Template for components that would be desirable in order to prepare a groundwater management plan for the Shasta Valley Siskiyou County, California

Prepared for the Shasta Valley Resource Conservation District

By Davids Engineering, Inc. Davis, CA

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Note to reviewers:
This template has been prepared as part of efforts by the Shasta Valley Resource Conservation District to help all parties recognize and understand the steps that ideally should be either in process or accomplished in order to prepare a Groundwater Management Plan (GMP) for the Shasta Valley. Preparation of a GMP is authorized by California Assembly Bill 3030 as expressed in California Water Code (CWC) sections 10750 – 10756. In general, the CWC authorizes certain qualified water management agencies to develop and adopt GMPs if they choose to do so, but only with voter approval.

The specific steps and procedures that need to be followed for adopting a plan can be found on the Department of Water Resources (DWR) website: http://www.water.ca.gov/groundwater/gwmanagement/ab_3030.cfm

The CWC suggests technical components that may be included in a plan and allows for other technical components to be included as needed to address any locally important issues occurring in a groundwater basin.

Additionally, the CWC specifies certain topics must be addressed in a GMP for it to qualify under the law and thereby ensure the agency’s eligibility for certain State funding for groundwater and groundwater quality projects. The mandatory topics are the following:

- Basin management objectives (BMO) for the groundwater basin that is subject to the GMP
- A plan to involve other agencies that enables the local agency to work cooperatively with other public entities whose service area or boundaries overlies the groundwater basin
- A map that details the area of the groundwater basin, as defined in DWR Bulletin 118, and the area of the local agency or agencies
- A map identifying the recharge areas for the groundwater basin (required beginning in 2013)
- Adopted groundwater monitoring protocols that are designed to detect changes in groundwater levels, groundwater quality, inelastic surface subsidence and flow and quality of surface water

This plan template has been developed to specifically include the mandatory CWC components so that any future GMP will be a qualifying plan and the sponsoring entity will be eligible for State loans and grants related to groundwater. Additionally, the outline provides a foundation for identifying the kind of data that should be collected to be better prepared to develop a GMP when the interest and resources become available to do so.
Annotated Groundwater Plan Template and Recommendations—A working Draft

Note: Development of a plan with the following components should both meet state requirements, and provide the information needed to be effective and useful locally.

Plan Contents (typical)
- Table of Contents
- List of Appendices
- List of Tables
- List of Figures
- Abbreviations and Acronyms

Section 1—Introduction
- Purpose and Organization
  - Statement of purpose of the Plan (E.g.: to ensure the protection and sustainable use of Shasta Valley groundwater resources)
  - Brief overview of GMP contents and organization

- Siskiyou County
  - Location
    - Figure 1-1. Location Map (map illustrating Siskiyou County boundary and boundary of Shasta River watershed within the county. Inset on map showing location of Siskiyou County within California.)
    - Governance and Administrative Structure of administering agency
    - Groundwater Management Plan Area
      - Figure 1-2. Groundwater Management Plan Area (map delineating the area covered by the Plan in relation to the county boundary, roads, and hydrologic features. Note: generally, the Plan area coincides with the groundwater basin as defined by the Department of Water Resources in Bulletin 118 but includes sub-areas identified by recent RCD/DWR investigations.)

- Authority to Prepare and Implement Groundwater Management Plan (cite the California code sections that authorize the local agency to prepare and implement the GMP)

- Relationship to Other Plans (describe relationship of the GMP to other plans, if any, including the county general plan, integrated regional water management plan [IRWMP] and others that may exist at the time the GMP is prepared)

- Factors Affecting Water Use and Management
  - Land uses within the Shasta River watershed
  - Shasta River Decree
  - Endangered species and related rulings
Section 2—Shasta Valley Water Resources

- Shasta River Watershed, Hydrology and Surface Water Supplies
  - Figure 2-1. Shasta River Watershed Features (map(s) showing Shasta River and tributaries, major springs, water development features [e.g. Lake Shastina, major irrigation canals, etc], topographic relief, precipitation.

- Surface Water Development and Facilities
  - Refer to Figure 2-1.

- Groundwater Supplies
  - Summary description of the Shasta Valley groundwater basin as defined by DWR per Bulletin 118 and sub-areas as identified by the RCD and DWR
  - Regional Geologic Setting (build upon Bulletin 118, Shasta Valley Data needs Assessment, Shasta Springs Ranch Hydrogeologic Assessment, Little Shasta Hydrogeology Report, other materials as available)
  - Characterization of Groundwater Elevations, Groundwater Flow, Basin Storage by each sub-area.
    - Figure 2-2. Selected Groundwater Hydrographs in the Shasta Groundwater Basin
    - Figure 2-3. Groundwater Elevations in each Shasta Groundwater sub-area (note: ideally two maps; one for historical and one for current conditions to reveal any changes in groundwater levels over time)
    - Discussion of Figures 2-2 and 2-3.
  - Groundwater Budget Components (discuss groundwater recharge and discharge components; more discussion of recharge and discharge may be included in Section 3 as a mandatory component)
    - Surface/Groundwater budget components for watershed, showing mutual interactions, absolute quantity limitations.
    - Data needs to develop a detailed water budget for watershed.

- Stream-Aquifer Interaction (discuss and map to the extent possible groundwater discharge to streams and stream leakage to groundwater; possible Figure 2-4)

- Land use interactions with groundwater (discuss and map to the extent possible areas dependent on groundwater for domestic and agricultural uses, along with areas where irrigation water management results in supplementation of naturally occurring groundwater)

- Groundwater Quality (summarize groundwater quality to the extent possible with available data, concentrating on constituents relevant to agricultural suitability and drinking water standards and temperature as related to fish habitat)

- Water Use in the Shasta River Basin (based on available information, present best estimates of the following):
  - Surface water diversions including springs
  - Groundwater pumping
  - Consumptive water use
  - Domestic well counts and distribution
  - Municipal GW usage, delivery areas and quantities. (Shastina, Grenada, Yreka, Weed)
Section 3—Plan Components

• Definition of the Groundwater Basin Subject to the Plan (mandatory)
  o Figure 3-1. Groundwater Basin Subject to the Groundwater Management Plan (probably the entire Shasta Valley Groundwater Basin (Basin Number 1-4) as identified in DWR Bulletin 118)

• Stakeholder Involvement Plan (mandatory)
  o Involving the Public
    ▪ (Describe the specific steps that the local agency took to comply with the CWC, specifically sections 10753.2 and 10753.3)
    ▪ (Identify the actions the local agency commits to take to promote public involvement)
  o Involving Other Agencies within the Basin
    ▪ (List of public agencies within or overlying the basin the local agency preparing the GMP has or intends to collaborate or coordinate with)
    ▪ (Map of the service areas or jurisdictions of local agencies identified for collaboration/coordination)

• Basin Recharge and Discharge Areas (mandatory)
  o Figure 3-2. Shasta Valley Groundwater Basin Recharge Areas (Map of the basin identifying recharge areas (mandatory) and discharge areas (optional).
  o Characterization of local recharge mechanisms and locations, and their relative magnitudes.
  o Discussion of contamination risks via recharge at various locations

• Basin Management Objectives (mandatory)
  o Groundwater Management Goal (e.g., “The goal of the Shasta Valley Groundwater Management Plan is to maintain a viable groundwater resource for to sustain beneficial uses by the people of Siskiyou County and to sustain fish and wildlife within the basin.”)
  o Basin Management Objectives (the following general/typical BMOs are suggested as a starting point for the local agency’s consideration):
    ▪ Maintain groundwater elevations that provide for sustainable long-term use of the groundwater basin (no overdraft)
    ▪ Manage groundwater to protect against adverse impacts to surface water flows in the Shasta River and its tributaries
    ▪ Improve understanding of the groundwater basin and its stressors
    ▪ Improve communication and coordination and cooperation among Shasta Valley groundwater basin stakeholders
    ▪ Maintain local control of the Shasta Valley groundwater resource
• Maintain and improve groundwater quality in the Shasta Valley groundwater basin for the benefit of groundwater and surface water users

• Preserve groundwater supplies to meet future local needs.

• Support fair and equitable sharing of the limited groundwater resource among all uses

• Provide a foundation of knowledge to assist residents of the Shasta Valley to make sound long-term financial decisions about their own groundwater development activities

• Provide predictability of water availability in varying water year types.

• Help provide the knowledge and information needed to minimize or avoid conflicts over water use.

• Provide guidance to the County Planning Department for consideration in future land development proposals.

• Develop a working understand the interactions occurring between ground and surface water within the Shasta Valley

• Develop a water budget for watershed for both surface and ground water.

• Monitoring Program (mandatory)

(\textit{In each of the following categories, describe the existing/historical monitoring activities performed by the local agency and collaborating agencies at the time the GMP is prepared and any plans/needs to expand or intensify monitoring activities, including anticipated costs and a timeline. Be as specific as possible. Including planned monitoring improvements may enhance potential for grant funding})

  o Groundwater Elevation and Storage Monitoring and interpretations
  o Groundwater Quality Monitoring
  o Groundwater and Surface Water Interaction Monitoring
  o Inelastic Subsidence Monitoring
  o Data Management (describe how groundwater monitoring data is quality controlled, stored, reported and shared)
  o Identification of both existing and additional GW monitoring sites needed to assess usage vs. safe yield/overdraft in each sub area
  o Identification of additional monitoring needed to meet evolving local needs, including improved knowledge of directions of GW flow, inform trigger points for management responses, inform water budget development, etc.

• Groundwater Resource Protection (\textit{In each category below, describe the policies and actions that the local agency(s) will/do take to protect groundwater resources})

  o Local Well Construction, Abandonment and Destruction requirements
  o Wellhead Protection
  o Protection of Recharge Areas


- Control and Remediation of Contaminated Groundwater
- Fuel Storage Tanks
- Control of Saline Water Intrusion

- **Groundwater Sustainability** *(In each category below, describe the policies and actions that the local agency will take to protect groundwater resources)*
  - Sustainable Management of the Groundwater Basin
  - Increase Understanding of Stressors in the Basin
  - Land Use Changes and Impact to Groundwater Resources
  - Identify/discuss potential for conjunctive use, enhanced recharge
  - Identify Factors/actions likely to lead to reduced recharge or otherwise diminished GW availability for beneficial uses
  - Assess impacts on agricultural economics of changes to GW elevations.

**Section 4 – Plan Implementation**

- Annual Monitoring Report
  - *(Present and interpret groundwater level and quality trends)*
  - *(Assess whether management actions are achieving BMOs)*

- Periodic Review and Update of Plan
  - *(Describe the conditions or events that would trigger a review and update of the GMP)*

**Section 5 – References**
*(List of references used in developing the GMP)*
Appendix 2

Shasta Valley Resource Conservation District

Stream-Aquifer Data Collection Program to Support Preparation of a Groundwater Management Plan for the Shasta Valley, Siskiyou County, California

Prepared by

DAVIDS ENGINEERING, INC

May 1, 2013
Shasta Valley Resource Conservation District

Stream-Aquifer Data Collection Program to Support Preparation of a Groundwater Management Plan for the Shasta Valley, Siskiyou County, California

Prepared by Davids Engineering, Inc.

May 1, 2013
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Abbreviations

ADCP  Acoustic Doppler Current Profiler
ADV  Acoustic Doppler Velocimeter
AF   acre-feet
cfs  cubic feet per second
CSD  Community Services District
CIMIS California Irrigation Management Information System
CTEMPs Center for Transformative Environmental Monitoring Programs
DTS  Distributed Temperature Sensing
DWR  California Department of Water Resources
EA   each
EST  estimate
ET   evapotranspiration
ft   feet or foot
ft/s  feet per second
GID  Grenada Irrigation District
GIS  Geographic Information Systems
gpm  gallons per minute
GW   groundwater
GW/SW groundwater/surface water
K    saturated hydraulic conductivity
LSH  Little Shasta
M&I  municipal and industrial
METRIC Mapping EvapoTranspiration at high Resolution with Internalized Calibration
MWCD Montague Water Conservation District
O&M  operations and maintenance
PRISM Parameter-elevation Regressions on Independent Slopes Model
PRK  Parks Creek
RCD  Shasta Valley Resource Conservation District
SCADA supervisory control and data acquisition
SDF  Stream Depletion Factor
SEBAL Surface Energy Balance Algorithm for Land
SW   Surface water
SWA  Shasta Water Association
SWT  Sweetwater
SS   specific storage
SY   specific yield
Trib tributary
USBR United States Bureau of Reclamation
USGS United States Geological Survey
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Appendix A. Shasta Valley Groundwater Workplan
Appendix B. Inventory of Historical and Existing Hydrologic Monitoring
1.0 Introduction

Water resource managers traditionally have tended to address surface water and groundwater systems as if they were distinct and separate. However, in most cases, as the development and use of water resources intensifies, it eventually becomes clear that changes in the management of one system affect the other. Most surface water bodies (i.e. streams, lakes etc.) are connected to the groundwater system to some degree, with the following three types of relationships: (1) surface water bodies losing water to the groundwater system (i.e. groundwater recharge or recharge), (2) surface water bodies gaining water from the groundwater system (i.e. groundwater discharge or discharge), and (3) some combination of recharge and discharge, typically varying over both space and time. Consequently, diversions from surface water bodies can deplete aquifer systems, and pumping from an aquifer can reduce discharge to streams, springs and lakes. Additionally, changes in land use, irrigation methods, and management of surface water storage and conveyance infrastructure can impact surface water and groundwater systems. Due to these linkages, it is obvious that an adequate understanding of the geographic extent and nature of interaction between surface water and groundwater systems (stream-aquifer interaction\(^1\)) is essential for effective water resource management (Alley, 2002).

Recognizing that the hydrogeology of the Shasta Valley is both complex and poorly understood, the Shasta Valley Resource Conservation District (RCD), with technical assistance by Davids Engineering, developed the Stream-Aquifer Data Collection Program (Program) described in this document. The RCD’s goal is to develop foundational knowledge of the basin’s groundwater system and the nature of its interaction with surface water bodies. The data collected through the Program is intended to eventually serve as a basis for groundwater management if that becomes desirable and acceptable in Siskiyou County. Additionally, the RCD understands that groundwater data collection is costly and resources are limited; therefore, the Program should include a feedback process based on periodic data review and analysis to ensure that the most meaningful data is gathered at minimum cost. Because existing data falls far short of that needed to adequately define a comprehensive data collection program at this time, the initial focus is on gathering data that will help to characterize the nature of stream-aquifer interactions in the basin. This priority reflects the importance of maintaining streamflow for both irrigation water supply and for habitat for anadromous fish species. As information is gained, it will eventually provide the basis for identifying, describing, and addressing specific groundwater issues and for additional data collection needs for the preparation of a Shasta Valley Groundwater Management Plan, if and when a decision is made by the County to prepare such a plan.

This document is organized into the following sections:

1.0 Introduction - Provides a brief introduction to the goals of the Program
2.0 Background - Develops some essential hydrologic principles that are fundamental to understanding stream-aquifer interactions in the Shasta Valley
3.0 Overview of Existing Monitoring Efforts - Inventories existing (and historical) hydrologic data collection in the Shasta Valley
4.0 Basic Regional Data Collection - Presents recommendations regarding specific baseline data that should be collected in the Shasta Valley
5.0 Monitoring Framework - Provides an overview of the framework used to develop data

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\(^1\) In this document, the terms “SW-GW interaction” and “stream-aquifer interaction” are used synonymously to refer to the interaction between surface water and groundwater systems.
specific monitoring recommendations

6.0 **Specific Monitoring Plans, Priorities and Cost Estimates** - Presents specific recommendations for additional monitoring, prioritized into three categories (A, B and C) and provides cost estimates for high priority recommendations (Priority A)
2.0  Background

A conceptual Shasta Valley Groundwater Study Workplan (Workplan) was prepared in 2011 (Davids Engineering 2011a). The Workplan (1) presents an overview of existing literature pertaining to Shasta Valley geology and hydrology, (2) provides an overview of the hydrogeologic setting of the Shasta Valley and (3) presents methodologies for characterizing stream-aquifer interactions. Readers are encouraged to review the Workplan, as it provides valuable background information that supplements the more detailed information in this report. The Workplan is attached as Appendix A for convenient reference.

2.1  Groundwater Recharge and Discharge

Understanding groundwater recharge and discharge is foundational to understanding any aquifer system. Once existing components of recharge and discharge are adequately defined, an aquifer’s response to changes in stressors (e.g., pumping or recharge reduction from canal lining) can be better understood.

2.1.1  Recharge

Components of groundwater recharge in the Shasta River basin include:

1. Deep percolation\(^2\) of precipitation,
2. Deep percolation of applied irrigation water,
3. Seepage from irrigation conveyances facilities,
4. Seepage from streams, and
5. Seepage from water storage reservoirs (most notably Lake Shastina).

Precipitation falls predominantly as rain at the lower elevations and as snow at the higher elevations, with average annual values ranging from 10 to 20 inches on the Shasta Valley floor to over 65 inches near the peak of Mount Shasta (Ward and Eaves 2008).

Infiltration rates on the north side of Mount Shasta are high as evidenced by the complete infiltration and consequent disappearance of Whitney Creek and some other creeks that emanate from the glaciers and seasonal snow pack on the mountain’s north side. This northside recharge sustains discharge from numerous spring complexes on the Valley floor, which provide more than half of the annual flow of the Shasta River (Nichols et al. 2010).

Recharge also occurs from any losing reaches of ephemeral and perennial streams, including the Shasta River and its main tributaries, including the Little Shasta River, Julian Creek, Willow Creek and Parks Creek.

About 65 percent of the irrigated acreage in the Shasta Valley is irrigated by surface application methods (e.g. flood, furrow, border-strip, etc.). Applied irrigation water that infiltrates the soil in excess of the amount that can be retained in the crop root zone becomes deep percolation, which is recharge to the

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\(^2\) Deep percolation is water that infiltrates the soil, flows downward through the root zone, and into underlying groundwater. Deep percolation can be from precipitation or applied irrigation water.
underlying aquifer system.

2.1.2 Discharge

Components of groundwater discharges in the Shasta River basin include:

1. Spring discharge,
2. Discharge to streams (i.e., gaining stream reaches),
3. Groundwater pumping, and
4. Evapotranspiration (ET) of shallow groundwater.

Spring discharge in the Shasta Valley constitutes a significant portion of total groundwater discharge. Large spring complexes near the center of the Valley generally emanate along a north-south trend near the geologic contact between the permeable basalt flows of the High Cascades (e.g. Pluto’s Cave Basalt) and the less permeable rocks associated with the older Pleistocene debris flow (Nichols et al., 2010). Additionally, several springs emanate near the up-gradient interface between the matrix and block facies of the debris flow (Davids Engineering 2011c). In the Little Shasta Valley, the majority of perennial springs occur near the interface of the Cascade Tertiary Volcanics and Quaternary Goosenest Basalt (Davids Engineering 2010). Springs tend to daylight at this location because groundwater traveling through the fractured and permeable Goosenest Basalt is forced to the surface by the older and less permeable Cascade Tertiary Volcanics.

Groundwater discharge also occurs along gaining stream reaches.

Groundwater pumping in the Shasta Valley is primarily for irrigation purposes (from a volume standpoint) but groundwater also sustains important municipal, domestic and livestock uses. As discussed below, groundwater pumping generally captures (reduces) other forms of groundwater discharge.

ET of shallow groundwater occurs at various locations in the Shasta Valley, evidenced by pastures (or meadows) that remain green even after weeks or months without precipitation or irrigation. It is evident that shallow groundwater is being consumptively used by vegetation in these areas, something confirmed by water balance analyses in certain areas (Davids Engineering 2011b). In general, ET of shallow groundwater occurs where plant roots extend downward to near the water table. This type of groundwater discharge typically has high temporal variability due to the seasonal fluctuation of ET and of the elevation of the groundwater table.

2.2 Hydrologic Conceptualization of the Shasta Valley

Historically, the Shasta Valley (and many other similar stream-aquifer systems) could be characterized as having a “full” aquifer, where groundwater was in dynamic connection³ with surface water bodies, particularly streams. Several studies have highlighted the importance of dynamic stream-aquifer interactions in support of human uses and to overall ecosystem health, including the health of anadromous fisheries (Stanford and Ward 1993; Power et al. 1999; Konrad 2006).

³ A “dynamic connection” in this case refers to an active exchange of water between surface water and groundwater that changes over both space and time.
Figure 1 is a simplified water balance diagram representing a historically perennial watershed\(^4\). The upper and lower diagrams depict two distinct climatic periods representing the two typical Mediterranean climatic patterns, respectively: wet (upper diagram) and dry (lower diagram). During the wet period, precipitation events occur that lead to either (1) direct runoff into the surface water system or (2) diffuse recharge into the groundwater system. During the dry period, both of these inflows (direct runoff and diffuse recharge) are reduced and may even approach zero. This leaves evapotranspiration (ET) from the stream and the groundwater system, stream outflow, and groundwater outflow as the only trans-watershed boundary flow paths. In other words, only ET, stream outflow, and groundwater outflow constitute net changes in water quantities within the watershed boundary (this assumes changes in storage within the watershed are zero). All other flow paths represent internal exchanges between the surface water and groundwater systems.

Figure 2 depicts a dry period water balance centered on surface streams. It is important to note that, in Mediterranean climates, once snowmelt has ended, the entire dry period streamflow is typically supplied from the groundwater system (i.e. net streamflow gains). For a stream to be perennial, groundwater discharges to it from springs, diffuse stream accretions, and spring fed tributaries must be greater than the sum of ET from the portions of the watershed that are in hydraulic connection with the stream and the net losses from the stream to the groundwater system, on a continuous basis. This dry period base flow is critically important for meeting agricultural and urban water demands and sustaining ecosystem health (including the mediation of stream temperature and flow during the warm dry periods). Additionally, in the Shasta Valley, base flow sustains the influx of important nutrients from water-rock interactions occurring within the underlying geologic materials (Nichols et al. 2010).

A new stressor was has been introduced to many stream-aquifer systems over the past 100 to 150 years, including those in the Shasta Valley, in the form of increased consumptive use (ET) associated with irrigated agriculture. This increase in consumptive use is generally associated with surface water diversions and/or groundwater pumping for irrigation. The effects of surface water diversions are almost immediately apparent but the effects of groundwater pumping generally occur on a slower and less obvious timescale (Alley et. 1999). As Theis (1940) pointed out, increased groundwater production leads to either (1) induced recharge, (2) reduced discharge or (3) changes in storage, or, more often than not, some combination of the three.

\(^{4}\)“Perennial watershed” is a watershed that has at least one stream that flows continuously.
Figure 1. Wet Period and Dry Period Historic Water Balance
It can be seen from Figure 3 that as consumptive use (ET) increases, there will be an equal and inverse change in the sum of stream and groundwater outflow. In the Shasta Valley, where the geology dictates that groundwater outflow is insignificant, it is clear that incremental changes in consumptive use (ET) have a direct, reducing effect on stream outflow. If consumptive use changes by more than the historical streamflow, for at least portions of the year, the stream can become ‘artificially ephemeral’. ‘Artificially ephemeral’ refers to a historically perennial stream that has been rendered intermittent due to anthropogenic effects. It is easy to see that diversion of streamflow will have a direct, and as previously mentioned nearly instantaneous effect on stream outflow. The effects of increased consumptive use on the groundwater system and how this in turn affects streamflow are less obvious.

