Oregon
Kate Brown, Governor

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MEMORANDUM

DATE: January 6, 2017
FOR: Public Distribution
FROM: Justin Iverson / OWRD Groundwater Section Manager
SUBJECT: Cooperative USGS/OWRD Harney Basin Groundwater Study Scope of Work

Introduction

The Oregon Water Resources Department (Department) has partnered with the United States Geological Survey (USGS) to conduct a cooperative water resource investigation of the Harney Basin groundwater system (the "study"). The study will address several needs identified in the Malheur Lake Basin Program Rules, OAR 690-512-0020, by collecting, evaluating, and synthesizing substantial data on the groundwater flow system(s) in the basin, including the Greater Harney Valley Area (denoted GHVGAC in the Basin Program Rules). The Department is committed to coordinating with the Harney Basin Groundwater Study Advisory Committee (SAC) to plan and conduct the study.

An improved understanding of the groundwater hydrology of the Harney Basin is needed to provide stakeholders and water resource managers with information to make informed decisions about how to sustainably manage groundwater resources. The study is intended to provide information to address four primary objectives identified by the Department:

- Define the effect of historical and current groundwater use on groundwater and surface water resources of the Harney Basin.

- Assess the effect of future groundwater use on water resources of the Harney Basin.

- Assess the past and potential future effects of climate on the groundwater system.

- Assess how existing and potential future groundwater uses may be managed to best meet demand while ensuring that groundwater in the Harney Basin is appropriated within the capacity of the resource.

Work Plan

Attached is "A Proposed Plan of Study for Investigation of the Groundwater System of the Harney Basin, Oregon" (work plan), prepared by hydrologists at the USGS Oregon Water Science Center with input from the Department and the SAC. The study is broken into two phases:

- Phase I will develop a quantitative conceptual understanding of the groundwater-flow system(s) of the Harney Basin, referred to as a "conceptual model".

- Phase II will develop a computer simulation model to test the conceptualization of the groundwater-flow system(s) and simulate its response to current conditions and proposed groundwater use, referred to as a "numerical model".

Each phase of the study will culminate in a scientifically peer-reviewed report in the format of a USGS Scientific Investigation Report (SIR). The recently completed Klamath Basin groundwater cooperative study provides an example of the content and format of USGS SIR reports documenting basin-wide conceptual and numerical models. Hard copies of these reports are available for review at the local Watermaster's office and the Watershed Council office. In addition, electronic copies of these reports are available online:

- Groundwater Hydrology Report (conceptual model) https://pubs.er.usgs.gov/publication/sir20075050

- Groundwater Simulation and Management Model Report (numerical model) https://pubs.er.usgs.gov/publication/sir20125062

The work plan includes a work breakdown structure table that identifies agency leads responsible for each component of the plan and a schedule for substantial completion of each component. While specific agencies are tasked with the responsibility of ensuring each component is completed, staff from both agencies will work collaboratively on these components. Phase I work is currently planned for completion in 2019 and will constitute the study described in OAR 690-512-0020(10). Phase II work is expected to be completed in 2022.

Stakeholder Coordination

The work plan presents a general framework of study components and leaves room for the scientific means and methods and the geographical focus areas of the study to evolve as data is collected and analyzed. Department and USGS staff will coordinate with the SAC during quarterly meetings to present recently-collected data and discuss investigation activities planned for future implementation. These quarterly meetings are open to the public and are announced via press releases, the project website, and a project email listserv.

In addition, the Department will work with the SAC to develop a quality assurance process to guide collection of water level data by stakeholders in the basin. The study team will review and consider relevant data provided by or through the SAC for use in the study.

		FY 16		FY 17				FY 18				FY 19				FY 20				FY 21				FY 22			
		Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Project management	Both																										
Team meetings (USGS, OWRD)	Both																										
Stakeholder meetings (Technical advisory committee, public meetings)	Both																										
Phase 1																											
Literature review	USGS																										
Geologic framework																											
Development of working surficial geologic map (compile maps, additional mapping)	OWRD																										
Develop subsurface stratigraphy database (Well logs inventory, lith coding, geophysics)	OWRD																										
Define hydrostratigraphic units (lump geologic map units)	Both																										
Create maps of hydrostratigraphic units (extent and thickness)	USGS																										
Field trip to discuss geology	Both																										
Drilling																											
Determine drilling-program objectives	Both																										
Identify well sites	Both																										
Conduct drilling operations	OWRD																										
Logging and analysis	OWRD																										
Well testing	OWRD																										
Hydrologic Data Collection and Flow-System Evaluation																											
Compile existing water-level data	OWRD																										
Field inventory wells	OWRD																										
Monitor well network and archive groundwater levels	OWRD																										
Enter data into NWIS	USGS																										
Develop water-level visualization tool	USGS																										
Evaluate and interpret water-level data	Both																										
Determine GW flow direction (horizontal, vertical)	OWRD																										
Determine GW trends (response to pumping and climate)	OWRD																										
Determine data gaps	Both																										
Evaluate role of structure in hydrology	OWRD																										
Evaluate possible groundwater subbasins	OWRD																										
Estimate hydrogeologic unit properties (K&S)	OWRD																										
Evaluate existing aquifer tests (long-term, single-well, specific capacity)	OWRD																										

