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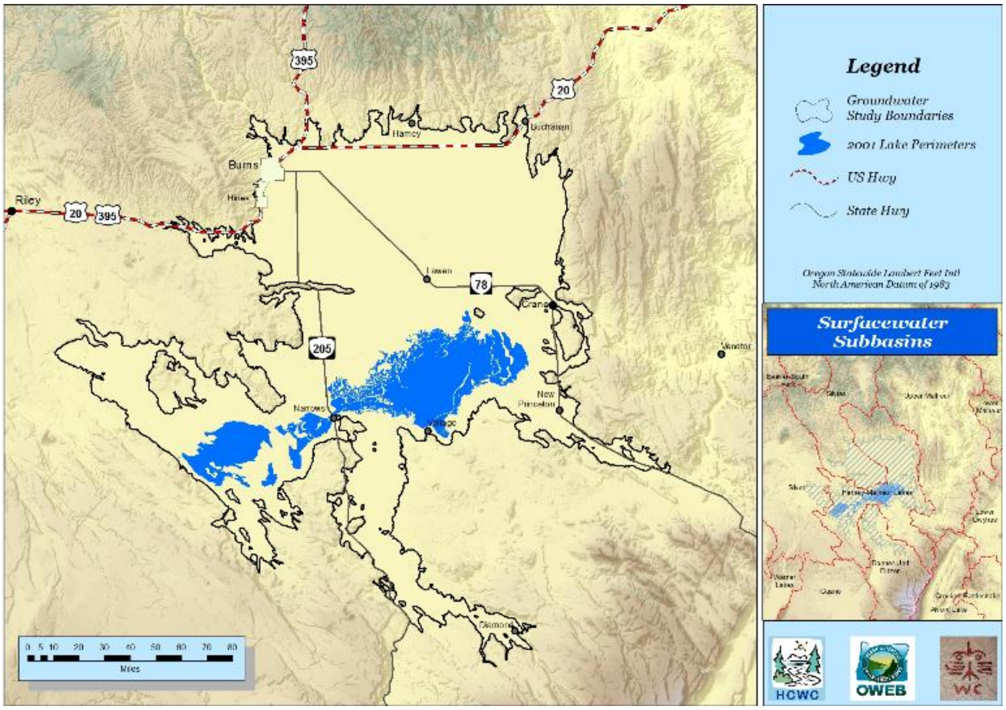
# Harney Basin Groundwater Study



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Harney County Final Report, December 27, 2012

Mark Yinger, an Oregon Registered Geologist, is responsible for the geologic and hydrogeologic content of this report titled “Harney Basin Groundwater Study”. Mark Yinger Associates, Sisters, Oregon.

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G1346

Expires: May 31st, 2013

## Table of Contents

## List of Figures

## List of Tables

## 1. Project Overview

The main purpose of this study is to characterize the groundwater system in the Harney Basin by compiling, organizing, and analyzing existing groundwater data. This study can provide the basis for developing management plans and planning activities in support of Harney County Watershed Council's (HCWC) mission to provide a healthy, resilient watershed for the benefit of people, wildlife and habitat.

Desired tasks for this phase of the project include identifying groundwater data available for the region, organizing the data in a standard GIS format database, describing the basin hydrogeology, developing tools for managing and presenting the groundwater data, documenting the basin characteristics and water usage, identifying data gaps, and providing recommendations for future monitoring in support of HCWC's goals. The council has already been involved in efforts to identify and locate wells and related bore logs, to provide water level data and available water usage information in the basin, and to review and convert the data into electronic data formats.

Unfortunately, the level of funding available for this phase of the study will be insufficient to provide a comprehensive study addressing all of the desired goals of the council. Issues related to climate, geochemistry, potential contamination, vulnerability, sustainability and groundwater-surface water interaction are addressed in the study, but only on a limited basis. Recommendations and prioritization for further study of these issues are included.

Although development of a comprehensive groundwater monitoring plan was not possible, this study identifies and organizes the data, discusses data gaps and provides recommendations for additional monitoring and data gathering activities. The focus of this study is to lay the groundwork for the longer term goals of developing a basin wide groundwater management plan, possibly including the development of a groundwater model to assess recharge potential and impacts of proposed or projected groundwater uses.

## 2. Literature and Data Review

The data gathering performed previously involved assessing well data for the approximately 2,000 wells in the basin. Initial work completed by the council involved identifying wells, assessing well locations, and converting well logs into an electronic format (pdf). This information was delivered to Aquaveo.

As part of the priority data gathering task, Aquaveo completed a literature review to determine additional available well data in the Harney Basin; Aquaveo gathered additional well data and reports from the USGS, the Oregon Water Resources Department (OWRD), Oregon Department of Environmental Quality (ODEQ), and other state and local agencies. Reports related to area geology, hydrogeology, precipitation, stream flows and other pertinent information were also reviewed. This task also included organizing and cataloguing the data for easy reference.

The results of the data gathering task and literature review are delivered in electronic format accompanying this report. Much of the literature reviewed was available as pdf files and these are included in the electronic deliverable. Some literature was only available in hard copy; these reports were scanned and saved as pdf files for inclusion in the electronic deliverable.

The literature and electronic data deliverables have been organized into subject folders. The following table lists the subject folders along with a brief description of the folder contents.

*Table 2-1. Subject Folders for Electronic Deliverable*

| Subject Folder Name | Content |
|---|---|
| Dept. of Geology and Mineral Industries (DOGAMI) | Oil and gas well logs and related data |
| Geographical Information System (GIS) | Well data, Raster data, Interferometric synthetic aperture radar (IFSAR) data |
| NAIP | High resolution aerial images of Harney County in 2003, 2004, 2005, 2006, 2009 and 2011 |
| OWRD Well Logs | Scanned well logs in pdf format; pump test data in excel/pdf format |
| WaterUse | Water use data for cities of Burns and Hines, and the Rattle Snake Land & Cattle |
| Hydrology | Deep Percolation Model executable file, input data files, model output |
| Geology and Hydrogeology | References, documents and maps in pdf format |

The reviewed data has been divided into three categories: (1) existing data, (2) hydrology literature and resources and (3) geologic, hydrogeologic and water resource literature. A description of the data in each category is given below.

## 2.1. Existing Data

Existing data includes the DOGAMI, GIS, NAIP, and OWRD Well Logs folders. Most of this data refers to existing wells and different forms of raster data in Harney County. A detailed explanation of the data in each folder follows.

### 2.1.1. DOGAMI Folder

The DOGAMI (Department of Geology and Mineral Industries) folder contains information of all the Oil/Gas Wells in Harney County. They are:

- 36-025-00012 (Central Oregon Oil Co.) – Unknown – **No Bore Log**
- 36-025-00018 (State Drilling Co) - Closed
- 36-025-00019 (United Co. of Oregon) - Unknown
- 36-025-00020 (United Co. of Oregon) – Closed

- 36-025-00021 (I.W. Love Drilling Co.) - Closed
- 36-025-00022 (Oroco Oil and Gas Co.) - Closed – **No Data**
- 36-025-00023 (Michel T. Halbouty) – Closed

Well 36-025-00022 is not included in this folder because no data is available. The DOGAMI folder also has an excel spreadsheet (OG_Permits_01-05-2012.xls). This spreadsheet provides some general information, such as locations, of all the oil/gas wells in the state including the 7 wells from Harney County.

The data in this folder can also be obtained from http://www.oregongeology.org/mlrr/oilgas-logs.htm.

### 2.1.2. GIS Folder

The GIS folder contains the following (described in subsequent sections):

- Rasterdata for part of Harney County (HCWC_GWSA_RasterData.gdb)
- IFSAR data
- Well data for all the wells in Harney County and nearby counties (HCWC_GWSA_WellData.gdb)
- Oregon Geologic Data Compilation from DOGAMI

#### 2.1.2.1. Rasterdata for Part of Harney County

The geodatabase, HCWC_GWSA_RasterData.gdb, contains data of the north part of Harney County included the aspect, canopy, elevation, hillshade and slope. The resolution size for all these rasters is 30 feet by 30 feet.

#### 2.1.2.2. IFSAR Data

Interferometric synthetic aperture radar (IFSAR) data is included in this folder. These IFSAR data are provided in raster format with resolution size of 15x15 ft. Three IFSAR rasters are available.

- Ifsar_dtm provides the terrain elevation of Harney County. Terrain elevation represents ground surface elevation without any objects such as plans or buildings.
- Ifsar_dsm provides the surface elevation of Harney County. Surface elevation represents the earth’s surface elevation including all the objects on it.
- Ifsar_mdowhs provides the shaded relief map of Harney County.

#### 2.1.2.3. Well Data

The geodatabase, HCWC_GWSA_RasterData.gdb, contains all of the wells in Harney County and nearby counties. Each well is associated with a specified type (Domestic, Geotechnical, Industrial, Irrigation, Other, Public/Community, or Stock), well log number, and elevation. The elevation is determined by using the well location combined with the IFSAR elevation data.

Tables in HCWC_GWSA_WellData.gdb geodatabase include:

- DOGAMI_gasoil: Information on 7 oil/gas wells in Harney County
- HCWC_supplemental_data: Precision of well locations
- OWRD_Master: Well data table
- OWRD_MonitorWells: Monitoring Wells table
- OWRD_Redrills: Well history table
- OWRRD_Waterlevels_20120217: Transient groundwater level for each well log

This well data can also be obtained from http://www.oregon.gov/OWRD/GW/well_data.shtml.

#### 2.1.2.4. Geo_Gis Folder - Oregon Geologic Data Compilation

The Oregon Geologic Data has two line features and two polygon features. The G_FAULT_LN line features contain all of the fault lines in the state of Oregon. Similarly, the G_FOLD_LN line features contain all of the fold lines. The G_MAP_UNIT polygon features contain geologic data for the entire state. The G_REF_MAP polygon features contain a reference outline of the geologic data. These data are located in the geo_gis folder.

These data can also be obtained from http://www.oregongeology.org/sub/ogdc/index.htm

### 2.1.3. NAIP Imagery Folder

The NAIP Imagery Folder has high resolution aerial images of Harney County in 2003, 2004, 2005, 2006, 2009 and 2011.

### 2.1.4. OWRD_WellLogs Folder

This folder has all the scanned well logs in pdf format. The file name corresponds with the well log name found in the HCWC_GWSA_WellData.gdb.

This data can be obtained from http://www.oregon.gov/OWRD/GW/well_data.shtml

### 2.1.5. Pump Test Data

Pump test data in excel format is available for 10 wells. This data has been included in the delivered geodatabase. Each pump test is attached to the corresponding well in the *Well* feature class inside the *framework* feature dataset. This data is located in the OWRD_WellLogs folder.

### 2.1.6. Water Use Folder

The OWRD water use reporting database contains usage data for the cities of Burns and Hines, and the Rattle Snake Land & Cattle. This data is located in the Water Use folder. The filename is Water_use_reports.xlsx.

## 2.2. Hydrology Literature and Resources

Many different resources related to hydrology were reviewed for this report. Most of these references have been obtained in pdf format and are included in the electronic deliverable. A more detailed description of the resources is provided below.

### 2.2.1. Hydrology Folder - Stream Gage Data

The Oregon Water Resources Department (OWRD) identifies 22 stream gages within Harney Basin having at least one year's worth of data[1] (Table 2-2, Figure 2-1). Of these gages only three are currently active. Stations are sorted in Table 2-2 by those having ten or more years of mean daily flow data (six stations), stations with less than 10 years of mean daily flow data (eight stations), and stations having only annual peak flow data (8 stations). As a rule of thumb ten or more years of data are generally required to characterize stream flow conditions within a watershed.

*Table 2-2. Stream gage data available for the Harney Basin*

| Map ID | Station number | Station Name | Status | Dra. Area ($mi^2$) | Elev. at gage (ft) | Mean daily flows: | | | Peak flows: | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | from | to | WYs | POR | WYs |
| Gages having 10 or more years of mean daily flow data: | | | | | | | | | | |
| 1 | 10393500 | Silvies R Nr Burns, Or | Active | 913 | 4200 | 6/1/1903 | 9/30/2011 | 87 | 1905 - 2011 | 94 |
| 2 | 10396000 | Donner Und Blitzen R Nr Frenchglen, Or | Active | 206 | 4320 | 4/1/1911 | 10/12/2010 | 80 | 1911 - 2007 | 81 |
| 3 | 10397000 | Bridge Cr Nr Frenchglen, Or | Discon. | 29.4 | 4200 | 4/1/1911 | 10/31/1970 | 36 | 1911 - 1970 | 39 |
| 4 | 10401500 | Donner Und Blitzen R Nr Voltage, Or | Discon. | 788 | 4100 | 11/1/1937 | 11/30/1977 | 10 | 1938 - 1977 | 15 |
| 5 | 10402800 | Claw Cr Nr Riley, Or | Discon. | 76.7 | 4690 | 1/8/1967 | 11/22/1978 | 11 | 1967 - 1978 | 12 |
| 6 | 10403000 | Silver Cr Nr Riley, Or | Discon. | 224 | 4450 | 10/1/1951 | 10/31/1980 | 29 | 1952 - 1980 | 29 |
| Gages having less than 10 years of mean daily flow data: | | | | | | | | | | |
| 7 | 10395000 | E Fk Silvies R Nr Lawen, Or | Discon. | - | - | 3/1/1972 | 9/30/1977 | 5 | - | - |
| 8 | 10395500 | W Fk Silvies R Nr Lawen, Or | Discon. | - | 4090 | 3/1/1972 | 9/30/1977 | 5 | 1916 - 1976 | 9 |
| 9 | 10395600 | Rock Cr Nr Burns, Or | Discon. | 12.2 | 4360 | 10/1/1963 | 9/30/1976 | 7 | - | - |
| 10 | 10396500 | Mud Cr Nr Diamond, Or | Discon. | 28.3 | 4200 | 10/1/1910 | 7/7/1930 | 0 | 1911 - 1916 | 6 |
| 11 | 10400000 | Mccoy Cr Nr Diamond, Or | Discon. | 48.9 | 4200 | 5/23/1910 | 7/31/1941 | 3 | 1911 - 1941 | 9 |
| 12 | 10402000 | Malheur Lake Outlet At Narrows, Or | Discon. | - | - | 3/1/1972 | 9/30/1977 | 5 | - | - |
| 13 | 10403400 | Silver Cr Bl Nicoll Cr Nr Riley | Active | 265 | - | 3/9/2010 | 9/30/2011 | 1 | 2011 - 2011 | 1 |
| 14 | 10403500 | Silver Cr Ab Suntex, Or | Discon. | 269 | 4350 | 2/1/1925 | 4/30/1926 | 0 | 1904 - 1925 | 18 |
| Gages having peak flow data only: | | | | | | | | | | |
| 15 | 10392300 | Silvies R Nr Seneca, Or | Discon. | 18.3 | 5020 | - | - | - | 1967 - 1981 | 15 |
| 16 | 10392500 | Silvies R At Silvies, Or | Discon. | 511 | 4500 | - | - | - | 1904 - 1923 | 9 |
| 17 | 10392800 | Crowsfoot Cr Nr Burns, Or | Discon. | 8.29 | 5250 | - | - | - | 1966 - 1979 | 14 |
| 18 | 10393900 | Devine Can Nr Burns, Or | Discon. | 5.11 | 4920 | - | - | - | 1965 - 1981 | 17 |
| 19 | 10395200 | Sage Hen Cr Nr Burns, Or | Discon. | 1.02 | 4400 | - | - | - | 1969 - 1975 | 7 |
| 20 | 10395700 | Donner Und Blitzen R Trib Nr Frenchglen, Or | Discon. | 0.95 | 5220 | - | - | - | 1964 - 1974 | 6 |
| 21 | 10401000 | Riddle Cr Nr Diamond, Or | Discon. | 112 | 4100 | - | - | - | 1917 - 1921 | 5 |
| 22 | 10406000 | Silver Cr Nr Narrows, Or | Discon. | - | 4140 | - | - | - | 1917 - 1923 | 6 |

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[1] http://apps.wrd.state.or.us/apps/sw/hydro_report/default.aspx

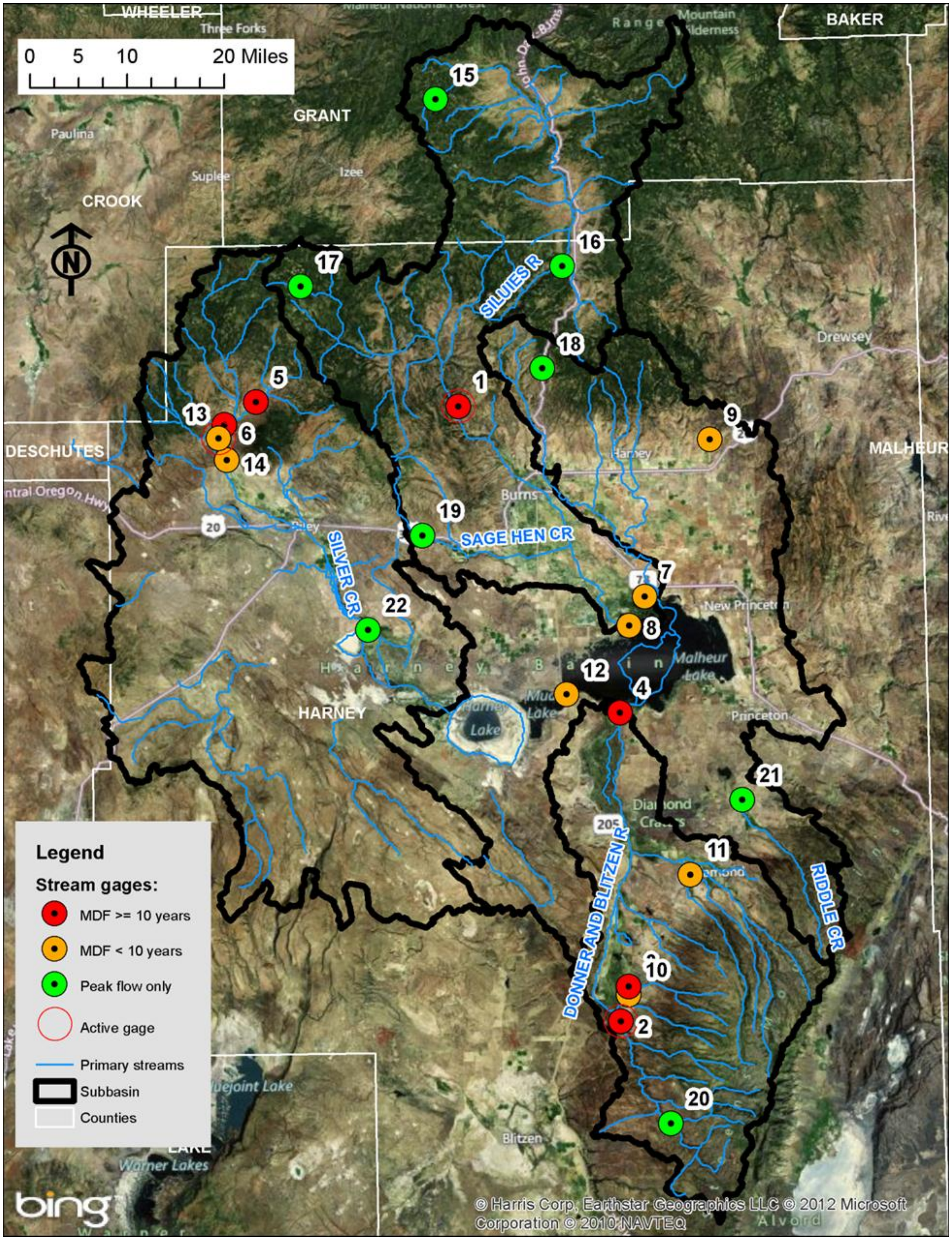

*Figure 2-1. Harney Basin stream gage map*

### 2.2.2. Water Budget Resources

No water budget is currently available for the Harney Basin. The Deep Percolation Model (DPM) developed by Bauer and Vaccaro (1987) has been used to estimate aquifer recharge in the adjacent Deschutes River Basin (Boyd, 1996), and would be appropriate for estimating recharge in the Harney Basin. A computer version of the Deep Percolation Model, based on the work of Bauer and Vaccaro (1987) and Bauer and Mastin (1997), is available from the USGS. The current version of this model (version 3.0) was developed in 2008.

Version 3.0 of the DPM is available for download at http://wa.water.usgs.gov/dpm/

## 2.3. Literature Folder - Geologic, Hydrogeologic, and Water Resource Literature

The geologic, hydrogeologic, and water resource literature have been researched and the majority of the references identified have been reviewed. All but a few of the references were obtained in pdf format. Several that were not available in pdf format were obtained, scanned, and added to the project library in pdf format (geologic and hydrogeologic folders). The literature review references can be found in this folder.

# 3. Database Development and Data Analysis

## 3.1. Stratigraphy Definition and Methodology

One of the goals of this study was to characterize the hydrostratigraphic units in the Harney Basin. To accomplish this task, it was necessary to review the existing borehole data and make interpretations of the subsurface layering. When interpreting borehole data, we have relied on Walker's stratigraphic interpretation of the basin (Walker, 1979). Figure 3-1 shows Walker's stratigraphic interpretation of the major Cenozoic lithologic units of the Harney Basin area. Walker worked extensively in this area of Oregon; prior to Walker’s formal designation of major volcanic units in the area, he had worked in the Harney Basin and Southeast Oregon since the early 1960’s. In addition to using borehole data to aid in our interpretation of the subsurface, we also used surficial geologic maps. The geologic map prepared by Greene, Walker, and Corcoran (1972) was used. This map covers the entire study area (Figure 4-1).

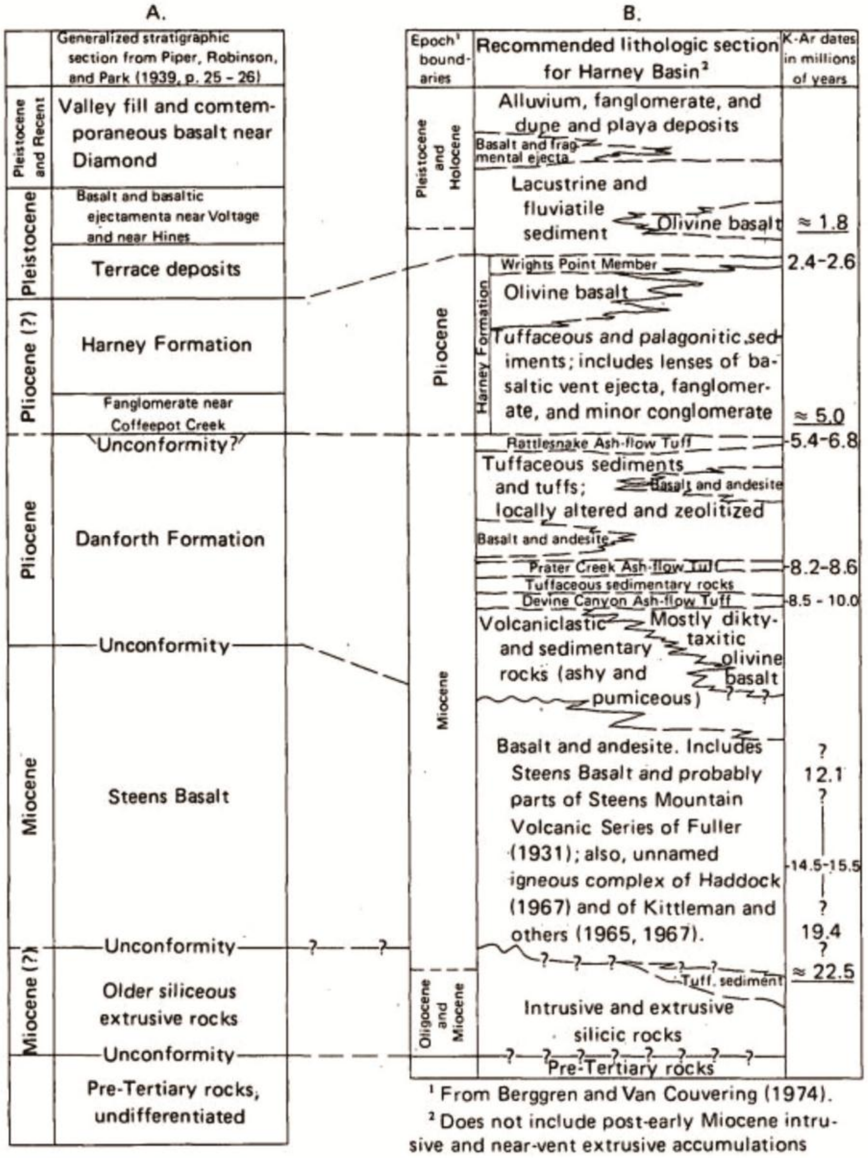

*Figure 3-1. Cenozoic stratigraphy of the Harney Basin area from Walker, 1979*

Table 3-1 below contains a list of lithologic units used for the classification of materials described in well logs for the purpose of entry into the project geodatabase. These units generally follow Walker's Cenozoic stratigraphy illustrated in Figure 3-1, and the Geologic Map of the Burns Quadrangle, Oregon, by Greene, Walker, and Corcoran (1972), and work by Milliard (2010). Not all of the wells in the geodatabase were used to characterize the subsurface. The wells used to develop a model of the subsurface stratigraphy were chosen based on the spatial distribution and for the apparent quality of the lithology descriptions. The distribution of wells closely correlates with agricultural development and as such the wells occur primarily in the valley bottom. The number of wells in the uplands surrounding the valley are limited, but were included in order to investigate the changes in the subsurface at the boundaries of the structural basin.

*Table 3-1. Project Geodatabase Geologic Units*

| **Geodatabase Geologic Units** | **Map Symbols**[1] | **Epoch** | **Lithology** |
|---|---|---|---|
| Basin Fill | Qs, Qal, Qp, Qf | Holocene-Pleistocene | Gravel, Sand, silt, clay, sandy-clay, clayey-sand, gravel, and clayey-gravel |
| Diamond and Voltage Basalts | Qb, Qlb, Qmv | Holocene-Pleistocene | Lavas flows, cinders, and vent complexes |
| Sedimentary Rocks | QTs | Pleistocene-Pliocene | Conglomerates and sandstone |
| Intra-Basin basalts and cinders | QTb, QTp, QTps | Pleistocene-Pliocene | Lavas flows, pyroclastics, palagonite, cinders |
| Mafic vent complex | QTmv | Pleistocene-Pliocene | Near vent related plugs, dikes, ejecta, lava flows |
| Harney Formation | Tst (?) | Pliocene | Sandstone, claystone and conglomerate |
| Drinkwater Basalt | Tdw | Miocene | Lava flows |
| Basalt lavas and cinders | Tb | Miocene | Lava flows and cinders |
| Rhyolite-Rhyodacite | Trr | Miocene-Pliocene | Domes and lavas |
| Tuffaceous and volcaniclastic sediments | Tst | Miocene | Clay, claystone, minor sand, sandstone, pumiceous |
| Rattlesnake Ash-Flow Tuff | Tdo | Late Miocene | Ash-flow tuff |
| Prater Creek ash-flow tuff | Twtp | Late Miocene | Ash-flow tuff |
| Devine Canyon ash-flow tuff | Tdv | Miocene | Ash-flow tuff |
| Volcaniclastic sedimentary rocks | Tts, Tsts | Miocene | Rhyolitic siltstone, claystone, sandstone, conglomerate |
| Steens Basalt | Tba | Miocene | Lava flows |

[1] Map symbols are from the *Geologic Map of the Burns Quadrangle*, *Oregon*, by Greene, Walker, and Corcoran (1972), and Milliard (2010).

The geodatabase geologic units presented in Table 3-1 group together some of units mapped by Greene, Walker, and Corcoran (1972) and Milliard (2010). The geodatabase geologic units are not listed in strictly chronologic order. These geologic units were defined in an iterative process involving the simultaneous reference to the geologic literature and well logs and the use of subsurface modeling tools in the Groundwater Modeling Systems (GMS).

The description of subsurface materials contained in well driller's logs is a large body of data that is based on actual observation of the material. There is no other comparable description of subsurface materials. The interpretation of the well driller's descriptions of subsurface materials for the selected wells depends on a broad understanding of geologic processes and the regional geologic setting, and an iterative process of review and edit. The GMS geologic modeling/visualizations tools are essential for accomplishing this iterative process. The geologic model developed relies to a large degree on the professional judgment of the interpreter.

## 3.2. Data Processing

In order to interpret the existing borehole data, we imported the scanned bore logs into an ArcGIS geodatabase. This process involved taking the scanned bore log reports and converting the information about drilling depths and material descriptions into an electronic format based on the Arc Hydro Groundwater (AHGW) data model. These depth and material descriptions are stored in the *BoreholeLog* table inside the geodatabase. The following figure shows the format of the *BoreholeLog* table and illustrates how information from drilling reports is related to boreholes.

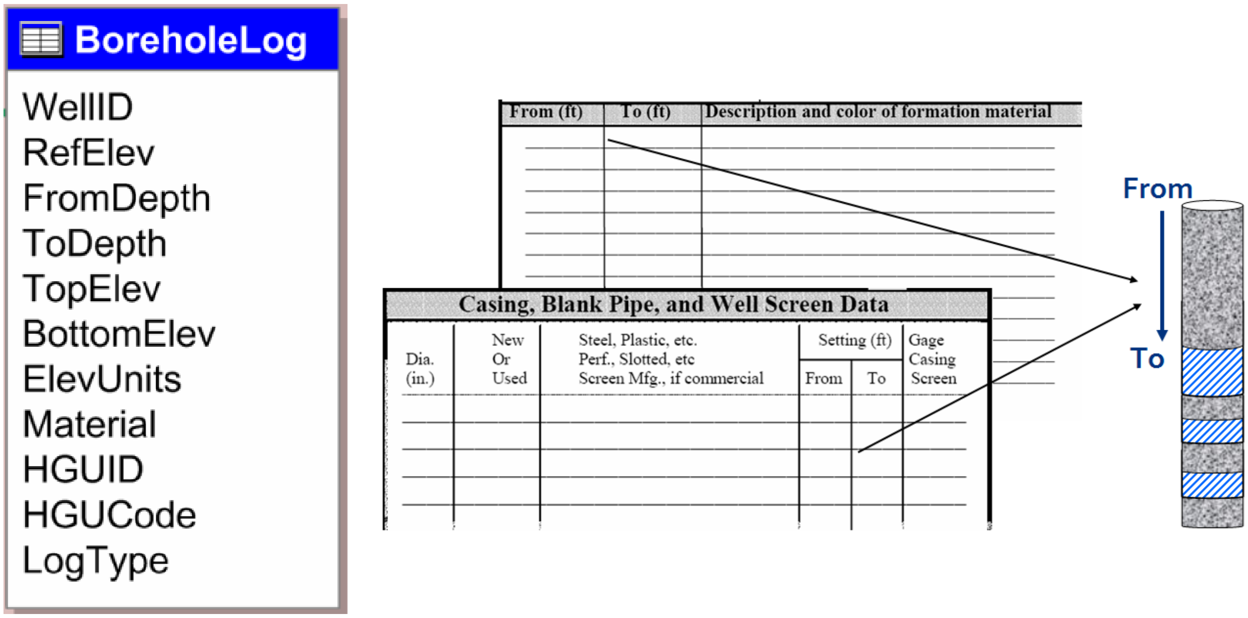

*Figure 3-2. Format of the BoreholeLog table.*

The depth information from the drilling reports was entered into the **FromDepth** and **ToDepth** fields in the *BoreholeLog* table. In addition, the description of the material from the drilling report was entered into the **Material** field in the *BoreholeLog* table.

## 3.3. Design and Create Geodatabase

The geodatabase delivered with this report follows the Arc Hydro Groundwater data model. Three main feature datasets were created in the geodatabase to represent different types of data.[1] The framework feature dataset includes hydrography, wells, monitoring points, and aquifers. The subsurface feature dataset contains the description of vertical information recorded along boreholes such as borehole log and well construction. The hydrostratigraphy feature dataset contains the cross sections beneath the study area.

## 3.4. Import Data

Three main categories of data were imported into the geodatabase: hydrostratigraphic (or hydrogeologic) unit information, well/borehole information, and water level information. Information about hydrostratigraphic units was imported into the *HydrogeologicUnit* table. Figure 3-3 shows an example of this table. Each hydrogeologic unit has a HydroID which is a unique identifier for each unit. In the *BoreholeLog* table there is an **HGUID** field that is used to relate a portion of a given borehole to a particular hydrogeologic unit. The **HGUID** specified in the *BoreholeLog* table would correspond to the **HydroID** in the *HydrogeologicUnit* table. These unit descriptions are described in section 4.2. The explanation of each field in the *HydrogeologicUnit* table is described in Appendix A.