2.3 Groundwater Management Approaches

Approaches for managing groundwater have evolved from being virtually nonexistent during the earliest period of groundwater development to the complex, highly structured, regulated and technically based approaches used in some groundwater basins today. Typically, groundwater management approaches evolve from simple to complex as groundwater extraction increases and, at some point, begins to exceed the “long-term capacity” of the aquifer. To minimize or avoid aquifer depletion or adverse impacts caused by it, provisions may be established to augment recharge or reduce pumping. Today, many water resource managers are interested in characterizing the volumes and patterns of groundwater extraction that can be sustained without causing long-term overdraft.

Scientists and engineers have worked toward developing methods for characterizing the “long-term capacity” of an aquifer to provide water in a sustainable manner. Two concepts that have been proposed for sustainable groundwater management are Safe Yield and Sustainable Yield, both of which are encompassed by the concept of “sustainable groundwater development” (Hiscock et al. 2002). To put the concept of sustainable groundwater development into practice, it is necessary to understand both safe yield and sustainable yield. Regrettably, developing this understanding is complicated in part
by wide diversity in the interpretation and definition of these concepts. Kalf and Woolley (2005) provide a thorough overview of the different definitions of safe yield and sustainable yield (Table 1), revealing the complexities of the topic.
Table 1. Summary of Safe Yield and Sustainability Concepts and Definitions from Kalf and Woolley (2005)

<table>
<thead>
<tr>
<th>Author</th>
<th>Concepts and Definition</th>
<th>Comments</th>
</tr>
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<tbody>
<tr>
<td>Lee (1915)</td>
<td>Safe Yield: “The limit to the quantity of water which can be withdrawn regularly and permanently without dangerous depletion of the storage reserve”.</td>
<td>Hydrologically based on something less than dangerous storage depletion. What does dangerous and regular mean? Yield available in perpetuity (i.e. sustainable).</td>
</tr>
<tr>
<td>Meinzer (1920)</td>
<td>Safe Yield: “...the practicable rate of withdrawing water from it (the aquifer) primarily for human use”.</td>
<td>Hydrologically based and a yield available in perpetuity (i.e. sustainable). “Sensible, but overdraft not evident until after it has occurred” (Kazmann 1988).</td>
</tr>
<tr>
<td>Meinzer (1923)</td>
<td>Safe Yield: “The rate at which water can be withdrawn from an aquifer for human use without depleting the supply to the extent that withdrawal at this rate is no longer economically feasible.”</td>
<td>Hydrologically based but dependent on the pumping economics of the production facility.</td>
</tr>
<tr>
<td>Theis (1940)</td>
<td>Perennial Safe Yield: [for non-artesian aquifers that are small and most artesian aquifers] “there is a perennial safe yield equivalent to the amount of rejected recharge [induced recharge] and natural discharge it is feasible to utilize”</td>
<td>Implies concept may not apply to large aquifer with low diffusivity (T/S) and isolated abstraction.</td>
</tr>
<tr>
<td>Stuart (1945)</td>
<td>Safe Yield: “is the maximum rate at which water may be withdrawn without impairing the quantity and quality of the supply”.</td>
<td>Hydrologically based on the Meinzer concept with water quality constraint added</td>
</tr>
<tr>
<td>Conkling (1946)</td>
<td>Safe Yield: “Taken over 1 year should not: (1) Exceed average annual recharge; (2) Lower watertable so that the permissible cost of pumping is exceeded ;(3) Lower watertable so as to permit intrusion of undesirable quality”</td>
<td>Hydrologically based on natural recharge but production facility economics included in definition plus water quality constraint.</td>
</tr>
<tr>
<td>Williams and Lohman (1949)</td>
<td>Perennial Yield: “ has been regarded as the maximum rate at which water can be salvaged from the natural discharge, or added to the [natural] recharge or both...In some reports economical pumping lift has been a factor in this definition; however, the economics of recovery seem to be irrelevant to the determination of the quantity of water which an aquifer will yield and so are not considered here”</td>
<td>Return to a hydrologically based definition. However, no consideration of storage capacity.</td>
</tr>
<tr>
<td>Thomas (1951, 1955)</td>
<td>Safe Yield: suggests abandoning the term because of its indefiniteness</td>
<td>US Geological Survey calls for abandonment of Safe Yield terminology about this time.</td>
</tr>
<tr>
<td>Synder (1955)</td>
<td>Overdraft/Overdevelopment: 5 types (1) Development overdraft-lowering of watertable in areas of natural recharge/discharge; (2)(3) Season or cyclic overdraft: - zero net change in water levels over specific time period year to year; Cyclic, water levels over two or more seasons and then return ;(4) Long-run overdraft: perennial pumping exceeding replenishment (i.e. mining); (5) Critical overdraft- pumping leads to irreversible undesirable result.</td>
<td>Definition of overdraft or overdevelopment in areas exceeding sustained (sic) yield (Domenico 1972). All overdraft yields are unsustainable.</td>
</tr>
<tr>
<td>Author</td>
<td>Concepts and Definition</td>
<td>Comments</td>
</tr>
<tr>
<td>-----------------</td>
<td>------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
<td>-----------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Kazmann (1956)</td>
<td>Safe Yield: - suggests abandoning the term because of its indefiniteness</td>
<td>“Compact, but adds nothing to clarify the situation in that the ‘undesirable results’ include concern for available water, economics of pumping, quality and water rights”. (Domenico 1972)</td>
</tr>
<tr>
<td>Todd (1959)</td>
<td>Safe Yield: “ the amount of water which can withdrawn from (a groundwater basin) annually without producing an undesirable result”</td>
<td></td>
</tr>
<tr>
<td>Domenico (1972)</td>
<td>“The question whether groundwater should be managed on a sustained or mining-yield basis is not yet fully resolved and is controlled by local conditions and demands than by policy decisions in advance of their absolute necessity. This is understandable in that there is likely to be little public sympathy for an announced depletion policy, whereas one of sustained use lends a ring of permanency. Whatever the merits of sustained and mining yield concepts, they are definitely ingrained in groundwater management”.</td>
<td>Page 80</td>
</tr>
<tr>
<td>ASCE 2 (1961)</td>
<td>Four concepts of Safe Yield; (1) Maximum sustained (sic) yield- maximum perennial abstraction ;(2) Permissive sustained yield- maximum perennial abstraction legally and economically for beneficial use without undesirable result;(3) Maximum mining yield – total volume in storage that can be extracted and utilized;(4) Permissive mining yield – maximum volume in storage that can be extracted for beneficial purposes without undesired result</td>
<td>Designed to remove ambiguity of Safe Yield concept. Definition is a mix between basin mass balance (water budget) and production facility response.</td>
</tr>
<tr>
<td>Freeze (1971)</td>
<td>Demonstrates relationship between basin water balances using 3D variably saturated model. Simulation defines the “Maximum Stable Basin Yield”</td>
<td>Illustrated variation of inflows and outflows and storage depletion over time.</td>
</tr>
<tr>
<td>Freeze and Cherry (1979)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ASCE (1972)</td>
<td>Two types (1) Maximum Mining yield – abstraction exceeds annual replenishment, (2) Perennial Yield - rate at which water can be salvaged from the natural discharge, or added to the [natural] recharge or both</td>
<td>(1) Exceeds natural plus induced recharge -unique value (2) based on changing values depending on groundwater levels in basin</td>
</tr>
<tr>
<td>Bouwer (1978)</td>
<td>Safe Yield: Three types. (1) [Normal] Safe Yield – is equal to the average replenishment rate of the aquifer. limited by intrusion near coast;(2) Economic Safe Yield – rate at which groundwater can be withdrawn without danger of wells drying up before adequate tax base for more expensive water is established (i.e. mining), (3) Legal safe yield – “rate at which a well owner can pump groundwater without getting involved in legal action.</td>
<td>Mixes hydrological based recharge, production facility maximum available drawdown and non-hydrological legal issues</td>
</tr>
<tr>
<td>Bredehoeft et al (1982,1997, 2002)</td>
<td>Sustainable groundwater development is determined by capture of natural discharge. Basing groundwater development sustainability on natural recharge (i.e. safe yield) is a myth and irrelevant.</td>
<td>Focus is on production facility transient phase leading up to equilibrium. Implies sustainability means groundwater system must reach equilibrium. Numerical modeling required to determine response.</td>
</tr>
</tbody>
</table>
1 Diffusivity T/S: Transmissivity divided by storativity
2 American Society of Civil Engineers

At this time, due to data limitations, it is impossible to quantify the safe or sustainable yield of the Shasta Valley with adequate certainty, but certain useful points can still be made based on these concepts. The Shasta Valley has a relatively shallow aquifer system comprised of metamorphic, volcanic and alluvial materials (Mack 1960). Due to the low permeability of the metamorphic materials near the down-gradient portion of the watershed (i.e. the Shasta River “canyon” north of Yreka), groundwater outflow from the basin is insignificant. Instead, groundwater flowing down-gradient through the watershed is expressed as spring flow, streamflow, or ET from shallow groundwater. Therefore, the three primary indicators in the Shasta Valley of groundwater extractions being in excess of the safe or sustainable yield are:

1. Persistent\(^5\) reduction of streamflow below historic levels\(^6\) (taking into account natural variability with time)
2. Persistent reduction of spring discharge below historical levels (taking into account natural variability with time)
3. Persistent reduction of groundwater levels below historic levels (taking into account natural variability with time).

Continued monitoring of streamflow, spring discharge and groundwater levels at existing sites, augmented by the addition of new strategically located monitoring sites, is essential to understanding sustainable groundwater extraction rates.

### 2.4 Groundwater Extraction and Streamflow Depletion - Theis’ Concept of Capture

Groundwater extraction can lead to a reduction in streamflow, affecting both human uses and ecosystems (Barlow and Leake 2012). When a groundwater system is pumped there is a lowering of the

\(^{5}\) What constitutes “persistent” for each indicator depends on various factors including basin scale, climate variability and the temporal and spatial sensitivity of human and ecological uses of water to changes in streamflow, spring discharge and groundwater levels.

\(^{6}\) A sufficiently representative characterization of historic streamflow, spring discharge and groundwater levels is needed but is beyond the scope of this document.
Data Collection Plan

water table near the well. Initially this lowering is accounted for by a change in storage within the aquifer surrounding the well. As pumping continues, and the cone of depression expands, impacts to both recharge and discharge areas can occur. In a discharge area, the cone of depression will reduce the water table gradient with a consequent reduction in discharge to streams, springs or ET of shallow groundwater. In a recharge area, the cone of depression will lower the water table, potentially leading to increased recharge in areas that historically rejected recharge because of high groundwater levels. These relationships are expressed in Theis’ (1940) concept of capture which, briefly summarized, states that when a groundwater aquifer is pumped, the pumping ‘captures’ water from either (1) induced recharge, (2) reduced discharge or (3) a change in storage. Figure 4 illustrates the three sources of water captured by groundwater pumping. With reference to Figure 4:

1. Induced recharge is caused by a lowering of the water table in an area that historically would have rejected recharge because of saturation (illustrated near ‘1’).
2. Reduced discharge occurs when water that otherwise would have discharged to a stream or to a spring, or as ET of shallow groundwater, is captured by pumping. In this case, water that historically discharged to a stream is being captured (illustrated near ‘2’).
3. Finally, a change in storage is caused by a lowering of the water table near the pumping well; this lower of the water table is often referred to as a ‘cone of depression’ (illustrated near ‘3’).

Figure 4. Theis Capture Concept adapted from Theis (1940)

In close proximity to a stream, a decrease in surrounding groundwater levels will cause a steepening of the gradient away from the stream, thereby inducing additional recharge (i.e. stream depletion). Glover and Balmer (1954) later derived a mathematical solution to stream depletion with a complementary error function. Later, Jenkins (1968a, 1968b and 1968c) popularized this analytic approach by presenting the stream depletion factor (SDF) shown in the equations below. Several authors have recently reintroduced SDFs into the literature with several publications addressing conjunctive water
Data Collection Plan

Bredehoeft (2010) investigated the impacts of seasonal pumping from a well (or series of wells) located at various distances from a stream. Regulatory agencies frequently use the SDF method (Miller and Dunford 2007), including the state of Colorado which utilizes SDFs for the management of conjunctive use programs along the South Platte and Arkansas rivers (Bredehoeft and Kendy 2007).

\[
q_s = Q_w \cdot erfC \cdot \left[ \frac{a^2 S}{4T} \right]^{1/2}
\]

\[
SDF = \frac{a^2 S}{T}
\]

\[
q_s = Q_w \cdot erfC \cdot \left[ \frac{SDF}{4c} \right]^{1/2}
\]

Where the variables are defined as:

- \( q_s \) = instantaneous stream depletion
- \( Q_w \) = pumping rate of the well
- \( erfC \) = complementary error function
- \( a \) = distance from the stream to the well
- \( T \) = aquifer transmissivity
- \( S \) = aquifer storage coefficient
- \( t \) = time since pumping started
- \( SDF \) = stream depletion factor (\( a^2 S/T \))

Over time, if the magnitude of groundwater discharge (both natural and anthropogenic) exceeds groundwater recharge, there will be a change in storage and a corresponding decline in the water table. Once the water table has been lowered below the elevation of a streambed, stream-aquifer interaction has been reduced to a one-way leakage from the stream into the aquifer. In this case, the stream is characterized as being “decoupled” from the aquifer and water leaks from it into the aquifer at a rate that is independent of the water table elevation. Also as groundwater elevations decline, spring discharges will inevitably be reduced.

2.5 Conjunctive Management

In the California Water Plan Update (2009), the Department of Water Resources (DWR) defines conjunctive management as “the coordinated and planned use and management of both surface water and groundwater resources to maximize the availability and reliability of water supplies in a region to meet various management objectives.” Within the Shasta Valley, potential conjunctive management objectives and strategies might be as follows:

1. Meet stream flow quantity and water quality targets by using groundwater in lieu of surface water at certain strategic times, and locations. For example, in places where surface water serves as the primary irrigation source but groundwater is also available, irrigation diversions could be suspended at key times to sustain instream habitat for fish provided that groundwater...
supplies could be developed to offset the loss of surface water, and accounting for the effects of pumping on streamflow and spring discharge.

2. Enable increased groundwater extraction and contribute to increased streamflow, modified streamflow timing or improved streamflow quality (cooler temperatures) by increasing aquifer recharge. For example, during periods of surplus streamflow, surface water could be diverted into canals and ditches and allowed to leak into the aquifer.

However, in general, the Shasta Valley does not have thick alluvial aquifers with substantial storage and yield potential. In most cases, it is the drawdown and subsequent refilling of available aquifer storage that facilitates large scale conjunctive management. There may be specific conjunctive management opportunities in certain subareas (Davids Engineering 2010 and 2012\(^7\)), but the potential for large scale groundwater development and conjunctive management in the Shasta Valley appears to be very limited. Conjunctive use to improve water quality (specifically water cooling) may have greater merit. One of the goals of the data collection activities discussed in Section 6 is to develop data that will help answer the questions of whether either of these, or other conjunctive management strategies could be implemented in the future as a means of supporting certain stream or aquifer management objectives.

### 2.6 Monitoring Areas and Groundwater Subareas

DWR defined eight hydrologic subareas within the Shasta River watershed (Figure 5) during the development of a Shasta Valley Data Needs Assessment (Ward and Eaves 2008). The hydrologic subareas were delineated based on a combination of hydrologic and geologic considerations and are useful for understanding hydrogeologic processes and variability in the Shasta Valley. Collectively, the subareas shown in Figure 5 encompass the entire watershed.

For purposes of developing this monitoring program, we have adopted a geographic breakout of the basin aligned with certain water management objectives rather than physical features. The following four monitoring locations or areas have been identified:

1. Stream Reaches
2. Groundwater Dependent Areas
3. Anthropogenic Recharge Areas and
4. Upland Watershed Areas

Additional information about the four monitoring areas, including maps, is provided in Section 5.1.

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\(^7\) The Hydrogeologic Assessment of the Little Shasta River explores the idea of increased pumping from the Pluto’s Cave Basalt formation underlying portions of the Hart Ranch as a substitute to surface water diversions.
Figure 5. Shasta Valley Hydrologic Sub-Areas (Ward and Eaves 2008)
3.0 Inventory of Historical and Existing Hydrologic Monitoring

To provide a basis for prescribing additional hydrologic monitoring in the Shasta River basin, Davids Engineering conducted an inventory of available information pertaining to past and ongoing monitoring activities. Publicly available streamflow, groundwater level, diversion, groundwater quality, precipitation, reservoir elevation/storage, and surface water quality data sources were reviewed and available data described in tabular format in an Excel spreadsheet for convenient access.

Table 2 lists the types and numbers of monitoring sites identified by the inventory, including how many sites are currently active.

<table>
<thead>
<tr>
<th>Monitoring Site Type</th>
<th>Total Number of Sites</th>
<th>Total Number of Active Sites</th>
</tr>
</thead>
<tbody>
<tr>
<td>Canal Diversion</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Groundwater Level</td>
<td>166</td>
<td>28</td>
</tr>
<tr>
<td>Groundwater Quality</td>
<td>22</td>
<td>13</td>
</tr>
<tr>
<td>Precipitation</td>
<td>6</td>
<td>5</td>
</tr>
<tr>
<td>Reservoir Elevation</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Reservoir Storage</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>River Stage</td>
<td>9</td>
<td>8</td>
</tr>
<tr>
<td>Snow Depth</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Snow Water Content</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Streamflow</td>
<td>7</td>
<td>5</td>
</tr>
<tr>
<td>Surface Water Quality</td>
<td>35</td>
<td>2</td>
</tr>
</tbody>
</table>

The inventory included defining the following attributes for each site:

- Site ID or Site Name
- Geographic coordinates
- Elevation
- Operating/maintaining Agency
- Web link for data access (if available)
- Data type, frequency and continuity
- Period of record
- Status (active/inactive)

The inventory is described in Appendix B and a copy of the inventory database is available from the Shasta Valley RCD upon request.
4.0 Basic Regional Data Collection

In addition to the existing (active) monitoring activities discussed in Section 3.0 and the expanded monitoring described in Sections 5.0 and 6.0, there are certain other types of basic data that are foundational to regional water and land resource management. This foundational data collection is not addressed in detail in this stream-aquifer monitoring program, but foundational data needs are described and certain recommendations are provided in the following subsections.

4.1 Land Use

4.1.1 DWR Surveys

For decades, DWR has conducted land use surveys of agricultural lands throughout the state. DWR’s goal is to survey land use in each county at approximately 5-year intervals. However, in recent years, the interval between surveys has increased. The most recent survey available for Siskiyou County is 2010.

The irrigated acreage and cropping information provided by the DWR surveys is invaluable for quantifying crop water consumption (evapotranspiration or ET), which represents the second largest outflow of water from the Shasta River basin after streamflow, and for detecting trends in land and water use. Additionally, some DWR surveys record the irrigation method and water source (surface water, groundwater or a combination of the two). These parameters are also useful for quantifying and analyzing water use. Table 3 provides a summary of the water source for roughly 64,000 acres being irrigated in the Valley as identified by the 2010 survey.

<table>
<thead>
<tr>
<th>Water Source</th>
<th>Totals</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface Water (SW)</td>
<td>53867</td>
</tr>
<tr>
<td>Mixed (SW/GW)</td>
<td>145</td>
</tr>
<tr>
<td>Groundwater (GW)</td>
<td>9498</td>
</tr>
<tr>
<td>Unknown</td>
<td>131</td>
</tr>
<tr>
<td>Reclaimed</td>
<td>52</td>
</tr>
<tr>
<td>Totals</td>
<td>63693</td>
</tr>
</tbody>
</table>

DWR uses aerial photos and, more recently, satellite imagery to define irrigated field boundaries. Presently, most of the land use survey data is entered directly into a digital map using geographic information system (GIS) software on a laptop computer. Georeferenced imagery is used as a background, and the land use boundaries are visible on top of the imagery. DWR staff typically visit and visually identify land uses and crops on more than 95 percent of the developed agricultural lands within each survey area.

After field work has been completed, a digital map of the survey area is created from the work of individual surveyors. Using GIS software, digital maps of quads, counties, water districts, and the DWR's hydrologic planning units (Detailed Analysis Units) can be overlaid on the land use data to develop acreage summaries of land use within these different geographic areas.
Given the high importance associated with this foundational dataset, the RCD or county officials should open dialogue with DWR about how to get the surveys completed at the 5-year interval nominally targeted by DWR, which is sufficiently frequent for most analytic purposes.

4.1.2 National Agricultural Statistics Service Surveys

At the federal level, the National Agricultural Statistics Service (NASS) has been developing and refining a Remote Sensing based approach to land use surveys. NASS has been using satellite images since 1972 to refine crop acreage estimates. Currently, NASS has three major applications of remote sensing with respect to crop acreage estimates. The following excerpt from the NASS website\(^8\) describes the three applications:

First is the operational construction of the nation's area sampling frame for agricultural statistics, which has used satellite imagery as a major input since 1978. The area sampling frame is the statistical foundation for providing agricultural estimates with complete coverage of American agriculture. Crop acreage estimation is only one part of this system. The second application, which is now done for seventeen states per year, has been the use of satellite imagery to improve the statistical precision of crop acreage estimate indicators, especially at the county level in those states. This was the first NASS application of Landsat data and it began in 1972. The third application, and most popular with Geographic Information System (GIS) data users, is the formation of a public use GIS data file called the Cropland Data Layer. The Cropland Data Layer is the crop specific categorization of the "best available" set of Landsat (30 meter resolution) digital imagery for the crop(s) season of interest. Data users have recently used the Cropland Data Layer to aid in watershed monitoring, soils utilization analysis, agribusiness planning, crop rotation practices analysis, animal habitat monitoring, prairie water pothole monitoring, and in the remote sensing/GIS value added industry.

Because they are based on remotely sensed data rather than ground based surveys, the cropping data generated by NASS is generally less reliable that that generated by DWR’s on-the-ground surveys, plus NASS does not provide any information on water source or irrigation method. However, the reliability of the NASS data appears to be improving over time as remote sensing procedures evolve, and this source of data may be relied upon more heavily in the future, especially if DWR surveys become increasingly less frequent.

4.2 Weather Data

4.2.1 Reference Evapotranspiration

As mentioned above, crop ET is believed to be the second largest outflow from the Shasta Valley after Shasta River discharge to the Klamath River. Traditionally, crop ET is calculated on a crop by crop basis (thus the importance of land use data) using the “crop coefficient times reference ET” approach, with crop coefficients established through research and reference ET derived from weather data.

DWR maintains a network of about 120 weather station statewide as part of its California Irrigation Management Information System (CIMIS) program, primarily to provide reliable reference ET data to water managers. However, there are no CIMIS weather stations in Valley, with the closest one being

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\(^8\) A more detailed discussion of NASS remotely sensed crop acreage estimates can be found at: [http://www.nass.usda.gov/Surveys/Remotely_Sensed_Data_Crop_Acreage/](http://www.nass.usda.gov/Surveys/Remotely_Sensed_Data_Crop_Acreage/)
Station #91 located on the grounds of a University of California Field Station near Tulelake. Using the Tulelake CIMIS weather station for estimating Shasta Valley reference ET introduces uncertainty due to differences in elevation and climate between the two areas. Uncertainty in the calculation of ET can end up impacting the results of a variety of water resource calculations and investigations that rely on accurate estimates of ET (e.g. water balance analyses). Therefore, it is recommended that a new CIMIS weather station be placed in the Shasta Valley.

