Wasco County Soil and Water Conservation District

Mosier Aquifer Recovery Feasibility Study

2011

Prepared by:

GSI Water Solutions, Inc.

In association with:

anderson perry & associates, inc.
engineering · surveying · natural resources

GSA GeoSystems Analysis, Inc.
Arizona • Nevada • Oregon

Greg McInnis Consulting

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For

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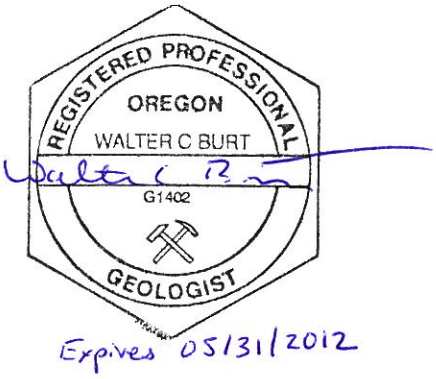

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Table of Contents

1.0 Introduction and Background 1-1
1.1 Background 1-1
1.2 Hydrogeologic Framework 1-2
1.3 Report Organization 1-5
Figure 1-1 Project Area 1-6
Figure 1-2 Geologic Setting 1-7
2.0 Aquifer Recharge Feasibility 2-1
2.1 Introduction 2-1
Recharge Concepts 2-1
Recharge Volume 2-2
2.2 Surface Recharge 2-3
Surface Recharge Systems 2-3
Surface Recharge Site Feasibility Criteria 2-4
Ranking Results 2-10
Data Gaps 2-10
Surface Recharge Costs 2-12
2.3 Well Recharge Feasibility 2-13
Well Recharge Feasibility Criteria 2-13
Water Quality 2-14
Injection Well Requirements 2-14
Aquifer Characteristics 2-15
Well Recharge Data Gaps 2-17
Well Recharge Costs 2-17
2.4 Diversion and Infrastructure Evaluation 2-19
Background 2-19
Diversion Feasibility 2-19
Treatment 2-21
Preferred Alternative 2-22
Diversion and Infrastructure Cost Estimate 2-22

2.5 Legal Process for Aquifer Recharge Projects in Oregon 2-24
Application of AR and ASR to the Mosier Aquifer Recovery Project 2-24
Source Water and Water Use Permitting 2-25
Recharge Authorization Requirements 2-28
Recharge Facility Permitting 2-29
Land Use Authorization 2-29
Figure 2-1 Aquifer Recharge Concepts 2-31
Figure 2-2 Surface Recharge Area of Interest 2-32
Figure 2-3 Soil Permeability in Area of Interest 2-33
Figure 2-4 Diversion Location and Vicinity Maps 2-34
Figure 2-5 Aerial Photo of Diversion Locations 2-35
3.0 Commingling Well Remediation 3-1
3.1 Introduction 3-1
3.2 Objectives and Approach 3-2
3.3 Commingling Potential 3-3
Pomona - Priest Rapids 3-3
Priest Rapids - Frenchman Springs 3-3
Dalles Formation/Pomona-Priest Rapids-Frenchman Springs 3-4
Summary 3-4
3.4 General Well Construction Observations within the Orchard Tract 3-4
Typical Well Construction 3-5
3.5 Well Repair Evaluation 3-6
Well Repair Methods 3-7
Well Repair Feasibility 3-9
3.6 Well Replacement 3-10
3.7 Well Repair and Replacement Cost Estimates 3-11
3.8 Prioritization and Assessment 3-13
Prioritization Process 3-13
Well Assessment Methods 3-14
Figure 3-1 Wells and Locations 3-16
Figure 3-2 Orchard Tract Well Types 3-17
Figure 3-3A Well Type 1 Commingling Well Repair Procedures 3-18

Figure 3-3B Well Type 2 Commingling Well Repair Procedures 3-19
Figure 3-3C Well Type 3 Commingling Well Repair Procedures 3-20
Figure 3-4 Well Decommissioning and Replacement 3-21
4.0 Water Conservation Strategies 4-1
5.0 SB 1069 Grant Requirements 5-1
5.1 Ecological and Peak Flow Analysis Road Map 5-1
Peak and Ecological Flows 5-1
Mosier Creek Road Map 5-3
5.2 Environmental Impact 5-7
Introduction 5-7
Land Use/Important Farmland/Formally Classified Lands 5-8
Wild and Scenic Rivers 5-8
Floodplain 5-8
Wetlands 5-9
Historic Properties 5-9
Biological Resources 5-9
Water Quality 5-10
Coastal Resources 5-10
Miscellaneous Issues (Air, Noise, Transportation, Visual Aesthetics) 5-10
Erosion/Slope Stability 5-11
5.3 Stream Flow Augmentation with Stored Water 5-11
5.4 Comparative Analysis of Alternatives 5-12
Figure 5-1 Aquifer Recovery Focus Area 5-17
6.0 References 6-1

1.0 Introduction and Background

The Mosier Watershed Council (MWC), through the Wasco County Soil and Water Conservation District (WCSWCD), contracted GSI Water Solutions, Inc. (GSI) in December 2010 to complete an evaluation of aquifer recovery strategies for the Mosier area. The study was funded through a grant from the Oregon Water Resources Department (OWRD) under the Conservation, Reuse and Storage program (Senate Bill [SB] 1069). The results of the study, including a comparative analysis of the aquifer recovery alternatives evaluated are summarized in this report.

The general area of interest for this work includes the Mosier Creek and Dry Creek drainages and is generally bounded by the Columbia River (north), Wasco Butte (south) and the drainage divides with Rowena Creek (east) and Rock Creek (west). The specific study area, as defined by geologic structures that bound the aquifers in the lower Mosier Creek watershed, coincides with the domain of the groundwater flow model developed by the U.S. Geological Survey (USGS) as part of their recently completed cooperative study with the MWC and WCSWCD. Figure 1-1 is a map showing the general setting of the Mosier area with the outline of the broader study area. The majority of this evaluation focuses on a 4 square-mile area known as the Orchard Tract, located in the lower portion of the study area (Figure 1-1) for several reasons related to the hydrogeology that will be discussed later in this report.

1.1 Background

Groundwater from aquifers hosted by basalt flows of the Columbia River Basalt Group (CRBG), and to a minor extent the sediments of the Dalles Formation, is the primary water supply for rural domestic, irrigation and municipal uses in the Mosier Creek watershed. Beginning in the 1970s, groundwater usage in the watershed increased significantly with drilling of new wells primarily for irrigation and domestic uses. OWRD began monitoring water levels in Mosier area aquifers in the 1960s, and documented rapid rates of decline particularly during the 1970s and later, coincident with the dramatic increase in well drilling in the watershed. Over 90 percent of the wells in the watershed in the 1980s had been drilled after 1970 (Lite and Grondin, 1988).

OWRD initiated a study of the Mosier area aquifers in 1985, which subsequently documented water level decline rates of 3.3 feet per year (ft/yr) in the Priest Rapids aquifers and 6.9 ft/yr in the Pomona aquifer (Lite and Grondin, 1988). De-pressurization through commingling wells was identified in the study as a potentially significant cause of water level declines in the Priest Rapids aquifers. In response to the water level declines, OWRD delineated an administrative area in 1988 and withdrew the Pomona and Priest Rapids aquifers from further appropriation other than for exempt uses. Despite the withdrawal of the aquifers, water level declines continued to occur at similar rates, with total declines of 150 to 200 feet recorded in some wells.

Stakeholders in the Mosier area have identified declining water levels and the consequent threat to a stable supply of water as the highest priority concern within the watershed because municipal, rural domestic and agricultural water users depend almost exclusively on groundwater. The threat that water level declines pose to agriculture and other economic bases in the watershed prompted MWC stakeholders to identify the following primary objectives for the watershed (1) stabilize or reverse water

level declines in principal aquifers of the Mosier area and (2) increase summer base flows in Mosier Creek, and (3) support a viable agricultural economy in the valley.

In 2005, the MWC and SWCD began a cooperative investigation of the groundwater system with the USGS to further develop the understanding of the hydrology of the basin and tools for evaluating strategies for accomplishing the goals of the MWC. The primary conclusion of the study is that groundwater flow simulation model predictive uncertainty analysis results indicate that commingling wells are a significant and likely dominant cause of observed declines in the Mosier area. This is supported by a borehole flowmeter test in the area identified as vulnerable to commingling (Erick Burns, USGS, written communication, 2011). The results of the USGS study are anticipated to be published in 2011.

In 2009, the Mosier Watershed Council (MWC) received a SB 1069 funded grant from the OWRD to complete a preliminary evaluation of the feasibility of using aquifer recharge to restore water levels in the basalt aquifers. The scope of the study funded by the grant was subsequently expanded in light of the USGS study findings to evaluate remediation of commingling wells.

1.2 Hydrogeologic Framework

This section summarizes key components of the hydrogeologic framework of the Mosier area that provide the basis for evaluating aquifer recharge and commingling well feasibility in subsequent sections. The geology and hydrogeology of the Mosier area has been described in detail by Newcomb (1969), Lite and Grondin (1988), Kienle (1995), Jervey (1996) and Tolan and Lite (2008). This section is intended to provide a brief synopsis of elements of these prior studies integral to this evaluation, and is not a comprehensive synthesis of prior work.

The Mosier area is underlain by flood basalts of the CRBG. The Pomona flow, the Lolo and Rosalia flows of the Priest Rapids basalt and flows of the Frenchman Springs basalt host the principal basalt aquifers of interest for this study. The Selah Interbed, consisting of alluvial sediments deposited between eruption of the Priest Rapids basalt and Pomona flow, is present within a portion of the study area. Clastic alluvial sediments and volcaniclastic deposits of the Dalles Formation overlie the CRBG flows. A small portion of the study area is covered with Quaternary fluvial sediments consisting of catastrophic Missoula Flood deposits and modern alluvium. Figure 1-2 illustrates the distribution of geologic units and structures within the study area.

CRBG sheet flows exhibit a basic three-part internal arrangement of intraflow structures that originate during the emplacement and cooling of these lava flows: flow top, flow interior, and flow bottom. The combination of a flow top of one flow and the flow bottom of the overlying flow is referred to as the interflow zone. The interflow zones, in comparison to the flow's dense interior, form the predominant water-transmitting zones (aquifers) within the CRBG. The water-transmitting and storage characteristics of an interflow zone are determined by the environment in which the lower flow (flow top) and upper flow (flow bottom) were emplaced. Many flows have simple vesicular flow tops which are less transmissive, whereas flows emplaced with rubbly, and sometimes thick brecciated flow tops are typically highly transmissive. Where the advancing CRBG lava encountered relatively dry conditions, the

flow bottom that results typically consists of a narrow zone of sparsely vesicular, glassy to very fine-grained basalt. In contrast, if the advancing lava encountered lakes, rivers, and/or areas of water-saturated, unconsolidated sediments, far more complex, and generally thicker and more transmissive flow bottom structures formed, such as pillow lava complexes and hyaloclastites. These types of features reflect the paleodrainage pattern that existed at the time of their emplacement. Interflow zones consisting of a pillow/hyaloclastite flow bottom and/or a flow top breccia are generally are highly transmissive, whereas interflow zones comprised of a simple vesicular flow bottom and flow top, generally are relatively thin and less transmissive.

The Mosier area is within the southern portion of the Yakima Fold Belt, a series of east-west trending folds consisting of a series of paired upwarps (anticlines) and downwarps (synclines). Deformation of the basalts in the Yakima Fold Belt was ongoing during emplacement of later basalt flows in the Mosier area, defining paleo-drainage systems and imparting control on the thickness and path of these subsequent basalt flows. The presence of water and deposition of sediments within these drainages created conditions favorable for development of highly transmissive features in basalt flows, including pillow basalt/hyaloclastite strata formed by sudden quenching of lava as it entered wet lowland areas. Later, less voluminous basalt flows commonly occupied only the topographic lows in drainages and are termed “intracanyon flows. The Pomona flow is a typical intracanyon flow. Figure 1-2 shows the generally distribution of structures in the Mosier area with faults depicted in red and folds depicted purple. Of significance to this study are five main structures, including:

1. The Rocky Prairie thrust fault, which trends in a northeasterly direction across the lower end of Mosier Creek in sections 7 and 12 (Figure 1-2). This feature appears to act as a barrier to groundwater flow, at least in shallower basalt flows, and thus defines the northerly edge of the study area (Lite and Grondin, 1988).
2. A small syncline subsidiary located south of the Mosier Syncline. The axis of this structure forms the bottom of a down-warped fold that trends northeasterly to easterly in sections 12 and 7 and is separated from the main Mosier Syncline by a small anticline and the Rocky Prairie thrust fault. The syncline is related to the Yakima folds and exerted an influence on paleodrainage and basalt flow emplacement.
3. The Columbia Hills anticline that defines the southern, upgradient boundary of the study area on Wasco Butte in sections 28, 32 and 33.
4. The Maupin wrench fault, a northwest-trending fault that defines the western boundary of the study area.
5. A second northwest trending fault that defines the eastern boundary of the focus area.

Within the study area, the basalt flows dip generally in a north-northwesterly direction, towards the axis of the syncline. As noted by Lite and Grondin (1988), the gradient of Mosier Creek is less than the dip of the CRBG units, and the creek is incised through the basalt interflow-hosted aquifers within the study area and thus likely is in hydraulic connection with the aquifers. The upper aquifers (Pomona and Priest Rapids) are exposed along the creek lower in the watershed, whereas the lower aquifers (e.g., Frenchman Springs) are exposed further upstream (Figure 1-2).

Structural control on paleo-drainage development and basalt flow emplacement affects the distribution and hydraulic characteristics of both sedimentary and basalt aquifers within the study area. Lite and Grondin (1988) noted that the permeability of the Pomona and Priest Rapids aquifers is highest within the Orchard Tract area, near the axis of the syncline. Higher permeability in the aquifers correlates with the presence of sedimentary interbeds, as well as coarser-grained alluvial sediments within the Dalles Formation, indicating that paleo-drainage development within the syncline exerted a strong influence on the development and distribution of permeability within both sediments and basalt flows.

The six principal hydrostratigraphic units relevant to this study include the following:

> Recent alluvial sediments: thin sequences of alluvial sediments are locally present along Mosier Creek and occupy limited areas within the flood plain of the creek. The sediments along Mosier Creek consist primarily of flood plain and terrace deposits (Lite and Grondin, 1988).
>
> Dalles Formation: coarse-grained alluvial sequences within the volcanic and volcaniclastic deposits of the Dalles Formation are sufficiently productive water-bearing units to host some wells in the study area.
>
> Pomona Aquifer: this aquifer occurs within a vesicular zone at the base of the Pomona flow. The Pomona flow is limited in extent and this productive vesicular zone appears to be limited primarily to the Orchard Tract where the Selah Interbed is present (Lite and Grondin, 1988).
>
> Selah Interbed: a sedimentary interbed (Selah Interbed) or time-equivalent weathered zone is present between the Priest Rapids and Pomona aquifers. Where present, the Selah Interbed separates the basal vesicular zone of the Pomona aquifer from the Priest Rapids aquifer with what is described in most well logs as a green clay or green claystone, although some coarser alluvial sediments also may be present. The interbed is primarily present within the lower Orchard Tract area, near the axis of the syncline.
>
> Priest Rapids Aquifer: The Priest Rapids basalt consists of two separate flows, the Lolo (upper) and Rosalia (lower). The weathered flow top of the Lolo flow is a productive aquifer within the Orchard Tract, and a permeable zone may also occur locally within a pillow/hyaloclastite zone at the base of the Priest Rapids.
>
> Frenchman Springs Aquifer: The Frenchman Springs consists of multiple flows within the study area; however, information regarding the nature and distribution of water-bearing zones within the unit is limited.

Glacio-fluvial flood sediments also blanket portions of the Orchard Tract, and host an important aquifer downstream (north) of the study area, but are not relevant to this study.

Ranges of hydraulic properties for the basalt aquifers described in this section were compiled from OWRD water well reports and publications by Lite and Grondin (1988), Kienle (1995), Jervey (1996), and OWRD water well records, and are summarized in Table 1-1. These parameters are discussed below in the evaluation of well recharge feasibility.

Table 1-1. Summary of Hydraulic Properties for Basalt Aquifers in Mosier Area

Aquifer	Transmissivity and Storativity	Typical Well Yield	Depth To Water
Pomona Basalt	11,000 to 24,000 ft^2/day, Storativity = 1 x 10^{-5}	<100 gallons per minute (gpm)	7 feet above ground surface (ags) (May, 2010 @ WASC 51778)
Priest Rapids Basalt	10,000 to 30,000 ft^2/day Storativity = Unknown	Up to 1,200 gpm	43.9 feet ags (Aug., 2006 @ WASC 51497)
Frenchman Springs Basalt	Unknown	<150 gpm	4.4 feet ags (Mar., 2010 @ WASC 50012)

Source and Notes: Transmissivity and storativity from aquifer testing performed by Lite and Grondin (1988) at wells in township 2N, Range 12E, Section 7 (Pomona basalt aquifer) and township 2N, Range 11E, Section 12 (Priest Rapids basalt aquifer), Well yield from OWRD well records and Jervey (1996), Depth to water from OWRD water well records. Depth to water is highly dependent on well location and wellhead elevation. Groundwater levels presented in the table are the most recent data available from each aquifer and are from wells generally located at lower elevations in the Orchards Tract. Water levels in wells located in higher elevations are commonly below ground surface.

