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Hydrogeology of the Thousand Springs to Malad Reach of the Enhanced Snake Plain Aquifer Model

Prepared for

Idaho Department of Water Resources
Boise, Idaho

September 2008

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INTRODUCTION

The Enhanced Snake Plain Aquifer Model (ESPAM) is an important tool used by the Idaho Department of Water Resources (IDWR) in estimating impacts between ground water use and surface water resources to support water management decisions (Cosgrove and others, 2006). A significant portion of the water that discharges from the aquifer is from springs that are located along the Snake River. Drain cells are used in the model to represent the springs. The drain cells were aggregated into six reaches: Devils Washbowl to Buhl, Buhl to Thousand Springs, Thousand Springs, Thousand Springs to Malad, and Malad to Bancroft.

The objectives of this report are as follows: 1) describe the hydrogeologic setting of the Thousand Springs to Malad reach of the Snake River, 2) describe how the model represents the hydrogeology of this area and 3) provide recommendations relative to changes of the model to better represent the field conditions. The report is based on a review of available reports (citations provided in the text), discussions with individuals who work for the IDWR and the Idaho Geological Survey (IGS) and two field site visits (February 8-9, 2007 and March 22-23, 2007). In addition, a test well was drilled in August 2008 in township 7 south, range 14 E, southeast quarter of the northwest quarter of section 32. Geologic maps of the general area, published in 2005 by the IGS, were particularly useful.

GENERAL GEOLOGIC SETTING

The Thousand Springs to Malad reach of the Snake River is located along the western edge of the Snake Plain aquifer. Figure 1 is a general location map. Figure 2 shows the geologic units in the vicinity of the Thousand Springs to Malad reach (Kauffman and others, 2005a). The stratigraphic units shown on Figure 2 east of the Snake River in the Thousand Springs to Malad reach are described below (Kauffman and others, 2005a; Kauffman and others, 2005b; Othberg and others, 2005).

- Quaternary Basalt Units –Pleistocene basalt units are mapped under a thin sediment cap on the plateau surface. The basalt units that outcrop in the Thousand Springs to Malad reach area are described below.
    - Qnb – Basalt of Notch Butte – The source of the basalt is Notch Butte located about 22 miles east of Tuttle. Outcrops of this basalt unit occur on the plateau surface and also along the Snake River west and south of Hagerman.
    - Qbby – Basalt of Bacon Butte, younger unit – The source of the basalt is believed to be Bacon Butte located about 14 miles east-northeast of Wendell. Outcrops of this basalt unit only occur on the plateau surface.
    - Qbbo – Basalt of Bacon Butte, older unit – The source of the basalt is believed to be Bacon Butte located about 14 miles east-northeast of Wendell. Outcrops of this basalt unit only occur on the plateau surface.
    - Qftb – Basalt of Flat Top Butte – The source of the basalt is Flat Top Butte located about 19 miles to the southeast. Outcrops of this basalt unit only occur along the Snake River in the southern portion of the area.

- Qgb – Basalt of Gooding Butte – The source of the basalt is Gooding Butte located about 6 miles northeast of Tuttle. Outcrops of this basalt unit only occur on the plateau surface.

- Quaternary Sedimentary Units – Sedimentary units are mapped at various locations mostly between the Plateau rim (general western limit of the Quaternary Basalt units) and the Snake River. The units that outcrop in the Thousand Springs to Malad reach area are described below.
  - Qam – Alluvium of main streams (Holocene and Pleistocene) – This unit includes channel and flood-plain deposits of the Snake and Malad River.
  - Qoam – Older alluvium of main streams (Pleistocene)
  - Qas – Alluvium of side streams (Holocene and Pleistocene) – This unit is primarily stratified clay silt and sand but also includes high-energy boulders associated with the Bonneville Flood.
  - Qoas – Older alluvium of side streams (Pleistocene)
  - Qls – Landslide deposits (Holocene and Pleistocene)
  - Qabf – Fine-grained deposits in slack-water basins (Pleistocene)
  - Qabg – Sand and gravel in giant flood bars (Pleistocene)
  - Qy – Yahoo Clay (Pleistocene) – This unit is attributed to sediment accumulation in a temporary lake formed by damming of the Snake River by basalt. The Yahoo Clay is younger than the basalt of Notch Butte (Qnb) but older than the Bonneville Flood.

- Tertiary Sedimentary and Basalt Units – Sedimentary and basalt units are mapped at various locations between the Plateau rim and the Snake River. Units that outcrop in the Thousand Springs to Malad reach area are described below.
  - Tt –Tuana Gravel (Pliocene) – This unit is described as a well-bedded and sorted pebble and cobble gravel that is interbedded with layers of sand and silt that formed on the top of the Glenns Ferry Formation.
  - Tsgf – Glenns Ferry Formation (Pliocene) – In the Hagerman valley, this formation consists primarily of flood plain deposits that include silt, clay, locally cemented sand and fine-pebble gravel.
  - Tos – Basalt of Oster Lakes (Pliocene) – This coarse-textured basalt outcrops in the southern portion of the Thousand Springs to Malad reach area where it has been stripped of cover material and scoured by the Bonneville Flood. This unit was previously included as part of the "Banbury Basalt" by Covington and Weaver (1990). The source area is unknown but may be to the southwest.
  - Tub – Older Tertiary Basalt Flows (Pliocene or Miocene) – This dense to altered and weathered basalt outcrops along the Snake River in the southern portion of the Thousand Springs to Malad reach and also near the confluence of the Malad and Snake Rivers. This unit was previously

included as part of the "Banbury Basalt" by Covington and Weaver (1990). The source area is unknown but may be to the southwest.

The Quaternary Basalt Units outcrop mostly on the Plateau east of the Snake River whereas the Quaternary sedimentary units and the Tertiary sedimentary and basalt units outcrop between the Plateau rim and the Snake River. Two outcrops of Quaternary Basalt are shown on Figure 2 west of the plateau. One (Qnb) is along the Snake River immediately west of Hagerman. A smaller outcrop (Qftb) occurs near the Snake River south of Hagerman. Dr. Kurt Othberg of the IGS (personal communication 2007) indicated that some of the Basalt of Notch Butte (Qnb) flowed over the plateau rim and onto the older sedimentary and basalt units along the Snake River near Hagerman.

The geologic map (Figure 2) shows that the Tertiary Glenns Ferry Formation (Tsgf) outcrops immediately below the plateau rim and apparently underlies the Quaternary Basalt Units within most of the Thousand Springs to Malad reach area. Tertiary Basalt Flows (Tub) outcrop in the southern portion of the Thousand Springs to Malad Reach and are believed to underlie the Quaternary Basalt Units in this area. The Tertiary basalt (Tub) also outcrops in the Malad River canyon near the confluence with the Snake River.

GENERAL HYDROGEOLOGIC SETTING

The Snake Plain aquifer in the general vicinity of the Thousand Springs to Malad reach is hosted by the Quaternary basalt units with thin sedimentary units. The effective base of the aquifer is the contact between the Quaternary basalt units and the underlying Tertiary sedimentary and/or basalt units. Almost all of the springs within the Thousand Springs to Malad reach are located along the contact between the Quaternary basalt units and the underlying Tertiary sedimentary and/or basalt units.

Dr. Kurt Othberg (personal communication 2007) postulated that the contact between the Quaternary basalt units and the underlying Tertiary sedimentary and/or basalt units generally dips to the east-northeast from the plateau rim in the Thousand Springs to Malad reach area. Dr. Othberg's theory is based on the large-scale structural setting of this portion of the Snake Plain where the center of the basin has been down-dropped relative to the margins of the basin. The structural center of the basin is believed to be east-northeast of the Thousand Springs to Malad reach.