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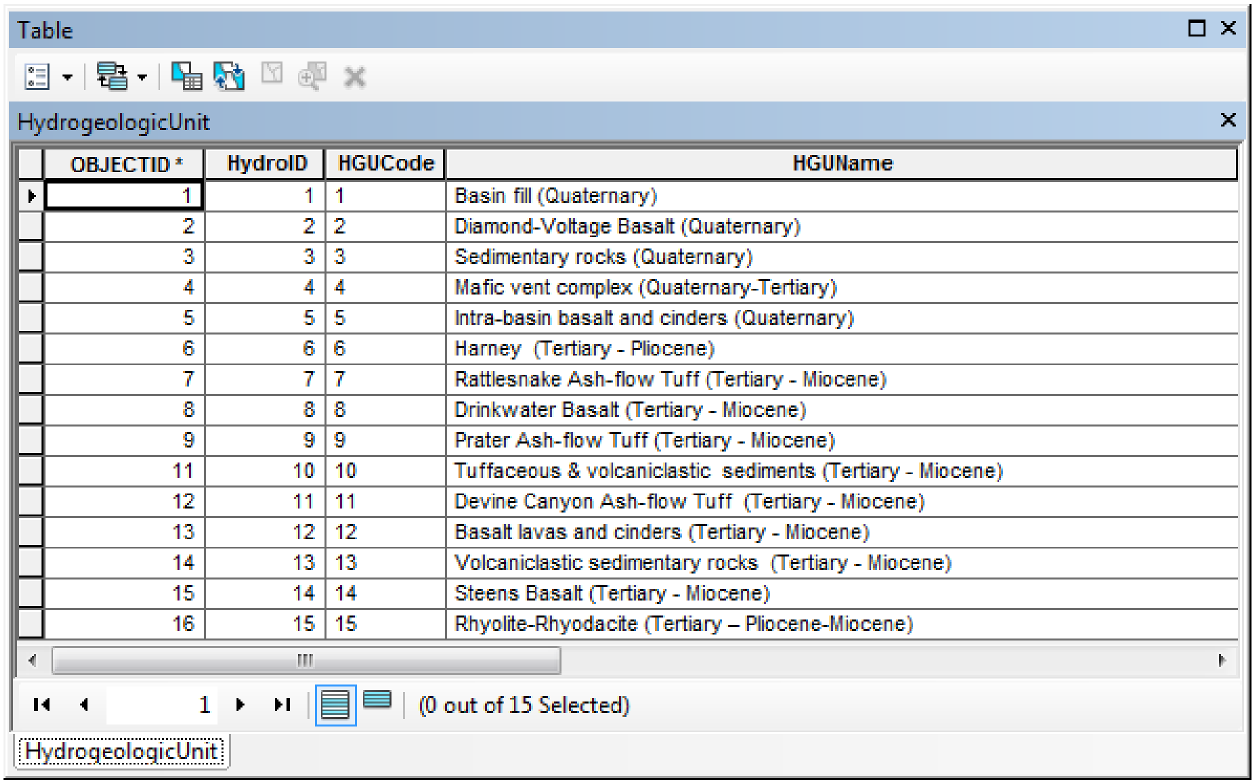
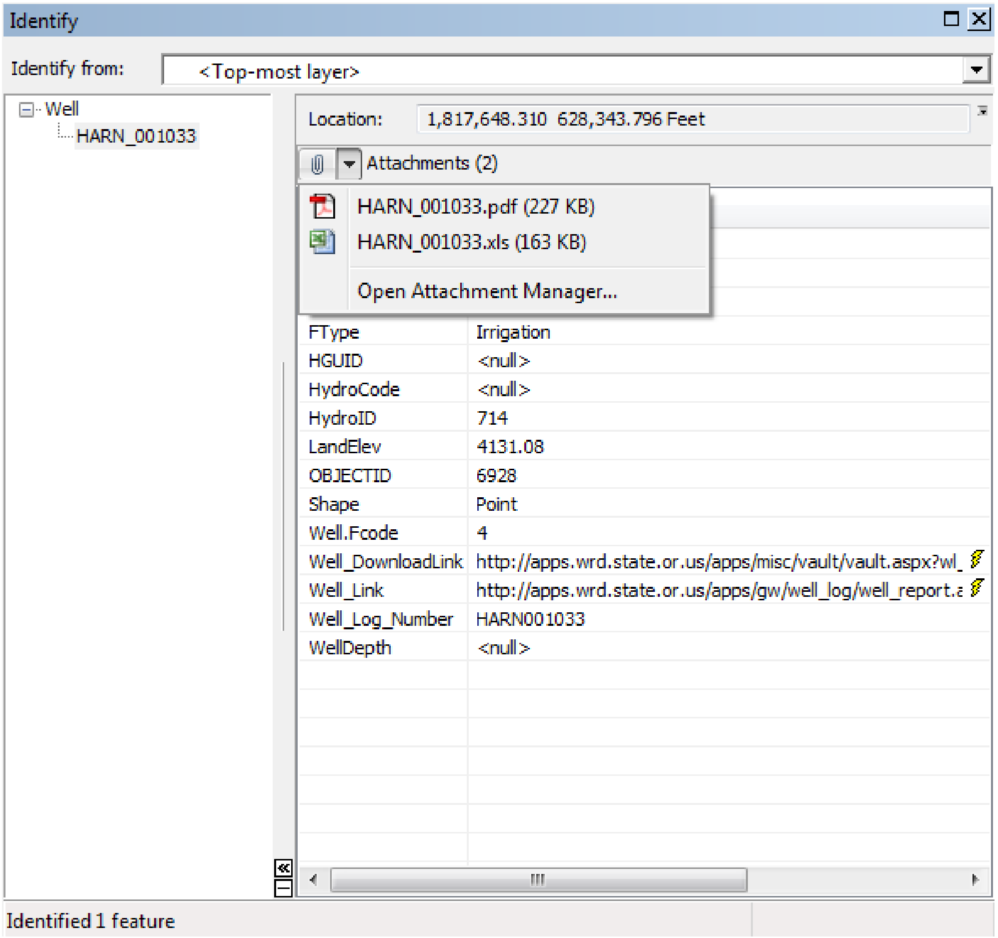
[1] A feature dataset is a collection of feature classes that have the same coordinate system. A feature class is a collection of geometry (points, polylines, polygons) with attributes. An example of a feature class in the AHGW data model is the Well feature class. This is a collection of point locations that describe wells. Some of the attributes associated with wells are land elevation, depth, aquifer, etc.. So the well feature class will look like a single table in the geodatabase that has a column for the geometry (in this case a point) and columns for each of the attributes.



| OBJECTID * | HydroID | HGUCode | HGUName |
|---|---|---|---|
| 1 | 1 | 1 | Basin fill (Quaternary) |
| 2 | 2 | 2 | Diamond-Voltage Basalt (Quaternary) |
| 3 | 3 | 3 | Sedimentary rocks (Quaternary) |
| 4 | 4 | 4 | Mafic vent complex (Quaternary-Tertiary) |
| 5 | 5 | 5 | Intra-basin basalt and cinders (Quaternary) |
| 6 | 6 | 6 | Harney (Tertiary - Pliocene) |
| 7 | 7 | 7 | Rattlesnake Ash-flow Tuff (Tertiary - Miocene) |
| 8 | 8 | 8 | Drinkwater Basalt (Tertiary - Miocene) |
| 9 | 9 | 9 | Prater Ash-flow Tuff (Tertiary - Miocene) |
| 11 | 10 | 10 | Tuffaceous & volcaniclastic sediments (Tertiary - Miocene) |
| 12 | 11 | 11 | Devine Canyon Ash-flow Tuff (Tertiary - Miocene) |
| 13 | 12 | 12 | Basalt lavas and cinders (Tertiary - Miocene) |
| 14 | 13 | 13 | Volcaniclastic sedimentary rocks (Tertiary - Miocene) |
| 15 | 14 | 14 | Steens Basalt (Tertiary - Miocene) |
| 16 | 15 | 15 | Rhyolite-Rhyodacite (Tertiary – Pliocene-Miocene) |

*Figure 3-3. Hydrogeologic Table*

Well information was imported into the *Well* feature class, which is a point feature class. Each point represents a well in the basin. There are 3,957 wells in this feature class. Basic information on each well such as well type and land elevation is associated with each well. This feature class also has additional fields to include the link to the Oregon Water Resource Department website for each well, the associated report PDF file, and the pump test data in excel format (where available). Figure 3-4 shows the well feature class with the associated links.


Identify

Identify from: <Top-most layer>

Well
HARN_001033

Location: 1,817,648.310 628,343.796 Feet

Attachments (2)

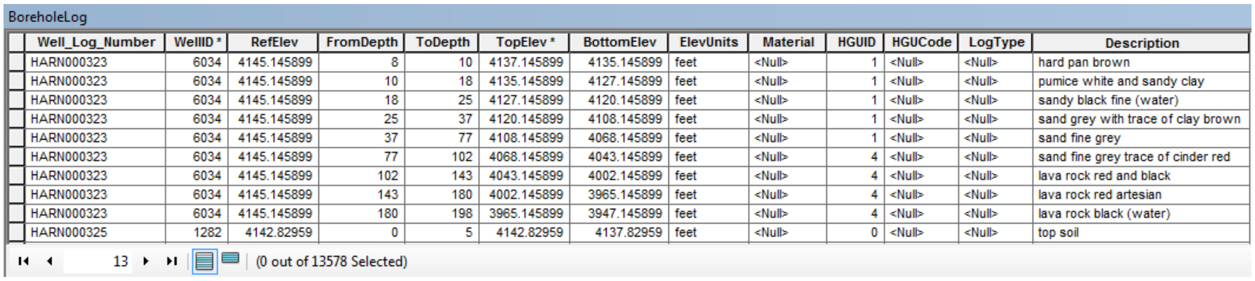
HARN_001033.pdf (227 KB)
HARN_001033.xls (163 KB)
Open Attachment Manager...

| | |
|---|---|
| FType | Irrigation |
| HGUID | <null> |
| HydroCode | <null> |
| HydroID | 714 |
| LandElev | 4131.08 |
| OBJECTID | 6928 |
| Shape | Point |
| Well.Fcode | 4 |
| Well_DownloadLink | http://apps.wrd.state.or.us/apps/misc/vault/vault.aspx?wl_ |
| Well_Link | http://apps.wrd.state.or.us/apps/gw/well_log/well_report.a |
| Well_Log_Number | HARN001033 |
| WellDepth | <null> |

Identified 1 feature

*Figure 3-4. Well Feature Example with Pump Test Data*

The *BoreholeLog* table inside the geodatabase contains all the electronic bore log data from Oregon Water Resource Department. The *BoreholeLog* table has a **WellID** field to relate borehole information back to the *Well* feature class. The **WellID** in the *BoreholeLog* table will match the **HydroID** of the corresponding well in the *Well* feature class. As described previously, all of the imported boreholes have depth information and descriptions of materials from the drilling logs. However, the **HGUID** is only specified for the logs that were analyzed and interpreted as part of the subsurface characterization task. The **HGUID** corresponds to the **HydroID** in the *HydrogeologicUnit* table. The zero (or null) value in **HGUID** field implies that the stratigraphy has not yet been defined. The following figure shows a section of this table. The explanation of each field is described in the Appendix A.



BoreholeLog

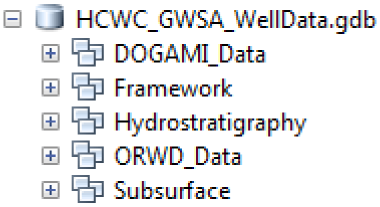
| | Well_Log_Number | WellID * | RefElev | FromDepth | ToDepth | TopElev * | BottomElev | ElevUnits | Material | HGUID | HGUCode | LogType | Description |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | HARN000323 | 6034 | 4145.145899 | 8 | 10 | 4137.145899 | 4135.145899 | feet | <Null> | 1 | <Null> | <Null> | hard pan brown |
| | HARN000323 | 6034 | 4145.145899 | 10 | 18 | 4135.145899 | 4127.145899 | feet | <Null> | 1 | <Null> | <Null> | pumice white and sandy clay |
| | HARN000323 | 6034 | 4145.145899 | 18 | 25 | 4127.145899 | 4120.145899 | feet | <Null> | 1 | <Null> | <Null> | sandy black fine (water) |
| | HARN000323 | 6034 | 4145.145899 | 25 | 37 | 4120.145899 | 4108.145899 | feet | <Null> | 1 | <Null> | <Null> | sand grey with trace of clay brown |
| | HARN000323 | 6034 | 4145.145899 | 37 | 77 | 4108.145899 | 4068.145899 | feet | <Null> | 1 | <Null> | <Null> | sand fine grey |
| | HARN000323 | 6034 | 4145.145899 | 77 | 102 | 4068.145899 | 4043.145899 | feet | <Null> | 4 | <Null> | <Null> | sand fine grey trace of cinder red |
| | HARN000323 | 6034 | 4145.145899 | 102 | 143 | 4043.145899 | 4002.145899 | feet | <Null> | 4 | <Null> | <Null> | lava rock red and black |
| | HARN000323 | 6034 | 4145.145899 | 143 | 180 | 4002.145899 | 3965.145899 | feet | <Null> | 4 | <Null> | <Null> | lava rock red artesian |
| | HARN000323 | 6034 | 4145.145899 | 180 | 198 | 3965.145899 | 3947.145899 | feet | <Null> | 4 | <Null> | <Null> | lava rock black (water) |
| | HARN000325 | 1282 | 4142.82959 | 0 | 5 | 4142.82959 | 4137.82959 | feet | <Null> | 0 | <Null> | <Null> | top soil |

*Figure 3-5. BoreholeLog Table*

The state observation well data was imported into the *Waterlevels_All* table. This table also includes the existing groundwater level data from the Oregon Water Resource Department. This table follows the AHGW format for the *TimeSeries* table. This same table can be used to store other time series data collected at wells such as concentrations, temperature, etc. The format for this table is documented in Appendix A. Any data that was interpreted as inconsistent was removed from the *Waterlevels_All* table and stored inside the *Waterlevel_outliers* table.

## 3.5. Create GIS Products

Once the wells, boreholes, and time series data were imported into the geodatabase, we used this data to create additional GIS data sets. The wells and time series were used to create water level maps from different time periods. These maps can be used to compare the changes in groundwater elevations over time. The boreholes were used to create boreline features and cross sections of the subsurface. The cross sections can be viewed in 3D in ArcScene or each cross section can be viewed in its own data frame in ArcMap. All of these GIS data sets are stored in the geodatabase. The following image shows all the feature datasets inside the geodatabase. The *subsurface* feature dataset contains the borelines. The cross sections are stored inside the *hydrostratigraphy* feature dataset.



- HCWC_GWSA_WellData.gdb
  - DOGAMI_Data
  - Framework
  - Hydrostratigraphy
  - ORWD_Data
  - Subsurface

*Figure 3-6. Feature Datasets inside the geodatabase*

The current stratigraphic definition does not group the hydrogeologic units into continuous layers. Therefore, we were unable to create a raster catalog with surfaces defining the top elevations of each hydrogeologic unit. For this reason, no geovolumes were created.

### 3.5.1. Groundwater Level Map

The groundwater level maps are located inside the geodatabase as raster data. These groundwater level maps were generated using the data from *Waterlevel_All* table and *Well* features. The mean groundwater level over a specified period of time at different wells is used to interpolate the groundwater for different time periods. Five different time periods were used to compare the water level changes over time: 1936 to 1969, 1970-1979, 1980-1989, 1990-1999, 2000-2009, and 2010-2012 (the last three years). Maps were also created showing the difference in groundwater levels between the "last three years" map and the other time period maps. Finally, a "water sensitivity" map was also created. This map shows the standard deviation of the groundwater levels and was created by calculating the standard deviation at each well that had at least 5 measurements. The details of these maps, including several examples, are shown in section 5.4.

### 3.5.2. Borelines

The Borelines feature is located inside the *Subsurface* feature dataset. These features are created using the information in the *Wells* feature class and the *BoreholeLog* table. Figure 3-7 shows all the borelines included in the geodatabase. The black borelines have not been interpreted and assigned to hydrogeologic units. These boreholes have shallow depths or questionable data which cannot be used to identify the geology of the study area. For areas surrounded with several boreholes within a short distance to one another, only the best available borehole is defined. As better data becomes available the undefined borelines could be defined by updating the **HGUID** in the *BoreholeLog* table and then regenerating the borelines. To identify the bore log quality, we added a field named **borelog_quality** into the *HCWC_supplemental_data* table inside the geodatabase. The enhanced locations for 7 verified wells are also updated in this table.

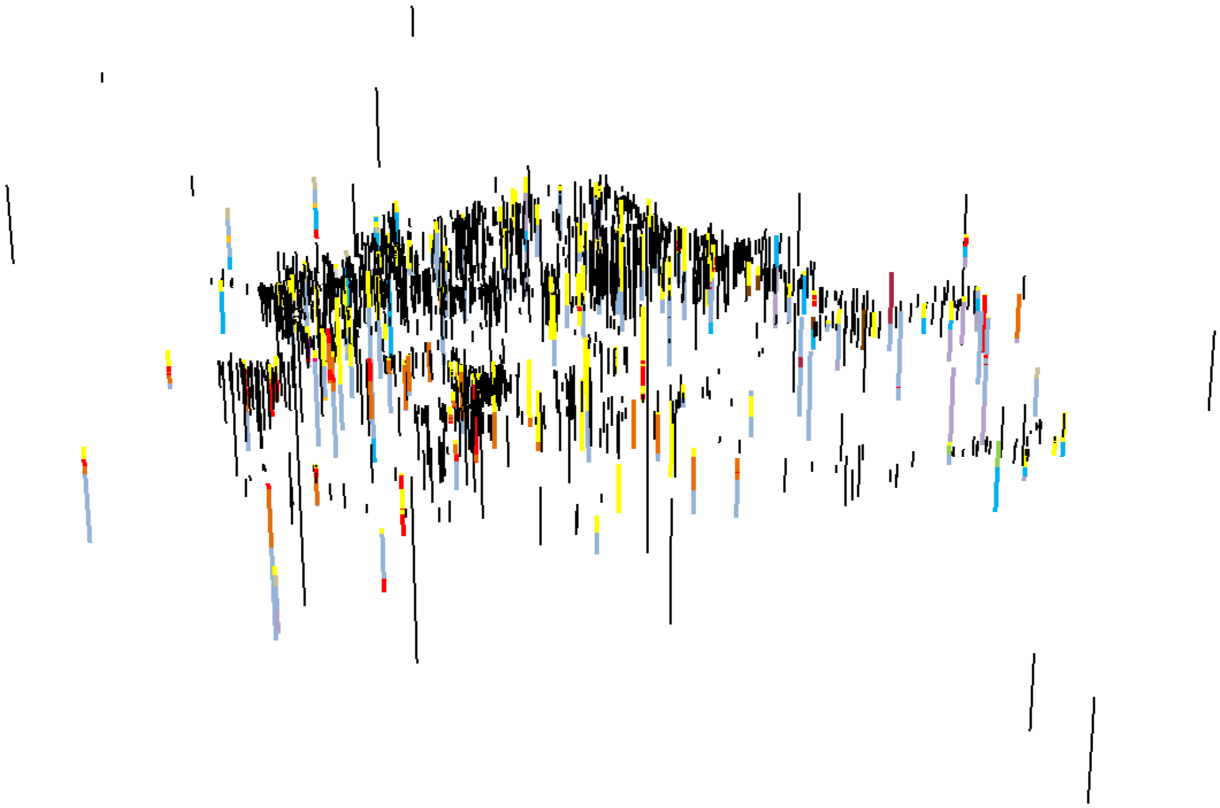


*Figure 3-7. Borelines in ArcScene*

Figure 3-8 shows only the borelines that were analyzed and assigned **HGUIDs**. This includes several borelines that are outside of the study area.

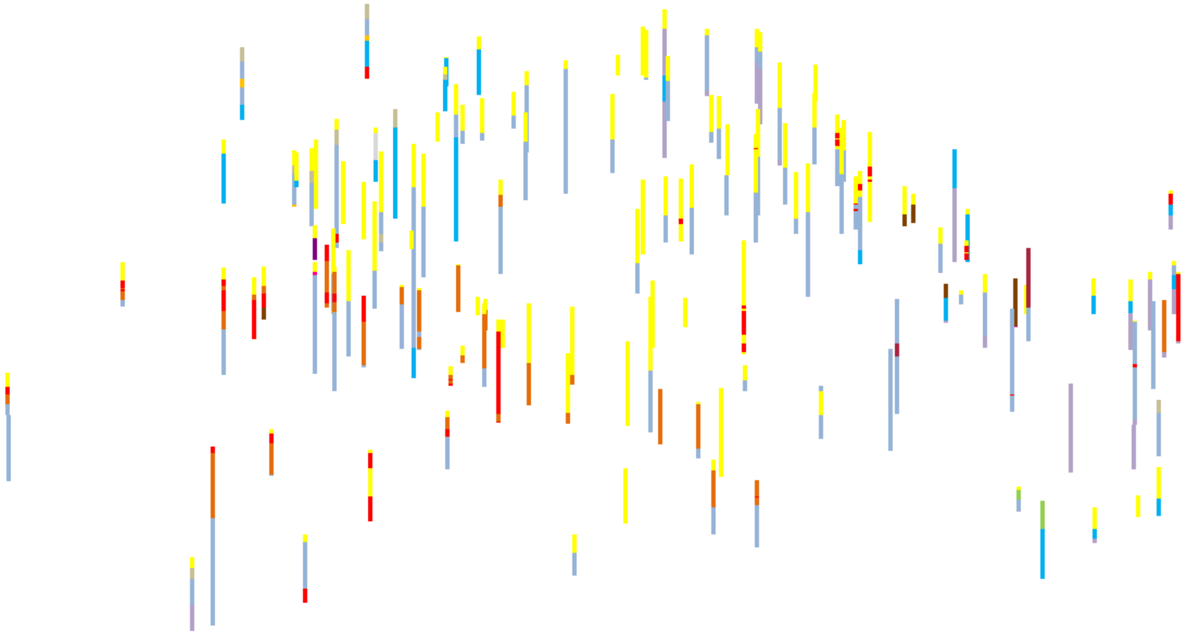


*Figure 3-8. Interpreted  Borelines in ArcScene*

### 3.5.3. Subsurface Cross Section (Stratigraphy)

The subsurface cross sections were generated using the defined boreholes and the surface elevation data. A significant amount of work and analysis went into the creation of the cross sections. The borehole data along with an understanding of the basin geology were used to create the cross sections.  The details of the basin geology are presented in section 5.2. The subsurface cross sections are shown in Figure 3-9. A vertical exaggeration factor of 50 is used in these maps to better visualize the stratigraphy. Figure 3-10 shows the subsurface cross section with the area surface imagery superimposed on top.

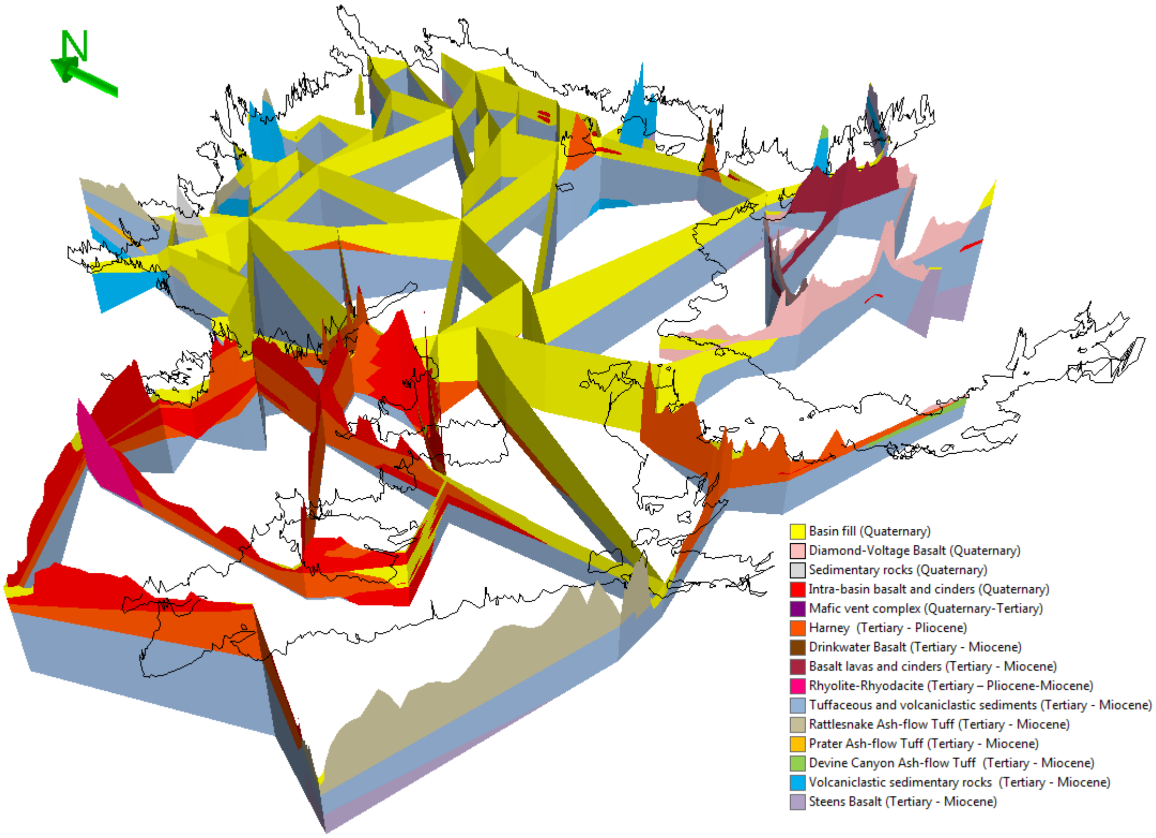


*Figure 3-9. Subsurface Cross Sections*

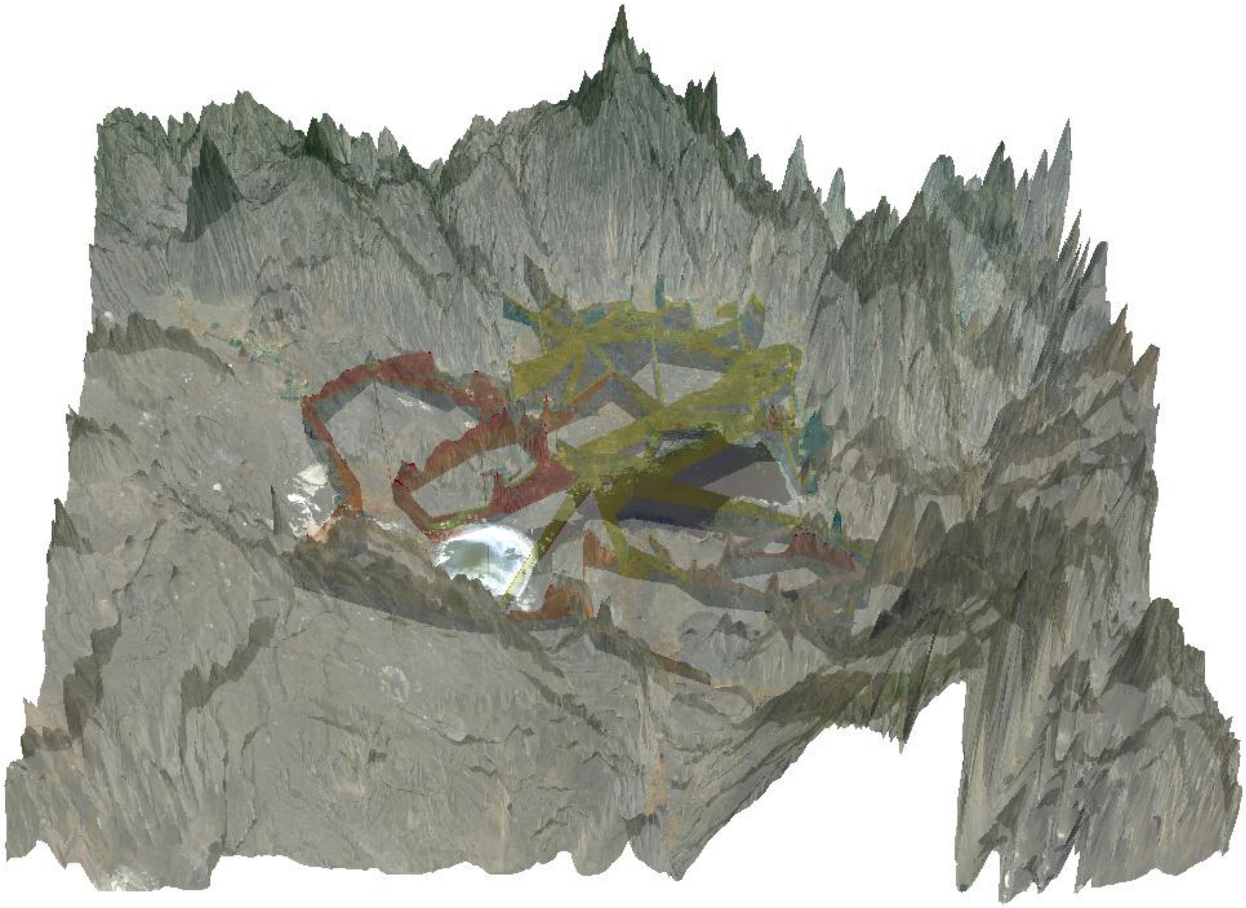


*Figure 3-10. Subsurface Cross Sections with Surface Imagery*

The cross sections can also be viewed and edited in ArcMap using the AHGW tools. Figure 3-11 shows multiple cross sections in layout view of ArcMap.

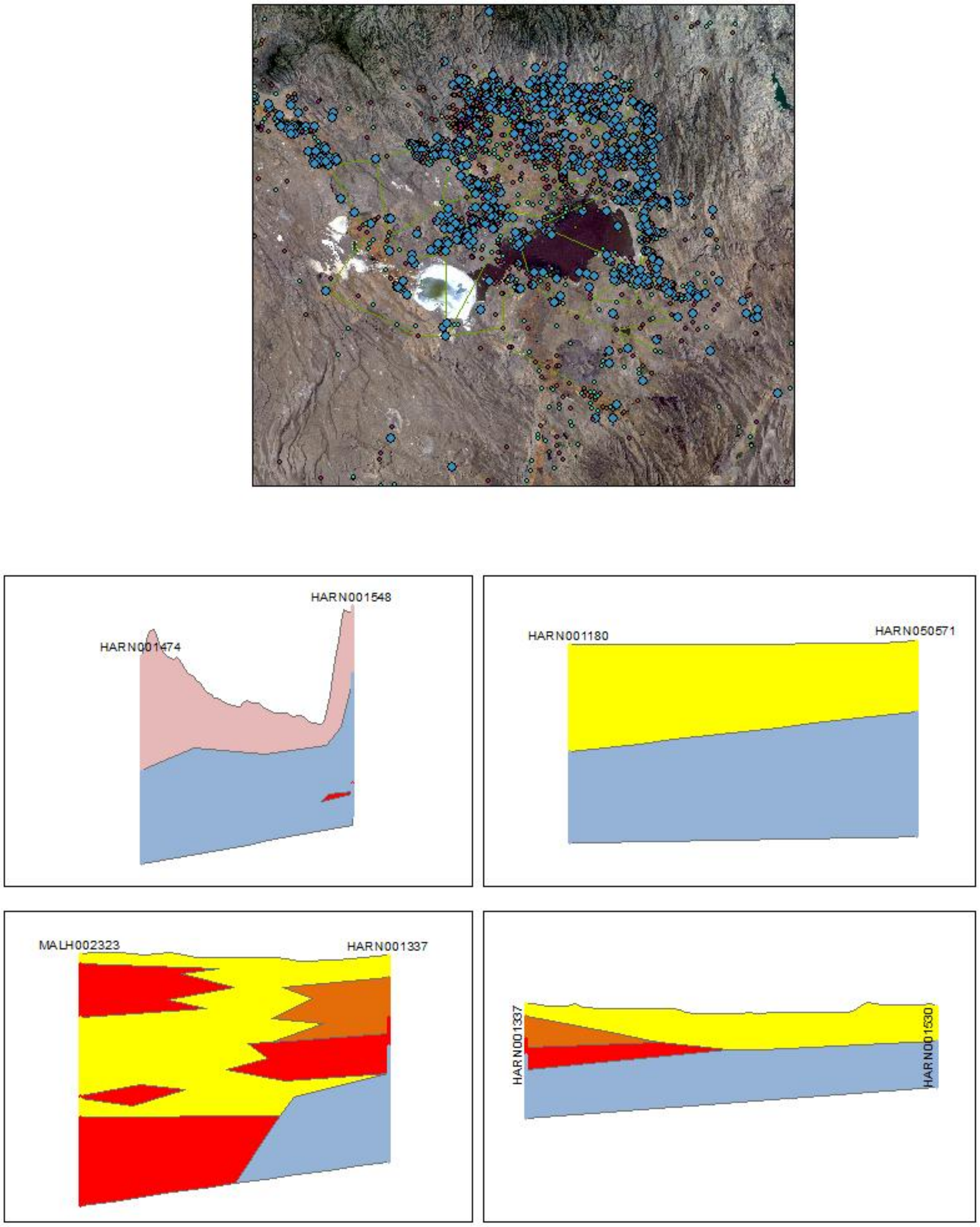


*Figure 3-11. Cross Sections in ArcMap*

### 3.6. Document Geodatabase

The delivered geodatabase was developed using the ESRI File Geodatabase (.gdb) format using the AHGW data model. The existing well data from ORWD is located in the ORWD_Data feature dataset.

The new well data with bore log and pump data attached is located in the *Well* feature class inside the Framework feature dataset. The borelines feature class is stored in the subsurface feature dataset. The cross sections are stored in the hydrogeologic feature dataset. Additional details about the GIS are described earlier in this section. The instructions on how to generate groundwater level maps and cross sections are explained in the AHGW tutorials located in the *Tutorials* folder. The assumptions made in defining the stratigraphic units for the subsurface are detailed in section 4.3.

## 4. Geologic Framework and Aquifer Definition

The geologic framework of the study area was developed starting with an understanding the regional geologic setting. Understanding the regional geologic setting informs the interpretation of the geology and hydrogeology of the study area. One of the primary tasks of this study is to develop a model or framework of the subsurface geology of the study area based on both the literature and well logs produced by well drillers. The collection of driller's well logs represents a large and detailed but unstandardized description of subsurface earth materials encountered while drilling boreholes for water wells. The driller's well logs also provide information concerning the groundwater such as the depth to and thickness of water bearing zones, static water levels, and water yields.

### 4.1. Regional Geologic Setting

The Harney Basin lies within and at the eastern end of the High Lava Plains physiographic province. The High Lava Plains extends west of Harney Basin approximately 130 miles to the Newberry Caldera. The Blue Mountain physiographic province lies to the north and northeast of Harney Basin. The Blue Mountain province consists of distinct blocks of Permian, Triassic and Jurassic (300 Ma to 145 Ma) marine rocks accreted to the North American tectonic plate. Adjacent to the Harney Basin these marine rocks are buried beneath Tertiary basalt flows, ash-flow tuffs and volcanic sediments. The much older Jurassic marine rocks are exposed approximately 16 miles north-northwest of the Burns and consist of interbedded volcanic greywacke and black mudstone of the Lonesome Formation (Imlay, 1964). The Basin and Range physiographic province lies to the south of the High Lava Plains and Harney Basin. Starting in the Miocene (5-23 Ma) the Basin and Range province developed in response to extensional tectonics, with movement along northerly trending faults. Large tilted fault blocks are evidenced by northerly trending mountain ranges and intervening basins. To the south of Harney Basin lie the Steens Mountains, a fault block mountain range, and to the west of the Steens Mountains are the Catlow Valley and Warner Valley structural basins. The extensional tectonics of the Basin and Range provinces was also marked by voluminous eruptions of basalt lava flows and volcanic ash.

The High Lava Plains is a bimodal tholeiite basalt and rhyolite province (Streck and Grunder, 2008). The Late Miocene to Quaternary High Lava Plains consists of roughly equal volumes mafic and siliceous volcanics (Streck and Grunder, 2008, and Streck, et al., 1999). The mafic volcanics consists of basaltic lava flows, tuffs and cinders, and the siliceous volcanics consists of rhyolite domes and flows, ash-flow tuffs, and volcanic ash. The Harney Basin depression developed as a result of extensional faulting and caldera collapse. The structural basin extends north-south from just north of Burns to Diamond, a distance of approximately 45 miles, and east-west from approximately Princeton to Riley, a distance of approximately 52 miles (Figure 4-1). The eastern portion of the structural basin is the lowest portion of the basin and consists predominantly of Harney Valley which is a plain with minimal relief that slopes very gently south toward Malheur and Harney Lakes. Much of the weste rn and southern portions of the structural basin has been filled with Late Miocene to Recent basaltic lava flows, cinders and palagonite tuff. The Harney structural basin has been a depositional center since Late Cenozoic to present (Walker, 1979, Streck and Grunder, 2008, and Millard, 2010).