1.3 Report Organization

The remainder of this report summarizes a preliminary feasibility evaluation and comparative analysis of four primary strategies for arresting or reversing water level declines in Mosier area aquifers, such as:

1. Aquifer recharge, including surface recharge and well recharge approaches
2. Remediation of commingling wells
3. Combination of aquifer recharge and commingling well repair
4. Conservation

The content of the remainder of this report is organized in the following sections:

Aquifer Recharge Feasibility: summarizes the evaluation of the feasibility of using surface recharge or direct well recharge to restore aquifer water levels. Contents of this section include:

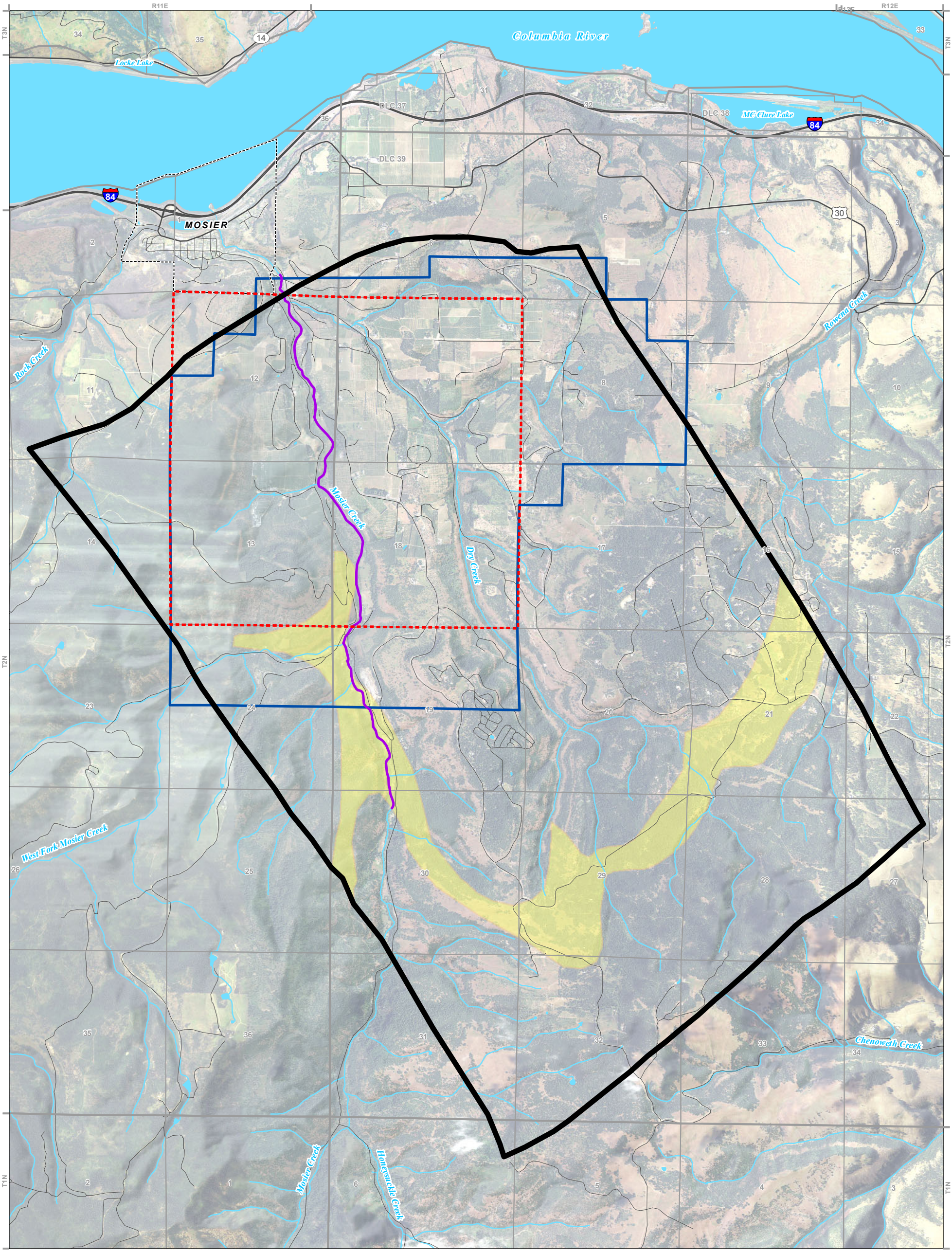
(1) assessment of direct well and surface recharge feasibility, including cost estimates
(2) evaluation of source water diversion feasibility, other infrastructure requirements and costs,
(3) the legal framework for conducting a recharge project in the Mosier Creek watershed

Commingling Well Remediation Feasibility: summarizes typical well construction in the watershed, recommended well repair techniques and costs. In addition, a summary of methods for confirmation of the presence and rate of commingling also is presented.

Conservation: summarizes conservation measures previously implemented in the watershed and their overall effectiveness in reducing water usage and the rate of groundwater level declines. Costs for additional conservation measures also are presented.

Additional Required Elements of OWRD Grant: provides analyses of specific requirements of the funding legislation, including:

(1) Preliminary analysis of peak and ecological flows of Mosier Creek and impact of the project on those flows
(2) Analysis of environmental harm or impacts from proposed project
(3) Evaluation of the need for and feasibility of using stored water to augment in-stream flows
(4) Comparative analysis of alternative means of supplying water, is presented in a matrix that summarizes the benefits, disadvantages, costs and key unknowns of the various aquifer recovery strategies.



LEGEND

- USGS Model Domain and Study Area
- Orchard Tract Focus Area
- Preliminary Area for Evaluation of Surface Infiltration Potential in the Priest Rapids Aquifer
- Reach of Mosier Creek for Potential Diversion

All Other Data

- Pomona/Priest Rapids Administrative Area
- Cities
- Highways
- Roads
- Watercourses
- Waterbodies

MAP NOTES:
Date: May 5, 2011
Data Sources: DOGAMI, USGS, OGIC, ESRI

N

0 1,500 3,000 4,500
Feet

GSI Water Solutions, Inc.

FIGURE 1-1

Project Area

Mosier Aquifer Recovery Feasibility Study
Mosier Watershed Council/Wasco Co. SWCD

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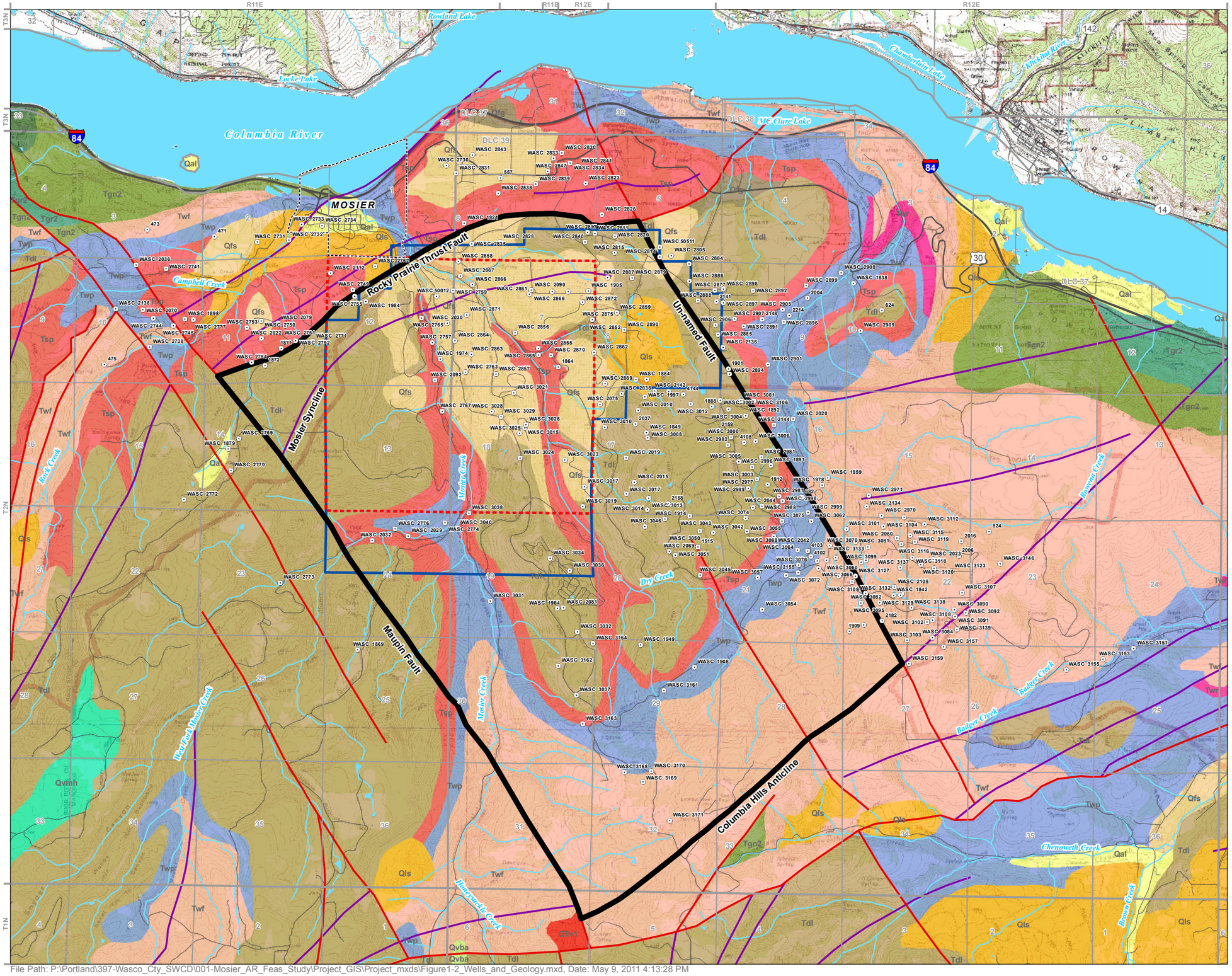

FIGURE 1-2

Geologic Setting

Mosier Aquifer Recovery Feasibility Study
Mosier Watershed Council/Wasco Co. SWCD

LEGEND

- Wells

Geology

- Qal - Alluvium
- Qfs - Missoula flood deposits, silts and sands
- Qfg - Missoula flood deposits, gravel
- Qls - Landslide
- QTv1 - Volcanic rocks, undifferentiated
- Qvba - Basaltic andesite and basalt flows, unnamed
- Qvmh - Andesite of Mount Hood
- Tdl - Dalles Formation
- Tsp - Saddle Mountains Basalt, Pomona Member
- Twp - Wanapum Basalt, Priest Rapids Member
- Twr - Wanapum Basalt, Roza Member
- Twf - Wanapum Basalt, Frenchman Springs Member
- Tgn2 - Grande Ronde Basalt, upper flows, normal magnetic polarity
- Tgr - Grande Ronde Basalt, undivided
- Tgr2 - Grande Ronde Basalt, lower flows, reverse magnetic polarity
- Faults
- Folds

All Other Data

- USGS Model Domain and Study Area
- Pomona/Priest Rapids Administrative Area
- Orchard Tract Focus Area
- Cities
- Highways
- Roads
- Watercourses
- Waterbodies

N

0 2,000 4,000 6,000
Feet

MAP NOTES:
Date: May 9, 2011
Data Sources: DOGAMI, USGS, OGIC, ESRI

GSI Water Solutions, Inc.

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2.0 Aquifer Recharge Feasibility

2.1 Introduction

An initial evaluation of the concept of using artificial recharge techniques to arrest or reverse water level declines in basalt aquifers in the study area is summarized in this section. The evaluation included consideration of hydrogeological, infrastructure and permitting requirements in identifying locations potentially favorable for conducting recharge and constructing related facilities. Costs also were developed as part of the evaluation. Commingling of aquifers through wells has been identified as a dominant cause of water level declines in the study area. The recharge techniques evaluated in this section are not likely to be effective in reversing water level declines without at least some reduction of commingling. Therefore, this assessment of recharge feasibility does not directly assess the effectiveness of recharge in restoring aquifer levels other than qualitatively in a comparative analysis of all aquifer recovery alternatives presented in Section 5.

The following specific aquifer recharge feasibility elements were evaluated in this section:

- Sites or areas potentially suitable for conducting artificial recharge of basalt aquifers using surface infiltration or direct well recharge techniques considering hydrogeological, infrastructure and permitting considerations.
- Locations in Mosier Creek potentially suitable for diverting water for recharge
- Potential infrastructure requirements for an aquifer recharge system
- Costs for implementing a recharge program using surface infiltration or direct well recharge
- Legal framework and requirements for an aquifer recharge program and identification of a preferred permitting path.

Evaluation of related issues, including potential environmental impacts and identification of a pathway for assessing the feasible timing, duration and rate of diversion considering the need to protect ecological flows on Mosier Creek also were evaluated and are summarized in Section 4 of this report.

Recharge Concepts

The two basic techniques for artificial recharge evaluated in this report include surface infiltration and recharge through a well. A schematic depiction of these two techniques as they pertain to the Mosier area is illustrated in Figure 2-1.

Surface infiltration involves identifying an area where the basalt interflow zones are present at or near the ground surface and directing water from Mosier Creek to an impoundment, infiltration basin or other recharge facility where the water infiltrates into the interflow zone and recharges the aquifer. Some advantages of surface recharge include:

- Avoid or minimize treatment requirements for recharge water
- Greater rates and volumes may be possible
- Can be relatively simple and low maintenance

However, because of the unique characteristics of CRBG aquifers, surface recharge has some significant disadvantages such as:

- A unique combination of geologic conditions near source water are required to ensure recharge reaches the target aquifer, and this combination is commonly not present
- The benefits of surface recharge in this environment are more difficult to quantify
- The risk of loss of water is greater
- The technique in this setting has a relatively high overall degree of uncertainty relative to well recharge.

Well recharge involves injecting source water directly into the aquifer, generally through a well drilled or retrofitted for that purpose. Figure 2-1 illustrates several alternatives for diverting water for well recharge, including (1) using an infiltration gallery to provide natural filtration of the water before injection, and (2) directly from the stream, through a treatment process and then injected. The significant advantages of well recharge include the following:

- The recharge can be applied directly in the area of need to maximize benefits and reduce uncertainty. The benefits are directly measurable and relatable to the rate and volume of recharge applied
- In some cases, existing wells may be suitable, saving the cost of drilling a new well

Significant disadvantages of well recharge include:

- Treatment of raw source water from a stream generally is necessary to remove biological constituents and suspended solids; treatment is typically costly.
- Well recharge involves one or more mechanical systems and power, which have operational and maintenance needs.

The focus of the aquifer recharge evaluation is the basalt aquifers within the Orchard Tract, which is the approximately 4 square mile area that roughly coincides with an area identified by Kienle (1995) as having the largest water level declines and also having the highest volume of annual groundwater use, particularly from the basalt aquifers. Furthermore, the trough in the aquifer system formed by the syncline within the Orchard Tract is hydrogeologically more favorable for recharge because the Pomona and Priest Rapids aquifers generally have greater overall transmissivity and, relevant to surface recharge feasibility, the aquifers crop out near the creek within this area.

Recharge Volume

The annual total groundwater pumpage in the study area is estimated to be approximately 1,000 acre-feet (AF), which equates to 326 million gallons. The MWC has estimated a maximum future annual withdrawal volume for the area of 1,500 AF. The relationship between the volume of pumped withdrawals in the basin and the declining water levels is not known because of the scale and role that inter-aquifer transfer through commingling wells has on groundwater level declines is not well understood. For the purposes of this evaluation, the estimated total annual volume of pumping withdrawals of 1,000 AF was used as a target volume for evaluating well recharge feasibility. The USGS

numerical flow model for the basalt aquifers in the watershed will provide a future tool for evaluating the relative contribution to water level declines of pumping and aquifer commingling in wells, and approximations of the actual volume of recharge needed to arrest and restore water level declines, both with and without commingling well repair.

Assuming that source water is available for diversion and injection for 5 to 7 months, an injection rate of 1,100 to 1,500 gpm would be required to artificially recharge a target volume of 1,000 AF. Taking a conservative approach and assuming a five month recharge period, the target recharge rate would be up to 1,500 gpm. The recharge rates ultimately desired will depend on aquifer recovery goals, whether repair/replacement of commingling wells is undertaken also, and the amount of commingling well remediation completed. Additional modeling analysis is necessary to look at incremental benefits to the aquifers as repair of commingling wells proceeds, starting with the highest priority wells.

2.2 Surface Recharge

Surface recharge involves recharging the aquifer system through enhanced surface infiltration. Under this method, water is ponded on the soil surface and the infiltrated water percolates through permeable material on its path to the aquifer. Because surface recharge relies on the downward percolation of water to recharge the aquifer, the target aquifer cannot be overlain by impermeable strata that restrict water flow below the location of infiltration.

Surface recharge may occur through constructed off-channel infiltration basins or may be achieved in-channel by placing a dam to back up water and increase the wetted surface area behind the dam. Possibly adverse ecological and regulatory effects could be created by placing a dam on Mosier Creek, making dam placement and in-channel surface recharge operations less attractive than off-channel surface recharge. For this reason the discussion of surface recharge feasibility would focus on off-channel recharge basins. Many of the feasibility requirements for off-channel recharge basins also apply to in-channel surface recharge siting.

As infiltrated water moves downward to the aquifer, the soil removes organics, metals, pathogens, and particles from the source water, greatly improving water quality. In Oregon, aquifer recharge by surface recharge is not regulated by established source water quality requirements other than setting forth that the recharged water will not degrade the existing water quality of the aquifer. It is expected that filtration of the water as it percolates through the soil and alluvium material would provide sufficient treatment to meet state requirements. However, during the limited license testing period regulators may require monitoring of surface water and groundwater quality during recharge operations to verify that degradation of groundwater quality is not occurring.

Surface Recharge Systems

Surface recharge operations are composed of five basic components, all of which feed into a feasibility analysis: (1) diversion of water from the source; (2) conveyance of water from the diversion to the infiltration basin; (3) spreading of water over the basin; (4) infiltration and recharge of the underlying aquifer; and (5) maintenance of the recharge basin to maintain infiltration rates. Each component is further discussed below.

Water Diversion: Mosier Creek would serve as the source for an aquifer recharge operation because of the existence of available flows, as discussed in the Legal Framework section below. Diversion from Mosier Creek may occur by simple gravity flow in areas where that is amenable; however, the majority of the Mosier Creek channel is incised below grade and would require that water be pumped from the creek. Further discussion of diversion for both surface recharge and well recharge is summarized in the Diversion/Infrastructure section of this report.

Water Conveyance: Conveyance of water may occur through an open channel or enclosed line. If conditions exist that allow the water to be gravity-conveyed, an open canal would be preferred; however, topographic constraints may require that an enclosed, pressurized line be used instead. Conveyance costs (e.g. construction and pumping costs) increase significantly with distance from the diversion, thus it is preferred to keep conveyance distances to a minimum.

Water Spreading: Water spreading practices follow typical flood irrigation methods. The constructed recharge basin is graded to promote surface spreading over the entirety of the basin.

Infiltration and Recharge: Recharge basins, if built and sited correctly, require little attention during recharge operations. However, infiltration rates should be monitored to determine when site maintenance is required to maintain target recharge rates.

