the shallow and intermediate units.

In addition to the observation wells, water levels were monitored in the Methow River prior to and during the pumping tests. The river is approximately 340 feet north-northeast of the pumping well and is between the pumping well and the Realty-Shallow and Deep observation wells pair.

3.2.2 Pumping Well Design and Installation

The 12-inch pumping well was drilled and installed by Okanogan Drilling from Okanogan, Washington, using a Chicago Pneumatic 650 WS air rotary drill rig. The test well was drilled and cased to depth of 143 feet bgs using 12-inch diameter steel casing. Pumping well construction details are shown on Figure 3-2.

Based on observations of water volume discharged during drilling and visual evaluation of formation samples that were collected, an approximate interval for screen placement was selected. Formation samples were selected for grain size analyses. The grain size analyses (sieve analysis) were performed by Okanogan Drilling. Grain size distribution plots were prepared (Appendix A) and used in design of the well screen and the screen placement depth.

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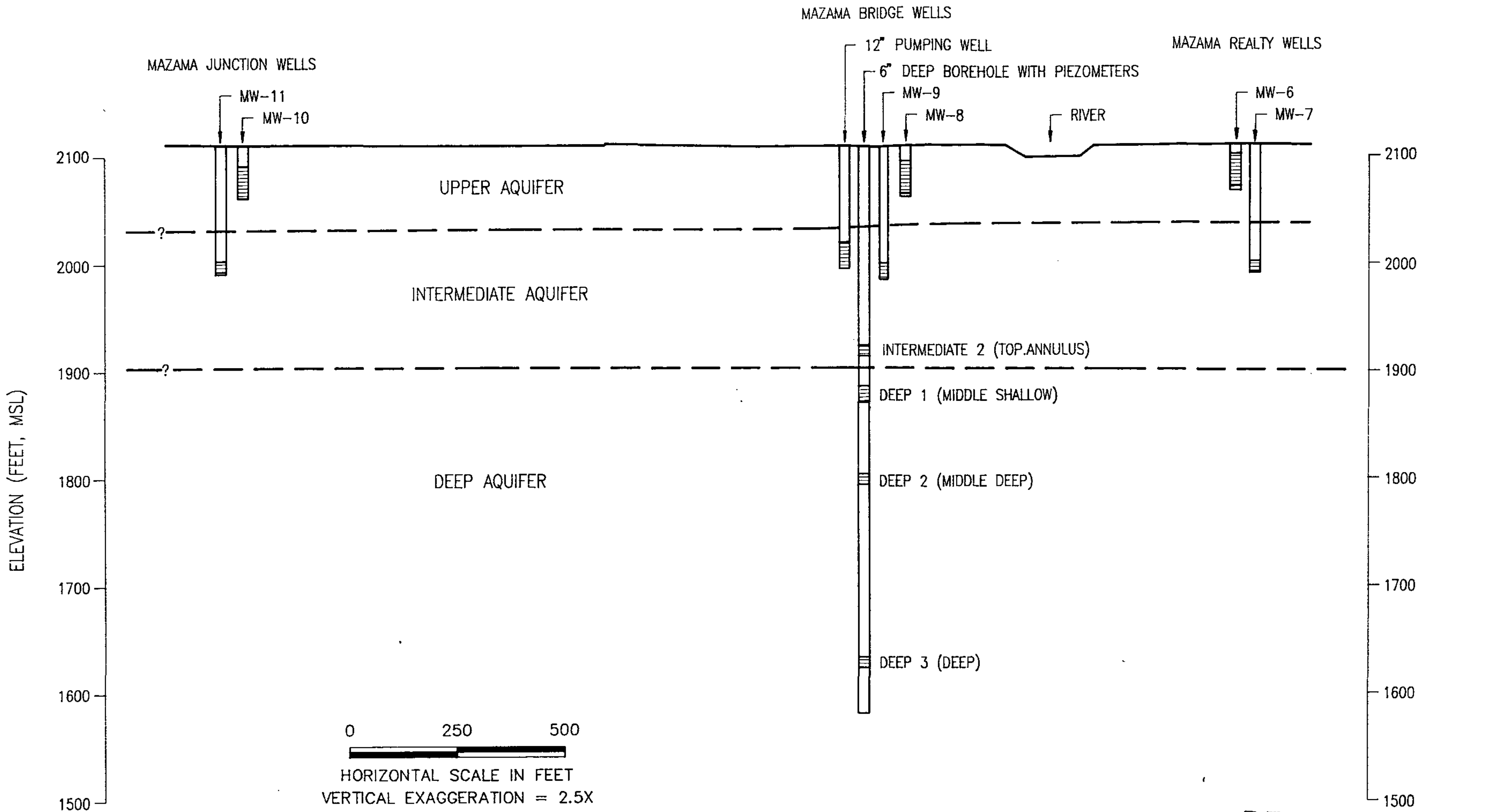

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Figure 3-2
METHOW VALLEY GWMA

MONITORING NETWORK SCHEMATIC

The screen design for the test well consisted of 12-inch telescoping size continuous slot, wire-wrapped U.O.P. Johnson screen. The screen was set using a neoprene K-packer welded to an overlap pipe (a 5.2-foot section of 10-inch steel casing). The well screen consists of a 15-foot section of 50 slot and 10-foot section of 70 slot. The designed screen capacity was calculated to be 1,120 gpm. A 5-foot section of 10-inch steel casing with steel bottom plate was used as a tail pipe. The screen was installed in the well by lowering the screen to the appropriate depth and backpulling the 12-inch casing to expose the full length of the screen to the aquifer.

The 12-inch well was developed by jetting and surging using compressed-air from the drill rig. An Imhof cone was used to monitor the progress of the development based on sand content of the discharge water. The well was considered clean when less than 20 medium sand sized grains were collected per liter of water. Following development, the entire length of the screen was surged with the air line continuously for 19 hours. The air lift pumping rate was estimated to be approximately 700 gpm.

3.2.3 Deep Test Boring/Observation Well Installation

The deep test boring at the Mazama Bridge site was drilled to a depth of 527 feet bgs. This boring was drilled for the purpose of evaluating deep hydrostratigraphic conditions underlying the glacial outwash/fluvial deposits. The intent was to determine the vertical extent of the aquifer and, if possible, the bedrock depth. Drilling of the deep test boring was initiated using 8-inch diameter steel casing. At 229 feet, the 8-inch casing was bent by a boulder and could not be advanced deeper. The borehole diameter was stepped down to a 6-inch steel casing. At a depth of 490 feet, the 6-inch casing was also bent. The hole was advanced an additional 37 feet to a total depth of 527 feet bgs. Increasing casing deflection at the bend precluded advancing the boring beyond 527 feet.

Prior to the initial pumping test, the deep test boring was perforated from 185 to 195 feet bgs to allow water level measurement at the base of the intermediate hydrostratigraphic unit. This was accomplished by

- Perforating the casing opposite a low permeability zone, which was identified at a depth of 217 to 223 feet bgs
- Pressure grouting the boring by placement of cement grout through a tremie pipe from the bottom of the boring up to a depth of 176 feet bgs
- Redrilling the cement plug to a depth of 200 feet bgs following hardening of the cement
- Perforating the casing from 185 to 195 feet bgs and developing the perforated zone to provide for hydraulic continuity between the aquifer and the well

Plugging of the casing and grouting through the perforations at 217 to 223 feet bgs was accomplished to minimize the hydraulic influence of the deeper hydrostratigraphic units on the measured water levels.

Prior to starting the second pumping test, piezometers were installed at three additional levels in the deep test boring. The cement plug below 200 feet in the 6-inch well casing was drilled out to a depth of 490 feet. Three additional zones were perforated in the 6-inch well casing (see Table 3-1). Following perforation of the casing, the well was redeveloped using drill rig air. Piezometers were installed in each of the zones using 1¼-inch schedule 80 PVC with a silica sand filter pack. The individual piezometers were isolated by placement of a cement grout plug between each perforated and sand packed interval. Including the perforated zone originally constructed, a total of four hydrostratigraphic zones were available for water level monitoring. As indicated in Table 3-1, these are designated as Top (185-195 feet bgs), Middle Shallow (223-239 feet bgs), Middle Deep (305-315 feet bgs), and Deep (475-485 feet bgs).

3.2.4 Monitoring Well Construction

The three shallow and intermediate well pairs at the Mazama Junction, Mazama Bridge, and Mazama Realty sites were drilled and installed by MVM Quality Drilling from Bridgeport, Washington. A Chicago Pneumatic

650 WS air-rotary drill rig was used. An 8-inch steel casing was advanced using a pneumatic casing hammer. During drilling, formation samples were collected at 5-foot intervals for lithologic characterization.

The six shallow monitoring wells ranged from 43 to 54 feet bgs. The intermediate zone monitoring wells ranged in depth from 43 to 124 feet bgs. Four-inch diameter, schedule 40, flush-threaded PVC screen and casing were installed in each of the six wells at Mazama. A sand filter pack, consisting of either 8-12 or 12-20 mesh Colorado silica sand, was installed opposite the screen in each well. Monitoring well completion data has been summarized in Table 3-1. Boring logs for the pumping and observation wells are included in Appendix B.

3.3 Aquifer Test #1

3.3.1 Test #1 Specifications

The first aquifer test was anticipated to run a minimum of three and a maximum of seven days. The test design specified a constant discharge pumping and recovery test with a constant discharge rate of 1,000 gpm. The specified discharge rate was approximately 10 percent less than the maximum design capacity of the well (1120 gpm). A schematic diagram of the monitored well network is shown in Figure 3-3.

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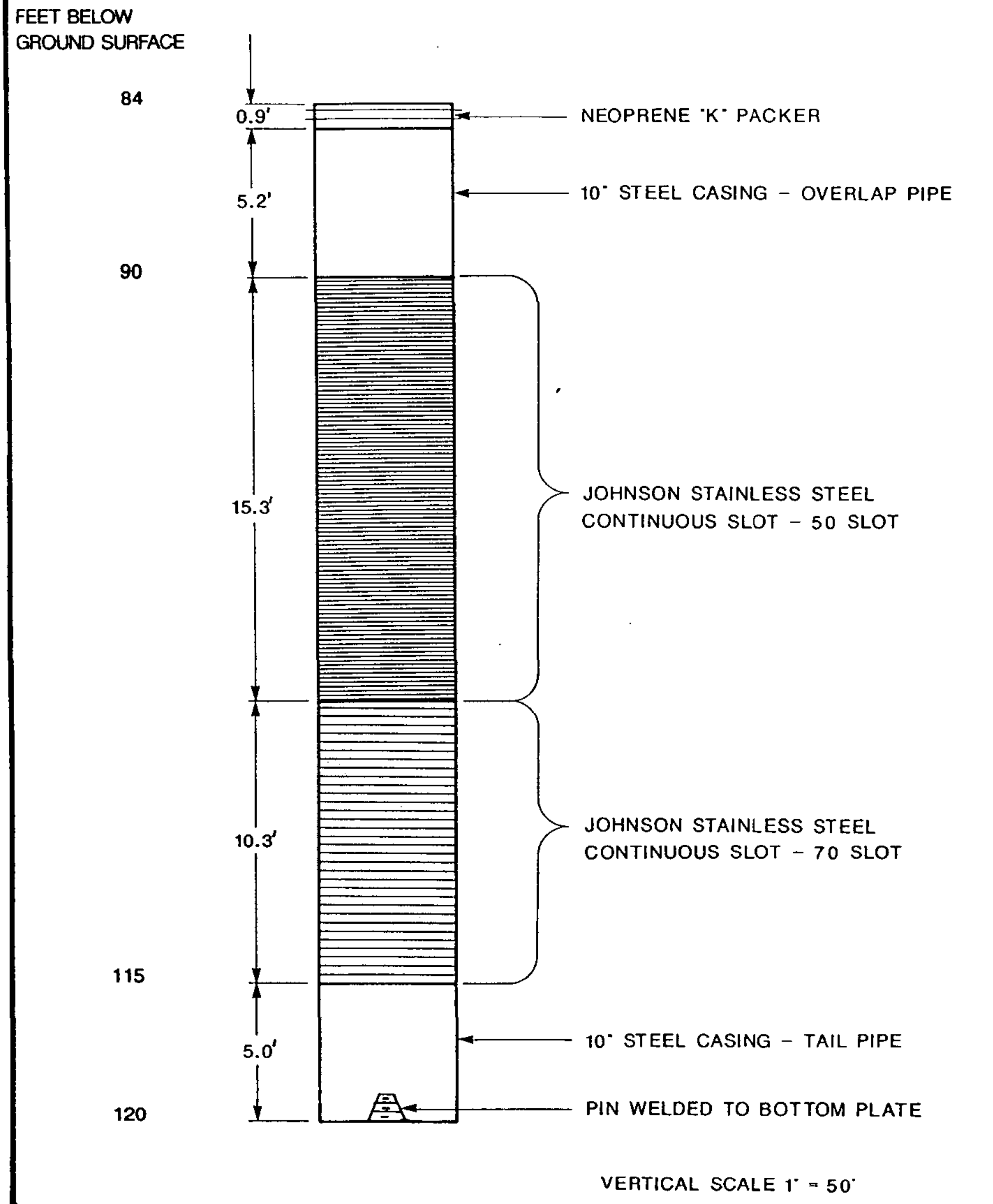

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Figure 3-3
METHOW VALLEY GWMA

PUMPING WELL CONSTRUCTION DETAILS

Seven wells were used as observation wells during the pumping test. Electronic data loggers and transducers were used to automatically record water levels in the pumping well and the three adjacent observation wells (Bridge-shallow, Bridge-intermediate, and deep test boring-annulus), and in the Methow River. Depth to water measurements were taken manually as a backup to the data logger/transducer measurements. Manual water level measurements were taken at the more distant observation well located at the Mazama Realty and Mazama Junction sites.

Field measurements of pH, temperature, and electrical conductance were measured periodically during the pumping period. Four water quality samples were to be collected during the pumping period at approximately logarithmic time scale intervals. The suggested sample times were at 30, 300, 3,000, and 10,000 minutes after start of pumping. The samples were analyzed for the following, in accordance with Ecology requirements:

- CLP metals plus silica
- Alkalinity - HCO_3
- Anion Scan - chloride and sulfate
- Specific Conductance - laboratory
- Total dissolved solids
- Hardness

- Turbidity
- pH - laboratory

A step drawdown test was performed prior to the constant discharge pumping test. The step test consisted of four progressively greater pumping rate steps of approximately equal duration. Pumping rates were approximately 350 gpm, 500 gpm, 720 gpm, and 1170 gpm. The step durations were approximately one hour each.

3.3.3 Test Completion

Power. A 50-hp electrical submersible pump supplied by Okanogan Drilling was installed in the 12-inch test well. The pump intake was set at approximately 83 feet bgs. A check valve was welded in the pump discharge line 10 feet above the submersible pump. A 1-inch PVC stilling tube was installed in the annular space between the 6-inch pump discharge line and the 12-inch steel well casing to facilitate water level measurements. The electric water level transducer was installed and manual water level measurements were taken in the stilling tube to minimize the effects of turbulence caused by the pump. The electrical power was supplied by public line power (440 volt, 3-phase) provided by the Okanogan County Electric Cooperative. Following step testing, the 12-inch test well was pumped at a constant discharge rate of approximately 1,050 gpm for 3¼ days, from September 12 to September 15, 1990.

Discharge. A 6-inch diameter PVC discharge line was installed from the pumping well to the bridge crossing the Methow River. The water was discharged into the approximate middle of the river to minimize bank erosion. The pumping rate was controlled by a 6-inch gate valve. Discharge rate was monitored using an in-line 6-inch 1,300 gpm maximum capacity McCrometer flowmeter located between the well head and the gate valve.

Water Level. Water level measurements were collected manually and using electronic automatic data loggers and pressure transducers in the pumping well and the three adjacent observation wells. The Methow River was also monitored with a data logger and transducer. A Terra 8D three channel data logger and two transducers were used to monitor water levels automatically at the 4-inch shallow monitoring well and the deep test boring at the Mazama Bridge site. A two- channel Hermit data logger and two transducers were used to monitor the 12-inch pumping well and the 4-inch intermediate monitoring well. An additional Terra 8D data logger and a pressure transducer were used to monitor the Methow River water levels.

The transducer used to monitor river level was placed in the Methow River approximately 200 feet upstream of the Mazama Bridge.

Manual water level measurements were taken as a check or backup for the transducer measurements automatically recorded by the data loggers. The hand measurements were completed using an Actat Model 150 Olympic Electric Well Probe and a 12-foot steel engineers tape.

Step Test. A step test was run on September 10, 1990, prior to initiating the long-term aquifer test. The 12-inch Test Well was pumped at four progressively increasing discharge rates of 350 gpm, 500 gpm, 720 gpm, and 1,170 gpm. Each pumping rate step had a planned duration of approximately 1 hour. The step test was initiated by starting the pump with the gate valve fully open, allowing a pumping rate of approximately 1000 gpm. Unrestricted discharge was allowed to avoid potential pump and discharge line damage that could occur with a restricted flow. Immediately after pump startup, the gate valve was closed down to provide for a flow rate of 350 gpm. Water level drawdown measurements taken during the very early portion of the first step may not representative of the 350 gpm flow rate.