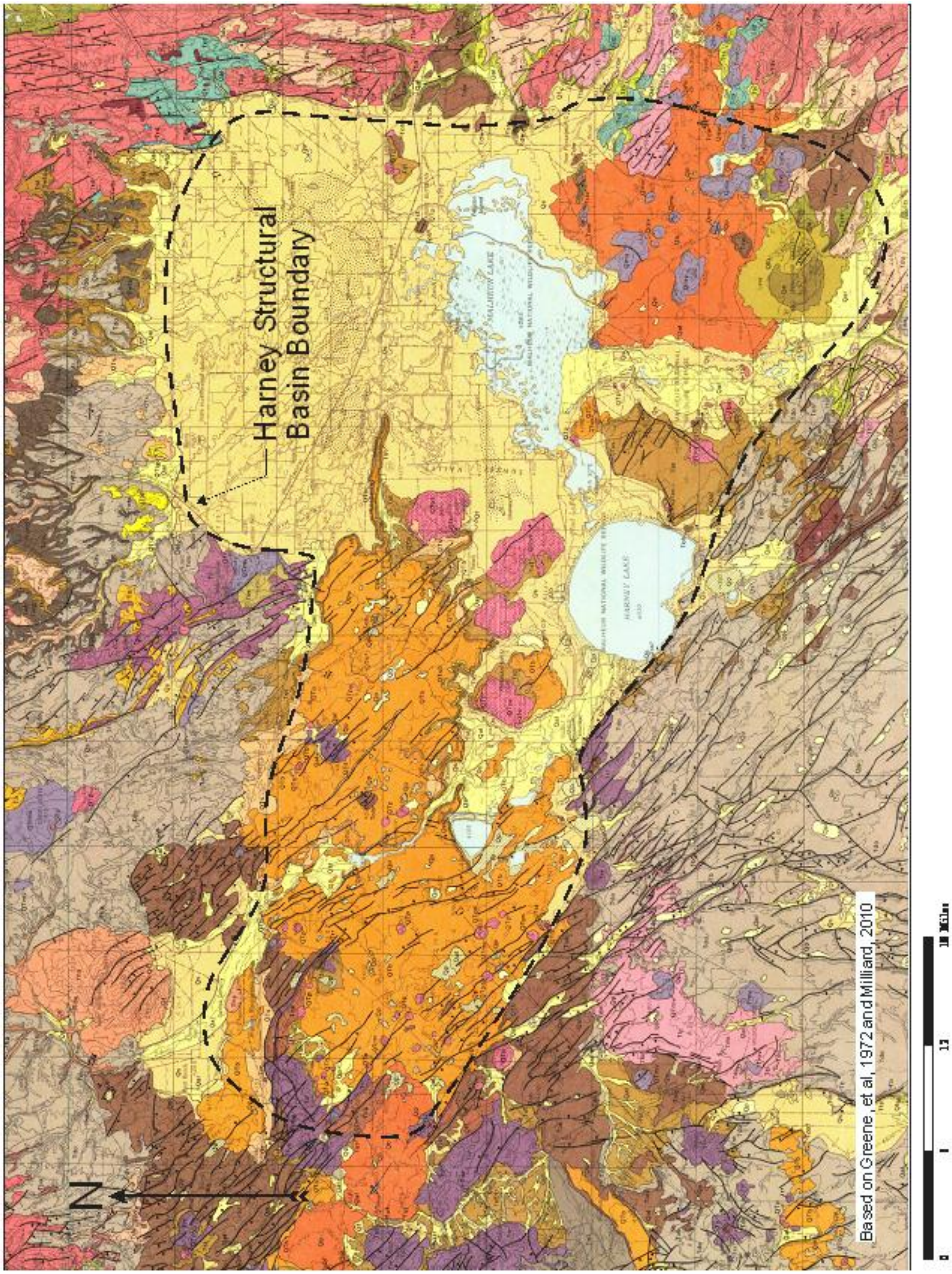


*Figure 4-1. Geology Map with Harney Structural Basin*

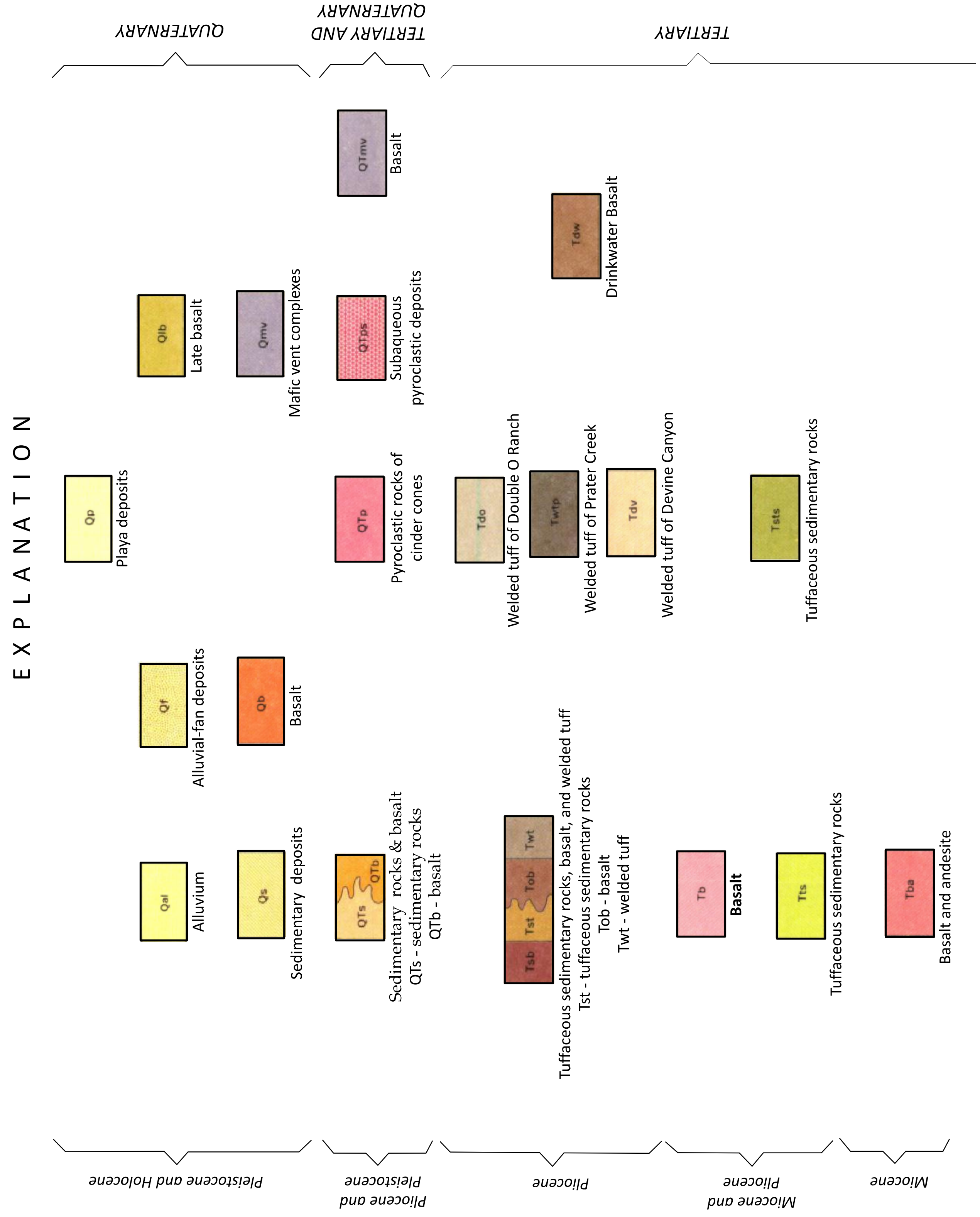


*Figure 4-2. Geology Map Legend*

## 4.2. Geodatabase Unit Descriptions

The geodatabase geologic units are described below generally in order from oldest to youngest.

*Steens Basalt – Miocene - Tba*

The middle Miocene Steens Basalt lava flows appear to be the oldest rocks encountered in the group of selected wells. The basalt is commonly described in well logs as black, grey and red. Steens Basalt flows generally vary from five to fifty feet thick and may be described as hard, firm, or broken. Between the lava flows there are commonly thin clays, two to ten feet thick, described as tan, yellow, red, green or grey in color. The Steens Basalt is encountered in wells located in the southeastern portion of the basin. The Steens Basalt is considered to be moderately permeable.

The log for the 6,380 foot deep Weed & Poteet #1 Oil Exploration well (Appendix B), located just east of Burns, describes a 620 foot thick sequence of lava flows starting at 3,730 feet beneath the surface. These may be equivalent to Steens Basalts. These basalt lava flows are underlain by 790 feet of clay and then with what the log describes as “Columbia basalts” from 5,140 feet to 6,380 feet.

*Volcaniclastic Sedimentary Rocks – Miocene – Tts, Tsts*

Volcaniclastic sedimentary rocks unconformably overlie the Steens Basalt. These rocks are encountered in wells located near the northern, eastern and southern boundaries of the basin. The lithologies include claystone, siltstone, sandstone, and conglomerate (Millard 2010, Walker 1979). Rhyolitic air-fall ash and lava are interbedded with volcaniclastic sedimentary rocks. These volcaniclastic sedimentary rocks are generally overlain by unconsolidated sediments. In well logs the unit is described as brown conglomerate, tan and brown clay and claystone, and sandstone. This unit is encountered in a 1,316 foot deep well, HARN 573, in the northwest portion of Harney Valley. In the log for this well the unit is described as hard to soft gray, black and yellow shale and hard sandstone from 1,148 to 1,316 feet beneath the surface. The log for a 4,550 foot deep oil exploration well, located near HARN 573, describes the subsurface below 1,316 feet as predominantly consisting of thick sequences of shale and sandstone (hard sand). The volcaniclastic sedimentary rocks are expected to have low permeability.

*Devine Canyon Ash-Flow Tuff – Miocene – Tdv*

The Devine Canyon Ash-Flow Tuff is interpreted to be encountered in several wells located near Diamond, in the southernmost part of the study area. It is described as a hard gray rock and gray pumice. It overlies sandstone and claystone. It may act as a low permeability confining layer.

*Prater Creek Ash-Flow Tuff – Late Miocene – Twpt*

The Prater Creek Ash-Flow Tuff is encountered in only one of the selected wells. This well is located outside of the basin to the north of Burns. Up to approximately 165 feet of tuff and tuffaceous sediments separates the Prater Creek Ash-flow Tuff from the underlying Devine Canyon Ash-flow Tuff (Walker, 1979). The Prater Creek Ash-Flow tuff is approximately 40 feet thick where exposed along Prater Creek north of Burns. The Prater Ash-flow Tuff is overlain by up to approximately 130 feet of tuffaceous sediments (Walker, 1979). The permeability of the Prater Ash-flow tuff is expected to be low and it is likely to act as aquitard and a confining layer.

*Rattlesnake Ash-Flow Tuff – Late Miocene - Tdo*

The Rattlesnake Ash-Flow Tuff, formerly known as the Double O Ranch tuff, covers extensive areas to the north, west and south of the structural basin. To the north and northwest of Harney Valley the Rattlesnake Ash-Flow Tuff overlies tuffaceous sediments and the Prater Creek Ash-flow Tuff. The Rattlesnake Ash-Flow Tuff is described as approximately 200 feet thick to the west of the basin and 66 feet thick where exposed along US Highway 395, approximately six miles north of Burns. The Rattlesnake Ash-Flow Tuff is encountered in five of the selected wells. Four of the wells are located to the north of the structural basin. At these locations the ash-flow tuff is described as hard red rock, 78 to 53 feet thick, and is underlain by sandstone, claystone and clayey-gravel. The Rattlesnake Ash-Flow Tuff is interpreted to be encountered in well HARN 441, located just southwest of the Burns Airport, at a depth of 464 feet beneath the surface. It is described as 49 feet of hard rock, which is overlain by four feet of grey sand and boulders, and then 20 feet of blue clay. The difference in elevation between the Rattlesnake Ash-Flow Tuff just north of the basin and what is interpreted to be the ash-flow tuff within the basin indicates a down faulting of 500 to 600 feet in the basin. The permeability of the Rattlesnake Ash-Flow Tuff is expected to be low. It is likely to act as aquitard and a confining layer.

*Tuffaceous and Volcaniclastic Sediments – Miocene – Tst*

These tuffaceous and volcaniclastic sediments constitute a major portion of the material that fills the structural basin. In a large number of the wells within the basin this is the oldest material encountered. It is commonly overlain by Quaternary sediments. The unit generally consists of unconsolidated to weakly indurated blue, green and gray clay with generally much thinner beds of sandy clay, sand and gravel. The thickness of this unit within the basin is not well defined as it appears that most of the wells in the basin do not fully penetrate it. One well, HARN 573, is interpreted to penetrate approximate 900 feet of these tuffaceous and volcaniclastic sediments. This unit also includes thin basalts and cinders that have been included in the geodatabase unit designated as intra-basin basalts and cinders. These tuffaceous and volcaniclastic sediments appear to interfinger with material of the Harney Formation in the western portion of the basin. The permeability of these sediments is expected to be generally low due to the predominance of clay, however, interbedded sands and gravels will have moderate permeability and the water in these permeable beds will be confined.

*Rhyolite-Rhyodacite – Miocene-Pliocene – Trr*

Rhyolite and Rhyodacite intrusive and extrusive rocks occur primarily as domes and irregular masses in the western portion of the Harney structural basin (Greene, et al., 1972). Iron Mountain is a rhyolite dome located approximately twelve miles west of Harney Lake. The dome is dated at 2.7 m.y. (Walker, 1979). Iron Mountain and Egli Ridge, another rhyolite mass, are located along the boundary of the structural basin and their source magma may have moved up faults bounding the basin. These silicic rocks are described as very fractured and thick talus commonly blankets the masses. The permeability of the rhyolite-rhyodacite intrusive and extrusive rocks is likely medium to high.

*Basalt lavas and cinders– Miocene - Tb*

Basalt lava flows and cinders are encountered in well HARN 1485, located approximately four miles south of Princeton in the southeast corner of the valley. The area is mapped as Miocene basalt overlying the volcaniclastic sedimentary rocks (Tts) described above (Greene, et al., 1972). Quaternary Diamond basalt laps onto this older basalt. Miocene basalts have also been mapped to the southwest of the structural basin where it appears to overlie tuffaceous sedimentary rocks (Tst) and with the Rattlesnake ash-flow lapping onto it. These basalts and cinders, based on the well log descriptions, are likely to have a moderate to high permeability.

*Drinkwater Basalt – Miocene - Tdw*

The Drinkwater Basalt occurs in the southeast corner of the basin. It appears to be encountered in only two the selected group of wells (HARN 50150, 51629). In these well logs the Drinkwater Basalt is described as broken black and brown rock. The permeability is expected to be high.

*Harney Formation - Miocene*

The Harney Formation is capped at the surface by basalt lava flows in the western portion of the structural basin. Along the western margin of Harney Valley the Harney Formation is covered by Quaternary basin-fill that is up to 350 feet thick. The Harney Formation is thickest along the west margin of Harney Valley at approximately 230 feet, based on interpretation of well log descriptions. Walker (1979) describes the Harney Formation as consisting of sandstone, siltstone, conglomerate, gravel, basaltic tuff and breccia, and basalt flows. Based on the well log descriptions extensive basalt lava flows and cinders (pyroclastics and palagonite) occur within and interfinger with the Harney Formation. The Harney Formation is distinguished from the tuffaceous and volcaniclastic sediments unit described above by the predominance of coarser clastic material. The basalt capping the Harney Formation and basalts and cinders that occur within and interfinger with Harney Formation sediments are herein addressed as a separate unit designated intra-basin basalts and cinders. The permeability of the Harney Formation is expected to be moderate.

*Mafic Vent Complexes – Late Miocene to Quaternary - Qmv*

Small mafic vent complexes are mapped around the margin of the structural basin (Greene, et al., 1972). There are a number of mafic vents in the area north of Diamond. The near vent deposits consist of basalt and andesite breccia, scoria, cinders and small flows. There are several wells located within areas mapped as mafic vent deposits. Two wells south of Harney Lake and north of the Diamond Craters penetrate from the surface 200 and 300 feet of hard black, gray, and red broken, cracked and creviced rock with minor cinders. These high permeability vent complexes are underlain by low permeability sandstone and claystone.

*Intra-Basin Basalts and Cinders – Miocene to Quaternary*

The intra-basin basalts and cinders unit includes the basalt that caps much of the Harney Formation to the west of Harney Valley and basalts and cinders that interfinger with and occur within the Harney Formation. Wright Point, which extends six miles into Harney Valley, is capped by two basalt flows of this unit (Niem, 1974). The subaqueous pyroclastic material of Freeman Butte and Dog Mountain and other buttes nearby mapped by Greene et al (1972) is also included in this unit. There are also minor basalts and cinders included in this unit that occur within Quaternary basin-fill and the older tuffaceous and volcaniclastic sediments unit. The intra-basin basalts and cinders unit appears thickest in the vicinity of Dog Mountain. Well HARN 50633, located just east of Dog Mountain, penetrates approximately 460 feet of brown and gray vesicular basalt. The intra-basin basalts and cinders are expected to have moderate to high permeability.

*Sedimentary Rocks – Pliocene to Pleistocene - QTs*

Conglomerates and sandstones of Pliocene to Pleistocene age occur in the western portion of Sage Hen Valley (Greene, et al., 1972). Sage Hen Valley is directly west of Harney Valley. These permeable sedimentary rocks likely fill an old paleo-valley. Pliocene to Pleistocene age sedimentary rocks are also mapped just to the north of the northern edge of Harney Valley. These sedimentary rocks are underlain by the less permeable Harney Formation and the Rattlesnake Ash-Flow Tuff.

*Diamond/Voltage Basalts – Quaternary – Qlb, Qb*

The late Quaternary Diamond Crater basalt lavas flows (Qlb) and the Quaternary Voltage basalt flows (Qb) to the north and northeast of Diamond Craters are combined. These very permeable basalt lavas and cinders are underlain by much less permeable tuffaceous and volcaniclastic sediments.

*Basin Fill – Quaternary*

The Quaternary basin-fill consists of unconsolidated material that occurs primarily in the lowest portion of the basin, Harney Valley. The mapped surficial extent of the Quaternary basin-fill was used to define the initial boundary for this study. The Quaternary basin-fill consists of lacustrine and alluvial deposits of clay, clay with sand, silt, sand and gravel. Clay and clay with sand are the predominant materials described in well logs. The unit varies from tens of feet thick at the margins of the valley floor to 500 feet thick in wells located just south of Malheur Lake. The basin-fill unit includes sand dunes and saline sediments (playa deposits) associated with Harney Lake. The coarser alluvial material generally occurs along the margins of the valley where streams enter the valley. The base of the Quaternary basin-fill is generally distinguished in the well logs when consolidated materials are first described. The permeability of the Quaternary basin-fill is expected to be quite variable. The predominant clay will have low permeability and sands and gravels will have moderate to high permeability.

### 4.3. Hydrogeologic Units

A hydrogeologic unit is a body or unit of unconsolidated earth material or rock that has distinct hydraulic properties due its porosity and permeability. A hydrogeologic unit may be a productive aquifer due to high porosity and permeability, or it may be an aquitard that acts as a confining unit due to its low permeability. A hydrogeologic unit may consist entirely of a single geologic unit, a portion of a geologic unit, several geologic units, or portions of several geologic units.

Within Harney Valley the primary hydrogeologic units are: basin-fill, tuffaceous and volcaniclastic sediments, Harney Formation, and intra-basin basalts and cinders. The Harney structural basin extends beyond the valley to the south and west and in these areas the primary hydrogeologic units are: basin-fill, tuffaceous and volcaniclastic sediments, Harney Formation, intra-basin basalts and cinders, Steens Basalt, Diamond/Voltage basalt, and volcaniclastic sedimentary rocks. The hydrogeologic units are listed in the following table.

*Table 4-1 Hydrogeologic Units*

| Hydrogeologic Units | Specific Capacity (gal/ft) | Estimated Hydraulic Conductivity (gal/day/ft$^2$) | Lithology |
|---|---|---|---|
| Basin Fill | 0.4 to 41 | 243 to 728 | Gravel, Sand, silt, clay, sandy-clay, clayey-sand, gravel, and clayey-gravel |
| Diamond/Voltage Basalt, includes Mafic vent complexes | 81 to 200 | 2,727 to 7,843 | Lavas flows, cinders, and vent complexes |
| Intra-Basin basalts and cinders, includes: flows within Basin-fill, Harney Formation and Tuffaceous and volcaniclastic sediments | 33.3 | 995 | Lavas flows, pyroclastics, palagonite, cinders |
| Harney Formation | 0.1 to 3.3 | 28.6 to 76.9 | Sandstone, claystone, conglomerate, sand and gravel |
| Tuffaceous and volcaniclastic sediments | 0.1 to 50 | 1.7 to 610 | Clay, claystone, minor sand, sandstone, pumiceous |
| Volcaniclastic sedimentary rocks | 1.5 to 7.5 | 20 and 600 | Rhyolitic siltstone, claystone, sandstone, conglomerate |
| Steens Basalt | 1.7 to 510 | 333 to 46,364 | Lava flows |

Appendix C contains a table that is a compilation of the data for all of the selected wells that were used to develop the three-dimensional geologic model. The specific capacity for most of the wells was calculated and is included in Table 4-1. The water producing zone could only be defined with relative certainty for a subset of the wells, based on an interpretation of the driller's log. Where the production zone could be identified the hydraulic conductivity (K) was estimated based on specific capacity (Driscoll, 1986). The estimated K value was calculated assuming the aquifer was confined.

### *Basin-Fill*

The basin-fill hydrogeologic unit is unconsolidated material deposited in alluvial and lacustrine environments in the Harney Basin. Basin-fill occurs at the surface over the floor of Harney Valley and up the major tributary valleys. The basin-fill permeability is predominantly low due to the abundance of clay. However, within the basin-fill unit there are sands and gravels that contain little in the way of fines (clay and silt) and thus have a high permeability. These coarser sediments are likely to be deposited at the margins of the valley by streams as their gradients become very shallow and the stream can no longer move the coarse material. Sands with relatively minor amounts of fines may be deposited some distance into the valley along meandering paleo-stream channels. The coarser material will predictably pinch-out laterally. The basin-fill appears to be thickest, up to 500 feet, along the southern edges of Harney and Malhuer Lakes. It appears to be very thick just upstream of the mouth of the Donner und Blitzen River.

A large number of wells are completed within the basin-fill. For those selected wells that appear to produce water only from the basin-fill, the yields range widely from 20 to 2,500 gallons per minute (gpm). The specific capacity of the wells range from 0.4 to 41 gallons per foot (gal/ft). For those wells with a reasonably identifiable production zone the hydraulic conductivity varied from 243 to 728 gallons per day per square foot (gal/day/$ft^2$). This range of hydraulic conductivity is within the range for a silty to clean sand (Freeze and Cherry, 1979).

The OWRD provided pump test data, plots and analysis for four wells within Harney Valley. The pump tests were performed by the well owner or someone hired by the owner. The pump test data is recorded on forms provided by OWRD. The well owner submits the data to the OWRD and it is evaluated by a staff hydrogeologist. If the pump test data is considered good enough then the OWRD hydrogeologist will use the data to determine transmissivity. The four wells for which transmissivity values were derived are completed in the Quaternary basin-fill unit. The following table is a summary of the pump test data and analysis.

*Table 4-2 Transmissivity of Basin-Fill Derived from OWRD Pump Test Data*

| Well Number | Well Depth | Pumping rate gpm | Transmissivity Pumping data, Cooper-Jacob method (gal/day/ft) | Transmissivity Recovery data, Theis method (gal/day/ft) | Hydrogeologic Unit |
|---|---|---|---|---|---|
| 198 | 260 | 600 | 158400 | 1049 | Basin-fill |
| 1213 | 205 | 850 | 6411 | 11936 | Basin-fill |
| 50238 | 200 (?) | 924 |  | 7623 | Basin-fill (?) |
| 51419 | ? | 700 | 5220 | 2888 | Basin-fill |

Note: The OWRD analyst characterized the test quality for well 50238 as fair and for other three wells as poor.

The transmissivity values in the above table vary over a larger range than the estimated transmissivity values given in the Table of Selected Well Data in Appendix C. The estimated transmissivity for the basin-fill unit in this table ranges from 14,286 to 53,180 gallons per day per foot (gal/day/ft).

*Tuffaceous and volcaniclastic sediments*

The tuffaceous and volcaniclastic sediments hydrogeologic unit underlies most of the study area. Many of the deeper wells on the valley floor and in the larger structural basin are terminated in this geologic and hydrogeologic unit. The predominant material is unconsolidated to weakly indurated blue, green and gray clay. Sands, gravels, and sandstones are minor, but when present they can yield large quantities of water. Very few wells fully penetrate this unit. Well HARN 573 appears to fully penetrate the tuffaceous and volcaniclastic sediments unit. In this well the tuffaceous and volcaniclastic sediments are approximately 900 feet thick. For those of the selected wells that appear to produce water only from this unit the specific capacity ranged from 0.1 to 50 gal/ft. For those wells with an identified production zone the estimated hydraulic conductivity varied from 1.7 to 610 gal/day/ft$^2$. This hydraulic conductivity range is within the range for a silty-sand (Freeze and Cherry, 1979). Well HARN 50668 located in the central part of the valley reportedly produces a large portion of 800 gpm from a 6-foot thick sandy-gravel within a thick section of blue and green clay.

### *Harney Formation*

The Harney Formation hydrogeologic unit occurs primarily to the west of Harney Valley and within the Harney structural basin. Basalt flows, cinders, and palagonite are associated with the Harney Formation, but are here considered a separate hydrogeologic unit. The Harney Formation consists of sandstone, siltstone, conglomerate, sand and gravel. The Harney Formation is generally capped by basalt flows. Many of the wells that intersect the Harney Formation fully penetrate and appear to produce water from the underlying tuffaceous and volcaniclastic sediments. Relatively few of the wells are terminated within the Harney Formation. The selected wells that produce water from the Harney Formation have yields that range from 10 to 490 gpm. Specific capacity ranges from 0.1 to 3.3 gal/ft. The hydraulic conductivity could only be estimated for two wells and the values were 28.6 and 76.9 gal/day/ft$^2$. These hydraulic conductivity values are within the range for sand and silty-sand (Freeze and Cherry, 1979).

### *Intra-basin basalts and cinders*

The intra-basin basalts and cinders hydrogeologic unit occurs primarily to the west of Harney Valley and within the Harney structural basin. The intra-basin basalts and cinders hydrogeologic unit also includes basalt flows that occur within the tuffaceous and volcaniclastic sediments, particularly along the eastern edge of Harney Valley in the vicinity of Crane. Of the selected wells only four appear to produce water from just the intra-basin basalts and cinders. The reported yields are 50, 1,000, 1,500 and 1,600 gpm. Well HARN 1214, which reportedly produces 1,600 gpm, is located just north of Crane. This well produces from two zones of cinders. The specific capacity of this well is 33.3 gal/ft and the estimated hydraulic conductivity is 995 gal/day/ft$^2$. This hydraulic conductivity value is within the range of hydraulic conductivity for sand, silty-sand, and permeable basalt (Freeze and Cherry, 1979).

### *Steens Basalt*

The Steens Basalt hydrogeologic unit occurs primarily just outside the structural basin to the northeast, east and southeast. The pumping rate of these wells ranges from 15 to 1,100 gpm. The specific capacity ranges from 1.7 to 510 gal/ft. The estimated hydraulic conductivity ranges from 333 to 46,364 gal/day/ft$^2$. This range of hydraulic conductivity values is within the range for permeable basalts (Freeze and Cherry, 1979).

### *Diamond/Voltage basalt*

The Diamond and Voltage basalts are combined in a single hydrogeologic unit because they are considered to be hydraulically well connected and both are expected to have high permeability. The unit also includes the mafic vent complexes in this area (Greene, et al., 1972). The Diamond/Voltage basalts and mafic vent complexes cover a large area directly south of Malhuer Lake. It appears that this geologic unit may only be saturated near Malhuer Lake. It is underlain primarily by much less permeable tuffaceous and volcaniclastic sediments. Precipitation percolates very rapidly through the lavas and cinders and is then impeded at the contact with the tuffaceous and volcaniclastic sediments. This contact slopes north, toward Malhuer Lake. It is likely that the Diamond/Voltage hydrogeologic unit is the primary source for springs and seeps that occur near the south shore of Malhuer Lake. Two wells near the south shore of Malhuer Lake produce water from the Diamond/Voltage basalt hydrogeologic unit. One well, HARN 1408, reportedly has a yield of 800 gpm and a specific capacity of 200 gpm/ft. and the other well, HARN 1363, yields 900 gpm and has a specific capacity of 82 gpm/ft. The estimated hydraulic conductivities are 2,727 and 7,834 gal/day/ft$^2$ respectively. These hydraulic conductivity values are within the range for permeable basalts (Freeze and Cherry, 1979).

*Volcaniclastic sedimentary rocks*

The volcanic sedimentary rock hydrogeologic unit is intersected by a relatively small number of wells that are located outside the structural basin; to the north, east and southeast. These indurated volcanic sediments generally overlie the Steens Basalt and are in turn generally overlain by the tuffaceous and volcaniclastic sediments. Wells that produce water from this hydrogeologic unit have reported yields that range from 15 to 150 gpm and have specific capacities that range from 1.5 to 7.5 gal/ft. Using the data from the two well logs, the hydraulic conductivities were estimated. The estimated hydraulic conductivities values are 20 and 600 gal/day/ft$^2$.

# 5. Groundwater Basin Description

In this section the basin hydrology, geology, hydrogeology and groundwater use will be described and discussed.

## 5.1. Hydrology and Water Budget

This section of the report focuses on two primary issues. The first is a summary of surface water data resources available in the Harney Basin, and a brief summary of the surface water regime. The second part of this section describes the development of, and preliminary results from, a Deep Percolation Model (DPM) that estimates groundwater recharge.

### 5.1.1. Surface Hydrology Summary

The Harney Basin consists of large areas of high desert prairie bounded by mountainous terrain in the Ochoco and Malheur National Forests to the north, the Steens Mountains to the southeast, and upland areas of relatively lower relief to the east and west. Much of the basin is non-forested, and primarily managed for dry land livestock production. Irrigated agricultural lands are located primarily in the vicinity of Malheur Lake, and in the Silver Creek valley.

The Harney Basin is located almost entirely within Oregon Climate Division 7 (South Central Oregon; established by the National Climatic Data Center). Annual precipitation is generally less than 15 inches, except in the mountainous areas where annual precipitation can exceed 40 inches. Most precipitation occurs in the winter and spring months. Precipitation during summer months predominantly occurs as isolated local thunderstorms.

Mean daily discharge, mean daily discharge per square mile, and estimated recurrence intervals for annual peak flows for three long-term stream gages within the Harney Basin are shown in Figure 5-1, Figure 5-2, and Figure 5-3, respectively. The three gages selected were the Silvies River near Burns (gage #10393500), the Donner Und Blitzen River near Frenchglen (gage #10396000), and Silver Creek near Riley (gage #10403000). Gage locations are shown in Figure 2-1, and station characteristics are summarized in Table 2-2.

Climate condition data was obtained and summarized from http://www.ocs.oregonstate.edu/county_climate/Harney_files/Harney.html.

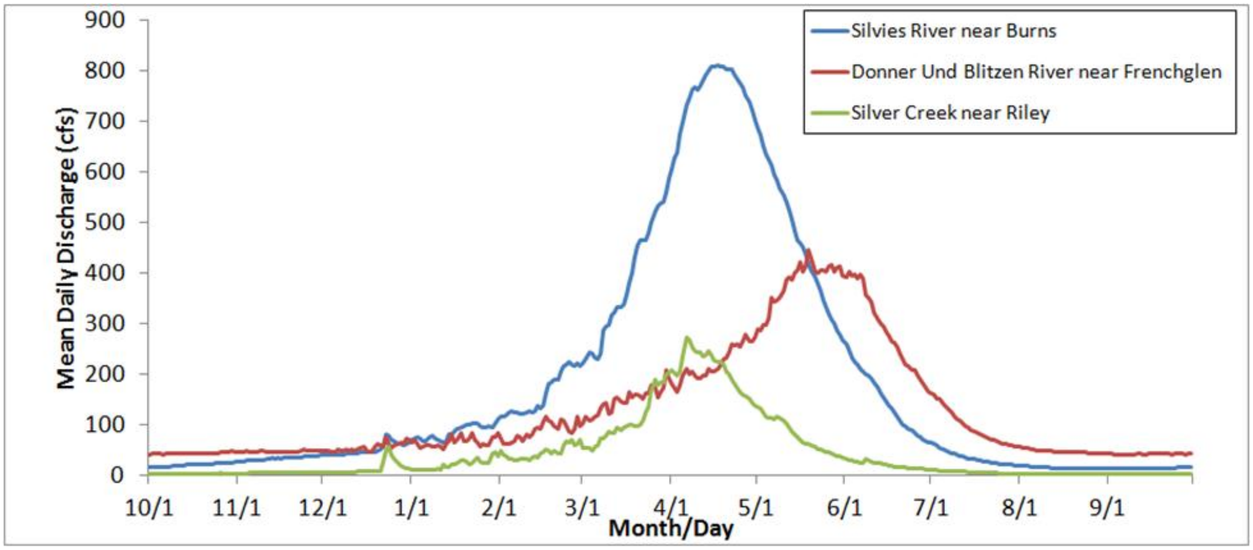


*Figure 5-1. Mean daily discharge for three long-term stream gages within the Harney Basin*

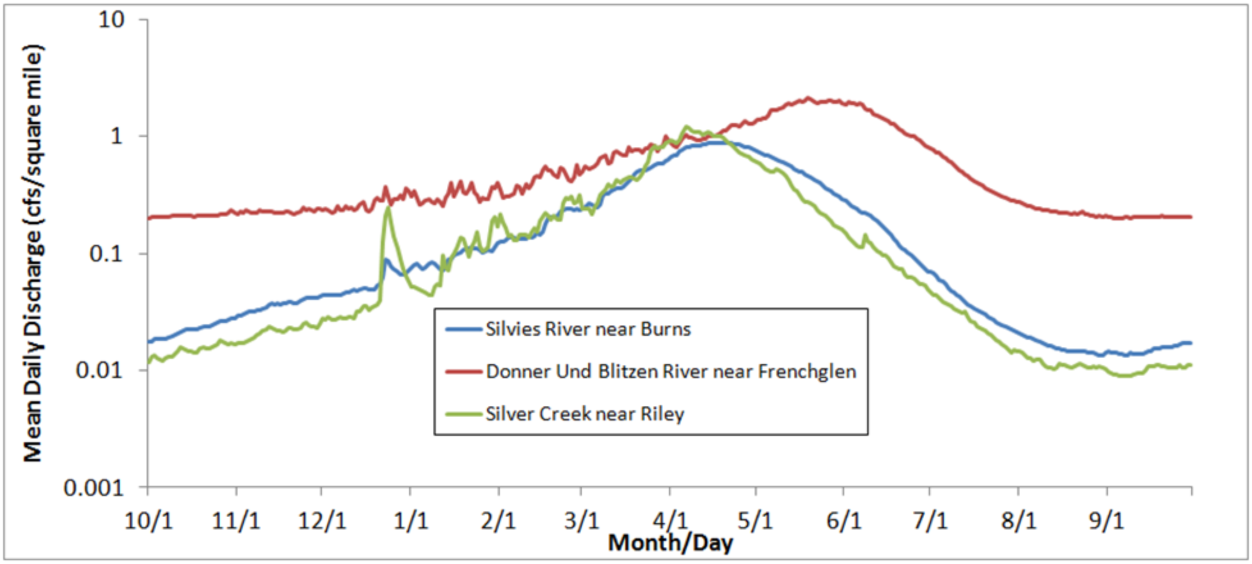


*Figure 5-2. Mean daily discharge/square mile for three long-term stream gages within the Harney Basin*

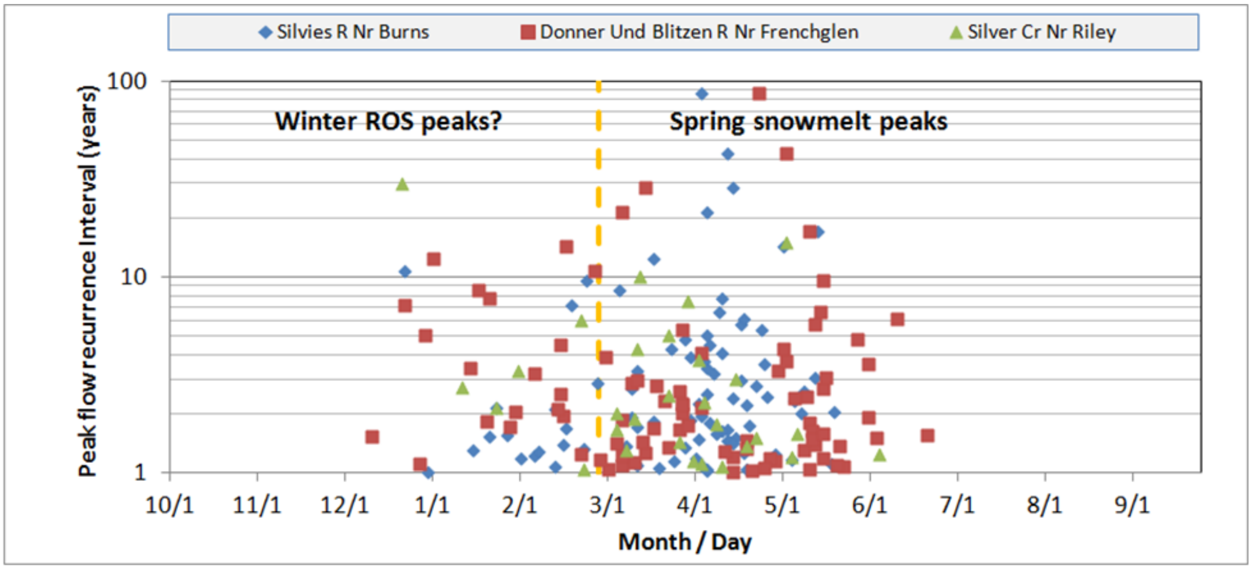


*Figure 5-3. Estimated recurrence intervals for annual peak flowsfor three long-term stream gages within the Harney Basin*

All three hydrographs in Figure 5-1 represent a snowmelt dominated hydrologic regime. The mean timing of maximum runoff for both the Silvies River and Silver Creek gages occur at approximately the same time; in early April. In contrast the mean timing of maximum runoff for the Donner Und Blitzen River is almost two months later; June 1st. The Silvies River and Silver Creek both drain areas on the north side of the basin, and are similar in terms of elevation, aspect and vegetative cover. In contrast, the Donner Und Blitzen drains an area on the south end of the basin, having generally higher elevations and a more northerly aspect than the other two streams; all of which likely account for the difference in snowmelt timing.