Maintenance: Over time, deposition and accumulation of suspended solids on the surface of the spreading basin results in clogging of the infiltration surface and decreased infiltration rates. The formation of biofilms on the soil surface also contributes to clogging. Regular drying of the recharge basin to promote cracking of the clogging layer or physical removal of the clogging layer would likely be necessary. The recurrence period of maintenance to maintain infiltration rates would ultimately be determined by the performance of the basin during pilot testing.

Surface Recharge Site Feasibility Criteria

The surface recharge feasibility evaluation focuses on recharging the Priest Rapids member of the Wanapum Basalt because the Priest Rapids aquifer system experiences the greatest groundwater declines and is most drawn on by irrigation wells in the Orchard Tract. The Priest Rapids aquifer system includes the interflow zone between the two Priest Rapids flows, the vesicular flow tops, and the pillow breccia at the bottom of the lower Priest Rapids flow. While of less importance from a groundwater use standpoint, this evaluation also considers recharging the Pomona flow bottom.

In order to recharge the Priest Rapids or Pomona aquifer system by surface recharge, the target aquifer cannot be overlain by strata that restrict water flow into the aquifer. Examples of restrictive strata are the Selah member and Pomona and Priest Rapids flow interiors. Furthermore, Mosier Creek would serve as the water source, and to reduce conveyance costs associated with both distance and topography, the recharge basin would ideally be located near Mosier Creek. The steep topography away from Mosier Creek serves as a primary physical constraint with land elevations greater than 20 feet above the banks of Mosier Creek deemed impracticable for surface recharge. Figure 2-2 presents the approximate area of interest (AOI) for surface recharge basin siting based on the initial criteria as identified by geologic mapping of the basin (OWRD, 1988) and elevation contours near Mosier Creek.

The AOI extends slightly south and north of the Priest Rapids exposure boundary to account for uncertainty in the location of this boundary and to incorporate the area of potential surface recharge into the Pomona aquifer system. Analysis of potential recharge into the Pomona aquifer system is restricted to the northern part of the AOI at the contact between the Pomona and Priest Rapids. The total area of the AOI is 61.4 acres.

The AOI was divided into ten, equal-length creek reaches (Figure 2-2) and the areas within each reach were further evaluated for surface recharge feasibility based on site criteria consisting of the following general parameters:

- Location
- Surface conditions
- Subsurface conditions
- Source water quality
- Acquisition and maintenance costs

During this preliminary evaluation, the basis for evaluating the surface and subsurface conditions is more subjective in nature, requiring information from existing studies in the basin.

Location

- The locations of potential recharge sites were evaluated based on the following parameters:
- Land ownership, land use, and access
- Distance of the site from:
    - Primary groundwater withdrawal area (Orchard Tract)
    - Known environmental issues such as landfills, remediation projects, and cultural resource sites

The application of the above parameters to the AOI is described in further detail below.

Land Ownership, Land Use, and Access: The entire AOI is zoned as forest land and privately owned. Neither designation is a fatal flaw with regard to recharge site feasibility, since water reservoirs are a permitted use in zoned forest land. Additionally, all sites are reasonably accessible by Mosier Creek Road.

Distance of the Site from Locations of Interest: The preferred location of a surface recharge basin is in the northern portion of the AOI for the following reasons: (1) Priest Rapids and Pomona permeable zones are thicker and more transmissive nearer the syncline axis (further north) and 2) It is advantageous to perform recharge nearer the Orchard Tract where the preponderance of Priest Rapids and Pomona groundwater withdrawals and/or leakage are occurring. Doing so increases the likelihood that recharged water is benefitting the area of most need.

The presence of existing groundwater or soil contamination sources or nearby waste disposal facilities is an important consideration due to the potential for a surface-recharge facility to increase groundwater elevation and saturate previously isolated contaminant sources. Furthermore, the recharge operation

may change the groundwater flow regime and negatively influence existing groundwater remediation activities. Existing subsurface contaminant sources have not been identified in or near the surface recharge AOI nor are there ongoing groundwater remediation activities in this area.

Also of consideration is the presence of cultural resources at the location of the recharge basin. An evaluation of cultural resources was not performed and is recommended for potential surface recharge sites targeted for further evaluation.

Surface Conditions

Surface soil conditions were evaluated for the following parameters:

- Soil permeability
- Effect of geomorphology and topography on engineering and cost related issues

The application of the above parameters to the AOI is described in further detail below.

Soil Permeability: Surface soil permeability was estimated based on United States Department of Agriculture Soil Survey (Green, 1982). Estimated permeabilities for soil series present in the AOI were grouped into three qualitative categories: high, moderate, and low. Table 2-1 summarizes these categories and the range in permeability for each group. Table 2-1 also summarizes the approximate basin surface area needed to recharge 1,000 acre-ft over a five month period for each permeability category. The required basin surface area includes a 1.5X basin size factor to account for operational design. The five-month recharge period represents the length of time when sufficient water is present in Mosier Creek for diversion and aquifer recharge. The operational design factor takes into account the actual basin footprint and potential operation interruptions during the five-month recharge period. Areas exhibiting high, moderate, and low permeability in AOI are graphically shown in Figure 2-3. Recharge basin size ranges from 0.3 acres for high permeability soils to 24.6 acres for low permeability soils. In order to increase site permeability and decrease required basin size it is possible to excavate the permeability limiting soil layer if the soil layer is not too deep or too thick.

Table 2-1. Soil phases grouped by permeability and estimated recharge basin area to meet recharge rate target

Map Color	Relative Permeability	Range of Permeabilities (inches/hr)	Soil Phase Name	Recharge Basin Area (acres)[1]
Green	High	2.0 to 19.8	Riverwash	2.5 to 0.3
Yellow	Moderate	0.6 to 2.0	Bald very cobbly loam	8.6 to 2.5
			Frailey loam	
			Bodell very cobbly loam	
			Hesslan complex	
			Skyline-Hesslan complex	
Pink	Low	0.2 to 0.6	Wamic loam	24.6 to 8.6

[1]Assumes target recharge of 1,000 acre-ft over 5 month period and 1.5X operational design factor

Geomorphology and Topography: The AOI is in the flood plain of Mosier Creek and may be inundated by large floods, particularly in areas where the Mosier Creek channel is not deeply entrenched. In addition to risk of flooding in these lower elevation landforms, topographic slopes at higher elevation landforms may create engineering design issues and increase construction and maintenance costs. As discussed previously, a limited topographic slope was considered in identifying the AOI.

Subsurface Conditions

Subsurface conditions were evaluated for the following parameters:

- Presence of locally unconfined Priest Rapids or Pomona permeable zones
- Discharge to Mosier Creek

The application of the above parameters to the AOI is described in further detail below.

Presence of Locally Unconfined Priest Rapids or Pomona Permeable Zones: The water-bearing zones of the Priest Rapids and Pomona are the target units for recharge; therefore these zones must be present and not overlaid by strata that restrict water flow into the aquifer. Field reconnaissance of exposed Priest Rapids and Pomona along Mosier Creek within the AOI did not identify locations where permeable zones were present. Detailed mapping and streamflow seepage run measurement would be needed to identify locations where significant exchanges between permeable interflow zones and the creek are taking place. Locally unconfined permeable zones may be present away from the creek, underneath the alluvium deposits. However, information is not available to further evaluate the presence of locally unconfined Priest Rapids or Pomona permeable zones in the area of the AOI, thickness of the permeable zones, and lateral extent.

A subsurface characterization program to identify the presence, thickness, and lateral extent of locally unconfined Priest Rapids or Pomona permeable zones is recommended for potential surface recharge sites targeted for further evaluation.

Discharge to Mosier Creek: Performing surface recharge in an area where the aquifer discharges to Mosier Creek, as opposed to gaining to the aquifer and providing benefit to the Orchard Tract, is to be avoided and may be a fatal flaw. Priest Rapids aquifer potentiometric surface mapping performed by the Oregon Water Resources Department (OWRD, 1988) indicates that the Priest Rapids aquifer discharged to Mosier Creek in the northern part of the AOI in 1986. Potentiometric data did not exist for the middle and southern part of the AOI to evaluate whether Mosier Creek is gaining or losing in those areas. The United States Geological Survey (USGS) recently performed a groundwater/stream connectivity survey; however, results were not available at the time of this study. It is possible that groundwater levels in the Priest Rapids have declined sufficiently such that the Mosier Creek is now losing to the Priest Rapids. The USGS study and research currently being initiated by OWRD and a Portland State University (PSU) graduate student may shed additional light on the relationship between the aquifers and Mosier Creek within the AOI.

Source Water Quality

A surface recharge basin would draw from Mosier Creek and would be expected to have similar water quality, regardless of location within the AOI. A detailed water quality sampling effort for Mosier Creek was performed in 1980 (http://waterdata.usgs.gov/usa/nwis/uv?14113200). Water quality results for Mosier Creek did not exceed Oregon Department of Environmental Quality groundwater quality reference levels. Constituent concentrations in Mosier Creek water for parameters tested also were less than basalt aquifer concentrations of the same constituents, indicating that water quality of the aquifer would not be negatively influenced by surface recharge of Mosier Creek water. Water quality data from Mosier Creek and groundwater quality data taken from Lite and Grondin (1988) are tabulated in Table 2-2.

From a basin operation standpoint, the greatest water quality concern would be the presence of large amounts of suspended solids and organic carbon during high Mosier Creek flow periods that coincide with the occurrence of surface recharge. Suspended solids and organic carbon would hasten the formation of a clogging layer, decreasing basin performance and eventually requiring recharge basin maintenance to remove the clogging layer.

Table 2-2.
Summary of Groundwater and Mosier Creek Water Quality

	ASR Standard	Unit	Pomona Groundwater					Priest Rapids Groundwater					Frenchman Springs Groundwater					Mosier Creek				
			Min	Max	Median	Nondetections	No. of Samples	Min	Max	Median	Nondetections	No. of Samples	Min	Max	Median	Nondetections	No. of Samples	Min	Max	Median	Nondetections	No. of Samples
Field parameters																						
Temperature	--	°C	15.5	15.5	15.5	0	1	15.7	16.3	16	0	3	14.8	14.8	14.8	0	2	10	19	14.8	0	7
Conductivity	--	umhos/cm	250	250	250	0	1	160	256	199	0	3	209	228	218.5	0	2	85	142	96	0	7
pH	6.5-8.5 (SMCL)	units	7.3	7.3	7.3	0	1	7	8.2	7.7	0	3	7.2	7.3	7.3	0	2	6.1	8.1	7.5	0	7
Turbidity	1 (MML)	ntu	12	12	12	0	1	--	--	--	3	3	--	--	--	2	2	0.2	1.7	1.4	0	7
General Chemistry																						
Alkalinity	--	mg/L	121	121	121	0	1	81	131	99	0	3	110	117	113.5	0	2	--	--	--	0	0
Chemical Oxygen Demand	--	mg/L	--	--	--	1	1	--	--	--	3	3	--	--	--	2	2	--	--	--	0	0
Total Dissolved Solids	500 (SMCL)	mg/L	190	190	190	0	1	158	198	158	0	3	175	186	180.5	0	2	75	115	81	0	7
Total Organic Carbon	--	mg/L	--	--	--	1	1	--	--	--	3	3	--	--	--	2	2	1.6	3.4	2.6	0	7
Total Organic Halides	--	mg/L	0.008	0.008	0.008	0	1	--	--	--	3	3	--	--	--	2	2	--	--	--	0	0
Dissolved Calcium	--	mg/L	18	18	18	0	1	13	20	19	3	3	17	18	17.5	0	2	6.4	11	7.3	0	7
Total Calcium	--	mg/L	18	18	18	0	1	--	--	--	3	3	--	--	--	1	1	--	--	--	0	0
Dissolved Chloride	250 (SMCL)	mg/L	5	5	5	0	1	2.9	3.6	3.3	3	3	3	3.5	3.3	0	2	1.4	2.4	1.6	0	7
Dissolved Fluoride	4 (MCL)	mg/L	0.2	0.2	0.2	0	1	0.1	0.5	0.3	0	3	0.1	0.1	0.1	1	2	0	0.3	0.1	0	7
Dissolved Hardness	--	mg/L	110	110	110	0	1	69	92	88	3	3	96	96	96	0	2	--	--	--	0	0
Dissolved Potassium	--	mg/L	2.4	2.4	2.4	0	1	1.9	4.1	2.1	3	3	2.8	4.5	3.7	0	2	1.1	1.6	1.5	0	7
Dissolved Sodium	--	mg/L	11	11	11	0	1	7.5	23	7.7	3	3	7.2	9.2	8.2	0	2	3.9	6.6	4.9	0	7
Dissolved Sulfate	250 (SMCL)	mg/L	11	11	11	0	1	1.9	8.9	7.3	3	3	3.4	4.5	4	0	2	0.1	1.2	0.3	0	7
Metals (Dissolved)																						
Dissolved Iron	0.3 (SMCL)	mg/L	0.93	0.93	0.93	0	1	0.07	0.07	0.07	0	3	--	--	--	1	1	0.02	0.04	0.03	0	7
Dissolved Magnesium	--	mg/L	16	16	16	0	1	8.7	10	9.6	3	3	13	13	13	0	2	3.4	6.1	3.8	0	7
Dissolved Manganese	0.05 (SMCL)	mg/L	0.06	0.06	0.06	0	1	--	--	--	3	3	--	--	--	1	1	M	M	M	0	7
Metals (Total)																						
Total Arsenic	0.01 (MCL)	mg/L	0.009	0.009	0.009	0	1	--	--	--	3	3	--	--	--	1	1	--	0.002	0.001	0	7
Total Barium	2 (MCL)	mg/L	--	--	--	0	0	--	--	--	3	3	--	--	--	1	1	--	--	--	7	7
Total Boron	--	mg/L	--	--	--	0	0	--	--	--	3	3	--	--	--	1	1	0.03	0.08	0.06	0	3
Total Chromium	.1 (MCL)	mg/L	--	--	--	0	0	--	--	--	3	3	--	--	--	1	1	--	0.01	--	1	7
Total Copper	1.3 (MCL Action Level)	mg/L	--	--	--	0	0	--	--	--	3	3	0.013	0.013	0.013	0	1	M	0.02	M	0	7
Total Iron	0.3 (SMCL)	mg/L	0.95	0.95	0.95	0	1	0.08	0.08	0.08	0	3	--	--	--	2	2	0.07	1.5	0.15	0	7
Total Lead	0.015 (MCL Action Level)	mg/L	--	--	--	1	1	--	--	--	3	3	--	--	--	1	1	0.001	M	M	1	7
Total Manganese	0.05 (SMCL)	mg/L	0.06	0.06	0.06	0	1	--	--	--	3	3	--	--	--	1	1	0.01	0.02	0.01	1	7
Total Selenium	0.05 (MCL)	mg/L	--	--	--	1	1	--	--	--	3	3	--	--	--	1	1	--	0.001	--	1	7
Total Silver	0.1 (SMCL)	mg/L	0.001	0.001	0.001	0	1	--	--	--	3	3	--	--	--	1	1	--	0.001	--	1	7
Total Zinc	5 (SMCL)	mg/L	--	--	--	1	1	--	--	--	3	3	0.21	0.21	0.21	0	1	0.01	0.21	0.03	0	7
Miscellaneous																						
Ammonia Nitrogen	--	mg/L	--	--	--	1	1	0.03	0.03	0.03	0	3	--	--	--	0	2	--	0.05	0.01	0	6
Nitrate+Nitrite Nitrogen	--	mg/L	--	--	--	1	1	0.56	0.65	0.605	0	3	0.2	0.4	0.3	0	2	--	0.06	0.02	1	7
Total Kjeldanl Nitrogen	--	mg/L	--	--	--	1	1	--	--	--	3	3	--	--	--	2	2	--	--	--	0	0
Total Phophorus	--	mg/L	0.3	0.3	0.3	0	1	0.028	0.26	0.067	3	3	0.1	0.1	0.1	0	2	0.01	0.05	0.03	0	7

Notes
M = presence verified but not quantified; assume smaller than detected quantified number but larger than nondetects
Non detects counted in stats for min, max & median

ASR = Aquifer Storage and Recovery
ASR Standard based on Oregon Administrative Rule 690-350-0010 (6)

References:
Mosier Creek water quality data collected by the USGS at gaging station #14113200 on the following dates: 5/25/1980, 6/6/1980, 6/11/1980, 6/15/1980, 6/20/1980, 7/16/1980, 10/18/1980
Groundwater quality data from DEQ's 1988 *Hydrogeology of the Basalt Aquifers near Mosier, Oregon: A Ground Water Resource Assessment* , Appendix D.

Acquisition and Maintenance Costs

Land Acquisition Cost: A Regional Multiple Listing Service database query of land transactions in the AOI since 2004 produced a single land transaction that occurred in 2008 for $13,500 per acre. 2011 land values in the Mosier area are approximately 85% of 2008 values, thus it is assumed that the current land value is approximately $11,500 per acre for the entire AOI. Based on required acreage values reported in Table 2-1, land acquisition values would be less than $28,500 for a high permeability location, $28,500 to $98,000 for a moderate permeability location, and greater than $98,000 for a low permeability location.

Maintenance Cost: Costs associated with the physical removal of the clogging layer are approximately $1,500 per acre. Physical removal of the clogging layer may be needed annually or less, depending on water quality and the ability to dry and crack the clogging layer to increase surface infiltration to meet the target recharge rates.

Additionally, site maintenance is estimated to cost approximately $5,000 to $10,000 per year for basic grounds maintenance and periodic checking of the system when recharge operations are occurring.

Ranking Results

The AOI was divided into ten, equal-length creek reaches and each reach was ranked for surface recharge feasibility based on the five general parameters: location, surface conditions, subsurface conditions, source water quality, and acquisition and maintenance cost. Reaches were ranked relative to each other based on each subset of the five general parameters on a scale of: 1- unfavorable, 2-satisfactory, and 3-favorable/ideal. Weighted average rankings were calculated to determine the most favorable reach (highest score) based on each of the five general parameters.

Table 2-3 displays a summary of the reach selection criteria and rankings, which are documented in the above sections describing the initial screening of recharge sites. Based on the analysis, creek reaches 1, 4 and 5 (Figures 2-1 and 2-2) are found to best meet the criteria and further evaluation of surface recharge should focus on these areas.

Data Gaps

Significant data gaps in the analysis of surface recharge feasibility exist that serve as potential fatal flaws to siting a surface recharge basin. These data gaps must be addressed to better define surface recharge feasibility and feasibility of project locations.