LOCAL HYDROGEOLOGIC SETTING

Information on the hydrogeologic setting of the Thousand Springs to Malad reach area is available from two primary sources: 1) geologic maps (available from IGS) and 2) well driller reports for wells constructed in the general area (available from the IDWR web site). Information from these sources was analyzed to develop an improved understanding of the geologic controls for ground-water flow in the area.

The elevations of mapped geologic contacts in the Thousand Springs to Malad reach, such as between the Quaternary basalt units and the underlying Tertiary sedimentary and/or basalt units, were estimated by transferring the location information from the IGS geologic maps to digital topographic maps. The accuracy of the contact elevations is approximately plus or minus 30 feet. The potential error is this large because many of the contacts are mapped on hill slopes such that small changes in location can result in large changes in elevation.

Information on subsurface geologic contacts was obtained from the driller reports for wells located in the area. The locations of selected wells were determined in the field using Global Positioning System (GPS) equipment (IDWR, 2007 and 2008). Well-head elevations were estimated using the GPS location information and digital topographic maps. Table 1 presents a summary of information on wells used in this analysis.

Geologic information on the well driller reports was interpreted in general ways. The depths noted for changes from sediment to basalt and back to sediment were assumed to be accurate. The Quaternary basalt was differentiated from the Tertiary basalt based on location of the well relative to surface geology and on the material descriptions. The Quaternary basalt generally is described with frequent layering of black basalt, red basalt or fracture zones. The Tertiary basalt generally is described as more uniform with fewer red or fracture zones. Information on depth to water was also reviewed. The accuracy of the subsurface contact information is approximately plus or minus 30 feet. Sources of error include driller error in measuring or noting depths plus errors introduced by locating the wells on the digital topographic maps. The water-level elevation estimates also represent the month and year when the well was drilled.

Characteristics of the Tertiary Units

Most of the area west of the plateau rim in the Thousand Springs to Malad reach is not underlain by Quaternary basalt. The well logs in this area generally include a considerable thickness of fine-grained sediment overlying basalt. The sediment is mapped as Holocene (such as Qam and Qas), Pleistocene (such as Qy) or Tertiary (such as Tsgf). Most of the basalt underlying the sediment is Tertiary in age and is likely that mapped as Tub on Figure 2. Quaternary basalt is also present west of the plateau rim in the Thousand Springs to Malad reach.

The approximate elevation of the top of the Tertiary basalt based on well log information is shown on Figure 3. The Tertiary basalt ranges in elevation from 2,837 to 3,026 feet with most elevations in the range of 2,880 to 3,000 feet. Some wells in the Hagerman Valley area penetrate basalt thought to be Quaternary in age. Three such wells are identified as Qnb on Figure 3.

Water-Level Elevations in Wells

Water-level elevations for wells in the Thousand Springs to Malad Reach were estimated using depth-to-water numbers given on the well driller reports and well elevations taken from digital topographic maps based on GPS location coordinates. Potential sources of uncertainty in the water-level elevation data include: 1) land elevation accuracy, 2) accuracy of depth-to-water measurements obtained by the drillers and 3) water-level measurements taken at different times of the year and in different years. Only general interpretation of the data is possible because of these issues.

The water-level elevation values, shown on Figure 4, range from 2,754 feet to 3,172 feet. A number of wells on the eastern side of the area that have water-level elevations in the range of 3,112 to 3,172 feet are all completed in the Quaternary basalt that hosts the Snake Plain aquifer. These water-level elevations generally fit those given by Cosgrove and others (2006) for the Thousand Springs to Malad reach. Most of the remaining wells are completed in Tertiary. Water-level data are available for three wells completed in Quaternary basalt southeast of Hagerman (see Qnb notation on Figure 3 for location).

The wells that are not completed in the Snake Plain Aquifer (most are located between the plateau rim and the Snake River) have water-level elevations in the range of 2,754 to 3,010 feet, as much as 400 feet lower than the Snake Plain aquifer. In general, the water-level elevations between the plateau rim and the Snake River are higher in the southern portion of the area than in the northern portion. This suggests ground-water flow is from south to north in the area between the plateau rim and the Snake River. The water-level elevations for the Snake River from the digital topographic maps are 2,890 feet above Upper Salmon Falls Dam, 2,802 feet above Lower Salmon Falls Dam and less than 2,740 feet below Lower Salmon Falls Dam. The water-level data for the northern two-thirds of the area suggest the aquifers between the plateau rim and the Snake River are hydraulically connected to the Snake River. Wells in the lower tier of section of Township 7 south have water-level elevations above the Snake River in the southern portion of the area. These wells may be influenced by discharge of water from the Snake Plain Aquifer as well as the river. Additional data collection and analysis is needed to confirm or refute these hypotheses.

The wells in the area west-southwest of the Plateau rim in the Thousand Springs to Malad reach obtain water from aquifers in sediment and basalt that are not hydraulically part of the Snake Plain Aquifer. There are several lines of evidence for this conclusion.

- First, most of the wells in the area west-southwest of the Plateau rim do not penetrate and obtain water from the Quaternary basalt units that host the Snake Plain aquifer. Most of the wells obtain water from the Tertiary sediment/basalt units.
- Second, the water-level elevations in wells in the area west-southwest of the Plateau rim are more than 140 feet lower than in wells completed in the Quaternary basalt on the plateau (the Snake Plain Aquifer). This includes wells completed in the Quaternary basalt near Hagerman.

The available data indicate that water producing zones (aquifers) in the area between the Plateau rim and the Snake River are not part of the Snake Plain aquifer, regardless of the age of the basalt units.

Characteristics of the Contact between the Quaternary and Tertiary Units

The topography of the geologic contact between the Quaternary basalt units and the underlying Tertiary sedimentary and/or basalt units along the plateau rim is an important controlling factor for ground-water flow and spring discharge characteristics in the Thousand Springs to Malad reach. Areas where the elevation of the geologic contact is low in comparison to the elevation of the regional water table in the aquifer have higher transmissivity (hydraulic conductivity times saturated thickness) and logically greater and more constant spring discharge. The aquifer transmissivity is less in areas where the elevation of the geologic contact is only slightly lower than the elevation of the regional water table. The lower aquifer transmissivity is associated with smaller spring discharge with a greater sensitivity to changes in the regional water table. The Snake Plain aquifer is not present where the elevation of the geologic contact is higher than the elevation of the regional water table.

The estimated elevation of the contact between the Quaternary basalt units and the underlying Tertiary sedimentary and/or basalt units is shown at selected sites on Figure 5 (A and B) based on information from IGS maps and well logs. The contact was identified in three ways: 1) the elevation of mapped contacts between Tertiary sediment/basalt units and the Quaternary basalt was estimated from digital topographic maps, 2) the highest elevation of Tertiary sediment/basalt units where a clear contact with Quaternary basalt is not identified was estimated from digital topographic maps and 3) the base of the Quaternary basalt was identified from well logs and the elevation was determined using digital topographic maps. The contact information is described in a north-to-south direction.

- The maximum elevation of the Tertiary basalt (Tub) that outcrops along the Malad River was estimated to be 2,892 feet (Figure 5). Springs discharge into the Malad River upstream of this contact.
- Elevations are given on Figure 5 for the contact between the Quaternary basalt (mostly Qgb) and the underlying Tertiary sediments (Tsgf) along the plateau rim between the Malad River and the Thousand Springs area. The contact elevations are in the range of about 3,080 feet to 3,190 feet. The range in values probably represents the topography prior to placement of the Quaternary basalt as well as mapping and transcription errors.
- The contact elevation from IGS maps in the Thousand Springs area ranges from 3,055 to 3,094 feet. The contact elevation of 3,008 feet is in an area where Quaternary basalt (Qftb) is present along the river and overlies Tertiary basalt (Tub). The Quaternary basalt in this area along the Snake River probably is not part of the Snake Plain aquifer.