Figure 5-2 shows long term mean daily flow per unit area. This way of displaying data removes the effect of different watershed size. Also, the y-axis for the middle graph in Figure 5-2 is shown as a logarithmic scale, which highlights the difference in flow at the lower stream flow levels. This graphic illustrates that the unit-area discharge for the Silvies River and Silver Creek are roughly similar over the course of the water year. In contrast, the maximum discharge per unit area for the Donner Und Blitzen River is approximately twice as great as for the Silvies River or Silver Creek, and the baseflow is an order of magnitude larger. These results are likely due to deeper snowpack in the Donner Und Blitzen watershed, and a greater influence of groundwater inputs.

The bottom graph in Figure 5-3 shows the distribution of annual peak flows for the three gages. Annual peak flows are the maximum observed instantaneous discharge observed in a given water year, and may be (usually are) significantly larger than the mean daily flow for the day. The recurrence interval (i.e., the "x year flood") was calculated for each peak flow occurrence using standard methodologies (Flynn et al., 2006), and this is the value plotted on the y-axis. The reason for displaying the data in this way is so we could compare peak flow events from different size watersheds on the same graph (this approach removes the effect of the watershed size). Again, the y-axis for the graph in Figure 5-3 is shown as a logarithmic scale, in order to magnify the smaller events which would otherwise not show up on a normal graph. Not surprisingly the majority of the annual flood events occur during the spring snowmelt, however, several of the largest flood events happen earlier in the winter (prior to ~3/1; orange line on graph). This suggests that wintertime rain-on-snow events are also important drivers of flooding in the Harney Basin.

### 5.1.2. Preliminary Recharge Model

We developed a Deep Percolation Model to estimate groundwater recharge in the Harney Basin following the approach of Bauer and Vaccaro (1987) and Bauer and Mastin (1997). Spatial input data were assembled in a Geographic Information System (GIS) and formatted to run in the computer model available from the USGS. The Deep Percolation Model is driven by climate station data, and an initial data set was developed from stations in the area to drive the initial model run. The preliminary model discussed below provides an initial platform from which further analyses can be performed at the discretion of the Harney County Watershed Council. A discussion of possible future uses of the model is provided in the recommendations section of this report

#### *Model overview*

The Deep Percolation Model calculates groundwater recharge to the aquifer on a daily time step. For the purposes of the model recharge is defined as moisture that passes through the soil rooting zone. Once moisture is below the rooting zone it is assumed to contribute to aquifer recharge. The principal inputs, outputs and processes of the Deep Percolation Model are shown in Figure 5-4.

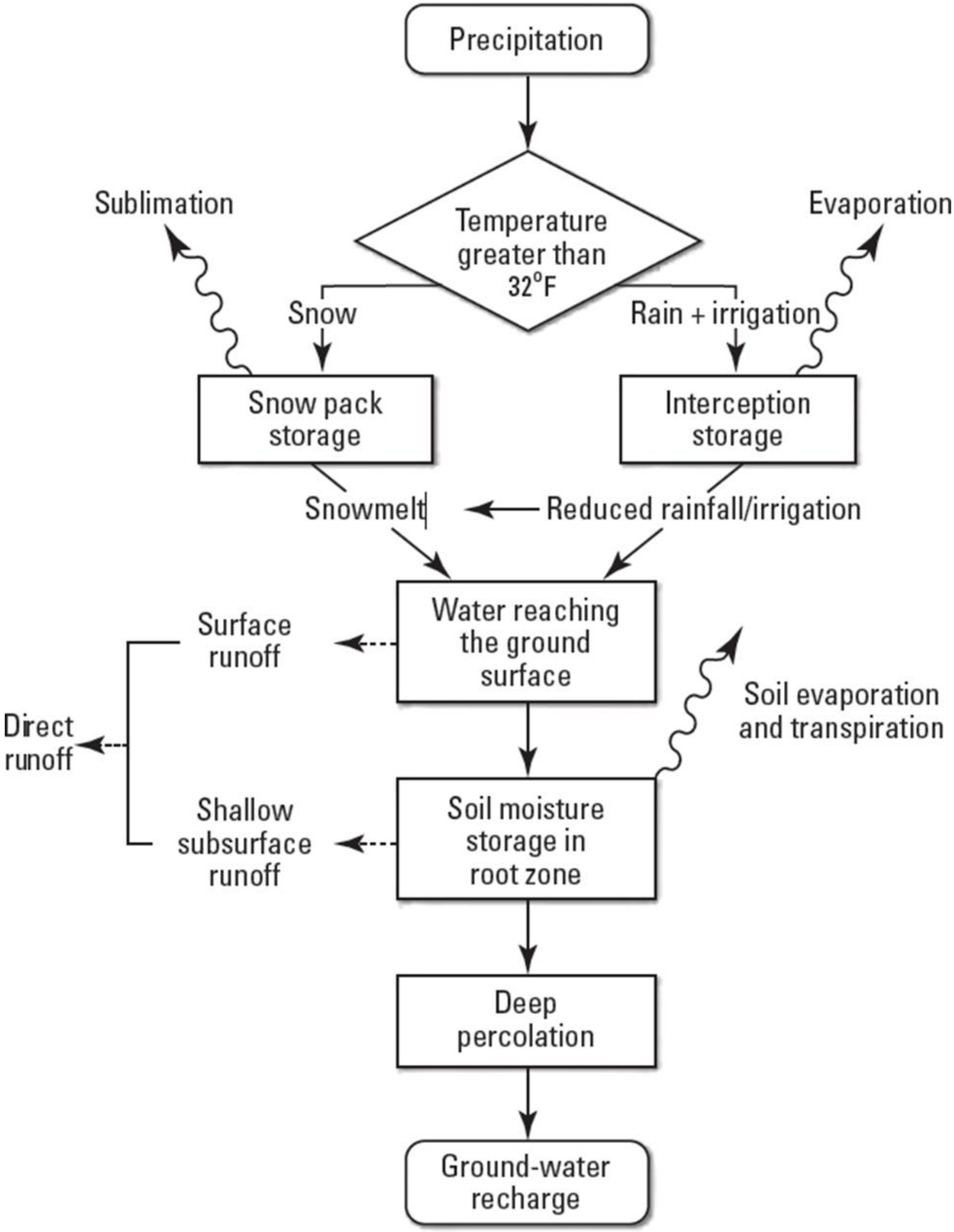


*Figure 5-4. Primary Inputs, outputs, and processes in the Deep Percolation Model (from Bauer and Vaccaro, 1987)*

The user must specify a series of cells, each of which is treated as a homogenous unit by the model. Data computations are made for each cell and summed for the entire model area. In developing the Deep Percolation Model presented here it was assumed that the groundwater recharge area was coincident with the USGS fourth-field sub-basins that drain to Malheur Lake. Model cells were defined within GIS as areas that were 0.01 degrees of latitude in width (x) and height (y). This is equivalent to a cell size of approximately 1/3 square mile (~220 acres). There were a total of 15,091 cells within the Harney Basin.

### *Meteorological data inputs*

The Deep Percolation Model is driven by the following four time-series data sets at a daily time step:

- Precipitation: Daily precipitation data is required from at least one climate station. Data from additional stations increases the resolution of the model results, particularly in complex topography.

- Air temperature: Daily minimum and maximum temperatures are required for at least one station.

- Solar radiation: Daily incoming solar radiation is an optional data element. Data from several stations can be incorporated into the model

- Throughfall: Throughfall is the difference between precipitation and the portion of precipitation that is intercepted by a vegetative canopy; it is the proportion of water that directly reaches the ground surface. It is possible to develop monitoring stations that measure throughfall. However, no throughfall data were available for the Harney Basin. This is an optional data element.

Station precipitation data is adjusted to each model cell based on proximity (several stations may influence the value at each cell), and long-term monthly precipitation maps. Mean monthly precipitation maps available from the PRISM Climate Group at Oregon State University were used to identify monthly correction factors for each cell (http://www.prism.oregonstate.edu/). Station air temperature data is distributed to each cell base on monthly elevational lapse rates (i.e., the change in temperature per 1,000 feet elevation change) calculated from the station data. If no solar radiation or throughfall data is used then the model estimates these values based on topography, meteorological data, latitude, and vegetation characteristics.

Twenty-four meteorological stations in or adjacent to the Harney Basin were considered for climate input data (Table 5-1; Figure 5-5). Most climate records have some periods of missing data. To run the model all missing data periods must be filled. Filling missing periods is a time consuming process, and was beyond the scope of the current effort. We selected nine stations (gray shaded rows, Table 5-1) that had a continuous ten year period (10/1/1994 to 9/30/2004) of available precipitation and temperature data with no data gaps. These data were prepared by the Fire Program Analysis (FPA) to provide continuous data sets for fire behavior modeling, and are available through the Western Regional Climate Center (http://www.wrcc.dri.edu/fpa/ ). The nine stations selected were well-distributed within the Harney Basin (Figure 5-5).

*Table 5-1. Meteorology stations in and adjacent to the Harney Basin. Gray-shading indicates stations and data elements used in the preliminary model*

| Station ID | Station Name | Elev. (ft.) | Source | Begin Record | Most Recent Record | Precip. Data | Air Temp Data | Solar Rad. Data |
|---|---|---|---|---|---|---|---|---|
| C0732 | CW0732 Seneca | 4665 | APRSWXNET/CWOP[a] | 10/16/2003 | 11/12/2012 | X | X | |
| C8689 | CW8689 Burns | 4219 | APRSWXNET/CWOP | 9/5/2007 | 9/18/2012 | X | X | |
| RLYO3 | CRN Site near Riley 10WSW | 4260 | CRN[b] | 12/16/2006 | 11/12/2012 | X | X | X |
| ORS1 | Seneca | 4777 | GPSMET[c] | 9/26/2005 | 11/12/2012 | | X | |
| KBNO | Burns Municipal Airport | 4144 | NWS/FAA[d] | 4/12/1997 | 11/12/2012 | X | X | |
| ODT37 | Buck Creek (US 20 MP 68) | 4560 | ODOT[e] | 12/13/2004 | 11/12/2012 | X | X | |
| ALFO3 | Allison | 5320 | RAWS[f] | 12/2/1999 | 11/12/2012 | X | X | X |
| BAFO3 | Bald Mtn | 5592 | RAWS | 10/6/1998 | 11/12/2012 | X | X | X |
| CWFO3 | Crow Flat | 5172 | RAWS | 10/6/1998 | 11/12/2012 | X | X | X |
| FMFO3 | Fall Mountain | 5949 | RAWS | 10/6/1998 | 11/12/2012 | X | X | X |
| FLFO3 | Foster Flat | 5000 | RAWS | 10/6/1998 | 11/12/2012 | X | X | X |
| LMCO3 | Little Mccoy Creek | 5080 | RAWS | 6/13/2003 | 11/12/2012 | X | X | X |
| OOFO3 | Moon Hill | 6100 | RAWS | 10/6/1998 | 11/12/2012 | X | X | X |
| FGFO3 | P Hill | 4860 | RAWS | 11/17/1998 | 11/12/2012 | X | X | X |
| RLFO3 | Riddle Mtn. | 6352 | RAWS | 10/6/1998 | 11/12/2012 | X | X | X |
| SHFO3 | Sage Hen | 4400 | RAWS | 11/17/1998 | 11/12/2012 | X | X | X |
| WTFO3 | Wagontire | 6420 | RAWS | 12/2/1999 | 11/12/2012 | X | X | X |
| FCKO3 | Fish Creek | 7900 | SNOTEL[g] | 1/20/2000 | 11/12/2012 | X | X | |
| LKCO3 | Lake Creek R.S. | 5200 | SNOTEL | 1/20/2000 | 11/12/2012 | X | X | |
| RCSO3 | Rock Springs | 5550 | SNOTEL | 1/20/2000 | 11/12/2012 | X | X | |
| SLVO3 | Silvies | 6900 | SNOTEL | 1/20/2000 | 11/12/2012 | X | X | |
| SNWO3 | Snow Mountain | 6220 | SNOTEL | 1/20/2000 | 11/12/2012 | X | X | |
| STRO3 | Starr Ridge | 5300 | SNOTEL | 1/20/2000 | 11/12/2012 | X | X | |
| 355162 | Malheur Refuge H.Q. | 4118 | COOP[h] | 4/1/1959 | 11/8/2012 | X | X | |

Notes: [a] Automatic Position Reporting System / Citizen Weather Reporting System
[b] Hydrometeorological Automated Data System
[c] Meteorological Assimilation Data Ingest System
[d] National Weather Service / Federal Aviation Administration
[e] Oregon Department of Transportation
[f] Remote Automated Weather Stations. USFS/BLM
[g] NRCS SNOpack TELemetry system
[h] NOAA National Climatic Data Center cooperative station

All data referenced in this table can be accessed through http://mesowest.utah.edu/ and http://www.ncdc.noaa.gov/

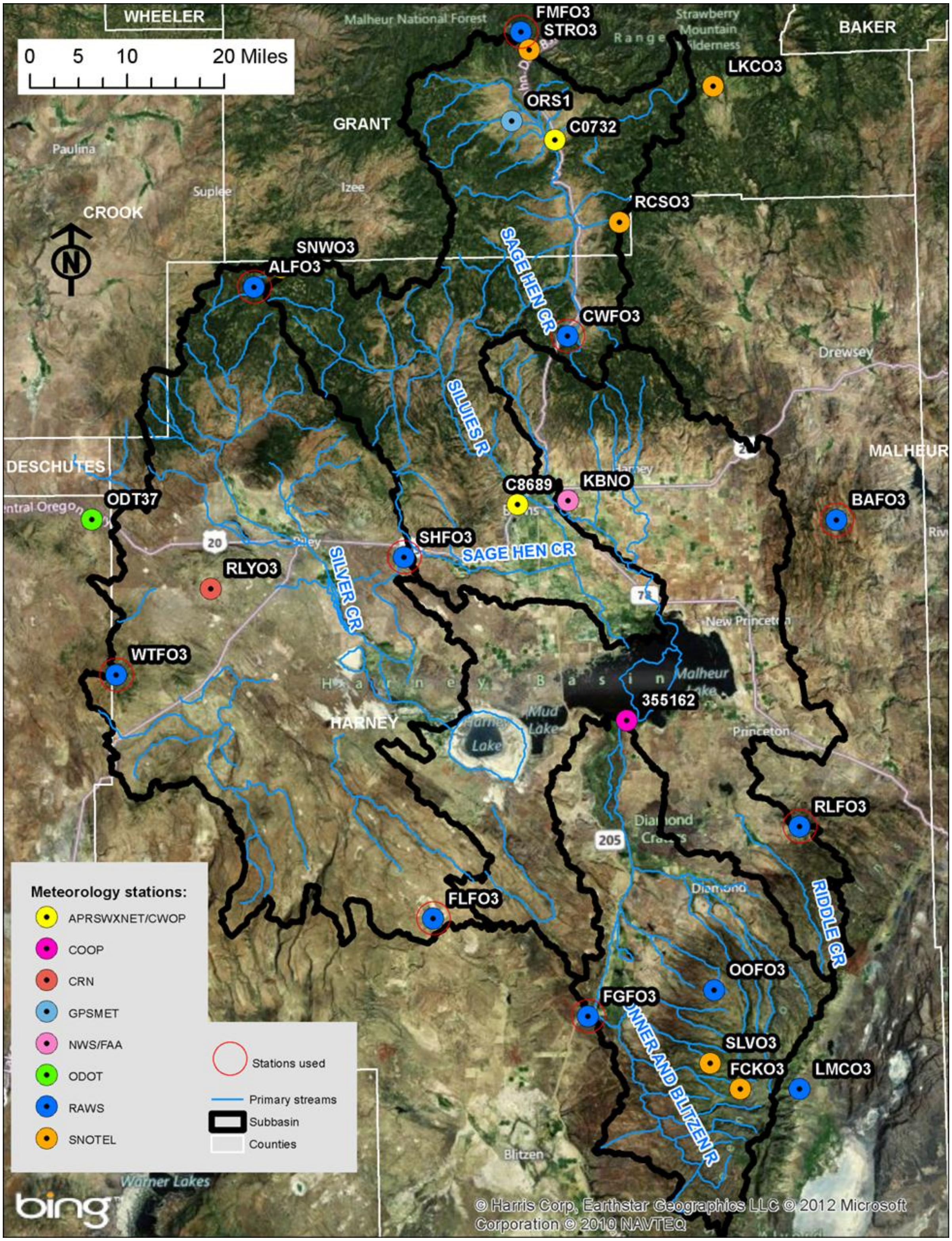


*Figure 5-5. Meteorology stations in and adjacent to the Harney Basin*

### *Topographical data inputs*

Topographical input data was derived from digital elevation model (DEM) data available for the Harney Basin (http://viewer.nationalmap.gov/viewer/). Elevation was recorded for the center of each model cell. Slope and aspect in the vicinity of each cell was calculated within a GIS.

### *Soil data inputs*

Detailed soil data are available for the Harney Basin from two sources; the National Resource Conservation Service (NRCS) soil surveys, and from the US Forest Service Soil Resource Inventory (SRI). The NRCS Soil Survey for Harney County Area covers the majority of the Harney Basin, with a small portion of the Basin to the west covered by the soil survey for Lake County, Oregon, Northern Part. Both NRCS soil surveys are available digitally at http://soildatamart.nrcs.usda.gov/. Two National Forest SRI soil surveys cover the remainder of the Basin; the Malheur National Forest and Ochoco National Forest (http://www.fs.fed.us/r6/data-library/gis/umatilla/index.shtml, and http://www.fs.fed.us/r6/data-library/gis/ochoco/).

Given the difficulty in combing soil surveys from different sources we chose to develop soil data inputs from the General Soil Map (STATSGO2) available for the United States (http://soildatamart.nrcs.usda.gov/USDGSM.aspx). Although these are lower resolution data than the detailed surveys described above they have the advantage of providing a single unified data set that covers the entire Harney Basin. Twenty-three soil units are located within the Harney Basin. Relevant soil parameter values for each unit are given in Table 5-2.

*Table 5-2. Soil units and parameter values*

| Map unit | Map unit name | Depth (in) | Texture | Available water capacity (decimal fraction) | Specific yield (decimal fraction) | Lateral hydraulic conduc-tivity (ft/day) | Saturated vertical conduc-tivity of subsoil (in./yr) |
|---|---|---|---|---|---|---|---|
| s6369 | Welch-Swalesilver-Swaler-Boulder Lake | 72 | Silty Clay Loam | 0.173 | 0.13 | 0.7 | 309 |
| s6372 | Westbutte-Robson-Ninemile-Felcher-Erakatak-Duff-Croesus | 33 | Loam | 0.110 | 0.19 | 1.5 | 642 |
| s6373 | Rock outcrop-Harcany family-Duff-Croesus-Clamp | 39 | Loam | 0.111 | 0.19 | 2.0 | 893 |
| s6446 | Rubble land | 60 | As Sand | 0.050 | 0.37 | 40.0 | 17525 |
| s6480 | Klicker-Hankins-Boardtree | 47 | Silty Loam | 0.153 | 0.16 | 1.8 | 780 |
| s6483 | Tolo-Klicker | 44 | Silty Loam | 0.171 | 0.16 | 2.1 | 921 |
| s6485 | Klicker-Helter-Brickel-Ateron | 54 | Silty Loam | 0.155 | 0.16 | 2.8 | 1221 |
| s6504 | Skullgulch-Rastus-Marack-Campcreek | 59 | Loam | 0.142 | 0.19 | 2.7 | 1176 |
| s6505 | Welch-Silvies-Damore-Damon | 60 | Silty Loam | 0.177 | 0.16 | 1.8 | 776 |
| s6515 | Observation-Menbo-Ateron | 34 | Loam | 0.111 | 0.19 | 1.7 | 726 |
| s6516 | Venator-Utley-Izee | 34 | Loam | 0.117 | 0.19 | 2.5 | 1085 |
| s6517 | Westbutte-Riddleranch-Pernty-Felcher | 35 | Loam | 0.111 | 0.19 | 1.8 | 797 |
| s6518 | Raz-Ninemile | 35 | Loam | 0.124 | 0.19 | 2.8 | 1236 |
| s6522 | Westbutte-Ninemile | 33 | Loam | 0.119 | 0.19 | 1.3 | 552 |
| s6523 | Reese-Playas-Mesman-Kewake | 60 | Sandy Clay Loam | 0.068 | 0.15 | 4.3 | 1891 |
| s6530 | Welch-Paulina-Histic Cryaquepts-Crump-Boulder Lake | 60 | Silty Clay Loam | 0.266 | 0.13 | 1.2 | 505 |
| s6533 | Widowspring-Voltage-Fury variant-Fury | 63 | Silty Loam | 0.177 | 0.16 | 2.9 | 1283 |
| s6534 | Lawen-Ausmus | 61 | Sandy Loam | 0.136 | 0.27 | 2.5 | 1091 |
| s6535 | Playas-Lolak-Crowcamp-Ausmus | 64 | Sandy Clay Loam | 0.078 | 0.15 | 1.0 | 455 |
| s6536 | Westbutte-Observation-Ninemile-Merlin-Madeline-Choptie | 32 | Loam | 0.124 | 0.19 | 1.8 | 791 |
| s6538 | Westbutte-Observation-Merlin | 31 | Loam | 0.119 | 0.19 | 1.8 | 797 |
| s6539 | Wagontire-Vil-Madeline-Gradon | 57 | Loam | 0.100 | 0.19 | 3.4 | 1479 |
| s8369 | Water | 0 | as Clay | 0.100 | 0.07 | 1.0 | 0 |

Values for all components within a soil unit were averaged to estimate total soil depth, available water capacity, and lateral hydraulic conductivity. Soil texture was calculated based on the average proportion of sand, silt and clay for each map unit. Specific yield is defined as the ratio of the volume of water that drains from a soil due to gravity to the total soil volume (Meinzer, 1923). Specific yield was calculated for each soils unit based on textural class using the Soil Water Characteristics Hydraulic Properties Calculator (Saxton and Rawls, 2009). Values for saturated vertical conductivity (equivalent to infiltration rate at saturation) of the subsoil are unknown, but were estimated for this preliminary model run as one order of magnitude lower than lateral hydraulic conductivity.

### *Land cover inputs*

The 2001 National Land Cover Dataset (Homer et al., 2007) was used to characterize current land cover conditions in the Harney Basin. The 12 National Land Cover Dataset types found within the Basin were consolidated into nine types for the purpose of the model. Land cover types and parameter values are given in Table 5-3. Data is available at http://www.mrlc.gov/nlcd01_data.php.

*Table 5-3. Land cover types and parameter values used in the Harney Basin Deep Percolation Model*

| National Land Cover Dataset cover type | Land cover type used in model | % basin area | Maximum root depth (inches) | Maximum foliar cover (decimal fraction) | Maximum interception storage capacity (inches) | Assumed irrigation period |
|---|---|---|---|---|---|---|
| Evergreen Forest | Evergreen Forest | 16% | 60 | 0.95 | 0.2 | n/a |
| Developed, Open Space | Developed | 1% | 6 | 0.5 | 0.04 | 6/1 - 9/30 |
| Developed, Low Intensity | | | | | | |
| Developed, Medium Intensity | | | | | | |
| Scrub/Shrub | Scrub/Shrub | 69% | 45 | 0.5 | 0.08 | n/a |
| Woody Wetlands | Wetlands | 2% | 36 | 0.75 | 0.04 | n/a |
| Emergent Herbaceous Wetland | | | | | | |
| Grassland/Herbaceous | Grassland/ Herbaceous | 1% | 36 | 0.9 | 0.04 | n/a |
| Open water | Open water | 1% | 0 | 0 | 0 | n/a |
| Barren Land | Barren Land | 2% | 0 | 0 | 0 | n/a |
| Pasture/Hay | Pasture/Hay | 8% | 36 | 0.9 | 0.04 | 6/1 - 9/30 |
| Cultivated Crops | Cultivated Crops | 1% | 12 | 0.5 | 0.04 | 6/1 - 9/30 |

Estimates of the annual depth of applied irrigation water are needed for each of the three irrigated land cover types shown in Table 5-4. Irrigation was assumed to be applied above the vegetation canopy for all three cover types. Estimates were made using mean evapotranspiration (ET) estimates for representative crops at the Christmas Valley Oregon AGRIMET station (http://www.usbr.gov/pn/agrimet/agrimetmap/chvoda.html). Mean annual precipitation was subtracted from the mean ET estimate for a given land cover type, and the difference was assumed to be the annual irrigation input. Total irrigation input was scaled by growing season requirements within the Deep Percolation Model.

*Table 5-4. Annual depth of irrigation for irrigated land cover types*

| Land Cover Type Used in Model | AGRIMET Crop Code | AGRIMET Crop Description | Mean ET Estimate 2009-2011 @ Christmas Valley AGRIMET Station (in.) | Mean of Mean Annual Precip. for Lands in this Classification (in.) | Estimated Depth of Annual Irrigation (in.) |
|---|---|---|---|---|---|
| Developed | LAWN | Lawn | 29.8 | 11.6 | 18.2 |
| Pasture/Hay | PAST | Pasture | 25.0 | 10.4 | 14.6 |
| Cultivated Crops | ALFM | Alfalfa (mean) | 30.6 | 10.6 | 20.0 |

### *Recharge model results*

Annual modeled groundwater recharge for the entire Harney Basin is shown in Figure 5-6. Annual recharge ranges from 0.1 to 5.5 inches per year over the ten -year model period, with a mean value of 1.3 inches per year. On an annual basis recharge tracks well with annual precipitation (Figure 5-6), with over 90% of the variability explained by precipitation alone (Figure 5-7).

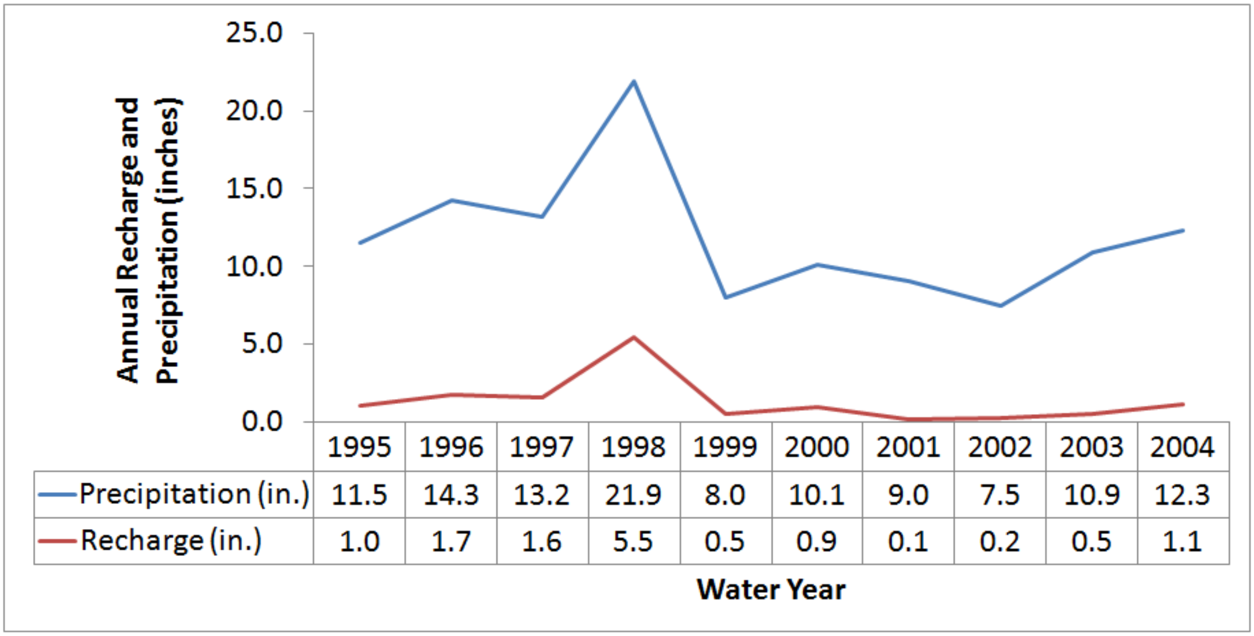


*Figure 5-6. Annual precipitation and recharge by water year for the Harney Basin*

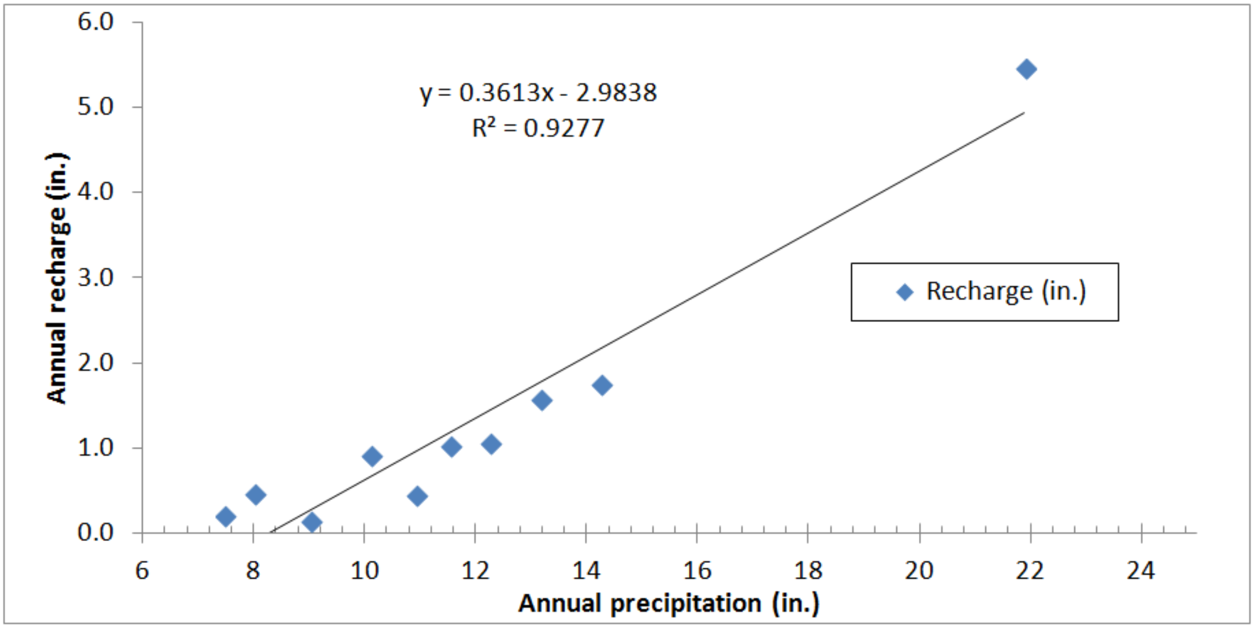
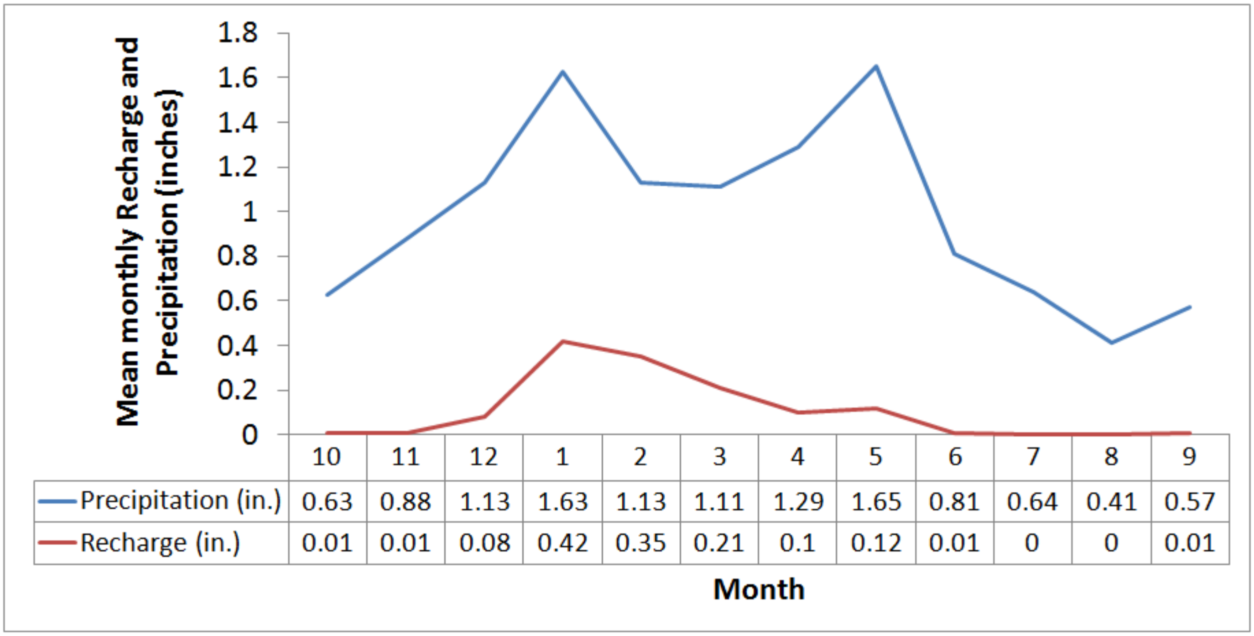


*Figure 5-7. Annual recharge as a function of annual precipitation*

Monthly modeled recharge has a bimodal distribution, with the highest levels in the winter months (January and May) prior to the beginning of the growing season (Figure 5-8). Recharge is not as well-correlated with precipitation on a monthly basis (Figure 5-9) as compared to an annual basis, probably due to the higher ET demands during the summer months.



| | 10 | 11 | 12 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Precipitation (in.) | 0.63 | 0.88 | 1.13 | 1.63 | 1.13 | 1.11 | 1.29 | 1.65 | 0.81 | 0.64 | 0.41 | 0.57 |
| Recharge (in.) | 0.01 | 0.01 | 0.08 | 0.42 | 0.35 | 0.21 | 0.1 | 0.12 | 0.01 | 0 | 0 | 0.01 |

*Figure 5-8. Mean monthly precipitation and recharge for the Harney Basin*

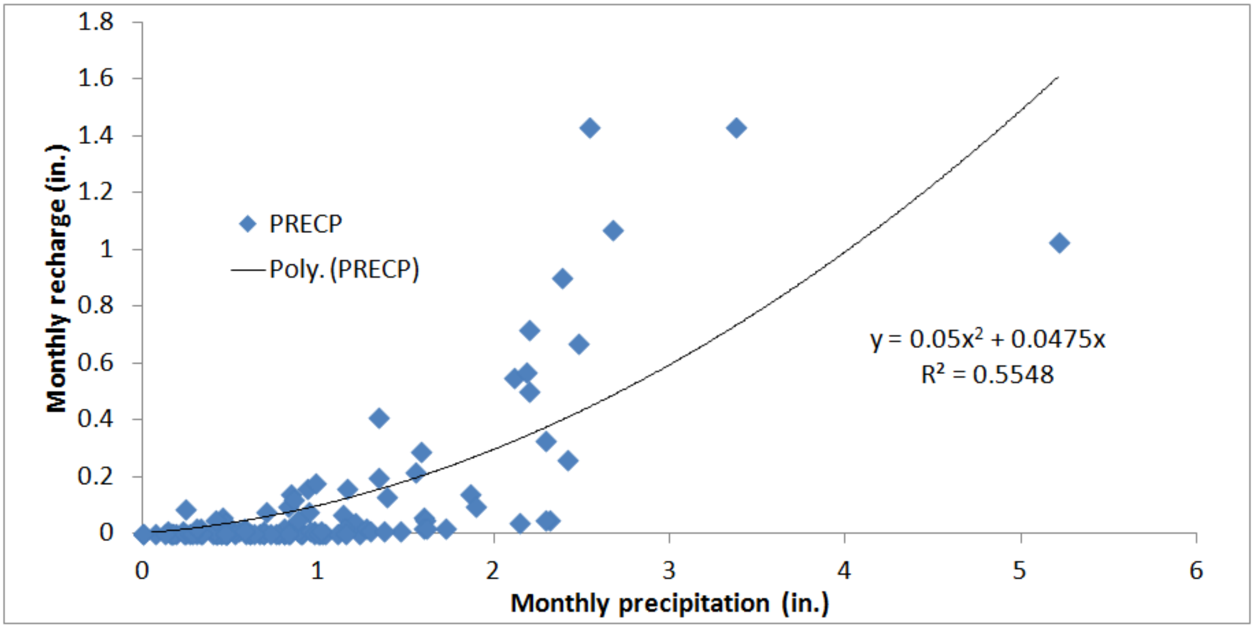


*Figure 5-9. Monthly recharge as a function of monthly precipitation*

### *Recharge model products*

All input data files, and model output, along with the Deep Percolation Model executable file, are included in the Hydrology Folder of the electronic deliverable.