There are certain critical factors that must be considered to correctly site weather stations, to ensure that the weather data are correct and the reference ET estimates derived from the data are sufficiently reliable. In general, CIMIS weather stations should be located within the area they are intended to represent. Additionally, a local sponsor is needed for day to day maintenance of each CIMIS station. Frequently the best sponsors are local public agencies with the sites placed near agency offices or facilities. Often tradeoffs are made between what is ideal from a technical perspective and what is practical from an access and maintenance perspective.

The Shasta Valley RCD or Siskiyou County should look for a CIMIS weather station sponsor and approach DWR about siting such a station in the Valley.

### 4.2.2 Energy Balance Modeling of ET

Over the past approximately 15 years, new remote sensing based methods for estimating ET through energy balance modeling have gained acceptance among many water resource analysts and managers. The methodology involves using satellite data to calculate an energy balance at the Earth’s surface. The balance is based on the principle of conservation of energy, so that net incoming solar radiation is used to heat either the air mass, the soil mass or to convert liquid water to water vapor, the latter term representing ET (Figure 6).

The original energy balance model is SEBAL developed by Wim Bastiaanssen from The Netherlands. SEBAL has been applied in many climatic conditions worldwide and is extensively validated. Later the METRIC model was developed by Rick Allen of the University of Idaho. METRIC is a variant of SEBAL with

---

**Figure 6. Conceptual Representation of Surface Energy Balance**

ET is calculated as a “residual” of the energy balance

\[
ET = R_n - G - H
\]

The energy balance includes all major sources \(R_n\) and consumers \((ET, G, H)\) of energy.
certain modifications made that may improve model performance in irrigated areas. Both models are most commonly applied using Landsat satellite data, although data from other satellites may be used. On a seasonal basis over large irrigated areas, both models are generally thought to provide ET estimates within ±5 percent of actual ET on a seasonal basis. This is considerably more accurate than the traditional ET estimating methods.

One interesting feature of energy balance modeling is that it does not require detailed cropping information or ground based weather data to provide reliable results, although model performance is enhanced with ground-based data.

The cost of running energy balance models is appreciable because the models are complex and significant labor is required by trained, skilled analysts. However, the cost on a unit area basis is very low because each Landsat image covers an area of roughly six million acres. The Landsat image that covers the Shasta River basin also covers the Scott Valley and a large portion of the Klamath River watershed, including the entire Klamath Project.

In addition to the foregoing recommendations to continue DWR land use surveys and to place a CIMIS weather station in the Shasta Valley for purposes of supporting crop ET calculations, the RCD should seek opportunities to co-sponsor a SEBAL of METRIC energy balance application to provide accurate estimates of water consumption in the Shasta River basin (and in other areas included in the satellite image).

4.2.3 Precipitation

The Parameter-elevation Regressions on Independent Slopes Model (or PRISM\(^9\)) is a unique knowledge-based system that uses point measurements of precipitation, temperature, and other climatic factors to produce continuous, digital gridded estimates of monthly, yearly, and event-based climatic parameters. This unique analytical tool is continuously updated and incorporates point data, a digital elevation model, and expert knowledge of complex climatic extremes, including rain shadows, coastal effects, and temperature inversions. PRISM data sets are recognized world-wide as the highest-quality spatial climate data sets currently available. PRISM is the US Department of Agriculture’s official climatological data source.

Additional ground based precipitation data should be provided to the PRISM Climate Group at Oregon State University to further refine PRISM data within the Shasta Valley.

Due to the highly variable nature of precipitation within the Shasta Valley, it is recommended that improvements to the precipitation measurement network be made. These improvements are discussed in detail in Sections 6.4.1 and 6.4.2.

\(^9\) More information about PRISM can be found at the following website: [http://www.prism.oregonstate.edu/](http://www.prism.oregonstate.edu/)
5.0 Monitoring Framework

5.1 Monitoring Areas

Four types of monitoring areas were previously introduced in Section 2; these are Stream Reaches, Groundwater Dependent Areas, Anthropogenic Recharge Areas and Upland Watershed Areas. In this section, a brief description of each type of area is provided and the general rationale and objectives for monitoring are described. The first three monitoring areas are not mutually exclusive geographically because, for example, Stream Reaches can cross Groundwater Dependent Areas, or Anthropogenic Recharge Areas can be located in Groundwater Dependent Areas.

5.1.1 Stream Reaches

The most extensive interaction between groundwater and surface water systems often occurs along the riparian corridors of streams. Streams provide an important source of water supply for irrigation in addition to critical habitat for aquatic and riparian species. Additional stream flow data will help to characterize temporal and spatial patterns of interaction between streams and aquifers. Streams with high environmental and/or economic significance include the following: Shasta River, Parks Creek, Willow Creek, Julian Creek, Yreka Creek and the Little Shasta River.

Specific Stream Reach monitoring objectives include the following:

- Identify gaining and losing stream reaches
- Quantify the magnitude of stream flow gains and losses
- Characterize temporal variability in stream flow gains and losses
- Identify recharge zones associated with (upgradient of) gaining stream reaches

Stream Reaches are shown on Figure 7, presented after Section 5.1.4.

5.1.2 Groundwater Dependent Areas

Groundwater dependent areas include areas of the Shasta Valley that rely on groundwater for municipal, industrial or agricultural water supplies. It is assumed that areas within the Shasta Valley that do not currently have significant groundwater development for urban or agricultural purposes probably overlie aquifers where well yields are too small for economic water production for those purposes (but may be sufficient for satisfying domestic water demands).

Table 4 provides a summary of water sources for the different population centers in the Shasta Valley. Gazelle CDP\textsuperscript{10}, Grenada CDP, Weed, Yreka\textsuperscript{11}, Carrick CDP, Edgewood CDP and Lake Shastina all depend on groundwater as their primary water supply.

\textsuperscript{10} CDP denotes Census Defined Place, essentially a small village or community without formal governmental infrastructure.
\textsuperscript{11} Yreka primarily depends on surface water from Fall Creek, relying on groundwater for emergency and backup purposes.
Figure 7. Shasta Valley Stream Reaches
### Table 4. Municipal and Industrial Groundwater Dependent Areas

<table>
<thead>
<tr>
<th>Population Center</th>
<th>Median Household Income</th>
<th>Population</th>
<th>Water source</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gazelle CDP</td>
<td>$30,625</td>
<td>136</td>
<td>Individual wells</td>
<td>Small lots, individual septic systems</td>
</tr>
<tr>
<td>Grenada CDP</td>
<td>$27,813</td>
<td>351</td>
<td>Private water system, one well</td>
<td>System recently upgraded</td>
</tr>
<tr>
<td>Montague</td>
<td>$22,991</td>
<td>1456</td>
<td>Lake Shastina and the Little Shasta River</td>
<td>Difficulties meeting drinking water quality standards</td>
</tr>
<tr>
<td>Weed</td>
<td>$36,300</td>
<td>2978</td>
<td>Spring</td>
<td>Lease M&amp;I water from Roseburg Lbr. Lease expires soon.</td>
</tr>
<tr>
<td>Yreka</td>
<td>$27,398</td>
<td>7290</td>
<td>Fall Creek (Tributary to Klamath), B.U. well tapping Yreka Creek underflow</td>
<td>Fall Creek system at or beyond capacity at times in summer</td>
</tr>
<tr>
<td>Carrick CDP</td>
<td>$22,986</td>
<td>156</td>
<td>Mix of community system water and individual wells</td>
<td>Individual septic systems.</td>
</tr>
<tr>
<td>Edgewood CDP</td>
<td>$50,750</td>
<td>67</td>
<td>Individual wells</td>
<td>Small lots, individual septic systems</td>
</tr>
<tr>
<td>Lake Shastina</td>
<td>Lumped with Weed</td>
<td>2500</td>
<td>Seven Community Service District operated wells.</td>
<td>Water system already at capacity at times in summer. Full build out population estimate 12,000. Central waste water system for most residents.</td>
</tr>
</tbody>
</table>

Specific Groundwater Dependent Area monitoring objectives include the following:

- Establish baseline groundwater levels and detect changes from baseline
- Establish baseline groundwater quality and detect changes from baseline
- Establish baseline spring discharge and detect changes from baseline
Groundwater Dependent areas are shown on Figure 8, presented after Section 5.1.4. Portions of the Valley irrigated with groundwater are indicated by green, while yellow indicates urban groundwater use areas.

5.1.3 Anthropogenic Recharge Areas

In the Shasta Valley, anthropogenic recharge sources primarily include:

1. Deep percolation of applied irrigation water,
2. Seepage from manmade water storage facilities, and
3. Seepage from manmade water conveyance facilities.

Specific Anthropogenic Recharge Area monitoring objectives include the following:

- Quantify the magnitude, temporal and spatial variability of deep percolation of applied irrigation water
- Quantify the magnitude, temporal and spatial variability of seepage from manmade water storage and conveyance facilities
- Determine destinations and temporal variability of anthropogenic recharge.

Potential anthropogenic Recharge Areas are shown on Figure 9, presented after Section 5.1.4. Portions of the Valley irrigated with either surface water or groundwater are shown in green, Lake Shastina is outlined in blue and the three largest water conveyance ditches are identified. Additionally, there are many relatively small irrigation ditches in the Shasta Valley that collectively may contribute substantially to anthropogenic recharge.

5.1.4 Upland Watershed Areas

Essentially, Upland Watershed Areas encompass the remainder of the watershed (i.e. the areas not included within the other monitoring areas). Upland Watershed Areas are critical from both a water supply and water quality perspective. The majority of precipitation and natural recharge occur in the Upland Watershed Areas.

Specific Upland Watershed Area monitoring objectives include the following:

- Detect land use changes that could affect recharge rates and water quality
- Establish baseline precipitation quantities and detect changes from the baseline

Upland Watershed Areas are not illustrated because they encompass the remainder of the watershed (outside the Groundwater Dependent Areas and Anthropogenic Recharge Areas).
Figure 8. Shasta Valley Groundwater Dependent Areas
Figure 9. Shasta Valley Anthropogenic Recharge Areas
5.2 **Monitoring Methods and Analyses**

Section 4 of the Shasta Valley Workplan (Appendix A) provides an overview of various technical methods available for characterizing the interactions between groundwater and surface water systems. Table 5 presents a brief summary of these methods, including monitoring methods to gather data and analytical methods, such as water balances, to make determinations from data.

5.3 **Monitoring Methods and Areas**

Table 6 presents a matrix of the Monitoring Areas discussed in Section 5.1 and the Monitoring Methods discussed in Section 5.2, indicating the types of monitoring methods that are generally applicable to each of the different monitoring areas. Cell entries are statements of the purpose for which a monitoring method would be applied to the different monitoring areas. Cell entries of “n/a” indicate that there is no meaningful application of a monitoring method to the type of monitoring area.
<table>
<thead>
<tr>
<th>Analytical Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Groundwater Level Monitoring</strong></td>
<td>Regular measurements over time of groundwater levels are the foundation of many types of groundwater analyses. Groundwater levels can be measured in existing private or public groundwater production wells or in 'dedicated' monitoring wells.</td>
</tr>
<tr>
<td><strong>Aquifer Performance Testing</strong></td>
<td>Aquifer performance testing is a field method used to quantify both the hydraulic conductivity (usually in the form of the transmissivity) and the storage coefficient (either SS or SY). In an aquifer performance test, the aquifer is stressed or stimulated through either constant rate or stepped rate pumping while the response of the aquifer is measured in nearby observation wells.</td>
</tr>
<tr>
<td><strong>Stream Flow Monitoring</strong></td>
<td>Continuous streamflow records provide foundational information for hydrologic investigations. Expanded and improved flow measurement within the Valley would be beneficial for several reasons, primarily for delineation of gaining and losing stream reaches, and how stream accretions and depletions vary over space and time.</td>
</tr>
<tr>
<td><strong>Land and Water Use Surveys</strong></td>
<td>By the mid 1960's DWR initiated an ongoing program to perform land use surveys. Understanding the source of applied irrigation water (groundwater, surface water, or both) is a critical component to understanding the evapotranspiration component of any water balance. More recently the National Agricultural Statistics Service (NASS) has begun providing a remotely sensed crop acreage data product; however, the reliability of the data has yet to be validated.</td>
</tr>
<tr>
<td><strong>Water Balance Analysis</strong></td>
<td>Water budgets, or water balance analyses, are prepared for study areas defined by specific spatial and temporal boundaries. Water balances quantify study area inflows, outflows, internal routing, and changes in water storage in each analysis time step. Water balances for irrigation dominated areas focus on characterizing spillage, seepage, deep percolation, drainage, and crop consumptive use flow paths under existing (or baseline) conditions. The baseline water balance serves as the basis for estimating the effects of different conservation measures or other changes in hydrology.</td>
</tr>
<tr>
<td><strong>Infiltration Tests</strong></td>
<td>The purpose of an infiltration test is to determine how quickly water goes from the surface of a soil to within the soil profile. Under steady conditions, once soil saturation is reached, an infiltration test quantifies the saturated vertical hydraulic conductivity of a surface geologic layer.</td>
</tr>
<tr>
<td><strong>Tracer Analysis</strong></td>
<td>Tracer studies are often used to help characterize groundwater-surface water interactions at small spatial scales. Tracers can be divided into two categories: natural and anthropogenic tracers. Natural tracers are parameters that are naturally part of the hydrologic cycle such as temperature, stable and radioactive isotopes, chloride and others. Anthropogenic tracers are parameters that are introduced into the hydrologic cycle with the specific goal of furthering the understanding of how the system functions. Examples of anthropogenic tracers generally include various fluorescent dyes and salts.</td>
</tr>
<tr>
<td><strong>Geochemical Investigations</strong></td>
<td>Bulk chemical analysis of groundwater and surface water samples can help determine water types, flow paths, residence times and water-rock interactions. Isotopes, as a complement to geochemistry and physical hydrogeology, are now routinely used to answer questions regarding groundwater provenance, movement and sustainable use (Clark and Fritz 1997).</td>
</tr>
<tr>
<td><strong>Numerical Groundwater Modeling</strong></td>
<td>In hydrogeology, there are two specific areas reliant on modeling: (1) understanding why a hydrogeologic system behaves in a certain way and (2) understanding how a hydrogeologic system will respond to new stressors (Fetter 1988). There is significant value in a groundwater model’s ability to (1) bring understanding to the types, trends and orders of magnitude of the responses we might expect when introducing new stressors (i.e. pumping, diversions, etc.) and (2) elucidate which parameters most strongly influence the behavior of the system.</td>
</tr>
<tr>
<td>Monitoring Methods</td>
<td>Monitoring Areas</td>
</tr>
<tr>
<td>------------------------------------</td>
<td>-----------------------------------------------------------------------------------</td>
</tr>
<tr>
<td><strong>Groundwater Level Monitoring</strong></td>
<td>Monitor shallow groundwater adjacent to streams to determine stream-aquifer exchanges</td>
</tr>
<tr>
<td><strong>Aquifer Performance Testing</strong></td>
<td>Determine the magnitudes and timescales of streamflow capture when pumping a well located near a stream</td>
</tr>
<tr>
<td><strong>Streamflow Monitoring</strong></td>
<td>Characterize temporal and spatial patterns of stream gains and losses</td>
</tr>
<tr>
<td><strong>Land and Water Use Surveys</strong></td>
<td>n/a</td>
</tr>
<tr>
<td><strong>Water Balance Analysis</strong></td>
<td>Utilize streamflow monitoring data to determine stream reach water balances</td>
</tr>
<tr>
<td><strong>Infiltration tests</strong></td>
<td>Calculate streambed vertical conductivities</td>
</tr>
<tr>
<td><strong>Tracer Analysis</strong></td>
<td>Characterize temporal and spatial patterns of stream gains and losses utilizing temperature as a durable tracer</td>
</tr>
<tr>
<td><strong>Geochemical Investigations (temperature and isotopes)</strong></td>
<td>Identify average recharge elevations and residence times from stable and radioactive isotopes respectively</td>
</tr>
<tr>
<td><strong>Numerical Groundwater Modeling</strong></td>
<td>Map areas of stream flow capture given certain well placements and pumping intervals/rates (Leake et al. 2010)</td>
</tr>
<tr>
<td><strong>Spring Flow Measurement</strong></td>
<td>Characterize groundwater discharge to the surface water system</td>
</tr>
</tbody>
</table>
6.0 Specific Monitoring Plans

This section identifies specific monitoring activities organized by the four monitoring areas described in the preceding section. Many of the activities employ combinations of the monitoring methods discussed in Section 5.2 and presented in Table 7. Table 7 provides a summary of 17 recommended activities organized by Monitoring Area. The tasks are prioritized into three groups (from highest to lowest priority): A, B, and C. Sections 6.1 through 6.5 further define each of the recommended Monitoring Activities. Additional detail is provided for priority A Monitoring Activities, including reconnaissance level cost estimates.

Table 7. Recommended Monitoring Activities and Priorities by Monitoring Area

<table>
<thead>
<tr>
<th>Monitoring Area</th>
<th>Task</th>
<th>Priority</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stream Reaches</td>
<td>Design/install permanent upstream boundary gages (Section 6.1.1)</td>
<td>A</td>
</tr>
<tr>
<td>Stream Reaches</td>
<td>Investigate and establish permanent intermediate stream gage locations (Section 6.1.2)</td>
<td>A</td>
</tr>
<tr>
<td>Stream Reaches</td>
<td>Prioritize, design, and install permanent intermediate gages (Section 6.1.3)</td>
<td>B</td>
</tr>
<tr>
<td>Stream Reaches</td>
<td>Conduct piezometer transect studies adjacent to high priority gaining stream reaches (Section 6.1.4)</td>
<td>B</td>
</tr>
<tr>
<td>Stream Reaches</td>
<td>Conduct longitudinal stream water temperature analysis (Section 6.1.5)</td>
<td>B</td>
</tr>
<tr>
<td>GW Dependent</td>
<td>Improve groundwater level monitoring, including expanded use of continuously recording water level sensors (Section 6.2.1)</td>
<td>A</td>
</tr>
<tr>
<td>GW Dependent</td>
<td>Site and construct new dedicated monitoring wells (Section 6.2.2)</td>
<td>B</td>
</tr>
<tr>
<td>GW Dependent</td>
<td>Conduct aquifer performance testing in alluvial and fractured rock aquifers (Section 6.2.3)</td>
<td>C</td>
</tr>
<tr>
<td>GW Dependent</td>
<td>Numerical groundwater modeling (Section 6.2.4)</td>
<td>C</td>
</tr>
<tr>
<td>Anthropogenic Recharge</td>
<td>Conduct Lake Shastina recharge assessment (Section 6.3.1)</td>
<td>A</td>
</tr>
<tr>
<td>Anthropogenic Recharge</td>
<td>Conduct irrigation conveyance system recharge assessment (primarily Montague Water Conservation District Main Canal, China Ditch, Grenada ID and Shasta Water Association conveyance systems) (Section 6.3.2)</td>
<td>A</td>
</tr>
<tr>
<td>Anthropogenic Recharge</td>
<td>Conduct irrigated lands water balance analyses to characterize temporal and spatial patterns of deep percolation (Section 6.3.3)</td>
<td>B</td>
</tr>
<tr>
<td>Upland Watershed</td>
<td>Install additional precipitation stations on the Shasta Valley floor (Section 6.4.1)</td>
<td>A</td>
</tr>
<tr>
<td>Upland Watershed</td>
<td>Install continuous snow water equivalent sensors at existing snow measurement stations (Section 6.4.2)</td>
<td>B</td>
</tr>
<tr>
<td>Upland Watershed</td>
<td>Monitor permitting processes related to land use changes (Section 6.4.3)</td>
<td>C</td>
</tr>
<tr>
<td>Springs</td>
<td>Implement spring discharge measurement - Big Springs, Little Springs, Kettle Spring, Clear Spring, Bridgefield Spring, Others? (Section 6.5.1)</td>
<td>A</td>
</tr>
<tr>
<td>Springs</td>
<td>Implement spring discharge measurement - Evans Spring, Martin Spring, Stewart Springs, Others? (Section 6.5.2)</td>
<td>B</td>
</tr>
</tbody>
</table>
6.1 Stream Reaches

6.1.1 Design and Install Permanent Upstream Boundary Stream Gages (Priority A)

Monitoring streamflow is critically important to characterizing groundwater in the Shasta Valley. Figure 10 shows the Shasta River and its five (5) main tributaries: Parks Creek, Big Springs Creek, Willow Creek, Julian Creek, and the Little Shasta River. The most upgradient streamflow gage on each stream should be located above all major diversions and artificial return flows. Correctly sited, these six (6) sites (one for each of the five tributaries and one for the Shasta River) will serve as Upstream Boundary Gages for measuring surface water inflows to the Valley, such as are needed to inventory water supplies and to enable hydrologic analyses. The locations of the Upstream Boundary Gages are identified on Figure 10 (see red dots). Additional details for the six (6) Upstream Boundary Gages are provided in Table 8. Among the six sites, Willow Creek and Julian Creek are ephemeral stream sites, while the others are perennial. The perennial stream sites should be given higher priority while the need and advisability of monitoring the ephemeral sites is further assessed.

The reconnaissance level cost estimate to install the six (6) Upstream Boundary Gages is $270,000 (i.e. 6 gages @ $45,000/EA). Developing operations and maintenance (O&M) costs for ongoing monitoring activities (e.g. stream gages, groundwater level monitoring wells, etc.) was outside of the scope of this effort. O&M costs for all ongoing monitoring activities will need to be determined as implementation is initiated. The following assumptions were made to develop this cost estimate:

- Substantial in-channel modifications will not be required
- The sites will be SCADA-Ready
- Land acquisition will not be required

<table>
<thead>
<tr>
<th>Stream Gage ID</th>
<th>Stream</th>
<th>River Mile</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Existing Gage</th>
</tr>
</thead>
<tbody>
<tr>
<td>SR1</td>
<td>Shasta River (perennial)</td>
<td>52.8</td>
<td>41.408165</td>
<td>-122.431783</td>
<td>no</td>
</tr>
<tr>
<td>BC1</td>
<td>Big Springs Creek (perennial)</td>
<td>0.0</td>
<td>41.594263</td>
<td>-122.437861</td>
<td>?</td>
</tr>
<tr>
<td>PC1</td>
<td>Parks Creek (perennial)</td>
<td>14.2</td>
<td>41.435212</td>
<td>-122.474421</td>
<td>no</td>
</tr>
<tr>
<td>WC1</td>
<td>Willow Creek (ephemeral)</td>
<td>13.9</td>
<td>41.487531</td>
<td>-122.558802</td>
<td>no</td>
</tr>
<tr>
<td>JC1</td>
<td>Julian Creek (ephemeral)</td>
<td>1.5</td>
<td>41.654691</td>
<td>-122.520425</td>
<td>no</td>
</tr>
<tr>
<td>LS1</td>
<td>Little Shasta River (perennial)</td>
<td>14.6</td>
<td>41.742378</td>
<td>-122.328183</td>
<td>no</td>
</tr>
</tbody>
</table>

Table 8. Upstream Boundary Stream Gage Details

12 “SCADA-Ready” describes a package of hardware and software that communicates and operates locally but has been specifically designed and installed to readily accept a data transmission and receiving device (radio, cellular modem, etc.) and to provide remote communication with an established base station and SCADA human machine interface (HMI).
Figure 10. Proposed Shasta Valley Boundary Stream Gage Locations
6.1.2 Investigate and Establish Permanent Intermediate Stream Gage Locations (Priority A)

Permanent Intermediate Stream Gages are needed to provide a more detailed spatial understanding of stream-aquifer interaction along Stream Reaches. However, currently available data is not sufficient to determine desirable locations for Intermediate Stream Gages, generally defined as the upper and lower ends of gaining or losing Stream Reaches. The Intermediate Stream Gage Siting Study will involve the collection of instantaneous flow measurements along the Shasta River and its five (5) primary tributaries. The instantaneous flow measurements will be performed downstream of the Upstream Boundary Gages discussed in Section 6.1.1.