The geologic contact information shown on Figure 5 illustrates that the Snake Plain aquifer, as hosted in the Quaternary basalt units, is present at a lower elevation in the Thousand Springs area and the Malad area than in the Thousand Springs to Malad reach. The saturated thickness and thus the transmissivity of the aquifer are greater in the Thousand Springs area and the Malad River canyon than anywhere in the Thousand Springs to Malad reach. The total discharge from the Thousand Springs area and from the Malad area both are greater than the intervening reach. The topography of the bottom of the Quaternary basalt is the dominant control for the locations and amounts of water discharged from springs and the sensitivity of the springs to changes in ground-water levels.

Only limited information is available to test of hypothesis forwarded by Dr. Kurt Othberg of the IGS that the contact at the bottom of the Quaternary basalt has a regional dip to the east-northeast in the Thousand Springs to Malad reach. Figure 5 shows contact information from one well in section 20 to T7S R14E and five wells in sections 29, 30 and 32 of T8S R14E. The bottom of the Quaternary basalt in the Briggs well in section 20 is more than 60 feet lower as compared to the outcrop on the edge of the Plateau. The bottom of the Quaternary basalt as identified in the Richardson, Prisbrey, IDWR and Tate wells in sections 29, 30 and 32 is about the same elevation as the outcrop on the edge of the Plateau. However, the Greer well did not fully penetrate the Quaternary basalt at a depth of 175 feet. This indicates that the bottom of the Quaternary basalt is at an elevation of less than 3,099 feet in this area (Figure 5). This is considerably lower than any of the outcrop contact elevations shown along the edge of the Plateau on Figure 5. Data from the Briggs and Greer wells support of concept of the structural dip to the east but are not sufficient to base a conclusion. Additional information is needed in order to support or refute the hypothesis of an east-northeastern structural dip to the bottom of the Quaternary basalt in this area.

Hydrogeologic Controls for Springs

Hydrogeologic information derived from geologic maps and well driller reports supports development of answers to three important questions relative to ground-water development impacts on spring discharge rates. The questions are posed and answered below.

- Does the nature (location and elevation) of the contact between the Quaternary basalt units and the underlying Tertiary sedimentary and/or basalt units provide the primary control for springs emanating from the Snake Plain aquifer?
    - The topography of the contact appears to be the primary control for the location and flow characteristics of the springs in the Thousand Springs to Malad reach. Likely, individual springs and groups of springs are associated with low elevation portions of the pre-basalt land surface (primarily the top of the Tertiary Glenns Ferry Formation). The saturated thickness of the aquifer is small near the Plateau Rim. Lowered ground-water levels result in not only decreased hydraulic head for the springs but also significantly decreased transmissivity.
- Does the postulated dip of the contact between the Quaternary basalt units and the underlying Tertiary sedimentary and/or basalt units in combination with the location of the Snake and Malad Rivers provide an explanation for the relative small combined discharge from springs in the Thousand Springs to Malad reach relative to the Thousand Springs reach to the southeast and the Malad reach to the northwest?
    - Insufficient information is available to support or refute the hypothesis that there is a regional eastward dip to the base of the Quaternary basalt. If such a dip is present, the Thousand Springs area (located in an eastward portion of the Snake River) would be down dip and thus have a lower base elevation for the Quaternary basalt than for the reach under study. The location of large springs in the Malad River canyon likely is more related to the erosion of the canyon than to the postulated regional dip of the bottom of the Quaternary basalt units.
- Is the Snake Plain aquifer, as represented in the ESPAM, contained only within the Quaternary basalt units that are located on the plateau?

- There is a large difference in water-level elevation (more than 140 feet) between wells completed in Quaternary basalt east of the plateau rim (Snake Plain aquifer) and wells completed in the Tertiary sedimentary and basalt units or the Quaternary basalt between the plateau rim and the Snake River. The available information indicates that ground-water systems present in the area between the plateau rim and the Snake River are not part of the Snake Plain aquifer and may have a hydraulic connection to the river in this reach.
- Quaternary basalt is present at two locations west of the plateau rim (near Hagerman and northwest of the Thousand Springs). Water level elevations from wells that are completed in the Quaternary basalt units in the Hagerman area are similar to wells completed in the Tertiary sedimentary and basalt units. No wells have been identified as penetrating the Quaternary basalt units in the area northwest of the Thousand Springs. However, water-level elevations from wells completed in Tertiary sedimentary and/or basalt units in the general area are much lower than in wells completed in the Quaternary basalt units on the plateau. The available information indicates that ground-water systems in the Quaternary basalt units in either of the outcrop areas located between the plateau rim and the Snake River are not part of the Snake Plain aquifer.

MODEL REPRESENTATION OF THE HYDROGEOLOGIC SETTING

Characteristics of the ESPAM

ESPAM is a single layer, confined model with 104 rows and 209 columns constructed using the MODFLOW code (Cosgrove and others, 2006). All model cells are 1 mile x 1 mile with a 31.4 degree counter-clockwise rotation relative to east-west. Several types of boundaries were used in the model: 1) no flow, 2) specified flux and 3) head dependent. The springs along the Snake River from Kimberly to King Hill (including the Thousand Springs to Malad reach) are represented as head dependent boundaries using the Drain Package. The River Package is used to represent reaches of the Snake River above Minnidoka. The Snake River in the Thousand Springs to Malad reach is not included as a boundary condition in the model.

Input data for individual drain cells includes drain elevation (feet) and drain conductance (ft^2/day). Cosgrove and others (2006, pp. 34-35) describe the establishment of drain elevation and conductance values as follows.

> "Initial values of drain conductance for the drain cells and a spring reach were estimated based on discharge for the group of springs and the estimated head differential between the aquifer and the spring elevation. Drain conductances were calibrated during model parameterization" (pages 34-35).
>
> "The ESHMC (Eastern Snake Hydrologic Modeling Committee) discussed the fact that the ending drain elevations were high relative to the ending steady state aquifer levels, with the potential result that the drains would shut off with minor declines in aquifer water level. It was agreed that the true elevations of the drains are unknown but that an absolute discontinuation of major portions of spring

discharge due to a minor change in aquifer water level would be unreasonable. ... The ESHMC discussed the fact that drain elevations could be changed with a corresponding change in drain conductance to alleviate this concern without changing the calibration or any major functionality of the model. To achieve this modification, all drain elevations were checked against the ending aquifer water levels in the same model cell. Any drain elevation which was within 30 feet of the ending steady state water level was adjusted to an elevation 30 feet lower than the ending state aquifer water level at the drain location. A corresponding adjustment was made to the drain conductance in that model cell to keep the drain discharge the same" (pages 108-109).

Information on the drain cells used to represent springs in the Thousand Springs, Thousand Springs to Malad and the southern portion of the Malad to Bancroft reaches of the model is presented in Table 2 (Cosgrove and others, 2006, Table 4; Wylie, personal communication, 2007). Drain cells where the drain elevation was lowered as described above are noted as bold in Table 2. The drain elevation was lowered an average of 21 feet for the four drain cells in the Thousand Springs to Malad reach. The drain elevations are within a range of about 100 feet for the three reaches with a low of 2,999 feet in the Malad to Bancroft reach and a high of 3,098 feet in the Thousand Springs to Malad reach.