## 5.2. Geology

An interpretation of the geology of the Harney Basin based on the literature and the interpretation of well logs is illustrated in Figure 3-9. This figure is a fence-diagram developed with the aid of Aquaveo’s Groundwater Model System (GMS). The fence-diagram is a collection of interconnected geologic cross-sections. The cross-sections illustrate the subsurface geology based on the interpretation of the well logs. The cross-sections that compose the fence-diagram run from borehole to borehole. A total of 120 boreholes were used. The surface geology between boreholes generally follows closely the geology as mapped by Green, Walker and Corcoran (1972). The primary departure from this geologic map is due to the fact that the authors of the map did not distinguish the Harney Formation from their tuffaceous sedimentary rocks, Tst. The majority of what was mapped as Tst in the western part of the basin is herein considered the Harney Formation.

The fence diagram gives a graphic visualization of the subsurface geology. It is apparent that many geologic units pinch out between boreholes and around the margins of the structural basin. Geologic units also terminate at or are offset at faults. Figure 4-1 shows the approximate boundary of the structural basin.

The floor of Harney Valley is underlain by the Quaternary basin-fill that thickens significantly to the south. The basin-fill is underlain by the Miocene tuffaceous and volcaniclastic sediments unit. This clay rich unit occurs in the subsurface throughout the larger Harney structural basin. Based on an interpretation of the log for an oil exploration well, the total subsidence in the structural basin is approximately 4,000 feet near Burns. The amount of subsidence throughout the structural basin is likely to vary significantly due to differential subsidence and multiple volcanic eruption events. Hydrothermal waters circulating through thick deposits of ash, ash-flow tuffs and volcaniclastic sediments within the collapse structure will have altered these deposits to thick beds of clay.

The fence-diagram reveals that the western portion of the structural basin is filled with Harney Formation sandstone, claystone, conglomerate, sand and gravel. The Harney Formation is inter-fingered with the basalts, cinders and palagonite of the intra-basin basalt and cinder unit. The intra-basin basalt and cinder unit is particularly thick in the vicinity of Dog Mountain. Dog Mountain and other buttes in the area are likely the sites of volcanic vents that were submerged for a period of time. Shield volcanoes and cinder cones within the western portion of the structural basin may be the primary source of the clastic material of which the Harney Formation is composed.

Basalt lava flows and cinders that occur within the basin-fill unit and the tuffaceous and volcaniclastic sediments unit are also included in the intra-basin basalt and cinder unit. There are a significant number of relatively thin basalt flows within the basin-fill unit and tuffaceous and volcaniclastic sediments unit along the eastern edge of the basin. The source of these basalt flows are likely magma migrating up faults along the perimeter of the structural basin.

In the southeastern corner of the structural basin the tuffaceous and volcaniclastic sediments unit is buried beneath lavas of the Diamond/Voltage basalt unit. These Quaternary lavas and pyroclastics erupted from vents within the collapse structure forming small coalescing shield volcanoes. The Diamond Craters represent the most recent volcanic activity in the area.

### 5.3. Hydrogeology

Of the seven hydrogeologic units described in Section 4.3, the basin-fill unit and the tuffaceous and volcaniclastic sediments unit are the principal aquifers in the Harney Basin. The majority of the wells in the study area produce water from the basin-fill and the underlying tuffaceous and volcaniclastic sediments aquifers.

*Basin-fill Aquifer*

The basin-fill aquifer is a complex heterogeneous aquifer. Clay and clayey-sand and the coarser sands and gravels were deposited in lacustrine and alluvial environments. The sands and gravels, deposited as alluvial fans and channel-fill deposits, are concentrated near the margins of the basin where streams enter the basin. The more productive sands and gravels are expected to pinch-out laterally and be confined by clays. There are also minor thin basalt flows and cinder deposits within the Quaternary basin-fill. The selected wells completed in the basin-fill have yields that range from 20 to 2,500 gpm. The range of estimated hydraulic conductivities given in Table 4-1 for the basin-fill is likely to be representative of the more permeable sands and gravels. The hydraulic conductivity of the clay and clayey-sand is likely to be 3 to 4 orders of magnitude less. Streams flowing into Harney Valley are expected to be the dominant source of water recharging the basin-fill aquifer. Recharge is enhanced significantly by the practice of flood irrigation during the period of spring runoff.

*Tuffaceous and Volcaniclastic Sediments Aquifer*

The tuffaceous and volcaniclastic sediments aquifer was also deposited in lacustrine and fluvial environments. It is a complex confined heterogeneous aquifer consisting predominantly of clay and claystone. This aquifer appears to underlie almost all of Harney Valley and the larger Harney structural basin. The most productive wells intersect relatively thin sands and weakly indurated sands and gravels deposited in higher energy alluvial environments. Both compaction and hydrothermal alteration will have greatly reduced the permeability of the original tuffaceous and volcaniclastic sediments deposited in the basin. There are also relatively thin basalt flows within the tuffaceous and volcaniclastic sediments. The reported yields of the selected wells completed in the tuffaceous and volcaniclastic sediments range from 10 to 1,323 gpm. The range of estimated hydraulic conductivity given in Table 4-1 for the tuffaceous and volcaniclastic sediments is likely to be biased toward the more permeable sands and weakly indurated gravels. The static water elevation in the basin-fill is generally higher than that of the tuffaceous and volcaniclastic aquifer. In Harney Valley the tuffaceous and volcaniclastic aquifer is likely primarily recharged from the overlying basin-fill aquifer. To the west of Harney Valley the tuffaceous and volcaniclastic aquifer will be recharged by precipitation and water from seasonal streams percolating through the much more permeable Harney Formation and inter-basin basalt and cinders. The elevation of the top of the tuffaceous and volcaniclastic aquifer and static water elevations in this aquifer are generally higher to the west of Harney Valley, and therefore, water groundwater flow in the aquifer in the area is expected to generally be toward the east, toward Harney Valley.

### Intra-basin Basalt and Cinder Aquifer

The intra-basin basalt and cinder aquifer occurs primarily to the north of Harney Lake in the vicinity of Dog Mountain and Freeman Butte. The intra-basin basalt and cinder aquifer also occurs beneath Sage Valley. The distribution of the intra-basin and cinder unit is shown on Figure 3-9. Intra-basin basalt and cinders aquifer is underlain by the tuffaceous and volcaniclastic aquifer and the Harney formation aquifer. In Sage Hen Valley the intra-basin basalt and cinder aquifer is overlain by the Harney Formation and Quaternary alluvium. This aquifer appears to be limited in extent. A well just east of Dog Mountain reportedly produces 1,500 gpm and a well in Sage Hen Valley produces 1,800 gpm. On the east side of Harney Valley a well produces 1,600 gpm from basalt flows that are within the Quaternary basin-fill unit.

### Harney Formation Aquifer

The Harney Formation occurs primarily west of and along the western edge of Harney Valley. The Harney Formation aquifer consists of sandstone, claystone, conglomerate, sand and gravel and appears to be limited in extent. Nine wells from the selected group appear to derive water only from the Harney Formation. The yield of these wells ranges from 10 to 50 gpm.. Two wells produce 250 and 490 gpm. The well that produces 490 gpm is located just south of Wright Point and intersects a repetitive sequence of claystones, sandstones, sands and gravels. The Harney Formation is likely recharged by percolating precipitation and seasonal streams.

### Diamond/Voltage Basalt Aquifer

The Diamond/Voltage basalt aquifer is limited in extent and occurs entirely within the Harney structural basin. It occurs along the south side of Malhuer Lake. This aquifer is unconfined and discharges to Malheur Lake and the lower end of Donner und Blitzen River valley. The Diamond/Voltage basalt aquifer is very permeable and is underlain by tuffaceous and volcaniclastic sediments of much lower permeability. The Diamond/Voltage basalts occur at the surface over a large area south of Harney Lake. Precipitation percolates rapidly through the basalt flows and cinders to recharge the aquifer. Few wells are completed in the Diamond/Voltage basalt aquifer. Two wells in the aquifer reportedly yield 800 and 900 gpm and have specific capacities of 82 and 200 gal/ft.

### Steens Basalt Aquifer

The Steens Basalt aquifer is a confined aquifer that is intersected by eight wells of the selected group. These wells are located just outside the eastern and southeastern boundary of the structural basin. With one exception, the reported yields range from 150 to 1,100 gpm. The Steens Basalt aquifer has the greatest estimated hydraulic conductivity. Wells drawing water from the Steens Basalt have the highest specific capacity values. The Steens Basalt is exposed over large areas to the east and southeast of the basin and these are primary areas of recharge.

### Volcaniclastic Sedimentary Rocks Aquifer

The volcanic sedimentary rocks aquifer is a confined aquifer that is intersected by several wells located outside of the Harney structural basin. Wells that appear to produce water from this aquifer only yield 15 to 1000 gpm. A 1,316 foot deep well in Harney Valley, east of Burns, intersects volcanic sedimentary rocks at 1,129 feet. This well produced only 21 gpm and the water was hot at 112˚ Fahrenheit.

## 5.4. Groundwater Levels

In this section, the state observation well hydrographs are discussed. The groundwater contour maps based on the state observation well records are then presented and discussed.

### 5.4.1. Observation Wells

The Oregon Water Resources Department's groundwater level database has fifteen observation wells within the basin that are or have been monitored for water level for a significant amount of time. The locations of these fifteen wells are shown in Figure 5-10.

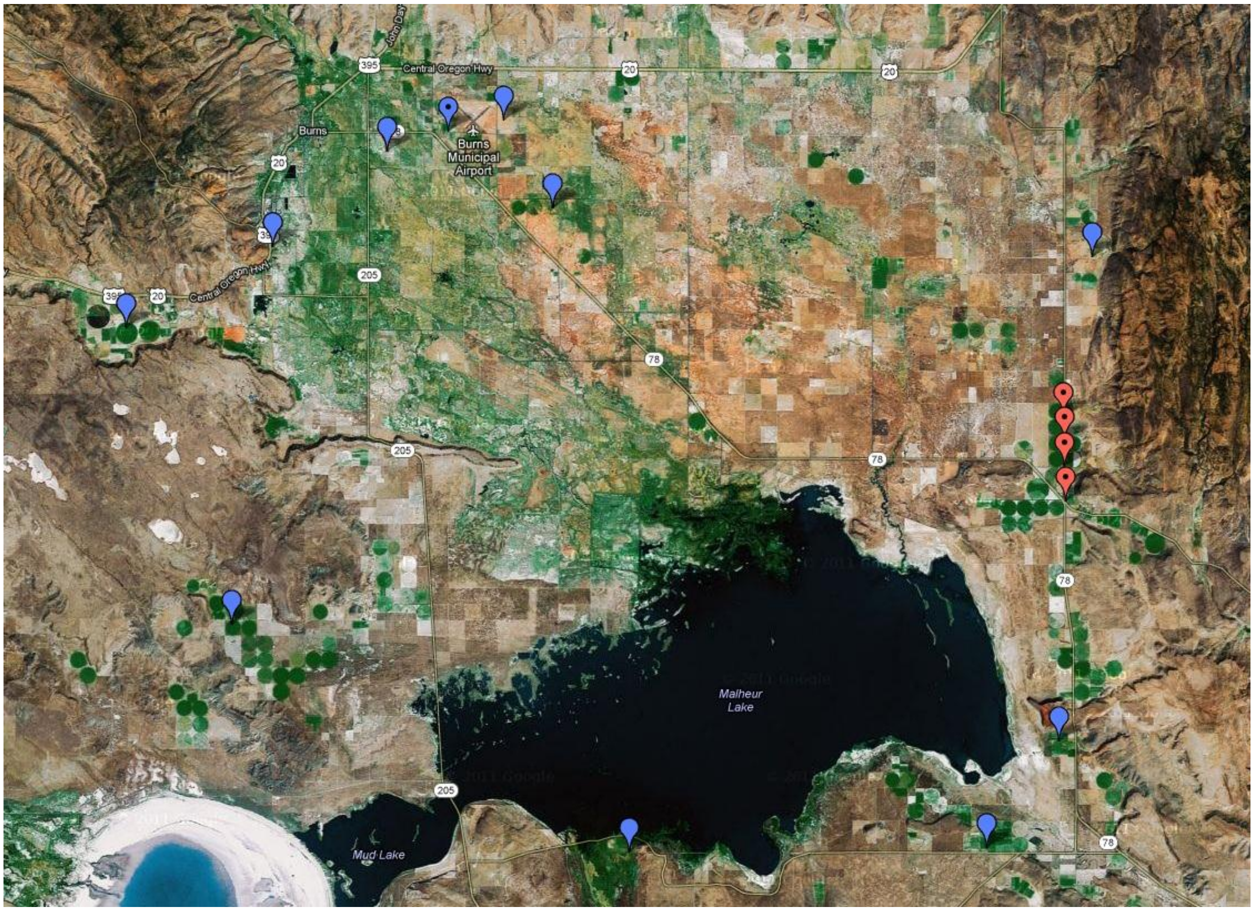


*Figure 5-10. Locations of State Observation Wells*

The monitoring periods for the wells range from 6 to 79 years. Of the fifteen observation wells only five were monitored through 2012.

The hydrographs for the fifteen observation wells are contained in Appendix D. A well hydrograph is simply a plot of the groundwater level in the well over time. It is common for the groundwater level in a well to rise and fall during the year. Generally groundwater levels are highest in the spring in response to recharge and then lowest in the fall. Hydrographs with records of several years or more can reveal trends in water levels. A trend of declining groundwater levels may be due to a drought or to pumping that exceeds the aquifer's recharge rate.

Table 5-5 is a list of the state observation wells. Nine of the fifteen wells are shallow and within the basin-fill hydrogeologic unit. Two of the wells are open to several hydrogeologic units.  Three of the wells are within the Diamond/Voltage basalt unit.

*Table 5-5 State Observation Wells*

| Well Number | Well Depth in feet | Aquifer-hydrogeologic unit | Period of Record |
|---|---|---|---|
| HARN 323 | 198 | Diamond/Voltage basalt – Mafic vent complex | 1/1965 to 9/2010 |
| HARN 440 | 120 | Basin-fill | 12/1959 to 4/2011 |
| HARN 463 | 300 | Basin-fill | 7/1956 to 9/2010 |
| HARN 547 | 93 | Basin-fill | 7/1931 to 9/2010 |
| HARN 607 | 240 | Basin-fill | 5/1968 to 4/1990 |
| HARN 741 | 207 | Basin-fill | 11/1971 to 10/2007 |
| HARN 813 | 347 | Open to two hydrogeologic units | 8/1962 to 9/2010 |
| HARN 1095 | 81 | Basin-fill | 5/1963 to 10/1993 |
| HARN 1245 | 160 | Basin-fill | 4/1987 to 4/2012 |
| HARN 1363 | 147 | Diamond/Voltage basalt | 6/1959 to 9/2010 |
| HARN 1387 | 108 | Intra-basin basalt and Cinders | 2/1957 to 9/2010 |
| HARN 1408 | 97 | Diamond/Voltage basalt | 5/1958 to 9/2010 |
| HARN 50751 | 148 | Basin-fill | 12/2001 to 6/2012 |
| HARN 51004 | 115 | Basin-fill | 12/2003 to 4/2012 |
| HARN 51238 | 325 | Open to two hydrogeologic units | 1/2006 to 4/2012 |

The hydrographs for HARN 463 and HARN 547 wells, which are located in the northwest corner of the Harney Valley, show a slight trend of declining water levels since about the mid-1980s. These two wells are completed in the basin-fill hydrogeologic unit. The groundwater levels have declined approximately 7 to 8 feet since the mid-1980s.

The groundwater level in well HARN 741, which is located on the northeastern edge of the valley, declined approximately 18 feet between 1984 and 1994.  From 1994 to 2007 there was no apparent downward trend in the groundwater level. This well is completed in the basin-fill hydrogeologic unit.

Well HARN 831, which is located in Sage Hen Valley, is open to both the basin-fill and tuffaceous and volcaniclastic sediments hydrogeologic units. The groundwater level in this well declined approximately 20 feet from 1985 to 1992. Since 1994, the downward trend appears to be insignificant.

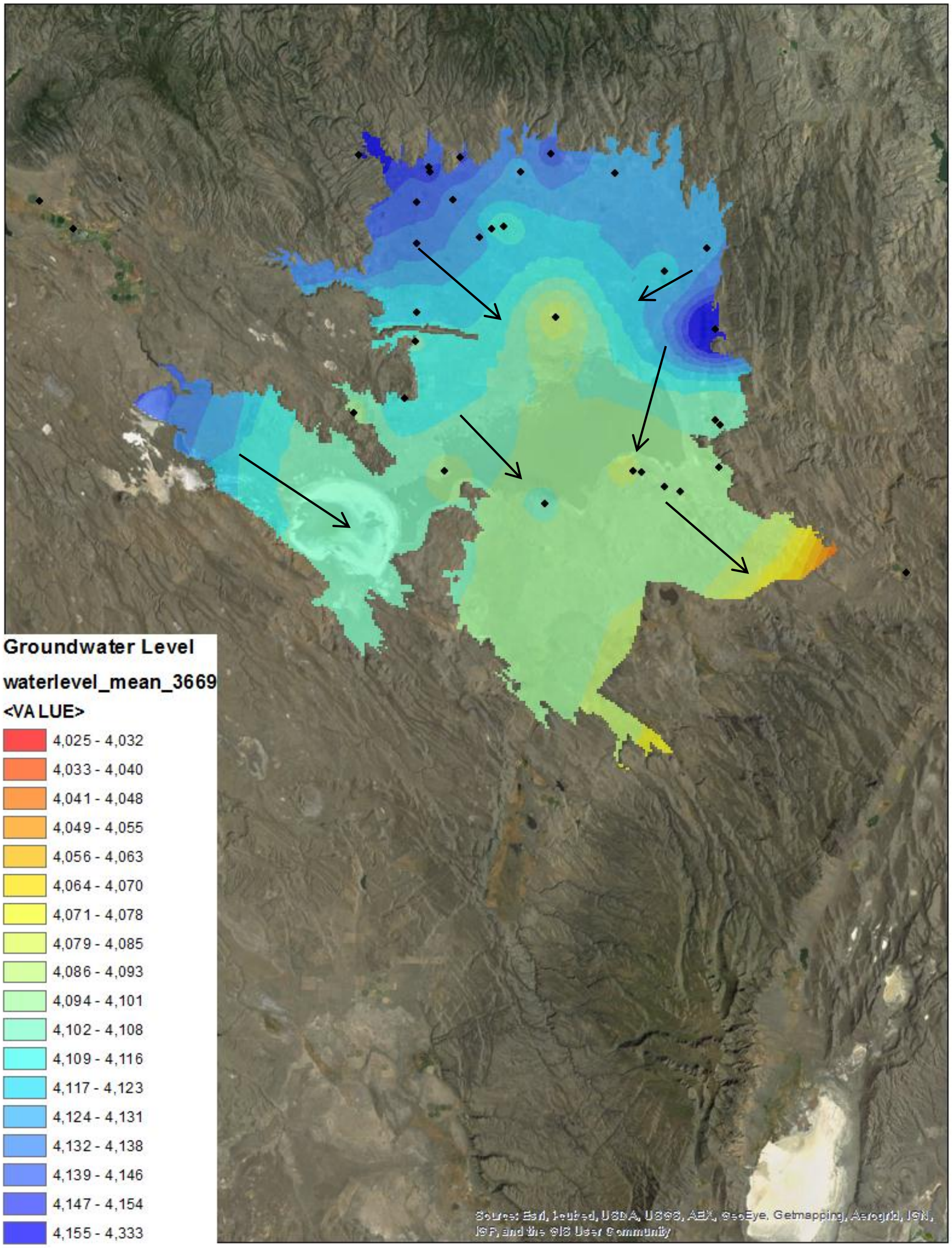
Wells HARN 1245 and HARN 51004 are completed in the basin-fill hydrogeologic unit. These two wells are located along the eastern edge of Harney Valley and north of Crane. They have a trend of declining groundwater levels. The downward trend at HARN 1245 may have ended in 2011. The total decline in groundwater level at this well has been approximately 3.8 feet since 1987. The groundwater level in a nearby well, HARN 51238, which is open to both the basin-fill and tuffaceous and volcaniclastic sediments hydrogeologic units, has declined approximately 3.4 feet since 2008.

The groundwater levels in wells HARN 1662 and HARN 1408, which are both in the Diamond/Voltage basalt hydrogeologic unit, have remained relatively unchanged since the late 1950s. These two wells are located near the southern shore of Malhuer Lake.

The state water level monitoring wells are concentrated in the basin-fill hydrogeologic unit. The monitoring of the other aquifers is very limited or nonexistent. The groundwater level monitoring of the tuffaceous and volcaniclastic sediments, Harney Formation, and intra-basin basalts and cinders hydrogeologic units is very limited or nonexistent. These three hydrogeologic units occur over large portions of Harney Valley and the larger Harney structural basin, and a significant number of wells pump groundwater from these three hydrogeologic units.

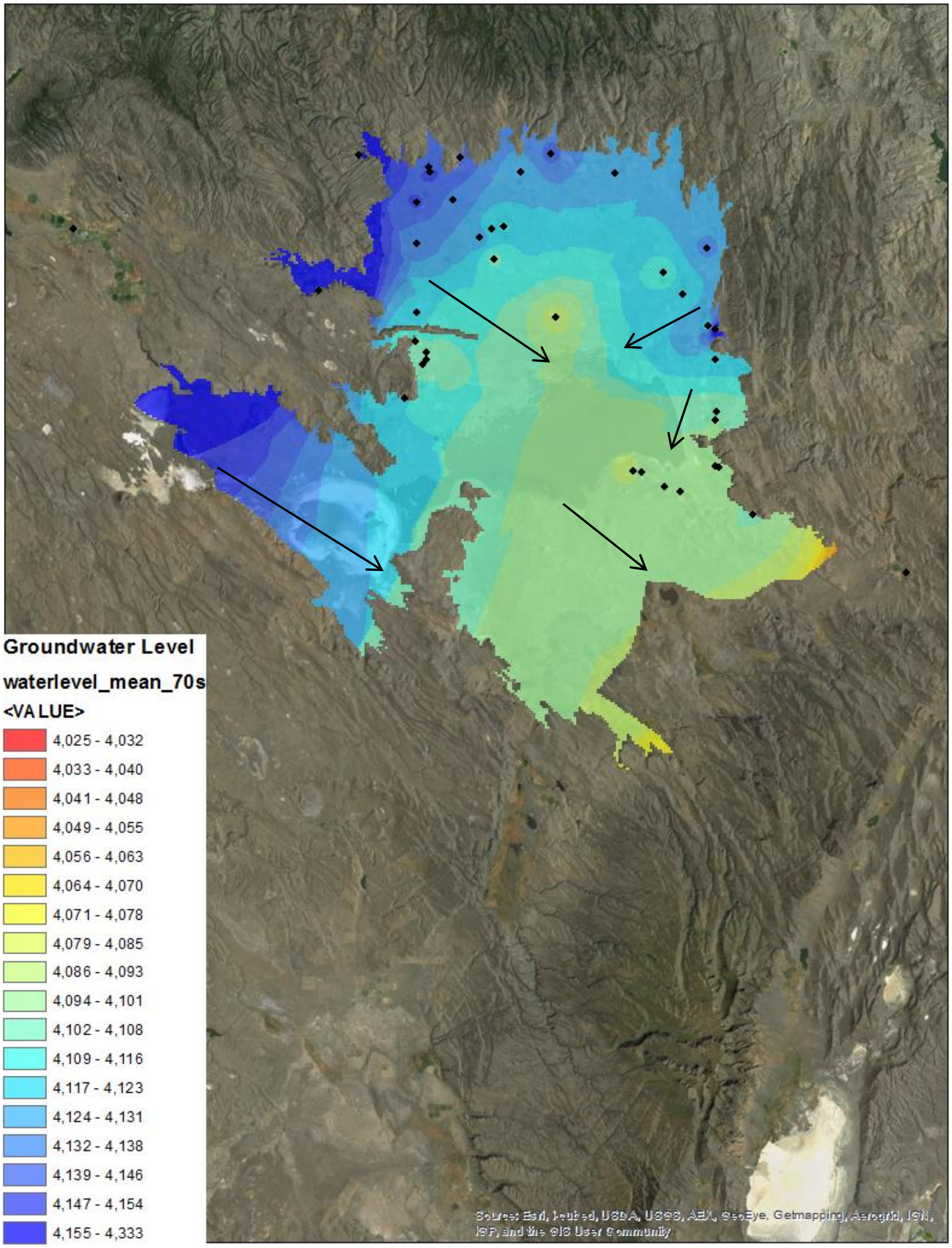
### 5.4.2. Groundwater Level Maps

To illustrate change in groundwater level over time a series of color contour maps were prepared. The contours are extrapolated over a large area and based on sparsely distributed data. The water level data used included all fifteen state observations wells and water level data for 95 other wells. Wells over 350 feet deep were excluded. Any data which are outside of 5 standard deviations from the groundwater level mean within 2 years are interpreted as inconsistent. They are removed from the *Waterlevels_All* table and stored inside the *Waterlevel_outliers* table. The maps provide a general sense of groundwater level change over the period of record. The following seven groundwater level contour maps represent the mean groundwater level for the following periods: 1936-1969, 1970s, 1980s, 1990s, 2000s and 2010-2012. Since the observation wells are shallow the maps are representative of the water level in the basin-fill aquifer. The arrows on the maps show the general direction of groundwater flow.



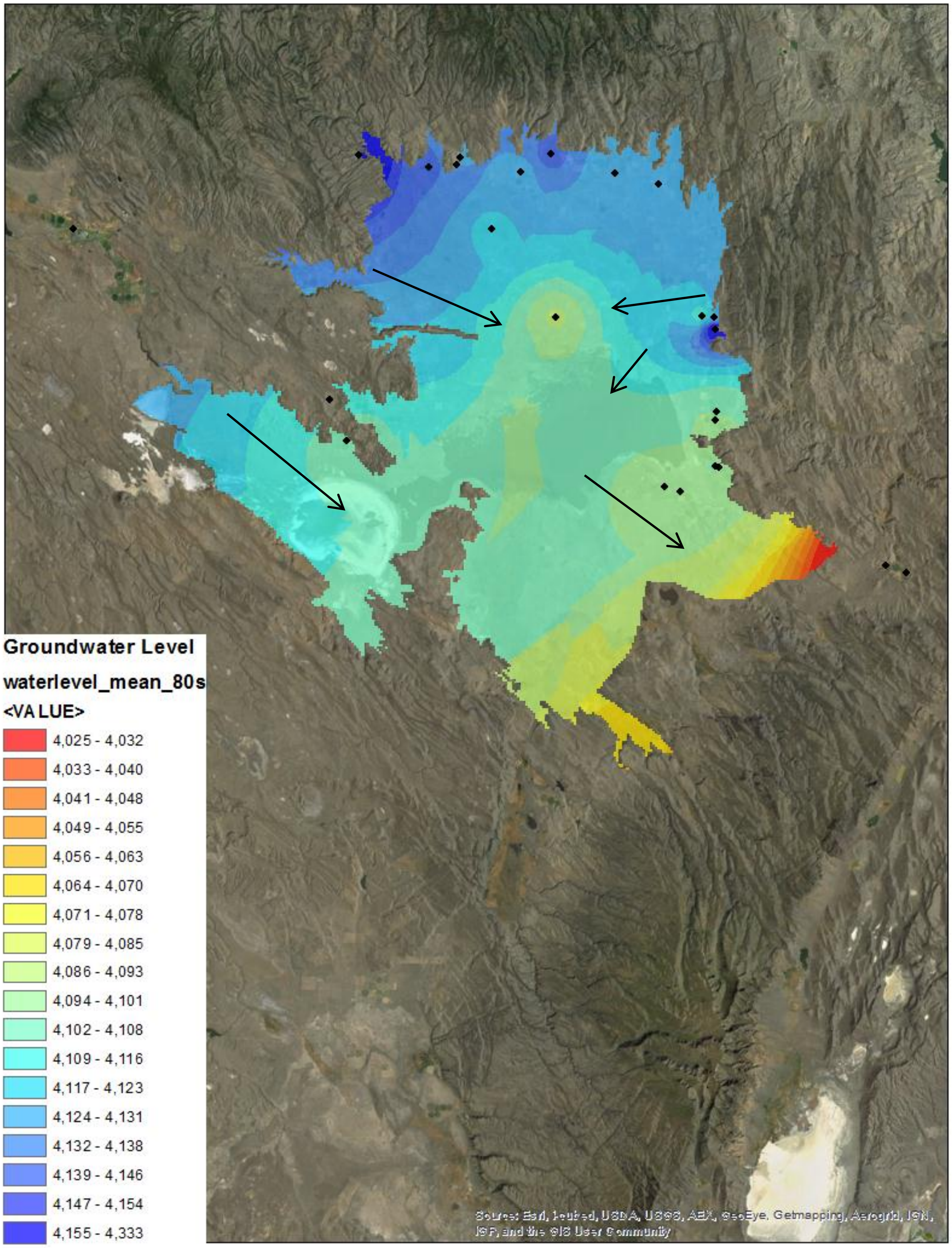
Source: Esri, i-cubed, USDA, USGS, AEX, GeoEye, Getmapping, Aerogrid, IGN, IGP, and the GIS User Community

*Figure 5-11. 1936-1969 Mean Groundwater Level Contour and Flow Direction Map*



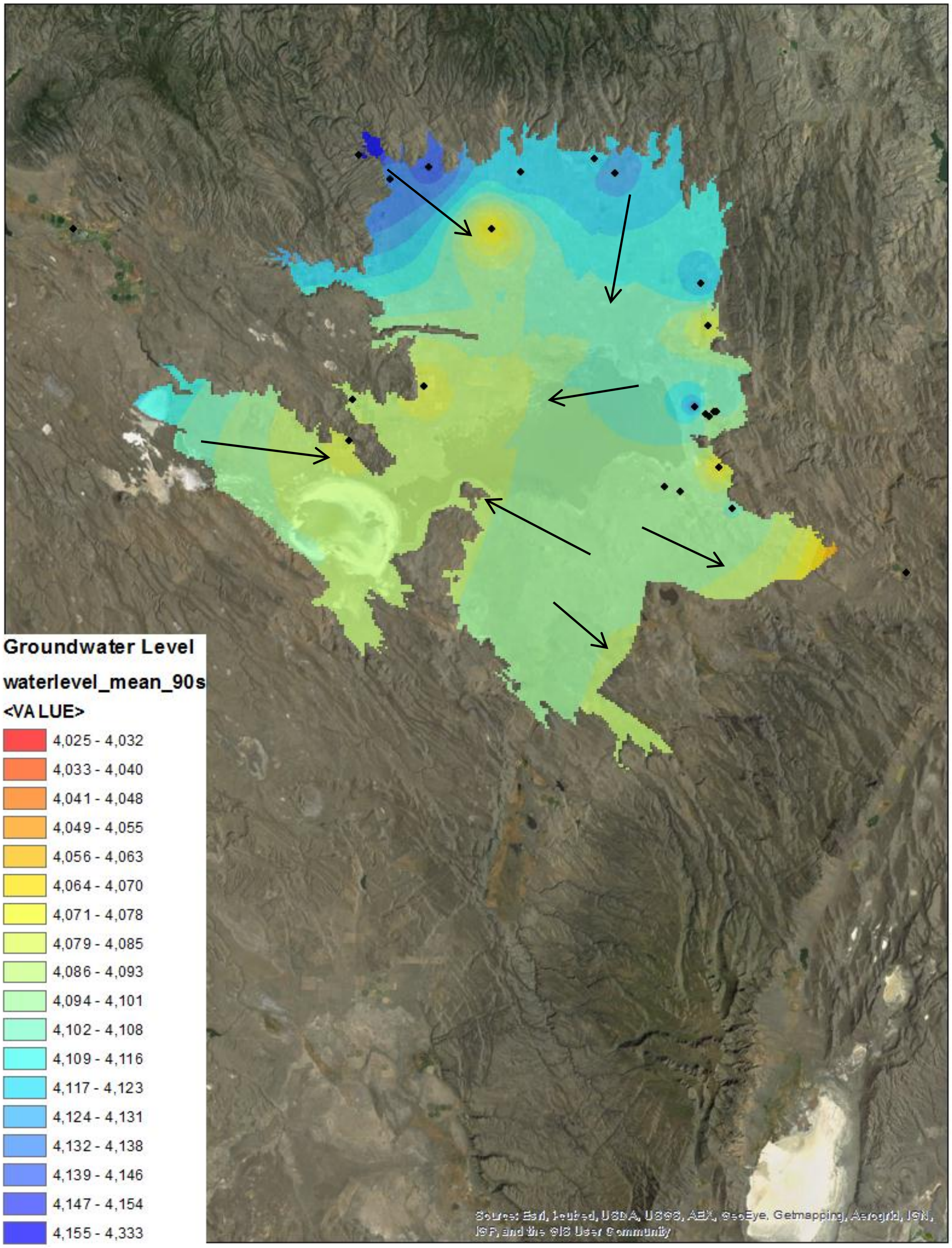
Source: Esri, i-cubed, USDA, USGS, AEX, GeoEye, Getmapping, Aerogrid, IGN, IGP, and the GIS User Community