The average flow rate for the first step was 350 gpm. After approximately one hour, the discharge rate was increased to 500 gpm. The 500 gpm pumping rate was maintained for a period of one hour. For the third step in the step test, the pumping rate was increased to approximately 720 gpm. Approximately 15 minutes after the pumping rate was stepped up to 720 gpm, an area-wide power outage stopped the test. Electrical power was restored after approximately 1½ hours. A final one-hour step was completed at a discharge rate of 1170 gpm. Following the one-hour pumping period, the pump was shut off and water level recovery measurements were monitored overnight.

During the step drawdown test, the water levels responded quickly to initiation of pumping and to increases in the pumping rate. Within approximately 2 minutes of the start of each pumping step, apparent stabilization of water levels occurred, suggesting that apparent steady state conditions were established. When pumping was stopped at the end of the 1170 gpm pumping step, and at the time the power outage occurred, measured water levels recovered to prepumping static conditions nearly immediately.

Pumping Test. The constant discharge rate pumping test began at 11:32:30 on September 12, 1990. The well was pumped at an average flow rate of 1,050 gpm. Water levels were measured and recorded at approximately uniform logarithmic time scale intervals. At approximately 17:19 on September 15, 1990, after 77 hours and 47 minutes, an electrical power surge tripped the circuit breaker, stopping the pump and ending the test. Although manual water level recovery measurements were immediately initiated, several minutes passed before the data loggers could be reset and restarted. Because of the high transmissivity of the aquifer, essentially complete recovery of water levels to pretest static conditions had occurred before the data loggers were restarted.

Water Quality Sampling. Field water quality measurements were recorded and water quality samples collected periodically during the pumping test. Field measurements of electrical conductivity, pH, and temperature were recorded and are presented in Table 3-2. Water quality samples were collected after 42 minutes, 330 minutes, and 3,000 minutes during the pumping test. The ground water samples were submitted to Columbia Analytical Services, Kelso, Washington for analyses. The analytical parameters included

- Total metals
- Alkalinity

Table 3-2

Methow Valley GWMA
Pumping Test #1
Summary of Field Water Quality Measurements

Date	Time	pH	Temp	Electrical Conductivity	Comments
Sept 12, 1990	12:14	7.42	8	284	Calibrated meter
	16:07	7.61	8	145	Collected sample #1
	16:15				Recalibrated meter
	16:50	7.43	8	139	Collected sample #2
	17:02	7.45	9	136	pH drifting
	17:47	7.33	9	130	pH drifting
	18:28	7.09	8	157	pH drifting
	19:40	7.24	8	159	pH drifting
	20:39	7.12	8	128	pH drifting
	21:15				Recalibrated meter, pH & conductivity are high
	21:37	7.3	8	140	pH drifting
	22:34	7.29	8	145	pH drifting
	23.11	7.13	8	141	pH drifting
Sept 13, 1990	08:50				pH meter would not hold calibration
	09:30				
	09:37	7.59	9	153	
	15:29	7.93	9	135	Recalibrated meter
Sept 14, 1990	09:46	7.65	8	196	Recalibrated meter, conductivity drifting
	13:20	7.97	8	132	Recalibrated meter, collected sample #3
Sept 15, 1990	09:18	7.71	8.5	135	Recalibrated meter
	17:12	7.52	9	144	

- Anion/cation balance
- Color
- Laboratory specific conductance
- TDS
- Hardness
- Turbidity
- Laboratory pH

The results are summarized in Tables 3-3A, -3B, and -3C and the laboratory data are included as Appendix C.

3.3.4 Recommended Additional Testing

The stated goals of the aquifer testing were to provide data that would allow characterization of the aquifer. In order to adequately characterize current ground water quality conditions and assess the potential for future impacts to ground water quality and water quality concerns, it is necessary to identify the physical characteristics of the aquifer. In addition to the water quality concerns related to development in the Methow Valley, the adequacy of available ground water supplies, particularly as they relate to minimum stream flows, are also at issue.

Results of the initial pumping test significant data was developed regarding aquifer characteristics, potential well yields, and, to some extent, the

Table 3-3A

Methow Valley GWMA
Pumping Test #1
Laboratory Water Quality Data
Indicator Parameters
(mg/L unless otherwise noted)

Analytical Parameter	Time After Start of Pump Test		
	42 Min.	330 Min.	3000 Min.
pH (units)	7.78	7.81	7.74
Conductivity (μmhos/cm)	152	134	128
Alkalinity as $CaCO_3$	63	61	60
Chloride	0.3	0.5	0.4
Color (color units)	<20	<20	<20
Fluoride	<0.2	<0.2	<0.2
Nitrogen, Nitrate	<0.2	<0.2	<0.2
Nitrogen, Nitrite	<0.2	<0.2	<0.2
Solids, Dissolved	95	86	106
Sulfate	4.0	4.0	3.8
Turbidity (NTU)	<1	<1	<1
Bromide	<0.2	<0.2	<0.2

Table 3-3B

Methow Valley GWMA
Pumping Test #1
Laboratory Water Quality Data
Total Metals (mg/L)

Analytical Parameter	Time After Start of Pump Test		
	42 Min.	330 Min.	3000 Min.
Aluminum	<0.05	<0.05	<0.05
Antimony	<0.05	<0.05	<0.05
Arsenic	<0.005	<0.005	<0.005
Barium	0.006	0.006	<0.005
Beryllium	<0.005	<0.005	<0.005
Cadmium	<0.002	<0.002	<0.002
Calcium	20.8	22.2	21.1
Chromium	<0.005	<0.005	<0.005
Cobalt	<0.01	<0.01	<0.01
Copper	<0.01	<0.01	<0.01
Iron	0.02	0.03	<0.02
Lead	<0.002	<0.002	<0.002
Magnesium	1.91	2.01	1.96
Manganese	<0.005	<0.005	<0.005
Mercury	<0.0005	<0.0005	<0.0005
Nickel	<0.02	<0.02	<0.02
Potassium	<2	<2	<2
Selenium	<0.005	<0.005	<0.005
Silver	<0.01	<0.01	<0.01
Sodium	2.2	2.8	2.3
Thallium	<0.005	<0.005	<0.005
Silicon	4.4	4.6	4.6
Vanadium	<0.01	<0.01	<0.01
Zinc	<0.01	<0.01	<0.01
Hardness	59.8	63.7	60.8

Table 3-3C

Methow Valley GWMA
Pumping Test #1
September 12-15, 1990
Laboratory Water Quality Data
Anion/Cation Balance

		Time After Start of Pump Test		
	Units	42 Min.	330 Min.	3000 Min.
Cation/Anion Balance				
Cations	meq/L	1.28	1.40	1.32
Anions	meq/L	1.35	1.31	1.29
Ratio	-	0.95	1.07	1.02
Calculated Dissolved Solids				
Cation and Anions*	mg/L	63	64	62
Silica (SiO_2)	mg/L	9.4	9.8	9.8

*Summation of inorganic dissolved solids by direct measurement.
Calculations provided by Columbia Analytical Services (see Appendix C)

relationship between different aquifers or aquifer zones and between the aquifer(s) and the Methow River. Review and preliminary evaluation of the first pumping test results indicated that the 3-day, 1050 gpm test did not induce sufficient stress on the aquifer to provide definition of key characteristics. It was proposed that a second pumping test of increased pumping rate and duration be completed.

The results of the initial pumping test indicated that the magnitude of the aquifer parameters (e.g., transmissivity, hydraulic conductivity) were such that the design of the second pumping test was limited by well construction (e.g., well diameter and screen design) and practical considerations (e.g., maximum available pump capacity, maximum practical test duration). It was proposed that the second pumping test be run for a minimum duration of 10 days at an anticipated pumping rate of approximately 2,000 gpm. The specific goals of the second pumping test were to

- Provide improved definition of vertical continuity within the aquifer (or between aquifer units)
- Provide improved definition of vertical aquifer boundaries
- Allow for identification of lateral boundary effects (e.g. valley wall or geologic boundaries)
- Provide improved definition of recharge/discharge relationships between surface water and ground water
- Allow refinement of aquifer values for transmissivity and hydraulic conductivity for one or more aquifer units, and permit calculation of a reasonable value for storativity (storage coefficient)

Although it was evident that the degree of aquifer stress to be generated by the second test would not fully satisfy requirements for aquifer test evaluation and interpretation by classical methods, it was determined that the combined data provided by both pumping tests allow the stated goals to be substantially satisfied.

3.4 Aquifer Test #2

3.4.1 Test #2 Specifications

The second aquifer test (March 29 - April 11, 1989) was conducted to provide additional data from a longer pumping period and increased pumping rate. The intent of the second pumping test was to increase the pumping rate from 1050 gpm to approximately 2,000 gpm and to increase the duration of the test to a minimum of 10 days, a maximum of 30 days, or until drawdown stabilized in the observation wells. It was anticipated that the increased pumping rate and longer duration would induce a greater stress on the aquifer than the first 3¼-day test. The design of the second pumping test was based in part on the results of the numerical aquifer model simulations as described in Section 4.3.

As previously discussed, the well screen design capacity of 1,120 gpm was based on a recommended entrance velocity of 0.1 feet per minute. The increased pumping rate of approximately 2,000 gpm proposed for the second pumping test significantly exceeded the design capacity of the 12-inch test well. It was projected that the increase in well yield would cause an additional decrease in well efficiency with a resultant increase in pumping head loss.

It was not anticipated that excessive erosion of the well screen would result from the increased entrance velocities that would occur with the increased pumping rate. While long term pumping could be expected to result in a reduced life expectancy for the well screen, the primary concern during the 10- to 30-day test period was the effect of decreased well efficiency on data evaluation.

A short term step drawdown pumping test was proposed to precede the second pumping test. The step test was conducted to quantify the increased well loss and to improve the very early drawdown data generated from the first step test and the first constant rate pumping test. The short term step test also served as a pretest to determine the probable maximum sustainable pumping capacity of the well. Limiting factors in establishing the maximum design capacity for the test were the maximum pump capacity and the maximum available drawdown. The highest capacity pump that was practically available and that could be installed in the 12-inch well had an estimated maximum capacity of 2,000 to 2,100 gpm at the projected pumping depth (discharge head).

The shallow and intermediate depth observation well network was as previously described for the first pumping test completed in September 1990 (see Figures 3-1 and 3-3). As previously discussed (Section 3.2.1), the deep boring was modified subsequent to the first aquifer test to provide for water level measurements to be taken at four depths below ground surface. In addition to the pumping well, the seven observation wells (two at both the Junction and Realty sites and three at Bridge site) provided for monitoring of water levels at 10 vertically and horizontally distinct locations. Surface water levels in the Methow River were also monitored. During the second pumping test, the electronic water level monitoring equipment previously described (e.g., data loggers and pressure transducers) were used in all wells and in the Methow River.

3.4.2 Aquifer Test #2 Completion

The second step test and constant pumping test were completed using a 100 hp electrical submersible pump supplied by Aquiflow of Auburn, Washington. The pump intake was set at approximately 67 feet bgs. To minimize the effects of turbulence on water level measurements, two 1-inch stilling tubes were installed in the annular space between the 8-inch steel pump column and 12-inch well casing. One stilling tube was used for installation of the transducer and the other provided access for manual water level measurements. The 440 volt 3-phase electrical power was supplied by Okanogan County Electric Cooperative.

Discharge. An 8-inch plastic "lay-flat" discharge line was installed from the pumping well to the middle of the bridge crossing the Methow River. The water was discharged into the middle of the river to minimize bank erosion. Flow rate was controlled with an 8-inch gate valve located near the pump. The discharge rate was monitored using an 8-inch diameter, 2,500 gpm McCrometer in-line flow meter located on the discharge side of gate valve. The flow meter recorded total cumulative discharge (totalized) as well as indicating the instantaneous flow rate. Flow rates recorded were based on both the indicated instantaneous discharge rate and on the calculated average of the metered discharge during a timed interval. The "lay-flat" discharge line provided sufficient back pressure for proper flow meter operation.

Water Levels. Water level measurements were collected automatically using electronic data loggers and pressure transducers. The following twelve locations were monitored during the pumping test:

Mazama Bridge Location	12 inch pumping well 8 inch deep well - four zones 4 inch intermediate 4 inch shallow
Mazama Realty Location	4 inch intermediate 4 inch shallow
Mazama Junction Location	4 inch intermediate 4 inch shallow
Methow River	Downstream from bridge

All of the transducer locations were also monitored periodically using a hand-held water level probe as a check or backup for the pressure transducers and data loggers. The hand measurements were completed using an Actat Model 150 Olympic Well Probe and a 12-foot steel engineer's tape. River stage was manually monitored from a surveyed reference mark on the bridge.

Step Test. The second constant rate drawdown-recovery pumping test (#2) was preceded by a second step test. The test well was pumped at five separate discharge rates; 1,725 gpm, 1,925 gpm, 1,979 gpm, 2,049 gpm, and 2,120 gpm. The first four steps were 30 minutes in duration. The final step (2120 gpm) had a duration of approximately 17 minutes. A fire in the electrical power cable terminated the test. Difficulty in controlling the pumping rate at capacities less than 1725 gpm did not allow overlapping step test rates of the first test with those of the second. Following pump shut off at the completion of the short term stepped pumping test, the water levels recovered to prepumping static conditions almost immediately.

Pumping Test. The long-term constant discharge test (#2) began on March 29, 1991, at 13:00.00 PST. The well was pumped at an average flow rate of 2,075 gpm for 13 days. Water level measurements were collected manually and with data loggers at approximate logarithmic time scale intervals at all twelve locations. The pump was shut off at 12:00 PST on April 11, 1991. Recovery was monitored for 24 hours, however, water levels were essentially recovered to prepumping static water levels within 2 minutes of pump shut off.

On the afternoon of April 8, 1991, it was noted that the needle that indicated instantaneous flow rate on the flow meter was not functioning properly. Flow rates recorded at this time were based on the calculated average flow rate of the metered discharge during a timed interval. On the morning of April 9, 1991, it was found that the totalizing function of the flow meter had failed. Repair or replacement of the flow meter was not considered practical or necessary. It was estimated that a minimum of one day would be required to obtain a replacement meter or repair parts, and the pump would need to be shut off while the meter was repaired or replaced. Shutting off the pump and stopping the test was not considered appropriate considering pumping test design parameters and data interpretation requirements. Little change in instantaneous or cumulative discharge had been noted up to the time the meter failed. Qualitative observations of the discharge did not give evidence of a change in discharge rate subsequent to meter failure and the electrical power consumption of the pump appeared to remain constant. For the purposes of test data evaluation it has been assumed that the discharge rate remained constant until the pump was shut off at the end of the pumping portion of the test.

Two water quality samples were collected during the pumping test. The first sample was collected by SE/E personnel at 13:30 on March 29, 1991, 30 minutes after pump startup. The second water sample was collected by Okanogan County Public Works Department personnel at 15:30 on April 10, 1991, 17,430 minutes (12 days, 2½ hours) after pump startup. The samples were sent to Century Testing Laboratory in Bend, Oregon. The samples were analyzed for the following:

- pH (laboratory)
- Specific conductance (laboratory)
- Alkalinity*
- turbidity
- Total suspended solids*
- Nitrate (NO_3-N)

- Nitrite (NO_2-N)
- Chloride (Cl)*
- Sulfate (SO_4)
- Ammonia (NH_3-N)**
- Orthophosphate*
- Metals (Calcium, iron, magnesium*, manganese, potassium*, sodium*, zinc)

  *These constituents were analyzed for the first sample only.

  **Ammonia was analyzed for the second sample only.

The test results are tabulated in Table 3-4. The laboratory reports are appended (see Appendix C).

3.5 Water Quality Sampling Analyses

3.5.1 Sampling

Ecology guidelines for data collection from monitoring wells (Ecology, 1988) used in the ground water management area program specify that water samples be collected at least twice during an aquifer test. Based on the prescribed aquifer test duration of 24 hours, the water samples are to be collected within the first 30 minutes and near the end of the test.

During the initial pumping test, three water samples were collected and submitted to Columbia Analytical Services in Kelso, Washington (CAS) for

Table 3-4

Methow Valley GWMA
Pumping Test #2
March 29-April 11, 1991
Laboratory Water Quality Data
(mg/L unless otherwise noted)

Analytical Parameter	Time After Start of Pump Test	
	30 Min	17,430 Min.*
pH (units)	7.5	6.8
Specific Conductance, µmhos/cm	127	132
Alkalinity (as $CaCO_3$)	58	NA
Turbidity (NTU)	0.70	0.1
Total Suspended Solids	3.5	NA
Nitrate-N	0.07	0.70
Nitrite-N	<0.01	<0.01
Ammonia-N	NA	<0.05
Chloride	5.0	NA
Sulfate	9.0	13
Orthophosphate	<0.08	NA
Calcium	21.6	21.7(1)
Iron, total	0.039	NA
Iron, dissolved	NA	<0.020
Magnesium	1.856	NA
Manganese, total	<0.015	NA
Manganese, dissolved	NA	0.020
Potassium	0.469	NA
Sodium	3.16	NA
Zinc, total	0.011	NA
Zinc, dissolved	NA	<0.006

NOTES:
*12 days, 2½ hours
NA= Not analyzed
(1)Corrected value verified by Century Testing Laboratory as per Okanogan County Public Works Dept., February 4, 1991.

laboratory analysis. Samples were collected after 42, 330, and 3000 minutes of pumping. An additional sample interval was planned at approximately 10,000 minutes but was not completed due to premature ending of the pumping test resulting from the area-wide power outage. The sample collected after 42 minutes of pumping was taken at the first available opportunity, given test startup and initial hydrology monitoring requirements.