Table 2 Drain Cell Information

Row	Column	Drain Elevation (ft)	Drain Conductance (ft^2/day)	Transmissivity (ft^2/day)	Reach
45	12	3,075	404,081	1,043,000	Thousand Springs
44	12	3,059	15,649,154	854,090	Thousand Springs
43	12	3,050	500,578	600,610	Thousand Springs
42	**12**	**3,072**	29,734	366,120	Thousand Springs
42	**13**	**3,096**	24,060	442,630	Thousand Springs to Malad
41	**13**	**3,098**	2,168	212,840	Thousand Springs to Malad
40	**13**	**3,095**	944	107,990	Thousand Springs to Malad
39	**14**	**3,074**	33,836	50,859	Thousand Springs to Malad
38	14	3,072	949	42,024	Thousand Springs to Malad
37	14	3,047	11,480	53,376	Thousand Springs to Malad
37	13	3,058	34,838	49,094	Thousand Springs to Malad
36	14	3,016	9,501	69,683	Thousand Springs to Malad
36	16	3,072	11,183	163,220	Malad to Bancroft
36	**15**	**2,999**	1,158,866	961,770	Malad to Bancroft

The drain conductance values are much lower for the Thousands Springs to Malad reach than for either the Thousand Springs or Malad to Bancroft reaches. The ranges in conductance values are as follows: 1) 29,060 to 15,649,154 ft^2/day for the Thousand Springs reach; 2) 944 to 34,838 ft^2/day for the Thousand Springs to Malad reach; and 3) 11,183 to 1,158,866 ft^2/day for the Malad to Bancroft reach. The drain conductance values are extremely low (<1,000 ft^2/day) for two cells (40,13 and 38,14) in the Thousand Springs to Malad reach.

The calibrated transmissivity values for the nodes in the portion of the model near the Thousand Springs, Thousand Springs to Malad and the Malad reaches was obtained from IDWR (Wylie, personal communication, 2007). The transmissivity values for the drain nodes in the area of interest are shown on Table 2. Figure 6 shows transmissivity values for this portion of the model in terms of ranges of values. The map shows that high transmissivity values (> 1,000,000 ft^2/day) are included in the model to represent aquifer characteristics the east of the Thousand Springs area. A band of elevated transmissivity values (>600,000 ft^2/day) also leads to the Malad Canyon discharge area. The nodes representing the immediate Malad discharge area have much higher transmissivity values.

Five of the eight drain cell nodes in the Thousand Springs to Malad reach have transmissivity values less than 70,000 ft^2/day. The southern three drain cells in the Thousand Springs to Malad reach have transmissivity values that range from 108,000 to 442,000 ft^2/day (cells 42,13; 41,13 and 40,13).

The scale of the model is an important consideration in the review of transmissivity values used for the cells where the drain function is used to represent spring discharges. Each model cell represents the average aquifer conditions over an area of one square mile of the aquifer, and not the conditions at springs located within that specific area.

Model Representation of Site Hydrogeology

An analysis of the ESPAM with respect to representing the hydrogeologic setting of the Thousand Springs to Malad reach is presented in this section. Four general topics are addressed.

- First, the model includes the general Hagerman area between the plateau rim and the Snake River in the Thousand Springs to Malad reach. This area should be excluded from the model because the Snake Plain aquifer is not present. Ground-water in this area is derived mostly from Tertiary sediment and basalt with some wells completed in Quaternary basalt that is not hydraulically part of the Snake Plain aquifer. The wells in the general Hagerman area are likely hydraulically connected to the Snake River although definitive evidence for this connection has not been developed.
- Second, the transmissivity of the Snake Plain aquifer likely is very low along the plateau rim in the Thousand Springs to Malad reach because the base of the aquifer (bottom of the Quaternary basalt) is at a relatively high elevation which leads to small saturated thickness of the aquifer. The transmissivity of the Thousand Springs reach is considerably greater than in the Thousand Springs to

Malad reach because the saturated thickness is greater. This is also the case for ground-water discharge in the Malad Canyon. The model representation of transmissivity reasonably fits with the hydrogeologic conceptual model. Figure 6 and Table 2 show that model transmissivity values are much lower in all but the southernmost portion of the Thousand Springs to Malad reach as compared to the other nearby portions of the model.

- Third, the drain elevations used in the model (3,016 to 3,098 feet) to represent springs in the Thousand Springs to Malad reach are as much as 100 feet lower than the mapped contact at the base of the aquifer (Quaternary basalt) in this area. As noted previously, this is in part because of an effort to keep the drains from going dry with small changes in aquifer water levels.
- Fourth, there is no direct field comparison for the drain conductance term used in the model. Preferential pathways related to fracturing and weathering in the basalt result in specific spring locations and flow rates. Tunnels have been constructed at several locations in an attempt to develop greater discharge from specific springs. In effect, the tunnel construction is an attempt to increase the conductance of the spring.

CONCLUSIONS AND RECOMMENDATIONS

The primary hydrogeologic control for spring location and discharge characteristics is the topography of the bottom of the aquifer, the bottom of the Quaternary basalt. This contact zone generally is higher in elevation in the Thousand Springs to Malad reach than either the Thousand Springs reach to the southeast or the discharge area in the Malad Canyon to the north. The transmissivity of the aquifer is a direct function of the saturated thickness. Thus, the transmissivity of the aquifer is greater in the Thousand Springs reach and in the Malad Canyon area than in the reach between the two. The locations and flow characteristics of individual springs in the Thousand Springs to Malad reach likely is controlled by zones where Quaternary basalt filled in the lower elevation (ancestral drainage channels) areas in the underlying Tertiary sediments.

Available information indicate that the area west and northwest of the Plateau rim, including Hagerman and the Hagerman Valley, is not underlain by the Snake Plain aquifer. Consideration should be given to excluding this area from the model.

The transmissivity array used in the model in general fits the hydrogeologic conceptual model of the site. The saturated thickness of the aquifer, and thus the transmissivity, is small along the plateau rim in the Thousand Springs to Malad reach. Model transmissivity values are low for all but the southern portion of the nodes representing the Thousand Springs to Malad reach.

The elevation of drains used for the Thousand Springs to Malad reach is lower (up to about 100 feet) than the estimated elevation of the bottom of the Quaternary basalt along the plateau rim. In part, this was done on purpose to insure that the drain nodes would not go dry.

Care must be taken in comparing estimated discharge elevations of springs and estimates of the base of the Snake Plain aquifer (bottom of the Quaternary basalt) with model parameters such as drain elevation and aquifer transmissivity. The model cells represent average hydrogeologic conditions over a one-square mile area.

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Table 1 Information for Selected Wells

Well Location		Owner	Well Depth (feet)	Coordinates Latitude Deg.	Coordinates Latitude Min.	Coordinates Longitude Deg.	Coordinates Longitude Min.	IDWR Well Elev. (feet)	RHS Well Elev. (feet)	Water Level Elev. (feet)	Bottom Younger Basalt Elev. (feet)	Top of Older Basalt Elev. (feet)	Comments
7S 13E	11 NENW	Idaho Power	305	42	50.401	114	54.083		2843	2773			
	11 SWSW	Turner	100	42	49.778	114	54.298		2867	2807			
	13 SWSESW	Hagerman	370	42	48.731	114	52.997		3084	2805		2913	
	13 SESW	Glauner	350	42	48.887	114	52.727	3077	3088	2829		2942	
	13 NWSW	Bell	320	42	49.142	114	53.127		2956	2754		2876	
	13 SWSW	Jayo	325	42	48.810	114	53.238	3078	3068	2816		2947	
	14 SWSW	Davis	165	42	48.921	114	54.232		2910	2807			Younger basalt
	22 SENE	Huntley	130	42	48.395	114	54.615		2916	2823		2914	
	23 NWNE	Secrest	305	42	48.546	114	53.562	3030	3020	2794			Younger basalt
	24 NENW	Bothwell	365	42	48.504	114	52.932	3080	3081	2793			Younger basalt
	24 NENW	Jester	345	42	48.660	114	52.740	3093	3086	2811			Younger basalt
	24 NENW	Guercherria	342	42	48.673	114	52.788	3093	3084	2802		2913	
	25 NENW	Thomas	237	42	47.730	114	52.854	3080	3079	2882		2924	
	27 SENW	Lorkowski	303	42	47.610	114	55.236	2895	2901	2812			No log to 175 feet
	27 SENW	Crist	125	42	47.581	114	55.108		2906	2814		2837	
	27 NENE	Ruf	200	42	47.708	114	54.634		2958	2825		2879	
	27 SWNW	S.R. Farms	200	42	47.409	114	55.388		2908	2802		2784	
	31 NWNE	Ramsey	405	42	46.964	114	51.626		3218				
	36 NWNE	Ross-1	200	42	46.812	114	52.704	2990	3014	2944		2928	
	36 NESE	Ross-2	248	42	46.326	114	52.434	2998	2991	2880		2896	
	36 NESE	Deacon	300	42	46.602	114	52.554	3060	3056	2916		2906	
	36 SWNE	Bolduc	225	42	46.692	114	52.574		3059	2944			
7S 14E	19 NWNW	Dayley	340	42	48.660	114	52.080	3093	3093	2897		2970	
	20 NWNW	Briggs	230	42	48.504	114	50.937		3283	3143	<3053		
	30 SESE	Anderson	435	42	47.118	114	51.216	3233	3238	2993		2865	
	30 NESE	Richardson	150	42	47.304	114	51.078	3248	3251	3164	3161		
	30 SESE	Prisbrey	180	42	47.220	114	51.000	3245	3251	3154	3186		
	30 SESE	Anderson	435	42	41.117	114	51.219		3229				
	31 NWNE	Hoskovec	363	42	46.955	114	51.474	3195	3196	3000		2886	
	31 NENE	Rangen	278	42	46.614	114	51.258	3100	3098	2986		2878	