*Figure 5-12. 1970s Mean Groundwater Level Contour and Flow Direction Map*



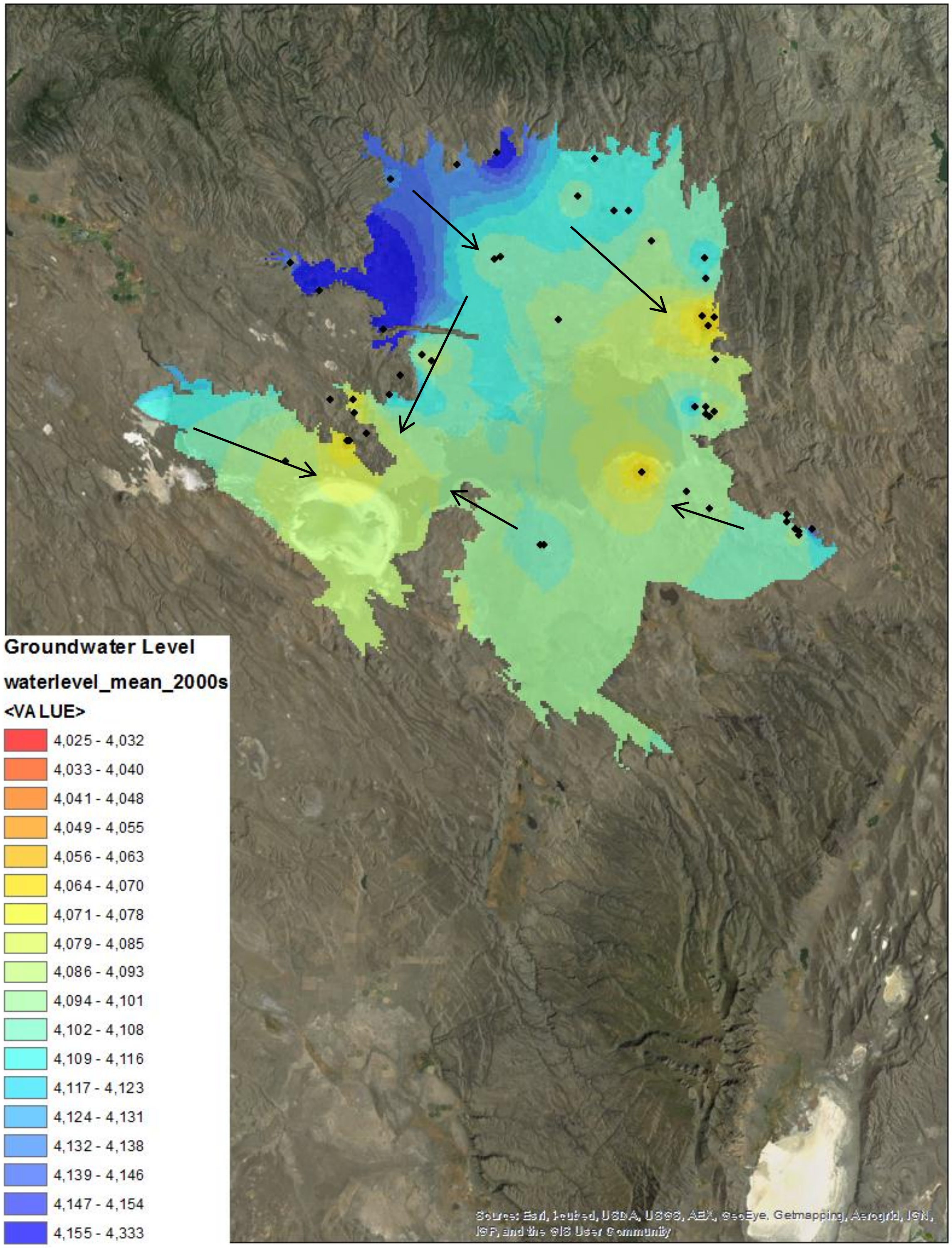
Source: Esri, i-cubed, USDA, USGS, AEX, GeoEye, Getmapping, Aerogrid, IGN, IGP, and the GIS User Community

*Figure 5-13. 1980s Mean Groundwater Level Contour and Flow Direction Map*



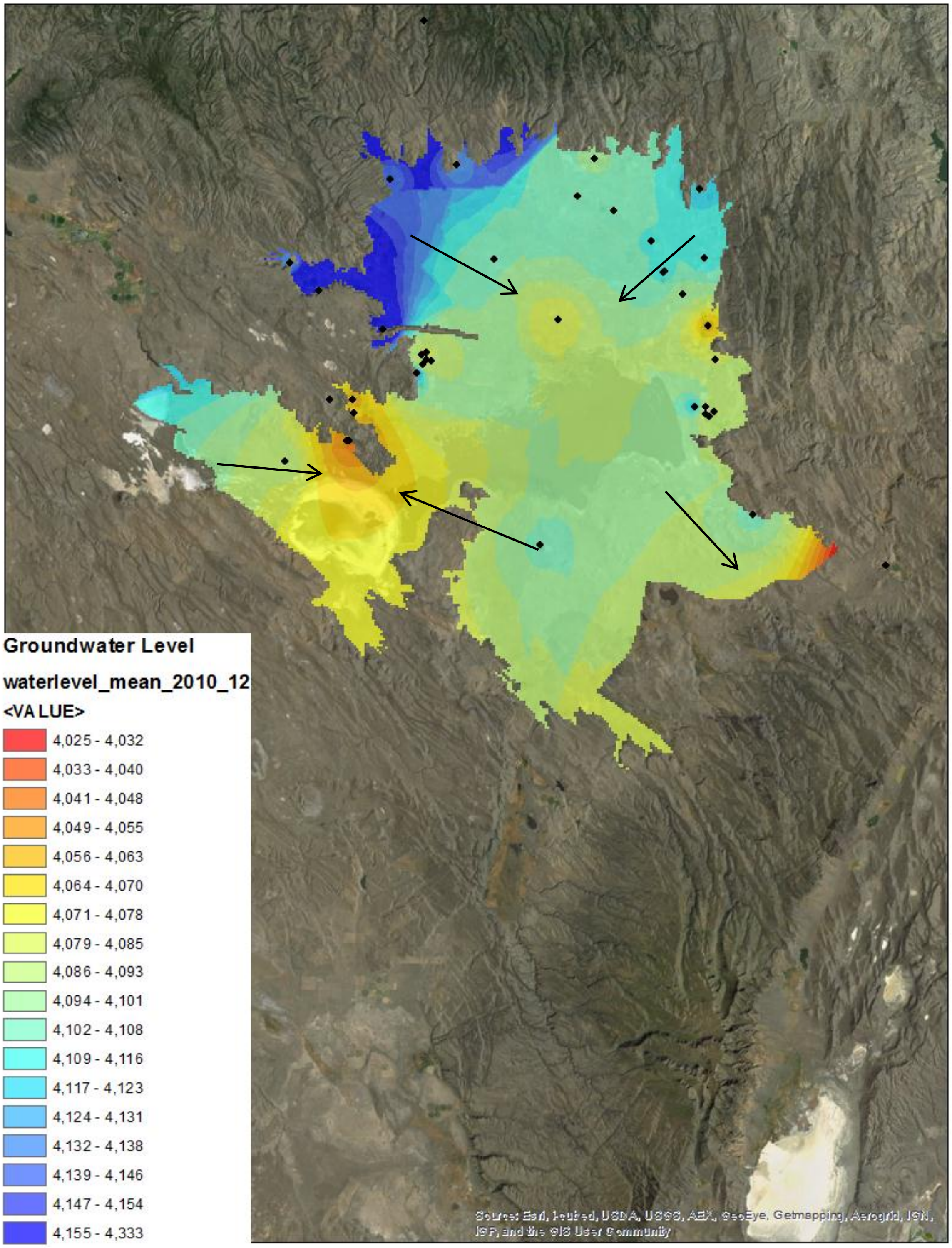
Source: Esri, i-cubed, USDA, USGS, AEX, GeoEye, Getmapping, Aerogrid, IGN, IGP, and the GIS User Community

*Figure 5-14. 1990s Mean Groundwater Level Contour and Flow Direction Map*



Source: Esri, i-cubed, USDA, USGS, AEX, GeoEye, Getmapping, Aerogrid, IGN, IGP, and the GIS User Community

*Figure 5-15. 2000s Mean Groundwater Level Contour and Flow Direction Map*

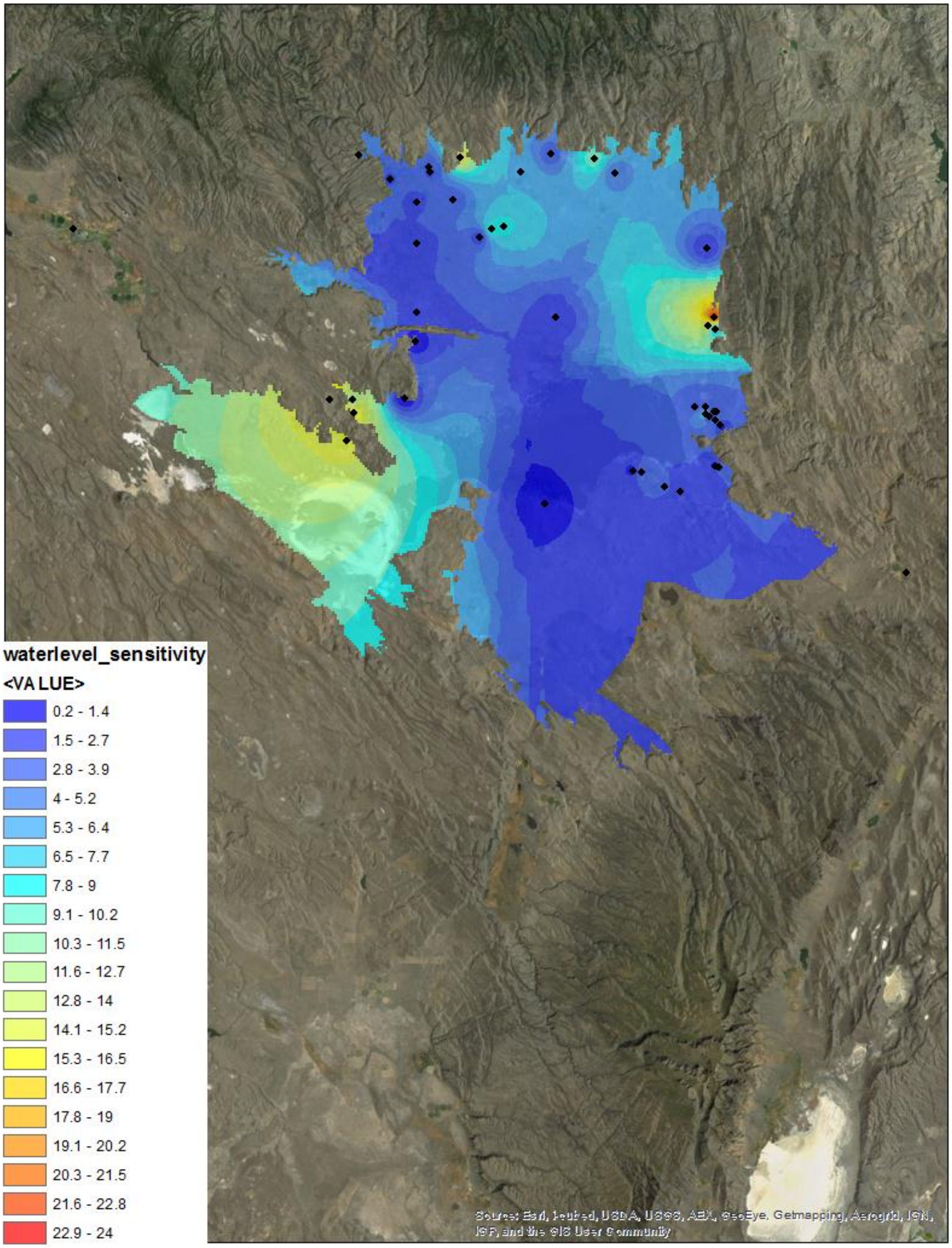


Source: Esri, i-cubed, USDA, USGS, AEX, GeoEye, Getmapping, Aerogrid, IGN, IGP, and the GIS User Community

*Figure 5-16. 2010-2013 Mean Groundwater Level Contour and Flow Direction Map*

Comparing the above six groundwater level contour maps reveals how the levels have changed over time in the Quaternary basin-fill aquifer. In general, there was little change in groundwater level until the 1990s. From the 1990s to the present groundwater levels have declined by the greatest amount in the northeastern and southwestern portions of the greater Harney Valley. There has been little change in groundwater levels in the northwestern corner of the valley; in the vicinity of Burns, Hines and Sage Hen Valley.

The following map shows the standard deviation for all the state observation wells that have at least five water level measurements.



Source: Esri, i-cubed, USDA, USGS, AEX, GeoEye, Getmapping, Aerogrid, IGN, IGP, and the GIS User Community

*Figure 5-17. Standard Deviation for Water Level Data for All Observation Wells Having a Record of at Least Five Water Level Measurements*

Figure 5-17 shows the relative significance of water level changes. Areas with higher values are shown in yellow. They indicate where the more significant water level changes have occurred over the period of record. The areas of most significant water level change are in the northeast and southwest corners of the greater Harney Valley. The most significant water level change has occurred in the area north of Harney Lake.

The following five maps illustrate the change in groundwater level by subtracting the mean groundwater level for a particular decade, for example the 1970s, from the mean groundwater level for the period from 2010 to 2012. The decades used are the 1970s, 1980s, 1990s and 2000s. The period from 1936 to 1969 is also compared to the 2010 to 2012 period. The five maps are presented in the following five figures.

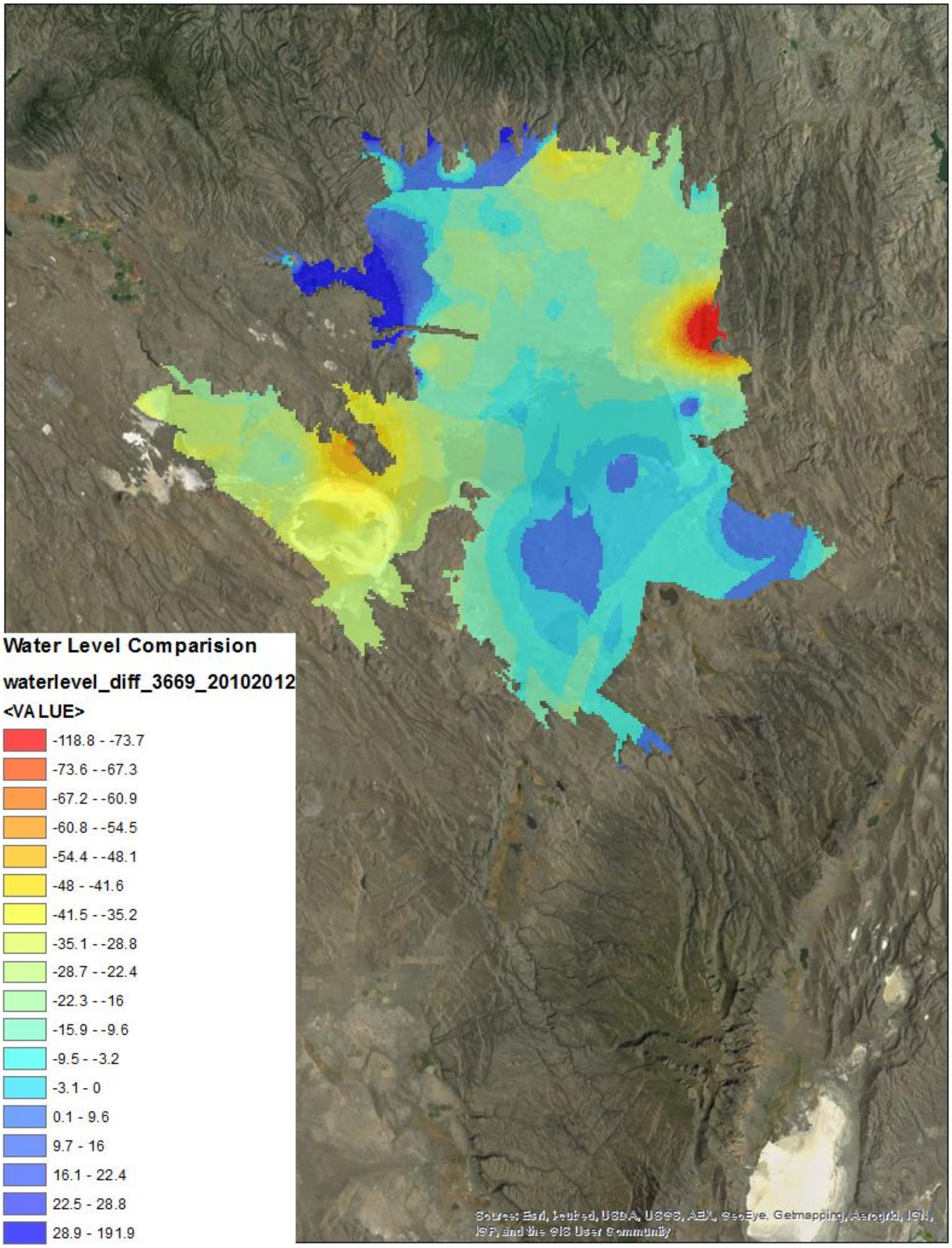
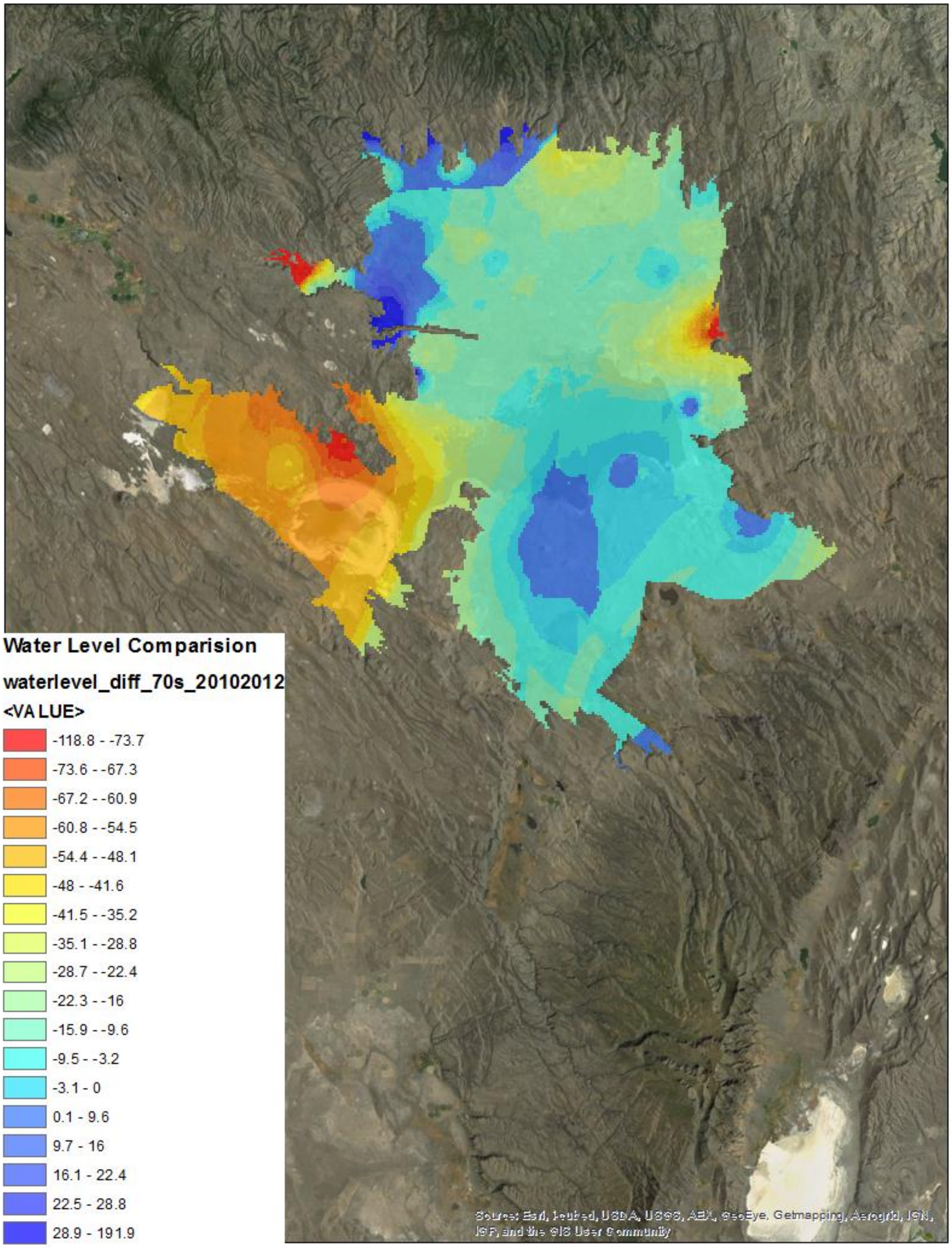
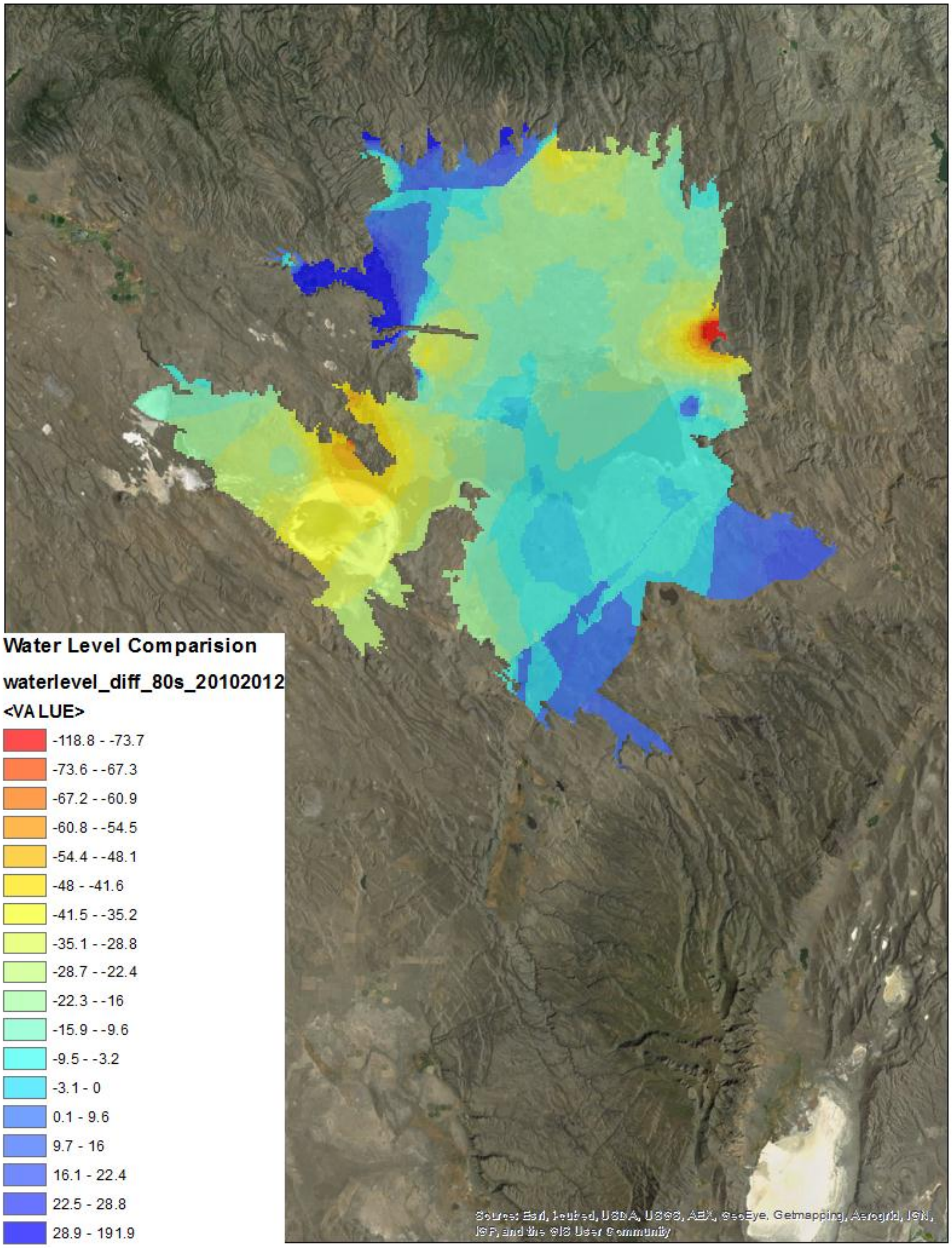


*Figure 5-18. 1936-1969 Mean Groundwater Level Subtracted from the Mean for 2010-2012*



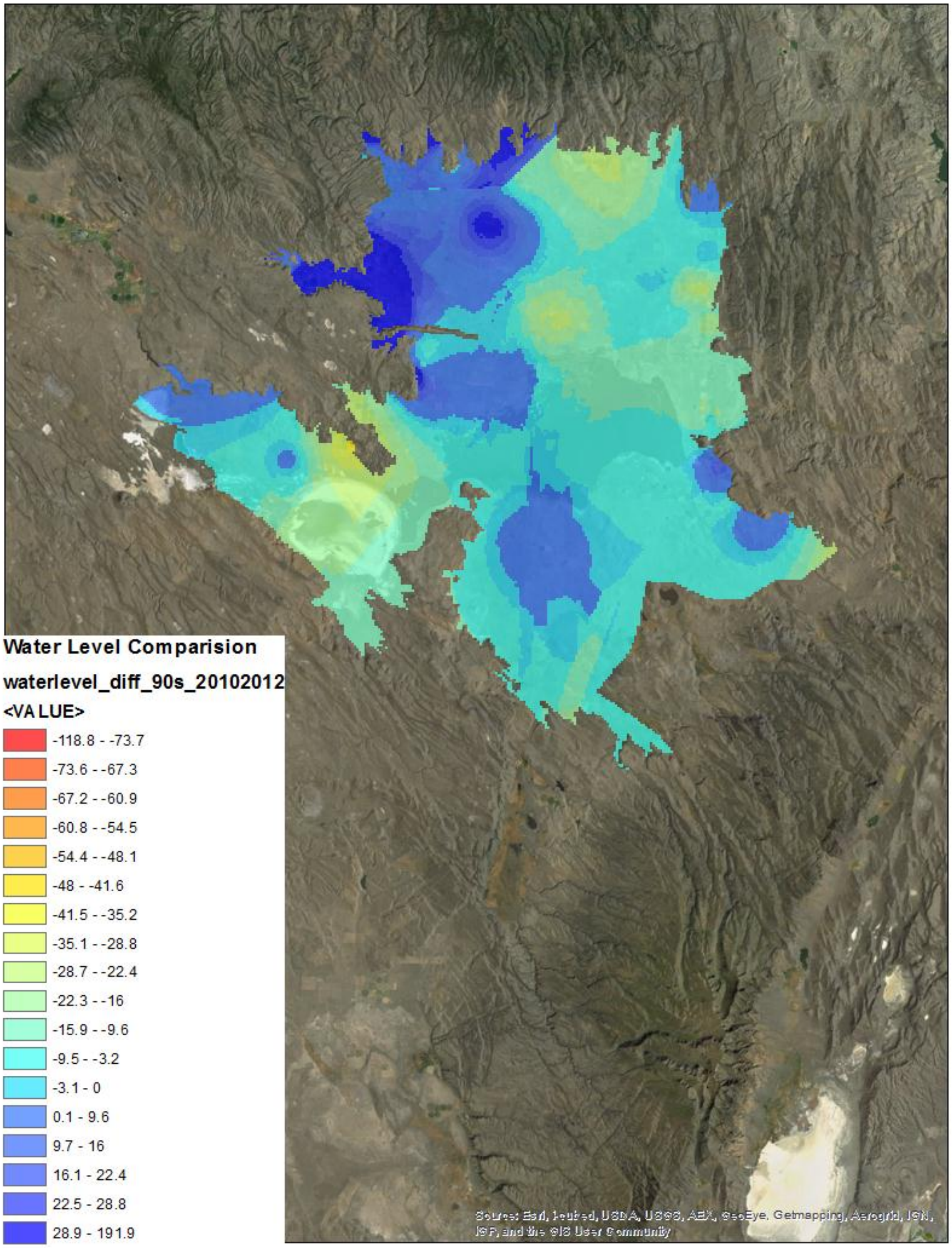
Source: Esri, i-cubed, USDA, USGS, AEX, GeoEye, Getmapping, Aerogrid, IGN, IGP, and the GIS User Community

*Figure 5-19. 1970s Mean Groundwater Level Subtracted from the Mean for 2010-2012*



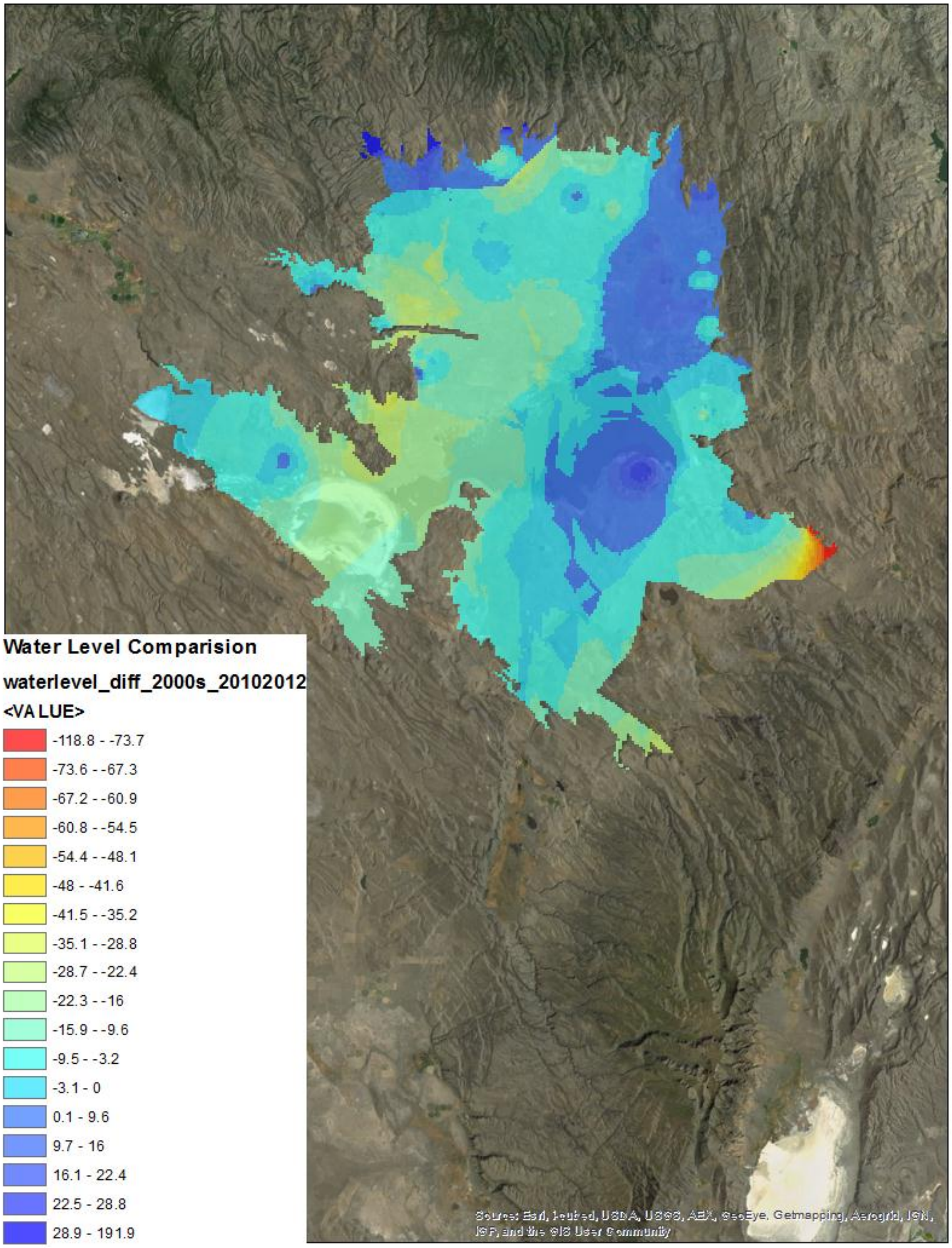
Source: Esri, i-cubed, USDA, USGS, AEX, GeoEye, Getmapping, Aerogrid, IGN, IGP, and the GIS User Community

*Figure 5-20. 1980s Mean Groundwater Level Subtracted from the Mean for 2010-2012*



Source: Esri, i-cubed, USDA, USGS, AEX, GeoEye, Getmapping, Aerogrid, IGN, IGP, and the GIS User Community

*Figure 5-21. 1990s Mean Groundwater Level Subtracted from the Mean for 2010-2012*



Source: Esri, i-cubed, USDA, USGS, AEX, GeoEye, Getmapping, Aerogrid, IGN, IGP, and the GIS User Community

*Figure 5-22. 2000s Mean Groundwater Level Subtracted from the Mean for 2010-2012*

The map comparing the 1970s mean groundwater level to the mean for the most recent three year period shows that groundwater levels were lower over most of the basin in the 1970s. The Sage Hen Valley area is the exception where the mean groundwater level was higher in the 1970s than for the most recent three years.

The map comparing the 1980s mean groundwater level to the mean for the most recent three year period differs very little from the 1970s map which shows that groundwater levels were lower over most of the basin. The notable difference between the two maps is in the Harney Lake area where the 1980s mean water level was higher than the 1970s mean.

The map comparing the 1990s mean groundwater level to the mean for the most recent three year period shows that groundwater levels were higher south of Malhuer Lake and in the area north-northwest of Malhuer Lake in the 1990s.

The map comparing the 2000s mean groundwater level to the mean for the most recent three year period shows that mean groundwater levels over much of the northern and western portions of the basin (blue) were higher than the mean groundwater level for the most recent three years.

## 5.5. Groundwater Use

There is limited data for groundwater use in the study area. State Statute, ORS 537.077, requires federal and state agencies, cities, counties, schools, irrigation districts and other special districts to report water use on an annual basis. Since 1990, many new permits have conditions requiring water meters to be installed and annual reports to be submitted to the state. Not all groundwater users are required to record and report their use. Owners of domestic wells are not required to report use.

The number of groundwater users in Harney Basin that are required by law or water permit conditions to report annual groundwater use is unknown. Older water rights and newer rights without a reporting condition will not be in the water use reporting database.

Our search of the OWRD water use reporting database found usage data for the cities of Burns and Hines, and the Rattle Snake Land & Cattle. The following table summarizes the water use reported by these three entities for the past three years.

*Table 5-6. Reported Groundwater Use in Millions of Gallons Annually*

| **User** | **2009** | **2010** | **2011** |
|---|---|---|---|
| City of Burns | 488.62 | 423.01 | 387.49 |
| City of Hines | 263.49 | 233.46 | 193.99 |
| Rattle Snake Land & Cattle | | | 574.10 |
| **Totals** | 752.11 | 656.47 | 1155.58 |

The U.S. Geological Survey estimates annual water use per county. The estimate for groundwater used for irrigation in 2000 in Harney County is 69.95 million gallons per day during the irrigation season (http://water.usgs.gov/watuse/data/2000/index.html).

# 6. Identifying Data Gaps and Proposed Monitoring

## 6.1. Borehole Data

The borehole data for the Harney Basin has been assembled and cataloged as part of this study. The cross sections created help provide a better understanding of the subsurface framework of the aquifers and provide tools to help communicate the subsurface characteristics to stake holders and the general public. The borehole data is not adequate however, to define with confidence the complete picture of the subsurface stratigraphy. Most of the wells are shallow wells which do not provide stratigraphic data for the deeper layers. The accuracy of the well locations is also suspect in many cases. Some work was done during this study to verify well locations for selected wells used to define the geologic cross sections. The locations of some of the wells could not be verified. The distribution of the wells is not uniform and some areas, particularly in the southwest area, do not have a sufficient number of wells to define the aquifer layers with adequate detail and confidence.

### 6.1.1. Recommendations

The preferred option of drilling additional deep bores in the underrepresented areas of the basin will likely be cost prohibitive. The following activities are recommended to help improve the borehole data for the basin.