USGS Lead
OWRD Lead
Joint Effort

Conduct and evaluate potential new aquifer tests	OWRD
Apply/evaluate geochemistry and age dating	USGS
Evaluate chemical tracer data: isotopes, age dating, major ions, temperature	USGS
Collect new chemical tracer data-reconnaissance	USGS
Hydrologic Budget	
Estimate GW discharge to wells (transient)	OWRD
Estimate GW use	OWRD
Link GW use to wells	OWRD
Link wells to hydrogeologic units	Both
Assign water use to wells	OWRD
Determine period of use	OWRD
Estimate GW discharge to streams	USGS
Seepage runs	Both
Hydrograph analysis	USGS
Evaluate alternate potential methods of estimating discharge to streams	Both
Estimate GW discharge to springs, lakes, wetlands	USGS
Compile existing data	USGS
Collect new measurements	Both
Estimate ET loss	USGS
Recharge (transient)	USGS
Review literature	USGS
Determine appropriate approach (SWB,PRMS, mass-balance, water-level response)	USGS
Implement recharge analysis	USGS
From precipitation	USGS
From irrigation	USGS
From surface water (streams, canals)	USGS
Determine mountain front recharge component	USGS
Evaluate possible interbasin flow	USGS
Write report to synthesize understanding of groundwater-flow system	**Both**

Phase 2	
Modeling	
Develop numerical GW-flow modeling approach	USGS
Determine model area	Both
Determine discretization (areal)	Both
Determine model units (vertical)	Both
Determine parameterization (K, S, stream conductance)	USGS
Implement boundary conditions	USGS
Specified flux	USGS
Recharge	USGS
Pumping	USGS
ET	USGS
Streams/lakes/drains	USGS
Model calibration	USGS
Build observation files	USGS
Sensitivities and weights	USGS
Fit to heads and streamflow	USGS
Run example simulations	Both
Write modeling and management report	Both

Last revised: December 2016

A Proposed Plan of Study for Investigation of the Groundwater System of the Harney Basin, Oregon

A Cooperative Water-Resources Investigation by the

U.S. Geological Survey
Oregon Water Science Center
Portland, Oregon
and
Oregon Water Resources Department
Salem, Oregon

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Problem Statement and Need for Study

The demand for groundwater in the Harney Basin is increasing primarily because little unappropriated surface water is available during the irrigation season (Oregon State Water Resources Board, 1967) and improvements in pump and drilling technology and the relatively recent availability of grid power has made groundwater-irrigated agriculture economical. Water uses include domestic, irrigated agriculture, livestock, and fish and wildlife needs.

The Oregon Water Resources Department (OWRD) has recognized this increasing demand and described it well in their draft work plan (Oregon Water Resources Department, 2015) as follows:

Harney County has experienced significant groundwater development over the years with most occurring in the "Greater Harney Valley Area." Irrigation is the largest permitted groundwater use. The most rapid development in the county occurred in the 1970's and after 2000. Over 610 groundwater permits for primary irrigation alone have been issued. Analysis of mapped places of use indicates there is an estimated 95,821 permitted acres of primary and supplemental irrigation groundwater rights in the entire Harney Basin with only 138 permitted acres outside the "Greater Harney Valley Area." That equates to more than 287,000 acre-feet of maximum allowable annual groundwater use …. An additional analysis of the mapped places of use compared to satellite imagery indicates approximately 30 percent of the permitted groundwater irrigation acres have not been developed.

OWRD also described declines in the Basin Study Program Rules and the need to ensure that groundwater uses are within the capacity of the resource (OAR 690-512-0020):

The Greater Harney Valley Groundwater Area of Concern (GHVGAC) is established to ensure that groundwater in the GHVGAC is appropriated within the capacity of the resource and that new appropriations of groundwater assure the maintenance of reasonably stable groundwater levels and prevent depletion of the groundwater resource. Current data, comprising substantial evidence, indicate that groundwater levels are declining in areas of the GHVGAC. Additional allocation of groundwater within the GHVGAC may exacerbate these declines. A comparison between estimated annual recharge and previously allocated groundwater volumes indicates that groundwater is fully allocated in some areas of the basin.

The groundwater-flow system(s) in the Harney Basin is poorly understood, and the ability of the resource to sustain existing uses and to accommodate additional uses is not well known. In addition, substantial uncertainty exists regarding the extent to which groundwater uses will impact surface-water resources and holders of senior surface-water rights throughout the basin. An improved understanding of the groundwater hydrology of the area is needed to provide stakeholders and water resource managers with information to make informed groundwater-resource decisions.

A thorough study to characterize and quantify the groundwater-flow system(s) in the basin is needed to address gaps in our present understanding. Such a study should include determining the rates and distribution of groundwater recharge and discharge throughout the region, characterizing the geologic controls on groundwater flow, and identifying major hydrogeologic units. The study should include the development of a numerical groundwater-flow model to assess the conceptualization of the flow system(s) and to provide a tool to for estimating effects of proposed development scenarios on groundwater levels and surface water depletion in the basin.