Table 1 Information for Selected Wells (continued)

Well Location		Owner	Well Depth (feet)	Coordinates Latitude Deg.	Latitude Min.	Longitude Deg.	Longitude Min.	IDWR Well Elev. (feet)	RHS Well Elev. (feet)	Water Level Elev. (feet)	Bottom Younger Basalt Elev. (feet)	Top of Older Basalt Elev. (feet)	Comments
7S 14E	31 NWSE	Shady Grove	165	42	46.410	114	51.342	3115	3120	2990		3026	
	31 NWNW	Exit Realty	137	42	46.960	114	52.004		3049	2961		<2908	
	32 SENW	IDWR	165	42	46.600	114	50.510		3237	3168		3173	
	32 NENE	Greer	175	42	46.920	114	49.896	3273	3274	3172	<3099		
	32 NESW	Tate	100	42	46.518	114	50.154	3236	3238	3166	3161		
	32 SWNW	Candy	145	42	46.530	114	50.982	3110	3106	3010			All sediment
	32 NESE	Sliviann	130	42	46.496	114	50.001		3242	3162		<3112	
	32 NWSW	Hosman	185	42	46.377	114	50.771		3215				
8S 14E	5 NWNW	Waters	300	42	46.086	114	50.964		3123	2984	3035		
	5 NENW	Kelley	165	42	46.504	114	50.680		3225	3123	3155		
	5 NWNW	Waters	300	42	46.036	114	50.755		3226	3087	3138		
	6 NESW	US Hatchery	249	42	45.540	114	51.588	2990	2979	2898		2924	
	6 SENWSE	UI Hatchery	245	42	45.534	114	51.396	2987	2976	2890		2961	
	6 NESW	Parker	97	42	45.502	144	51.771		2963	2951			
	8 NENE	Chappell	143	42	45.053	144	49.900		3192	3112		<3049	
	8 NWNE	Berges	145	42	45.145	144	50.142		3189	3115		<3044	
	17 NENE	Scott	80	42	44.142	114	50.256	3168	3169	3121	3130		

Notes:
1) Location for Hagerman city well was not field checked
2) Well elevations were indepently estimated using coordinates and digital topographic maps by Dennis Owsley of IDWR and Dale Ralston of RHS
3) Water level elevation was calculated using depth to water from well driller's reports and estimated well elevation
4) Elevation of bottom of younger basalt was calculated using geologic data from well driller's reports and estimated well elevation
5) Elevation of top of older basalt was calculated using geologic data from well driller's reports and estimated well elevation