Temporary water level sensors will be deployed at selected measurement locations to verify that steady-state conditions exist. If flow rate fluctuations are detected during the instantaneous flow measurement periods, water level data will be used to make adjustments to compensate for the fluctuations. Field data collection will be performed during periods when the streams do not have substantial surface outflows due to either irrigation diversions or inflows due to storm runoff and tailwater. These conditions are most likely to occur between late fall and early spring. If these conditions do not exist, then inflows and outflows will need to be measured.

A stream reach water balance will be applied to each of the test reaches to determine net gain or loss between the measurement points. A conceptual stream reach water balance is shown in Figure 11. As indicated in the figure, inflows to a stream reach may include inflow from upper reaches, tributary inflows, return flows (which could include surface or subsurface inflows from agricultural lands), and other subsurface inflow (accretion). Outflows may include outflow to lower reaches, diversions, evaporation, and subsurface outflow (seepage or depletion).

![Figure 11. Conceptual Stream Reach Water Balance](image-url)
The permanent Intermediate Stream Gage locations (and associated stream reaches) will be sited based on the water balance results and consideration of geologic and other information, such as water temperature data, tempered by professional judgment. The effects of seepage and evaporation do not need to be accounted for specifically in the analysis, but are reflected in the calculated net stream-aquifer interaction (i.e. closure term) of each reach, to the extent that they are significant. As previously mentioned, for stream reaches with appreciable irrigation diversions and return flows, it may only be practical to perform stream reach water balances during the non-irrigation season.

The reconnaissance level cost estimate to perform the Intermediate Stream Gage Location Study is **$60,000**. The following assumptions were made to develop this cost estimate:

- 2 person flow measurement crew
- 10 days of field data collection and flow measurements
- Roughly 40 flow measurements (i.e. 4 measurements per day)
- Measurements performed with either a SonTek FlowTracker Acoustic Doppler Velocimeter (ADV) or a RiverSurveyor M9 Acoustic Doppler Current Profiler (ADCP)
- Temporary installation of water level and temperature sensors to detect and correct for unsteady flow conditions
- Preparation of a Technical Memorandum that summarizes flow measurements performed, stream reach water balance results and identifies recommended Intermediate Stream Gage locations
- Permission to access required measurement sites will be acquired ahead of time by others

### 6.1.3 Prioritization, Design, and Installation of Permanent Intermediate Stream Gages (Priority B)

This task involves the Prioritization, Design, and Installation of Intermediate Stream Gages according to the Intermediate Stream Gage Location Study (see Section 6.1.2). Preliminary Intermediate Stream Gage locations are shown in Figure 12 and site attributes are summarized in Table 9, based on current understandings of stream-aquifer interactions along each of the streams. Two of the intermediate gages are existing sites operated and maintained by the United States Geological Survey (sites SR6 and SR7). The remainder of the suggested nine new Intermediate Stream Gage sites will be grouped into two implementation phases to ensure that the most important and cost-effective sites are constructed first.
Figure 12. Intermediate Stream Gage Locations
### Table 9. Preliminary Intermediate Stream Gage Locations

<table>
<thead>
<tr>
<th>Stream Gage ID</th>
<th>Stream</th>
<th>River Mile</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Existing Gage</th>
</tr>
</thead>
<tbody>
<tr>
<td>SR2</td>
<td>Shasta River</td>
<td>46.1</td>
<td>41.488918</td>
<td>-122.431571</td>
<td>no</td>
</tr>
<tr>
<td>SR3</td>
<td>Shasta River</td>
<td>39.9</td>
<td>41.548735</td>
<td>-122.380276</td>
<td>no</td>
</tr>
<tr>
<td>SR4</td>
<td>Shasta River</td>
<td>35.0</td>
<td>41.580474</td>
<td>-122.429033</td>
<td>no</td>
</tr>
<tr>
<td>SR5</td>
<td>Shasta River</td>
<td>24.1</td>
<td>41.648033</td>
<td>-122.499376</td>
<td>no</td>
</tr>
<tr>
<td>SR6</td>
<td>Shasta River</td>
<td>45.5</td>
<td>41.709019</td>
<td>-122.538127</td>
<td>yes (USGS)</td>
</tr>
<tr>
<td>SR7</td>
<td>Shasta River</td>
<td>0.6</td>
<td>41.823364</td>
<td>-122.595155</td>
<td>yes (USGS)</td>
</tr>
<tr>
<td>PC2</td>
<td>Parks Creek</td>
<td>8.3</td>
<td>41.497803</td>
<td>-122.465109</td>
<td>no</td>
</tr>
<tr>
<td>PC3</td>
<td>Parks Creek</td>
<td>0.2</td>
<td>41.579562</td>
<td>-122.431328</td>
<td>no</td>
</tr>
<tr>
<td>WC2</td>
<td>Willow Creek</td>
<td>0.0</td>
<td>41.639793</td>
<td>-122.496191</td>
<td>no</td>
</tr>
<tr>
<td>LS2</td>
<td>Little Shasta River</td>
<td>11.8</td>
<td>41.722804</td>
<td>-122.369623</td>
<td>no</td>
</tr>
<tr>
<td>LS3</td>
<td>Little Shasta River</td>
<td>0.2</td>
<td>41.70137</td>
<td>-122.526251</td>
<td>no</td>
</tr>
</tbody>
</table>

### 6.1.4 Piezometer Transect Study of High Priority Gaining Reaches (Priority B)

Once high priority gaining stream reaches are identified through intermediate stream flow measurements, additional focused monitoring efforts should be utilized to further characterize stream-aquifer interaction and delineate connected recharge areas. Monitoring shallow groundwater elevations via a transect of piezometers aligned more or less perpendicular to the stream can help identify the direction and gradient of groundwater flow near the stream-aquifer boundary.

Figure 13 provides a conceptual sketch of a piezometer transect. By measuring the water level in the stream, and in the aquifer on either side of the stream it is possible to determine whether the stream is gaining or losing at the location of the piezometer transect. The magnitude of stream gain or loss can be estimated based on the flow gradient, saturated flow thickness and hydraulic conductivity of the alluvium.

### 6.1.5 Longitudinal Temperature Analysis (Priority B)

Distributed Temperature Sensing (DTS) utilizes fiber optic cables to perform temperature measurements. By accurately measuring changes in the frequency and amplitude of light waves, DTS can measure temperatures at a spatial resolution between 1 and 7 feet over a total distance of more than 15 miles, with temperature accuracies in the range of 0.05 to 0.9 degrees Fahrenheit (Selker 2006). By placing a continuous fiber optic cable along the center line of a streambed, stream reaches with significant groundwater accretions can be located. The Center for Transformative Environmental Monitoring Programs (CTEMPs) is cooperatively managed by Oregon State University, Corvallis and the University of Nevada, Reno, and funded by the National Science Foundation. CTEMPs provides interested parties with training and access to five field-deployable DTS systems that can be rented and delivered to project locations.

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13 “High Priority Gaining Reaches” are defined as stream reaches that gain substantial flow from groundwater discharge, provide valuable ecosystem functions and provide water supply for irrigation and other uses.
In the event that DTS is infeasible due to limited access or other issues, a similar analysis may be performed utilizing strategically located discrete temperature measurement points. The flow rate of point source inflows to streams (i.e. localized springs) can be estimated from thermal mixing equations if the following information is known:

1. Streamflow and temperature upstream of spring
2. Temperature of spring water
3. Stream temperature sufficiently downstream of spring to allow for thermal mixing and homogeneity

For either methodology, studies conducted outside the period of influence of stream diversion and return flow will provide the most meaningful temperature data.

Additionally, stream-aquifer temperature gradient measurements can be used to (1) qualitatively determine if the stream is gaining (receiving water from the aquifer) or losing (discharging water to the aquifer) and (2) quantitatively measure the vertical groundwater flux in the hyporheic zone (Constantz and Stonestrom 2003). Temperature measurements can further the understanding of focused hyporheic stream-aquifer interactions and can further substantiate and refine results from a Stream Reach Water Balance Analysis (Section 6.1.6).

As shown in Figure 14, Shasta Valley streams have large diurnal water temperature fluctuations caused by surficial heat transfer mechanisms (conduction, radiation and convection). In contrast, groundwater bodies have a relatively steady temperature due to (1) thermal insulation of the overlying geologic media and (2) the relatively large thermal reservoir provided by the aquifer system. In gaining stream reaches (portion A of Figure 14), adjacent shallow groundwater temperature will not show a strong
diurnal signature because water is flowing from depths where temperature is steady. In losing stream reaches (portion B of Figure 14), the downward flow of water will advectively carry the stream’s diurnal temperature into adjacent shallow groundwater.

6.2 Groundwater Dependent Areas

6.2.1 Improved Groundwater Level Monitoring (Priority A)

According to the U.S. Geological Survey (Taylor and Alley 2001), ‘Groundwater systems are dynamic and adjust continually to short-term and long-term changes in climate, ground-water withdrawal, and land use. Groundwater level measurements from observation wells are the principal source of information about the hydrologic stresses acting on aquifers and how these stresses affect groundwater recharge, storage, and discharge.’ Regular measurements over time of groundwater levels are the foundation of many types of groundwater analyses, including (1) evaluating long term trends and changes in aquifer storage (2) developing and calibrating numerical groundwater flow models, (3) performing water balance analyses, and (4) designing, implementing, and monitoring the effectiveness of groundwater management and protection programs.

All 28 active monitoring wells within the Shasta Valley are measured manually at varying frequencies of one, two or four times per year. However, spot measurements of groundwater levels in a well can miss critical stresses and the associated aquifer responses that occur over shorter timescales (e.g. days to months). One example of such a stress and response would be groundwater level drawdown and recovery due to pumping of a nearby well. Two additional examples would be the groundwater level response due to the start of irrigation in an adjacent area, or the start of water deliveries through an adjacent water conveyance facility (i.e. irrigation ditch).

The most important initial investment for improved groundwater level monitoring in the Shasta Valley is the addition of continuously logging water level sensors to existing monitoring wells. Twelve existing monitoring wells were selected for instrumentation based on (1) proximity to groundwater dependent areas, (2) length of historical records, and (3) overall geographic distribution. The 12 monitoring wells selected are shown on Figure 15. Areas dependent on groundwater as an irrigation supply are shown in...
The reconnaissance level cost estimate to instrument 12 of the existing monitoring wells with continuously logging water level sensors is **$48,000** (i.e. 12 wells @ $4,000/EA). The following assumptions were made to develop this cost estimate:

- Substantial well casing modifications will not be required
- The sites will be SCADA-Ready
- Pressure transducers that are equipped with direct-read MODBUS registers will be utilized for water level measurements
- Water levels will be recorded once an hour
- No land acquisitions will be required
- Permission to access required measurement sites will be acquired ahead of time by others

### 6.2.2 Siting and Construction of New Dedicated Monitoring Wells (Priority B)

The Shasta Valley does not have a large relatively homogenous alluvial aquifer. Rather, the Valley has various small quaternary alluvial sub-basins separated by geologic deposits associated with the Klamath Province, the Cascade Province and the Debris Flow. Therefore, siting additional monitoring wells is significantly more complicated than just looking for ‘holes’ in the existing groundwater level monitoring network. It is likely that areas requiring additional groundwater level monitoring will be identified during the implementation of Priority A monitoring tasks. Therefore, it is recommended that New Dedicated Monitoring Wells be sited after the completion of Priority A monitoring tasks.

### 6.2.3 Aquifer Performance Testing in Alluvial and Fractured Rock Aquifers (Priority C)

The ability of a geologic unit to transmit water under saturated conditions is an important hydraulic parameter. The saturated hydraulic conductivity (K) of a geologic formation is a function of several variables and can vary over several orders of magnitude and can often exhibit high spatial variability. In addition to characterizing how readily an aquifer transmits water, it is important to characterize the aquifer’s ability to store and release water under dynamic conditions; this is quantified by the storage coefficient. If the aquifer is confined, the storage coefficient is generally referred to as the specific storage (S<sub>S</sub>). The specific storage characterizes the ability of an aquifer to release groundwater from storage in response to a decline in the piezometric surface. If the aquifer is unconfined, the storage coefficient is generally referred to as the specific yield (S<sub>Y</sub>). The specific yield characterizes the ability of an aquifer to release groundwater from storage under the force of gravity.

Aquifer performance testing is a field method used to quantify both the hydraulic conductivity (usually in the form of the transmissivity) and the storage coefficient (either S<sub>S</sub> or S<sub>Y</sub>). In an aquifer performance test, the aquifer is stressed or stimulated through either constant rate or stepped rate pumping while the response of the aquifer is measured in nearby observation wells. The inverse of this can also be used, commonly referred to as the slug test, whereby a ‘slug’ of water is introduced into a well. Aquifer test results are then typically compared to an analytical model (the most common being the Theis solution), with the assumption that the real world case is sufficiently similar to the criteria used within
Figure 15. Distribution of Proposed Continuously Logging Groundwater Monitoring Wells
the analytic solution. In some cases it is necessary to compare aquifer test results to a numerical groundwater flow model to simulate real world complexities that are beyond the capabilities of analytical solutions.

Aquifer performance testing in the Shasta Valley could help to characterize basic aquifer parameters for the various hydrogeologic formations (e.g. Pluto’s Cave Basalt, Matrix portion of the Debris Flow, etc.) that at present are largely unknown. Among other things, improved understanding of the aquifer hydraulic conductivities and storage coefficients would support development of numerical models that could be used to compare and assess alternative groundwater management strategies within groundwater dependent areas. For example, appropriately conceived and coded groundwater models could help to evaluate alternative pumping and recharge scenarios aimed at identifying workable conjunctive management alternatives.

6.2.4 Numerical Groundwater Modeling (Priority C)

In hydrogeology, there are two specific areas reliant on modeling: (1) understanding why a hydrogeologic system behaves in a certain way and (2) understanding how a hydrogeologic system will respond to new stressors (Fetter 1988). “Model” is a generic term, referring to any representation of a real physical system. Modeling has now almost become synonymous with numerical computer modeling, which is only one specific type of groundwater model. Other types of groundwater models include analytic models, scale models, electrical analog models, and viscous-fluid models. Advances in computational devices in the 1970’s and 80’s led to numerical computer modeling being the most commonly used groundwater modeling technique.

The fundamental equations used in numeric groundwater modeling are (1) Darcy’s Law and (2) the conservation of mass. To solve the groundwater flow equation, all of the boundary conditions must be known. Delineation of the boundary conditions of a groundwater flow model is one of the most difficult tasks (Fetter 1988). Additionally, assigning proper parameter values for hydraulic conductivity of the aquifer (i.e. Kx) and of the stream bed material (i.e. Ksb) can also be a challenge given the inherent heterogeneities found in natural systems. Even though a groundwater model for the Shasta Valley should not be used to predict things such as groundwater levels at location x and time t or stream flow at location x and time t, there still could be significant value in a groundwater model’s ability to (1) bring understanding to the types, trends and orders of magnitude of the responses we might expect when introducing new stressors (i.e. pumping, diversions etc.) and (2) elucidate which parameters most strongly influence the behavior of the system.

Recent efforts have sought to improve the understanding of the nexus between modeling, data collection, calibration and uncertainty (Hill and Tiedeman 2007). Most recently, transient groundwater flow models have been used to map areas of capture given a certain well placement and pumping interval. In 1940, Theis illustrated that all groundwater withdrawals are balanced initially by a removal of water somewhere at some time. Initially the removal, or “capture”, comes from a change in storage of the aquifer, while later capture occurs in the form of induced recharge or reduced discharge. Capture maps illustrate the amount of water captured from various surface water features during a specified period of pumping. Capture maps are helpful in explaining the connections between groundwater and surface water, specifically the spatial and temporal characteristics of those connections. To develop a capture map it is critical that (1) a reasonably well constructed transient groundwater flow model with head-dependent boundary conditions representing surface water features of interest is used and (2) an automated well placement and model run process is developed. The USGS has recently published
Numerical modeling of hydrogeologic systems as complicated as the Shasta Valley poses significant challenges. However, depending on the types of questions being asked, useful information can be derived from appropriately constructed models. The development of Capture Maps is an example of one of the utilities (Leake et al. 2010 and others). Several of the datasets that would be developed though the implementation of the monitoring activities discussed in this document could be incorporated into a groundwater model including (1) groundwater levels, (2) aquifer performance tests, (3) streamflow rates, (4) land and water use surveys and (5) SEBAL or METRIC evapotranspiration estimates. Additionally, locally refined models (spatially) of individual groundwater dependent areas could help answer questions of how the groundwater system might respond to changes in irrigation practices, groundwater production and land use (Barlow and Harbaugh 2006).

### 6.3 Anthropogenic Recharge Areas

#### 6.3.1 Lake Shastina Recharge Assessment (Priority A)

The largest water storage facility in the Shasta Valley is Lake Shastina (also referred to as) Dwinnell Reservoir. Dong et al. (1974) performed a water balance analysis on Lake Shastina using data from 1972. Water balances are based on the principle of conservation of mass. In other words, the change in storage within the accounting center (ΔS) must equal the amount of water that goes into the accounting center (I) minus the amount of water leaving the accounting center (O). The following water balance components were used by Dong et al. (1974) in their formulation of the Lake Shastina water balance:

\[
\Delta S = I_S + I_G + I_P - (O_S + O_E + O_L)
\]

**Where:**

- \( \Delta S \) = change in Lake Shastina storage annually
- \( I_S \) = Inflow of surface water including Garrick Creek, Shasta River (plus Parks Creek inflows) inflows plus direct runoff
- \( I_G \) = Inflow from groundwater system
- \( I_P \) = direct precipitation
- \( O_S \) = Outflow of surface water including Montague Main Canal and Shasta River
- \( O_E \) = Outflow to evaporation loss
- \( O_L \) = Outflow to groundwater system

Figure 16 illustrates the water balance components. Note that the Ground Water Leakage flow path as calculated by Dong et al. (1974) is 30,100 acre-feet, or 49.9 percent of the total outflow from Lake Shastina. If the volume of leakage occurred at a uniform annual rate, the equivalent flow rate would be about 42 cubic feet per second (cfs). This represents a significant source of recharge to the aquifer, but there is significant uncertainty in the recharge estimate due to uncertainty in the measured and estimated values used for the analysis and because the analysis was developed for just one year.
To improve the estimates of groundwater recharge from Lake Shastina, it is recommended that the reservoir water balance analysis be updated and refined, including more accurate measurement of reservoir inflows and outflows.

Shasta River gaging station #2 (SR2) shown on Figure 12 provides a record of the dominant inflow to Lake Shastina. Carrick Creek (misspelled as ‘Garrick’ Creek on Figure 16), the second largest inflow source, could be measured at the culvert undercrossing of Dwinell Way. Precipitation can be estimated from the proposed Big Springs Complex precipitation gage discussed in section 4.2.2. Montague Water Conservation District (MWCD) Main Canal gaging station #1 (MWCD1) discussed in Section 6.3.3 could provide a record of the controlled outflow from Lake Shastina. Figure 17 provides an overview of the monitoring components required to perform a Lake Shastina Recharge Assessment.

It is recommended that this investigation be performed for at least one full year and preferably a series of several consecutive years. A multi-year investigation offers the advantages of increased confidence in Lake Shastina recharge estimates and reduced cost per year of the investigation. The reconnaissance level cost estimate to perform the Lake Shastina Recharge Assessment is $125,000 for the first year of data collection and $75,000 for each subsequent year. The following assumptions were made to develop this cost estimate:

- Operation and maintenance of three (3) stream gage locations\(^{14}\)
- Measurements performed with either a SonTek FlowTracker Acoustic Doppler Velocimeter (ADV) or a RiverSurveyor M9 Acoustic Doppler Current Profiler (ADCP)
- Rainfall runoff analysis for unmeasured watersheds draining directly into Lake Shastina
- Evaporation is estimated
- Permission to access required measurement sites will be acquired ahead of time by others
- An annual Technical Memorandum that summarizes the Lake Shastina Recharge Assessment will be prepared

\(^{14}\) The three gage locations assumed for cost estimating purposes include (1) Shasta River Inflow (SR2), (2) Shasta River Outflow (SR3), and (3) Carrick Creek Inflow. It is assumed that flow records for MWCD Outflow will be available from the MWCD. Cost savings are possible if gaging stations are installed at SR2 and SR3 as part of the Intermediate Stream Gage monitoring activities discussed in Section 6.1.3.
Figure 17. Lake Shastina Recharge Assessment Overview
The results from the Lake Shastina Recharge Assessment will provide estimates of the net volume of water recharged to the groundwater system. Answering additional questions regarding the location and timing of the eventual downgradient discharge of these waters to the surface water system will require integration of these data with other datasets developed during this data collection program.

The next largest surface water storage facilities in the Shasta Valley are the three lakes operated by the California Department of Fish and Wildlife in the Shasta Valley Wildlife Area (i.e. Bass Lake, Trout Lake, and Steamboat Lake). Because these lakes overly the matrix and block facies of the Debris Flow, and not Pluto’s Cave Basalt, it is anticipated that recharge rates are lower than rates from Lake Shastina. However, consultation with the operators of the storage facilities, and other knowledgeable persons, with regards to the anthropogenic recharge potential of these lakes is advised. Additionally, several small catchments around the rim of the Shasta Valley are used to store ephemeral runoff and irrigation diversions for subsequent delivery. Most of these catchments are small and probably do not contribute significantly to recharge.

6.3.2 Irrigation Conveyance System Recharge Assessment (Priority A)

Many unlined (or partially unlined) water conveyance facilities traverse the Shasta Valley. The most significant of these from a recharge standpoint include the Montague Water Conservation District (MWCD) Main Canal, the Grenada Irrigation District (GID) Main Canal, the Shasta Water Association (SWA) Canals near Grenada and the China Ditch, which diverts from Parks Creek and flanks the west side of the Valley. Most other ditches and canals are much smaller and/or are located closer to the river, with the result that leakage from them likely discharges to streams relatively quickly.