Presence of Locally Unconfined Priest Rapids or Pomona Permeable Zones: The location, thickness, and lateral extent of locally unconfined Priest Rapids and Pomona permeable zones are not delineated. Nonexistence of these zones or lack of hydraulic communication with the Priest Rapids or Pomona aquifer system in the Orchard Tract would serve as a fatal flaw for a potential surface recharge site. Site feasibility for surface recharge will require subsurface characterization activities to determine if a locally unconfined Priest Rapids or Pomona permeable zone exists and its connectivity with the Orchard Tract.

Permeability of Alluvium: The permeability of alluvium overlying the receiving basalt permeable zone will ultimately control recharge basin design area and feasibility, necessitating that site specific

characterization of alluvium permeability be performed at depth. This evaluation can focus on higher feasibility areas.

Discharge to Mosier Creek: A better understanding of which Mosier Creek reaches are gaining (i.e. receiving discharge from Priest Rapids) or losing (i.e. discharging to Priest Rapid) is needed. An area where Mosier Creek is receiving discharge from the target aquifer is a surface recharge site fatal flaw and would disqualify that site for further consideration. A groundwater/stream connectivity survey for Mosier Creek has been performed by the USGS. Release of their findings and the current OWRD/PSU groundwater/surface water interaction study will aid in filling this data gap.

Table 2-3. Summary of selection criteria and ranking results

Recharge Site Selection Parameters		Surface Recharge Area of Interest Reach									
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Location	Land Ownership, Land Use, and Access	3	3	3	3	3	3	3	3	3	3
	Distance to Orchard Tract	3	3	3	2	2	2	1	1	1	1
	Distance to known environmental issues	3	3	3	3	3	3	3	3	3	3
Average		**3.0**	**3.0**	**3.0**	**2.7**	**2.7**	**2.7**	**2.3**	**2.3**	**2.3**	**2.3**
Surface Conditions	Soil Permeability	2	1	1	3	3	2	2	3	3	3
	Geomorphology and Topography	2	2	2	2	2	2	2	2	2	2
Average		**2.0**	**1.5**	**1.5**	**2.5**	**2.5**	**2.0**	**2.0**	**2.5**	**2.5**	**2.5**
Subsurface Conditions	Presence of Locally Unconfined Priest Rapids/Pomona Permeable Zone	U	U	U	U	U	U	U	U	U	U
	Discharge to Mosier Creek	U	U	U	U	U	U	U	U	U	U
Average		-	-	-	-	-	-	-	-	-	-
Source Water Quality	Mosier Creek	3	3	3	3	3	3	3	3	3	3
Acquisition and Maintenance Costs	Land Acquisition Costs	3	3	3	3	3	3	3	3	3	3
	Maintenance Costs	3	3	3	3	3	3	3	3	3	3
Average		**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**
Weighted Total Average		**2.8**	**2.6**	**2.6**	**2.8**	**2.8**	**2.6**	**2.5**	**2.6**	**2.6**	**2.6**

Ranking Scale

1 = Unfavorable
2 = Satisfactory
3 = Favorable
U = Unknown

Surface Recharge Costs

Estimated costs for implementing and operating a surface recharge program, including site-specific feasibility analysis, design, construction and operation and maintenance (O&M) are presented below in Table 2-4.

Table 2-4. Estimated Surface Recharge System Costs

Capital Cost	O & M
• Site Feasibility Investigation: $100,000 to $150,000 • Design/Construction Services: $60,000 to $80,000 • Land Acquisition: $30,000 to $50,000 • Excavation: $280,000 to $340,000 • Diversion: $45,000 (gravity) to $85,000 (pump) • Conveyance pipe/ditch: $3,000 to $6,000 • **Total: $518,000 to $711,000** **<u>Assumptions</u>**: • 2.5 acre spreading basin. • Excavate 7 ft bgs, short haul offsite. • Conveyance distance of 100 ft	• Removal of clogging layer: $3,000/yr to $6,000/yr • Site Maintenance: $5,000/yr to $10,000/yr (basic grounds maintenance, checking of system when running) • Electrical: $2,000/yr to $4,000/yr (pumped diversion) **Total: $10,000/yr to $20,000/yr**

2.3 Well Recharge Feasibility

This section summarizes the evaluation of the feasibility of using direct recharge via a well as an alternative for aquifer recovery in the Mosier area. The well recharge concept for aquifer recovery involves injecting water through a well into one or more of the basalt aquifers to offset groundwater discharge, whether by pumping or through commingling wells. For the purposes of aquifer recovery in the Mosier area, source water, likely diverted from Mosier Creek, would be injected into the target aquifer(s), which in this case include the Pomona and/or Priest Rapids aquifers primarily, although the evaluation also is applicable to the Frenchman Springs basalt aquifers. This type of application of recharge would be implemented under the state of Oregon artificial recharge (AR) rules in OAR 690-350 for reasons discussed in a later sub-section describing the legal framework for a recharge project.

Well Recharge Feasibility Criteria

Well recharge feasibility is dependent on the ability to divert and inject required rates and volumes of adequate quality source water into the target aquifer at a reasonable cost. A description of the feasibility and costs of source water diversion and treatment is provided in Diversion and Infrastructure section of this report. The feasibility of using well recharge for aquifer recovery hinges on several key factors described as follows:

- Suitable Source Water Quality: the quality of source water to be used for recharge must meet regulatory and other feasibility standards for injection
- Suitable Aquifer Characteristics: the aquifer must be sufficiently transmissive and continuous to achieve target injection rates and benefit areas experiencing the greatest water level declines. Hydrogeologic characteristics affecting recharge feasibility are described in more detail below.
- Cost: Diversion, treatment, as needed and injection of water into the target aquifer(s) must be cost effective.

Important hydrogeologic considerations related to well recharge feasibility include:

- Transmissivity of the aquifer: transmissivity is a measure of the rate water is transmitted through a unit width of an aquifer, and determines in part the achievable rates of injection. Physical variability within individual basalt flows includes lateral changes in interflow zone thickness which can reduce the overall transmissivity of an aquifer.
- Aquifer boundaries: the presence of negative aquifer boundaries, typically faults or lateral reduction in aquifer thickness, limit storage volume. An aquifer test conducted by Lite and Grondin (1988) indicated the presence of at least one negative boundary in the Pomona basalt aquifer. The presence of positive aquifer boundaries, typically drainage from overlying aquifers or interaction with streams or lakes, can indicate the potential for water to discharge from the target aquifer as injection increases water levels within the recharged aquifer.
- Available Storage: water levels in aquifers in the lower portion of the Orchard Tract are near ground surface or above (flowing). Consequently, injection pressure would likely be required in wells near the creek in the lower part of the watershed. The presence of negative (no-flow)

aquifer boundaries increases the rate of water level rise during injection and reduces the rate of injection, and thus may limit achievable storage volume.

The following sections describe the feasibility of well recharge relative to these factors.

Water Quality

State of Oregon rules governing groundwater recharge require source water used for recharge meet specific water quality requirements, as detailed in the Legal Process section of this report. It is anticipated that source water for well recharge would be Mosier Creek or potentially water extracted from an infiltration gallery or well completed in alluvial floodplain sediments near Mosier Creek. Under the AR rules, concentrations of water quality constituents in source water must not degrade the quality of groundwater in the target aquifer, whereas under the ASR rules, constituent concentrations in source water must or meet or exceed drinking water standards. As will be described in the Legal Framework section, a surface or a well recharge project would be permitted under the AR rules, which requires compliance with anti-degradation standards. Water quality data for Mosier Creek and the Pomona, Priest Rapids, and Frenchman Springs Basalt aquifers within the watershed are tabulated in Table 2-2. In Section 2-2, constituent concentrations in Mosier Creek were compared to those in the basalt aquifers for assessment of compliance with anti-degradation standards.

As discussed in Section 2-2, constituent concentrations in Mosier Creek water for tested parameters were lower than basalt aquifer concentrations of the same constituents, and also are lower than ASR water quality standards. Although water quality constituent concentrations available for Mosier Creek do not exceed background or regulatory concentrations, it is likely that treatment of Mosier Creek source water (filtration at a minimum) would be required prior to well injection both for removal of suspended solids and any potential biological contaminants. However, if source water were diverted through a well or infiltration gallery that provided sufficient filtration to remove biological constituents and suspended solids, it is possible that water treatment would not be necessary prior to well injection. Additional information regarding water treatment methodologies and costs are presented in the Diversion and Infrastructure section of this report.

Although the available groundwater and source water quality data are not inclusive of all analyses, available water quality constituent data do not identify any fatal flaws for well injection related to water quality. However, available water quality data for Mosier Creek and basalt groundwater are not comprehensive and may not be representative of the likely time period of diversion for well recharge. In addition, water quality data from the shallow alluvium near the stream are not available. These data and a more complete set of analyses of Mosier Creek and basalt aquifer water would be needed to fully assess the feasibility of using this source for well recharge.

Injection Well Requirements

Following diversion and potentially water treatment, water would be conveyed via buried or above-ground pipe to a well completed in the Pomona or Priest Rapids basalt aquifer for recharge. Several criteria for the injection well(s) have been identified. These criteria and whether an existing well can be used for injection based on the criteria are discussed below:

Proximity to Recharge Source Water: An injection well in close proximity to Mosier Creek would be advantageous to reduce pumping and conveyance costs for recharge. Pumping and conveyance costs for injection in a well at a distance above the creek could be substantial and also would require negotiation of easements across intervening properties.

Availability: The well must be available for recharge use during the season in which source water can be diverted. Existing domestic and municipal wells are in use during the entire year, precluding conversion into injection wells. While irrigation wells generally are not used during the winter months, use of an irrigation well for injection would require some conversion work, possibly including removing the pump during the recharge season and installing instrumentation.

Recharge Water Losses: The benefit to water levels derived from recharging the aquifer through a well may be lost due to leakage through either commingling wells or to Mosier Creek. Loss of water to Mosier Creek may in itself be a desirable side effect of aquifer recovery. However, the greatest benefit in terms of water level recovery would be derived by placement of recharge wells nearer to the axis of the syncline, and further downstream of where the target aquifer crops out in the stream to maximize aquifer recovery before initiating significant leakage losses to the stream (Figure 1-2).

The recharge well should be sealed to prevent commingling such that recharge is directed solely into the intended target aquifer and that the benefit of recharge in the vicinity of the injection well is maintained (i.e., the recharged water and pressure is not lost through commingling). A new well dedicated for injection purposes would be required to be sealed to prevent commingling per OAR 690-210. As is described in Section 3 of this report on commingling well remediation, very few non-commingling wells presently exist in the Orchard Tract and none are in close proximity to Mosier Creek, which would be a preferable location to reduce pumping lifts and conveyance/easement costs.

Assessment of existing wells relative to the above criteria indicate the likely need for a new, dedicated injection well or wells to implement a well recharge program for aquifer recovery. While ideally, a recharge well would be located downstream within the Orchard Tract, nearer the axis of the syncline, other practical considerations may dictate moving the location further upstream to be nearer to more ideal diversion sites.

Aquifer Characteristics

Pomona Basalt

Pomona aquifer characteristics appear to vary greatly within the Orchard Tract, based on available testing results. Although data from a pumping test conducted by OWRD (Lite and Grondin, 1988) show that the Pomona aquifer at that location may be sufficiently transmissive to support significant injection rates, review of testing reported on OWRD well logs for Pomona aquifer wells indicate that average specific capacities of wells completed in the Pomona are not favorable for well recharge at the rates and scale contemplated. These differing indications of aquifer characteristics are discussed further below.

The Lite and Grondin (1988) tested a Pomona well in township 2 north, range 12 east, section 7. The well was pumped at a rate of approximately 200 gpm and experienced roughly 2.5 feet of drawdown after 25 hours of pumping, for a resultant specific capacity of 80 gpm/ft, which is highly favorable for well recharge. This well is located in the northerly portion of the Orchard Tract, near the axis of the syncline, and therefore may represent more favorable conditions within the Pomona aquifer.

Conversely, review of Pomona well logs from OWRD indicate that the average test rate of 30 gpm and drawdown of approximately 60 feet during typical 1 hour well tests at the completion of drilling. This results in an average well specific capacity of 0.5 gpm/ft of drawdown[1]. Whether the low specific capacities are due to low transmissivity in the aquifer or the presence of negative boundaries in the aquifer that exacerbate drawdowns is not known. The range in specific capacity (0.5 gpm/ft to 80 gpm/ft) illustrates the significant variability of hydraulic properties in the Pomona aquifer within the Orchard Tract. Aquifer testing would be necessary to verify favorable Pomona aquifer characteristics in the vicinity of a selected well recharge site.

A characteristic of the Pomona aquifer that may also complicate well recharge feasibility is the presence of several boundaries. First, a negative (no-flow) boundary was identified by Lite and Grondin (1988) during an aquifer test completed in the Pomona aquifer, reinforcing that the aquifer is of limited extent. Negative aquifer boundaries cause additional drawdown (or draw up during injection) in wells, and thus may significantly reduce achievable injection rates in a given well. Also, the Pomona basalt aquifer is connected to Mosier Creek near the center of the Orchard Tract, and discharged to the stream at an estimated rate of at least 230 gpm in 1986 (Lite and Grondin, 1988). Recent work by the USGS indicates that Mosier Creek may now be recharging the Pomona basalt aquifer as a result of declining water levels in the aquifer, although this has yet to be verified. The interconnection between the aquifer and Mosier Creek in the vicinity of the Orchard Tract may provide a potential short-circuit for recharged water to flow back to Mosier Creek, particularly from injection wells located near the connection with the creek. While discharge to the creek is not necessarily an unfavorable result of well recharge, placement of a recharge well in close proximity to the connection with the creek could negate the full benefit to water level recovery from well recharge. Improved understanding of the connection of the Pomona aquifer with Mosier Creek and whether the stream is gaining or losing would aid in evaluating potential loss of recharge water to the stream and benefits that could be derived from recharge given those losses.

Considering the likely distribution of favorable aquifer properties in the Mosier Syncline, maximizing the benefit of recharge to aquifer levels, and given other infrastructure considerations, the most favorable area for well recharge to the Pomona aquifer is near the stream within sections 7 and 12.

Priest Rapids Basalt

Favorable aquifer properties for well recharge to the Priest Rapids aquifer are present within the Orchard Tract, based on aquifer testing conducted by Lite and Grondin (1988) (Table 1-1) and OWRD well logs. For example, the City of Mosier's new Priest Rapids Well #4 (WASC 51497), located in Section 12, has a specific capacity of 52 gpm/ft, which is favorable for recharge. Aquifer testing by Lite and

[1] Specific capacity is a measure of the combination of well performance and aquifer yield and is expressed as the capacity of the well per unit of drawdown or gallons per minute per foot.

Grondin (1988) using a Priest Rapids well (township 2 north, range 12 east, section 7) was pumped at a rate of approximately 360 gpm with 17 feet of drawdown after 29 hours for a specific capacity of 21 gpm/ft, which also is favorable.

The Priest Rapids aquifer is of greater areal extent than the Pomona, extending under most of the study area. Lite and Grondin (1988) did not report any significant boundaries during the Priest Rapids aquifer test. The aquifer also is potentially connected to Mosier Creek where it crops out in the creek in Section 18. However, the present nature of the connection between the aquifer and stream is not well understood. Newcomb (1969) suggested that the Priest Rapids discharged to Mosier Creek at the time of his study. Lite and Grondin (1986) indicated that groundwater elevations suggested that the Mosier Creek was losing water to the Priest Rapids at the time of their study, and postulated that the Mosier Creek may have transitioned from a gaining to a losing stream to the Priest Rapids because of water level declines in the aquifer over the period after the Newcomb (1969) study. Improved understanding of the connection of the Priest Rapids aquifer with Mosier Creek would aid in evaluating potential loss of recharge water to the stream and benefits that could be derived from well recharge given those losses.

The characteristics of the Priest Rapids aquifer indicate that a target recharge rate of 1,500 gpm could be achieved with one to three recharge wells. Based on existing well specific capacity data, it is anticipated that potential head rise during injection at the target rate could exceed 100 feet (43 psi) at a single well, depending on site specific hydrogeologic characteristics. An injection well constructed for well recharge should be designed for wellhead injection pressures of at least 75 psi.

Well Recharge Data Gaps

No fatal flaws were identified for implementing well recharge in the basalt aquifers. The feasibility of implementing well recharge in a particular aquifer and location will depend on evaluation of the following data gaps:

- The distribution of favorable aquifer properties for recharge, particularly in the Pomona aquifer.
- The nature of the connections of the aquifers with Mosier Creek, and the amount of groundwater level recovery relative to losses to the stream that can be achieved with recharge to the Pomona or Priest Rapids aquifers.

Well Recharge Costs

Table 2-4 presents a preliminary cost estimate for implementation of well recharge, including operation and maintenance. These costs are approximate and were developed using conservative assumptions to capture significant uncertainties. The following assumptions were used to develop the cost presented below:

- Capital and operation/maintenance cost estimate is provided for a single injection well.
- Injection well depth is 400 feet below ground surface based on depth to Priest Rapids basalt aquifer.
- Injection well maintenance will be necessary to mitigate potential well clogging, which will require periodic short-term pumping of the well ("backflushing") and discharging to an onsite retention system.

- Rehabilitation of injection well is anticipated to be necessary at 3 to 5 year intervals.
- Injection is occurring under less than 200 feet of artesian pressure.
- Diversion and water treatment costs associated with a well recharge project would be in addition to the costs in Table 2-4 and are presented in the Diversion and Infrastructure section.