Background

Location of study area

The Harney Basin encompasses about 5,240 square miles in southeast Oregon (fig. 1). The basin covers most of Harney County and includes small parts of Grant, Lake and Crook Counties. The basin represents the surface-water drainage area of the Malheur and Harney Lakes which are fed by the watersheds of Silver Creek, Silvies River and Donner und Blitzen River. The smaller Greater Harney Valley Area (GHVA) is defined informally and unofficially by the Oregon Water Resources Department (OWRD) as the area that includes Harney Valley, adjoining valleys, and lower-elevation flanks of uplands facing those valleys (Oregon Water Resources Department, 2015). They delineated this 2,440 square mile area by selecting the 6th-level Hydrologic Units from the USGS Watershed Boundary Dataset that are within the above-referenced boundaries.

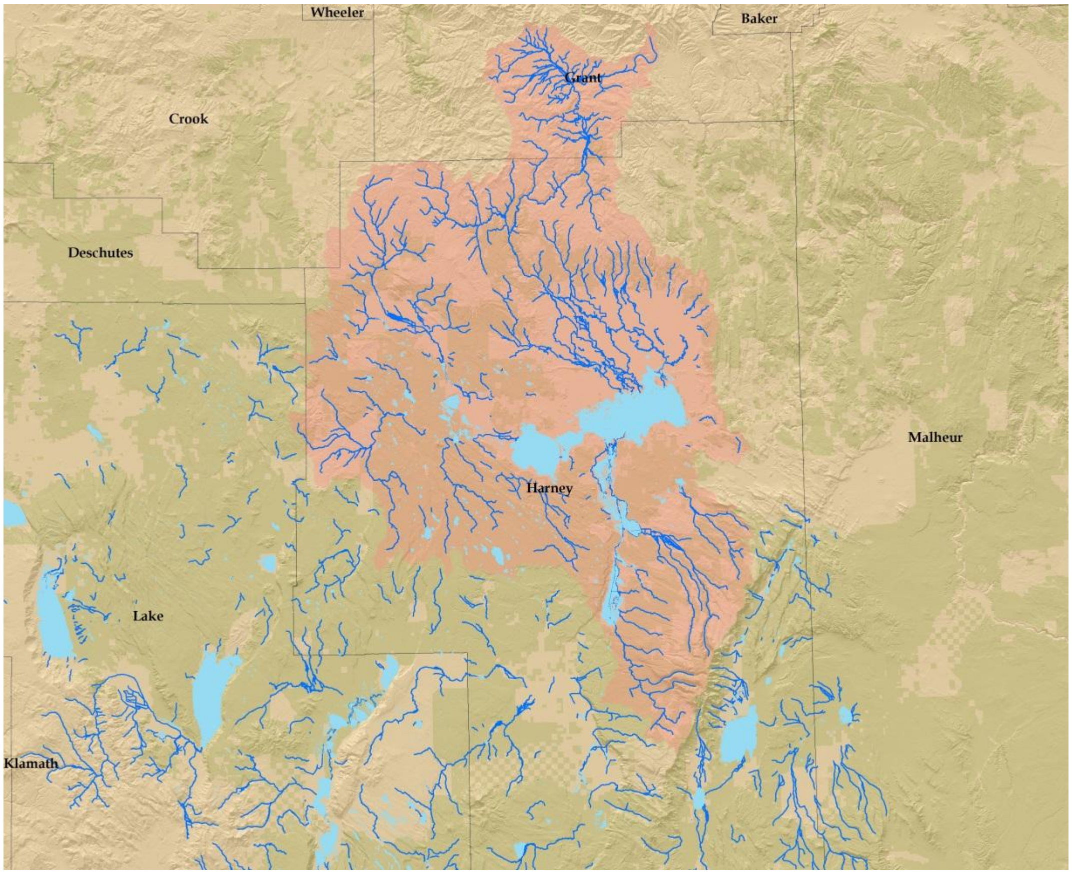

Figure 1. Harney Basin, Oregon

Geography and climate

The Harney Basin covers a relatively high plateau with valley elevations above 4,000 feet, benchland elevations around 4,500 feet, and adjacent mountains up to 9,670 feet (Oregon State Water Resources Board, 1967). Harney Basin and adjacent uplands to the east, north, and northwest constitute part of a closed basin draining into the playa of Malheur Lake. The basin is in the High Lava Plains, a middle and late Cenozoic volcanic upland, contiguous with and gradational into the Basin and Range province to the south (Meigs and others, 2009).

Previous studies (Russell, 1903; 1905; Waring, 1908; 1909; Piper and others, 1939; Leonard, 1970) indicate the Harney Basin is a predominantly volcanic terrain with lowland basin-fill fluvial-lacustrine deposits, and the basin's landform is largely a result of fault-block structures and erosion. The volcanic deposits include various lava flows, pyroclastic rocks, and volcanicderived sediments. The chemical composition, depositional environment, lateral extent, and thickness of the volcanic deposits vary. The source, depositional environment, grain size, and thickness of the basin-fill sediments vary also.