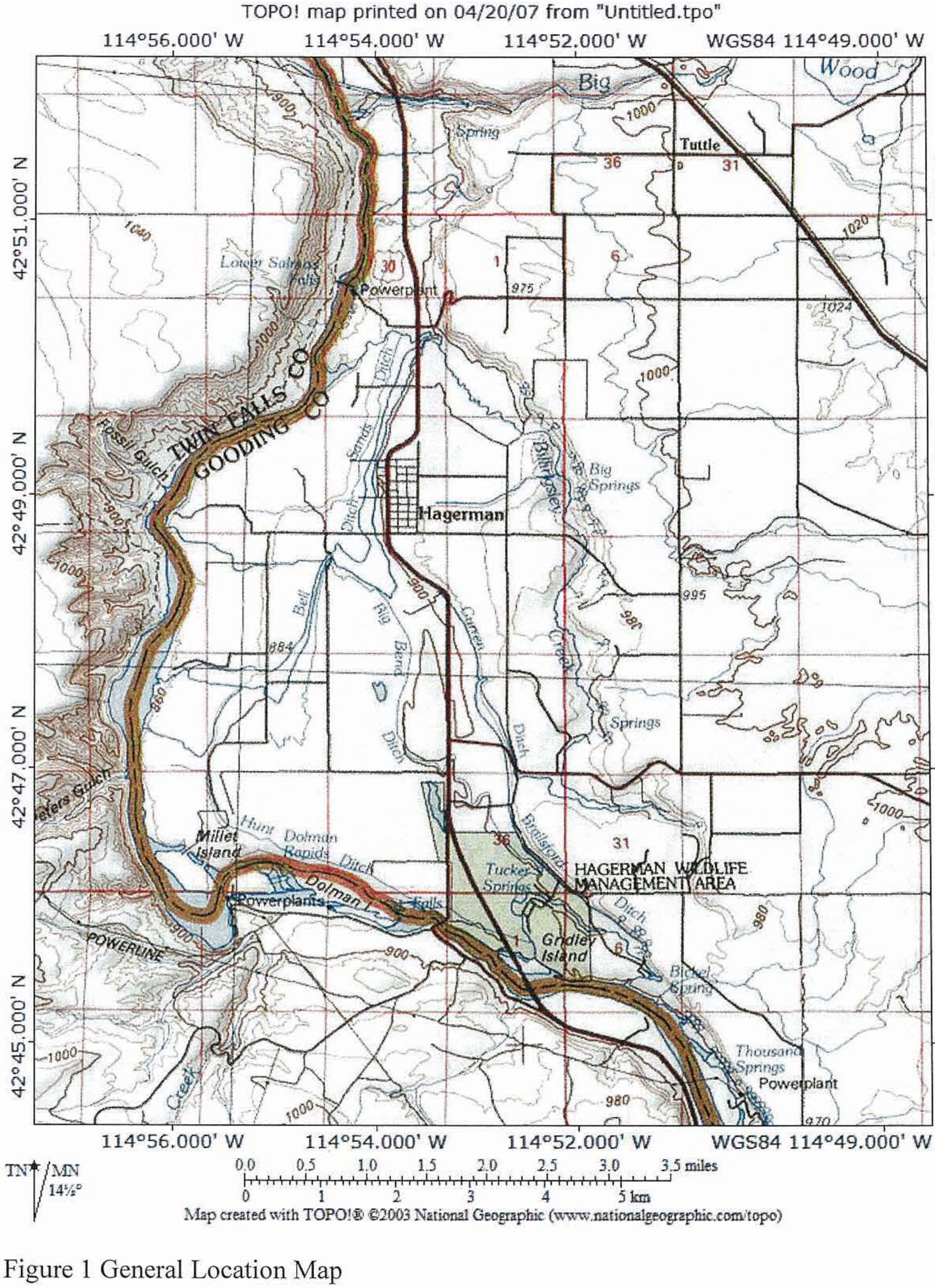

Figure 1 General Location Map

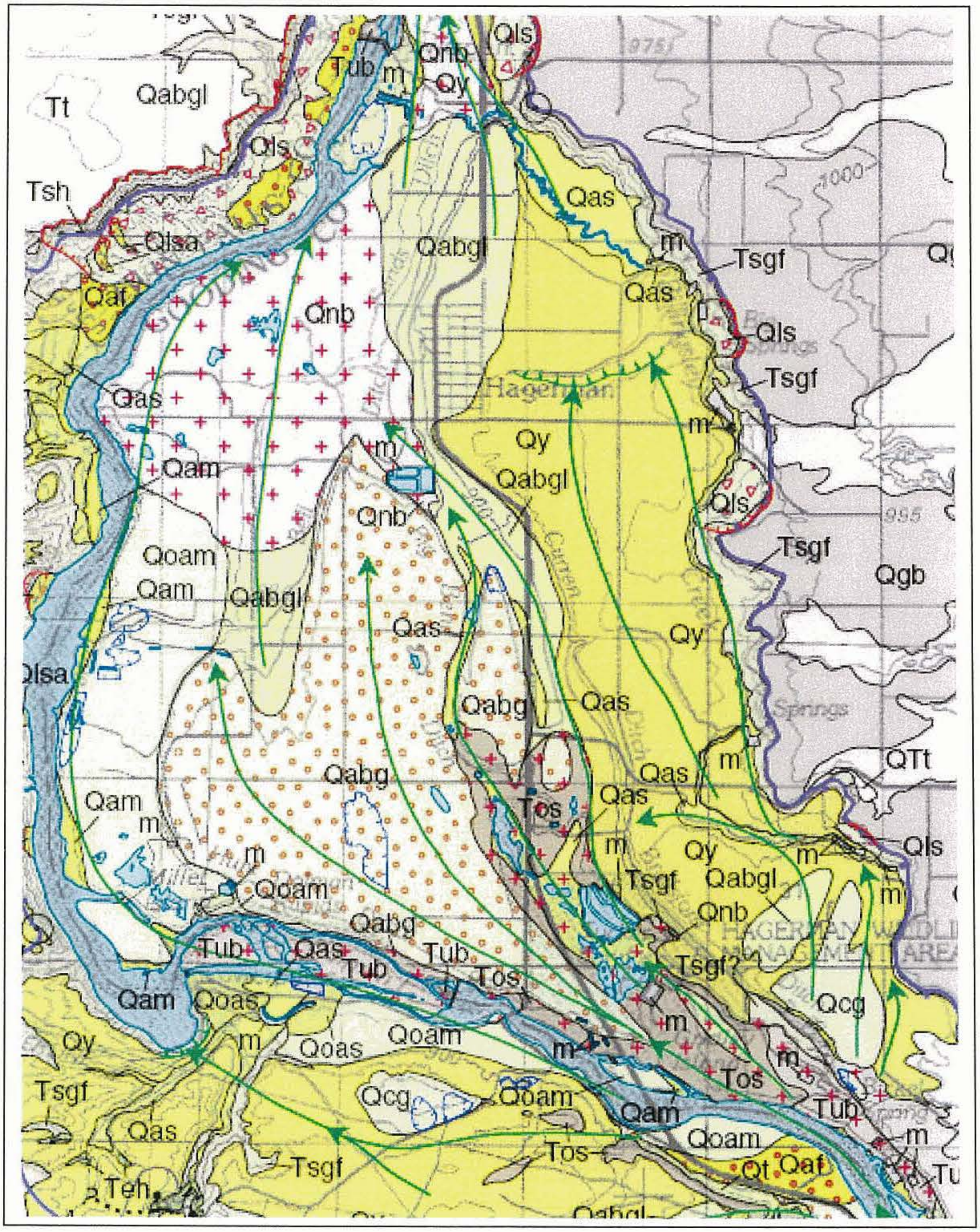

Figure 2 Geologic Map (from Kauffman and others, 2005a)