During the second aquifer test, samples were collected and submitted to Century Testing Laboratory for analysis. Samples were collected after 30 and 17,430 minutes of pumping. Based on a review of the water quality data from the first pumping test, the number of parameters analyzed was reduced. It was also not considered necessary to collect samples other than at the beginning and end of the pumping test.

3.5.2 Analytical Results

Water quality results for ground water samples collected during the pumping tests are presented in Tables 3-3A, -3B, and -3C and Table 3-4. A detailed discussion of aquifer water quality characterization will be provided in subsequent reports to the County and Ecology, based on pumping test and quarterly monitoring data.

Distance of Draw. Sampling and analyses completed as part of the aquifer testing program were designed to provide preliminary aquifer water quality data. Comparison of results for samples collected near the beginning and end of the pumping test also provide some indication of general or "area-wide" water quality. Samples typically collected from monitoring wells are drawn from the immediate vicinity of the well screen and are representative of what is essentially a horizontal point in the aquifer with a vertical dimension equal to the screen length. Time series water quality samples collected during pumping are provide ground water samples from increasingly greater distances (distances of draw) from the well. The distance of draw is dependant on the aquifer thickness and porosity, concentricity of radial flow toward the well, and the pumping rate and duration. Assuming generalized and uniform aquifer conditions, and a pumping rate of 2,075 gpm, the ground water samples collected during the second pumping test, after 30 and 17,430 minutes, are estimated to have moved 3-10 feet and 100-300 feet, respectively, through the aquifer. The lower pumping rate and shorter test duration of test #1 would have resulted in a maximum estimated distance of draw of 30-90 feet.

Water Quality Evaluation. Water quality of the aquifer as represented by samples collected during both tests is typically good. Conductivity, an indicator of dissolved solids, has a reported range of 127 to 152 and overall average of 135 μmhos/cm for both pumping tests. The reported conductivity values (see Tables 3-3A and 3-4) are generally consistent during each pumping test and between the first and second tests.

Inorganic constituents and metals that were detected display generally low variability during each pumping test and between both pumping tests. Concentrations of all constituents are low relative to the applicable water quality criteria and to natural ground water quality conditions in general.

Minor concentration differences were noted for certain constituents between the first and second pumping test.

- Chloride - Average concentration of 0.4 mg/L during the first pumping test is significantly lower than the 5.0 mg/L concentration reported during the second pumping test. ✓ *
- Sulfate - Average sulfate concentration of 3.9 mg/L during the first pumping test is approximately 1/3 of the 11 mg/L concentration noted during the second test. *
- Nitrate-N - Not detected during the first test, detections at 0.07 and 0.70 during the second test.

The magnitude of the chloride and sulfate concentration differences noted above are not considered significant because both parameters are at very low levels. In neither case do the concentrations reported represent a water quality concern. The reported concentrations may reflect seasonal influences to water quality or nonseasonal variations due to migration of different quality recharge waters along preferential flow paths.

The samples collected during the first pumping test had reported nitrate-nitrogen concentrations less than the method reporting limit of 0.2 mg/L. The first sample taken during the second pumping test (after 30 minutes) had an equivalent reported concentration of 0.07 mg/L. The sample collected after 17,430 minutes of pumping during the second test had a reported nitrate concentration of 0.70 mg/L, an order of magnitude greater than the first sample.

The reason for the difference between these nitrate-nitrogen concentrations is unknown. The difference noted may be due to laboratory error (e.g., the 0.70 mg/L concentration appears to be anomalous) or may reflect a local source of elevated nitrates. Although not likely, fertilizer use and/or animal waste on adjacent pastures, or some other cultural feature (e.g., domestic subsurface sewage disposal systems) may cause temporary fluctuations in nitrate levels.

Seasonal monitoring of NO_3

4 PUMPING TESTS INTERPRETATION

Interpretation of pumping tests provides information about aquifer properties and character. Two important aquifer properties that can be estimated are transmissivity (T), the rate that water can flow through a section of the aquifer, and the coefficient of storage (S), which includes both storativity for confined aquifers and specific yield for unconfined aquifers. Storativity is a measure of the amount of water that is released from the aquifer by a change in pressure. Storativity may be estimated for either confined or semi-confined aquifers, i.e., an aquifer where the water is released to the well from the aquifer matrix and/or leakage from other parts of the aquifer. Values of storativity in confined aquifers range from 0.005 to 0.00005. For an unconfined aquifer, i.e., where the water is supplied by drainage from the upper aquifer part as the water level drops, the specific yield (S_y) is estimated. Specific yield represents dewatering of soil pores in the aquifer, rather than water expansion and aquifer compaction (as in the case with storativity). Specific yield values range from 0.01 to 0.30. Values of storage coefficient given in the following discussions are considered to be either storativity or specific yield, as appropriate.

The aquifer character, that is, how it varies from place to place and the patterns of water flow through it, can be evaluated by reviewing and comparing changes in water level before, during and after a pumping test. This information can be used to develop a conceptual model of the aquifer that guides interpretation of the test data. Additionally, a conceptual model is useful in planning further investigations and development of the aquifer. At Mazama, defining the aquifer character is as important a result of the pumping tests as aquifer parameter estimation. The data used to evaluate aquifer character is described in Section 4.1.

The analytical methods used to interpret the pumping test data and estimate aquifer parameter values are described in Section 4.2. Both pumping tests (3-day and 13-day) were interpreted using a variety of methods. Each method described is based on different assumptions about the aquifer character. Because no single method was found to fully represent aquifer conditions found at Mazama, each interpretation method indicates something different about the aquifer. In addition, a simple numerical computer model of the aquifer was developed to evaluate combinations of aquifer conditions that the analytical interpretation methods could only deal with singly. This model is described in Section 4.3.

All methods used to analyze the pumping test data estimate transmissivity, not hydraulic conductivity. Transmissivity is defined as the hydraulic conductivity multiplied by the thickness of the aquifer (Freeze and Cherry, 1979). The numerical computer model described in Section 4.3 is used to estimate appropriate aquifer thickness to be used in obtaining hydraulic conductivities.

4.1 General Observations

This discussion focuses on water level data collected during the tests. Water level variations were measured before, during and after each test and are described in Sections 4.1.1 through 4.1.4. The hydrographs (water level fluctuation over time) are included in Appendix D. The discussion focuses primarily on the second test because the data record for that test is more complete and the test was conducted under more controlled conditions with greater stress to the aquifer. The implications of the various water level fluctuations are discussed in Section 4.1.5.

4.1.1 Methow River Fluctuations

The Methow River level showed both large, long term and small, diurnal (daily) fluctuations during the 13-day test. The longer term fluctuations have a greater effect on pumping test interpretations because the aquifer displayed similar fluctuations. During the 3-day test, the river level fell less than 0.1 feet, following a drop of approximately 0.15-foot during the 6 days prior to the test. During the 13-day test, the river level declined less than 0.1-foot during the first 24 hours, and then rose approximately 0.63 feet during the next 6½ days before falling about 0.26 feet during the remainder of the test. Two similar magnitude, though shorter term, fluctuations were observed during the 16 days prior to the test. Comparison and correlation of these river level changes with aquifer fluctuation provides insight into the interaction between the river and aquifer and also the validity of assumptions used to interpret the pumping tests.

The smaller diurnal river fluctuations have limited affect on the pumping test interpretation. Diurnal fluctuations appear as a relatively regular rise and fall over a 24-hour period. During the 3-day test, these fluctuations were superimposed on and were sightly larger than the long term decline in water levels. The cycle was asymmetric, rising gradually from mid-afternoon until early morning before falling more steeply to mid-afternoon. The total fluctuation during the 3-day test was typically about 0.11 feet per day.

For the 13-day test, diurnal fluctuations were generally smaller than the long term fluctuations. During the 3 days prior to the test and before the long term rises began, diurnal fluctuations were approximately 0.05 feet per day, about half the size measured during the first test, and followed a similar asymmetric pattern.

Fluctuations in the Methow River water level were likely caused by a combination of weather factors including direct precipitation and temperature, which causes daily changes in snow melt. The character of the aquifer and its connection to the river affects the rate of fluctuation depending on the difference in water levels. As the river falls below the level of the aquifer, water can flow to the river, reducing the rate at which the river falls. If the aquifer is lower than the river, the opposite effect is true. This effect is controlled by the continuity between the aquifer and river and the hydrologic character of the aquifer, specifically the transmissivity, specific yield, and gradient.

4.1.2 Pre-pumping Conditions

Water levels were measured prior to starting the pumping test to evaluate the static condition of the aquifer. This information was used to determine whether, and how much, to correct the test data so that the interpretations consider water level changes caused only by the pumping exclusive of river level fluctuations. The static condition of the aquifer is also used to evaluate the usefulness of a particular interpretation method by confirming analysis method assumptions.

A limited number of hand measurements of the water level in wells are available for the days prior to the 3-day pumping test. These measurements indicate that water levels were relatively stable (i.e. generally fluctuated by less than 0.1 foot). Both increases and declines in the water level were observed depending on the location of the measured well. The data support the conclusion that the water levels were generally stable.

Three hydrographs (continuous record) are available for the 18 days prior to the beginning of the 13-day test. These include measurement at the Mazama Bridge shallow (MW-8) and intermediate depth (MW-9) wells and at the Methow River. The hydrographs for MW-9 and the Methow River are shown on Figure 4-1. These hydrographs show three distinct hydrologic periods: the first and third periods show slow declines in water levels while the middle period shows two large fluctuations. The three hydrographs are similar for both wells and river but occur at different elevations and the size and timing of the fluctuations vary. The water levels in the shallow well at Mazama Bridge are generally 0.7 feet higher than the river level, which is about 1 foot higher than the level in the intermediate well. The first and third periods for both shallow and intermediate well hydrographs display very similar magnitude and rate of decline, which are roughly twice that of the river.

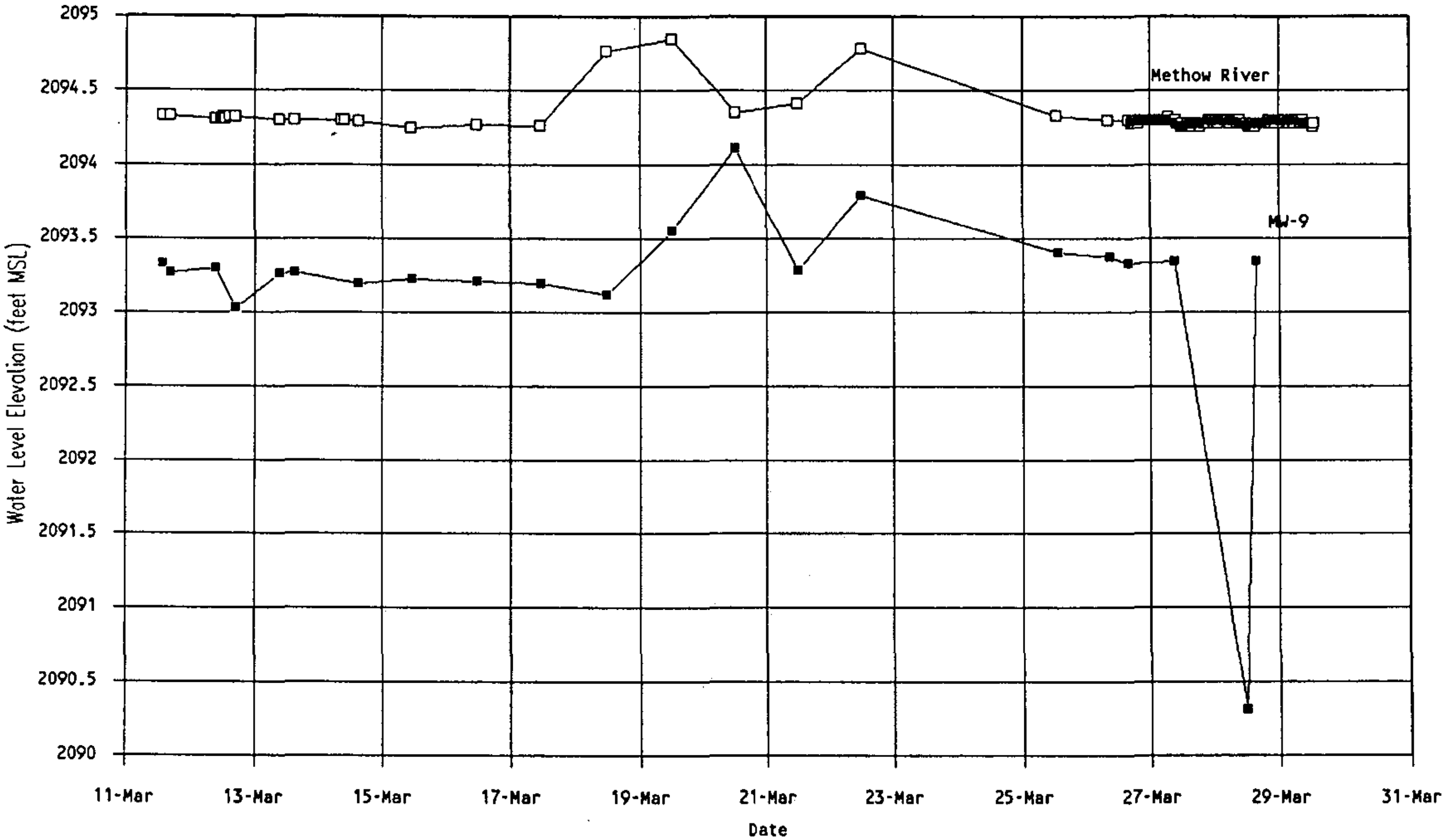

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Figure 4-1
METHOW VALLEY GWMA

PRE-PUMPING PERIOD HYDROGRAPH OF MW-9 AND METHOW RIVER

During the second period, the first fluctuation begins and ends in the shallow well and river approximately one day before it does in the intermediate well. The occurence of the second fluctuation of the second hydrologic period is roughly coincident on all three hydrographs, however, the magnitude of the fluctuation varied considerably between measured sites. The first fluctuation in the intermediate well was about 0.4 feet greater than in the river, which was 0.2 feet greater than in the shallow well. The second fluctuation was generally smaller but was similar in size in the intermediate well and river. The shallow well hydrograph displayed a fluctuatuion that was approximately 0.1 foot larger than the intermediate well and the river. One other notable observation is that in the third period, the water levels in the shallow and intermediate wells were approximately 0.1 foot higher than during the first period but the river levels were essentially at the same level during both periods.

The data indicate that, in the absence of pumping stress, there are gradients from the shallow zone to both the intermediate zone and to the river. The fact that the aquifer responds to changes in the river even though the shallow zone is higher than the river near the site may indicate that the shallow zone is recharged at an upstream relocation where the river (or a tributary) is at a higher elevation. The delay in the response of the intermediate zone to a rise in river level during the first hydrologic period indicates that a gradient has to be established before additional water can flow to this zone. The greater magnitude of this delayed response, and the lack of a response delay during the second hydrologic period of fluctuation, indicates that once this gradient is established it takes some time to decay. Finally, the higher level and greater rate of decline in aquifer water levels following the peaking of water levels in wells as compared to the river, indicate that water stored in the shallow zone may be discharging downward at a greater rate than to the river.

Data available for the four deep Mazama Bridge piezometers covers only the third part of the pre-test period. The data define a significant downward component to the gradient between the intermediate and deeper portions of the aquifer. Water levels in the top and middle-shallow piezometers (deeper intermediate and upper deep hydrostratigraphic zones, respectively) were consistently 0.25 feet higher than in the intermediate zone monitoring well. However, the middle deep and deep piezometers (middle and lower deep zones) were 4.5 and 6.2 feet lower, respectively, than the shallow monitoring well (shallow hydrostratigraphic zone) and 1.45 feet lower than the upper intermediate hydrostratigraphic zone (intermediate monitoring well). The similarity of the water levels in the middle portion of the aquifer (the intermediate to upper deep zones) indicates that flow is probably primarily horizontal through this section of the aquifer. The general lack of a vertical gradient in the pumped zone makes several pumping test interpretation methods useable, depending on the magnitude of the horizontal gradient. The large vertical difference in water level between this and deep (the middle deep and deep zones) hydrostratigraphic units indicates that significant downward flow of water should be occurring. Additionally, this implies that water flowing down into these zones is flowing horizontally downvalley through these zones, because it is assumed that insignificant volumes of water flow into the surrounding bedrock.

The "top" (lower intermediate) and "middle shallow" (upper deep) hydrographs are stable for the first half of the third pretest period but decline during the second half. The middle deep and deep piezometer water levels display a continuous decline with an overall magnitude of about 0.2 feet during this period. The rate of decline in all the deeper wells is significantly greater than in shallow and intermediate wells and increases with depth. This pattern would tend to maintain or increase the substantial downward gradients, indicating that flow of water into and through these lower zones is maintained.