The Harney Basin climate is characterized by short, mild summers and long, cold winters with a wide range of daily and seasonal temperatures. Annual basin precipitation amounts range from about 11 inches in the valleys to 20 inches on the Steens Mountain uplands. Most of the precipitation occurs from November through June.

Hydrogeology

The Harney Basin lies in a transitional zone between the High Lava Plains and the Basin and Range Province and, as a result, the geology is complex. Geologic mapping exists for much of the study area at 1:250,000 scale (Greene and others, 1972) with subareas mapped at 1:24,000 scale (Walker and Swanson, 1968; Johnson, 1994; 1996). The geology of the basin is one of the important factors controlling the occurrence and movement of groundwater.

The basin is mostly covered with Quaternary sediments and seasonal lakes with basalt flows, tuffs, volcanic ash, and volcanic centers. Recent geophysical studies indicate the presence of at least two buried calderas beneath the basin (Khatiwada and Keller, 2015)

Piper and others (1939) and Leonard (1970) described the basin's primary hydrogeologic units as: 1) shallow unconfined aquifers in the valley fill, 2) confined aquifers in the deeper alluvium, and 3) confined aquifers in the underlying Tertiary volcanic and sedimentary rocks. Harney Valley and the surrounding water-contributing uplands are considered a closed hydrologic system. Inflow to the system is mainly from precipitation; outflow, or discharge, is by evapotranspiration. Because the uplands around the valley contain undrained depressions and commonly are underlain by highly permeable volcanic rocks, the outer margins of the groundwater basins are not sharply defined (Leonard, 1970).

The regional movement of groundwater is generally toward the valley from uplands on the northwest, north and east, and within the valley toward Malheur Lake. This pattern of movement is consistent with interpretations of the geology of the valley area and with the interpretation that the uplands are areas of recharge and the playa area near Malheur Lake is an area of discharge. The recharge areas in the mountains north, west, and east of Harney Valley provide one of the essential features for an artesian system (Leonard, 1970). The many beds of clay, tuff, and fine sediments sandwiched between water-bearing beds in the bedrock and valley fill serve as confining layers. If most of the hydraulic head in the confined aquifers were not dissipated as the water moves through the beds, artesian wells would occur throughout most of the valley. According to Leonard (1970), two extensive areas of flowing wells were near Hines and along the eastern edge of the valley; elsewhere in the valley, flowing wells were scattered widely. Much of the flowing water is thermal with temperatures up to 80°C reported in earlier investigations (Piper and others, 1939; Leonard, 1970). Currently, information is not available as to the amount or location of flowing wells that may still be present in the study area.

Water levels in wells fluctuate seasonally, being highest in early spring and lowest in late summer and autumn. During wet seasons, water levels rise largely in response to additions of water to storage, and water levels decline owing to the movement and withdrawal of water by natural discharge and by pumping during summer. The deeper, confined-water wells show fluctuation patterns similar to those of the shallow wells, but commonly the fluctuations are greater (Leonard, 1970).

A geothermal system within the basin is indicated by the occurrence of warm water wells in the Hines area and hot water wells along the north edge of Harney Valley (Leonard, 1970). The hot water wells tap deep confined sand and gravel aquifers in the Tertiary sedimentary deposits. The high temperature (up to 80°C) of water from these wells may result from deep circulation along a concealed fault zone. The unusually high concentrations of boron and arsenic in the water from one well also supports the idea that the water may be circulating deep enough to encounter a magmatic heat source. The relation of the thermal groundwater system to the shallow non-thermal system is not well understood.

Water Resources Issues

An increasing demand for a limited supply of water has been observed in the Harney Basin. The increasing demand is due not only to the economic growth of the region, but to the growing recognition of the need for water for wildlife and other habitat uses.

An analysis of mapped places of use by Oregon Water Resources Department (2015) indicates an estimated 95,821 permitted acres of primary and supplemental irrigation groundwater rights in the entire Harney Basin with only 138 permitted acres outside the GHVA. That equates to more than 287,000 acre-feet of maximum allowable annual groundwater use calculated by multiplying the permitted acres by the typical permitted maximum allowable annual volume of three acre-feet per acre per year. An additional analysis of the mapped places of use compared to satellite imagery indicates approximately 30 percent of the permitted groundwater irrigation acres have not been developed.

In recent years, OWRD Groundwater staff has identified groundwater-level declines in the GHVA (Oregon Water Resources Department, 2015). Persistent declines indicating likely groundwater over-appropriation were identified in the Crane-Buchanan and Weaver Springs areas, which led the Department to cease issuing groundwater permits in those areas. Subsequent data analysis by OWRD Groundwater staff indicated declining groundwater levels are occurring over a broad portion of the Greater Harney Valley Area with some exceptions.

Additionally, OWRD Groundwater staff compared the Harney Basin groundwater budget to permitted groundwater rights in the GHVA using currently available data (Oregon Water Resources Department, 2015). The results indicated the total annual groundwater volume permitted for irrigation for the GHVA alone exceeds the total estimated groundwater recharge for the entire Harney Basin. This further indicates the groundwater resource is likely over-appropriated, and the permitted groundwater usage is not sustainable. That puts the groundwater resource at risk, and it puts senior surface water rights and groundwater rights at risk of injury.