Table 2-4. Preliminary Cost Estimate for Artificial Well Recharge

Capital Costs	
Description	**Cost Estimate**
Injection Well Construction (one well)	$300,000
Land acquisition (assume 1 to 2 acres)	$12,000 - $24,000
Well "backflushing" system	$30,000
Well instrumentation (pressure transducer, etc.)	$10,000
Administration, legal, engineering, and contingencies @ 35%	$119,000
Total Capital Cost	$471,000 - $483,000
Operation and Maintenance	
Description	**Cost Estimate**
General well maintenance (backflushing, etc.)	$10,000/yr
Water quality and water level data collection	$15,000/yr
Injection well rehabilitation (anticipated every 3 to 5 years at a cost of $20K to $40K)	$8,000/yr (amortized)
Total O & M Cost/yr	$33,000/yr

2.4 Diversion and Infrastructure Evaluation

Background

This section summarizes a preliminary evaluation of potential needs and alternatives for above-ground infrastructure for an aquifer recharge project. Specific infrastructure needs may differ, at least in part for a surface recharge system versus a well recharge system. Aquifer recharge systems commonly include the following basic types of facilities: (1) source water diversion facilities, (2) conveyance for delivery of source water to the recharge site and from the recharge site to the place of use, (3) treatment facilities, (4) recharge facilities and (5) recovery facilities. Recharge facilities for surface recharge and well recharge systems were described in prior sections. Because the primary objective of a recharge project in the Mosier Creek watershed is aquifer restoration, recovery facilities are not contemplated in this evaluation. This section focuses primarily on source water diversion alternatives, but also includes a summary of potential source water treatment needs and alternatives and general conveyance requirements. Evaluation of diversion site feasibility summarizes the advantages and disadvantages of each diversion type, general areas where each alternative may be appropriate and key unknowns in determining whether a diversion is feasible at a given location.

Preliminary estimates of diversion/recharge rates needed to accomplish the goals set out earlier in this report from 1.6 to 2.1 MGD (~1,100 to 1,500 gpm), based in part on the potential need to replace the estimated annual pumping volume from the aquifer of 1,000 AF during a 5 to 7 month recharge cycle.

Treatment of raw creek water would be necessary for use as source water for recharge via direct well injection to remove suspended solids and biological components. Initial review of limited data from Mosier Creek (Table 2-2) did not identify other treatment needs; however, final treatment needs would be determined through water quality sampling of a comprehensive suite of constituents, completed as part of a feasibility study. Direct treatment of source water for surface recharge would be less likely to be necessary because of filtration as part of the surface recharge process. However, there is a benefit to identifying a low-cost step to reducing suspended solids content in source water for surface recharge to minimize clogging and operations and maintenance (O&M) costs.

Diversion Feasibility

One of the key components of an aquifer recharge project is the ability to divert water from the surface source for injection. Diversion alternatives that utilize gravity flow and/or provide natural filtration for removal of turbidity and biological water quality components are particularly desirable from an overall feasibility standpoint to reduce or eliminate potential treatment requirements and reduce pumping needs. Mosier Creek is a deeply incised drainage which presents several significant challenges to identifying sites for a diversion with these characteristics and of sufficient capacity to serve a recharge project in the watershed.

Some of the features to consider when evaluating a surface water diversion for recharge include physical constraints, geology, surface water depth, channel incision, operation and maintenance requirements, water quality, cost, and potentially others. Work completed for this study included:

- Review of diversion rates and locations of existing irrigation diversions on the creek to evaluate whether any of these diversion structures could be suitable for providing source water to an aquifer recharge project
- Review of aerial photos to assess stream characteristics
- A reconnaissance and preliminary evaluation of Mosier Creek and adjacent lands to assess diversion feasibility and alternatives from approximately one-half mile above the confluence with the West Fork to approximately one-half mile upstream of the confluence with Dry Creek.

Existing Diversions

Mosier Creek has several irrigation diversions along the length of the creek, but all of them appear to be relatively low capacity pumped withdrawals consisting of small pipe intakes to booster pumps. These types of diversions are prevalent because of the incised nature of the main creek channel and also because the application sites for the irrigation water are on higher benches above the narrow valley bottom. No existing irrigation diversions appear to be useful for diverting water to a recharge site due to site constraints and the fact that the existing pumped diversions are designed for a specific flow and pumping head that are not adequate for the scale of recharge contemplated. However, a similar type of pumping diversion could be constructed for the recharge flow and pumping head that is needed. Because the selection of an appropriate diversion type is specific to the location of the recharge project, the diversion type should be chosen after the type and location of the recharge site have been identified.

Diversion Alternatives

Three types of diversions were identified as possibilities for a recharge project on Mosier Creek. These include an infiltration gallery (or shallow alluvial well), gravity surface diversion, and a pumped surface diversion. See figures 2-4 and 2-5 for possible locations for these diversions. The following discusses each type of diversion:

<u>Infiltration Gallery</u>: This alternative requires a suitably transmissive alluvial sedimentary aquifer in connection with the stream to produce sufficient water for diversion to the recharge project. This aquifer must be well connected to the surface water source. Several areas within the lower sections of Mosier Creek shown in figures 2-4 and 2-5 have relatively thin alluvial sediment packages adjacent to the stream with the potential to meet these conditions. This alternative may include the following types of diversion facilities:

- Horizontal, screened collector located in the near bank at an elevation just below the bottom of the stream. This screened pipeline system would drain into a concrete sump that has a pump in it to pump the naturally filtered water to recharge sites.
- A series (2 to 4) of shallow vertical wells near the stream channel to collect shallow groundwater and pump it to recharge site(s) in a common pipeline.
- A surface diversion to a shallow pond constructed in the alluvium adjacent to a horizontal collector (see first bullet) which would capture the water infiltrating from the pond through the alluvium. The filtered water captured by the horizontal collector would be pumped to the recharge site.

The advantage to this alternative is that the shallow alluvial aquifer may provide sufficient natural filtration to remove suspended solids and biological constituents to meet water quality criteria for recharge through a well. The primary disadvantages include the need for additional data from the alluvial aquifer being proposed for use and access and use of land suitable for such a system. Key uncertainties for determining the feasibility of a diversion utilizing an infiltration gallery or other means of extracting water from the alluvial sediments to provide pre-treatment include the yield and filtration capacity of alluvial sediments near stream. Data needed to address these uncertainties and evaluate feasibility and achievable diversion and injection rates include the saturated thickness and hydraulic characteristics of the alluvial sediments, and water quality data from the stream and from a test well completed in the alluvial sediments derived after extended pumping

Gravity Surface Diversion: This alternative consists of an in-stream check structure to stop the water in the creek and divert it out to a ditch or pipeline for conveyance to the point of use. The installation of a check structure would require a fish ladder to maintain fish passage around the structure for native fish movement. One of the issues identified with using a gravity surface diversion on Mosier Creek is the depth of the channel. A tall check structure or one located a longer distance upstream from the point of use would be necessary in Mosier Creek. There are several locations along the creek that have a shallower channel that might not require a tall check structure, but these locations may not be close to the point of use for the recharge system. The advantage to this alternative is the ability to assure that the volume of water needed is removed from the creek and taken directly for treatment and then storage. The primary disadvantages to this alternative are (1) the need to maintain a check structure and a fish ladder at the diversion, which would be required mostly likely during periods of higher flows, making operation and maintenance of this diversion more difficult; and (2) the water diverted using this method would need to be treated prior to use for recharge through a well.

Pumped Surface Diversion: This alternative requires the installation of a pump next to the creek with a pump suction placed in the creek. Generally, the pump suction is placed in a pool in the bottom of the channel that is maintained from natural scour or periodically cleaned of sediment. Occasionally streamflows will decline to levels that require the installation of a shallow sill or structure to direct flows to the pump intake. The advantages to this alternative is that it can be placed almost anywhere along the creek. The disadvantages are that this alternative requires power, regular maintenance and the diverted water would need to be treated prior to use for well recharge.

Treatment

Additional infrastructure that may be needed includes treatment to meet water quality requirements for direct recharge through a well, and a conveyance system to take the water from the stream to the recharge site. The conveyance system for this type of project would typically be a piped system in an effort to maintain the highest water quality possible and because, in the case of a direct well recharge system, the injection wells likely would be located above the diversion. The treatment for this type of system would require filtration at a minimum to remove suspended solids and biological constituents.

Filtration of the surface water source can be achieved by either collecting the water from the shallow alluvium adjacent to the creek (infiltration gallery) as discussed above, or by pumping it through a

mechanical filtration system. The ability to use an infiltration gallery will depend on the condition of the aquifer, and its ability to effectively filter surface water and transmit the water to the withdrawal location. The identification and characterization of a suitable shallow alluvial aquifer can only be made through field testing, but the site reconnaissance did identify one general area (Figures 2-4 and 2-5) where these conditions may be present.

In the instance that a shallow alluvial aquifer is unavailable or unsuitable, mechanical filtration with possible disinfection would need to be provided for the surface water prior to injection into the deeper aquifer. The most common form of mechanical filtration available today is membrane filtration. The number of membrane manufacturers has reduced the cost of membranes to make this filtration method preferred in most cases. The membrane can also be custom ordered to provide the filtration size that is needed for the pollutants targeted for removal. The membrane will require a pump to push the water through the membrane and a pump to back flush the membrane for cleaning. All associated piping and valves would also need to be provided. The use of a membrane filtration system has a higher capital and operation and maintenance cost.

Disinfection may also be necessary after filtration to meet water quality requirements for well recharge, and to reduce the chances of bio-fouling of the injection well(s). Disinfection would be more likely with the mechanical filtration option than it would be with the shallow aquifer option. Disinfection for this size and type of system would normally be using a liquid chlorine bleach solution (sodium hypochlorite). The disinfectant is pumped into the pipeline containing the filtered water and allowed to mix with the water for a “contact” time period of about 60 minutes. This requirement would add costs for operation and maintenance.

Preferred Alternative

The preferred diversion and treatment methods would be to utilize a diversion with natural filtration in the shallow alluvial aquifer. This has the best opportunity to not require construction of a treatment plant. Disinfection might still be necessary to prevent clogging and to meet water quality requirements; the need for disinfection would be determined after field testing.

Diversion and Infrastructure Cost Estimate

Table 2-6 presents a preliminary cost estimate for diversion and infrastructure for either well or surface recharge, including operation and maintenance. These costs are approximate and were developed using conservative assumptions to capture significant uncertainties.

Table 2-6. Preliminary Cost Estimate for Diversion and Infrastructure

Capital Costs		
Description		**Cost Estimate**
Mobilization		
Without Treatment Facility		$30,000
With Treatment Facility		$120,000
Diversions		
Surface Diversion		$20,000
Infiltration Gallery		$40,000
Booster Pump Station (required for either diversion type)		$200,000
Conveyance		
Yard Piping (required for either diversion type)		$50,000
Treatment		
Membrane Filtration Equipment w/ Installation		$1,200,000
Equipment Piping		$50,000
Settling Pond		$40,000
Filtration Building		$500,000
Well Recharge	Infiltration Gallery w/ No Treatment Total Construction Cost	$320,000
	Administration, Legal, Engineering, and Contingencies @ 35%	$112,000
	Infiltration Gallery w/ No Treatment Total Capital Cost Estimate	***$432,000***
	Surface Diversion w/ Treatment Total Construction Cost	$2,180,000
	Administration, Legal, Engineering, and Contingencies @ 35%	$763,000
	Surface Diversion w/ Treatment Total Capital Cost Estimate	***$2,943,000***
Surface Recharge	Surface Diversion w/ No Treatment Total Construction Cost	$300,000
	Administration, Legal, Engineering, and Contingencies @ 35%	$105,000
	Surface Diversion w/ No Treatment Total Capital Cost Estimate	***$405,000***
Operation and Maintenance		
Description		**Cost Estimate**
Infiltration Gallery or Surface Diversion w/ No Treatment O & M		
Booster Pumping Cost		$30,000/yr
General Maintenance		$10,000/yr
Infiltration Gallery or Surface Diversion w/ No Treatment Total O & M Cost		***$40,000/yr***
Surface Diversion w/ Treatment O & M		
Membrane Filtration and Equipment Maintenance		$65,000 to $100,000/year
Booster Pumping Cost		$30,000/yr
General Maintenance		$10,000/yr
Surface Diversion w/ Treatment Total O & M Cost/yr		***$105,000 to $140,000/yr***

2.5 Legal Process for Aquifer Recharge Projects in Oregon

This section summarizes the permitting requirements and considerations for implementing aquifer recharge alternatives in the vicinity of Mosier Creek for the purpose of aquifer restoration and improving groundwater sustainability. The Oregon Administrative Rules (OAR) 690-350 describe the permitting requirements for diversion, storage and use aspects of the two aquifer recharge alternatives, ASR and AR. The utility of the two permitting frameworks in Oregon, whether ASR or AR, in accomplishing project objectives are dictated by certain constraints of permitting for source water diversion and use, in addition to other considerations. These are further discussed below.

Application of AR and ASR to the Mosier Aquifer Recovery Project

One distinction relative to ASR permitting that has significant impact on this project is that aquifer restoration is not allowed as a primary purpose under the ASR rules (OAR 690-350-0010). Therefore, ASR cannot be used in the context of a programmatic project that specifies aquifer restoration as its primary purpose. However, storage projects conducted under the ASR rules by individuals with existing water rights (or a new surface water permit) could be used to replace or supplement individual irrigation or municipal groundwater uses, which could benefit the aquifer by reducing net groundwater usage in the basin.

AR permitting includes a diversion authorization for source water as part of the permitting process. This diversion authorization for source water specifies a beneficial use described as groundwater recharge (OAR 690-350-0120(1)). Thus, in contrast to the ASR rules, the source water authorization and AR permit allow recharge and storage of water in the aquifer for the purposes of aquifer restoration. If the project contemplates recovery and use of the water stored under the AR rules, a separate authorization and permitting process (called a secondary permit) would be required with a beneficial use and place of use specified by the applicant.

Since the AR rules allow basin-scale aquifer restoration as a permissible use, the AR rules are interpreted as the preferred permitting pathway for a programmatic approach to address the general project objective of aquifer restoration. Other favorable aspects of the AR pathway include potential to access more source water for recharge applications. However, this section also includes a summary of the permitting steps for ASR projects and consideration of how projects conducted under the ASR rules by individual water rights holders within the basin could contribute to accomplishing the overall goals of the Mosier Watershed Council.

Permitting considerations and requirements for MUS alternatives related to aquifer restoration in the Mosier area are summarized as follows:

- Source water: a new permit from OWRD is required to divert source water from Mosier Creek or the alluvial aquifer near Mosier Creek for recharge and storage under the AR rules in OAR 690-350-0110 - 0130. ASR rules allow use of an existing permit for water used for storage and recovery, with a beneficial use and place of use that does not change from diversion to recovery.

- Recharge Authorization: an authorization from OWRD is required to store diverted source water under the ASR and AR rules (OAR 690-350).
- Secondary Permit: under the AR rules, a secondary permit is needed if stored water is intended to be recovered. Under the ASR rules, a secondary permit is not required to recover stored water; stored water is recovered under authorization of the source water permit, subject to the conditions of that permit.
- Recharge facility permit: injection of water using a well requires an underground injection control (UIC) permit from Oregon Department of Environmental Quality (ODEQ).
- Land use permit: a permit or other permission may be required for use of land, depending under whose jurisdiction the land is where the recharge/recovery facilities are located.

These permitting considerations are described in more detail in the following sections.

Source Water and Water Use Permitting

OWRD rules for AR require a source water use permit specific for groundwater recharge, which in effect requires application for a new permit, as the use of an existing permit is not allowed. In contrast, OWRD rules for ASR describe ASR as an inherent beneficial use of all water rights and therefore any water right can be utilized for source water (OAR 690-350-0010(3)), provided that the proposed use of the water is consistent with the type of use specified for the water right.

New Source Water Permit

OWRD evaluates new requests for water use from surface water or groundwater hydraulically connected to surface water relative to water availability in the specific surface water body. Therefore, issuance of a new permit for recharge source water will depend on the determination of the amount and timing of water availability in Mosier Creek or tributary relative to the desired withdrawal rate.

Limited License for Source Water Diversion

Another option for source water permitting for AR or ASR is a limited license. A limited license in the context of source water is a temporary authorization from OWRD to divert water for up to 5 years. The initial processing of a limited license request includes a general water availability evaluation completed by the local Watermaster to determine if water would be available during the time requested. This is a more informal water availability evaluation than the process completed by OWRD for a new water use permit. A limited license to divert water from Mosier Creek would likely request water during the winter months when demands are low and water would be more likely be determined by the Watermaster to be available than under the public interest review for a new permit. Water diverted under a limited license has no priority date and water use would be curtailed if demands of any user were not being met. Thus, use of a limited license generally provides less certainty than a permit that water will be available, and only provides temporary access. If stored water is not intended for direct recovery, it is possible that a limited license to conduct AR could be utilized for long-term aquifer restoration.

Water Availability

Surface water availability is assessed by OWRD for all new permits that could potentially impact surface water to assure water will be available for use by the applicant for a reasonable amount of time and to determine if water is over-appropriated. In general, OWRD assesses surface water availability by summing all existing water uses in a basin and comparing them to streamflow. Since streamflow is highly variable seasonally and from year-to-year, OWRD utilizes many years of streamflow in each basin to statistically evaluate the percentage of time a streamflow is exceeded for each month of the year, which is known as an exceedance streamflow. Depending on the type of use requested by an applicant, OWRD utilizes two levels of exceedance streamflow to determine if water is available for diversion: 50 percent exceedance for storage applications and 80 percent exceedance for all other uses. An initial evaluation of water availability for Mosier Creek above the confluence with the Columbia River indicates that water is available during the months of April, May, and July through November at 80 percent exceedance and water is available during all months of the year at 50 percent exceedance.

As previously described, AR requires a type of use defined as groundwater recharge, and a new permit to divert water for AR would be evaluated as a storage permit at the 50 percent exceedance streamflow. If a new permit to divert water for ASR was sought, because the appropriation would be a direct use such as irrigation or municipal, it would be evaluated for at the 80 percent exceedance streamflow. Although surface water is available from Mosier Creek for a new appropriation for use with either AR or ASR, a significantly greater amount is available for AR.

In addition, OWRD reserved approximately 6,400 acre-feet (AF) of un-appropriated water from Mosier Creek for storage (OAR 690-504-0140) in the early 1990's. This water can be utilized for AR, but not ASR. Water under this reservation is available throughout the year and nearly doubles the rate and volume of water available for AR. Water under the reservation is required to be stored in a "multipurpose reservoir" which is described as a reservoir storing water to serve multiple potential beneficial uses such as irrigation, power generation, municipal water supply, recreation, and flow augmentation for instream purposes. A water use permit to access water under this reservation requires specific elements described in OAR 690-504-0100 (5) (a-d)[2]. Table 2-6 shows monthly water available for AR from a new permit for storage as groundwater recharge (50% exceedance), OWRD's water reservation, and monthly water available for ASR (80% exeedance). For comparison purposes, the USGS has estimated that total groundwater usage in the Mosier Creek watershed is approximately 900 to 1,000 AF.