- Verify the location of the existing wells, particularly the deeper wells and update the database.
- Develop a procedure to ensure that the well logs for all new or replacement wells drilled in the basin are received by the council and imported into the database.
- Explore opportunities to involve geologist(s) in the logging of new wells.
- Encourage the use of handheld GPS units to identify the location of new wells.

- Update the hydrogeologic framework developed in this study every five years or at intervals determined by the council.
- Geologic mapping is needed to better define the Harney Formation and stratigraphic relationships between the geology on the eastern and western sides of the basin.

### 6.2. Groundwater Monitoring

This study provides the available groundwater level data in the database deliverable. The groundwater level data is available from the Oregon Water Resource Department (OWRD). Water level maps have been created to provide an understanding of trends in groundwater levels. Water levels at this time do not show significant decline except in some localized areas in the southwest and northeast part of the basin.

There are limitations related to the water level data. The data included in the database comes from 180 wells. Only 132 of these wells are located inside the study area. Water levels have been recorded for varying lengths of time. The data quality is questionable for some of the wells. Relatively few of the monitoring wells are located in the south and southwest area of Harney Basin. There are both temporal and spatial gaps in the data.

At present there is limited groundwater quality monitoring being done in the basin. Adding a groundwater quality monitoring component to the data collection program would be helpful for future management of groundwater in the basin.

#### 6.2.1. Recommendations

- Increase the amount of water level monitoring in the basin.
- Increase water level monitoring by using existing wells.
- Focus on adding monitoring of groundwater levels in the south, southwest and western areas of the basin.
- Consistently monitor groundwater level and groundwater quality data.
- Review existing water level monitoring. Ensure that the monitoring frequency is consistent throughout the basin. Monitoring frequency should be at least semiannual.
- Establish a program that would identify new wells that would be of particular value for water level and water quality monitoring. The program could, for example, facilitate long term access and the installation of sounding tubes.
- Existing and future monitoring wells should be associated with a particular aquifer to the extent practical.
- Establish long-term groundwater monitoring in the south, southwest and western areas of the basin not currently well represented with monitoring wells. Additional wells should be monitored in the northeast area where the water level data indicates a significant decline. Identify wells and monitoring parameters for water quality monitoring.
- Groundwater monitoring should be expanded to include the deeper aquifers.

## 6.3. Surface Water Hydrology

Streamflow data are necessary for validating hydrologic models, monitoring water use at the basin level, and are critical for implementing surface water quality and stream habitat projects.

### 6.3.1. Recommendations

- Maintain all existing gages in the Harney Basin. Two of the three active gages have periods of record over 80 years in length, and the third was reestablished close to a gage with close to 30 years of data. Long-term records are needed to discern trends in water quantity, and it is critical to leverage these station records into the future.
- Reestablish gages in other parts of the basin that are currently not monitored. Reestablishing a gage at a former location allows us to build on to existing data sets for long term monitoring.

The Deep Percolation Model developed as part of this analysis could be enhanced in some relatively simple ways to increase our confidence in its ability to predict recharge under current conditions, and assess future land management and/or climate scenarios.

- Develop additional meteorological data sets for additional stations, for a longer period of record, and for additional data elements. As discussed previously in Section 5, we chose a relatively short modeling period (ten years) for a subset of the stations, based on the availability of a complete data set (i.e., no missing data) for these stations/time periods. Precipitation and temperature data sets should be developed for all stations for the longest possible period where data is available. In addition, solar radiation data should be included for those stations where it has been recorded.
- Incorporate stream runoff into the existing Deep Percolation Model. Because the Harney Basin is a "closed basin" it was not necessary to include surface runoff as a loss in the model. However, it may be interesting to evaluate recharge in different portions of the basin to better define the spatial distribution of recharge.

The Deep Percolation Model results presented in this report are for the current land use and climate condition. However, the model could be used to evaluate how alternative land management strategies, combined with possible climate change scenarios, might affect groundwater recharge in the Harney Basin.

- Evaluate climate change impacts on recharge by modifying existing meteorological data sets to reflect possible climate change scenarios. Data sets reflecting climate change scenarios are readily available from institutions in the region. These data sets can be used to modify station data following the approach used by Waibel (2011).
- Evaluate alternative land use management effects on recharge. Several land use issues within the Harney Basin have a possibility of affecting recharge, including the spread of western juniper, possible impacts of catastrophic fire, and the possible benefits of irrigation efficiencies and alternative irrigation strategies. The Deep Percolation Model developed here could be used to evaluate these effects.

## 6.4. Pump Test

Data from well designed and executed pumping tests (aquifer tests) would be very helpful for determining the hydraulic properties of aquifers. Future groundwater flow modeling will depend on accurate aquifer parameters. Pump tests are required as a permit condition for some water rights. When OWRD receives pump test data they judge the quality of the data. If the quality is adequate, the aquifer transmissivity is derived. The problem is very few tests are judged to be of good quality. The available pump test reports are attached to the appropriate well records in the database. Transmissivities calculated for pump tests deemed to be of good quality are also included in the well record.

### 6.4.1. Recommendations

- Explore ways to involve hydrogeologists in the design, supervision and analysis of pump tests.
- Establish a future task to perform pump tests on a subset of wells in various aquifers.

## 6.5. Groundwater Use

State Statute, ORS 537.077, requires federal and state agencies, cities, counties, schools, irrigation districts and other special districts to report water use on an annual basis. Since 1990, many new permits have conditions requiring water meters to be installed and annual reports to be submitted to the state. The number of groundwater users in Harney Basin that are required by law or water permit conditions to report annual groundwater use is unknown. Older water rights and newer rights without a reporting condition will not be in the water use reporting database. Our search of the OWRD water use reporting database found usage data for the cities of Burns and Hines, and the Rattle Snake Land & Cattle.

### 6.5.1. Recommendations

- An effort should be made to encourage groundwater users to keep a record of water use and to report water use annually.
- Develop a water demand model which would incorporate known pumping data and make estimates of private well use and irrigation based on a water budget analysis of the basin. This analysis is outside the scope of the current study.
- Perform a specific yield analysis for the basin.

## 6.6. Groundwater Model

A 3D Groundwater model would assist the county to manage the groundwater data in the basin. The groundwater model could be used to:

- Estimate the sustainable yield of groundwater for the basin.
- Determine the impact of pumping one or multiple wells on the groundwater level.
- Assist in the well permitting process.
- Predict groundwater level based on the proposed groundwater use.

### 6.6.1. Recommendations

- Define the proper boundary conditions for the area of interest.
- Use the Deep Percolation Model to estimate the recharge for the model.
- Group the interpreted hydrogeologic units into continuous layers to define the material properties for the model grid.
- Use the existing observation data to calibrate the model.

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# Appendix A. Explanation of Database Fields

*BoreholeLog* table – table for representing vertical data along boreholes

| | |
|---|---|
| WellID | References the HydroID of a Well feature |
| RefElev | A reference elevation (e.g., land elevation, top of casing) giving the starting elevations for data measure as depth along the borehole |
| FromDepth | The top elevation of an interval measured as depth along the borehole |
| ToDepth | The bottom elevation of an interval measured as depth along the borehole |
| TopElev | Top elevation of an interval represented in absolute elevation units (e.g., feet above mean sea level) |
| BottomElev | Bottom elevation of an interval represented in absolute elevation unites (e.g., feet above mean sea level) |
| ElevUnits | Units of elevations soted in the TopElev and BottomElev attributes. |
| Material | Description of strata observed along a borehole. Usually documented in drilling logs and later classified into geologic/hydrogeologic units |
| HGUID | Hydrogeologic unit identifier. Classifies borehole data into hydrogeologic units defined in the HydrogeologicUnit table |
| HGUCode | Hydrogeologic unit code. Text for classifying, symbolizing, and labeling hydrogeologic units. |
| LogType | Distinguishes between types of borehole logs (e.g., well completion, hydrostratigraphy. |
| Description | Text for storing detailed descriptions written in the borelog PDFs. |
| Well_Log_Number | The well log number assigned by the OWRD. |

*Boreline* feature class – polyline Z feature class for representing interval data along boreholes

| | |
|---|---|
| HydroID | Unique feature identifier in the geodatabase used for creating relationships between classes of the data model. |
| HydroCode | Permanent public identifier of the feature used for relating features with external information systems |
| WellID | References the HydroID of a Well feature |
| Material | Description of strata observed along a borehole. Usually documented in drilling logs and later classified into geologic/hydrogeologic units |
| HGUID | Hydrogeologic unit identifier. Classifies borehole data into hydrogeologic units defined in the HydrogeologicUnit table |
| HGUCode | Hydrogeologic unit code. Text for classifying, symbolizing, and labeling hydrogeologic units. |
| TopElev | Top Elevation of the Boreline feature. |
| BottomElev | Bottom elevation of the Boreline feature. |
| Ftype | Distinguished between types of Borelines features (e.g., well completion, hydrostratipgraphy). |

*GeoSection* – 3D panels for constructing vertical cross sections

| | |
|---|---|
| HydroID | Unique feature identifier in the geodatabase used for creating relationships between classes of the data model. |
| HydroCode | Permanent public identifier of the feature used for relating features with external information systems |
| SectionID | Equal to the HydroID of a SectionLine feature. Relates GeoSection feature with SectionLine features |
| SName | Section name. Text descriptor of the section line for labeling, symbolization, and queries (e.g., A-A') |
| HGUID | Hydrogeologic unit identifier. Relates GeoSection features with more detailed descriptions of hydrogeologic units defined in the HydrogeologicUnit table. |
| HGUCode | Text descriptor of the hydrogeologic unit used for labeling, symbolization, and queries. |
| HorizonID | Index for describing the depositional sequence of hydrogeologic units |
| Ftype | Distinguished between types of GeoSection features. |

*HydrogeologicUnit* table – Table for representing hydrogeologic units

| | |
|---|---|
| HydroID | Unique identifier in the geodatabase used for creating relationships between classes of the data model. Used to relate between hydrogeologic units defined in the table and special features within the hydrostratigraphy component. |
| HGUCode | Hydrogeologic unit code. The permanent identification code of hydrogeologic units, used to establish a linkage with external information systems |
| HGUName | Text descriptor of hydrogeologic units used for labeling and symbolization |
| AquiferID | Aquifer identifier for grouping hydrogeologic units. AquiferID is also used to relate hydrogeologic units in the table with a Aquifer features |
| AqCode | Aquifer code. Text descriptor of the aquifer used for labeling, symbolization, and querying. |
| Description | Text for storing detailed descriptions of hydrogeologic units. |
| HorizonID | Index for describing the depositional sequence of hydrogeologic units. |
| HGUColor | The color code associated with each hydrogeologic unit code. |

*Sectionline* – 2D polyline features defining cross sections on a map

| | |
|---|---|
| HydroID | Unique feature identifier in the geodatabase used for creating relationships between classes of the data model. |
| HydroCode | Permanent public identifier of the feature used for relating features with external information systems. |
| SName | Section name. Text descriptor of the section line for labeling symbolization and queries (e.g. A-A') |
| VertExag2D | Vertical exaggeration that will be applied when creating XS2D features (see section on representing vertical cross sections in 2D). |
| FType | Distinguishes between types of SectionLine features. |

*TimeSeries* – Table storing single-variable time series

| | |
|---|---|
| FeatureID | Unique feature identifier. Is equal to the HydroID of the feature associated with the time series value. |
| VarID | Numerical identifier for the variable within the geodatabase. |
| TsTime | Time stamp specifying the data and time associated with the time series value. |
| UTCOffset | Number of hours the time coordinate system used to define TsTime is displaced from Coordinated Universal Time. |
| TsValue | Numerical value of the variable at the given location and time. |

*VariableDefinition* – Table for storing time series value

| | |
|---|---|
| VarID | Unique numerical identifier for the variable within the geodatabase. |
| VarName | The name of the variable. |
| VarDesc | The description of the variable. |
| VarUnits | Units of measure of the variable. |

*Well* feature class – Point feature class for representing well locations and their attributes

| Field Name | Description |
|---|---|
| HydroID | Unique feature identifier in the geodatabase used for creating relationships between classes of the data model |
| HydroCode | Permanent public identifier of the feature used for relating features with external information systems |
| LandElev | The elevation of the land surface at the well location. Is commonly used to reference vertical information (measured as depth along the well) |
| WellDepth | The depth of the well. Together with LandElev provides a description of the well's 3D geometry |
| AquiferID | Relates a Well feature with an Aquifer feature. The AquiferID of a Well feature is equal to the HydroID of a Aquifer feature |
| AqCode | Text describing the aquifer. Is used to symbolize wells based on the related aquifer |
| HGUID | Relates the well to a hydrogeologic unit |
| FType | Distinguished between types of wells (e.g., domestic, industrial) |
| FCode | Unique code associated with each well type |
| Well_Log_Number | The well log number associated with each well |
| Well_Link | The link to online well information at OWRD website |
| Well_DLink | The link to download the well log |
| filename | File name associated with the well |

# Appendix B. Weed & Poteet #1 Oil Exploration Well Log

COMPOSITE LOG OF UNITED CO. WEED & POTEET #1

Section 9, Township 23 south Range 31 East

HARNEY COUNTY OREGON. 10/25/49

***********************************************************

DEPTH & THICKNESS

0--480-- Tuffaceous clay, sand & gravel.

480--610--130'--soft white tuffaceous clay; some gravel embedded in clay. tan & coffee colored tuffaceous clays. few pieces of green shale.

610--650--40'--Grayish tan to grayish black lava; green mineral in lava.

650--660--10'--altered sediments.

660-690--30'--grayish tan to grayish black lava.

690--708--18'--red to brick colored altered material; red sandy shale

708--750--43'--grayish tan lava.

750--790-40'--vari-colored altered material; clear quartz? in altered material.

790--1000--210'-- vari-colored volcanic agglomerate;gray & green bentonitic clays; white clay.

1000--1100--100'--hard grayish black lava with high iron Pyrite.

1100--1140--40'-- streaks of grayish black lava & gray tuffaceous clays and shales.

1140--1290--150'-- gray , green & white tuffaceous shale & clay with some sandy streaks; Some vari-colored tuffaceous shale with large quartz crystals; some cream colored clays.

composite log page 2.

DEPTH & THICKNESS

1290--1430--140'--cream colored limey clay vari-colored tuffaceous clays.

1430--1585-155'--tuffaceous material & some sandy streaks grayish green to grayish tan clay which has been partly altered to quartz? by hydrothermal action vari-colored sand.

1585--1860--275'--very hard grayish white hydrothermally altered sediments; the original material was probably volcanic ash.

1860--3730--1870'--vari-colored bentonitic clays; tuffaceous shales grayish black altered sediments; green shales and streaks of limey ash; some hydrocarbons? in tan & brown shales.

3730--3850--120'-- hard ,fine grained,grayish tan to grayish black lava.

3850--3950--100' grayish black altered sediments.

3950--4010--60'-- grayish tan to grayish black lava

4010--4065--55'-- grayish to grayish green altered sediments

4065--4092--27'-- grayish black lava

4092--4100--8'-- altered material

4100--4118--18'--grayish black lava

4118--4121--3'-altered material

4121--4143--22'--grayish black lava

4143--4310--167'--vari-colored altered sediments with sandy streaks.

4310--4350--40'--grayish black ,fine grained lava.

4350--5140--790'--gray,green & tan bentonitic clays and some

composite log page 3.

continued.

altered sediments .

DEPTH & THICKNESS

5140--5155--15'-- top of Columbia basalts of lower Miocene age. grayish tan to grayish black lava.

5155--5228--73'-- bentonitic clays; tuffaceous shales.

5228--5260--32'-- grayish tan lava

5260--5290--30'-- tan & green clay & altered material.

5290--5300-10'-- grayish tan lava

5300--5320--20'-- vari-colored altered material.

5320--5390--70'--grayish tan to grayish black lava

5390--5410--20'--vari-colored altered sediments

5410--5470--60'--very hard grayish tan to grayish black lava

5470--5560--90'--soft bentonitic clays & vari colored altered sediments.

5560--5680--120'--grayish tan lava with black mineral specks.

5680--5800--120--grayish tan & green bentonitic clay ;brick red altered material & altered material in streaks.

5800-5830--30'-- grayish tan lava

5830--5955--125'--vari-colored altered sediments & thin streaks of lava.

5955--6000--45'--grayish tan lava;

6000--6060--60'-- gray,tan & green altered sediments

6060--6103--43'-- grayish tan to grayish black lava

6103--6330--227'--soft gray, tan & green bentonitic clays & streaks of altered material.

6330--6380--50'--grayish black& grayish green lava.

composite log page 4.

DEPTH & THICKNESS

6380--6420--40' tan & green bentonitic clays

6420--6480--60'-- TOTAL DEPTH--grayish black & grayish green lava and grayish tan lava.

All samples were checked with a fluorescope and there were no worth while shows of oil and gas. There is a very close correlation between sample log, drilling time and Schlumberger log. The high resistivity values on the Schlumberger log correlate with the lava beds. The high drilling time also correlates with the lava beds.

There were some streaks of dry hydrocarbon in the brown and tan shales. It appears that this has been burned by high temperatures.

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Burns, Oregon October 26,1949

# Appendix C. Data for Selected Wells Used in Fence Diagram

| Well Number | Static Water Level (feet) | Well Depth (feet) | Production Zone Interval (feet) | Production Zone Thickness (feet) | Pumping Rate (gpm) | Drawdown[1] (feet) | Specific Capacity[2] (gpm/foot) | Transmissivity[3] Estimated (gal/day/foot) | Hydraulic Conductivity[4] Estimated (gal/day/feet$^2$) | Hydrogeoligic Unit - Production Zone |
|---|---|---|---|---|---|---|---|---|---|---|
| HARN 000080 | 12 | 360 | | | 900 | NA | | | | |
| HARN 000089 | 385 | 410 | 385-410 | 25 | 15 | 2 | 7.5 | 15000 | 600.0 | Volcaniclastic sedimentary rocks |
| HARN 000134 | 18 | 725 | | | 800 | 122 | 6.6 | | | |
| HARN 000169 | 38 | 620 | | | 135 | 120 | 1.1 | | | |
| HARN 000181 | artesian | 880 | 780-820 | 40 | NA | NA | | | | Volcaniclastic sedimentary rocks |
| HARN 000191 | 22 | 330 | | | 150 | 78 | 1.9 | | | Volcaniclastic sedimentary rocks |
| HARN 000219 | 8 | 835 | | | 190 | 182 | 1.0 | | | Steens Basalt |
| HARN 000222 | 8 | 275 | | | 200 | 92 | 2.2 | | | Basin-fill |
| HARN 000227 | 10 | 280 | | | 850 | 190 | 4.5 | | | Basin-fill |
| HARN 000323 | artesian | 198 | 143-198 | 55 | 400 | | | | | Mafic vent complex |

| Well Number | Static Water Level (feet) | Well Depth (feet) | Production Zone Interval (feet) | Production Zone Thickness (feet) | Pumping Rate (gpm) | Drawdown1 (feet) | Specific Capacity2 (gpm/foot) | Transmissivity3 Estimated (gal/day/foot) | Hydraulic Conductivity4 Estimated (gal/day/feet2) | Hydrogeoligic Unit - Production Zone |
|---|---|---|---|---|---|---|---|---|---|---|
| HARN 000327 | 10 | 300 | | | 853 | 120 | 7.1 | | | |
| HARN 000358 | 11 | 348 | | | 1000 | 44 | 22.7 | | | |
| HARN 000359 | 15 | 200 | 15-120 | 105 | 700 | 55 | 12.7 | 25460 | 242.5 | Basin-fill |
| HARN 000407 | 8 | 364 | | | 1100 | 65 | 16.9 | | | Basin-fill |
| HARN 000440 | 12 | 120 | | | NA | NA | | | | |
| HARN 000463 | 9 | 300 | | | 1100 | NA | | | | |
| HARN 000493 | 5 | 320 | | | 50 | 6 | 8.3 | | | Basin-fill |
| HARN 000522 | 9 | 603 | | | 300 | 32 | 9.4 | | | |
| HARN 000541 | 11 | 160 | 135-160 | 25 | 500 | 70 | 7.1 | 14286 | 571.4 | Basin-fill |
| HARN 000563 | 9 | 490 | 32-166 | 134 | NA | NA | | | | Basin-fill |

| Well Number | Static Water Level (feet) | Well Depth (feet) | Production Zone Interval (feet) | Production Zone Thickness (feet) | Pumping Rate (gpm) | Drawdown1 (feet) | Specific Capacity2 (gpm/foot) | Transmissivity3 Estimated (gal/day/foot) | Hydraulic Conductivity4 Estimated (gal/day/feet2) | Hydrogeoligic Unit - Production Zone |
|---|---|---|---|---|---|---|---|---|---|---|
| HARN 000573 | 9 | 1316 | | | 21 | 26.5 | 0.8 | | | |
| HARN 000625 | 12 | 115 | | | 1000 | NA | | | | |
| HARN 000637 | 17 | 205 | 100-205 | 105 | 80 | 11 | 7.3 | 14546 | 138.5 | Tuffaceous and valcaniclastic sediments |
| HARN 000651 | 7 | 450 | 400-450 | 50 | 1323 | 88 | 15.0 | 30060 | 601.2 | Tuffaceous and valcaniclastic sediments |
| HARN 000677 | 8 | 365 | 37-110 | 73 | 1250 | 47 | 26.6 | 53180 | 728.5 | Basin-fill |
| HARN 000699 | 7 | 580 | | | 60 | 65 | 0.9 | | | |
| HARN 000719 | 9 | 420 | | | 400 | NA | | | | |
| HARN 000721 | 5 | 515 | | | 170 | 95 | 1.8 | | | Steens Basalt |
| HARN 000741 | | 207 | | | NA | NA | | | | Basin-fill |
| HARN 000765 | 27 | 245 | | | 20 | 2 | 12.0 | | | |

| Well Number | Static Water Level (feet) | Well Depth (feet) | Production Zone Interval (feet) | Production Zone Thickness (feet) | Pumping Rate (gpm) | Drawdown1 (feet) | Specific Capacity2 (gpm/foot) | Transmissivity3 Estimated (gal/day/foot) | Hydraulic Conductivity4 Estimated (gal/day/feet2) | Hydrogeoligic Unit - Production Zone |
|---|---|---|---|---|---|---|---|---|---|---|
| HARN 000794 | artesian | 478 | | | 400 | NA | | | | |
| HARN 000813 | 8 | 347 | | | 1800 | 84 | 21.4 | | | Intra-basin basalt and cinders |
| HARN 000825 | artesian | 597 | 540-597 | 57 | 75 | 30 | 2.5 | 5000 | 87.7 | Tuffaceous and valcaniclastic sediments |
| HARN 000827 | 2 | 700 | 579-660 | 81 | 2100 | 85 | 24.7 | 49420 | 610.1 | Tuffaceous and valcaniclastic sediments |
| HARN 000878 | 10.5 | 365 | 110-365 | 255 | 50 | NA | | | | Tuffaceous and valcaniclastic sediments |
| HARN 000882 | 270 | 270 | | | 10 | 1 | 10.0 | | | Harney Formation |
| HARN 000933 | 8 | 505 | | | 150 | 22 | 6.8 | | | Tuffaceous and valcaniclastic sediments |
| HARN 000984 | 8 | 515 | | | NA | NA | | | | |
| HARN 001006 | 22 | 216 | | | NA | NA | | | | |
| HARN 001012 | 11 | 612 | | | NA | NA | | | | |

| Well Number | Static Water Level (feet) | Well Depth (feet) | Production Zone Interval (feet) | Production Zone Thickness (feet) | Pumping Rate (gpm) | Drawdown1 (feet) | Specific Capacity2 (gpm/foot) | Transmissivity3 Estimated (gal/day/foot) | Hydraulic Conductivity4 Estimated (gal/day/feet2) | Hydrogeoligic Unit - Production Zone |
|---|---|---|---|---|---|---|---|---|---|---|
| HARN 001028 | 16 | 227 | | | 820 | 84 | 9.8 | | | |
| HARN 001034 | 15 | 349 | | | 1150 | 60 | 19.2 | | | |
| HARN 001040 | 17 | 348 | | 120 | 800 | 220 | 3.6 | | | |
| HARN 001101 | 32 | 100 | | | 1050 | 22 | 47.7 | | | |
| HARN 001118 | 6 | 180 | 72-165 | 93 | 490 | 145 | 3.3 | 6600 | 71.0 | Harney Formation |
| HARN 001139 | 6 | 722 | | | | | | | | Harney Formation |
| HARN 001142 | 14 | 440 | | | 150 | 88 | 1.7 | | | |
| HARN 001180 | 13 | 757 | | | 1600 | NA | | | | |
| HARN 001214 | 22 | 190 | 88-140,<br>155-170 | 67 | 1600 | 48 | 33.3 | 66660 | 994.9 | Intra-basin basalt and cinders |
| HARN 001281 | 340 | 720 | | | 150 | NA | | | | Steens Basalt |

| Well Number | Static Water Level (feet) | Well Depth (feet) | Production Zone Interval (feet) | Production Zone Thickness (feet) | Pumping Rate (gpm) | Drawdown1 (feet) | Specific Capacity2 (gpm/foot) | Transmissivity3 Estimated (gal/day/foot) | Hydraulic Conductivity4 Estimated (gal/day/feet2) | Hydrogeoligic Unit - Production Zone |
|---|---|---|---|---|---|---|---|---|---|---|
| HARN 001304 | 11 | 1005 | | | 180 | 90 | 2.0 | | | |
| HARN 001327 | 40 | 300 | | | 90 | NA | | | | |
| HARN 001337 | 36 | 329 | | | 200 | NA | | | | |
| HARN 001363 | 7 | 147 | 87-147 | 60 | 900 | 11 | 81.8 | 163640 | 2727.3 | Diamond-Voltage basalt |
| HARN 001382 | 20 | 258 | | | NA | NA | | | | |
| HARN 001387 | 43 | 108 | | | 1000 | NA | | | | Intra-basin basalt and cinders |
| HARN 001408 | 23 | 81 | 30-81 | 51 | 800 | 4 | 200.0 | 400000 | 7843.1 | Diamond-Voltage basalt |
| HARN 001418 | | 297 | 146-190 | 44 | 1000 | 15 | 66.7 | 133400 | 3031.8 | Volcaniclastic sedimentary rocks |
| HARN 001440 | 39 | 410 | | | 100 | 131 | 0.8 | | | |
| HARN 001457 | 170 | 310 | | | 30 | NA | | | | Harney Formation |

| Well Number | Static Water Level (feet) | Well Depth (feet) | Production Zone Interval (feet) | Production Zone Thickness (feet) | Pumping Rate (gpm) | Drawdown1 (feet) | Specific Capacity2 (gpm/foot) | Transmissivity3 Estimated (gal/day/foot) | Hydraulic Conductivity4 Estimated (gal/day/feet2) | Hydrogeoligic Unit - Production Zone |
|---|---|---|---|---|---|---|---|---|---|---|
| HARN 001465 | 10 | 500 | | | 150 | 300 | 0.5 | | | Basin-fill |
| HARN 001472 | 280 | 646 | 560-646 | 86 | 20 | 270 | 0.1 | 148 | 1.7 | Tuffaceous and valcaniclastic sediments |
| HARN 001474 | 382 | 572 | | | 10 | NA | | | | |
| HARN 001485 | 425 | 520.5 | | | 8 | 5 | 1.6 | | | |
| HARN 001498 | 38 | 325 | 41-325 | 284 | 450 | 5 | 90.0 | 180000 | 633.8 | Steens Basalt |
| HARN 001501 | 25 | 150 | | | 800 | 35 | 22.9 | | | |
| HARN 001506 | 20 | 200 | | | 900 | 60 | 15.0 | | | |
| HARN 001530 | 10 | 235 | | | 1130 | NA | | | | |
| HARN 001535 | 52 | 420 | | | 42 | 76 | 0.6 | | | |
| HARN 001548 | 400 | 578 | 515-578 | 63 | 10 | NA | | | | Tuffaceous and valcaniclastic sediments |

| Well Number | Static Water Level (feet) | Well Depth (feet) | Production Zone Interval (feet) | Production Zone Thickness (feet) | Pumping Rate (gpm) | Drawdown$_1$ (feet) | Specific Capacity$_2$ (gpm/foot) | Transmissivity$_3$ Estimated (gal/day/foot) | Hydraulic Conductivity$_4$ Estimated (gal/day/feet$^2$) | Hydrogeoligic Unit - Production Zone |
|---|---|---|---|---|---|---|---|---|---|---|
| HARN 001552 | 39 | 171 | | | 1100 | 171 | 6.4 | | | Steens Basalt |
| HARN 001560 | 75 | 840 | | | 100 | 10 | 10.0 | | | |
| HARN 001563 | 67 | 655 | | | 300 | 133 | 4.5 | | | Tuffaceous and valcaniclastic sediments |
| HARN 001854 | 7 | 145 | 135-145 | 10 | 15 | 9 | 1.7 | 3334 | 333.4 | Steens Basalt |
| HARN 001906 | 15 | 396 | | | 15 | 10 | 1.5 | | | |
| HARN 001914 | 42 | 600 | | | 540 | 200 | 2.7 | | | |
| HARN 001923 | 14 | 355 | | | 2500 | 61 | 41.0 | | | Basin-fill (Quaternary) |
| HARN 001930 | 22 | 160 | | | 15 | 10 | 1.5 | | | Volcaniclastic sedimentary rocks |
| HARN 001974 | 33 | 530 | 85-150 | 65 | 250 | 100 | 2.5 | 5000 | 76.9 | Harney Formation |
| HARN 001977 | 14 | 250 | | | 25 | 8.33 | 3.0 | | | Volcaniclastic sedimentary rocks |

| Well Number | Static Water Level (feet) | Well Depth (feet) | Production Zone Interval (feet) | Production Zone Thickness (feet) | Pumping Rate (gpm) | Drawdown1 (feet) | Specific Capacity2 (gpm/foot) | Transmissivity3 Estimated (gal/day/foot) | Hydraulic Conductivity4 Estimated (gal/day/feet2) | Hydrogeoligic Unit - Production Zone |
|---|---|---|---|---|---|---|---|---|---|---|
| HARN 001991 | 280 | 335 | | | NA | NA | | | | Harney Formation |
| HARN 001998 | 101 | 375 | 133-137 | 4 | 10 | 33 | 0.3 | | | Harney Formation |
| HARN 002044 | 30 | 240 | | | 100 | 6 | 16.7 | | | |
| HARN 050010 | 8 | 320 | | | 250 | 80 | 3.1 | | | Tuffaceous and valcaniclastic sediments |
| HARN 050052 | 20 | 225 | | | 500 | 50 | 10.0 | | | Basin-fill |
| HARN 050150 | 38 | 225 | 40-225 | 185 | 100 | NA | | | | |
| HARN 050249 | 17 | 410 | | | 900 | 100 | 9.0 | | | Tuffaceous and valcaniclastic sediments |
| HARN 050285 | 22 | 370 | | | 100 | 2 | 50.0 | | | Tuffaceous and valcaniclastic sediments |
| HARN 050308 | 69 | 300 | | | 30 | 69 | 0.4 | | | |
| HARN 050516 | 66 | 115 | | | 50 | NA | | | | Intra-basin basalt and cinders |

| Well Number | Static Water Level (feet) | Well Depth (feet) | Production Zone Interval (feet) | Production Zone Thickness (feet) | Pumping Rate (gpm) | Drawdown1 (feet) | Specific Capacity2 (gpm/foot) | Transmissivity3 Estimated (gal/day/foot) | Hydraulic Conductivity4 Estimated (gal/day/feet2) | Hydrogeoligic Unit - Production Zone |
|---|---|---|---|---|---|---|---|---|---|---|
| HARN 050571 | 10.5 | 750 | | | 40 | NA | | | | |
| HARN 050621 | 37 | 525 | | | 50 | NA | | | | Tuffaceous and valcaniclastic sediments |
| HARN 050633 | 70 | 580 | | | 1500 | 510 | 2.9 | | | Intra-basin basalt and cinders |
| HARN 050668 | 28 | 750 | | | 600 | 160 | 3.8 | | | Tuffaceous and valcaniclastic sediments |
| HARN 050774 | 164.5 | 220 | | | 15 | NA | | | | |
| HARN 050940 | 13 | 350 | | | 500 | NA | | | | |
| HARN 050941 | 30 | 315 | | | 400 | NA | | | | |
| HARN 050945 | 213 | 355 | | | 25 | 85 | 0.3 | | | |
| HARN 051021 | 20 | 460 | 408-455 | 47 | 1000 | 420 | 2.4 | 4762 | 101.3 | Tuffaceous and valcaniclastic sediments |
| HARN 051040 | 237 | 440 | 290-440 | 150 | 30 | 20 | 1.5 | 3000 | 20.0 | Volcaniclastic sedimentary rocks |

| Well Number | Static Water Level (feet) | Well Depth (feet) | Production Zone Interval (feet) | Production Zone Thickness (feet) | Pumping Rate (gpm) | Drawdown1 (feet) | Specific Capacity2 (gpm/foot) | Transmissivity3 Estimated (gal/day/foot) | Hydraulic Conductivity4 Estimated (gal/day/feet2) | Hydrogeoligic Unit - Production Zone |
|---|---|---|---|---|---|---|---|---|---|---|
| HARN 051044 | 27 | 265 | | | 50 | 18 | 2.8 | | | Harney Formation |
| HARN 051088 | 95 | 270 | 233-243 | 10 | 25 | 175 | 0.1 | 286 | 28.6 | Harney Formation |
| HARN 051090 | 44 | 505 | | | 200 | 100 | 2.0 | | | |
| HARN 051209 | 10 | 412 | 390-412 | 22 | 1020 | 2 | 510.0 | 1020000 | 46363.6 | Steens Basalt |
| HARN 051327 | 14 | 375 | | | 20 | 50 | 0.4 | | | Basin-fill |
| HARN 051408 | 20 | 400 | | | 400 | 90 | 4.4 | | | |
| HARN 051456 | 49 | 380 | 310-380 | 70 | 200 | NA | | | | Steens Basalt |
| HARN 051473 | 35 | 252 | | | 520 | NA | | | | |
| HARN 051507 | 32 | 480 | 35-317 | 282 | 300 | NA | | | | Basin-fill |
| HARN 051548 | 27 | 475 | | | 50 | 20 | 2.5 | | | |

| Well Number | Static Water Level (feet) | Well Depth (feet) | Production Zone Interval (feet) | Production Zone Thickness (feet) | Pumping Rate (gpm) | Drawdown1 (feet) | Specific Capacity2 (gpm/foot) | Transmissivity3 Estimated (gal/day/foot) | Hydraulic Conductivity4 Estimated (gal/day/feet2) | Hydrogeoligic Unit - Production Zone |
|---|---|---|---|---|---|---|---|---|---|---|
| HARN 051569 | 60 | 400 | | | 75 | NA | | | | Harney Formation |
| HARN 051571 | 29.5 | 300 | | | 1000 | NA | | | | |
| HARN 051577 | 30.5 | 600 | | | 1000 | NA | | | | |
| HARN 051582 | 63 | 600 | | | 125 | 177 | 0.7 | | | |
| HARN 051615 | 192 | 405 | 265-390 | 125 | 15 | NA | | | | Harney Formation |
| HARN 051629 | 48 | 165 | 160-165 | 5 | 825 | 50 | 16.5 | | | Drinkwater Basalt |
| MALH 002323 | 32 | 400 | | | NA | NA | | | | |

NOTES:

1. Drawdown is the depth to the pumping water level minus the static water level. Expressed as feet.
2. Specific capacity is the rate of pumping divided by the drawdown. Expressed as gallons per foot.

3. Transmissivity is a unit volume of water flowing through the unit thickness of the aquifer in a unit time. Expressed as gallons per day per foot. Calculation based on Driscoll, 1986.

4. Hydraulic conductivity is a unit volume of water flowing through a unit cross-sectional area of the aquifer in a unit time. Expressed as gallons per day per square foot.