Objectives

The overall objectives for the proposed study are as follows:

Objective 1. Develop a quantitative conceptual understanding of the groundwater-flow system(s) of the Harney Basin.

A quantitative conceptual understanding encompasses estimation of the entire groundwater budget including the rates and distribution of recharge and discharge, evaluation of the geologic controls on groundwater flow and factors controlling the occurrence of groundwater, and the assessment of the interaction between groundwater and surface water. This objective will be addressed in Phase I of the study and provides the basis for other elements of the study and a framework for assessing groundwater development proposals.

Objective 2. Develop numerical hydrologic models to test the conceptualization of the groundwater-flow system(s) and simulate its response to current conditions and future groundwater use.

Properly calibrated numerical (computer) models provide a test of the conceptualization and quantification of the flow system(s). Models often reveal important gaps in data or problems in the understanding of the physics of a flow system(s). The model(s) will be developed in Phase II of the study and will enable assessment of the likely effects and sustainability of various groundwater development proposals.

Objective 3. Describe the groundwater-flow system(s) through reports and presentations to communicate the results of Objectives 1 and 2.

Development of a strategy for water-resources management in the Harney Basin and the proper development and use of the groundwater resource requires a common and accurate understanding of the hydrologic system. Technical and non-technical reports generated as part of this study along with presentations will promote such common understanding and communicate the results of the Phase I and Phase II work.

Specific objectives and products for each phase of the study are discussed in subsequent sections of the proposal.

General Approach

This study will be carried out as a cooperative effort between the ORWSC and the OWRD in two phases. Phase I activities include gathering and evaluating existing hydrologic data, collecting additional hydrologic data including exploratory well drilling, development of a conceptual model of the groundwater-flow system(s) including a detailed hydrologic budget, and, if warranted, construction of a preliminary model to test concepts. In phase II, a numerical groundwater-flow model will be constructed, calibrated, and used to simulate groundwater conditions under various management scenarios, and a long-term hydrologic monitoring program will be designed for the basin. The major tasks, agency responsible for performing each task, and estimated duration of each task are summarized in table 1.

Project Coordination

The magnitude and scope of this study make it essential that there be good coordination not only between the agencies involved in the work, but also other state and Federal agencies with land- or water-management or scientific roles in the basin, Tribal governments, local governments, and other stakeholders in the basin.

Project progress and plans as well as initial findings will be presented to cooperators and other stakeholders at quarterly meetings to be held in the basin. The meetings also will serve to facilitate communication between various agencies working in the basin. Basic data, such as stream discharge and groundwater levels, will be available to cooperators as soon as possible.

Basic geohydrologic data, GIS data files, models, and ancillary information developed during the study will be discussed in its preliminary form with project cooperators at quarterly meetings so that this information can be used in the management of Harney Basin resources as soon as it is feasible.

Phase I –Data Compilation and Evaluation, Data Collection and Stakeholder Involvement

Objectives

- Gather existing data and water-resource information, assess the data accuracy and reliability, and enter data into appropriate project databases.
- Construct a project webpage for information and data distribution
- Collect the data required to define the hydrogeologic system.
- Develop an improved conceptual model of the Harney Basin groundwater-flow system(s) to serve as the basis for a numerical groundwater-flow model.
- Develop a detailed water budget of the study area

Approach

A preliminary description of essential tasks required to define each component of the conceptual model of the basin is detailed below. The tasks comprise the work necessary to quantitatively define a surface water and groundwater system sufficiently to construct a numerical groundwater-flow model. An accurate and reliable understanding of the hydrologic system in the Harney Basin can only be developed from the analysis of accurate and reliable geohydrologic data. Results from data evaluations will indicate the value of existing data and guide how project resources will be allocated to collect new data to improve the understanding of the hydrogeologic system.

Before a numerical groundwater model can be constructed, a conceptual model of the flow system(s) (a working understanding of how the system operates) must be developed. The process of developing a conceptual model is analogous to assembling pieces of a puzzle to create a finished picture. The pieces of the puzzle include 1) the hydrogeologic framework of the groundwater system (the thickness, extent, and boundaries of the hydrogeologic units), 2) water budgets for the groundwater and surface-water systems (recharge and discharge), 3) hydraulic characteristics of hydrogeologic units (hydraulic conductivity and storage), and 4) flow-system definition (recharge/discharge areas, direction and rate of flow, and changes in conditions with time). Many of the "pieces" of the conceptual model will "fit" smoothly into the "picture". Unlike a picture puzzle, however some of the water-budget "pieces" may not be well defined during early phases of the investigation. Therefore, the conceptual model, or picture, may change as the understanding of how the system operates is improved by integrating new information.