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[2] In addition to the requirements of OAR Chapter 690, Division 310, an application for a permit to store reserved water shall include:
(a) An assessment of the effect of the proposed reservoir on fish and wildlife developed after consultation with the Oregon Department of Fish and Wildlife;
(b) An assessment of the effect of the proposed reservoir on water quality developed after consultation with the Oregon Department of Environmental Quality;
(c) An analysis of water supply alternatives to the proposed reservoir, such as off-stream storage, water right transfers and implementation of conservation measures; and
(d) An analysis summarizing and describing how the proposed project will enhance instream values, including but not limited to instream flows.

Table 2-6. Water Available in Mosier Creek for Aquifer Recharge

	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
Water Available for Direct Use (80%)	NA	NA	NA	3.23 cfs 192 AF	0.28 cfs 17 AF	NA	0.04 cfs 2.5 AF	0.12 cfs 7.4 AF	0.28 cfs 17 AF	0.93 cfs 57 AF	1.08 cfs 64 AF	NA	**360 AF**
Water Available for Storage (50%)	20.5 cfs 1,220 AF	34.3 cfs 2,041 AF	33.6 cfs 1,999 AF	18.9 cfs 1,125 AF	4.14 cfs 246 AF	1.03 cfs 61 AF	0.64 cfs 38 AF	0.62 cfs 37 AF	0.78 cfs 46 AF	1.53 cfs 91 AF	2.90 cfs 173 AF	7.91 cfs 471 AF	**7,560** AF
Reservation (OAR 690-504-0140)	17.3 cfs 1,029 AF	29 cfs 1,726 AF	28.5 cfs 1,696 AF	16 cfs 952 AF	3.5 cfs 208 AF	0.87 cfs 52 AF	0.54 cfs 32 AF	0.53 cfs 32 AF	0.66 cfs 39 AF	1.29 cfs 77 AF	2.44 cfs 145 AF	6.68 cfs 398 AF	**6,385 AF**

Note:
cfs = cubic feet per second
AF = acre-foot
NA = no water available during month

The actual amount of water that OWRD may allow to be diverted for recharge would also depend on evaluation of peak and ecological flow needs and other considerations.

Recharge Authorization Requirements

AR and ASR are conducted initially under a limited license, which provides the authorization needed to conduct pilot testing. Once pilot testing under the limited license provides sufficient information to determine the size, rates, volumes and potential impacts of recharge, storage and recovery, a permit is issued for permanent operation. By rule, AR can be conducted by surface infiltration through surface recharge facilities (e.g., basins or ditches) or through a well. ASR must be conducted through a well.

Artificial Recharge (AR)

AR is generally conducted under a limited license for testing purposes for an initial period of time to develop specific hydrogeologic data necessary to apply for an AR permit. An AR limited license has a maximum duration of 5 years, but can be renewed an unlimited number of times. Before applying for an AR limited license, OWRD requires that the applicant meet with regulatory stakeholders in a pre-application meeting to describe the project. An AR limited license application requires submittal of specific information described in OAR 690-350-0120, which includes: a project description report, a water quality permit from ODEQ, a description of the purpose of recharge, the volume of water to be stored, and a [3]hydrogeologic feasibility report. Water quality of source water is evaluated relative to the Oregon Department of Environmental Quality (ODEQ) anti-degradation rules (OAR 340-040). Water quality of the source water and groundwater in which storage occurs must be compatible, and the quality of the source water for AR must not be such that it degrades the quality of the native groundwater in the aquifer utilized for storage. An important part of limited license testing for AR is to establish an understanding of the hydraulic response of groundwater levels as a result of artificial recharge. The groundwater level response to recharge provides the principal basis on which the effectiveness of recharge is judged and is used to determine the availability of stored water. An annual report describing hydrogeologic data collected on the project and general operational information is required by OWRD.

A secondary groundwater permit is required to directly recover water stored under the AR rules. However, a secondary permit to directly recover stored water and apply it to it's intended beneficial use cannot be obtained until an AR permit is issued. An AR permit is typically applied for after sufficient data from AR testing under a limited license is collected to define storage volume, water level response to recharge, recharge rates, and recovery rates. Water stored during AR testing conducted under a limited license may not be withdrawn for use during the testing period under the limited license, which could last several years or more. AR rules require groundwater monitoring in the storage aquifer to determine the availability of stored water that can be utilized by the secondary permit, based on observed groundwater level changes that can be correlated to artificial recharge. During the first five years of recharge, OWRD will limit the available recovery under a secondary permit to 85% of the recharge volume, regardless of groundwater monitoring information. If after five years of recharge,

[3] This requirement is described in OAR 690-350-120 (3)(f): Hydrogeologic Feasibility Report. The applicant shall demonstrate that the proposed recharge project is hydrologically feasible. The report should include an assessment of groundwater conditions in the reservoir and anticipated changes due to the proposed recharge project. This report shall be sealed and signed by a professional(s) registered or allowed, under Oregon law, to practice in this area of geology.

data indicate that a higher percentage of stored water can be recovered without a net loss to the aquifer, a request can be made to OWRD to increase recovery percentage above 85%.
It is assumed that recovery of stored water is not a primary objective of AR in the context of this project, so whether testing is conducted under a limited license or under a permit is not necessarily an important distinction

Aquifer Storage and Recovery (ASR)

ASR is required to be conducted initially under a limited license before application for an ASR permit. As with a limited license for AR, an ASR limited license has a maximum duration of 5 years and can be renewed an unlimited number of times. A pre-application meeting with OWRD also is required to discuss project details prior to applying for an ASR limited license. An ASR limited license application requires submittal of specific information described in OAR 690-350-0020, including: source of water, maximum injection and recovery rates, maximum storage volume, project description and hydrogeologic feasibility report, and water quality assessment of proposed source water.

Source water for ASR must meet drinking water standards, and in certain cases, must have concentrations less than 50% of drinking water standards. An ASR limited license typically allows recovery of up to 95% of the volume of stored water on an annual basis. If testing indicates that a higher percentage of stored water can be recovered without loss, OWRD can allow up to 100% of stored water to be recovered. ASR is considered by OWRD as an inherent beneficial use with all water rights and as such, the maximum rate, duty (volume), and character of use described in the source water authorization utilized for ASR is retained during storage and cannot be changed or exceeded. In other words, an irrigation water right utilizing ASR to store water cannot be used for aquifer restoration purposes or at a rate or duty higher than the original authorization when the stored water is recovered. However, utilization of a surface water irrigation right could be used for recharge and recovery under the ASR rules to benefit aquifer recovery by reducing net groundwater withdrawals on an individual well owner basis.

Recharge Facility Permitting

In addition to the permitting described above, use of a well for AR or ASR injection requires completion of an underground injection control (UIC) application for Oregon Department of Environmental Quality (DEQ). In general, UIC rules require compliance with EPA's Safe Drinking Water Act (SDWA) for water used for injection. AR or ASR wells are categorized as a Class V injection system and require completion of a form detailing project information and a map.

Land Use Authorization

A storage and recharge facility may require a land purchase or a permanent lease agreement with a landowner. During the evaluation phase of the project, a land agreement prior to purchase would eliminate the risk of up-front costs of purchasing land prior to knowing if the project will be successful. Based on a preliminary review of Wasco County zoning information, the project area consists of Exclusive Farm Use and Forest zoning designations. It is uncertain if a storage and recharge facility is compatible within these zoning designations, but based on a cursory review does not appear to preclude development of these facilities. A detailed land use compatibility review should be completed in

subsequent phases of the project. In addition, ASR and AR limited license applications require completion of a Land Use Compatibility Statement (LUCS).

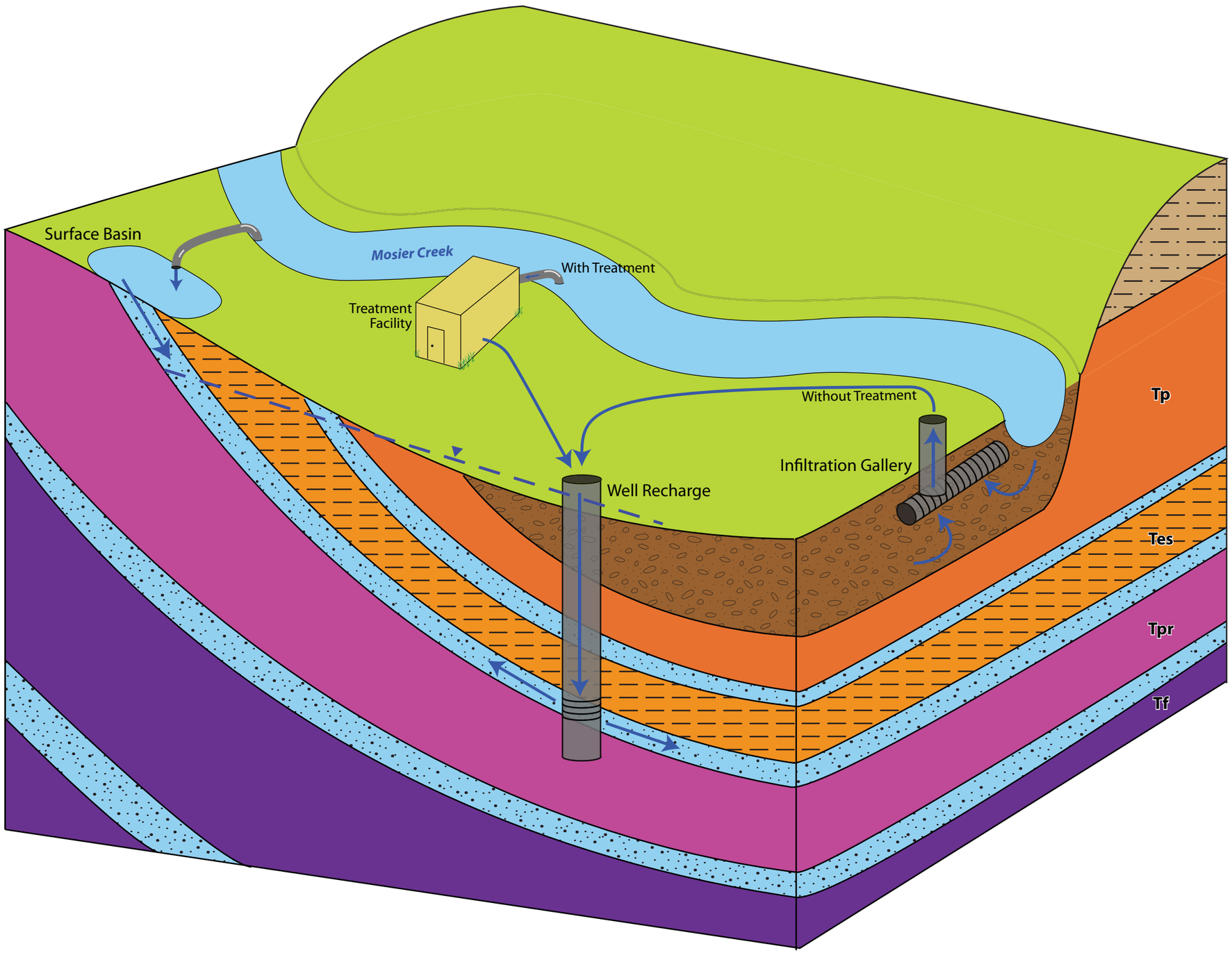

FIGURE 2-1

Aquifer Recharge Concepts

Mosier Watershed Council /Wasco Co. SWCD

LEGEND

- Dalles Formation
- Recent Alluvium
- Pomona Member
- Priest Rapids Member
- Frenchman Springs Member
- Columbia River Basalt Group
- Selah Interbed
- Interflow
- Groundwater Level in Aquifer

GSI Water Solutions, Inc.

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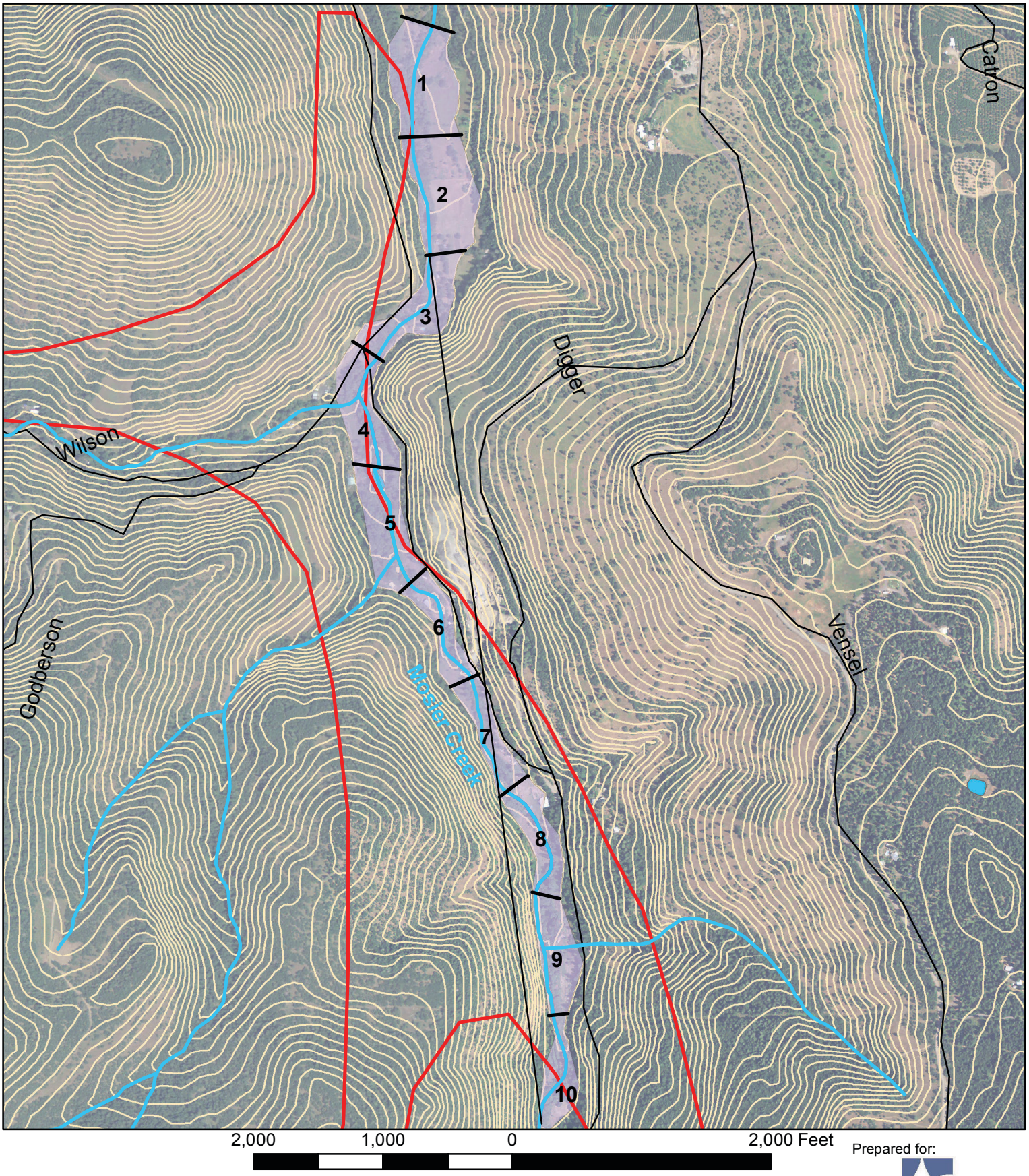


Legend

- Surface Recharge Area of Interest
- Priest Rapids Exposure Boundary
- Elevation (ft amsl), 20-ft intervals
- Water Courses
- Water Bodies
- Roads

N

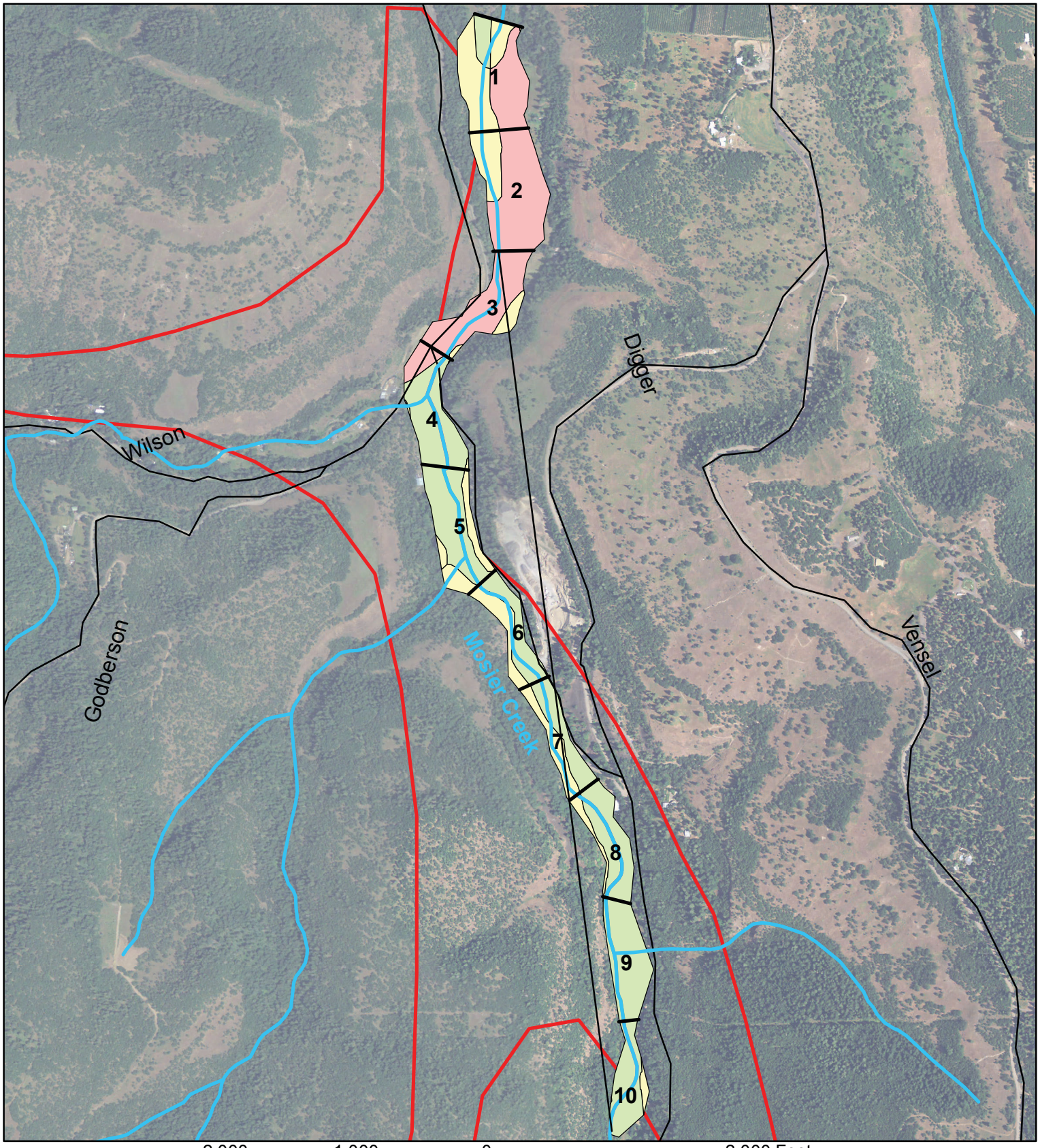
Prepared for:

GSI Water Solutions, Inc.