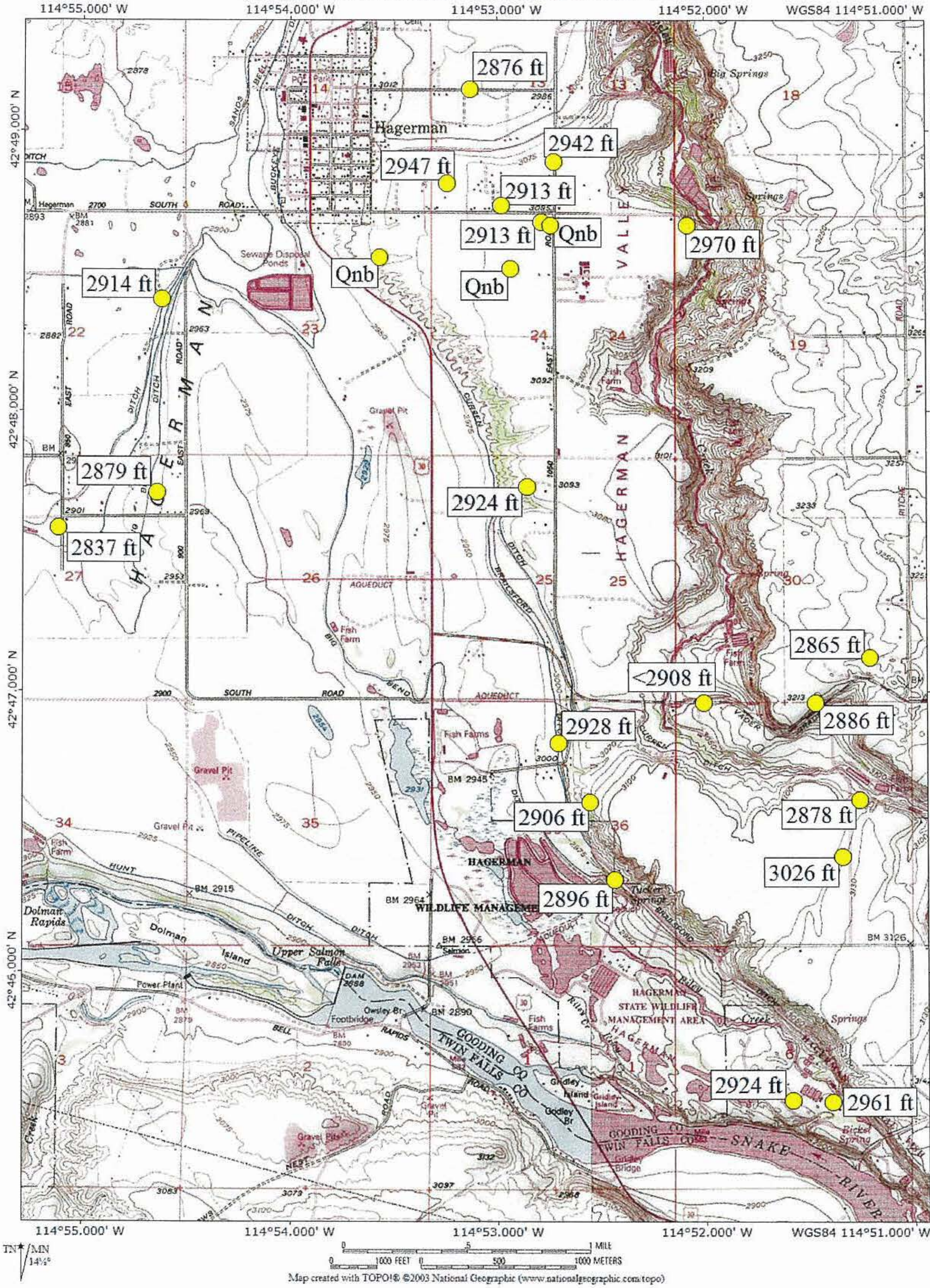

Figure 3 Map Showing the Elevation of the Top of the Tertiary Basalt Unit

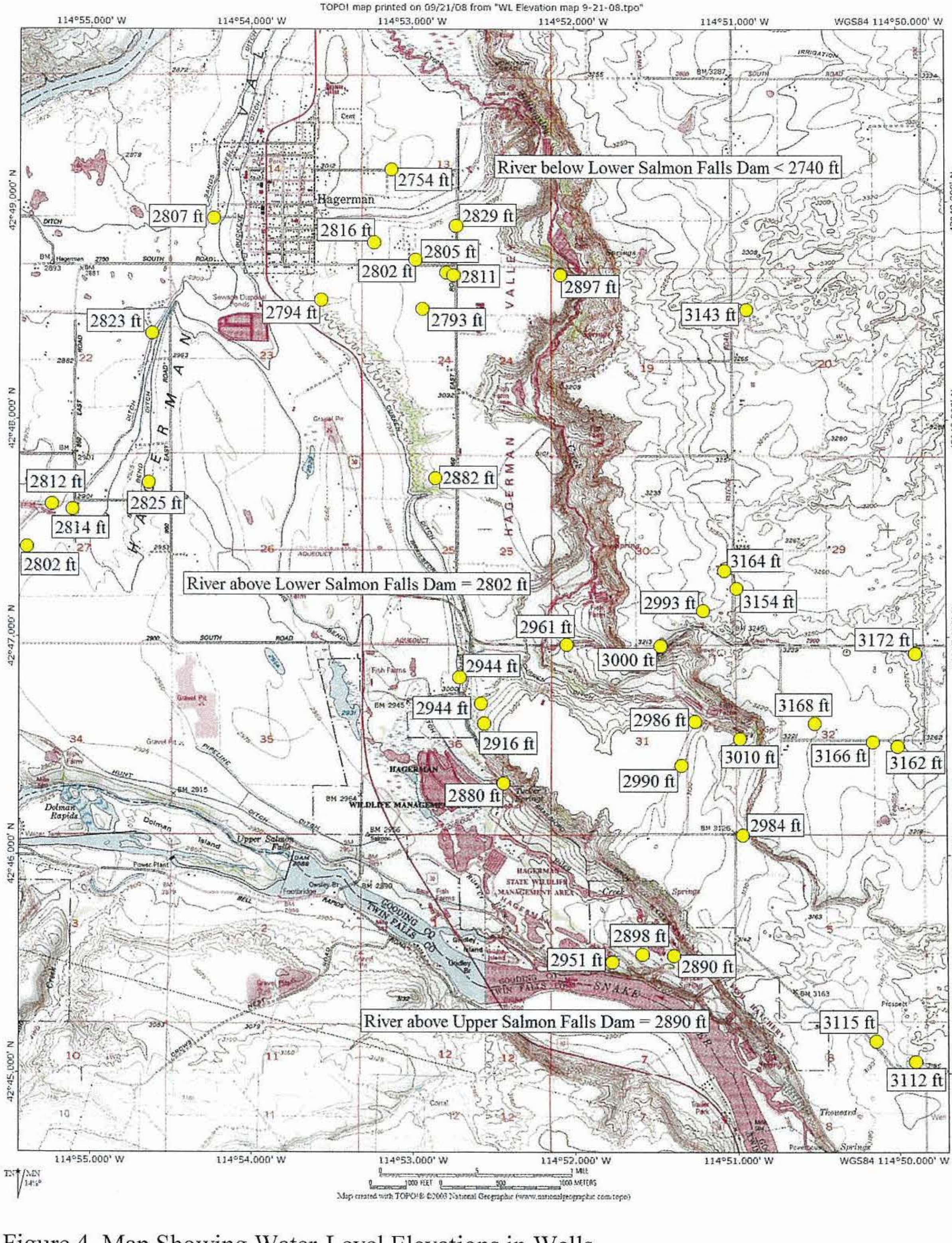

Figure 4 Map Showing Water-Level Elevations in Wells

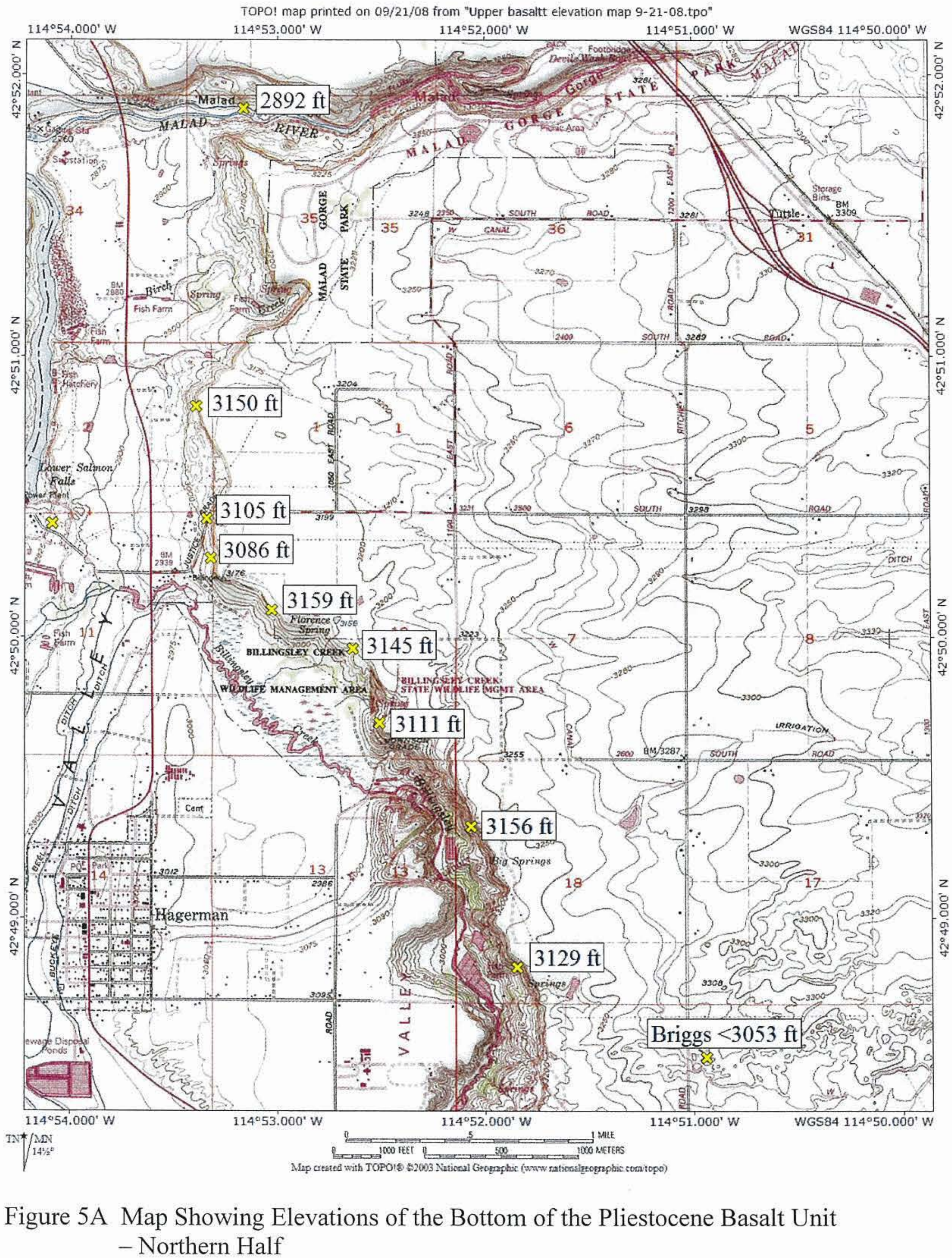

Figure 5A Map Showing Elevations of the Bottom of the Pliestocene Basalt Unit – Northern Half