Data covering only the third pretest period is also available for the Mazama Junction and Mazama Realty wells. These wells all follow a pattern that includes a slight rise followed by stable water levels, except for the Realty shallow well, which showed an initial slight decline. The water levels in all of these wells, except the Junction intermediate site, are higher than the river. The Junction intermediate well water levels were approximately 6.5 feet below the river, indicating strong gradients and flow toward and through this portion of the aquifer.

4.1.3 Pumping Conditions

Start Up. During the 13-day test, a readily identifiable drop in water levels was measured in all wells, including the Mazama Realty and deepest Mazama Bridge wells, although the response was delayed and of lesser magnitude in these three wells than at the other locations. This indicates that pumping affected a large portion of the aquifer including areas on the opposite side of the river. As expected, the amount of drawdown measured was greatest in the intermediate, "top" (lower intermediate) and "middle shallow" (upper deep) piezometers closest to the pumping well. The least drawdown was observed in the Realty shallow, Realty intermediate, Junction shallow, and the Bridge deep wells. This pattern indicates that the pumped water came mainly from semi-confined storage in the intermediate aquifer zone with some leakage from the shallow or upper zone. Since the river level was relatively stable during the initial 24 hours of the pumping period, this period may be used to estimate aquifer parameters. In all cases, apparent full drawdown was achieved within approximately 200 minutes of the start of the test. Figure 4-2 illustrates the pumping period hydrographs for MW-9 and the Methow River.

Recovery. Water level recovery at the end of the test was measured in all wells. Though the magnitude of recovery was similar in size to the drawdown, the recovery was superimposed on a large, weather-related fluctuation in water levels and could not be interpreted on its own.

Pressure Response. Oscillation in water levels was measured in the Mazama Bridge intermediate well, and the "top", and "middle shallow" piezometers during the first 30-60 seconds of the test. Figure 4-3 illustrates the oscillation present in the Bridge intermediate well. This type of pressure response, known as underdamping, is caused by rapid pressure fluctuations and is analogous to ripples created in a body of water when an inverted glass is raised suddenly. Although this phenomenon makes interpretation of this part of the test nearly impossible, it can only happen in very transmissive aquifers, and confirms, in a qualitative manner, estimated transmissivity values. This oscillation was not measured in the shallow zone, indicating that it is a pressure effect that was not transferred to the water table.

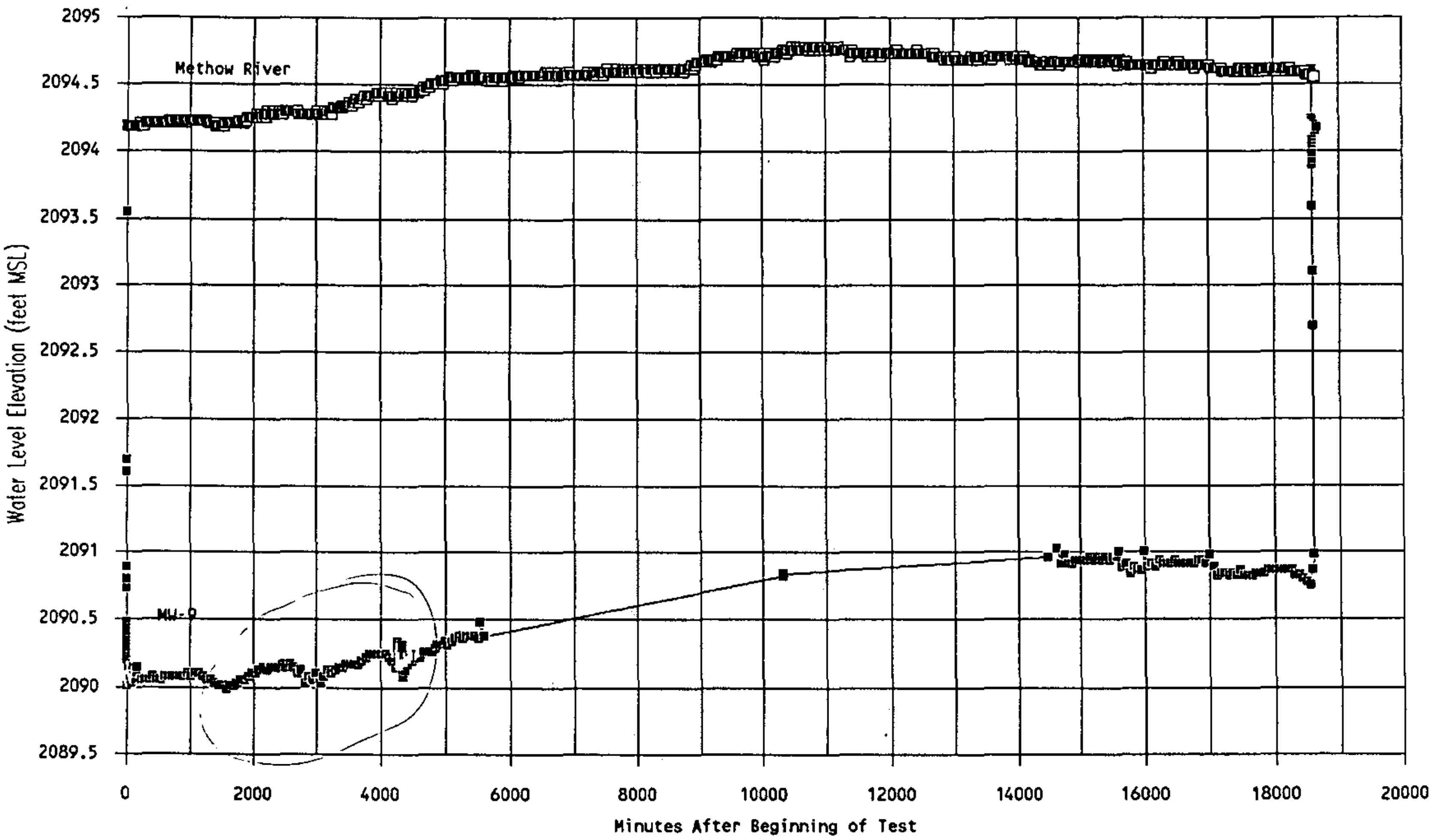

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Figure 4-2
METHOW VALLEY GWMA

PUMPING PERIOD HYDROGRAPH OF MW-9 AND METHOW RIVER

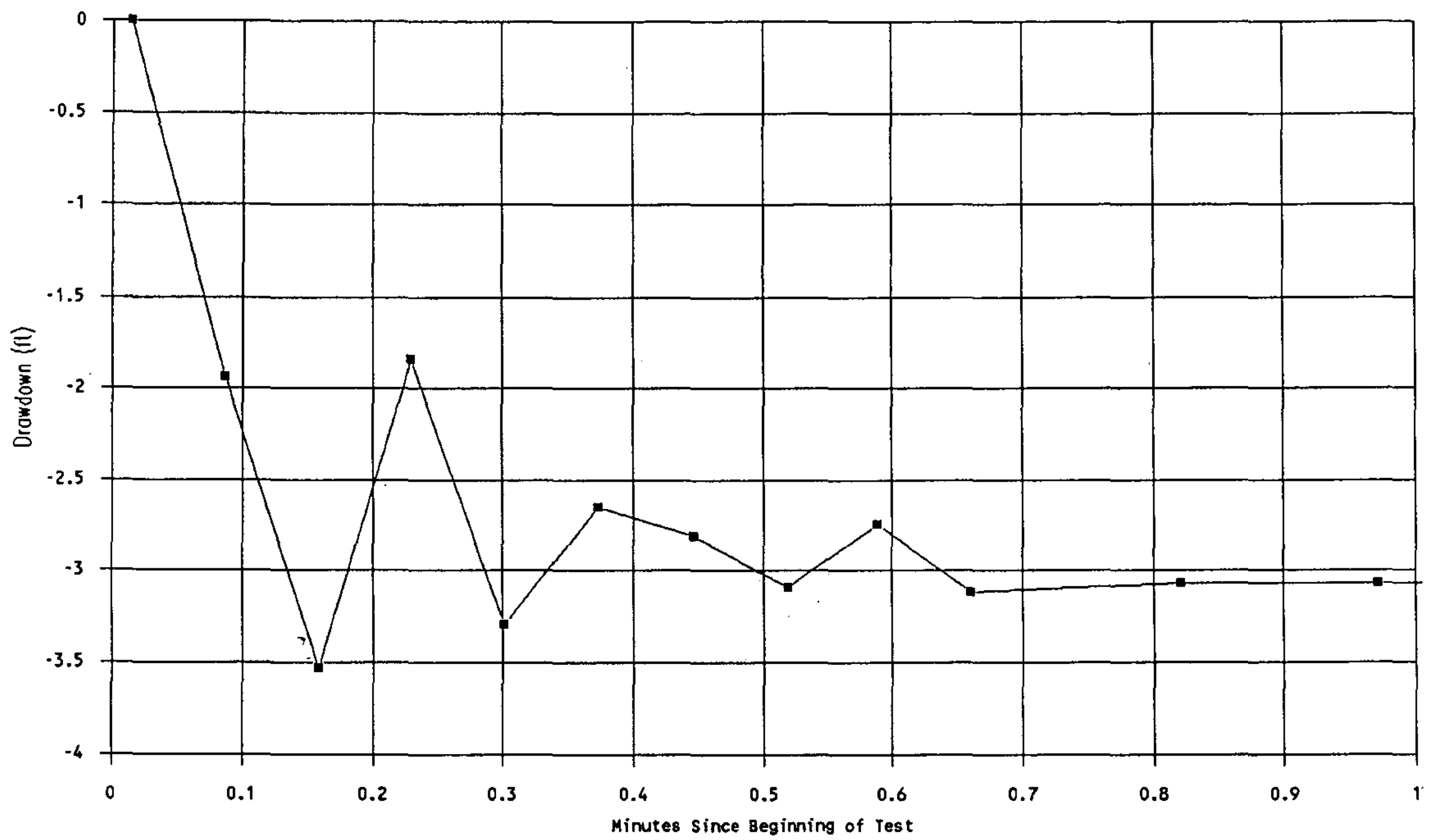

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Figure 4-3
METHOW VALLEY GWMA

POST-PUMPING PERIOD HYDROGRAPH
OF MW-9 AND METHOW RIVER

System Fluctuations. A large, weather-related fluctuation was measured in all wells during the test. The magnitude and duration of this fluctuation was significantly greater in the aquifer than in the river. The river level rose about 0.6 feet in seven days before falling 0.2 feet in six days. The water levels in all wells at all three locations rose approximately 1 foot in eight to nine days before falling less than 0.2 feet during the following three days. The end of the period of water level decline is obscured by the recovery of water levels resulting from the termination of the pumping test. Water levels in the Junction and Realty wells and in the deeper zones at Bridge displayed fluctuation that lagged behind the river. The observation that fluctuations were larger and at higher elevations in the aquifer than in the river indicates that the aquifer is responding to an inflow of water upstream from Mazama, i.e., a recharge phenomenon. The delay in response in several zones indicates that the effect of the fluctuation took some time to be transmitted through the aquifer. Unfortunately, since the aquifer fluctuations were variable and did not exactly mirror river fluctuations, it was not possible to precisely correct the data to remove this effect.

Diurnal fluctuations are evident on hydrographs for all Bridge site wells, the Junction shallow well, and in the Methow River. These fluctuations are most distinct on the Mazama Bridge well hydrographs, where they are generally twice the amplitude of the river level fluctuations. However, there is no

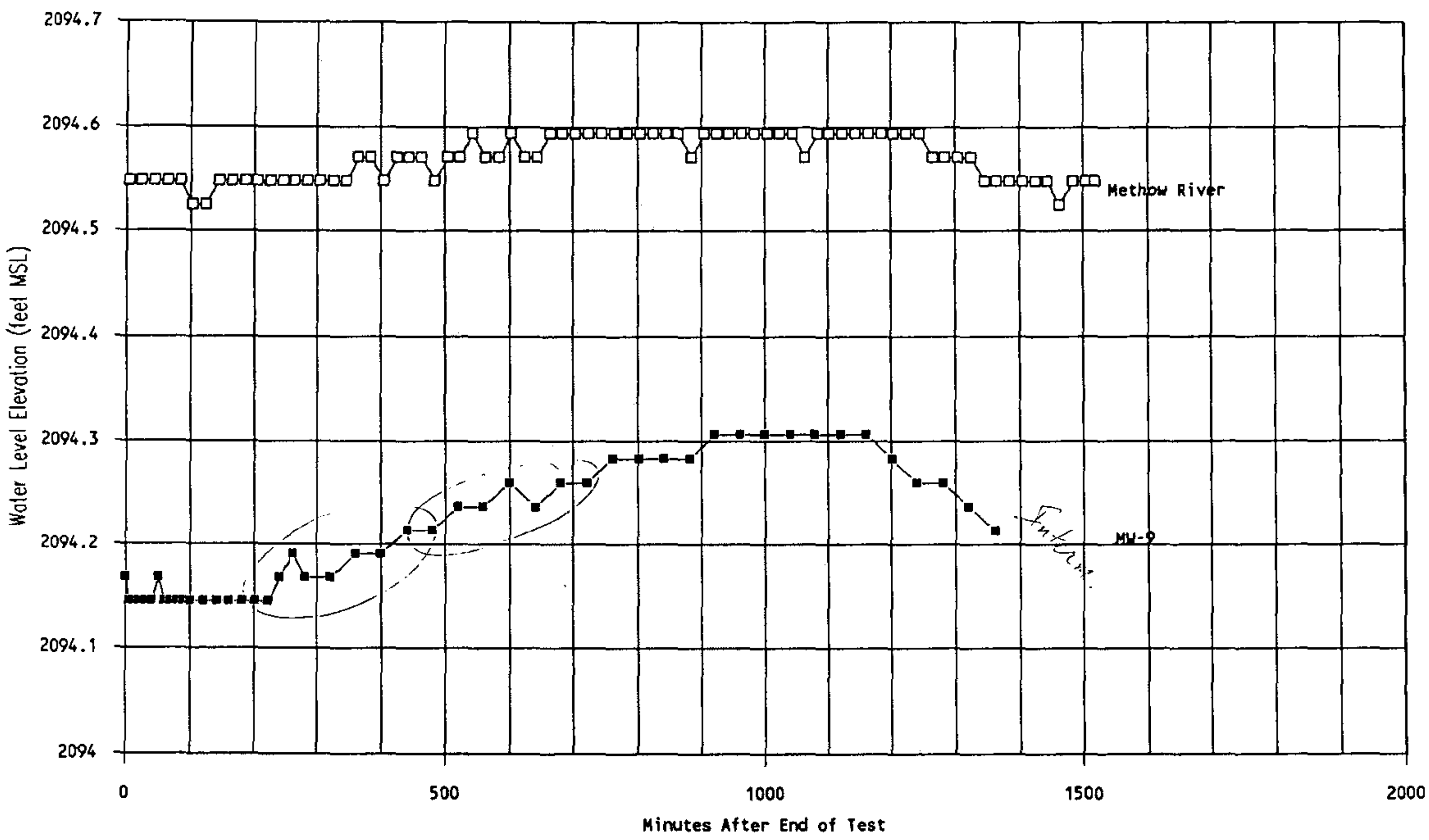

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Figure 4-4
METHOW VALLEY GWMA

PRESSURE RESPONSE IN MW-8 DURING DRILLING

4.1.5 Summary

Measured water levels from before, during, and after the test indicate that the pumping well primarily affected the intermediate aquifer zone, and that the effects extended to the opposite side of the river. Because the vertical gradient in this portion of the aquifer under static conditions was small, pumping test interpretation methods should be generally valid. Although changes in water level were less in the shallow zone and were more obscured by diurnal and seasonal fluctuations, this zone did respond to pumping, indicating that water leaked from the upper hydrostratigraphic zone into the intermediate zone. These observations support the assumption that the intermediate aquifer behaves as a semi-confined aquifer.

Water level changes in both the lower intermediate and upper deep ("top" and "middle shallow" piezometers) zones indicate that water was induced to flow up to the partially penetrating pumping well. The smaller response in, and overall downward gradient to, the deeper zones indicates that pumping may have reduced downward leakage during the test, thereby reducing the effect of this leakance on pumping test interpretation. Corrections cannot be accurately made for large weather-related fluctuations and equipment failures that occurred during the test and which obscured portions of the test results.

The large weather fluctuation, which had a similar effect on every aquifer zone at every location, may indicate that recharge to the aquifer occurs upstream of the Mazama test site in a manner that can be quickly transmitted through the aquifer. This transmission of recharge effects appears primarily as a pressure wave. Since the period of water level rise was larger and over a longer period of time in the aquifer than in the river, recharge to the aquifer may occur in a somewhat different manner than for the river. Since different long-term fluctuations showed varying response characteristics, clues as to recharge mechanisms may be indicated. The large vertical gradients between upper and intermediate depth zones measured at the Mazama Bridge and Mazama Junction wells point out the complex character of the aquifer and imply that stratigraphy and transmissivity are not laterally or vertically uniform within the aquifer.