Prepared by:

GSA GeoSystems Analysis, Inc.

Figure 2-2. Surface Recharge Area of Interest



2,000 1,000 0 2,000 Feet

Legend

- Priest Rapids Exposure Boundary
- Water Courses
- Water Bodies
- Roads

Soil Permeability

- High (2 to 19.8 in/hr)
- Moderate (0.6 to 2 in/hr)
- Low (0.2 to 0.6 in/hr)

N

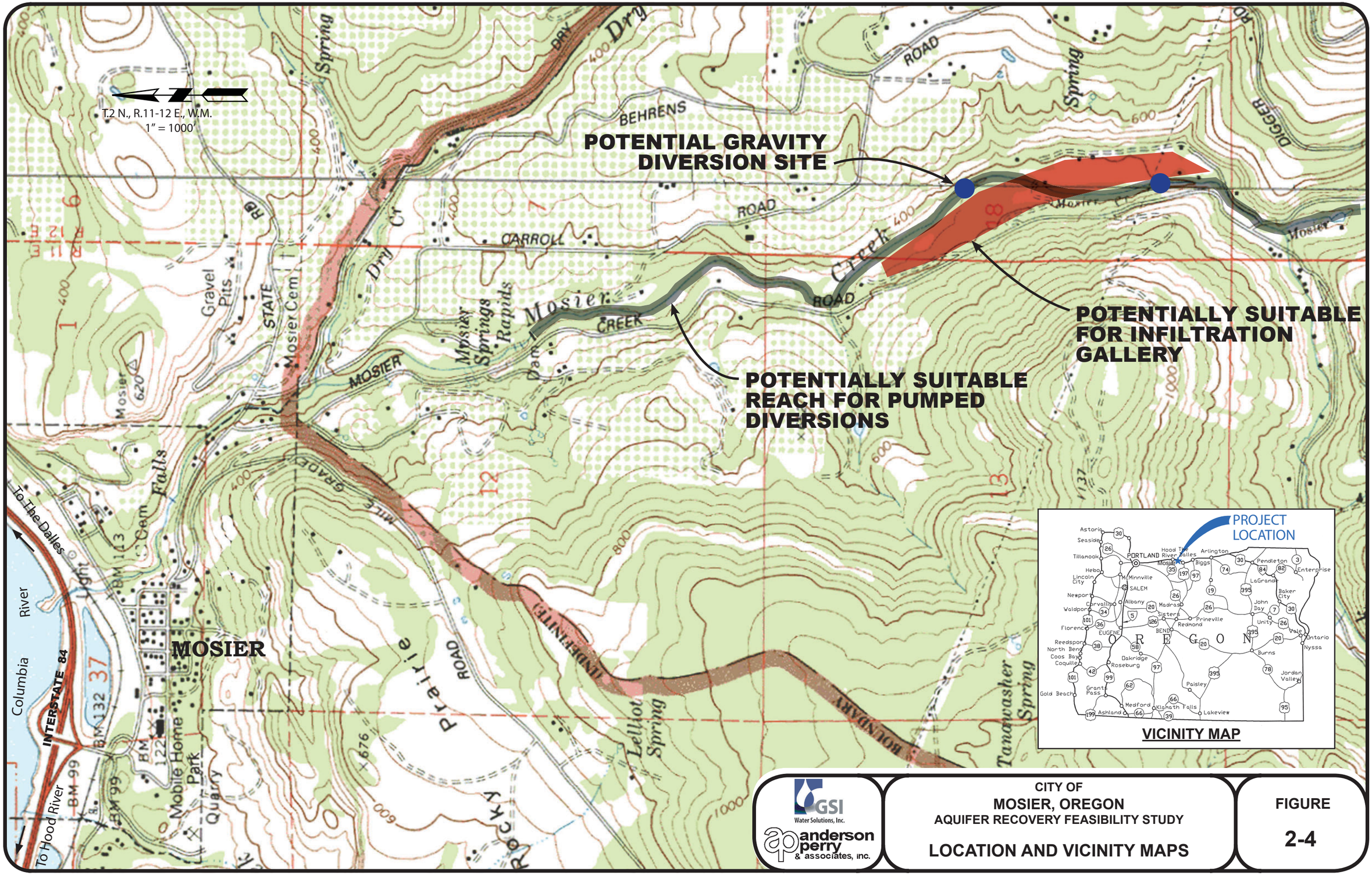
Prepared for:

GSI Water Solutions, Inc.

Prepared by:

GSA GeoSystems Analysis, Inc.

Figure 2-3. Soil Permeability in Area of Interest



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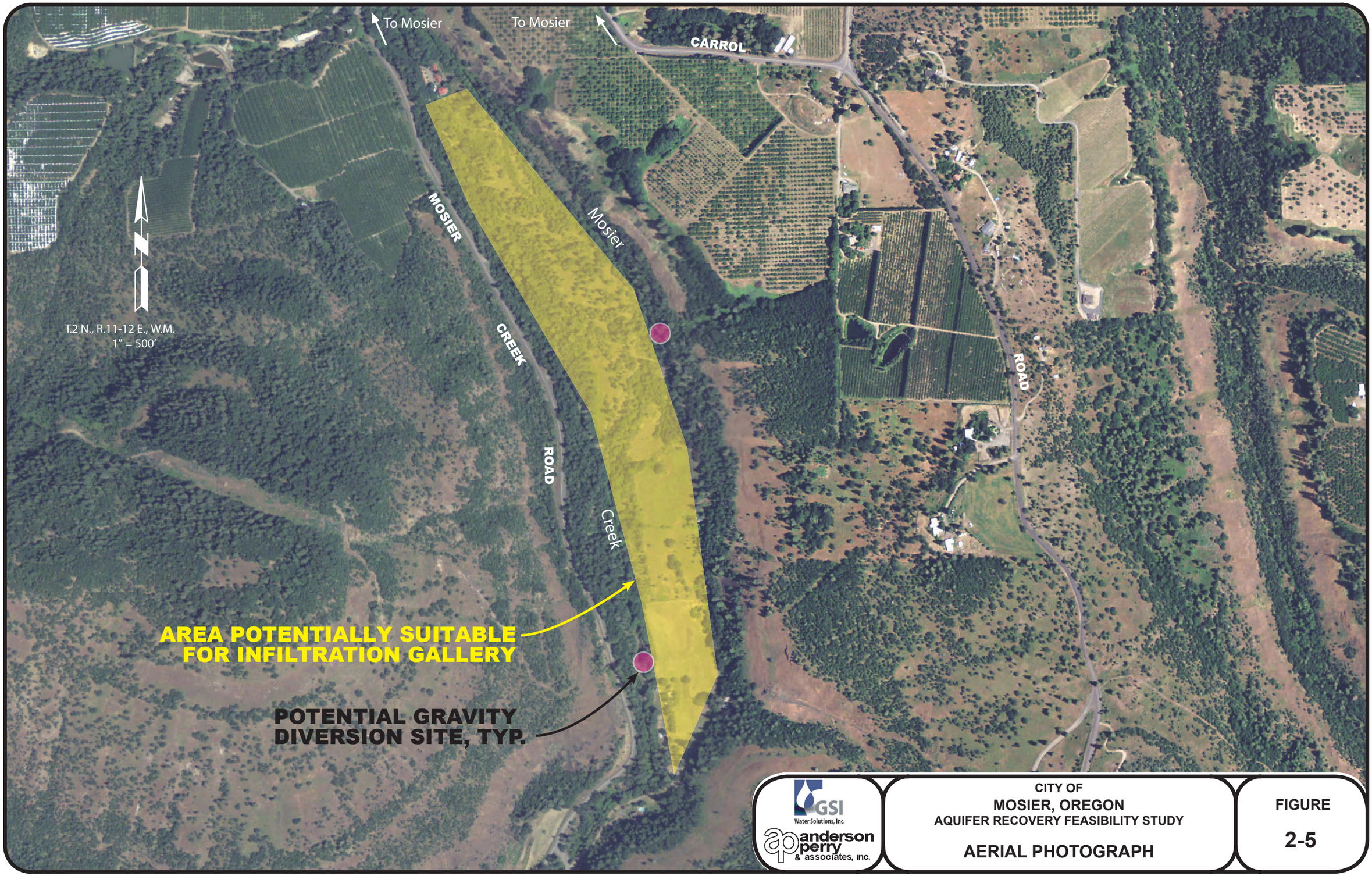
CITY OF
MOSIER, OREGON
AQUIFER RECOVERY FEASIBILITY STUDY

LOCATION AND VICINITY MAPS

FIGURE
2-4

Job# 1199-430-020 Apr. 8, 2011 lbauer



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CITY OF
MOSIER, OREGON
AQUIFER RECOVERY FEASIBILITY STUDY

AERIAL PHOTOGRAPH

FIGURE
2-5

Job# 1199-430-020 Apr. 8, 2011 lbauer

3.0 Commingling Well Remediation

3.1 Introduction

This section summarizes the evaluation of the feasibility and effectiveness of options for repair or replacement of wells to eliminate aquifer commingling. Commingling between aquifers occurs in wells that hydraulically connect two or more aquifers with different hydraulic heads causing groundwater to flow from the aquifer with higher hydraulic head to that with lower head. The resulting water level in a commingling well will be a composite of the water levels in the two connected aquifers. Commingling will cause the overall pressure in the aquifer with higher water levels to decline until the head difference between the two connected aquifers are equalized by flow through the commingling wells.

Previous studies within the Mosier Creek watershed concluded that commingling wells likely have played a role in the observed groundwater level declines within the basin (Lite and Grondin, 1988; Kienle, 1995; and Jervey, 1996). In response to water level declines of between 3 and 4 feet per year, OWRD withdrew the Pomona and Priest Rapids aquifers from further appropriation in 1988, creating the Pomona-Priest Rapids Groundwater Withdrawal Area (GWA). As stated earlier in this report, recent commingling wells are a significant and likely dominant cause of observed declines in the Mosier area (E. Burns, USGS, 2011 written communication).

This area is most vulnerable to adverse effects of commingling wells because of several factors:

- The area is located within the topographic and structural low point of the basalt aquifers which maximizes potential water level declines in the aquifers.
- The hydraulic conductivities of the aquifers are generally higher in this area than upslope in the watershed because geologic conditions favorable for development of high permeability aquifers (e.g., pillow/hyaloclastite complexes) during emplacement of basalt flows. Greater flow rates occur between commingling aquifers with higher hydraulic conductivities.
- The area contains a high density of potentially commingling wells.

The GWA encompasses the area where the most significant groundwater level declines were observed and includes an area of roughly 6 mi^2 southeast of the town of Mosier, in the lower portion of the Mosier Creek and Dry Creek watersheds. Based on OWRD records, there are approximately 116 water wells within the GWA, the majority of which are used for exempt domestic purposes. Of these 116 wells, approximately 40% (~48 wells) have been deepened since their original construction, in many cases as a result of declining groundwater levels (Kienle, 1995). Figure 3-1 shows the locations of mapped wells within the watershed, including those within the Orchard Tract.

The commingling well remediation evaluation presented in this section uses information regarding wells that are located within a 4-mi^2 area encompassing the majority of the Orchard Tract to identify typical well configurations and evaluate repair methods and cost. The wells within this area include likely higher priority wells for remediation. Wells outside the Orchard Tract within the Mosier Creek basin do not differ significantly from those within the Orchard Tract other than the average depth tends to be

greater. Consequently, well "types," and general repair methodologies developed as part of this evaluation generally are applicable to most wells within the Mosier Creek watershed. This evaluation updated compilations of well construction information completed by Kienle (1995) and Jervey (1996) using the OWRD well report database. Based on the updated compilation, the Orchard Tract contains approximately 71 water wells. Of these 71 wells, approximately 25 wells (35% of all wells) have been deepened since their original construction.

3.2 Objectives and Approach

The purpose of this evaluation was to assess the feasibility of remediating commingling wells within the basin to arrest water level declines related to commingling. The objectives of the evaluation included the following:

1. Evaluate the effectiveness and cost of repairing commingling wells relative to decommissioning and replacing the wells.
2. Identify methods and develop an approach for verifying commingling and prioritizing which wells stakeholders should focus on for repair or replacement.

The approach to accomplishing the first objective included the following steps:

- Reviewed aquifer conditions as described in previous studies to assess the potential for commingling and identify commingling repair objectives and challenges.
- Reviewed construction details for wells and identify "types" of wells with common characteristics requiring a distinct repair approach. Well types were determined from the depth and intervals of casing and annular seals relative to interpreted aquifer contacts.
- Identified potential repair methods applicable to the identified well "types"
- Assessed methods relative to feasibility criteria listed below, including soliciting feedback from area drilling contractors and OWRD well construction staff regarding repair implementability and effectiveness
- Obtained cost estimate ranges from contractors.

Possible well repair methods were evaluated for further consideration and costing based on their ability to meet several specific criteria, including:

- The well must be capable of producing the accustomed (exempt) and/or permitted (non-exempt) capacity after repair. The reduced diameter of the well resulting from a repair might necessitate replacement of the pump, which would increase the overall cost of repair.
- The repair method must be approved by OWRD either through strict compliance with well construction standards or by granting of a variance.
- The repair method must be effective, reliable and it must provide a high degree of certainty that the seal can be placed as intended and will last.

3.3 Commingling Potential

Aquifers within the Frenchman Springs and Priest Rapids basalt in the lower portion of the Orchard Tract historically have had higher hydraulic heads than the overlying Pomona basalt and Dalles Formation, resulting in up-hole flow within unsealed boreholes. Many wells completed in these aquifers within the lower watershed commonly flowed in the past, whereas water levels in most of these wells are now below ground surface. Further up-slope within the watershed, the hydraulic head between the deeper and shallower units may be reversed, resulting in downward flow or cascading water from the Pomona to Priest Rapids and Frenchman Springs. Commingling potential between different aquifers in the Mosier area is discussed below.

Pomona - Priest Rapids

The vesicular flow bottom of the Pomona basalt is the primary water-producing zone within the Pomona. Water-bearing zones within the Priest Rapids basalt may include the brecciated flow top of the Lolo (upper) flow and a hyaloclastite present at the base of the lower, Rosalia flow. The Selah sedimentary interbed ranges in thickness from several feet up to 170 feet, though generally is present at thicknesses of 30 to 50 feet (Lite and Grondin, 1988). The Selah Interbed, where present, typically acts as a confining unit separating the upper Priest Rapids aquifer from the Pomona aquifer.

Measurements from wells located within the lower part of the Orchard Tract illustrate the potential for commingling between the Pomona and Priest Rapids basalt aquifers, as well as the magnitude of water level declines since the 1970s. The shut-in pressure of the Priest Rapids aquifer in Mosier Well #4 in 2006 was approximately 22 pounds per square inch (psi) in 2006 whereas the water level in the Pomona aquifer at approximately the same time was 88 feet below ground surface, for a pressure differential across the Selah Interbed between the Priest Rapids and Pomona aquifers of 57 psi. Historically, the pressure differential between these aquifers may have exceeded 100 psi within the lower drainage. This differential between the aquifers decreases up-slope in the drainage to a point where the gradient reverses.

In general, wells interconnecting the Pomona and Priest Rapids basalt aquifers appear to be a primary source of commingling in the Orchards Tract (Lite and Grondin, 1988, Kienle, 1995, and Jervey, 1996). Wells completed in the lower portions of the Mosier Creek watershed, near the synclinal axis generally exhibit uphole flow, whereas wells up-slope may exhibit higher heads within the Pomona and resulting downhole flow.

Priest Rapids - Frenchman Springs

The interaction between the Priest Rapids and Frenchman Springs basalt aquifers is poorly understood because very little information regarding hydraulic heads or hydraulic conductivities within the Frenchman Springs aquifers is available. However, Lite and Grondin (1988) indicated that the water level dropped approximately 28 feet during deepening of a Priest Rapids well into the Frenchman Springs aquifer in 1959 in northeast section of the Orchard Tract, indicating a lower water level in the Frenchman Springs aquifer relative to the Priest Rapids aquifer. Water levels measured in well constructed in the north-central portion of the Orchard Tract (OWRD Well Log: WASC 50012) were 37 feet above ground surface in the Priest Rapids basalt aquifer and 48 feet above ground surface in the

Frenchman Springs aquifer, representing a pressure differential of 11 feet (~5 psi) higher in the Frenchman Springs aquifer. Anecdotally, a recent well completed in the Frenchman Springs basalt encountered decreasing hydraulic heads with greater depth within Frenchman Springs flows in the highlands within the southeasterly portion of the study area (K. Lite, OWRD, pers. comm., 2011). The direction of flow between the units will vary depending on the location of the well, with wells located near Mosier Creek and the axis of the syncline anticipated to exhibit uphole flow.

Dalles Formation/Pomona-Priest Rapids-Frenchman Springs

The potential for commingling between the Dalles formation and basalt aquifers depends on the location within the Mosier Creek watershed and whether the Dalles Formation is present. Flowing artesian conditions within the Priest Rapids creates potential for flow from the Priest Rapids into the Pomona basalt and the Dalles Formation sediments down-slope within the drainage, towards the synclinal axis.

Coarse-grained, higher permeability sediments within the synclinal axis will allow more flow into or from the Dalles Formation than finer-grained sediments. Further up-slope within the watershed, where the Dalles Formation contains water, down hole flow from the Dalles Formation to the basalts can be expected. As the basalt aquifers have become depressurized, the area of potential for cascading water from the Dalles Formation to the basalts likely has extended down-dip towards the synclinal axis.