Literature Review

Existing information related to wells, springs, stream and canal flow, climate, soils, water-use, and other geohydrologic data will be gathered with special attention given to assessing the accuracy and reliability of the information. Available information can be obtained from published reports, government agencies, public utilities, and other sources. Published reports contain information on wells used to assess geology, water levels, hydraulic properties, water use, and streamflow characteristics and include maps of geology, soils, land use, water tables, and other geohydrologic features. The OWRD maintains well information that can be used to help describe geology, water levels, hydraulic properties, and water use. All hydrogeologic data will be stored in digital format. Map data will be acquired and stored in GIS format whenever possible.

Geologic Framework

A key element of developing a conceptual model of the basin is defining the geologic framework and how it affects groundwater distribution and movement and the interactions between groundwater and surface water within the basin. Many sources of new and existing data will be used to interpret the regional geologic framework, including: existing literature, interviews with previous investigators, lithologic descriptions on water well reports, aerial photographs, drill cuttings submitted by well drillers, geophysical logging, and some field reconnaissance. The interpretations will be presented on a composite geologic map, geologic cross sections, and, where appropriate and feasible, contour maps of hydrogeologic units. Table 1 identifies the agency responsible for the main tasks to be performed. Some of the key efforts to develop the geologic framework are listed below:

- Delineate stratigraphy of sedimentary deposits
- Construct regional lithofacies maps
- Determine location and offset of major structures
- Assess effects of faults and other structures on groundwater movement
- Assess change in permeability with depth due to secondary mineralization
- Assess the relation between the thermal and non-thermal groundwater systems
- Analyze drill cuttings from water wells and OWRD test holes
- Geophysical logging of selected wells
- Construct regional cross sections
- Compile regional geologic map and develop consistent stratigraphic nomenclature
- Define and map regionally significant hydrogeologic units

Hydrogeologic units are regions within the subsurface which have relatively uniform hydraulic characteristics and which can be differentiated from adjacent units. Regionally significant units will be delineated using geologic maps and subsurface information. Subsurface information can come from water well reports, other well reports, available geologic logs, and available or possibly project-derived geophysical logs. Borehole geophysical logging can include natural-gamma, resistivity, temperature, flow-meter, downhole camera, and caliper logs.

Drilling

A program of exploratory well drilling will be carried out primarily by the OWRD with input from the USGS to refine the well locations to best meet the objectives of the basin study. New wells will be sited in areas where geologic and hydrologic information is most needed. OWRD will conduct all of the drilling operations, logging, and testing in the timeframe shown in table 1.

Hydrologic Data Collection and Flow-System Evaluation

This project will include compilation of existing water-level data as well as collection of new data from the OWRD well network, analysis of aquifer-test data representing different hydrogeologic units, and evaluation of geochemistry and age-dating techniques for understanding groundwater-flow paths. The OWRD will conduct most of the hydrologic data-collection activities including new aquifer-test data collection (table 1).

Field inventory of wells

Much of the data that will be used to define the geologic framework, estimate hydraulic properties, define SW/GW relationships, estimate groundwater pumpage, and quantify seasonal and long-term groundwater level changes, will be collected from existing water wells. Relatively few wells have been inventoried in the basin since the studies by Reed and others (1984a; 1984b) and Gonthier (1985). Additional wells may be field inventoried in order to provide the spatial coverage required for this study.

Some emphasis will be placed on choosing wells that will enhance the knowledge of vertical head gradients, the effects of structure on horizontal head gradients, and obtaining head data in areas where none is available. Assistance will be sought from other government agencies in securing information on wells that they have drilled, particularly those near streams or canals that can be used to evaluate SW/GW relationships. This assistance is essential to obtain accurate locations and elevations for these wells.

Locations will be determined using global positioning system receivers and will be accurate to within 50 feet. For most wells, land surface elevations will be determined from USGS 7.5-minute scale topographic maps and will be accurate to within half of the mapped contour interval (typically 10 feet). Where horizontal hydraulic head gradients are low or where wells are near surface-water bodies and small head differences must be resolved, land surface elevations may be determined using more precise methods as needed.

Water-level data collection

Existing water-level data will be compiled, along with any necessary field inventorying of wells, and all data deemed acceptable will be added to NWIS. The USGS will develop an on-line water-level visualization tool to provide a way for project team members and the public to access and better understand the hydrologic data available in the basin.

Aquifer-test data may come from existing reports, pump tests submitted to OWRD, well logs, and new aquifer tests conducted by OWRD. New aquifer tests will be conducted where data representing a geographic area and/or hydrogeologic unit is inadequate or missing.

Data analyses will include aquifer hydraulic properties (transmissivity or hydraulic conductivity, and storage coefficients), delayed yield, and boundary conditions. The analyses are needed to assess:

- the ability of different hydrogeologic units to transmit water;
- the existence of confined versus unconfined conditions;
- the presence of interconnections between different hydrogeologic units;
- the presence of recharge boundaries indicating groundwater/surface-water interaction; and
- the presence of no-flow boundaries which may relate to geologic structures or changing lithology.

OWRD will continue to monitor and expand their well network throughout the entire course of the study to collect longer term water-level records.