Because the MWCD Main Canal conveys a substantial amount of water and seepage from it is thought to be appreciable, it is recommended that continuous, high-accuracy gaging stations be added near the canal heading (e.g. at the Big Springs Road crossing) and at the Little Shasta River siphon (see Section 6.1.3 and Figure 12). The difference in cumulative volume, less any deliveries made from the canal between the two gaging stations, represents canal loss to seepage (less evaporation), which is recharge to the groundwater system. For the China Ditch, GID Main Canals and SWA Canals, spot flow measurements should be performed to determine average seepage rates utilizing an analysis similar to a stream reach water balance (Section 6.1.2).

The United States Bureau of Reclamation (USBR) devised a methodology for a ponding seepage rate test commonly employed in canals (Figure 18). One significant improvement of the ponding seepage rate test over the double-ring infiltrometer test is that a much larger area of soil is tested. The larger the test footprint, the more likely it is that the heterogeneities present will be sufficiently reflected in the test results. The data collection procedures implemented during ponding infiltration tests for this assessment will be predominantly from the USBR Irrigation Operation and Maintenance Bulletin No. 65 dated September 1968 titled ‘Measuring Seepage in Irrigation Canals by the Ponding Method’.
Following is a brief description of the sequence of events involved in conducting a seepage test:

- Place downstream earthen berm in canal
- Turn water into reach to fill pond
- Turn water off once water level reaches normal operating stage
- Place upstream earthen berm in canal
- Install level sensors near upstream and downstream earthen berms
- Verify that there are no visible leaks through plugs or ditch cuts
- Let the pond level drop through seepage (and minimal evaporation)
- Measure top widths, wetted perimeters and ponded water depths at regular intervals along the canal (25 or 50 feet), at the start and at the end of the test period.

Additionally, seepage tests can be conducted using an inflow-outflow methodology, whereby flow measurements are made at the head and tail of a selected canal reach, with the difference between the two representing canal loss (seepage and evaporation). Error in flow measurements should be minimized by making the most accurate measurements practically possible; however, the effect of error on the confidence of the results should always be evaluated. In general, it is desirable to delineate long canal reaches for inflow-outflow testing to maximize the magnitude of the loss relative to the canal flow. In this manner the effect of measurement error on the confidence in the results is minimized.

Figure 19 illustrates what are currently regarded as the canal or ditch reaches with greatest potential seepage, making them highest priority candidates for seepage testing.

The reconnaissance level cost estimate to conduct the Irrigation Conveyance System Recharge
Figure 19. Irrigation Conveyance System Map
Assessment is $115,000. The following assumptions were made to develop this cost estimate:

- 2 person test crew
- 45 days of field data collection and flow measurements
- Permission to access selected measurement sites will be arranged ahead of time by others
- Flow measurements will be performed with either a SonTek FlowTracker Acoustic Doppler Velocimeter (ADV) or a RiverSurveyor M9 Acoustic Doppler Current Profiler (ADCP)
- Temporary installation of water level and temperature sensors to correct for the presence of non-steady-state conditions
- Preparation of a Technical Memorandum that summarizes Irrigation Conveyance System Recharge in the Shasta Valley

Detailed plans and test procedures would be developed based on field reconnaissance, allowing for possible refinement in reach delineation.

6.3.3 Irrigated Lands Water Balance Analysis (Priority B)

Deep percolation of applied surface water is likely an appreciable source of recharge in the Shasta Valley. Figure 9 shows the areas of the valley that apply irrigation water to meet crop water demands. The areas highlighted green are the ones that are most likely to have deep percolation of applied water.

Deep percolation cannot be measured directly and must instead be estimated based on water balances. The basic methodology is to first define the water balance domain (a soil volume defined by a specified land area and the root zone depth) and the period of analysis. This usually involves reviewing available water delivery and cropping data to determine what calculations are possible. Water balances can be performed at the field, farm or regional scale, depending on data availability. And, the period of analysis can be an irrigation event or an entire irrigation season, again depending on data availability. For purpose here, seasonal water balances conducted for large aggregations of fields would provide the most representative, useful results.

With water balance domain and period of analysis defined, data is assembled to calculate (or independently estimate) all of the inflows and outflows and internal changes in water storage. This is typically done on a monthly time step for seasonal balances. Deep percolation, because it cannot be measured, is usually computed as the water balance closure (the sum of inflows minus the sum of outflows minus any change in storage). Uncertainty in the calculated value can be large if the calculated value is small relative to the other water balance flow paths.

Areas that have substantial acreage under flood irrigation are the priority areas for the application of an Irrigated Lands Water Balance Analysis. These areas include the Montague Water Conservation District, Shasta Water Association, China Ditch service area, Grenada Irrigation District, Musgrave Ditch Service Area, the Hart and Cowley Ranches, and Shasta Springs Ranches. Additional priority should be given to areas for which water balances have not been previously developed, including the Montague Water Conservation District, Shasta Water Association and the China Ditch service area.

6.4 Upland Watershed Areas

The upland watershed areas are the portions of the Shasta Valley that are generally upgradient from the lands developed for irrigated agriculture, municipal, industrial or residential uses. Land in these areas is
predominantly owned by state or federal agencies, or by timber corporations. Land use and land management practices tend to change very little with time. Therefore, for the purposes of this data collection plan, it is assumed that little additional monitoring is necessary in these areas.

Even though the recommended precipitation stations discussed below in Section 6.4.1 aren’t all located in Upland Watershed Areas, they have been included in this section because they do not fall neatly into any one of the individual monitoring areas.

### 6.4.1 Install Additional Precipitation Stations on Valley Floor (Priority A)

Additional precipitation stations should be sited to improve the understanding of precipitation patterns in both (1) the Valley floor and (2) the upland watershed areas. In support of the first goal, precipitation stations should be added in the following areas: Big Springs Complex, Gazelle, Montague and Little Shasta. Snow surveys should be performed at one station on the north slopes of Mount Shasta as well as one station in each of the following watersheds: upper Parks Creek (i.e. China Mountain), Shasta River (i.e. Mount Eddy) and Little Shasta River (i.e. Goosenest Mountain). Surveys should be performed at the same locations every January, March and May to help develop baseline precipitation data for the upland watershed areas.

### 6.4.2 Install Continuous Snow Water Equivalent Sensors at Existing Snow Measurement Stations (Priority B)

Based on the inventory of existing monitoring (Section 3.0 and Appendix B), there are three snow depth monitoring stations in the Shasta River Watershed: Little Shasta (LSH), Parks Creek (PRK), and Sweetwater (SWT). Snow depth and water content are measured at all three stations manually. Measurements are taken between one and three times a year during the spring. Recent innovations in snow measurement technology have led to the development of several non-contact snow water equivalent sensors. It is recommended that these non-contact sensors be deployed at the three existing monitoring stations to improve the data record and ensure that the peak snow water equivalent for each year is measured and recorded.

### 6.4.3 Monitor Permitting Processes Related to Land Use Changes (Priority C)

As previously stated, land use in the Upland Watershed Areas is unlikely to significantly change in the near future. However, monitoring permitting processes associated with potential changes in land use can be helpful.

### 6.5 Springs

#### 6.5.1 Spring Discharge Measurements Downgradient of Anthropogenic Activities (Priority A)

In relatively shallow and heterogeneous aquifer systems like the Shasta Valley, changes in spring discharge are often the first noticeable sign of changes within the hydrologic system. Therefore, monitoring Spring Discharge is a critical component of the data collection plan. This Section identifies five springs for measurement that are downgradient from Anthropogenic Activities: Big Springs, Little Shasta, Gazelle, Montague and Little Shasta.

---

15 The Nature Conservancy may already operate and maintain a precipitation station.
Springs, Clear Spring, Kettle Spring and Bridgefield Spring. These springs were chosen as Priority A monitoring sites because they are (1) downgradient from anthropogenic activities, (2) close to critical stream reaches from an ecological perspective and (3) provide a significant portion of cool water to the surface water system. The Spring Discharge Gages on Figure 20 are identified by the purple dots. Additional details for the five (5) Spring Discharge Gages are provided in Table 10.

The reconnaissance level cost estimate to install the five (5) recommended Spring Discharge Measurement Gages is $150,000 (i.e. 5 gages @ $30,000/EA). The following assumptions were made to develop this cost estimate:

- Substantial in-channel modifications will not be required
- The sites will be SCADA-Ready
- Land acquisition will not be required

### 6.5.2 Spring Discharge Measurements Upgradient of Anthropogenic Activities (Priority B)

The siting of additional Spring Discharge Gages should be established by a feedback process based on periodic data review and analysis of data collected. It is likely that areas requiring additional Spring Discharge monitoring will be identified during the implementation of Priority A monitoring tasks. Therefore, it is recommended that additional Spring Discharge Gages be sited after the completion of Priority A monitoring tasks.

<table>
<thead>
<tr>
<th>Spring Name</th>
<th>Drains to</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Existing Gage</th>
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</thead>
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<tr>
<td>Big Springs</td>
<td>Shasta River</td>
<td>41.599149</td>
<td>122.409346</td>
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<tr>
<td>Little Springs</td>
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<td>41.592391</td>
<td>122.420576</td>
<td>no</td>
</tr>
<tr>
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<td>Shasta River</td>
<td>41.56189</td>
<td>122.416616</td>
<td>no</td>
</tr>
<tr>
<td>Kettle Spring</td>
<td>Parks Creek</td>
<td>41.549358</td>
<td>122.428462</td>
<td>no</td>
</tr>
<tr>
<td>Bridgefield Spring</td>
<td>Parks Creek</td>
<td>41.521932</td>
<td>122.426338</td>
<td>no</td>
</tr>
</tbody>
</table>
Figure 20. Priority A Spring Discharge Measurement Sites
References Cited


Theis, C. V. 1940. The Source of Water Derived from Wells. Civil Engineering 10.


Appendix A. Shasta Valley Groundwater Workplan
Shasta Valley Groundwater Study Workplan
Shasta Valley, California

Prepared by

August 2011
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Abbreviations

ADCP   Acoustic Doppler Current Profiler
AF      acre-feet
cfs     cubic feet per second
CTEMPs  Center for Transformative Environmental Monitoring Programs
DWR     California Department of Water Resources
ET      evapotranspiration
ETc     crop evapotranspiration
ETr     reference evapotranspiration
ft      feet/foot
ft/sec   feet per second
gpm     gallons per minute
GW/SW   groundwater surface water
K       hydraulic conductivity
Ksb     stream bed hydraulic conductivity
Kx      horizontal hydraulic conductivity
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1.0 Introduction

The Shasta River and its tributaries provide critical west coast spawning and rearing habitat for salmonid fish (Deas, 2004; Nichols, 2010). Flows in the Shasta River and tributaries reflect interaction between the surface water system and groundwater system including spring discharges to surface streams and diffuse stream accretions and depletions. Surface stream behavior can be readily observed and historical streamflow records are available from a number of stream gauging stations. However, the groundwater system within the Shasta Valley (Valley) is complex and not well understood.

This document presents a groundwater study workplan to advance understanding of the Shasta Valley groundwater system with the overarching goal being to characterize groundwater/surface water (GW/SW) interactions. Understanding these interactions is foundational to understanding and ultimately managing flows in the Shasta River and its tributaries. Development of this workplan was funded by Cal Trout as part of that organization’s efforts to improve conditions in the Shasta River for anadromous fish. Cal Trout retained AquaTerra Consulting and Davids Engineering to develop the workplan.

The workplan includes the following elements:

- A summary of existing hydrogeologic literature and investigations pertaining to the Shasta Valley (Section 2)
- A description of the hydrogeology of the Shasta Valley subject to the limits of existing knowledge (Section 3)
- Descriptions of nine analytical methods that could be employed to advance understanding of SW/GW interactions in the Shasta Valley (Section 4).

Essentially, there are two main categories of analytical methods: (1) foundational data collection and (2) data analysis and synthesis. Initially, priority should be placed on foundational data collection activities. Over time, as sufficient data sets become available, a greater number of analysis and synthesis tasks can be initiated. However, it is critical that the foundational data collection activities continue in conjunction, as opposed to being suspended as focus shifts to analysis and synthesis.

For each analytic method, a brief background statement is provided that describes the methodology and its general pertinence to groundwater investigations. This is followed by discussion of how the methodology could be applied in the Shasta Valley and presentation of approximate costs for implementing the methodology. This modular workplan structure allows investigations to be scaled and directed to match funding as it becomes available from various sources. Strategic program direction will be needed to establish priorities and provide coordination among studies as they are launched.
2.0 Literature Review

Table 1 provides a summary of the available literature pertaining to the Shasta Valley. The topics addressed by the various works cited include fisheries, geology, hydrology, limnology, geography and meteorology. Additionally, some of the literature addresses material specific to the Shasta Valley, while others address GW/SW interaction in general. The table provides information on the author(s), date, title, discipline and whether the work is specific to the Shasta Valley. A full citation of each reference can be found in the bibliography of this document.

Table 1. Summary of Available Shasta Valley Groundwater Literature and Supporting Hydrogeologic Material

<table>
<thead>
<tr>
<th>Author(s)</th>
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<td>1985</td>
<td>A water-resources appraisal of the Mount Shasta area in northern California</td>
<td>Hydrology</td>
<td>Yes</td>
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<tr>
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<td>2009</td>
<td>Groundwater Development – The Time to Full Capture Problem</td>
<td>Hydrology</td>
<td>No</td>
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<td>2005</td>
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<td>Meteorology</td>
<td>Yes</td>
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<td>1961</td>
<td>Isotopic Variations in Meteoric Waters</td>
<td>Hydrology</td>
<td>No</td>
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<tr>
<td>Crandell, D.R.</td>
<td>1989</td>
<td>Ancestral Debris Avalanche Analysis</td>
<td>Geology</td>
<td>Yes</td>
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<td>Criss, R.E. and M.L. Davison</td>
<td>1996</td>
<td>Imaging of Surface Water/Groundwater Interactions, Sacramento Valley, CA</td>
<td>Hydrology</td>
<td>No</td>
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<td>Dansgaard, W.</td>
<td>1964</td>
<td>Stable Isotopes in Precipitation</td>
<td>Hydrology</td>
<td>No</td>
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<td>Davis, C.L.</td>
<td>2002</td>
<td>Statistics and Data Analysis in Geology</td>
<td>Geology</td>
<td>No</td>
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<td>Deas, M.L. and E. Vignola</td>
<td>2005</td>
<td>Lake Shastina Limnology</td>
<td>Limnology</td>
<td>Yes</td>
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<td>DFG (Department of Fish and Game)</td>
<td>2003</td>
<td>Recovery Strategy For CA Coho Salmon</td>
<td>Fishery</td>
<td>Yes</td>
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<td>Dong, A.E., K.W. Beatty, and R.C. Averett</td>
<td>1974</td>
<td>Limnological study of Lake Shastina, Siskiyou County, CA</td>
<td>Limnology</td>
<td>Yes</td>
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<td>DWR (Department of Water Resources, CA)</td>
<td>2004</td>
<td>Bulletin 118 – Shasta Valley Groundwater Basin</td>
<td>Hydrology</td>
<td>Yes</td>
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<td>DWR (Department of Water Resources, CA)</td>
<td>2006</td>
<td>Areal Geology and Geologic Cross Sections – Shasta Valley, CA</td>
<td>Geology</td>
<td>Yes</td>
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<td>DWR (Department of Water Resources, CA)</td>
<td>2007</td>
<td>Unpublished Groundwater Analytical Data</td>
<td>Hydrology</td>
<td>Yes</td>
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<td>Gat, J.R.</td>
<td>1996</td>
<td>Oxygen and Hydrogen Isotopes in the Hydrologic Cycle</td>
<td>Hydrology</td>
<td>No</td>
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<td>GRD (Goosenest Ranger District)</td>
<td>1997</td>
<td>Pluto's Cave Goosenest Ranger District Klamath National Forest</td>
<td>Geography</td>
<td>Yes</td>
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<td>Hem</td>
<td>1985</td>
<td>Study and Interpretation of Chemical Characteristics of Natural Water</td>
<td>Geology</td>
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<td>Author(s)</td>
<td>Date</td>
<td>Title</td>
<td>Discipline</td>
<td>Specific to the Shasta Valley</td>
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<td>Ingraham, N.L. and B.E. Taylor</td>
<td>1991</td>
<td>Light Stable Isotope Systematics of Large-Scale Hydrologic Regimes in CA., and NV.</td>
<td>Hydrology</td>
<td>Yes</td>
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<td>Jenkins, C.J.</td>
<td>1968</td>
<td>Computation of Rate and Volume of Stream Depletion by Wells</td>
<td>Hydrology</td>
<td>No</td>
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<td>KNF (Klamath National Forest)</td>
<td>1997</td>
<td>Pluto's Cave Goosenest Ranger District Klamath National Forest</td>
<td>Geography</td>
<td>Yes</td>
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<td>Mack, S.</td>
<td>1960</td>
<td>Geology and Groundwater Resources of the Shasta Valley, Siskiyou County, CA</td>
<td>Geology/Hydrology</td>
<td>Yes</td>
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<td>Marchetti, M.P., P.B. Moyle</td>
<td>2001</td>
<td>Effects of Flow Regime on Fish Assemblages in a Regulated California Stream</td>
<td>Fishery</td>
<td>No</td>
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<td>Moran, J.E., G.B. Hudson, G.F. Eaton, and R. Leif</td>
<td>2005</td>
<td>California GAMA Program: Results for the Sacramento Valley and Volcanic Provinces of Northern CA</td>
<td>Hydrology</td>
<td>Yes</td>
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<td>Nilsen, T.H.</td>
<td>1993</td>
<td>Stratigraphy of the Cretaceous Hornbrook Formation, Southern OR. and Northern CA</td>
<td>Geology</td>
<td>Yes</td>
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<td>Null, S.E., M.L. Deas and J.R. Lund</td>
<td>2009</td>
<td>Flow and Water Temperature Simulations for Habitat Restoration in the Shasta River, CA</td>
<td>Hydrology</td>
<td>Yes</td>
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<td>PGS (Peninsula Geological Society)</td>
<td>2001</td>
<td>Peninsula Geological Society and Stanford GES-052Q Field Trip</td>
<td>Geology</td>
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<td>Poage, M.A. and C.P. Chamberlain</td>
<td>2001</td>
<td>Empirical Relationships Between Elevation and the Stable Isotope Composition of Precipitation and Surface Waters</td>
<td>Hydrology</td>
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<td>PRISM Project</td>
<td>2007</td>
<td>Oregon Climate Service PRISM PROJECT</td>
<td>Meteorology</td>
<td>No</td>
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<td>Rose, T.P., M.L. Davisson and R.E. Criss</td>
<td>1996</td>
<td>Isotope Hydrology of Voluminous Cold Springs in Fractured Rock from an Active Volcanic Region, NE CA.</td>
<td>Hydrology</td>
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<td>Rozanski, K., L. Araguas-Aragus and R. Gonfiantini</td>
<td>1993</td>
<td>Isotopic Patterns in Modern Global Precipitation</td>
<td>Hydrology</td>
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<td>Strand, R.G.</td>
<td>1963</td>
<td>Geologic Map of California (Weed Sheet)</td>
<td>Geology/Geography</td>
<td>Yes</td>
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<td>Theis, C.V.</td>
<td>1940</td>
<td>The Source of Water Derived from Wells: Essential Factors Controlling the Response of an Aquifer to Development</td>
<td>Hydrology</td>
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<td>Wagner</td>
<td>1987</td>
<td>Geologic Map of California (Weed Quadrangle), Map No. 4A</td>
<td>Geology</td>
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<td>Walther, J.V.</td>
<td>2009</td>
<td>Essentials of Geochemistry</td>
<td>Geochemistry</td>
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<td>Ward, M. and N. Eaves</td>
<td>2008</td>
<td>Shasta Valley Data Needs Assessment</td>
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<td>Yes</td>
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<td>Williams, H.</td>
<td>1949</td>
<td>Geology of the Macdoel Quadrangle, CA</td>
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</table>
3.0 Hydrogeologic Setting

The Shasta Valley is located at the boundary of the two of the major geomorphic provinces in northern California: the Klamath Province and the Cascade Province. Both provinces are the product of compressional tectonic settings resulting from the Paleozoic through Mesozoic subduction of the Farallon Plate, which resulted in the rocks of the Klamath Province, and Cenozoic subduction of the Juan de Fuca and Gorda Plates, which resulted in the much younger volcanic rocks of the Cascade Province. Cascade volcanic deposits cover much of the eastern half of the valley while older rocks formed in marine settings underlie a majority of the western half. Younger volcanic debris flow and surficial alluvial materials comprise the remainder of the deposits within the valley.

The Shasta Valley’s complex geologic history resulted in a heterogeneous hydrogeologic setting, which is illustrated by the wide range (several orders of magnitude) of aquifer hydraulic properties. Traditional hydrogeologic methods commonly used for analysis of porous media do not necessarily apply due to the anisotropy associated with preferential flows paths found in fractured basalts and lava tubes common throughout the Valley.

The geologic framework of the greater Shasta Valley will be discussed in terms of the regional geology and study area geology. Five (5) geologic groupings are delineated: (1) Klamath Province marine rocks and their metamorphic equivalents, (2) Cascade Province volcanic rocks, (3) Pluto’s Cave Basalt, (4) Pleistocene debris flow deposits and (5) Quaternary (presumed Holocene) alluvium.

3.1 Regional Geologic Units

Figure 1 displays the surficial geology of the Shasta Valley.

3.1.1 Klamath Province

The Klamath Province is comprised of rocks ranging in age from the early Paleozoic to late Mesozoic eras (Mack, 1960). In the vicinity of the Shasta Valley, the Klamath Mountains are comprised of marine mafic and ultramafic volcanic rocks, marine sediments and their metamorphic equivalents (Ward and Eaves, 2008).

Marine parent material ranges in size from sand to silt and underwent extensive metamorphism. Heat and pressure recrystallized the individual quartz grains and cementing materials within the marine sandstone deposits forming quartzite. The resulting quartzite deposits are highly resistant to weathering and provide poor conditions for the formation of soil. The initial metamorphic product of clay sized sedimentary rocks is slate; with continued metamorphism leading to the formation of phyllite and eventually mica schist.

Ultramafic rocks within the valley are mainly located in the China Mountain Area (Figure 1). Rocks in this region consist of structurally weakened, sheared, faulted and weathered metamorphic products of
serpentine providing a relatively impermeable surface restricting infiltration. These rocks underlie the headwaters of the Shasta River, Parks Creek and the South Fork of Willow Creek (Ward and Eaves, 2008).

The Cretaceous Hornbrook Formation continuously outcrops for a distance of roughly 50 miles from the Medford Valley in southwestern Oregon to the Shasta Valley (Nilsen, 1993). The majority of the exposures within the Shasta Valley lie to the north and east of Montague in the Little Shasta River watershed (Figure 1). The rocks comprising the Hornbrook Formation consist of inter-fingering beds of shallow marine sandstone, deep marine mudstone, and siltstone with thin shale partings and megafossils (Nilsen, 1993).

### 3.1.2 Cascade Province

The most prominent feature of the Cascade Province near the Shasta Valley is Mount Shasta - a large stratovolcano located near the southern terminus of the Cascade Range (Figure 1). Mount Shasta is comprised of at least four main cones formed in the last 250,000 years with the most recent eruptions taking place only 200 years ago (Blodgett et al., 1985). Rocks in the Cascade Range are generally subdivided into two volcanic series: the Western Cascade Series and the High Cascade Series (Ward and Eaves, 2008). The High Cascade Series consists of volcanic materials that are Quaternary in age while the Western Cascade Series contains older volcanic rocks erupted during the Tertiary Period.