4.2 Analytical Methods

In order to evaluate the data from both the first and second aquifer tests, several analytical methods were used. This was done in order to compare results, and to determine a range of possible aquifer parameter values. Each method is based on a series of assumptions that simplify the actual aquifer system. Since the aquifer system is known to be complex, no single method is considered fully adequate to represent test conditions. Methods were chosen based on the appearance of the plotted time-drawdown data and known geologic conditions. The analytical methods used to analyze the aquifer were:

- Theis non-steady state method
- Jacob non-steady state method
- Jacob distance-drawdown method
- Hantush partial penetration method
- Stallman linear recharge source method

More detailed descriptions of these analytical methods can be found in Heath (1982) or Freeze and Cherry (1979) for the Theis and Jacob methods, and Kruseman and de Ridder (1970) for the Hantush and Stallman methods. Summaries of the results for aquifer transmissivity and storativity obtained by the different methods are presented in Tables 4-1 and 4-2. Plots of the drawdown over time for each well are found in Appendix D. Documentation of the application of each analytical method is included in appendices referred to in the description of each method.

4.2.1 Theis Non-Steady State Method

The Theis method is a graphical technique used to assess hydraulic parameters of the aquifer. It involves matching plots of the measured drawdown in observation wells with theoretic type curves. Drawdown data

Table 4-1

Methow Valley GWMA
Mazama Pumping Tests Analyses Summary
Transmissivity (T)(gpd/ft)

Observation Well	Monitored Zone	Depth of Screened Interval	Analytical Method			
			Theis	Jacob	Hantush	Stallman
3-Day Test (#1)						
Bridge Intermediate (MW-7)	I	108-118	---	1,100,000	450,000	400,000
13-Day Test (#2)						
Bridge Shallow (MW-6)	S	14-44	4,639,000	5,100,00	8,200,000	4,172,000
Bridge Intermediate (MW-7)	I	108-118	68,600	1,300,00	183,000	340,000
Deep Boring-Top	I	185-195	1,063,000	1,505,000	699,000	1,252,000
Deep Boring-Middle Shallow	D	223-238	328,000	1,200,000	377,000	1,190,000
Deep Boring-Middle Deep	D	295-305	2,795,000	4,460,000	2,142,000	2,380,000
Deep Boring-Deep	D	475-485	---	---	553,000	23,800,000
Junction Shallow (MW-10)	S	19-49	3,858,000	3,600,000	1,640,000	2,642,000
Junction Intermediate (MW-11)	I	108-118	969,000	2,200,000	440,000	780,000

NOTES: Pumping well screened interval is from 89 to 114 feet below ground surface
gpd/ft = gallons per day per foot
--- = Not possible to estimate using this method.
S = Shallow aquifer zone **I** = Intermediate aquifer zone **D** = Deep aquifer zone

Table 4-2

Methow Valley GWMA
Mazama Pumping Tests Analyses Summary
Storativity (S) Values (unitless)

Observation Well	Monitored Zone	Depth of Screened Interval	Analytical Method: Theis	Jacob	Hantush	Stallman
3-Day Test (#1)						
Bridge Intermediate (MW-7)	I		---	0.022	$4.0x10^{-4}$	$1.1x10^{-4}$
13-Day Test (#2)						
Bridge Shallow (MW-6)	S	14-44	0.22	0.13	0.53	$3.2x10^{-3}$
Bridge Intermediate (MW-7)	I	108-118	$1.1x10^{-3}$	---	$2.5x10^{-5}$	$1x10^{-6}$
Deep Boring-Top	I	185-195	0.025	$2.9x10^{-3}$	$9.5x10^{-3}$	$6x10^{-6}$
Deep Boring-Middle Shallow	D	223-238	0.053	$5.9x10^{-3}$	$5.1x10^{-3}$	$8x10^{-6}$
Deep Boring-Middle Deep	D	295-305	*	*	*	0.03
Deep Boring-Deep	D	475-485	---	---	---	0.043
Junction Shallow (MW-10)	S	19-49	0.10	0.088	0.068	0.03
Junction Intermediate (WM-11)	I	108-118	$7.3x10^{-4}$	$2.4x10^{-4}$	$3.2x10^{-4}$	$2.1x10^{-4}$

NOTES: Pumping well screened interval is from 89 to 114 feet below ground surface.
--- = Not possible to interpret the data using this method.
* Calculated storativity resulted in values 1.0. Storativity values above 1.0 are not possible and are not reported.
S = Shallow aquifer zone **I** = Intermediate aquifer zone **D** = Deep aquifer zone

are plotted versus time (or distance from the pumping well) on logarithmic scales. Figure 4-5 illustrates a typical logarithmic plot for drawdown and time data from the shallow Bridge well. A match point for the curves is selected and values corresponding to the match point are entered into a set of equations, which estimate the transmissivity and storage of the aquifer.

Theis used several important assumptions about aquifer characteristics to develop his "Theis equations." These assumptions are needed to simplify the aquifer so that it can be evaluated mathematically. The main assumptions are as follows:

- A confined aquifer
- An isotropic, homogeneous, and unlimited aquifer (or the hydraulic character is the same in all directions)
- Instantaneous withdrawal of water from storage
- A pumping well screened from the top to the bottom of the aquifer (i.e., fully penetrating)
- Observation wells within the same horizon as the pumping well
- Horizontal ground water flow

These assumptions are all violated to a greater or lesser degree when applying the Theis solution to the Mazama test site or to any real set of aquifer conditions and test design parameters. The tested aquifer is

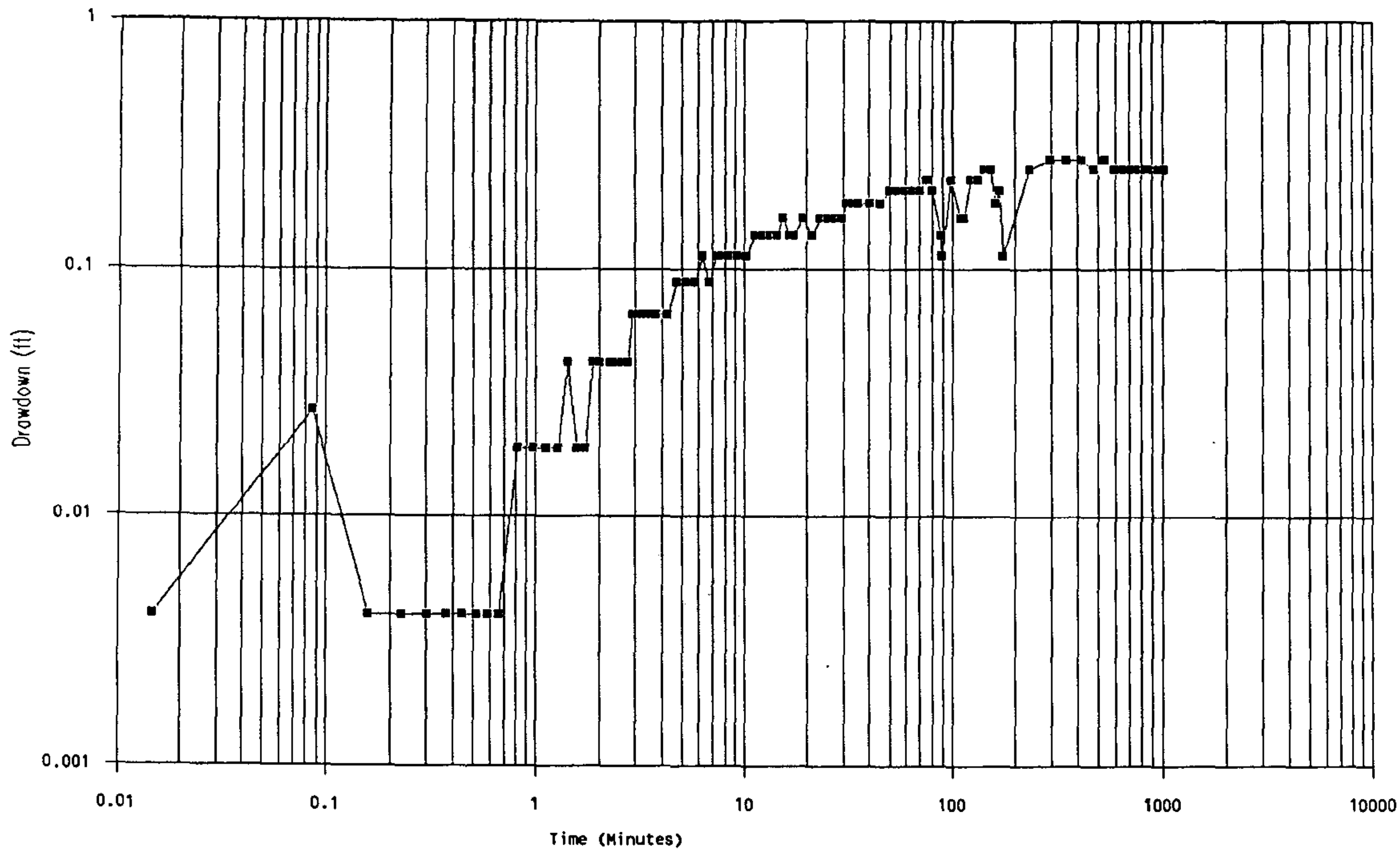

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Figure 4-5
METHOW VALLEY GWMA

LOGARITHMIC PLOT OF TIME-DRAWDOWN DATA PLOT MW-8

semiconfined, anisotropic, layered, and restricted by bedrock at the sides of the valley, the pumping well is partially penetrating, and not all observation wells are in the same horizon as the pumping wells. However, the Theis equations have been modified to account for unconfined or semiconfined conditions and the results can be used to evaluate effects of the other assumptions. Since the aquifer is relatively coarse-grained, withdrawal from storage can be considered instantaneous (fine-grained materials would tend to release water over a long period of time, not instantaneously), and although the aquifer is neither homogeneous nor isotropic, the resulting hydraulic conductivity and storage values give an indication of the actual values of these parameters.

The drawdown data from the 13-day test was matched to Theis type curves using the THCVFIT computer program from the International Ground Water Modeling Center (van der Heijde, 1987). The data, resulting match points, calculated parameters and plots of the drawdown data are included in Appendix E. Estimated transmissivity and storativity values are listed in Tables 4-1 and 4-2, respectively. Data from the 3-day test were insufficient to apply this method.

Transmissivity values using this method range from 68,600 to 4,640,000 gallons per day per foot (gpd/ft) width of aquifer. Storativity values range from 0.00073 to 0.22. There is considerable variation according to which observation well is used. Values calculated from the Mazama Bridge intermediate well data were probably affected by oscillation that occurred during the first minute of the test. These values, therefore, are not considered reliable. The deep Mazama Bridge piezometers and both Mazama Realty wells did not respond strongly enough to be interpreted using the Theis method.

The general magnitude of the transmissivity values confirms that the aquifer is highly transmissive. The storativity values indicate that the aquifer is generally semiconfined. The variability may be due to layering in the aquifer, the use of a partially penetrating pumping well, and the pressure oscillations (underdamping) that obscured the first minute of the pumping response data.

4.2.2 Jacob Non-Steady State Method

The Cooper-Jacob method (also called the Jacob straight-line method) is a modification of the Theis method. It is only valid at relatively large test times or small distances from the well. The test times and distances where this method is applicable depends on the aquifer characteristics and must be calculated separately. It is more convenient than the Theis method because data generally falls along a straight line on a semi-logarithmic plot of the time-drawdown data. No type curve matching is involved. Time is plotted on the logarithmic side of the plot and drawdown is plotted arithmetically. Figure 4-6 illustrates a typical Jacob-type plot for the shallow Bridge well. Values of time and drawdown are selected from the plot and used to calculate transmissivity and storage values. Since the Jacob method is based on the Theis method, the limitations of the Theis method also apply. However, it is further limited because it can only be applied to part of the data. This method is used as a check on the Theis method and to evaluate differences that may exist between the useable part of the data and the data as a whole.

Using the Jacob straight-line method, estimated transmissivities range from 1,100,000 to 4,640,000 gpd/ft. Estimated storativity values ranged from 0.0004 to 0.13. The data plots and calculations are presented in Appendix F. The transmissivities and storativities are summarized on Tables 4-1 and 4-2, respectively.

The transmissivity values estimated for the middle portion of the aquifer (intermediate to middle shallow zones) are relatively consistent using this method. This consistency probably results from not using the early, oscillatory data and from the relative comparability of the intermediate and shallow well water levels. The variations may indicate the effect of partial

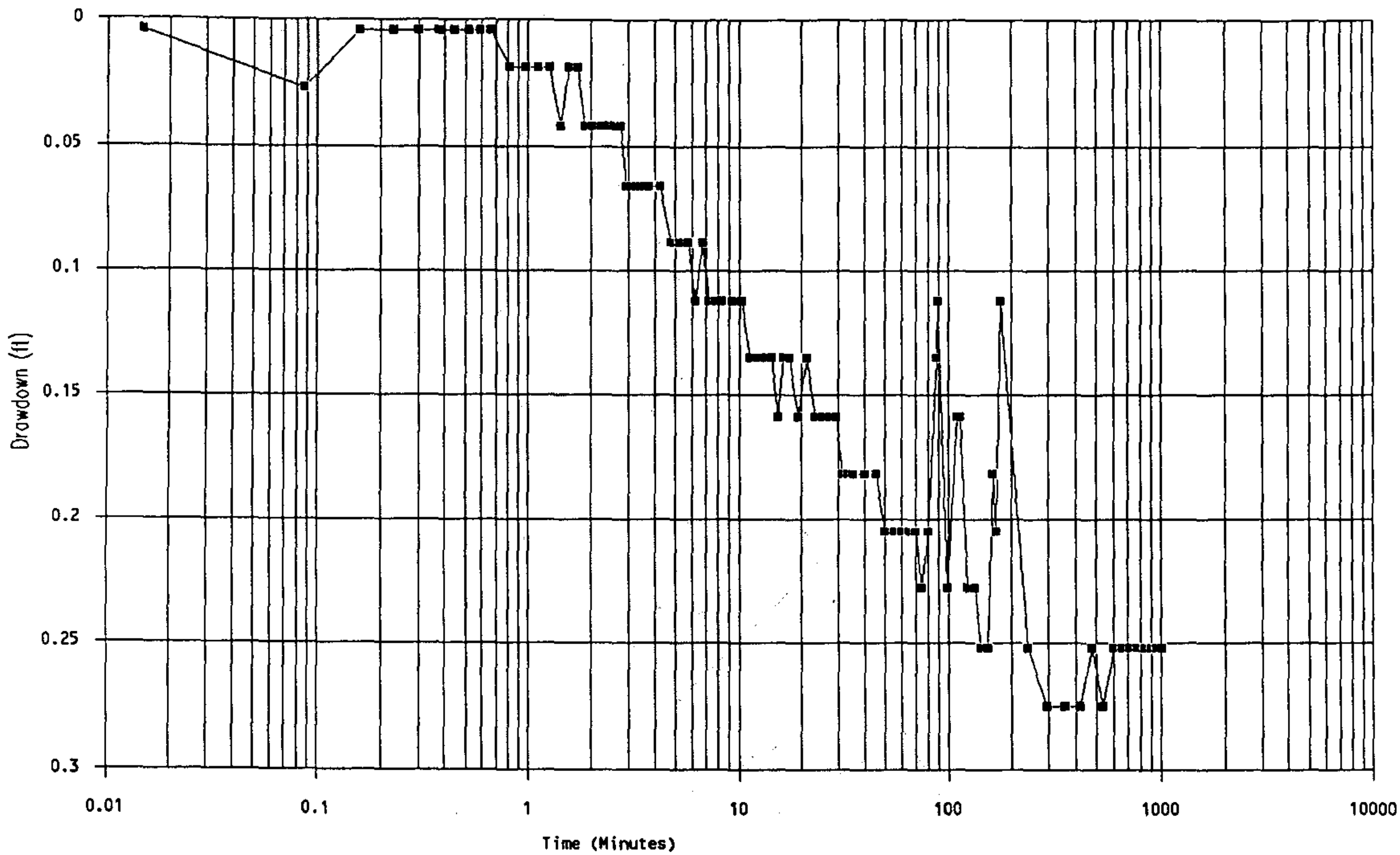

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Figure 4-6
METHOW VALLEY GWMA

JACOB TIME-DRAWDOWN
DATA PLOT MW-8

penetration and aquifer layering. Storage values for the shallow wells indicate unconfined to semi-confined conditions, while storage values for the deeper wells indicate semi-confined conditions.

4.2.3 Jacob Distance-Drawdown Method

The Jacob distance-drawdown method is similar to the Jacob straight-line method described in Section 4.2.2, except that the logarithm of distance to each observation well is plotted against drawdown rather than the logarithm of time. Figure 4-7 illustrates a typical Jacob-type distance drawdown plot using 13-day test data. The assumptions and procedures described in Section 3.2.2 are the same for this method. The drawdown data used on the plot are for the same period of time and from the same depth interval. This method is used to evaluate the effects of changes in the aquifer with distance from the pumping well using essentially the same theory as for changes with time.