Geochemistry data collection

Geochemistry will be used in conjunction with water-level data to help delineate groundwater recharge and discharge areas and determine flow paths and residence times for groundwater. This information will be valuable in developing the conceptual model of the system and, ultimately, in calibrating the numerical groundwater model. The types of analyses that will be most useful from wells and springs would likely include temperature, major ions, environmental isotopes, and age dating. The USGS will lead the geochemical sampling effort.

Develop Hydrologic Budget

Groundwater and surface-water budgets will be estimated for the Harney Basin. Budgets must be developed for specific time periods (such as predevelopment and current) in order to quantify how changes in land- and water-use and climate in the basin have affected the hydrologic system. Water-budget components will be inputs for any future groundwater-flow model. The USGS will take the lead in developing the hydrologic budget for the study area (table 1).

Surface-Water Budget

The surface-water system includes the Donner und Blitzen River, Silvies River, Silver Creek, smaller tributaries to Malheur and Harney Lakes, Malheur Lake, Harney Lake, smaller ephemeral lakes, and irrigation canals. Water budgets will be developed for Malheur and Harney Lakes and selected reaches of streams and rivers in the basin. The primary purpose of developing water budgets for these surface water features is to independently estimate the exchange of water between them and the groundwater system. These estimates will be used to calibrate the groundwater model developed in the study. Gain/loss, or seepage, studies of selected stream reaches will also be conducted as described below under "groundwater discharge".

Groundwater Budget

Recharge
Principal sources of recharge to the groundwater system are precipitation, irrigation return flow, canal leakage, stream leakage, lake leakage, and possibly underflow from adjacent basins. The potential contribution of each of these sources will be assessed in the groundwater-budget analysis.

Water- and energy-balance modeling will be used to estimate the recharge distribution from precipitation and irrigation return using a method such as SWB (Westenbroek and others, 2010) or PRMS (Markstrom and others, 2015). Many types of spatial and temporal data are required to simulate daily water balances within the subbasin. Spatial data include land use and cover, soils, geology, elevation, slope, and aspect. Temporal data consist of daily records of precipitation and evapotranspiration from local weather stations, and weekly or biweekly estimates of irrigation application rates.

Water exchange between the groundwater system and rivers and streams in the basin will be evaluated using existing stream-gage information and project measurements at additional sites.

Measurements, in the form of seepage runs, will occur during low-flow periods to better define groundwater/surface-water interaction. Existing shallow wells near perennial streams will be used to determine elevation differences between groundwater and the streams, to assess groundwater response to stream elevation.

Leakage from irrigation canals will be assessed using existing canal loss data and new gaging where necessary. Water-level data from existing shallow wells near canals will be used to assess groundwater response to canal losses.

Discharge

Potential groundwater-system discharge is to pumping wells, flowing wells, springs, streams and canals, lakes, and evapotranspiration.

Historic and current groundwater withdrawals for irrigation will be estimated by OWRD, using a variety of remote-sensing techniques and field-data collection. The methods used and amount of effort applied will be agreed upon as the study progresses. Irrigated crops will be among the land-use/land-cover classes mapped using images of the basin. To the extent possible, individual crop types will be mapped; however, crops may be grouped according to their consumptive-use requirements and typical irrigation methods and efficiencies. Ground-truth data will be collected to verify the interpretations. Actual water use will be determined using totalizing flow meters or a combination of instantaneous discharge measurements and power-consumption records.

Well discharge for any municipal and industrial uses in the basin will be estimated using data from the OWRD water-reporting system, and water-rights information files. Where possible, transient groundwater withdrawal since predevelopment will be estimated based on historic data by OWRD.

Evaporation from Malheur and Harney Lakes is expected to be a significant component of groundwater discharge in the study area. Existing evaporative-rate estimates will be field checked with other measurement techniques including remote sensing or a weather-station network.

Existing spring-discharge data will be evaluated as to its usefulness in quantifying groundwater discharge to springs within the basin. Some springs may be field located and measured or sampled by project personnel.

Phreatophytes (plants that draw water directly from the water table) that grow along streams, lakes, and canals can discharge large amounts of groundwater to the atmosphere. Phreatophyte area can be mapped from aerial photographs and combined with climatic and physiologic data to estimate groundwater evapotranspiration (ET) using established techniques. Another approach is using AVHRR (Advanced Very High-Resolution Radiometry) remote-sensing data to estimate ET.

Preliminary Groundwater Model

A preliminary version of the regional model will be constructed during this phase. This model will most likely be a highly simplified representation of the groundwater-flow system(s) with a coarse grid and relatively few layers. This will limit the size of the model datasets making the model more efficient to run and change. The primary purpose of this model will be to test components of the conceptual model through the data collection and analysis processes. The modeling insights gained during this phase will directly benefit the project in phase II when the detailed regional model is developed.