The Western Cascade Series is a complex assemblage of andesitic lava flows, consolidated volcanic ash, igneous breccias, reworked volcanioclastics and substantial pyroclastic mudflows (Mack, 1960; Ward and Eaves, 2008). Rocks from this series underlie much of the western portion of the valley and constitute the bedrock along the eastern margins (Mack, 1960). The age of Western Cascade materials has provided sufficient time for extensive weathering, fracturing and subsequent infilling. As a result, the deposits have a high degree of spatial variability in both permeability and anisotropy. Yields of wells located in the Western Cascade Series vary greatly due to these lateral and vertical variabilities (Mack, 1960).

The High Cascade Series overlies the older materials of the Western Cascade Series and is predominantly comprised of highly fractured andesitic and basaltic lava flows. These highly permeable flows originated from peaks along the eastern edge of the Shasta Valley including: Goosenest Mountain, Deer Mountain, Whaleback Mountain and Mount Shasta (DWR, 2004). The High Cascade Series acts as an important groundwater reservoir and source for springs within the Valley (Mack, 1960).

### 3.1.3 Pluto’s Cave Basalt

Pluto’s Cave Basalt, a formation of particular hydrogeologic interest in the study area, is considered part of the High Cascade Series. This basalt flow covers more than 50 square miles of the eastern portion of the Shasta Valley (Williams, 1949) and overlies older materials associated with the Western Cascade Series. The formation is a composite of several flows each composed of black, vesicular olivine-rich augite basalt (DWR, 2004). Individual flow units are considered to be approximately 10 – 30 feet thick while the total thickness ranges from 400 feet near the flanks of Mount Shasta to 50 feet or less at its northern edge near the Little Shasta River (Williams, 1949). The interface between individual lava flows, fractures and lava tubes provides preferential flow-paths capable of transmitting large quantities of
water (DWR, 2004). Accordingly, the unit provides substantial quantities of water to wells with yields averaging 1,300 gallons per minute (gpm) and as high as 4,000 gpm (DWR, 2004).

The source and age of the Pluto’s Cave Basalt is a point of contention among prior investigators. DWR Groundwater Bulletin 118 for the Shasta Valley Groundwater Basin states that the formation is Holocene in age placing the flow within the last 10,000 years while another publication by DWR titled ‘Shasta Valley Data Needs Assessment (Data Needs Assessment)’ places the flow in the Pleistocene epoch at 160,000 to 190,000 years ago. A study by the United States Geological Survey (USGS) led by Mack titled ‘Geology and Groundwater Features of Shasta Valley’ published in 1960 states that the basalt flow was a ‘product of recent volcanic activity’ and is ‘probably no more than several thousand years’ old.

Regarding source, Mack states that ‘Pluto’s Cave Basalt appears to have issued from fissures close to the northeastern base of Mount Shasta’. According to DWR’s Data Needs Assessment, ‘Deer Mountain and Whaleback Mountain are the source of Pluto’s Cave basalt flows’.

3.1.4 Pleistocene Debris Flow

Materials deposited by a catastrophic debris flow cover approximately 264 square miles of the valley floor (Figure 1). The deposits cover an area from just northeast of the peak of modern Mount Shasta to the Shasta River Canyon north of Yreka. The debris flow originated from ancestral Mount Shasta during the Pleistocene epoch roughly 300,000 to 380,000 years ago (Crandell, 1989). The debris flow formed the unusual geology and topography of this portion of the valley: the hundreds of hummocks, ridges, hills and flat surfaces.

Crandell (1989) separated the deposits associated with the debris flow into two classes: (1) block facies and (2) matrix facies. The block facies consists mostly of large portions of solid andesite rock measuring tens to hundreds of feet in dimension. The hummocks, ridges and hills within this region consist of the block facies from the debris flow. The matrix facies is similar in nature to a mudflow and contains an unstratified and poorly sorted mixture of pebbles, cobbles, boulders and consolidated silty sand (Crandell, 1989). The matrix facies forms the flat areas between the block facies. The debris flow incorporated existing deposits of alluvium, lahars and pyroclastic flows as it progressed northward scouring the preexisting landscape. This led to a gradation in the percentage of non-Shasta materials incorporated within the debris flow ranging from 0 percent in the south to 75 percent at the northern terminus.

The debris flow played a significant role in the redirection of both groundwater and surface water flow. The debris flow deposits provided a barrier to the deposition of the subsequent basalt flows from Mount Shasta, including Pluto’s Cave Basalt. The interface between the highly fractured and permeable basalt flow and the low permeability debris flow deposits resulted in the issuance of numerous springs (Ward and Eaves, 2008).

3.1.5 Quaternary Alluvium

Alluvial deposits from Parks Creek, Willow Creek, Julian Creek, Yreka Creek, Whitney Creek, the Little Shasta River and the Shasta River comprise the remainder of the surficial deposits within the valley.
(Figure 1). Significant accumulations of alluvium are present along the A12 corridor south of Big Springs, in the Gazelle-Grenada area and the Little Shasta Valley. Alluvial deposits range from course grained sand in high-gradient locations to silt and clay in low-gradient locations. The majority of the agricultural production within the valley occurs in areas containing alluvial deposits because they provide the soil structure and water holding capacity necessary for plant growth.
4.0 Analytical Methods for Characterizing the Interaction of Groundwater and Surface Water Systems

Historically, water resource managers have generally addressed surface water and groundwater systems as if they were distinct and separate. However, as the development and use of water resources intensifies, it eventually becomes clear that changes in the management of either system inevitably affects the other. Most surface water bodies (i.e. streams, lakes etc.) are connected to the groundwater system to some degree. Interactions between surface water and groundwater systems fall into three general conditions: (1) surface water features *losing water to* the groundwater system, (2) surface water features *gaining water from* the groundwater system and (3) some combination of gain and loss over both space and time. Consequently, diversions from surface water features can deplete an aquifer system while pumping from an aquifer can have a direct impact on stream flow. Due to these linkages, it is obvious that a clear understanding of the geographic extent and magnitude of GW/SW interactions is critical to effective water resource management (Alley, 2002).

There are several analytical techniques that can be applied to characterize GW/SW interactions. Nine of these techniques are described in the following subsections, each selected because of its pertinence to the Shasta Valley. The background portion of each subsection describes the analytical method in general terms. This is followed by a discussion of the hydrologic sub-areas delineated within the Data Needs Assessment of the Shasta Valley (Ward and Eaves, 2008) that would benefit from application of the methodology. This discussion relies heavily on the recommendations found the Shasta Valley Data Needs Assessment (Ward and Eaves, 2008). Unit costs are [provided for each methodology in order to inform future funding solicitations to be prepared by others. Figure 2 shows the eight (8) hydrologic sub-areas delineated with the Data Needs Assessment (Ward and Eaves, 2008).

It is beyond the scope of this general workplan to establish priorities among the various methodologies identified or to describe in specific terms how the methodologies could be applied in the various hydrologic sub-areas within the Shasta Valley. Development of a more detailed workplan would address these factors.

4.1 Groundwater Level Monitoring

4.1.1 Background

According to the U.S. Geological Survey (Taylor and Alley, 2001), ‘Groundwater systems are dynamic and adjust continually to short-term and long-term changes in climate, ground-water withdrawal, and land use. Groundwater level measurements from observation wells are the principal source of information about the hydrologic stresses acting on aquifers and how these stresses affect groundwater recharge, storage, and discharge.’ Regular measurements over time of groundwater levels are the foundation of many types of groundwater analyses, including (1) evaluating long term trends and changes in aquifer storage (2) developing and calibrating numerical groundwater flow models, (3) performing water balance analyses (discussed further in Section 4.5 below) and (4) designing, implementing, and monitoring the effectiveness of groundwater management and protection programs.
Groundwater levels can be measured in existing private or public groundwater production wells or in ‘dedicated’ monitoring wells. Groundwater level measurements can be performed manually or semi-automatically using pressure transducers. Data can be documented by hand on a field data sheet, or recorded digitally in a data logger. Data can be manually downloaded via a hard-wired connection, or transmitted remotely by some form of telemetry. All of these options have advantages, disadvantages and costs associated with them.
4.1.2 Application to the Shasta Valley

Additional groundwater level monitoring in the Shasta Valley would improve the understanding of the direction and gradient of groundwater flow in the Valley. It is suggested that dedicated monitoring wells be constructed adjacent to the Shasta River in areas with suspected groundwater accretions. Areas where significant accretions are thought to occur include the Big Springs Complex, the A-12 corridor and at the confluences with Willow and Yreka creeks. Longitudinal Distributed Temperature Analysis should be used to further inform the placement of additional monitoring wells. Ward and Eaves (2008) suggested focusing additional groundwater level monitoring wells in the following sub-areas of the Shasta Valley:

- Gazelle/Grenada
- Little Shasta Valley
- Yreka
- Yreka East
- Weed

4.1.3 Cost Estimates

Table 2 provides order-of-magnitude per well cost estimates for different types of groundwater level measurement sites.

<table>
<thead>
<tr>
<th>Well Type</th>
<th>Monitoring Frequency</th>
<th>Permanent Equipment</th>
<th>Assumptions</th>
<th>Initial Cost</th>
<th>Annual Reoccurring Cost</th>
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<tbody>
<tr>
<td>Existing Production Well (Public or Private)</td>
<td>Bi-annual (Spring/Fall)</td>
<td>none</td>
<td>Willing landowner and right of entry secured, minor modifications to well</td>
<td>$200</td>
<td>$1,000</td>
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<tr>
<td>Existing Production Well (Public or Private)</td>
<td>Continuous</td>
<td>Pressure Transducer</td>
<td>Willing landowner and right of access secured, minor modifications to well</td>
<td>$2,500</td>
<td>$1,000</td>
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<tr>
<td>New Dedicated Monitoring Well</td>
<td>Bi-annual (Spring/Fall)</td>
<td>none</td>
<td>Well placed on public land, maximum 50’ depth through drillable materials</td>
<td>$5,000</td>
<td>$1,000</td>
</tr>
<tr>
<td>New Dedicated Monitoring Well</td>
<td>Continuous</td>
<td>Pressure Transducer</td>
<td>Well placed on public land, maximum 50’ depth through drillable materials</td>
<td>$7,000</td>
<td>$1,000</td>
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</table>
4.2 Aquifer Performance Testing

4.2.1 Background

The ability of a geologic unit to transmit water under saturated conditions is an important hydraulic parameter. The saturated hydraulic conductivity (K) of a geologic formation is a function of several variables and can vary over several orders of magnitude and can often exhibit high spatial variability. In addition to an understanding of how readily an aquifer transmits water, it is important to characterize the aquifer’s ability to store and release water under dynamic conditions; this is quantified by the storage coefficient. If the aquifer is confined, the storage coefficient is generally referred to as the specific storage ($S_s$). The specific storage characterizes the ability of an aquifer to release groundwater from storage in response to a decline in the piezometric surface. If the aquifer is unconfined, the storage coefficient is generally referred to as the specific yield ($S_y$). The specific yield characterizes the ability of an aquifer to release groundwater from storage under gravity drainage, or a decline in the water table.

Aquifer performance testing is a field method used to quantify both the hydraulic conductivity (usually in the form of the transmissivity) and the storage coefficient (either $S_s$ or $S_y$). In an aquifer performance test, the aquifer is stressed or stimulated through either constant rate or stepped rate pumping while the response of the aquifer is measured in nearby observation wells. The inverse of this can also be used, commonly referred to as the slug test, whereby a ‘slug’ of water is introduced into a well. Aquifer test results are then typically compared to an analytical model (the most common being the Theis solution), with the assumption that the real world case is sufficiently similar to the criteria used within the analytic solution. In some cases it is necessary to compare aquifer test results to a numerical groundwater flow model to simulate real world complexities that are beyond the capabilities of analytical solutions.

4.2.2 Application to the Shasta Valley

Aquifer performance testing in the Shasta Valley would help to characterize basic aquifer parameters for the various hydrogeologic units that at present are largely unknown. Among other things, improved understanding of the hydraulic conductivities and storage coefficients would support development of numerical models that could be used to compare and assess alternative groundwater management strategies. Ward and Eaves (2008) suggested focusing additional aquifer performance tests in the following sub-areas of the Shasta Valley:

1. Gazelle/Grenada
2. Pluto’s Cave Basalt

4.2.3 Cost Estimates

Table 3 provides order-of-magnitude per aquifer test cost estimates for several different options of how to configure the test.
### Table 3. Aquifer Performance Test Cost Estimates

<table>
<thead>
<tr>
<th>Pump Configuration</th>
<th>Test Method</th>
<th>Pumping Period</th>
<th>Assumptions</th>
<th>Field Data Collection</th>
<th>Analysis and Reporting</th>
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</thead>
<tbody>
<tr>
<td>Existing Pump and Motor</td>
<td>Constant Rate</td>
<td>30 days</td>
<td>Pumping well and up to four adjacent monitoring wells temporarily equipped with pressure transducers</td>
<td>$8,000</td>
<td>$4,000</td>
</tr>
<tr>
<td>Existing Pump and Motor</td>
<td>Constant Rate</td>
<td>3 days</td>
<td>Pumping well and up to four adjacent monitoring wells temporarily equipped with pressure transducers</td>
<td>$4,000</td>
<td>$3,500</td>
</tr>
<tr>
<td>Existing Pump and Motor</td>
<td>Step Test</td>
<td>1 day</td>
<td>Pumping well and up to four adjacent monitoring wells temporarily equipped with pressure transducers</td>
<td>$3,000</td>
<td>$4,000</td>
</tr>
<tr>
<td>Existing Pump and Motor</td>
<td>Recovery</td>
<td>-</td>
<td>Pumping well and up to four adjacent monitoring wells temporarily equipped with pressure transducers</td>
<td>$3,000</td>
<td>$3,000</td>
</tr>
<tr>
<td>Temporary Pump and Motor</td>
<td>Constant Rate</td>
<td>3 days</td>
<td>Pumping well and up to four adjacent monitoring wells temporarily equipped with pressure transducers</td>
<td>$7,000</td>
<td>$3,500</td>
</tr>
<tr>
<td>Temporary Pump and Motor</td>
<td>Step Test</td>
<td>1 day</td>
<td>Pumping well and up to four adjacent monitoring wells temporarily equipped with pressure transducers</td>
<td>$4,500</td>
<td>$4,000</td>
</tr>
<tr>
<td>Temporary Pump and Motor</td>
<td>Recovery</td>
<td>-</td>
<td>Pumping well and up to four adjacent monitoring wells temporarily equipped with pressure transducers</td>
<td>$4,500</td>
<td>$3,000</td>
</tr>
</tbody>
</table>

### 4.3 Stream Flow Monitoring and Telemetry

#### 4.3.1 Background

Continuous stream flow records provide foundational information for hydrologic investigations. People have been interested in quantifying flow in open channels at least as far back as the ancient Egyptians who used the Nilometer to quantify stage (and, consequently flow) in the Nile River (Popper, 1951). Various methodologies have been developed over the years to measure stream flow, with some of the more common flow measurement methods described in the following subsections. Advances in wireless telemetry (i.e. data transfer) via radio, cellular and satellite protocols have also made it cost effective to have real-time access to stream flow (and other types of environmental data).
4.3.1.1 Standard Critical-Depth Structures

Standard critical-depth flow measurement structures are generally divided into weirs and flumes. The devices are referred to as critical-depth structures because the weir or flume causes the flow to pass through critical depth (i.e. the Froude number is greater than or equal to 1). When the flow passes through critical depth, there is a unique relationship existing between flow rate and upstream water level. In other words, when utilizing a critical-depth flow measurement structure, a flow record can be developed by simply measuring water level upstream of the structure. For a more detailed discussion of the theory behind critical-depth flow measurement structures refer to Chapters 2, 7 and 8 from the United States Bureau of Reclamation (USBR) ‘Water Measurement Manual (WMM), 3rd Edition’ (USBR, 2001). Weirs are considered to be an overflow structure built perpendicular to an open channel axis while a flume is a shaped, open channel flow section that forces flow to accelerate (USBR, 2001).

In either the case of the weir or the flume, the goal of the structure is to force flow through critical depth to ensure the unique relationship between upstream water level and flow rate. If the weir or flume is designed and constructed in conformance to standards put forth by the Water Measurement Manual (or other similar document) a theoretical equation can be used to calculate flow rate from upstream water level. This is what ‘standard’ refers to: that the structure is a standard design that has theoretical stage-discharge equations developed in a laboratory setting. Standard critical-depth weir structures include contracted rectangular, suppressed rectangular, Cipolletti contracted and contracted Triangular (or V-notch). It is generally recommended that the accuracy of the theoretical stage-discharge curve be verified by an independent current metering at a low and high flow rate.

4.3.1.2 Non-Standard Critical-Depth Structures

Non-standard critical-depth structures are locations in an open channel where the flow passes through critical depth because of an obstruction or change in channel cross section that was not specifically designed to the specifications of a standard critical-depth structure. These types of locations are usually characterized by a significant drop in the water surface elevation due to a change in the channel profile or channel cross section. All else remaining equal, the transition of flow through critical depth ensures that there will be a unique relationship between upstream water level and flow rate. Unlike standard critical-depth structures, the stage-discharge relationship for a non-standard critical-depth structure must be empirically derived from a series of flow measurements over the range of potential flows.

4.3.1.3 Acoustic Doppler

A volumetric flow rate (i.e. m$^3$/s) is simply the product of (1) the cross section area and (2) the average perpendicular velocity through that area. Acoustic Doppler flow measurement methods measure water velocity indirectly by measuring the velocity of acoustic reflectors within the water column. The cross sectional area is determined by measuring water level and having a detailed understanding of the cross sectional geometry at the site. In some cases, such as a full pipe application, the cross sectional area can be assumed to be constant (ignoring changes due to sediment deposition or scouring).

Acoustic Doppler Current Profilers (ADCP) such as the SonTek Argonaut measure the velocity of water using the Doppler Principle. Most long term, stationary deployment ADCP’s including the Argonaut are known as monostatic current meters; mono in that both the transmitter and receiver are part of the
same unit, static in that the unit does not move during operation. There is a simple relationship between the Doppler Shift, the transmitted frequency and the velocity of the sound source relative to the receiver. In other words, the magnitude of the phase change in frequency is proportional to the flow velocity (Rehmel 2007). Equation 5 illustrates this principle.

\[ \Delta F_R = -2F_T(V/C) \]

where:
\( \Delta F_R \) – Doppler Shift (change in received frequency)
\( F_T \) – Frequency of transmitted sound
\( V \) – Velocity of source relative to receiver
\( C \) – Speed of sound (in medium)

The Argonaut is equipped with three (3) transducers each generating a beam at strategic angles to allow for complex velocity measurements. Two beams are transmitted from the Argonaut with a known frequency and then reflected back and the receiver measures the returned frequency. The system uses the relative orientation of these two beams to determine either two or three-dimensional velocity data. The device does not directly measure the velocity of the water but instead measures the velocity of particles (sediment, small organisms and bubbles) suspended in the flow and makes the assumption that these particles travel at the same velocity as the water (Rehmel 2007).

The third beam is transmitted in a vertical direction and a beam return time is measured to determine the distance from the unit to the water surface. This water height measurement is displayed, as well as used internally for the determination of the cross-sectional area. The unit supports four different types of channel geometry including Irregular, Trapezoid, Round Pipe and Elliptical Pipe. The geometry for the irregular channel cross-section is defined by two-dimensional coordinates input by the user. The cross-sectional area is also displayed and used internally for flow computations. The actual algorithms used for internal velocity calculations are proprietary and cannot be obtained. The velocity calculations are based on the geometry of the transmitted and/or received acoustic signals, the measured change in frequency and the physical and chemical characteristics of the fluid in which the measurement is made.

\(4.3.1.4\) Rated Section

A rated section is simply a reach of a waterway, generally without a critical-depth transition, where a stage-discharge relationship has been empirically developed over a range of flows. Rated sections require large amounts of flow measurements and usually entail developing seasonal shifts in the stage-discharge curves to account for dynamic backwater conditions due to vegetative growth. Additionally, dynamic geomorphic channel settings present further challenges in implementing a rated section flow measurement method. The United States Geological Survey (USGS) frequently employs this method in locations where the installation of standard and/or non-standard critical-depths structures is not possible.
4.3.2 Application to the Shasta Valley

Expanded and improved flow measurement within the Valley would be beneficial for several reasons, primarily for delineation of gaining and losing stream reaches, and how stream accretions and depletions vary over space and time. Stream and canal reach water balances are discussed further in Section 4.5.1. Additionally, improved stream flow records, especially with real-time data access, would support river system management.

The following is a list of potential locations for additional or improved flow measurement:

- **Shasta River**
  - Inflow to Lake Shastina
  - Outflow from Lake Shastina
  - Confluence with Big Springs Creek
  - Near Grenada
- **Parks Creek**
  - Old Hwy 99 crossing
  - Cross tie to Lake Shastina
  - Confluence with Shasta River
- **Little Shasta River**
  - Near Ball Mountain Road crossing
  - Confluence with Shasta River
- **Others**
  - Big Springs Creek near confluence with Shasta River
  - Willow Creek near confluence with Shasta River
  - Julian Creek near confluence with Shasta River
  - MWCD Main Canal near heading
  - MWCD Main Canal near Ball Mountain Road

4.3.3 Cost Estimates

Table 4 provides order-of-magnitude cost estimates on a per site basis for several different flow measurement options.
### Table 4. Stream Flow Monitoring and Telemetry Cost Estimates

<table>
<thead>
<tr>
<th>Flow Measurement Method</th>
<th>Site Visit Schedule</th>
<th>Assumptions</th>
<th>Initial Cost</th>
<th>Annual Reoccurring Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard Critical Depth</td>
<td>Quarterly</td>
<td>Applicable in non-fish supporting waterways such as MWCD Main Canal or other ephemeral waterways. Assumed flow range from 0 to 100 cfs</td>
<td>$15,000</td>
<td>$3,500</td>
</tr>
<tr>
<td>Non-Standard Critical Depth</td>
<td>Quarterly</td>
<td>Adequate drop in waterway is present such that backwater effects are negligible. Initial cost includes rating curve development with manual FlowTracker measurements</td>
<td>$7,500</td>
<td>$3,000</td>
</tr>
<tr>
<td>Acoustic Doppler</td>
<td>Quarterly</td>
<td>Proper cross section for installation present (i.e. culvert, road crossing etc.). Initial cost includes velocity-index rating curve development</td>
<td>$15,000</td>
<td>$4,000</td>
</tr>
<tr>
<td>Rated Section</td>
<td>Bi-Monthly</td>
<td>After initial rating curve development (roughly eight points), bi-monthly site visits, maintenance and flow measurements will be sufficient to correct for rating curve drift</td>
<td>$7,500</td>
<td>$6,000</td>
</tr>
<tr>
<td>Telemetry Add On</td>
<td>-</td>
<td>Assumes a cellular data service package is utilized with a 20 MB maximum data transfer rate</td>
<td>$2,000</td>
<td>$1,000</td>
</tr>
</tbody>
</table>

### 4.4 Land and Water Use Survey

#### 4.4.1 Background

In the mid 1940’s, California lawmakers requested that an inquiry be conducted of the water resources and present and future water needs for all hydrologic regions in California. Consequently, DWR began to collect urban and agricultural land and water use data. DWR began examining land use in the early 1950’s for specific projects and investigations. By the mid 1960’s DWR initiated an ongoing program to perform land use surveys Understanding the source of applied irrigation water (groundwater, surface water or both) is a critical component to understanding the evapotranspiration component of any water balance. More recently the National Agricultural Statistics Service (NASS) has begun providing a remotely sensed crop acreage data product; however, the reliability of the data has yet to be validated.