The Jacob distance drawdown method was applied to the intermediate depth wells for the 13-day test data. Three data points (drawdown at 200 minutes) from the Bridge, Junction, and Realty intermediate wells were plotted and analyzed. The plot and calculations are included in Appendix G. The results of this analysis give a transmissivity value of approximately 750,000 gpd/ft for the intermediate zone. Storativity is shown to vary with

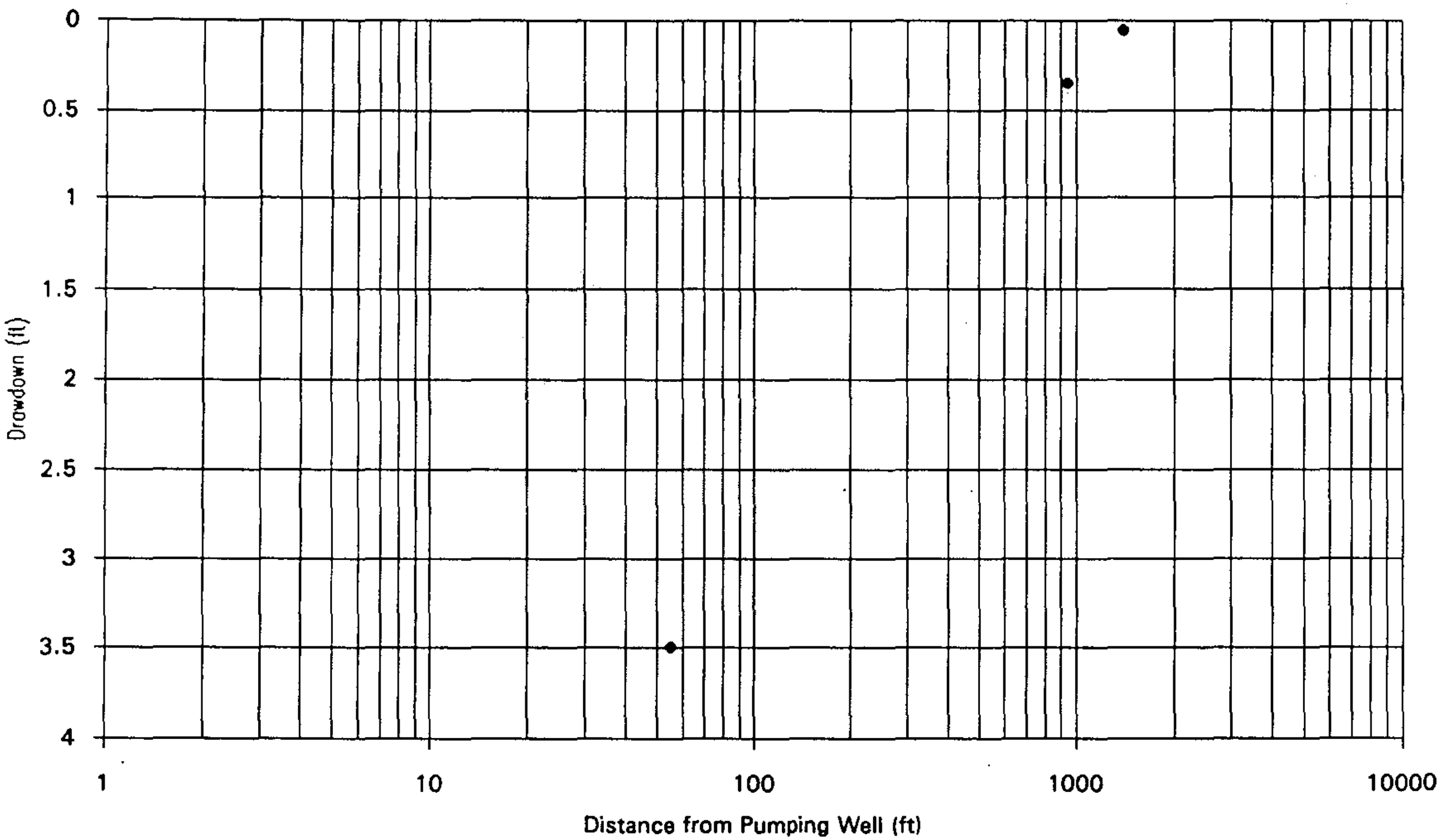

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Figure 4-7
METHOW VALLEY GWMA

JACOB DISTANCE-DRAWDOWN PLOT

time but is estimated to be on the order of 0.01. These results provide somewhat lower estimates of transmissivity than the time drawdown plots. This may be due to the effect of recharge or leakage from other portions of the aquifer, which would tend to reduce the effect of pumping with distance from the pumping well.

4.2.4 Hantush Partial Penetration Method

The Hantush partial penetration method is a correction to the Theis method to account for partially penetrating pumping and observation wells. Since it is an extension of the Theis method, many of its limitations are similar to those described in Section 4.2.1. Additionally, whereas the Theis solution is valid for all times, the Hantush correction is only valid for the relatively early part of the test. However, this part of the test should also show the least effect of any recharge to the aquifer. This method uses curve matching procedures similar to those of the Theis method, except that a different type curve is created and used. Data are plotted in the same manner as the Theis method (Figure 4-5). This type curve was created using the construction details of the test and observation wells and parameter values contained in Kruseman and de Ridder (1970).

The Hantush method returned transmissivity values that ranged from 183,000 to 8,200,000 gpd/ft. Storage values range from 2.5×10^{-5} to 0.068.

The data used to create the type curves, the type curves, the curve matches, and the parameter calculations are presented in Appendix H. The estimated transmissivities and storativities are listed in Tables 4-1 and 4-2, respectively.

The transmissivity estimates are more variable than for the Jacob method. This may indicate that the different layers in the aquifer have contrasting hydraulic conductivities. Although the early time oscillations may affect the interpretations, the influences of layering are apparent in all the zones. However, the delay of the pumping response in the middle deep and deep piezometers may have resulted in data that is not valid within the interpretation limitations of this method. This method is generally valid for a period of less than one minute after start of pumping.

4.2.5 Stallman Linear Recharge Source Method

A major limitation of all the methods previously described is the inability to account for interaction between the aquifer and the Methow River. Stallman's method is designed to compensate for the effects of one or more linear sources of recharge (a river, for example) that fully penetrate the aquifer in the vicinity of the test. The Methow River does not fully penetrate the aquifer at the test site. However, because the aquifer is made up of coarse material that quickly transmits water, it may act similarly to a fully penetrating recharge source for this test or at least for the upper part of the aquifer. If this were true, the effects should be apparent in the interpretation. In general, assumptions of Stallman's method are similar to the Theis method except for the recognition that one or more fully penetrating recharge boundaries are present. In addition, the method is also valid for either confined or unconfined aquifers. As for the Hantush method, the Stallman method is based on the use of a special type curve produced using the distance from the pumping well to the observation well and values contained within Kruseman and De Ridder (1970). Data are plotted in the same manner as the Theis method (Figure 4-5). The curve matching and calculation procedure is similar to the Theis method. The Stallman method is used to evaluate the effect of the river on the drawdown data and test interpretation.

The Stallman method returns transmissivity (T) values that range from 340,000 to 23,800,000 gpd/ft. Storativity values range from 1.0×10^{-6} to 0.043. The data used to create the type curves, the type curves, the curve matches, and the parameter calculations are presented in Appendix I. The estimated transmissivities and storativities are summarized in Tables 4-1 and 4-2, respectively.

The highest transmissivity was estimated for the Bridge deep well and is probably not accurate because this well is very deep (>400 ft) and the river only penetrates the top 5 feet of the aquifer. This method should not be applied to this well, however, the very high estimate does indicate that correcting for a river recharge source at depth overcompensates for this effect and shows that downward flow is not instantaneous. Because the interaction between the aquifer zones and river decreases with depth, this method probably progressively overestimates hydraulic values at lower depths.

4.2.6 Summary

Taken as a whole, the pumping test interpretation results appear to confirm that the aquifer is highly transmissive, semiconfined, and affected by layering and by recharge. Major factors that have influenced the interpretations are the early time oscillation (underdamping) and the partial penetration of the wells. Recharge from the Methow River appears to have a varying effect with depth and may not substantially or directly affect more than the uppermost shallow zone, which may be largely controlled by upstream recharge. Delayed yield was not observed in the shallow zone during the longer 13-day high yield test, confirming the semiconfined nature of the pumping response. It appears that infiltration of water from the shallow zone to the lower zones occurs as leakance.

Since the Hantush and Jacob methods compensate for the partial penetration and early time water level oscillation conditions, respectively, the estimated transmissivity and storage values should be weighted toward these methods. Therefore, the transmissivity of the aquifer is estimated to be between 400,000 and 1,000,000 gpd/ft, depending on aquifer layer. Results from the 13-day test indicate a somewhat higher transmissivity than for the 3-day test. This estimate is derived primarily from the middle portion of the aquifer where the methods were most valid.

The shallow zone appears to be more conductive than the intermediate depth portion of the aquifer. For the shallow aquifer, the estimates of transmissivity included on Table 4-1 may be overestimated because of river infiltration and values between 2,000,000 to 3,000,000 gpd/ft may be more accurate. A high volume pumping test of the shallow zone would be needed to accurately assess this zone.

The high transmissivity estimates for the lower portions of the aquifer are probably affected by the vertical gradients from the middle zones. The transmissivity of this zone is probably less than 2,000,000 but cannot be accurately estimated without direct testing. If the shallow and deep portions of the aquifer are in fact more conductive than the middle portion, the overall aquifer transmissivity could be at the high end of the estimated range (or about 1,000,000 gpd/ft).

Storage of the aquifer also varies with depth. The estimated storage coefficient for the shallow zone is between 0.1 and 0.2. This is typical of unconfined conditions. For the intermediate aquifer zone, the storativity was estimated to be between $3x10^{-3}$ and $1x10^{-4}$. This is typical of semiconfined to confined conditions. Semiconfined conditions indicate that water leaks into this zone from another zone, such as the shallow zone. This is supported by the measurable but reduced shallow zone response to pumping.

Factors other than confined or semiconfined conditions may result in storage coefficients that are artificially low. The vertical hydraulic conductivity is inherently lower than the horizontal hydraulic conductivity in the same aquifer materials. These differences can be observed in aquifer materials that are essentially homogeneous as well as where obvious stratification occurs.

4.3 Numerical Computer Model

A numerical ground water model (FLOW3D) (Durbin and O'Brien, 1987) was used to simulate the first 3-day pumping test, to evaluate the results, and to develop parameters for a longer test. A numerical model has the advantage that it can combine conditions evaluated individually by the previously discussed methods. FLOW3D, a U.S. Geological Survey finite element computer program, was used in this modeling effort. FLOW3D was selected due to its ability to simulate unconfined aquifers, the flexibility inherent to finite element models, and the users familiarity with this model. When unconfined conditions are detected by the model, the storage values used in calculations is specific yield, rather than storativity (both parameters are input to the model).

A numerical ground water computer model consists of a computer program (or code) that solves the mathematical equations that describe the way in which water flows beneath the ground in relation to various boundaries. Boundaries represent the physical or hydrologic limits of an aquifer. Stresses on an aquifer, such as the pumping of a well, can be simulated in a model. Most computer models use either a finite element or of finite difference approximation to solve the mathematical equations. These approximations are systematic approaches for solving the complicated equations governing aquifer behavior (Wang and Anderson, 1982). With either type of model, a series of points (called "nodes") are used to produce a grid that represents the aquifer. The grid can be designed to represent the aquifer in two or three dimensions. Aquifer parameters (storage and hydraulic conductivity) and initial conditions (water levels) are assigned to each node in the grid based on field knowledge of the aquifer or literature values for similar aquifer types. The grid is used to develop and solve the complex system of mathematical equations defining aquifer behavior.

The FLOW3D model used to simulate the pumping tests completed at the Mazama pumping test site uses the finite element method. In this method, the nodes that make up the grid are at the corners of triangular elements. The piezometric head (or water level) at each node is calculated based on a balancing of flows into and out of each element and storage changes in each element. The finite element method is flexible and can account for irregular aquifer boundaries and changes in the character of the aquifer (Wang & Anderson, 1982). Documentation for the FLOW3D model is included in Appendix J.

In order to limit the cost of the modeling, several simplifying assumptions were used and the goal of the modeling effort limited. The primary objective of the model was to see if concepts and assumptions concerning aquifer characteristics derived from the pumping test analysis could be used to simulate the aquifer. The model was not intended to simulate the aquifer exactly, but only to provide a preliminary testing of combinations of conditions that might be encountered.

The main assumptions used in model setup were:

- The pumping caused water to flow radially into the well
- The non-pumping water table was flat
- The aquifer is made up of a limited number of distinct and continuous layers
- The water levels at the boundaries of the model can be held constant

Although able to accommodate more of the aquifer conditions than the analytical methods previously described in Section 4.2, a computer model is still a simplification of the aquifer. Because detailed information about variations within the aquifer are not available, the model is used to evaluate the level of understanding of aquifer conditions in the vicinity of the area of interest (i.e., the Mazama bridge area). The model area coverage is shown in Figure 4-8.

4.3.1 Model Design and Assumptions

The ground water model used to evaluate the Mazama pumping test was designed to

- Aid in interpreting pumping test results
- Guide the design of a second pumping test
- Assess potential pumping impacts on the Methow River
- Simulate alluvial aquifer conditions
- Evaluate the effect of potential layering in the aquifer

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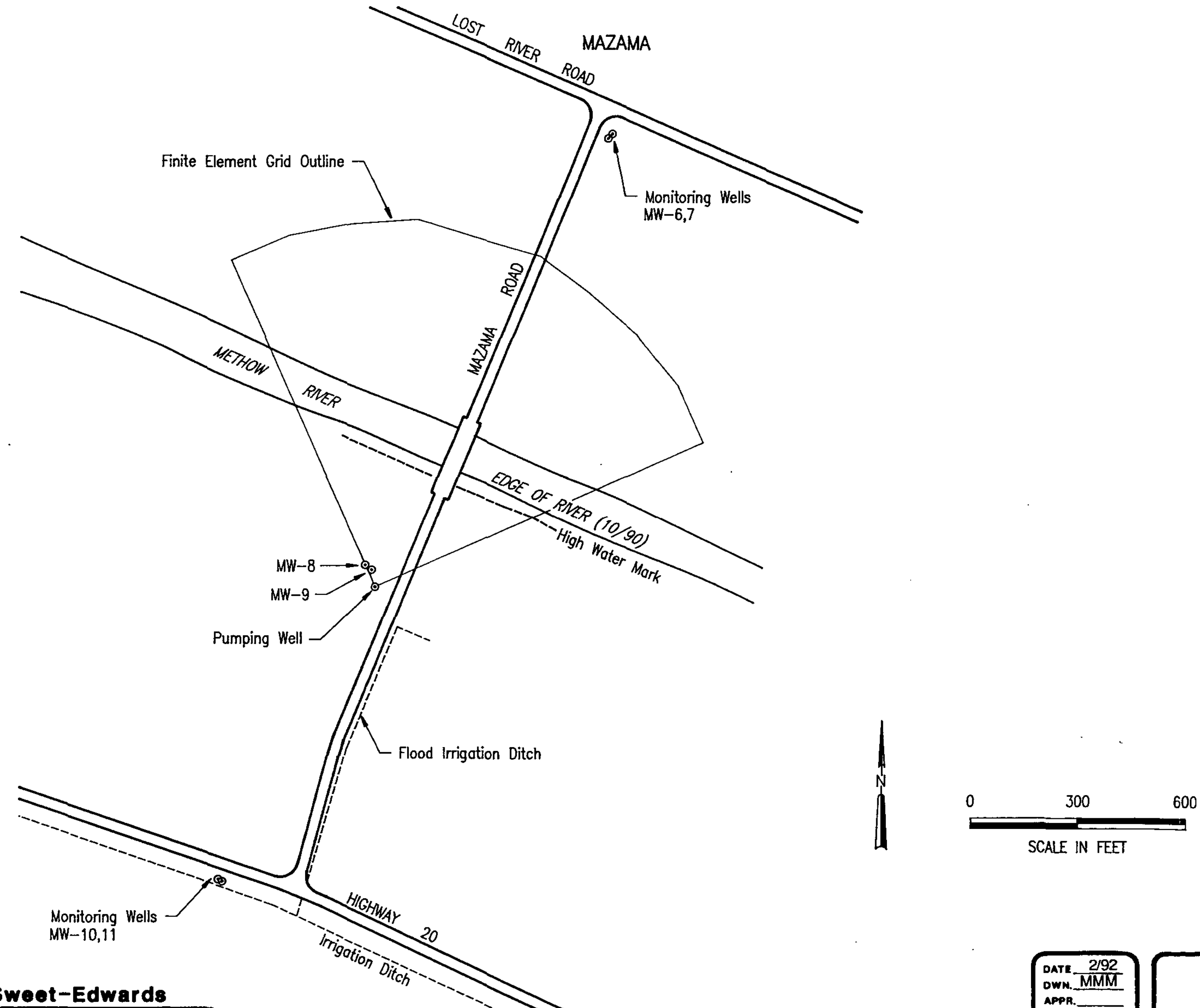

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Figure 4-8
METHOW VALLEY GWMA

NUMERICAL SIMULATION AREA

- Attempt to simulate the vertical hydraulic gradients measured at the test site

A primary model assumption regarding the aquifer test is that all flow in the aquifer is directly toward the pumping well during the test. The assumption is inherent in most aquifer test analysis methods and allowed the model to be designed as a wedge (see Figure 4-9) with the pumping well at the point. This greatly simplified the model structure and reduces its cost, but also resulted in decreased flexibility. This simplification, in itself, was used when evaluating the model results and provides insight into the character of the aquifer.