Products

The outcome of this phase of the study will be a synthesis of our understanding of the regional groundwater-flow system(s) documented in a USGS Scientific Investigations Report. The report will include:

- A quantitative conceptual understanding of the groundwater-flow system(s) of the Harney Basin
- A water-budget model for the basin
- An extensive database of hydrogeologic information for the basin, examples include:
    - Extent, thickness, and hydraulic characteristics of major hydrogeologic units
    - Head maps for the basin from synoptic measurements and other available data
    - Recharge estimates
    - Groundwater-withdrawal estimates
    - Location and rate of groundwater exchange with surface-water features

Phase II – Development of Groundwater-Flow Model and Simulation of Management Scenarios

Objectives

- Refine and calibrate the preliminary groundwater-flow model of the Harney Basin to steady-state conditions so that it accurately represents the hydrogeologic system and can be used to address water-resource management issues in the basin.

- Expand the capability of the groundwater model to simulation of hydrologic change with time (transient conditions) by calibrating the model to historic data.

- Demonstrate the use of the model to simulate the effects of management scenarios on hydrologic conditions in the basin.

- Design a long-term hydrologic monitoring network for the basin that will allow detection of effects resulting from resource-management decisions, evaluation of model predictions, and future updates and refinements of the model developed in this study.

Approach

Predictive Groundwater-Flow Model and Simulation of Scenarios

The preliminary groundwater model developed during phase I will be used as an investigative tool to improve our understanding of how the groundwater-flow system(s) functions. In phase II, the primary goal of modeling will be to develop a tool that can be used for predictive purposes. The exact approach to developing the predictive model in phase II depends on results from the modeling design work conducted in phase I. For planning purposes, a possible strategy to construct and calibrate steady-state and transient models is described below.

As previously described, a simple, steady-state model would be developed during phase I. This model will probably have a coarse grid and few layers so that it can be run efficiently, and used to test concepts of the flow system(s). A limited amount of calibration will be done to this model.

At the beginning of phase II, the model grid would be refined so that the model would have the appropriate resolution for the data available to calibrate it, and for eventual predictive use. This refined steady-state model would then be carefully calibrated. When a reasonable match with predevelopment conditions is achieved, the model will be used to simulate initial conditions for the transient calibration period.

During phase II, historical stress data (recharge and pumpage), developed during phase I, for the period between predevelopment and current conditions will be used for transient model development. Available hydrologic-response data (heads, stream flux) will also be used in transient calibration of the model; this calibration period would probably have seasonal or annual stress periods. The model may also be calibrated to the 2016–2020 period of intensive data collection for this study with monthly to quarterly stress periods. Once the model is calibrated, a few representative management scenarios will be framed by the cooperating agencies and stakeholders. The USGS will develop model input data based on the scenarios and demonstrate the use of the model to simulate the effects of these scenarios on hydrologic conditions in the basin. The results of these simulations will be presented in the report describing the model and its calibration. The possibility of including density-dependent flow modeling will be evaluated as we develop an understanding of any potential saline-water flow system(s) beneath or near Harney Lake.

The groundwater model will be sufficiently detailed so that the effects of managed changes in water use can be evaluated at a scale commensurate with the scale of management questions in the basin. Groundwater interaction with canals, rivers, and lakes will be represented at appropriate scales that produce useful estimates of the effects of management scenarios on these features. The uncertainty in model predictions will be estimated so that it may be considered in any management decisions formulated on the basis of model results.

Although the modeling described in this proposal is only designed to define flow at a regional scale, it may be possible to utilize embedded-mesh techniques (Leake and Lilly, 1997; Panday and others, 2013) to build more detailed sub-regional models of site specific areas within the larger regional model to evaluate management at a smaller scale. The regional model would provide boundary fluxes to such an effort; therefore, the entire Harney Basin would not have to be modeled in uniformly small space and time increments.

It is anticipated that OWRD staff will be involved in all phases of model development and implementation. While all cooperators will be involved in developing scenarios for testing with the model, OWRD will maintain technical expertise for operating the model and interpreting the results. Ultimately, the model will be transferred to OWRD for use after the project.

Long-Term Hydrologic Monitoring Plan Design

Finally, using the information and data compiled in phases I and II, a long-term hydrologic monitoring plan will be designed for the basin. At the end of the study, data collection for this study will be significantly reduced; however, it is important that an adequate monitoring network be maintained beyond this study to support future water-resource assessments in the basin.

Products

The following reports are planned at this time. The exact number of reports and their topics may change as a result of planning during phase I. The phases listed for each report indicate the phase in which data collection or analysis would occur; actual publication of the report may occur in subsequent phases.

Phase	Short Title	Outlet
I	Overview of Harney Basin Groundwater Study	Factsheet
I	Hydrogeology and conceptual model of the Harney Basin	SIR
II	Simulation model analysis of the Harney Basin	SIR
II	Summary of significant findings in Harney Basin study	Factsheet

Estimated Schedule

As it is currently scheduled, both phases of the project would be completed within about seven years (see attachment). This schedule could be accelerated if additional funding sources could be identified.

Quality Assurance/Quality Control

Data-collection and review procedures from the USGS Quality Assurance Plan for Ground-water Activities in the Oregon Water Science Center and the Quality-Assurance Plan for Water-Quality Activities in the Oregon Water Science Center will be used to guide groundwater-data collection during the study. The groundwater data will be archived and documented according to the Policies and Procedures for the Management and Archiving of Data, U.S. Geological Survey, Oregon Water Science Center.

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