#### 4.4.2 Application to the Shasta Valley

Coupling an updated land use data set with remotely sensed evapotranspiration data (Section 4.5.1.2) would provide insight into the amount of water consumptively used from both surface water and groundwater sources. The entire Valley would benefit from an updated land and water use survey.
4.4.3 Cost Estimates

Order-of-magnitude costs for the various components, and the associated methods for completing each component, are detailed in Table 5. Costs reflect collecting a Valley wide land and water use dataset.

Table 5. Land and Water Use Survey Cost Estimates

<table>
<thead>
<tr>
<th>Survey Type</th>
<th>Site Visit Schedule</th>
<th>Assumptions</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Land Use</td>
<td>NASS Remotely Sensed Dataset</td>
<td>Publicly available NASS dataset is ground truthed for a minimum 10% of the land use within the Valley. Map file deliverable.</td>
<td>$10,000</td>
</tr>
<tr>
<td>Land Use</td>
<td>Field Based Dataset</td>
<td>Field delineations and acreages from the most recent DWR land use surveys are updated based on field inspections, photographed and documented as access permits. Map file deliverable.</td>
<td>$100,000</td>
</tr>
<tr>
<td>Water Source</td>
<td>Aerial Image and Interview Based Dataset</td>
<td>Using field delineations, knowledge of surface water delivery areas and groundwater production well locations, each field will be assigned a water source and 25% will be verified by interviews. Map file deliverable.</td>
<td>$25,000</td>
</tr>
<tr>
<td>Water Source</td>
<td>Field Based Dataset</td>
<td>A field based inventory of wells and surface water delivery points will be performed. Each water source will be linked to irrigated areas. Map file deliverable.</td>
<td>$50,000</td>
</tr>
</tbody>
</table>

4.5 Water Balance Analysis

4.5.1 Background

Water budgets, or water balance analyses, are prepared for study areas defined by specific spatial and temporal boundaries. Water balances quantify study area inflows, outflows, internal routing, and changes in water storage in each analysis time step. Figure 3 shows a conceptual water balance diagram for a range of topography and land uses.

Water balances for irrigation dominated areas focus on characterizing spillage, seepage, deep percolation, drainage, and crop consumptive use flow paths under existing (or baseline) conditions. The baseline water balance serves as the basis for estimating the effects of different conservation measures or other changes in hydrology.
Water balances developed for irrigated areas include both surface and subsurface flow paths and are designed to mirror the physical and operational structure of the irrigation and drainage network within the study area. Water balance structure varies depending on the specific characteristics of the study area and depending on available data. Water balances generally cover a multi-year period of record using a monthly time step. The high level of spatial and temporal detail incorporated in the water balance structure provide a powerful tool to assess the effectiveness of conservation practices to reduce water demands and the impact of these practices on local groundwater levels and neighboring surface water systems.

The same principles discussed above in the context of performing a water balance on an irrigation dominated area can be applied specifically to groundwater systems. In this case the specific spatial boundaries would be the extent of the aquifer in question. Inflows to an aquifer often include (1) diffuse recharge from applied irrigation water or precipitation, (2) focused recharge from surface water bodies or (3) groundwater inflow. Outflows from the aquifer often include (1) groundwater pumping for municipal, agricultural or urban purposes, (2) groundwater discharge into surface water bodies, (3) evapotranspiration or (4) groundwater outflow. Additionally, an assessment of the change in storage within the aquifer is critical.
4.5.1.1 Stream/Canal Reach Water Balance

A conceptual stream reach water balance is shown in Figure 4. As indicated in the figure, inflows to a stream reach may include inflow from upper reaches, tributary inflows, return flows (which could include surface or subsurface inflows from agricultural lands), and other subsurface inflow (accretion). Outflows may include outflow to lower reaches, diversions, evaporation, and subsurface outflow (seepage or depletion).

Stream reach water balances are often assembled based on the monthly mean flows (cubic feet per second) for each flow path. If the area of the surface water feature is significantly small enough (i.e. a small stream or river), the effects of evaporation can generally be considered negligible, but is reflected in the closure term of each reach, to the extent that it is significant. Stream reach water balances can help to provide quantitative estimates of bulk exchanges between streams and the underlying groundwater systems; however, they cannot elucidate the spatial variability associated with these GW/SW exchanges.

4.5.1.2 SEBAL® Evapotranspiration Analysis

In the context of a water balance analysis, often the most difficult flow path to compute is the evapotranspiration (ET) component of both irrigated agriculture and riparian vegetation. The traditional method of computing crop evapotranspiration (ET_c) involves multiplying reference ET (ET_r) values and by unique crop coefficients (K_c). Several problems arise with this method including the fact that (1) ET_r varies over both space and time and (2) K_c values assume optimal crop conditions (i.e. no crop stress). Furthermore, using traditional methods for computing riparian ET is problematic in that (1) riparian species are intermixed and composite riparian K_c values are not widely published or available and (2) riparian vegetative stresses are not accounted for. SEBAL® (version 2009) solves many of the problems
associated with traditional ET computational methods by using spectral radiances recorded by satellite-based sensors along with ground-based weather data to solve the energy balance at the Earth's surface, yielding spatially distributed estimates of actual evapotranspiration (Figure 5).

The basic physical principle of SEBAL is that energy from the Sun that is available at the Earth’s surface drives heating of the air, heating of the ground surface, and evaporation of water. SEBAL first determines (1) the available energy from the Sun (net radiation, $R_n$), (2) heating of the ground surface (soil heat flux, $G$), and (3) heating of air at the surface (sensible heating, $H$). Then, the difference between the available energy from the Sun and the amount of energy used to heat the ground surface and air is the amount of evaporation at the surface (latent heat flux, LE or ET). A detailed explanation of SEBAL is provided by Bastiaanssen et al. (2005).

![Figure 5. Conceptual Representation of Surface Energy Balance](image)

SEBAL offers three distinct advantages compared to the generally accepted "$K_c \times \text{ET}_0$" method for computing ET:

- SEBAL does not need crop type to solve the energy balance, so records of cropping patterns are not needed.
- The acreage of water-using land is observed directly from the satellite image, so accurate land use is implicit to the process. These features overcome the typical difficulty of assembling accurate records of irrigated areas and cropping patterns, particularly for historical analyses.
- SEBAL computes actual evapotranspiration ($\text{ET}_a$), inherently accounting for the effects of salinity, deficit irrigation, disease, poor plant stands, etc., on the ET flux. Including these influences in the standard $K_c \times \text{ET}_0$ computation requires considerable additional data (often unavailable) as well as substantial time and effort.

SEBAL (version 2009) has been continuously updated based on continuing research and growing experience through practical application. Differences between the original published version of the model and the current commercially applied version include:

- Correction of incoming solar radiation based on actual surface topography,
• Correction of surface temperature to normalize for elevation effects,
• Use of spatially distributed weather surfaces from MeteoLook (Voogt, M.P., 2006) for improved representation of actual surface conditions,
• Advection correction for each pixel within the image,
• Atmospheric correction of albedo (Tasumi et al., 2008), and
• Improved soil heat flux estimation.

4.5.2 Application to the Shasta Valley

Neglecting any changes in storage, and assuming that subsurface outflows are negligible, precipitation into the Valley must equal the sum of stream outflow (i.e. the Shasta River outflow to the Klamath) and evapotranspiration. In this conceptual model, assuming all else remains equal, stream outflow is inversely proportional to evapotranspiration. Developing net precipitation amounts for a topographically complex and snow dominated watershed such as the Shasta Valley is a complex task. Performing a Valley wide water balance in conjunction with SEBAL evapotranspiration estimates will improve the understanding of net precipitation values for the watershed.

Additionally, a stream or canal reach water balance can quantify the bulk SW/GW exchanges for the analyzed reach. Completing a stream reach water balance during the October to April period could simplify the process of having to account for numerous tailwater return flows. Performing a water balance on the groundwater system, assuming sufficient groundwater level information is available, can (1) indicate if the current rates of groundwater extraction are sustainable and (2) quantify the valley wide groundwater inputs into the surface water system. The degree to which these groundwater inputs into the surface water system can be captured is of particular interest in future management of groundwater supplies.

4.5.3 Cost Estimates

Order-of-magnitude costs for performing (1) a Valley wide water balance, (2) a stream or canal reach water balance and (3) a SEBAL evapotranspiration analysis are provided in Table 6 below.

4.6 Infiltration Tests

4.6.1 Background

The purpose of an infiltration test is to determine how quickly water goes from the surface of a soil to within the soil profile. Under steady conditions, once soil saturation is reached, an infiltration test quantifies the saturated vertical hydraulic conductivity (KV) of a surface geologic layer. A frequently used infiltration, referred to as the double-ring infiltrometer test, has been standardized by the American Society for Testing and Materials (ASTM) as Standard D-3385-03. The double-ring infiltrometer is often constructed from thin-walled steel pipe with the inner and outer cylinder diameters being 20 and 30 cm, respectively; however, other diameters may be used.
### Table 6. Water Balance and Associated Cost Estimates

<table>
<thead>
<tr>
<th>Task</th>
<th>Geographic Scope</th>
<th>Assumptions</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water Balance</td>
<td>Valley Wide</td>
<td>Reference evapotranspiration methods used to for evapotranspiration analysis. Balance performed on monthly or annual time step</td>
<td>$70,000</td>
</tr>
<tr>
<td>Water Balance</td>
<td>Valley Wide</td>
<td>SEBAL used for evapotranspiration analysis. Balance performed on monthly or annual time step</td>
<td>$95,000</td>
</tr>
<tr>
<td>Stream or Canal Reach Water Balance</td>
<td>1 to 2 mile reach of Stream or Canal</td>
<td>Accretions or losses in the selected stream reach are larger than potential measurement errors in upstream and downstream flow measurements. Two flow measurement stations operated for a period of 6 months to a year</td>
<td>$25,000</td>
</tr>
<tr>
<td>SEBAL</td>
<td>Valley Wide at Minimum</td>
<td>30-meter pixel resolution evapotranspiration dataset for annual period based on analysis of up to 8 Landsat images</td>
<td>$50,000</td>
</tr>
</tbody>
</table>

Using the same double-ring infiltrometer hardware, there are two different types of techniques used to measure the flow of water into the underlying soil profile. In the constant head test, the water level in the inner ring is held at a fixed level and the volume of water used to maintain this level is recorded. In the falling head test, the inner ring is filled to a known level and then the rate at which the water decreases is measured. In both cases (the constant and falling head tests), the water level in the outer ring is maintained at a constant level to (1) prevent leakage between rings and (2) to force vertical infiltration from the inner ring.

As commonly observed with most geologic parameters, infiltration rates can be highly heterogeneous with large variations occurring over small geographic regions. Double-ring infiltrometer tests are performed over such a small area that these heterogeneities are often not captured. The United States Bureau of Reclamation (USBR) devised the methodology for a ponding infiltration rate test commonly employed in canals. One significant improvement of the ponding infiltration rate test over the double-ring infiltrometer test is that a much larger area of soil is tested. The larger the test footprint the more likely it is that the heterogeneities present will be sufficiently reflected in the test results. The data collection procedures implemented during ponding infiltration tests are predominantly from the USBR Irrigation Operation and Maintenance Bulletin No. 65 dated September 1968 titled ‘Measuring Seepage in Irrigation Canals by the Ponding Method’.

#### 4.6.2 Application to the Shasta Valley

Improved understanding of the saturated vertical hydraulic conductivities of the various geologic units found within the Valley will (1) improve understanding of infiltration processes and (2) improve numerical modeling efforts.

#### 4.6.3 Cost Estimates

Table 7 provides order-of-magnitude cost estimates for performing either a Double Ring Infiltrometer infiltration test or ponding test per USBR methods.
Table 7. Cost Estimates for Infiltration Tests

<table>
<thead>
<tr>
<th>Task</th>
<th>Geographic Scope</th>
<th>Assumptions</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Double Ring Infiltrometer Infiltration Test</td>
<td>30 cm diameter</td>
<td>Double ring infiltrometer is available and an adequate seal with the underlying soil can be made</td>
<td>$2,500</td>
</tr>
<tr>
<td>USBR Ponding Test</td>
<td>Extent of ponded water</td>
<td>Temporary earth dam placed upstream and downstream of test reach will be sufficient to stop inflows and outflows</td>
<td>$5,000</td>
</tr>
</tbody>
</table>

4.7 Tracer Analysis

4.7.1 Background

Tracer studies are often used to help characterize groundwater-surface water interactions at small spatial scales. Tracers can be divided into two categories: natural and anthropogenic tracers. Natural tracers are parameters that are naturally part of the hydrologic cycle such as temperature, stable and radioactive isotopes, chloride and others. Anthropogenic tracers are parameters that are introduced into the hydrologic cycle with the specific goal of furthering the understanding of how the system functions. Examples of anthropogenic tracers generally include various fluorescent dyes and salts.

An ideal tracer would be one that is conservative, in that it does not significantly react with the surrounding environment within the timescales of the study. Additionally, it is beneficial if the tracer is easily, and inexpensively, quantifiable. Tracers are used to delineate flow paths, and when used in conjunction with dilution equations, can help determine specific recharge and discharge areas in hydrogeologic investigations. Recent improvements in data-acquisition and computational techniques have led to temperature receiving much attention as a tracer of great utility. Temperature tracer studies take advantage of the difference between temperatures in surface water bodies and those in the underlying groundwater and geologic materials (Constantz and Stonestrom, 2003).

4.7.1.1 Longitudinal Distributed Temperature Sensing (DTS)

Distributed Temperature Sensing (DTS) utilizes fiber optic cables to perform temperature measurements. By accurately measuring changes in the frequency and amplitude of light, DTS can measure temperatures at a spatial resolution between 1 and 7 feet, for a total distance of over 15 miles, with temperature accuracies in the range of 0.05 to 0.9 degrees Fahrenheit (Selker, 2006). By placing a continuous fiber optic cable along the center line of a streambed, stream reaches with significant groundwater accretions can be located. The Center for Transformative Environmental Monitoring Programs (CTEMPs) is cooperatively managed by Oregon State University, Corvallis and the University of Nevada, Reno, and funded by the National Science Foundation. CTEMPs provides interested parties with training and access to five field-deployable DTS systems which can be rented and delivered to project locations.
4.7.1.2 Nested Vertical Temperature Flux Analysis

Stream-aquifer temperature gradient measurements can be used to (1) qualitatively determine if the stream is gaining (receiving water from the aquifer) or losing (discharging water to the aquifer) and (2) quantitatively measure the vertical movement of groundwater in the hyporheic zone (Constantz and Stonestrom, 2003). Temperature measurements can further the understanding of focused hyporheic GW/SW interactions and can further substantiate and refine results from a stream/canal reach water balance analysis (discussed in Section 4.5.1.1 above).

Streams have large diurnal temperature fluctuations due to surficial heat transfer mechanisms (conduction, radiation and convection). In contrast, groundwater bodies have a relatively steady temperature due to (1) thermal insulation of the overlying geologic media and (2) the relatively large thermal reservoir provided by the aquifer system. In gaining stream reaches, adjacent shallow groundwater will not show a strong diurnal signature because water is moving up from depths where temperature is steady. In losing stream reaches, the downward movement of water will advectively carry the stream’s diurnal temperature signature into adjacent shallow groundwater.

Figure 6 is a conceptual design of a temperature piezometer with isolated, discrete temperature measurement zones. Figure 7 is an example of a self-contained thermistor temperature logger.

![Figure 6. Conceptual Temperature Piezometer Design](image)
Self-contained temperature loggers can be installed with seals immediately above and below isolating discrete aquifer zones. An additional advantage of using this type of instrumentation would be continuous records of temperature at different depths as opposed to monthly spot measurements. Temperature data will be logged at 1hr intervals and downloaded monthly. A continuous record will also improve the understanding of the temporal variability associated with stream-aquifer interactions. Water level in the piezometer (Figure 8) will be measured during data download as an auxiliary verification of the direction of groundwater movement.

4.7.2 Application to the Little Shasta Valley

DTS used along the streambed of the Shasta River would help in delineating areas of groundwater accretion. Temperature measurements should be made in either (1) reaches of the stream where
insignificant tailwater contributions occur or (2) during the winter months to avoid tailwater completely. In the areas shown to have substantial groundwater accretions via DTS analysis, nested vertical temperature analysis could be performed to compute the vertical flux rates. Additionally, a fluorescent dye or salt tracer study could be performed to characterize GW/SW interactions between a well and a surface water body in close proximity.

4.7.3 Cost Estimates

Order-of-magnitude costs for (1) DTS, (2) nested vertical temperature analysis and (3) a fluorescent dye or salt tracer investigations are presented in Table 8 below.

<table>
<thead>
<tr>
<th>Task</th>
<th>Cost Per</th>
<th>Assumptions</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>DTS</td>
<td>5000 feet of Stream</td>
<td>Landowner approval is obtained. No breaks in cable occur. One month data collection period.</td>
<td>$15,000</td>
</tr>
<tr>
<td>Nested Vertical Temperature Analysis</td>
<td>Shallow Monitoring Well (i.e. 2 to 10 feet)</td>
<td>Average of five (5) nested thermistors per well. Wells can be drilled and placed by hand.</td>
<td>$3,500</td>
</tr>
<tr>
<td>Tracer Investigation</td>
<td>Investigation</td>
<td>Environmental permitting issues easily addressed. Maximum of 2 days field work with 2 person crew.</td>
<td>$10,000</td>
</tr>
</tbody>
</table>

4.8 Geochemical Investigations

4.8.1 Background

Bulk chemical analysis of groundwater and surface water samples can help determine water types, flow paths, residence times and water-rock interactions. During the hydrologic cycle various pieces of geochemical information become encoded into water (Mazor, 1997). Evaporation occurring over different regions of the oceans, each with different average ambient temperatures, result in varying isotopic compositions. Large scale air movements carry sea spray, or small salt grains, in addition to water vapor which leads to precipitation containing differing amounts of sodium and chloride ions. Rainwater dissolves noble and diatomic atmospheric gases, in addition to naturally occurring and anthropogenic tritium, $^{14}$C and $^{36}$Cl. Subsequent to infiltration, chemical interactions between groundwater and the surrounding geologic materials place an additional ‘finger print’ on water. Each of these unique processes can be exploited to address various hydrogeologic questions, including the nature of GW/SW interactions.

Isotopes, as a complement to geochemistry and physical hydrogeology, are now routinely used to answer questions regarding groundwater provenance, movement and sustainable use (Clark and Fritz, 1997). Isotopes can be used to establish the location of groundwater recharge areas, delineate groundwater flow paths and determine the amount of time since groundwater has directly interacted with the atmosphere (Fetter, 1988). There are two main types of isotopes used in hydrogeologic investigations: stable and radioactive. Stable isotopes are generally used to deduce the locations of recharge areas while radioactive isotopes (radioisotopes) are used to determine the residence time of
groundwater within the aquifer system (i.e. how long it has been since direct atmospheric interaction). The latter parameter is generally referred to as the age of the groundwater. Groundwater age data can then be used to further understand the physical properties of both groundwater movement and the surrounding geologic environment.

4.8.2 Application to the Shasta Valley

The tritium-helium-3 method of groundwater age dating can be used to date the apparent age of groundwater samples to an accuracy of roughly three (3) years for modern groundwater (i.e. groundwater that infiltrated in the last 50 years). Stable oxygen and hydrogen isotopes can be used to determine recharge sources including apparent recharge elevation and if the sample has undergone evaporation subsequent to precipitation (e.g. tailwater or lake water). General geochemical analysis, including basic cations and anions, indicates water types and indicates water rock interactions and residence times.

4.8.3 Cost Estimates

Table 9 presents order-of-magnitude costs for specific types of water sample analyses in addition to an estimate for the interpretation and reporting of the data.

<table>
<thead>
<tr>
<th>Task</th>
<th>Assumptions</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basic Suite Water Sample</td>
<td>Includes collection of water sample. Eh, DO, pH, temperature, basic cations and anions, EC, TDS, Iron, Copper, Zinc and Silicon</td>
<td>$500</td>
</tr>
<tr>
<td>Stable Hydrogen and Oxygen</td>
<td>Includes collection of water sample. Analysis performed at UCDSIF.</td>
<td>$200</td>
</tr>
<tr>
<td>Tritium Age Dating</td>
<td>Includes collection of water sample. Measure tritium and decay product helium-3</td>
<td>$1,500</td>
</tr>
<tr>
<td>Interpretation and Reporting</td>
<td>Plotting on meteoric water line, charge balance analysis, stiff and piper diagram creation.</td>
<td>$7,500</td>
</tr>
</tbody>
</table>

4.9 Numerical Groundwater Modeling

4.9.1 Background

In hydrogeology, there are two specific areas reliant on modeling: (1) understanding why a hydrogeologic system behaves in a certain way and (2) understanding how a hydrogeologic system will respond to new stressors (Fetter 1988). Model is a generic term, simply referring to any representation of a real system. Modeling has now almost become synonymous with numerical computer modeling, which is only one specific type of groundwater model. Other types of groundwater models include analytic models, scale models, electrical analog models, and viscous-fluid models. Advances in computational devices in the 1970’s and 80’s has led to numerical computer modeling being the most
commonly used groundwater modeling technique.

The fundamental equations used in numeric groundwater modeling are (1) Darcy’s Law and (2) the conservation of mass. To solve the groundwater flow equation, all of the boundary conditions must be known. Delineation of the boundary conditions of a groundwater flow model is one of the most difficult tasks (Fetter 1988). Additionally, assigning proper parameter values (i.e. Kx, Ksb etc.) can also be a challenge given the inherent heterogeneities found in natural systems. The predictive value of groundwater models, in an absolute sense, such as the head at location x and time t or the flow at location x and time t, has perhaps been oversold. Nevertheless, there is significant value in a groundwater model’s ability to (1) bring understanding to the types, trends and orders of magnitude of the responses we might expect when introducing new stressors (i.e. pumping, diversions etc.) and (2) elucidate which parameters most strongly influence the behavior of the system. Recent efforts have sought to improve the understanding of the nexus between modeling, data collection, calibration and uncertainty (Hill and Tiedeman 2007).

Most recently, transient groundwater flow models have been used to map areas of capture given a certain well placement and pumping interval. In 1940, Theis illustrated that all groundwater withdrawals are balanced initially by a removal of water somewhere at some time. Initially this removal, or ‘capture’, comes from (1) a change in storage of the aquifer, while later capture occurs in the form of (2) induced recharge or (3) reduced discharge. In essence, capture maps visually demonstrate the amount of water captured from various surface water features after a stated period of pumping. Capture maps are often quite helpful in explaining the connections between groundwater and surface water, specifically the spatial and temporal components of those connections. To develop a capture map it is critical that (1) a reasonably well constructed transient groundwater flow model with head-dependent boundary conditions representing surface water features of interest is used and (2) an automated well placement and model run process is developed. The USGS has recently published several reports on the development and use of capture maps of the upper San Pedro Valley in Arizona, areas along the Colorado River in Arizona and California, Paradise Valley in Nevada, and the Deschutes Valley in Oregon (Leake et al., 2005 and others).