The FLOW3D model was constructed with 1098 nodes and 1664 elements in eight layers. The finite element grid is in the shape of a wedge in order to accurately simulate flow to the pumping well (see Figure 4-9) located at the point of the wedge. Based on the assumption that radial flow is toward the well, the radial sides of the wedge are considered to be 'no-flow' boundaries, and water must flow parallel to these boundaries. The model was run several times using different configurations of the aquifer parameters (hydraulic conductivity and storage) and layering (anisotropy).

The Methow River was modeled as a series of "fixed-head" nodes. At these points, the water level is set to a certain level and not allowed to change during the simulation. Fixed heads were considered reasonable for this

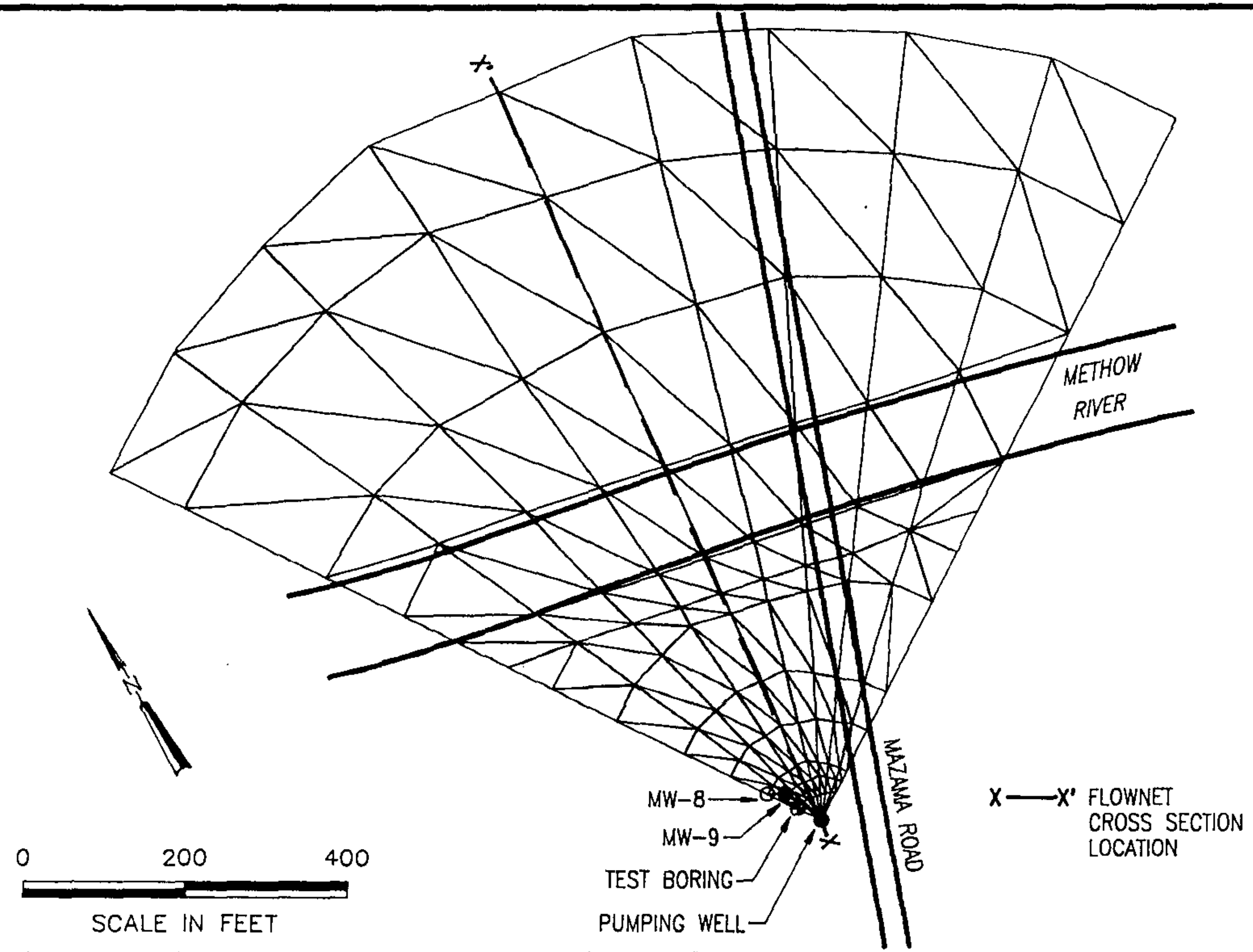

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Figure 4-9
METHOW VALLEY GWMA

FLOW3D FINITE ELEMENT GRID

simulation because the upper aquifer is made of coarse gravel that should provide a high degree of continuity and because, as evidenced by monitoring data, river levels are relatively constant with head changes of less than 0.5 feet over short intervals. A more complex mathematical procedure for simulating river nodes was tested but did not provide accurate results.

The outer edge of the finite element model was made up of fixed head nodes set 1000 feet from the pumping well (see Figure 4-9). This distance approximates the distance from the pumping well to the Realty wells and was deemed adequate to evaluate the limited objectives of the pumping tests.

The model was originally applied to aid the interpretation of the 3-day aquifer test, completed in September 1990. A numerical model was needed because the results of the test (and its short duration due to power failure) were not easily interpreted by standard methods. This in part, also justified the second pumping test. The model was used to test pumping scenarios for the second test. Following the second test, information and insights obtained from the additional test data were used to refine the model.

Different model runs were completed assuming different aquifer configurations. These configurations essentially consisted of varying the thickness of the eight layers and the values of hydraulic aquifer parameters (e.g., hydraulic conductivity and storage). The values of aquifer parameters used in model runs should be considered as qualitative only.

4.3.2 Model Runs

In order to evaluate the objectives of the modeling exercise, several simulations were performed. Each simulation involved slight modifications in the model set up to evaluate or assess the aquifer assumptions. The simulations can be broadly grouped as follows:

- Three-day pumping test
- Predictive hypothetical 30-day pumping test
- Thirteen-day pumping test
- Conceptual model assessment

Three-Day Pumping Test. Six time steps of ½-day were used to model the three-day pumping test. Total aquifer thickness (eight layers) was set to 200 feet because it was originally thought that a silty layer at a depth of approximately 200 feet might represent the bottom of the aquifer. The river was modeled by setting the surface nodes corresponding to the river locations as fixed heads (at 2093.7 feet MSL). The aquifer was assumed to be homogeneous and isotropic, with the river being approximately 360 feet from the pumping well. The initial hydrologic parameter values used in the model were: hydraulic conductivity of 267 ft/day (transmissivity of 400,000 gpd/ft), specific yield of 0.20, and storativity of 0.001. Well discharge during the simulated test was 1000 gpm. The bottoms of the eight layers were set to correspond to the bottom of the screened intervals of the pumping and observation wells used during the test. Table 4-3 shows the parameter values used in this model run.

Predictive 30-Day Pumping Test. A predictive numerical model of a 30-day pumping test was constructed based on the 3-day test run calibration to assess the probable effects of a longer test and the potential impacts of the test on (or from) the Methow River. Thirty 1-day time steps were used to simulate a pumping period with a simulated pumping well discharge of 1700 gpm. Parameter values were the same as for the 3-day test. A longer pumping test was designed based on the model output.

Thirteen-Day Pumping Test. Following the 13-day pumping test, the finite element model was used to evaluate the hydraulic conductivities estimated using the previously described analytical methods (Sections 4.2.1 through 4.2.5). A simulation of the 13-day test was also developed. For this simulation, the model configuration was altered. Deeper layers were added

Table 4-3

Methow Valley GWMA
FLOW3D Model Setup
3-Day Pumping Test Simulation

Layer	Hydraulic Conductivity (ft/day)	Storativity* (unitless)	Bottom Elevation (feet)
1	267.5	0.2 (0.001)	2070
2	267.5	0.2 (0.001)	2025
3	267.5	0.2 (0.001)	2010
4	267.5	0.2 (0.001)	1995
5	267.5	0.2 (0.001)	1975
6	267.5	0.2 (0.001)	1930
7	267.5	0.2 (0.001)	1920
8	267.5	0.2 (0.001)	1900

* Values in parentheses used if model does not detect unconfined conditions.

and layer thicknesses were varied based on the drilling logs, pumping tests, and geophysical surveys carried out in the Mazama area. The total thickness of the modeled aquifer was increased to 1100 feet for eight layers. As in previous runs, the Methow River was modeled by setting fixed head surface nodes (2093.7 ft) corresponding to river locations. Fixed head elevations (referenced to MSL) were set at the far edges of the model using water levels measured in the Mazama Realty wells. Initial static water levels were set for each layer based on measured water levels. The following additional assumptions were applied: The aquifer is layered (or heterogeneous) but homogeneous within the layers; the horizontal and vertical hydraulic conductivities are different (vertical anisotropy); and the horizontal conductivity within a layer is 10 times greater than the vertical conductivity between layers. This last assumption is common for alluvial aquifers (Freeze and Cherry, 1979). Pumping well discharge was set to 2075 gpm, a discharge rate corresponding to actual pumping test discharge. Table 4-4 summarizes the parameter values used in this model scenario.

In order to simulate the 13-day pumping test (March/April 1991), transmissivities which were calculated from the pumping test data were input into the model. Because the model uses hydraulic conductivities to characterize matter in each layer, and because estimated transmissivities

Table 4-4

Methow Valley GWMA
FLOW3D Model Setup
13-Day Pumping Test Simulation

Layer	Hydraulic Conductivity (ft/day)		Storativity* (unitless)	Bottom Elevation (feet)
	Scenario 1	Scenario 2		
1	16700	445	0.2 (0.001)	2070
2	242	63	0.2 (0.001)	1835
3	1980	63	0.2 (0.001)	1700
4	334	74	0.2 (0.001)	1400
5	100	100	0.2 (0.001)	1300
6	100	100	0.2 (0.001)	1200
7	100	100	0.2 (0.001)	1100
8	100	100	0.2 (0.001)	1000

NOTE: Value in parentheses used if model does not detect unconfined conditions.

represent the capacity of the entire aquifer, the distribution of transmissivities in each layer was evaluated. An adequate distribution of the transmissivity values is very important because the pumping well was only screened in a small part of the aquifer and vertical flow appears to be an important part of aquifer behavior.

Two scenarios were run using the interpreted and distributed aquifer transmissivities. Scenario 1 relied on hydraulic conductivity values using the thickness of each layer and the estimated transmissivity for that layer. Scenario 2 calculated hydraulic conductivities using the entire estimated aquifer thickness (1000 ft) with the estimated transmissivity for each layer. One-half-day time steps were used to simulate the pumping test with a pumping rate of 2075 gpm.

Conceptual Model Assessment. Two simulation runs were used to evaluate a conceptual model of the alluvial aquifer. These simulations attempted to compensate for simplifications of the aquifer assumptions used in the model setup. The results of these simulations can only be used qualitatively. Hydraulic conductivity values from Scenario 2 of the 13-day aquifer test simulation were used in both runs.

Run 1 removed water from nodes near the bottom of the model below the pumping well. The purpose of this model run was to simulate water flowing to a highly conductive layer at the bottom of the aquifer. This run was an attempt to simulate the downward vertical gradients measured during the 13-day test. Recharge equal to the amount to water removed from the aquifer was added over the surface of the model. The recharge was necessary to ensure that water would flow along the vertical gradients. The river was not simulated in this run in order to restrict aquifer recharge from the river. This was done in order to evaluate the concept that the upper part of the aquifer is highly conductive and water entering it from the river is quickly distributed throughout the shallow zone. Recharge to the deeper aquifer zones would, therefore, occur over a large area rather than in a local area. The flownet derived from this run is presented in Figure 4-10.

Run 2 was completed, as a comparison, without the withdrawal of water from the deep boundary nodes. The flownet derived from Run 2 is presented in Figure 4-11.

4.3.3 Interpretations of Model Runs

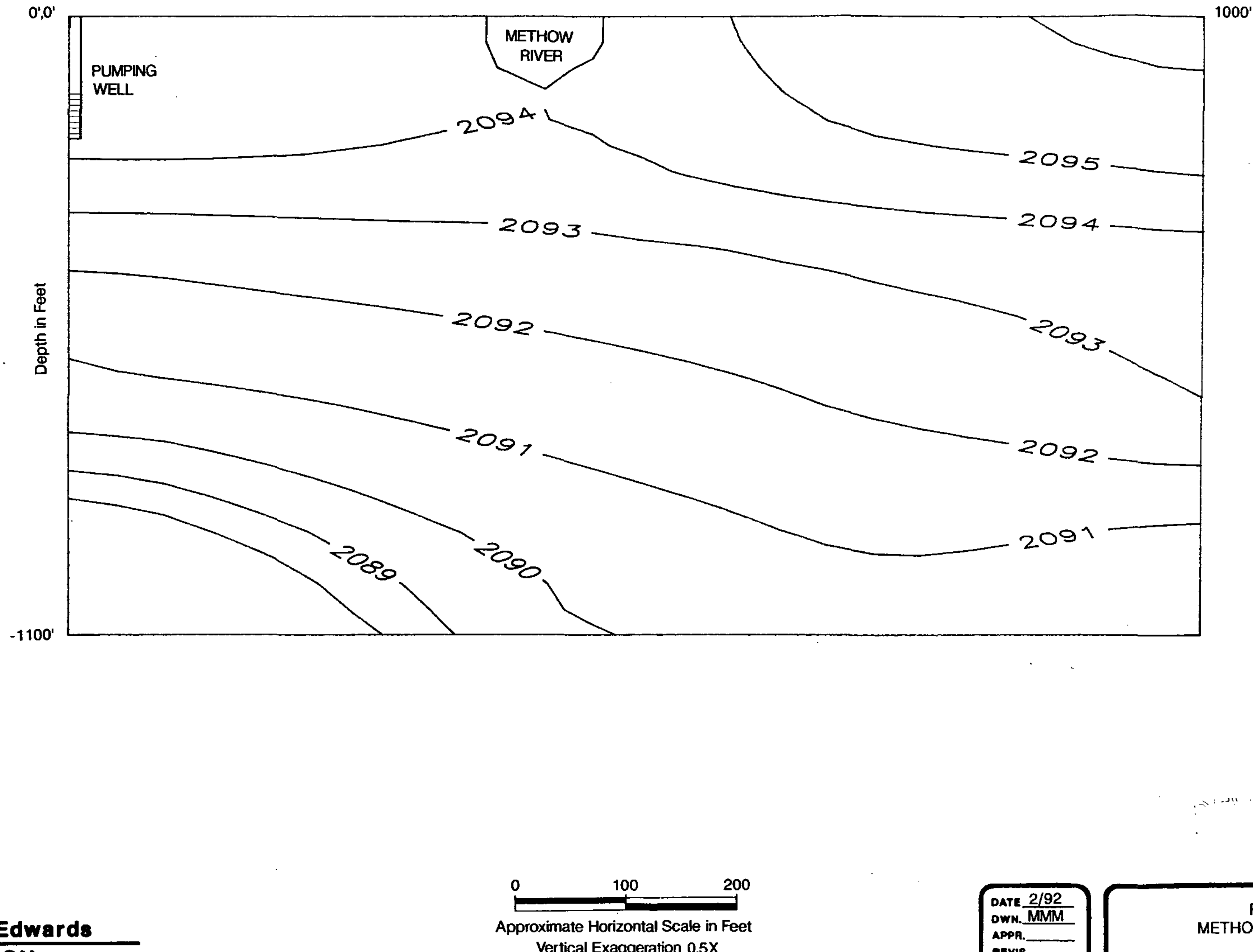

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Figure 4-10
METHOW VALLEY GWMA