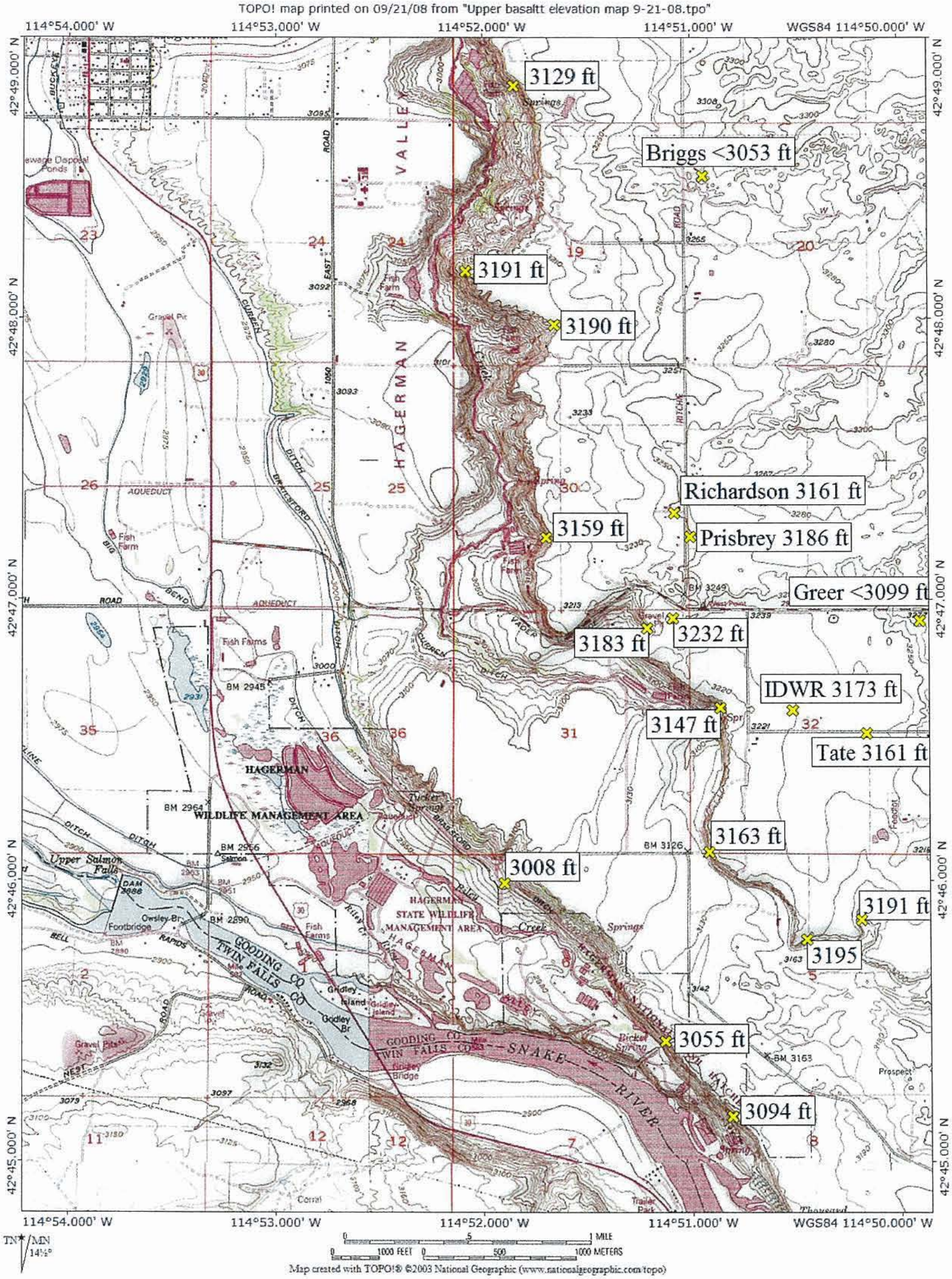

Figure 5B Map Showing Elevations of the Bottom of the Pliestocene Basalt Unit
-- Southern Half

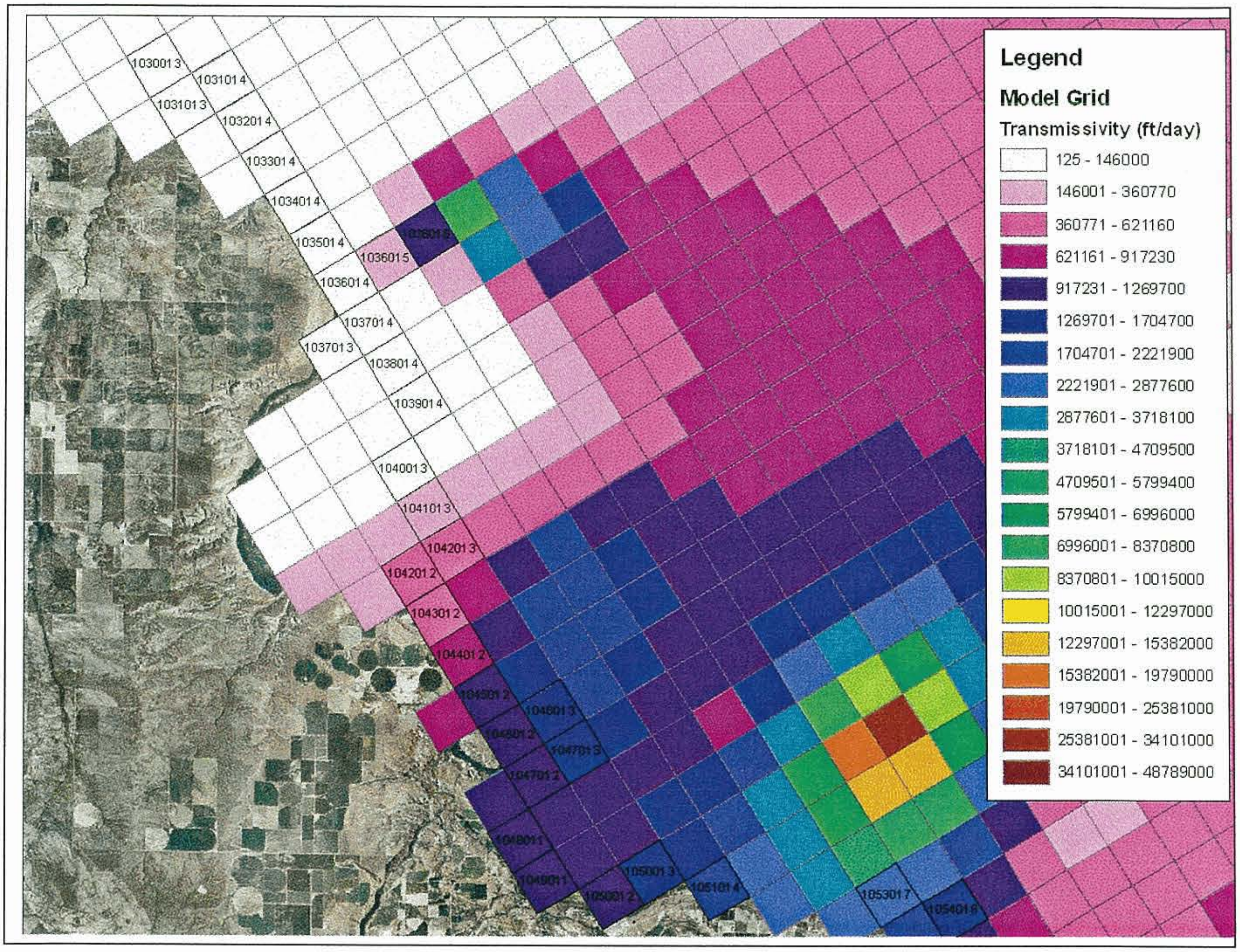

Figure 6 Map Showing Transmissivity Values for the Thousand Springs to Malad Reach