4.9.2 Application to the Shasta Valley

Numerical modeling of hydrogeologic settings as complicated as the Shasta Valley poses significant challenges. However, depending on the types of questions being asked, much utility and worth came still come from an appropriately constructed model. The development of Capture Maps is a great example of one of these utilities. Several of the datasets developed in the previous sections of this workplan could be incorporated into a groundwater modeling effort including (1) groundwater levels, (2) aquifer performance tests, (3) stream flow rates, (4) land and water use surveys, (5) SEBAL evapotranspiration rates, (6) DTS analysis for gaining and losing reaches and (6) infiltration rates.

4.9.3 Cost Estimates

Table 10 contains order-of-magnitude costs for developing (1) a numerical groundwater model with sufficient detail to (2) develop groundwater capture maps.
### Table 10. Cost Estimates for Groundwater Modeling Efforts

<table>
<thead>
<tr>
<th>Task</th>
<th>Geographic Scope</th>
<th>Assumptions</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Groundwater Model Development</td>
<td>North of 97, West of Harry-Cash, East of 5</td>
<td>Well completion reports can be obtained on the basis of an agency request.</td>
<td>$200,000</td>
</tr>
<tr>
<td>Capture Map Development</td>
<td>Same as Above</td>
<td>Maps developed at same spatial resolution as GW model grid.</td>
<td>$50,000</td>
</tr>
</tbody>
</table>
References Cited


Appendix B. Inventory of Historical and Existing Hydrologic Monitoring
Introduction

The Shasta Valley Resource Conservation District (RCD) is developing a stream – aquifer data collection program to guide efforts to expand and improve hydrologic monitoring in the Shasta Valley over time. The purpose of the program is to identify and address existing data deficiencies on a prioritized basis, in order to derive the greatest benefit from limited resources. The intent of the project is to assist Siskiyou County in working with the local community to understand groundwater resources, to identify any potential future challenges facing the resource and, in particular, to characterize the physical interaction between groundwater aquifers and streams.

As part of developing the stream – aquifer data collection program, a comprehensive inventory was conducted of publicly available hydrologic data. This was done by identifying the agencies that have historically collected hydrologic data in the basin, primarily including the United States Geologic Survey (USGS) and the State of California. Online data sources supported by these agencies were accessed and available data systematically inventoried. The purpose was not to compile the data available from these sources because the data are readily available online and, for active sites, new data are continuously being added. Rather, the purpose was to create a means for conveniently identifying the types, locations and periods of hydrologic data available within the Shasta River basin. This serves as one means of exposing data collection gaps and evaluating data improvement priorities.

The results of the inventory are summarized in an Excel spreadsheet (also referred to herein as a database) and are discussed in the following sections:

Data Types and Sources

The primary objective of conducting the data inventory was to identify all the surface water data (streamflow, water quality and precipitation) and groundwater data (level and quality) data that are publically available within Shasta River watershed. Some of the identified sites also report other data types that are pertinent to hydrologic analyses. These data were included in the database. Table 1 summarizes the unique data types reported for the identified sites and included in the database.
The various resources utilized for conducting this inventory are discussed below:

- **Groundwater Level and Groundwater Quality Data:** The United States Geologic Survey (USGS) National Water Information System (NWIS) and the California Department of Water Resources (WDR) Water Data Library (WDL) were accessed to identify wells reporting groundwater level and/or groundwater quality data within the basin.

  Wells from NWIS were identified by selecting all wells within Siskiyou County, importing the well coordinates into ArcGIS, and intersecting the coordinates with Shasta River watershed boundary. Wells located within the Shasta River watershed were included in the database.

  The Water Data Library ground water level data is accessible by groundwater basin or by township. Wells within the Shasta Groundwater basin (the only groundwater basin within the watershed) were selected and included in the database.

- **Streamflow and Other Surface Water Data:** An inventory of sites reporting streamflow data was obtained from NWIS and the California Data Exchange Center (CDEC). Sites within Siskiyou County were selected, imported into ArcGIS, intersected with Shasta River watershed boundary to identify those located within the Shasta River watershed and included in the database.

  In addition to streamflow data, some sites report other surface water data, including canal diversion, reservoir elevation, reservoir storage and river stage data. These data sets are pertinent and were included in the database.

- **Surface Water Quality Data:** NWIS and Water Data Library were utilized for inventorying the sites with water quality data. These sites (excluding groundwater wells) were obtained for Siskiyou County, imported into ArcGIS, intersected with Shasta River watershed boundary and selected only if they were within the Shasta River watershed.
• **Precipitation Data**: Sites reporting precipitation data were inventoried from the California Irrigation Management Information System (CIMIS), CDEC and the National Oceanic and Atmospheric Administration (NOAA) National Climatic Data Center (NCDC) for the Shasta River watershed and the surrounding area. Some of these sites also include snow water content and snow depth measurements and were included in the database.

The locations of the selected sites described above are illustrated in a series of maps organized by data type (Attachment A). The sites shown in each figure are listed in a series of tables (Tables B1-B6; Attachment B).

The maps provided in Attachment A are listed below:

1. Map of streamflow measuring sites from USGS and DWR.

   Note that sites with Map IDs 185 and 186 shown in this map are inactive. Additionally, Streamflow data for USGS’s sites with Map IDs 187 and 188 is also available from DWR’s CDEC website, though for a shorter period of record compared to the data available for these sites at the USGS’s NWIS website. Information on accessing the data for all these sites is discussed under the ‘Database Operation’ section of this document.

2. Map of all (active and inactive) groundwater level measuring sites from USGS and DWR.

3. Map of active groundwater level measuring sites from USGS and DWR.

4. Map of surface water quality measuring sites from USGS and DWR.

5. Map of groundwater quality measuring sites from USGS and DWR.

6. Map of sites with precipitation, snow depth and snow water content data.

7. Sites with other surface water measurements. This map includes the sites reporting canal diversion, reservoir elevation, reservoir storage and river stage data.

The sites in all the aforementioned maps are labeled using the ‘Map ID’ column/attribute of the database, which is defined under the Database Content section of this document. On Maps 1-5 the sites are grouped by operating agency; on Maps 6 and 7 the sites are grouped by data type.

**Database Content**

The various columns/attributes of the database containing the inventory of surface and groundwater sites within the Shasta River watershed are defined and discussed below:

• **Map ID**: These are serial numbers used for labeling the individual sites on the maps. The Map ID for a given site from its respective map can be traced back to the database. The Map ID in the database provides a unique number for each site and data type combination. A site can have multiple Map IDs if it reports more than one data type.
- **Site ID**: These are the IDs for individual sites, originating from their respective data sources. Some of the entries in this column are left blank for the sites that didn’t had any Site ID specified by their respective originating sources.

- **Site Name**: These are names of individual sites originating from their respective data sources.

- **Latitude**: Latitude represents the geographic coordinate of a site with respect to its north-south location.

- **Longitude**: Longitude represents the geographic coordinate of a site with respect to its east-west location.

- **Site Elevation**: This provides elevation of the site above mean sea level in feet.

- **Agency**: The agency responsible for operating the site is specified in this column.

- **Source/Link**: This column provides the source/website link where data can be accessed for each site.

- **Data Type**: This column specifies the type(s) of data pertinent to this inventory that are available for each site.

- **Data Frequency**: This column specifies the time-steps at which data is collected for a given site. The following sub-categories are used in defining the various time-steps of data collection:
  
  a. **High**: Site with regular data collections, sampling frequency being less than or equal to one month.
  
  b. **Periodic**: Site with regular data collection, sampling frequency being greater than one month.
  
  c. **Spot**: Site with an irregular frequency of data collection/sampling.

- **Data Continuity**: This column defines how active the site is in terms of data collection using the following sub-categories:
  
  a. **Continuous**: Continuous records with no gaps or inactive periods.
  
  b. **Intermittent**: Data records containing inactive periods.

- **Begin Date**: This column specifies the date of first available measurement for a given site.

- **End Date**: This column specifies the date of last available measurement for a given site.

- **Record Count**: This column provides the total number of records/measurements available between begin and end dates for a given site (as of the date this memo was drafted).
• **Site Status**: This column categorizes individual sites as ‘Active’ or ‘Inactive’ based on a combination of type of data available, frequency and continuity of data and the latest set of data that is available for a site.

The entries in this column are subject to revision once a detail data inventory for all the individual sites is performed and information regarding ‘Data Frequency’ and ‘Data Continuity’ is available. Sample criteria that can be used in defining the site status are provided below:

a. A high frequency data collection site (such as a surface water measurement site) is classified as active if the latest data available is from 2012; otherwise it is inactive.

b. A site with periodic/spot data collection (such as a groundwater measurement site/well) is classified as active if the latest data available is from 2007 or later (less than years relative to 2012).

**Database Operation**

This section highlights the operational aspects of the database and discusses a few possible ways users can quickly identify data of interest. Additionally, this section also provides background on accessing data from their respective sources.

• **Filtering based on ‘Data Types’**: The database contains eleven unique data types (Figure 1) and allows users to apply filters specifying one or more data type.

• **Filtering based on ‘Begin’ and ‘End’ dates**: Date filters can be used to specify the period of interest by using a beginning and end date to select all the data types that fall within the specified period. Figure 2 provides a screen shot showing various options that could be utilized under a date filter.

• **Filtering based on the ‘Site Status’**: The database lists all the sites with hydrologic data within the Shasta River watershed irrespective of whether the site is active or inactive. Once the Site Status’ column is finalized, filters can be applied based on a combination of type of data available, frequency and continuity of data and the latest set of data that is available for a site.

In addition to applying individual filters, filters can be applied in various combinations for more specific searches.

• **Data Access**: The web links provided under ‘Source/Link’ column can be used to access the websites that host the data for the respective sites. However, these web links are not direct links to the data for any specific site. Therefore following needs to be done in order to access site specific data:

  a. **Groundwater Level and Groundwater Quality Data**: These data sets are available from USGS’s NWIS and State of California’s WDL websites and data for individual sites can be accessed as explained below:
USGS’s NWIS website: The link to this website for accessing groundwater level data is http://nwis.waterdata.usgs.gov/ca/nwis/gw. On the first page of this website, the user needs to
scroll down and click/select on ‘Field Measurements’. The next page provides multiple options to search for a site. On this page user can check the box in front of ‘Site Number’ and click submit. On next the page, Site ID for the site whose Groundwater level data needs to be accessed can be entered. Next, the user needs to scroll down to the bottom of this page and click submit again. This takes the user to another page where the site’s information is summarized in a table and groundwater level data for this individual site can be obtained by clicking/selecting the site number in the table.

The Groundwater Quality Data for USGS sites can be accessed from the website http://nwis.waterdata.usgs.gov/ca/nwis/qwdata. A similar procedure to accessing Groundwater level data is followed in this case too. First, the box in front of ‘Site Number’ is selected, then the Site ID for the site of interest is entered on the next page and finally the Groundwater quality data is obtained by clicking/selecting the site number from the summary table.

- **DWR’s WDL website:** The link to this website for accessing Groundwater level data is http://www.water.ca.gov/waterdatalibrary/groundwater/hydrographs/index.cfm. On the first page of this website, user needs to select the Hydrologic Region as ‘North Coast’ and click on ‘search’. This populates the ‘Groundwater Basin’ list just below Hydrologic region list. Next the user needs to select ‘Shasta Valley’ from the groundwater basin list as this is the only basin which lies within the Shasta River watershed. Once again ‘search’ is clicked after selecting the Shasta River Groundwater basin and this populates a list of ‘Townships’.

Under this list an individual ‘Township’ can be selected (no option for multiple selections). The ‘Townships’ are based on the first six letters/numbers of a given site’s name (found under the ‘Site Name’ column in the database). Once the ‘Township’ of interest is selected, click ‘Next’. This takes the user to another page where all the wells under the selected township will be listed. The Groundwater level data for an individual well can be accessed by selecting the respective well from the list and choosing the output format for the data. For a quick preview of the data, ‘HTML’ could be selected as output format.

The Groundwater quality data hosted on DWR’s WDL website can be accessed via the following link: http://www.water.ca.gov/waterdatalibrary/waterquality/station_county/index.cfm. The first page that opens on the aforementioned web link provides an option to search sites in a particular county and/or by station number/name. The user here can enter the particular site’s name either under station number or name (since both are same in this case) to access the Groundwater quality data for that site.

b. **Streamflow and Other Surface Water Measurements Data:** These data sets are available from USGS’s NWIS and DWR’s California Data Exchange Center (CDEC) websites. Data for individual sites can be accessed as explained below:

- **USGS’s NWIS website:** The link to this website for accessing Streamflow data is http://waterdata.usgs.gov/ca/nwis/dv/?referred_module=sw. On the first page of this website, check the ‘Site Number’ box, click on ‘submit’ and on the next page enter ‘Site ID’ from the database for the site whose Streamflow data needs to be accessed.

Next, scroll down to the bottom of this page and hit submit again. This takes the user to another page where the site’s information is summarized in a table and Streamflow data for this
individual site can be obtained by clicking/selecting the site number in the table.

- **DWR’s CDEC website**: The link to this website for accessing Streamflow data is [http://cdec.water.ca.gov/staMeta.html](http://cdec.water.ca.gov/staMeta.html). On the first page of this website, the ‘Site ID’ for the site whose Streamflow data needs to be accessed can be entered under the ‘Station ID or partial name’. The same website can be used for accessing other surface water measurement data as well.

c. **Surface Water Quality Data**: This data is available from USGS’s NWIS and DWR’s WDL websites and data for individual sites can accessed as explained below:

- **USGS's NWIS website**: The link to this website for accessing surface water quality data is [http://nwis.waterdata.usgs.gov/ca/nwis/qwdata](http://nwis.waterdata.usgs.gov/ca/nwis/qwdata). On the first page of this website, check the ‘Site Number’ box, click ‘submit’ and on the next page enter ‘Site ID’ of the site whose surface water quality data needs to be accessed. Next, scroll down to the bottom of this page and hit submit again. This takes the user to another page where the site’s information is summarized in a table and groundwater level data for this individual site can be obtained by clicking/selecting the site number in the table.

- **DWR’s WDL website**: The surface water quality data hosted on WDL website can be accessed via the following link: [http://www.water.ca.gov/waterdatalibrary/waterquality/station_county/index.cfm](http://www.water.ca.gov/waterdatalibrary/waterquality/station_county/index.cfm). The first page that opens on the aforementioned web link provides an option to search sites for a particular county and/or by station number/name. The user can either enter the site’s name and/or ID here whose surface water quality data needs to be accessed.

d. **Precipitation Data**: Precipitation data including measurements of snow water content and snow depth are available from CIMIS, CDEC and NOAA’s NCDC websites. The data sets for individual sites can accessed as explained below:

- **CIMIS**: The precipitation data available at CIMIS can be accessed via the following link: [http://wwwcimis.water.ca.gov/cimis/data.jsp](http://wwwcimis.water.ca.gov/cimis/data.jsp). This website requires a free registration before the data could be accessed. After logging in, the user have the options to select the time-step (e.g., hourly, daily or monthly) of the data, the data type (under ‘Sensors’), choice between English or Metric units for data output, period of interest and reporting method/format.

- **CDEC**: The precipitation data available at CDEC can be accessed via the following link: [http://cdec.water.ca.gov/staMeta.html](http://cdec.water.ca.gov/staMeta.html). On the first page of this website, ‘Site ID’ for the site whose precipitation data needs to be accessed can be entered under the ‘Station ID or partial name’.

- **NOAA’s NCDC**: The precipitation data available at NCDC can be accessed via the following link: [http://www.ncdc.noaa.gov/cdo-web/#t=secondTabLink](http://www.ncdc.noaa.gov/cdo-web/#t=secondTabLink). On the first page of this website, ‘Site Name’ and ‘data set/product’ needs to be entered/selected respectively for the site whose precipitation data needs to be accessed.

### Further Database Development

The primary objective of this task was to conduct an inventory of the available surface and groundwater
data collection within the Shasta River watershed. Additional information/fields that could be useful for this inventory such as site elevation, data frequency, data continuity and record count have also been included in the database. However, not all of these additional fields are completed since this entails beyond the current scope.
Figure A1. Streamflow Sites within the Shasta River Watershed (Sites 185 and 186 are inactive)
Figure A2. All (Active and Inactive) Groundwater Level Sites within the Shasta River Watershed.
Figure A. Active Groundwater Level Sites within the Shasta River Watershed.
Figure A. Surface Water Quality Sites within the Shasta River Watershed.
Figure A5. Groundwater Quality Sites within the Shasta River Watershed.
Figure A6. Precipitation Sites within the Shasta River Watershed.
Figure A7. Other Surface Water Monitoring Sites within the Shasta River Watershed.
Attachment B: Summary Tables of all the Sites shown in Maps presented in Attachment A.

**Table B1. Streamflow Sites within the Shasta River Watershed**

<table>
<thead>
<tr>
<th>Map ID</th>
<th>Site Name</th>
<th>Agency</th>
<th>Begin Date</th>
<th>End Date</th>
<th>Site Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>185</td>
<td>SHASTA R NR EDGEWOOD CA</td>
<td>USGS</td>
<td>10/1/1962</td>
<td>9/30/1967</td>
<td>Inactive</td>
</tr>
<tr>
<td>186</td>
<td>LITTLE SHASTA R NR MONTAGUE CA</td>
<td>USGS</td>
<td>10/1/1957</td>
<td>9/30/1978</td>
<td>Inactive</td>
</tr>
<tr>
<td>187</td>
<td>SHASTA R NR MONTAGUE CA</td>
<td>USGS</td>
<td>10/1/1911</td>
<td>8/7/2012</td>
<td>Active</td>
</tr>
<tr>
<td>188</td>
<td>SHASTA R NR YREKA CA</td>
<td>USGS</td>
<td>10/1/1933</td>
<td>8/7/2012</td>
<td>Active</td>
</tr>
<tr>
<td>191</td>
<td>DWINNELL DAM SEEPAGE WEIR</td>
<td>DWR, CA</td>
<td>7/20/2012</td>
<td>8/7/2012</td>
<td>Active</td>
</tr>
<tr>
<td>194</td>
<td>MWCD PARKS CK DIVERSION NR EDGEWOOD</td>
<td>DWR, CA</td>
<td>2/28/2005</td>
<td>8/7/2012</td>
<td>Active</td>
</tr>
<tr>
<td>205</td>
<td>SHASTA R CROSS CNL WEIR AT DWINNELL DAM</td>
<td>DWR, CA</td>
<td>7/20/2012</td>
<td>8/7/2012</td>
<td>Active</td>
</tr>
</tbody>
</table>

**Table B2. Active Groundwater Level Sites within the Shasta River Watershed**

<table>
<thead>
<tr>
<th>Map ID</th>
<th>Site Name</th>
<th>Agency</th>
<th>Begin Date</th>
<th>End Date</th>
<th>Record Count</th>
<th>Site Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>133</td>
<td>42N04W18P001M</td>
<td>DWR, CA</td>
<td>9/4/1990</td>
<td>4/21/2011</td>
<td>34</td>
<td>Active</td>
</tr>
<tr>
<td>134</td>
<td>42N05W08E001M</td>
<td>DWR, CA</td>
<td>5/20/1954</td>
<td>10/20/2011</td>
<td>44</td>
<td>Active</td>
</tr>
<tr>
<td>135</td>
<td>42N05W20J001M</td>
<td>USGS</td>
<td>4/2/1953</td>
<td>10/20/2011</td>
<td>189</td>
<td>Active</td>
</tr>
<tr>
<td>136</td>
<td>42N06W10J001M</td>
<td>USGS</td>
<td>4/6/1953</td>
<td>10/20/2011</td>
<td>201</td>
<td>Active</td>
</tr>
<tr>
<td>137</td>
<td>43N04W07M001M</td>
<td>DWR, CA</td>
<td>8/1/1990</td>
<td>10/20/2007</td>
<td>30</td>
<td>Active</td>
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<td>138</td>
<td>43N05W02C002M</td>
<td>DWR, CA</td>
<td>8/9/1990</td>
<td>10/20/2011</td>
<td>41</td>
<td>Active</td>
</tr>
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<td>140</td>
<td>43N05W11A001M</td>
<td>DWR, CA</td>
<td>10/28/1971</td>
<td>10/20/2011</td>
<td>83</td>
<td>Active</td>
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<tr>
<td>141</td>
<td>43N05W18G001M</td>
<td>DWR, CA</td>
<td>9/4/1990</td>
<td>10/20/2011</td>
<td>41</td>
<td>Active</td>
</tr>
<tr>
<td>142</td>
<td>43N05W36G001M</td>
<td>DWR, CA</td>
<td>9/4/1990</td>
<td>4/21/2011</td>
<td>31</td>
<td>Active</td>
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<td>143</td>
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<td>DWR, CA</td>
<td>10/26/1971</td>
<td>10/20/2011</td>
<td>59</td>
<td>Active</td>
</tr>
<tr>
<td>144</td>
<td>43N06W22A001M</td>
<td>DWR, CA</td>
<td>12/11/1952</td>
<td>10/20/2011</td>
<td>155</td>
<td>Active</td>
</tr>
<tr>
<td>145</td>
<td>43N06W33C001M</td>
<td>DWR, CA</td>
<td>4/20/1973</td>
<td>10/20/2011</td>
<td>79</td>
<td>Active</td>
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<tr>
<td>146</td>
<td>44N05W14M002M</td>
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<td>9/4/1990</td>
<td>10/20/2011</td>
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<td>Active</td>
</tr>
<tr>
<td>147</td>
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<td>5/12/1954</td>
<td>10/20/2011</td>
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<td>Active</td>
</tr>
<tr>
<td>148</td>
<td>44N05W32C002M</td>
<td>DWR, CA</td>
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<td>10/20/2011</td>
<td>43</td>
<td>Active</td>
</tr>
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<td>149</td>
<td>44N05W34H001M</td>
<td>DWR, CA</td>
<td>11/2/1952</td>
<td>10/20/2011</td>
<td>117</td>
<td>Active</td>
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<tr>
<td>150</td>
<td>44N06W10F001M</td>
<td>DWR, CA</td>
<td>4/6/1953</td>
<td>10/20/2011</td>
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<td>151</td>
<td>44N06W27B001M</td>
<td>DWR, CA</td>
<td>11/4/1975</td>
<td>10/20/2011</td>
<td>74</td>
<td>Active</td>
</tr>
<tr>
<td>152</td>
<td>45N05W07H002M</td>
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**Table B3. Surface Water Quality Sites within the Shasta River Watershed**

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**Table B4. Groundwater Quality Sites within the Shasta River Watershed**

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Table B5. Precipitation Sites within the Shasta River Watershed

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<td>8/7/2012</td>
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<td>LITTLE SHASTA R NR MONTAGUE</td>
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<td>9/7/2010</td>
<td>8/7/2012</td>
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