5. NA, not available.

# Appendix D. State Observation Hydrographs

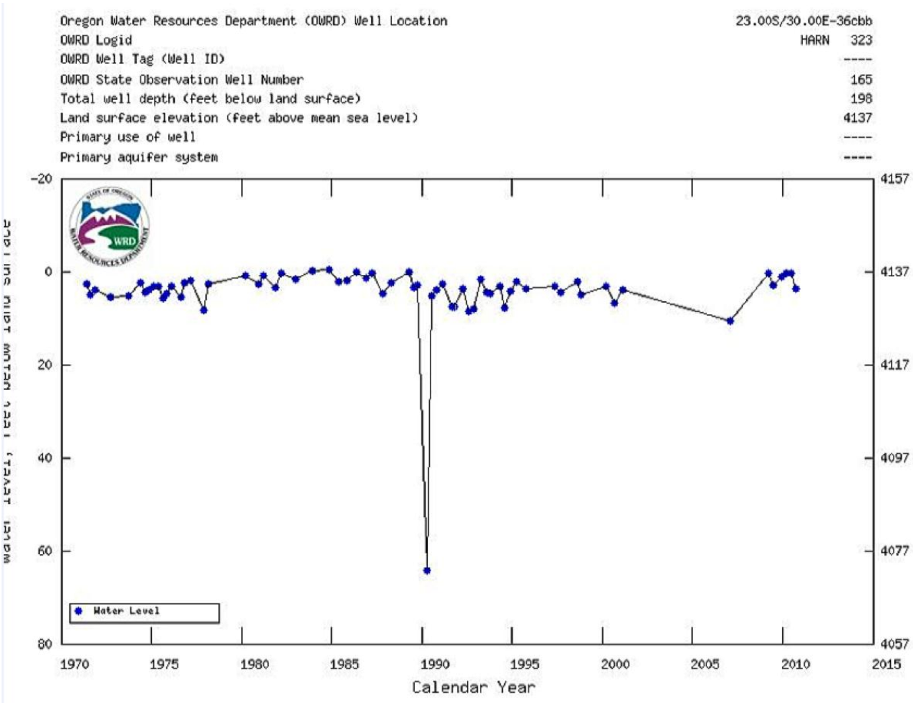


*Figure D-1. Well HARN000323 Hydrograph*

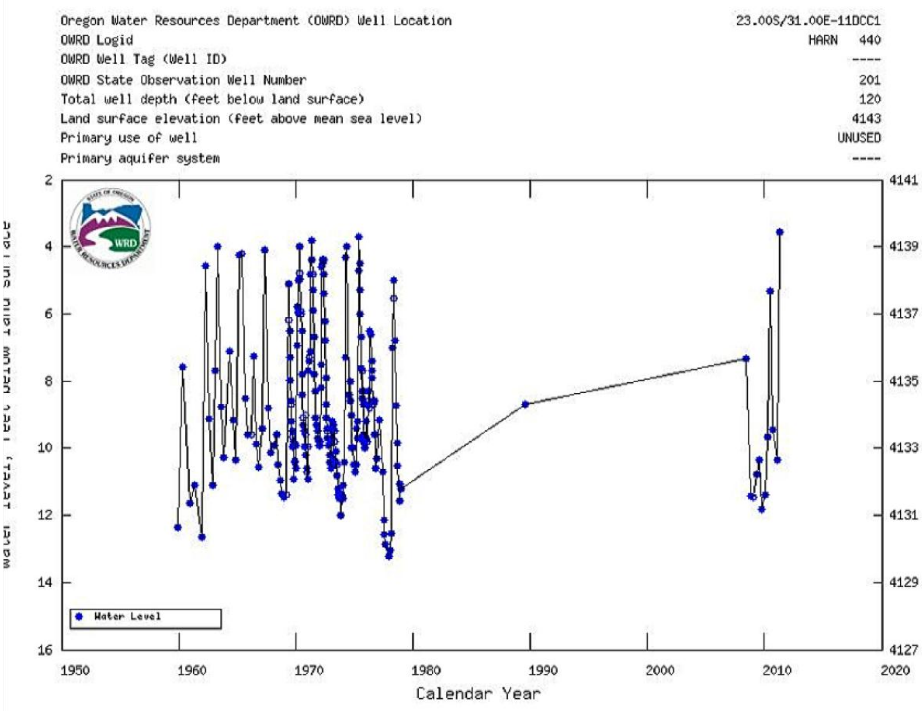


*Figure D-2. Well HARN000440 Hydrograph*

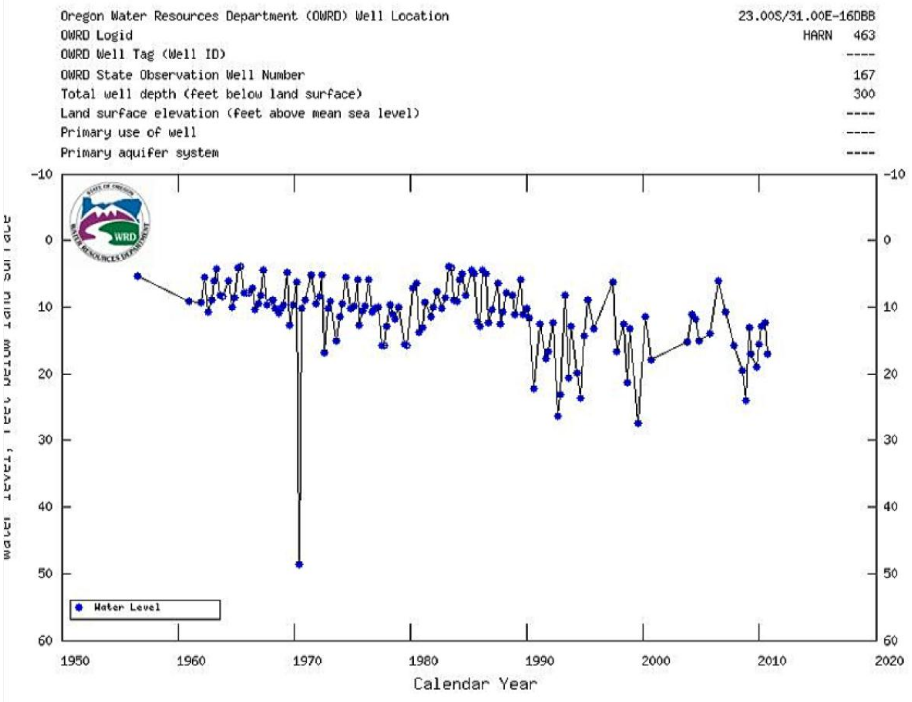


*Figure D-3. Well HARN000463 Hydrograph*

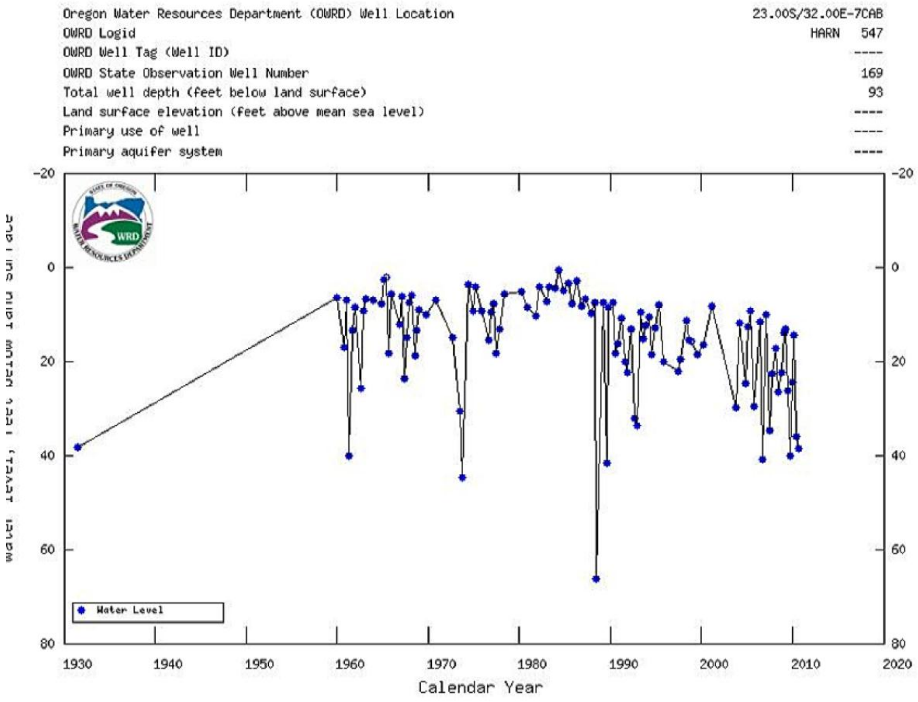
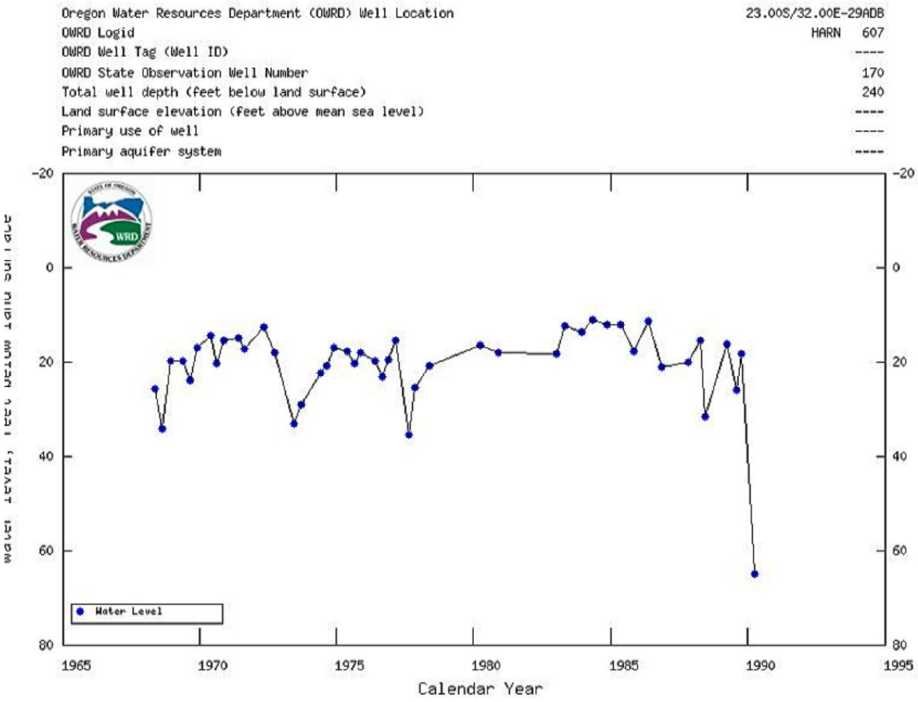
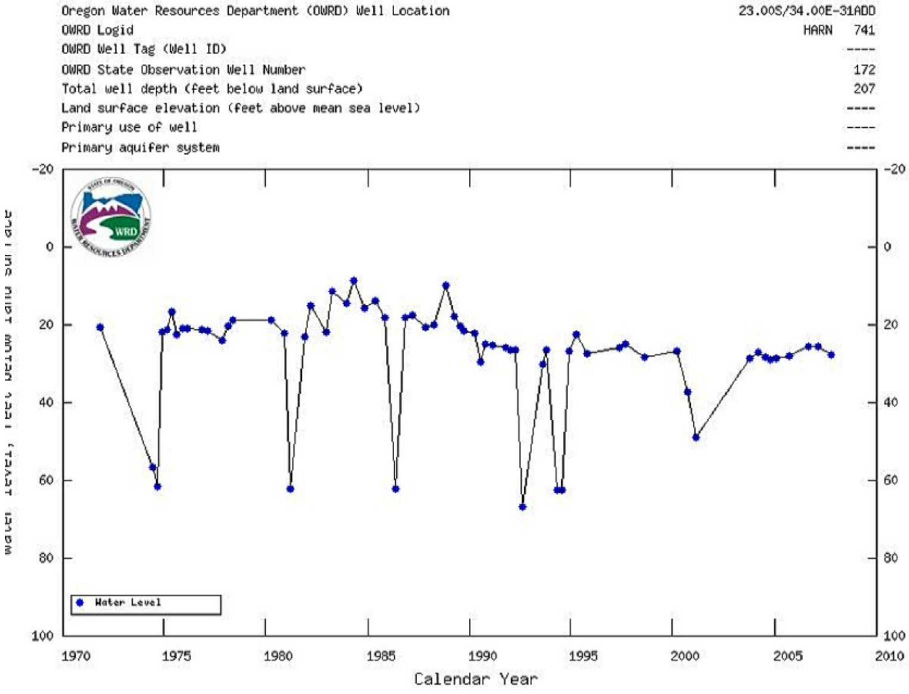


*Figure D-4. Well HARN000547 Hydrograph*



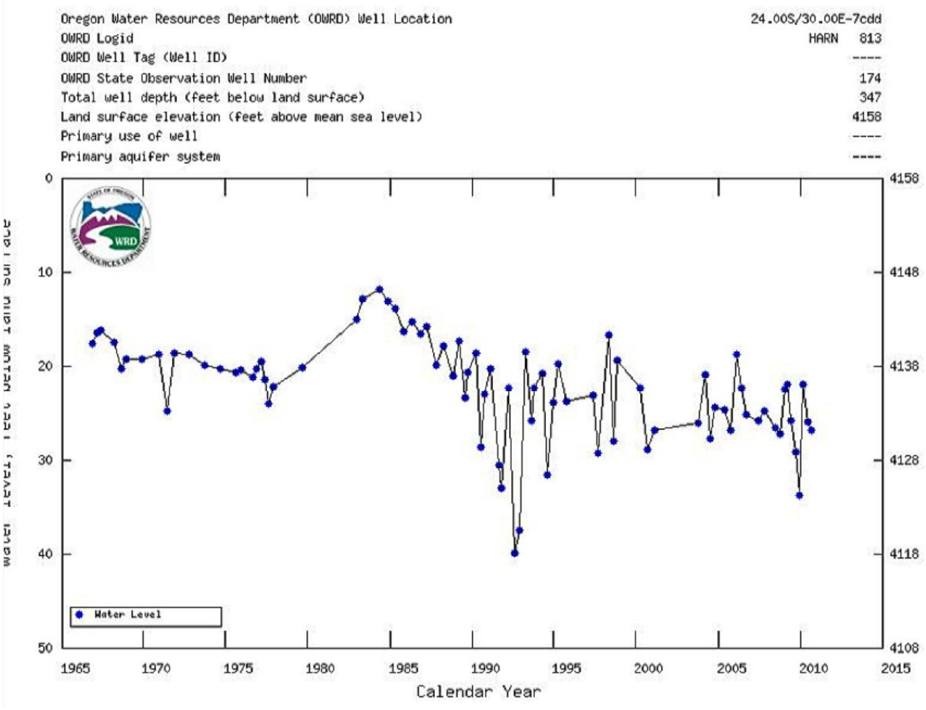
| | |
|---|---|
| Oregon Water Resources Department (OWRD) Well Location | 23.00S/32.00E-29ADB |
| OWRD Logid | HARN 607 |
| OWRD Well Tag (Well ID) | ---- |
| OWRD State Observation Well Number | 170 |
| Total well depth (feet below land surface) | 240 |
| Land surface elevation (feet above mean sea level) | ---- |
| Primary use of well | ---- |
| Primary aquifer system | ---- |

*Figure D-5. Well HARN000607 Hydrograph*



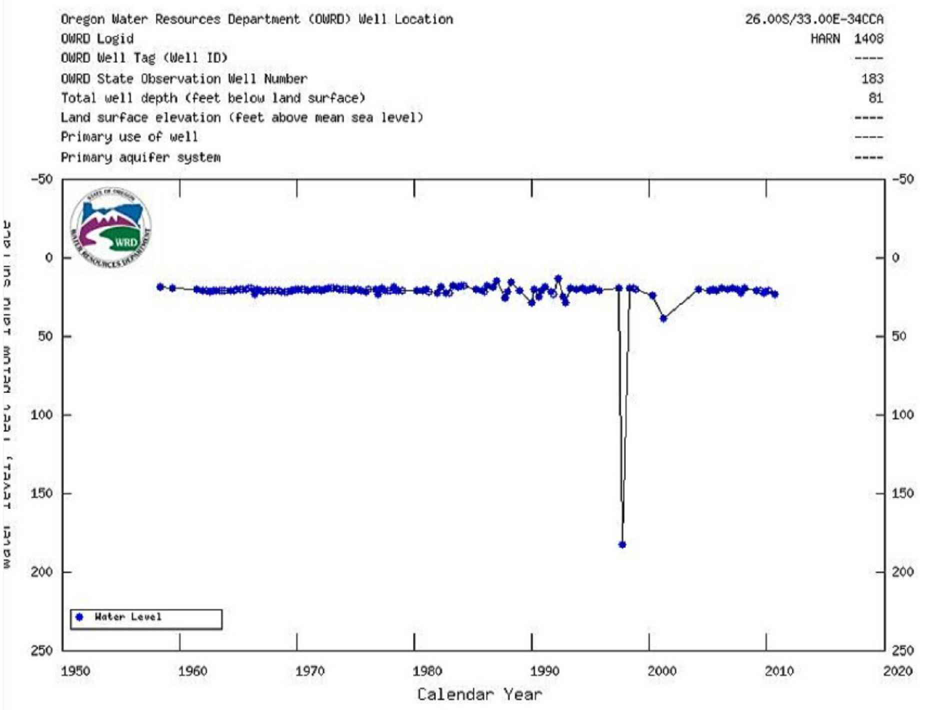
| | |
|---|---|
| Oregon Water Resources Department (OWRD) Well Location | 23.00S/34.00E-31ADD |
| OWRD Logid | HARN 741 |
| OWRD Well Tag (Well ID) | ---- |
| OWRD State Observation Well Number | 172 |
| Total well depth (feet below land surface) | 207 |
| Land surface elevation (feet above mean sea level) | ---- |
| Primary use of well | ---- |
| Primary aquifer system | ---- |

*Figure D-6. Well HARN000741 Hydrograph*



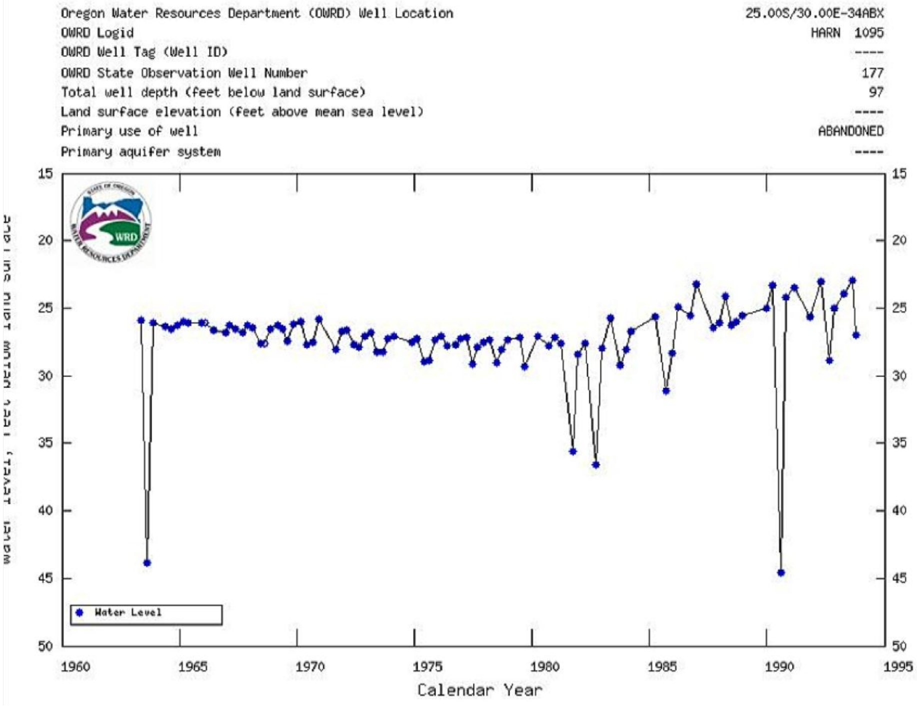
| | |
|---|---|
| Oregon Water Resources Department (OWRD) Well Location | 24.00S/30.00E-7cdd |
| OWRD Logid | HARN 813 |
| OWRD Well Tag (Well ID) | ---- |
| OWRD State Observation Well Number | 174 |
| Total well depth (feet below land surface) | 347 |
| Land surface elevation (feet above mean sea level) | 4158 |
| Primary use of well | ---- |
| Primary aquifer system | ---- |

*Figure D-7. Well HARN000813 Hydrograph*



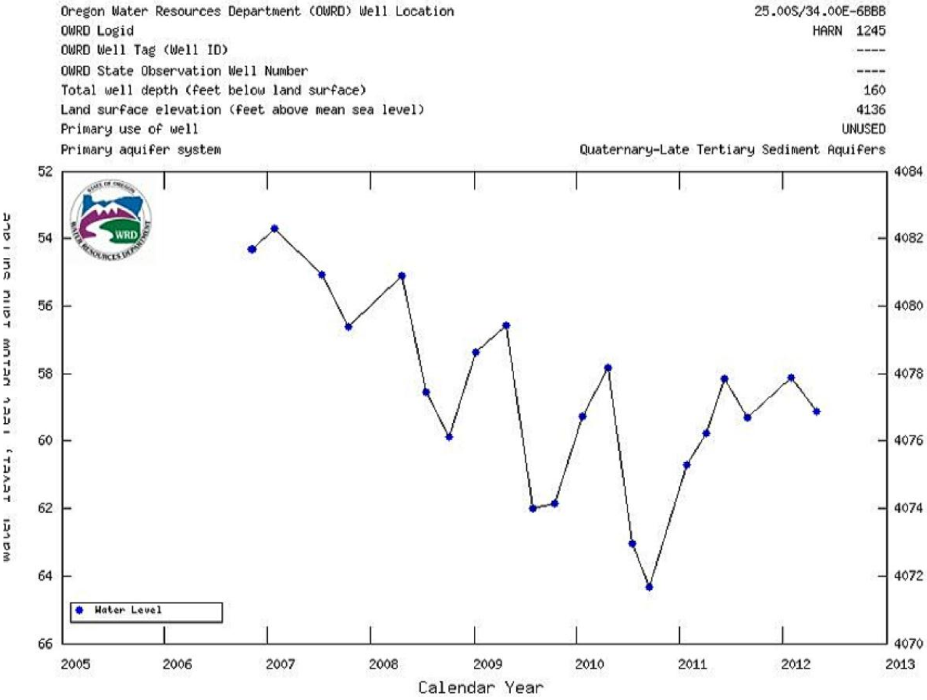
| | |
|---|---|
| Oregon Water Resources Department (OWRD) Well Location | 26.00S/33.00E-34CCA |
| OWRD Logid | HARN 1408 |
| OWRD Well Tag (Well ID) | ---- |
| OWRD State Observation Well Number | 183 |
| Total well depth (feet below land surface) | 81 |
| Land surface elevation (feet above mean sea level) | ---- |
| Primary use of well | ---- |
| Primary aquifer system | ---- |

*Figure D-8. Well HARN001408 Hydrograph*



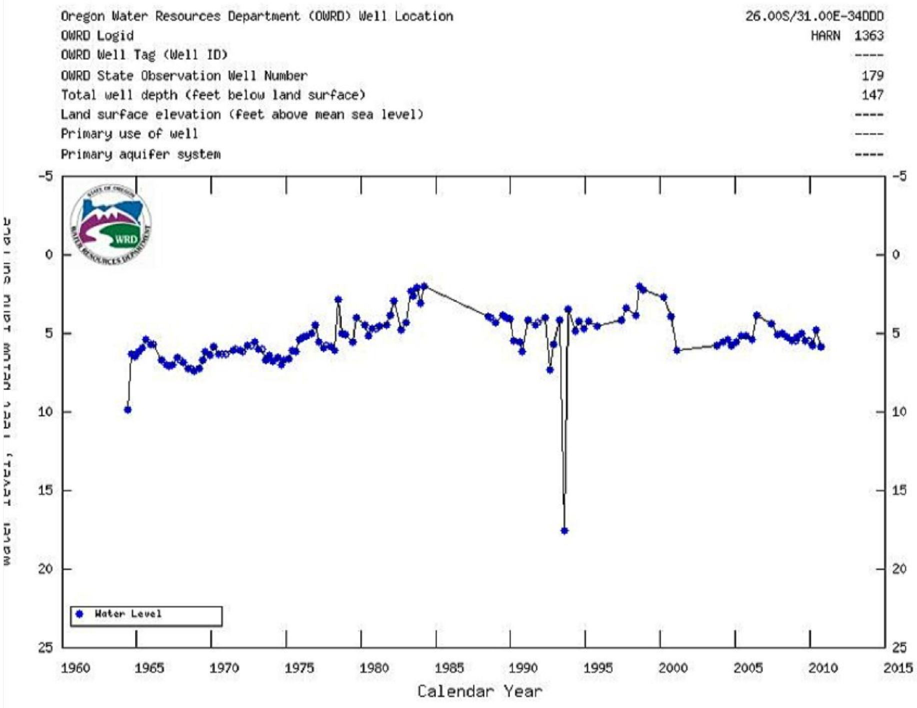
| | |
|---|---|
| Oregon Water Resources Department (OWRD) Well Location | 25.00S/30.00E-34ABX |
| OWRD Logid | HARN 1095 |
| OWRD Well Tag (Well ID) | ---- |
| OWRD State Observation Well Number | 177 |
| Total well depth (feet below land surface) | 97 |
| Land surface elevation (feet above mean sea level) | ---- |
| Primary use of well | ABANDONED |
| Primary aquifer system | ---- |

*Figure D-9. Well HARN001095 Hydrograph*



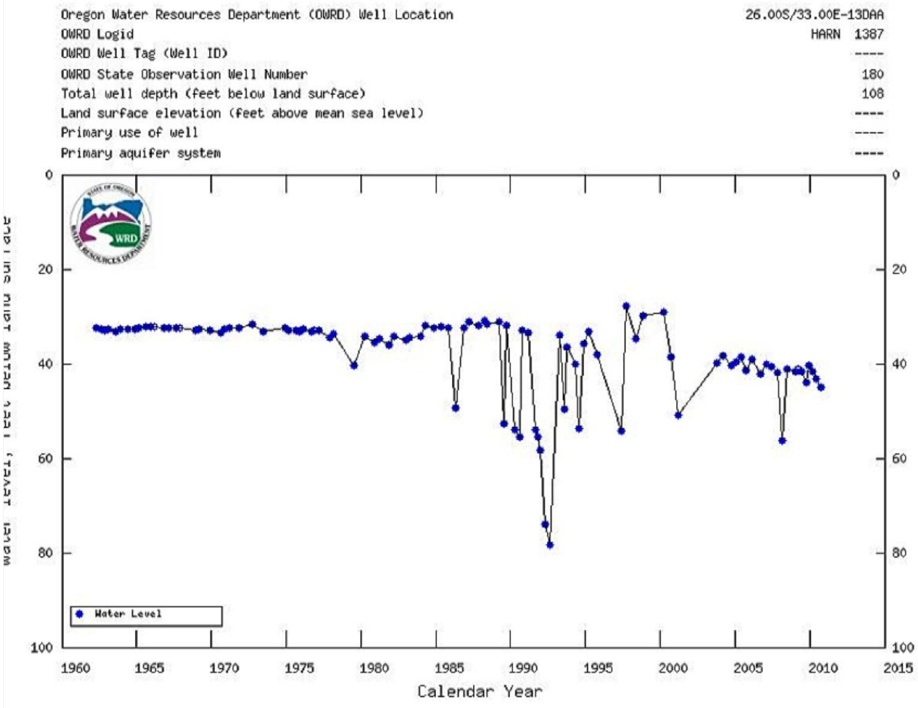
| | |
|---|---|
| Oregon Water Resources Department (OWRD) Well Location | 25.00S/34.00E-6BBB |
| OWRD Logid | HARN 1245 |
| OWRD Well Tag (Well ID) | ---- |
| OWRD State Observation Well Number | ---- |
| Total well depth (feet below land surface) | 160 |
| Land surface elevation (feet above mean sea level) | 4136 |
| Primary use of well | UNUSED |
| Primary aquifer system | Quaternary-Late Tertiary Sediment Aquifers |

*Figure D-10. Well HARN001245 Hydrograph*



| | |
|---|---|
| Oregon Water Resources Department (OWRD) Well Location | 26.00S/31.00E-34DDD |
| OWRD Logid | HARN 1363 |
| OWRD Well Tag (Well ID) | ---- |
| OWRD State Observation Well Number | 179 |
| Total well depth (feet below land surface) | 147 |
| Land surface elevation (feet above mean sea level) | ---- |
| Primary use of well | ---- |
| Primary aquifer system | ---- |

*Figure D-11. Well HARN001363 Hydrograph*



| | |
|---|---|
| Oregon Water Resources Department (OWRD) Well Location | 26.00S/33.00E-13DAA |
| OWRD Logid | HARN 1387 |
| OWRD Well Tag (Well ID) | ---- |
| OWRD State Observation Well Number | 180 |
| Total well depth (feet below land surface) | 108 |
| Land surface elevation (feet above mean sea level) | ---- |
| Primary use of well | ---- |
| Primary aquifer system | ---- |

*Figure D-12. Well HARN001387 Hydrograph*

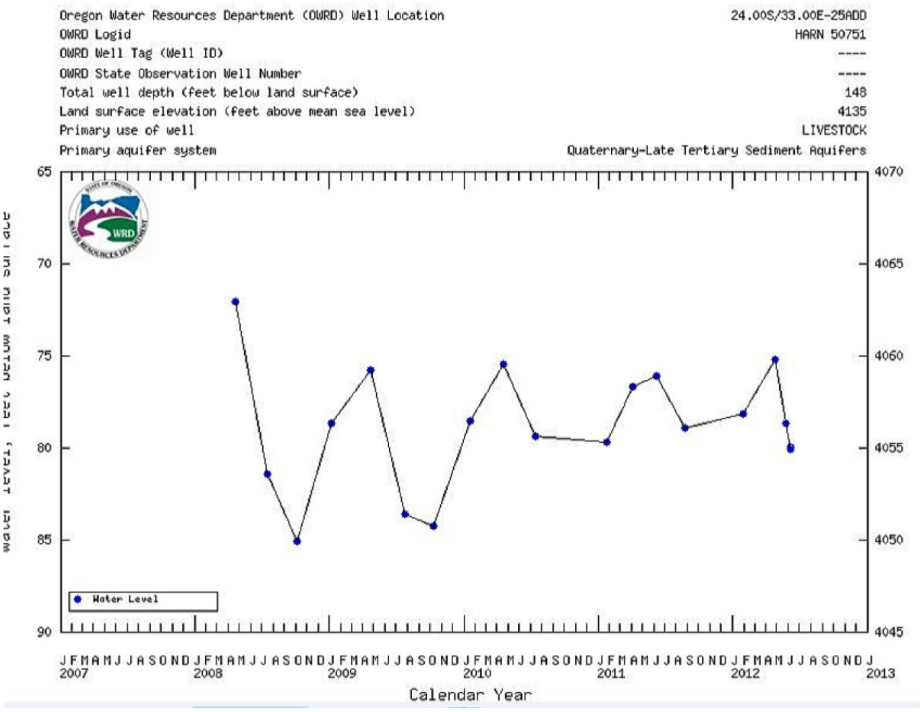


*Figure D-13. Well HARN050751 Hydrograph*

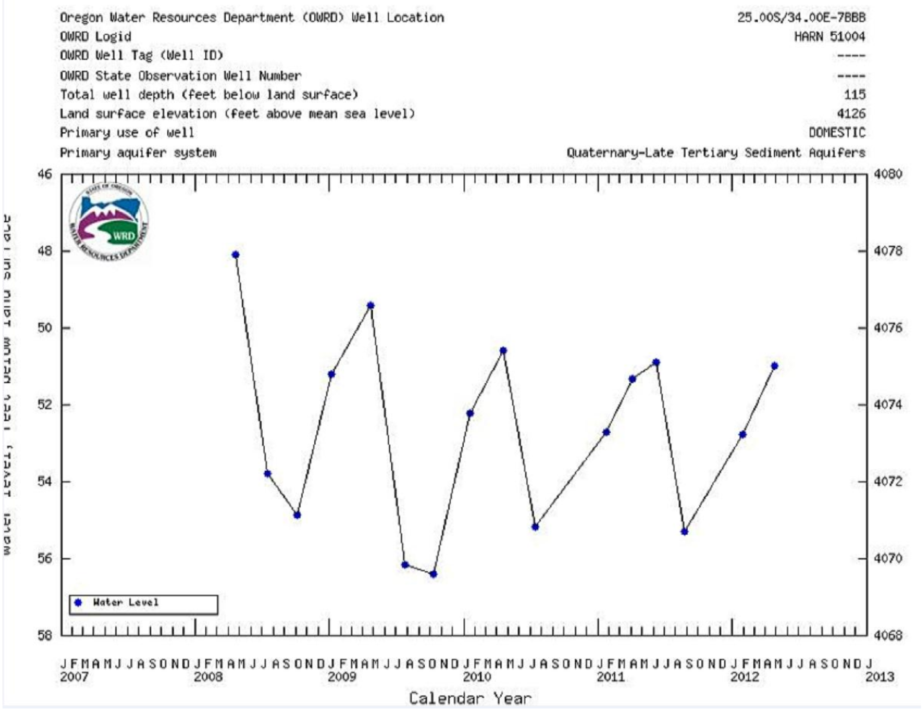


*Figure D-14.Well HARN051004 Hydrograph*

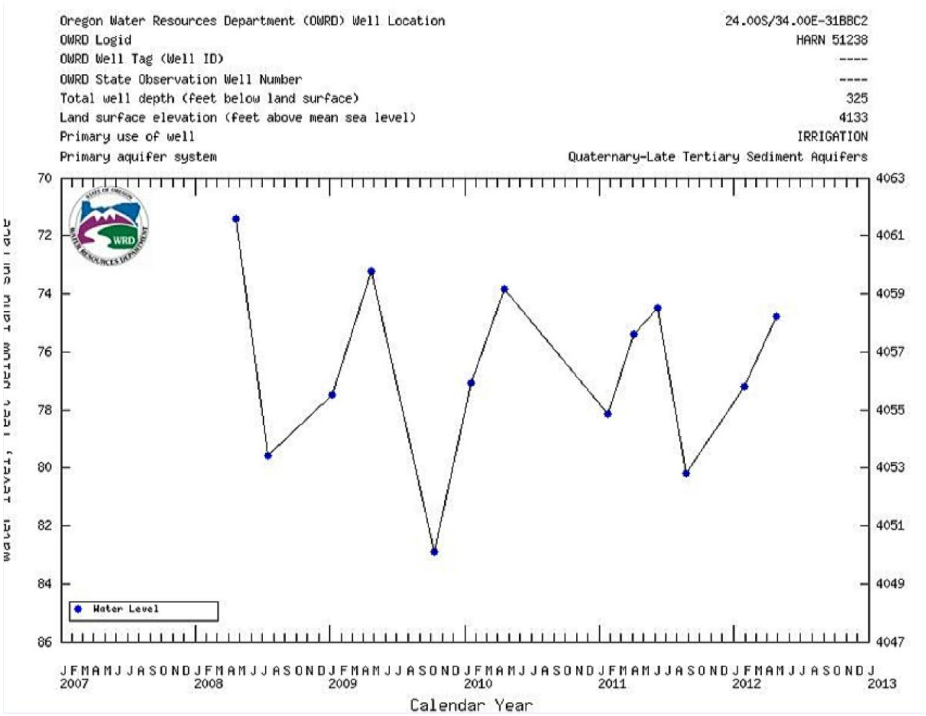


*Figure D-15. Well HARN051238 Hydrograph*