FLOWNET CROSS-SECTION, RUN #1

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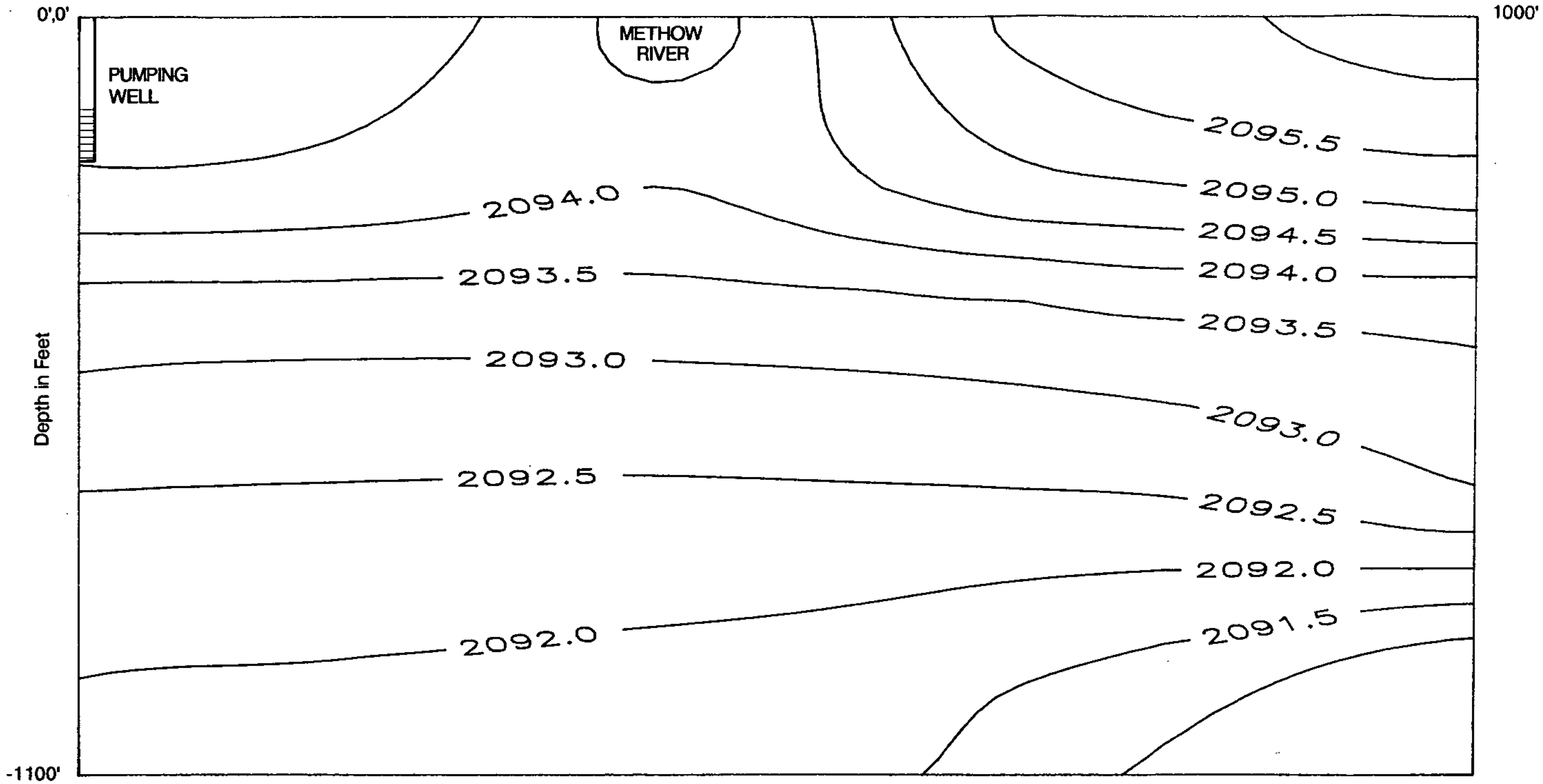

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0 100 200
Approximate Horizontal Scale in Feet
Vertical Exaggeration 0.5X

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Figure 4-11
METHOW VALLEY GWMA

FLOWNET CROSS-SECTION, RUN #2

Three-Day Pumping Test. The observed and computed drawdowns were comparable for the intermediate depth observation well. This well is screened in the same zone as the pumping well. The estimated transmissivity of the aquifer (400,000 gpd/ft) is realistic and compares with the analytical estimates (see Table 4-1).

Computed drawdowns of the shallow well, however, are greater than the measured drawdowns. This indicates that either the shallow layer is more conductive than the intermediate or deep layers, or the specific yield is higher. It was also considered possible that the observed drawdowns were influenced by delayed yield effects and that a longer pumping test would produce drawdowns more comparable to the predicted drawdowns.

> vert K?

The computed drawdowns for the deep well are also greater than measured drawdowns. This may be due to the assumed simple aquifer character (i.e., isotropic and homogeneous). Actual flow from deeper zones up to the pumping well is likely not to be as great as in the numerical model simulation because the vertical hydraulic conductivity is probably less than the horizontal hydraulic conductivity. Additionally, the deep piezometer is screened near the base of the model, which is not at the same depth as the bottom of the aquifer. Water induced to flow through this zone due to pumping would cause the measured water levels to be less affected by pumping than those predicted in the model.

Modeling of the 3-day pumping test demonstrated that aquifer behavior and parameters could not be adequately evaluated by this pumping test. It was indicated that a higher discharge and longer duration aquifer test was needed to stress the shallow zone and better define the effects of vertical flow. Additionally, the model indicated that water level data from below the deepest observation well would be needed to evaluate the deeper portions of the aquifer. Finally, the model was unable to evaluate river/aquifer interactions except in a limited, qualitative manner.

Predictive 30-Day Pumping Test. This simulation indicated that, for the simple wedge-shaped aquifer, the river would replace essentially all the water pumped from the aquifer after approximately four days. In directions away from the river, the hydrologic effects of pumping would spread to the edge of the model in four days. This simulation provides a base of comparison for the 13-day pumping test, because differences between the simulation and observed response would be expected to indicate aquifer complexities.

Thirteen-Day Pumping Test. Drawdown plots (Appendix J) from nodes corresponding to observation wells showed that Scenario 2 (using a conductivity calculated from the transmissivity for the entire aquifer) produced relative drawdowns more closely resembling actual drawdowns than those produced by Scenario 1. It should be noted that water levels predicted by the model are relative and these levels are not the same as observed water level values. Absolute water levels calculated by the model were highly sensitive to the initial water level values used as part of the assumptions. Also, because of the simplified design of the model, the boundary conditions of the aquifer were not simulated in a realistic way. Again, note that the model was simplified to control costs and was intended to be used qualitatively.

These pumping test model simulations (Appendix J) indicate that the pumping test analytical results make reasonable estimates of the aquifer properties (i.e., within one order of magnitude of the actual values) and also support the assumption of a multi-layered system at the site as shown by drilling and geophysical survey data.

Conceptual Model Assessment. By comparing the observed (Figure 4-12) and calculated flownets contained in Figures 4-10 and 4-11 (see Appendix J), the Run 1 flownet (Figure 4-10) is shown to more closely

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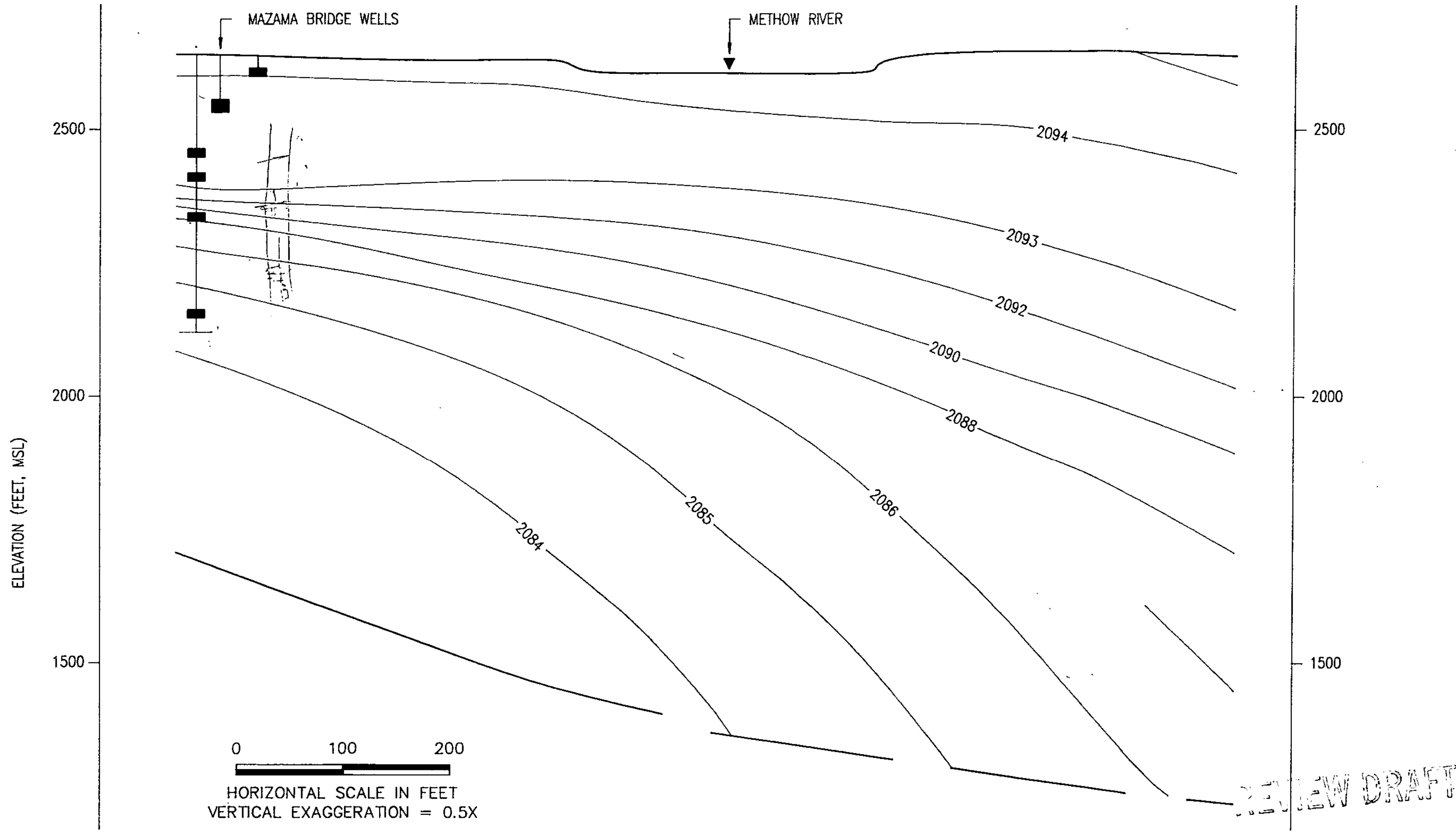

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Figure 4-12
METHOW VALLEY GWMA

FLOWNET CROSS-SECTION, OBSERVED

resemble the observed flow patterns than Run 2 (Figure 4-11). Again, exact matches between computed and observed water levels are not possible due to the simplified model design. Qualitatively, however, the model indicates that water may flow rapidly through coarse gravel and cobbles at the top of the aquifer. Part of this water could infiltrate downward to the intermediate and deep aquifer zone to supply water flowing horizontally downgradient, possibly through a highly conductive zone that may be present on the south side of the valley. It should be emphasized that the model simulates a general pattern of potentiometric heads that is similar to but not the same as the measured patterns. As a result, these conclusions are speculative and neither the model nor direct measurement in the observation wells provide a complete definition of aquifer characteristics and dynamics.

Summary. In summary, the results of the finite element FLOW3D model conform to the results obtained from aquifer test analyses and supports the conceptual model of the aquifer at this location. This overall aquifer conceptualization is based on boring log data, geophysical survey analysis, hydrogeologic facies models, and the pumping test results. The model is limited because it does not allow realistic simulation of the aquifer boundaries.

This model has been extended as far as is reasonable. A model that covers the full width of the aquifer and extends up- and downstream of the test area should be used for further characterization of the aquifer.

5 CONCLUSIONS AND RECOMMENDATIONS

The pumping test analyses and numerical model simulations performed for the Upper Methow Valley aquifer provide an important body of information on which to base estimates of hydrologic parameters and conclusions regarding aquifer behavior and interactions. The conclusions and recommendations presented are limited primarily to technical aspects of the evaluation and direct conclusions on aquifer behavior based on these estimations of aquifer parameters. This report is not intended to address broader questions of aquifer capacity, water quality, or the management issues related to allocation of surface and ground water resources.

5.1 Limitations of Characterization

The interpretations of pumping tests and model simulations are limited by the type and quality of data available, and by the complexity of the aquifer. The following limitations to characterization are intended to provide a context for conclusions and recommendations.

- High conductivity and the resulting rapid aquifer response to pumping precludes the precise estimation of aquifer storativity values.

- Aquifer response in the area of the tests may be significantly affected by recharge in the Early Winters Creek area, approximately 0.5 miles to the northwest. Data are insufficient to characterize this effect.

- The interpretation of aquifer response to short term fluctuations in recharge from and discharge to surface water during the 13-day pumping test was limited by the fact that a number of the water level recorders (transducers) went off line after five days and were not restarted until approximately the ninth day.

- The correction of aquifer pumping test data for meteorologic and diurnal stream flow variations is limited by the complex response of different aquifer levels to upstream recharge conditions, and by the lack of data on those conditions.

- Overall, pumping test interpretations were capacity limited due to very high aquifer transmissivities. The ability to stress the aquifer was limited by the available well sizing and pumping capacities.

- Confidence in calculated aquifer parameters and predicted aquifer characteristics decreases with increased depth due to limitations of available data.

5.2 Aquifer Characterization/Conclusions

- Two aquifer tests were performed with instrumentation on up to 12 observation wells. The first aquifer test was conducted for a period of approximately 3 days at a pumping rate of approximately 1050 gallons per minute. The second aquifer test duration was 13 days and the pumping rate was approximately 2,100 gallons per minute. Neither test was able to fully stress the aquifer.

- The aquifer tests performed provided a significant amount of useful data for interpreting aquifer behavior and in defining aquifer characteristics.

- The aquifer tests provide critical information on the interaction between the intermediate and shallower aquifer zones and the interaction between these aquifer zones and the Methow River.

- The extremely high hydraulic conductivities of the aquifer limited the application of classical methods of aquifer test interpretation due to the extremely rapid response of the aquifer to both drawdown and recovery. As a result, multiple analysis methods were used to provide a range of interpretations.

- The pumping tests indicate that the aquifer is sufficiently conductive to support hydraulic pressure waves, as a result of underdamping, for distances of at least 50 ft.

- In spite of extremely rapid drawdown and recovery times, estimates of storativity, transmissivity and hydraulic conductivity were possible for shallow, intermediate, and the upper deep portions of the aquifer.

- Based on pumping test analyses, the transmissivity of the intermediate aquifer zone is estimated at 800,000 to 1,000,000 gpdf, with storativity of 0.0001 to 0.003, indicating semi confined conditions.

- Based on pumping test data, the shallow aquifer zone has a transmissivity of well over 1,000,000 gpdf with a storativity of 0.1 to 0.2, indicative of unconfined conditions.

- The aquifer tests provide strong indications of recharge to both the shallow and intermediate aquifer zones as a result of recharge sources upgradient of the test area.

- The aquifer tests provided a significant body of information regarding the interactions of hydrostratigraphic units (aquifer zones) to depths as great as 450 feet in response to diurnal changes in the Methow River level as well as recharge patterns from upgradient sources.

- The numerical model simulation indicated that, because of lateral boundary conditions and the high hydraulic conductivity, expansion of aquifer model interpretations may require a wider array of calibration monitoring wells located linearly along the long axis of the valley, i.e., up- and downgradient.

- Although aquifer tests results may be generally applied with some caution to the upper valley portion of the Methow River aquifer, they cannot be applied with any degree of confidence below the Weeman Bridge area, due to changes in geology and the resulting changes in the hydrogeologic characteristics.

- Consideration of the aquifer test results alone does not clearly address or answer Ecology concerns regarding aquifer and surface water continuity.

- In order to significantly stress the aquifer, a pumping test of roughly 10,000 gallons per minute would be required. Pumping time should be approximately 10 days. A pumping test of this magnitude was beyond the scope of the current project and is unlikely to be cost effective.

- The results of the two aquifer tests and numerical simulations provide data that result in a basis for identifying additional data needs.

5.3 Recommendations

The results presented in this report should be used with a considerable degree of caution in making recommendations, due to the limitations on technical interpretation and the dynamic complexity of the aquifer. Recommendations based on the results of the aquifer tests are limited to technical conclusions and the data necessary to more fully understand aquifer capacity and behavior.

The primary areas of uncertainty at this time relate to the areas of recharge to the aquifer (the degree of aquifer and stream interaction), and the importance and characterization of flow in the deeper aquifer zone. Current testing indicated pressure connections between the upper, intermediate and deep zones, but did not clarify the characteristics of deep aquifer transport or the areas of recharge. In order to address these data gaps, additional deep wells and concomitant aquifer testing may be necessary in the Mazama Bridge and/or Weeman Bridge areas.

Because the pumping test analyses indicated that hydrologic responses in the Mazama Bridge area were apparently affected by upstream recharge (Early Winters Creek area) dynamics, a clearer interpretation of aquifer capacities may be obtained at locations further removed (at least 1 mile) from tributary stream recharge source areas. Investigations in the areas above Early Winters Creek or below Goat Creek would be recommended to compare aquifer response with and in the absence of shallow recharge.

The interaction between the different hydrostratigraphic units, or aquifer zones, and between the aquifer(s) and the Methow River has not been adequately addressed. Accurate assessment of the degree of interaction and the rate of response, particularly as they apply to changes in the ground water/surface water recharge-discharge relationships would require long term water level monitoring with a high frequency of water level measurements. Current hydrology monitoring is completed on a quarterly basis with some additional monitoring completed at a frequency of no greater than monthly. To assess ground water/surface water interactions would require a monitoring frequency of at least daily, and preferably hourly, measurements of the Methow River and selected monitoring wells. To identify recharge-discharge relationships would require that the intensive hydrogeologic monitoring of nonpumping conditions continue through a full year to identify seasonal reversals in the relationship.

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