Summary

Evaluation of water level data from wells within the Orchard Tract indicating a potential for either upward or downward flow within an open borehole, depending on the elevation of the well location, as well as the position of the well relative to the axis of the Mosier syncline and bounding thrust fault. The rate of flow between the aquifers will depend on the hydraulic conductivities of each unit to which the borehole is open and pressure differential between the units. Generally, further up-slope an open borehole connecting two or more aquifers may experience decreasing hydraulic heads with greater depth, and thus downward flow. Further down in the drainage, in a down-dip direction, the deeper basalt aquifers generally have higher hydraulic heads than the shallower units, resulting in up hole flow.

3.4 General Well Construction Observations within the Orchard Tract

This section describes the range of general characteristics of wells drilled and constructed within the Orchard Tract to provide the basis for developing well types for evaluating well repair and replacement alternatives and costs. As previously described, approximately 71 water wells are located within the 4 mi^2 area of the Orchard Tract. Table 3-1 provides a summary of general characteristics of these 71 wells.

Table 3-1. General Characteristics of Wells in the Orchard Tract

Well Depth		
Average	*Maximum*	*Minimum*
339 feet	675 feet	27 feet
Well Diameter[1]		
10-inch	*8-inch*	*6-inch*
2 wells	20 wells	49 wells
Well Use		
Domestic	*Irrigation*	*Municipal/Community Supply*
54 wells	15 wells	2 wells
Dates of Well Construction and Deepening		
Decade	*Wells Constructed*	*Wells Deepened*
1940's	2	0
1950's	1	1
1960's	4	0
1970's	19	3
1980's	16	6
1990's	16	7
2000's	11	6
Since 2010	2	2

Note: [1] This column lists the smallest interior casing or open borehole diameter of the well.

Typical Well Construction

Construction details and geologic information for each of the identified 71 Orchard Tract wells were evaluated to identify differences and similarities to determine whether wells could be categorized in terms of evaluating well repair methods and developing well repair and replacement costs. Based on review of well construction information, the following generalizations were identified.

Table 3-2. Well Construction in the Orchard Tract

Well Casing and Seal Information		
	# of Wells	*% of Wells*
Fully cased and fully sealed to below the Pomona basalt	5	7%
Cased and sealed into basalt, no Glaciofluvial/Dalles Formation present	5	7%
Partially cased and partially sealed through Glaciofluvial/Dalles Formation	18	25%
Fully cased and fully sealed through Glaciofluvial/Dalles Formation into basalt	19	27%
Fully cased and partially sealed through Glaciofluvial/Dalles Formation into basalt	24	34%
Deepest Geologic Unit Penetrated by Well		
	# of Wells	*% of Wells*
Glaciofluvial Deposits/Dalles Formation	6	9%
Pomona Basalt	20	28%
Priest Rapids Basalt	27	38%
Frenchman Springs Basalt	18	25%

The most "typical" well completion categories in the Orchard Tract summarized in Tables 3-1 and 3-2 are described below and shown on Figure 3-2.

Type 1: 6-inch diameter domestic well (more common) or 8-inch irrigation well (less common), fully cased and partially sealed through the glaciofluvial deposits/Dalles Formation, and completed with an open borehole (uncased and unsealed) to the Priest Rapids basalt (Well Type 1A) or Frenchman Springs basalt (Well Type 1B). This type of construction represents approximately 24 of 71 wells within the Orchard Tract.

Type 2: 6-inch diameter domestic well (more common) or 8-inch irrigation well (less common), fully cased and sealed through the glaciofluvial deposits/Dalles Formation, and completed with an open borehole (uncased and unsealed) to the Priest Rapids basalt (Well Type 2A) or Frenchman Springs basalt (Well Type 2B). This type of construction represents 19 of 71 wells within the Orchard Tract.

Type 3: 6-inch diameter domestic well (more common) or 8-inch irrigation well (less common), partially cased and partially sealed through the glaciofluvial deposits/Dalles Formation, and completed with an open borehole (uncased and unsealed) to the Priest Rapids basalt (Well Type 3A) or Frenchman Springs basalt (Well Type 3B). This type of well represents approximately 18 of 71 wells within the Orchard Tract.

Other types of well completions noted within the Orchard Tract include the following:

- At locations where the glaciofluvial deposits and/or the Dalles Formation are not present, wells are cased and sealed into the Pomona basalt at the ground surface (five wells).
- Five wells have been constructed with fully penetrating casing and well seals to a depth below the Pomona basalt, and thus likely do not allow commingling between the Pomona and Priest Rapids basalts. Three of these wells appear to be completed within the Priest Rapids basalt aquifer, and two appear to be completed in the Frenchman Springs basalt aquifer and are open to both the Priest Rapids and Frenchman Springs basalt aquifers. The degree of commingling between the Priest Rapids and Frenchman Springs basalts in the two wells open to these units is unknown.

3.5 Well Repair Evaluation

The feasibility of repairing commingling wells was assessed relative to three criteria: (1) the repair must eliminate aquifer interconnection; (2) the repaired well must retain the ability to produce water from the well at an accustomed rate and duration; and (3) the tooling required for the repair and subsequent well maintenance must be standard equipment, and owned by local contractors. Well replacement was assumed to be necessary if any one of these criteria could not be met. The ability to produce water at an accustomed rate and duration is primarily based on whether the post-repair borehole size is large enough to accommodate a pump system capable of yielding an adequate rate and pressure.

Completion of effective and reliable repairs of commingling wells may necessitate management of significant pressure differentials, which experience with Mosier Well #3 have shown to be problematic. Further, the upper basalt flow of the Priest Rapids basalt in this area appears to be relatively thin, and highly fractured and rubbly (K. Lite, pers. comm.), adding to the repair difficulty, particularly for employing certain types of repairs, including inflatable packers and zonal or “split” grout seals.

Well Repair Methods

OWRD water well repair standards are defined by rule under Oregon Administrative Rules, Chapter 690, Division 215 (OAR 690-215) and are applicable to the well repair options described in this section. Any well repair which does not meet standards outlined in these rules would require a special standard (as defined in OAR 690-200-0021), subject to approval by OWRD well construction staff. Several repair options described within this section would require a special well repair standard and are identified as such. The consultant team held informal discussions with OWRD staff to discuss possible well repair methodologies, with a particular focus on well repairs that may require a special standard. In general, OWRD staff indicated that repair options requiring a special standard would need to be evaluated on a case-by-case basis, but were generally supportive of certain repairs discussed (J. Pandian, OWRD, pers. comm., March 15, 2011).

Repairs to eliminate aquifer interconnection in many wells would require casing and sealing large sections of the well which currently either do not have an adequate seal or are completely open to multiple aquifers. Repair methods identified as best suited to meet the objectives involve perforating existing casing where not sealed, installing a smaller diameter casing and installing a full length cement seal between the smaller diameter casing and borehole/outer casing. This method provides a reliable and effective repair, but also results in a reduced well diameter. Other well repair techniques were considered, including:

- Overdrilling ("overwashing") around the outside of the outer casing to remove the surface seal and establish a larger diameter borehole to install a deeper seal around the casing,
- Deployment of partial or "split" seals
- Deployment of swaged liners or packers.

Over-drilling the existing casing may be feasible in certain cases, but generally is prohibitively expensive and has a potential to damage the casing and well, particularly if the existing well casing is not plumb or straight. Split seals, which involve placement of partial seal segments at the base of the casing and at the surface to reduce the overall seal volume and costs, are difficult to install under conditions of high pressure differentials, such as found in the Mosier area, and the proper seal placement also is difficult to verify during construction. Also, OWRD would be unlikely to grant a special standard for a split seal given the issues listed above. Therefore, a split seal is not considered suitably reliable for further consideration for this evaluation. Swaged liners and packers are also not considered reliable or potentially effective repair methods under anticipated conditions in the Mosier area and therefore were not considered further.

A general summary of well repair methods that meet the objectives of producing the accustomed rate, OWRD approval and effectiveness and reliability depends on the method approved and initial well diameter. General well repair approaches are described below.

<u>Upper Borehole</u>

- Several options exist for Type 1 wells where the contact between the Dalles Formation and the Pomona basalt is cased but not sealed. Options include (1) re-drill the cased portion of the well

so that a proper seal can be placed, although this type of repair may be cost prohibitive; (2) perforate the existing casing, install an inner casing and place a grout seal under pressure behind a smaller diameter interior casing under an OWRD well repair special standard. OWRD well repair rules do not explicitly allow for placement of a seal behind a perforated casing, as described in this repair, but OWRD staff have indicated that they would generally support this type of repair in the case of Mosier area wells (J. Pandian, Personal Communication, March 15, 2011).

- Type 2 wells where the contact between the Dalles Formation and the Pomona basalt is cased and sealed, commingling between these two units is assumed not be occurring and a repair of the upper borehole would not be necessary.
- The proposed well repair for Type 3 wells where the contact between the Dalles Formation and the Pomona basalt is not cased or sealed, would be to install a smaller diameter casing and place a continuous grout seal behind the casing. The depth of the repair casing would be based on the depths of the aquifers to be sealed and the production aquifer.

<u>Basalt Borehole</u>

- Most wells have open boreholes throughout the basalt section penetrated. The repair option consists of extending the smaller diameter casing such as would be installed for the upper borehole repair from the surface to the necessary depth and placing a continuous grout seal behind the casing to seal all overlying aquifers open in the well. OWRD rules (OAR 690-215-0030(2)) require a minimum 4-inch nominal diameter difference between the permanent casing and the borehole to allow for an adequately thick and continuous seal between the casing and the borehole. OWRD has indicated that they might allow a 2-inch nominal diameter difference between the outer and inner casing under a special standard in certain circumstances. OWRD would be less likely to grant a special standard to install a 4-inch casing to repair an existing 6-inch well than allowing installation of a 6-inch casing in an existing 8-inch well for reasons summarized in the following discussion of repair feasibility.
- Wells completed within the Pomona basalt (20 wells, Table 3-2), which are not open to the underlying Priest Rapids or Frenchman Springs aquifers, in some cases may be constructed such that commingling between the Pomona basalt and the overlying glaciofluvial deposits and/or the Dalles Formation could occur. While not the focus of this evaluation, the repair methods described for well types 1 and 3 generally apply in these cases.
- In wells open to the Frenchman Springs basalt aquifer (Well Types 1B, 2B, and 3B) and the target aquifer of the repaired well is the Priest Rapids basalt aquifer, a grout plug may be required to seal the Frenchman Springs aquifer to eliminate aquifer interconnection between these two aquifers.

Permutations of the selected repair methods to eliminate commingling at the “typical” Orchards Tract wells described in the previous section are summarized in Table 3-3. Figures 3-3A through 3-3C provide a sequential illustration of the steps of the well repair procedures outlined for each well type.

Table 3-3. Well Repair Steps

Well Type:	Well Construction Description:	[1]Well Repair Procedure:
Well Type 1	-Fully cased and partially sealed through the glaciofluvial deposits/Dalles Formation -Open hole (uncased and unsealed) to the Priest Rapids basalt (Well Type 1A) or Frenchman Springs basalt (Well Type 1B)	1. Plug borehole interval within Frenchman Springs basalt aquifer with grout seal (Well Type 1B) 2. Perforate existing casing below location of current seal (requires special standard) 3. Install inner casing 4" smaller diameter (2" with special standard) than outer casing and borehole and set within fine-grained portion of the Selah Interbed or competent section at top of Frenchman Springs 4. Place fine sand from well bottom to just below bottom of interior casing to prevent grout migration 5. Pressure grout annulus between casing and borehole to land surface 6. Remove fine sand, residual grout, and develop well
Well Type 2	-Fully cased and sealed through the glaciofluvial deposits/Dalles Formation -Open hole (uncased and unsealed) to the Priest Rapids basalt (Well Type 2A) or Frenchman Springs basalt (Well Type 2B)	1. Plug borehole interval Frenchman Springs basalt aquifer with grout seal (Well Type 2B) 2. Install inner casing 4" smaller diameter (2" with special standard) than outer casing and borehole from the surface and set within a fine-grained portion of the Selah Interbed or competent section at top of Frenchman Springs 3. Place fine sand from well bottom to just below bottom of inner casing to prevent grout migration 4. Pressure grout annulus between casing and borehole to land surface 5. Remove fine sand, residual grout, and develop well
Well Type 3	-Partially cased and partially sealed through the glaciofluvial deposits/Dalles Formation -Open hole (uncased and unsealed) to the Priest Rapids basalt (Well Type 3A) or Frenchman Springs basalt (Well Type 3B)	1. Plug the borehole interval within Frenchman Springs basalt aquifer with grout seal (Well Type 3B) 2. Install interior casing 4" smaller diameter (2" with special standard) than outer casing and borehole and set within a fine-grained portion of the Selah Interbed or competent section at top of Frenchman Springs 3. Place fine sand from well bottom to just below bottom of interior casing to prevent grout migration 4. Pressure grout annulus between casing and borehole to land surface 5. Remove fine sand, residual grout, and develop well

Note: [1]Repairs presented assume that the Priest Rapids is the post-repair target aquifer. If the Frenchman Springs is the post-repair target aquifer, plugging the Frenchman Springs aquifer (step 1) would not be required and the interior casing would be set within a solid, competent section between the Priest Rapids and the uppermost Frenchman Springs aquifer (instead of the Selah Interbed described above). Completion within the Pomona would involve plugging the borehole interval within the Frenchman Springs and Priest Rapids aquifers and terminating the plug within the Selah Interbed.

Well Repair Feasibility

Consideration of tolerances, standard well tooling, OWRD's willingness to approve a special standard, and the ability to produce the accustomed capacity from a well using readily available pumps imposes practical limitations on repair feasibility for 6-inch wells. An assessment of repair feasibility for different diameter wells based on these considerations and repair objectives is summarized in Table 3-4.

Table 3-4. Well Repair Feasibility Summary

Commingling Well Diameter	Repaired Diameter	Special Standard Needed (Y/N)	Assessment	Feasibility
6-inch	2-inch	N	• Non-standard tooling required and likely not locally available • To narrow for suitable pump to serve domestic needs.	Not practically feasible
	4-inch	Y	• Sufficient diameter for domestic supply pump • Non-standard tooling required for future work on well • Relatively straight boring required to install casing	Technically feasible, but OWRD less likely to approve variance from well construction standards because of borehole tooling limitations and tight tolerances
8-inch	4-inch	N	• Sufficient diameter for domestic supply pump • Diameter likely not sufficient for a pump to supply irrigation needs, depending on pumping lift and accustomed rates. • Non-standard tooling required for future work on well • Very straight boring required to install casing	Feasible, but should determine practicality on case-by case basis
	6-inch	Y	• Sufficient diameter for domestic supply pump and most irrigation applications, depending on pumping lift and accustomed rates. • Standard tooling accommodated. • Straight boring required to install casing	Feasible for most applications with a variance from OWRD
10-inch	6-inch	N	• Sufficient diameter for domestic supply pump and most irrigation needs, though potentially not all • Straight boring required to install casing	Feasible in most cases
	8-inch	Y	• Sufficient diameter for domestic supply pump and most if not all irrigation needs • Straight boring required to install casing	Feasible for most applications with a variance from OWRD

3.6 Well Replacement

Decommissioning and replacement of a commingling well may be necessary should repair of the well prove to be infeasible or too costly. Decommissioning of the existing commingling well is described in OWRD well abandonment rules (OAR 690-220), and generally consists of filling the well with a cement grout from the bottom of the well to the land surface. Wells with casings will require removal of the casing prior to placement of cement grout. If casing removal is not possible, ripping or perforating the casing prior to placement of cement grout is permitted (OAR 690-220-0040). Additionally, abandonment of wells under artesian pressure requires pressurized application of cement grout as described in OAR 690-220-0070. Figure 3-4 shows the general process for well abandonment.

A new well intended to replace an existing commingling well would be designed to produce water from a single aquifer. This would be accomplished by installing a casing within a borehole with a nominal diameter that is 4-inches greater than the desired casing diameter, followed by installation of a grout seal between the casing and the borehole at each aquifer encountered during the drilling process. Drilling then continues at the nominal interior diameter of the casing utilized and is repeated at each aquifer until the target aquifer is reached. Practically, for the purposes of completing a 6-inch well in

the Priest Rapids aquifer within the Orchard Tract under conditions with significant pressure differentials, this process would entail the following steps: (1) drill 10-inch upper borehole through the Dalles Formation and Pomona basalt and terminate the boring within a fine-grained section of the Selah Interbed, where present; (2) install a 6-inch production casing in the upper borehole and cement the casing in place with a full-length seal; (3) Drill below the cemented casing into the Priest Rapids aquifer and complete the well. Additional casing strings and grouting steps, which would require a wider initial boring diameter, may be needed to complete the well in the Frenchman Springs aquifer.

A similar process also would be used to target the Pomona aquifer, but the upper borehole and sealed casing would terminate in the upper portion of the Pomona flow and the lower borehole would terminate at the base of the Pomona flow within the productive zone above the Selah Interbed. Good examples of wells constructed by this process include the City of Mosier's Well #4 (WASC 51497) and WASC 51793. Both of these wells are cased and sealed down to the target aquifer to prevent aquifer interconnection between the target aquifer and the overlying aquifers encountered during the drilling process. Figure 3-4 illustrates the well construction process to complete a well as described above.

Effective well design and installation to replace a commingling well or for new construction requires several key decisions, including: selection and identification of casing and seal set depths, and selection and identification of the target production aquifer. A process for making the latest pertinent information and resources available to facilitate those decisions will be the best insurance for implementing commingling well repairs and preventing installation of additional commingling wells.

3.7 Well Repair and Replacement Cost Estimates

Based on the well repair procedures and well replacement information presented in the previous section, cost estimates were obtained from several drilling contractors in March 2011. Cost estimates applicable to each well repair option and various well replacement configurations were developed from some general assumptions mostly applicable to the Orchard Tract. These assumptions include:

- Well depth is assumed to be approximately 400 feet, which is roughly equal to the average well depth in the Orchard Tract. Generally, replacement or repair of a well deeper than the assumed 400 feet would cost more; however, the increased costs would not necessarily be entirely proportional to the increased depth.
- The thickness of the glaciofluvial deposts and Dalles Formation is assumed to be 150 feet, which is roughly equal to the average thickness of these units in the Orchard Tract, based on data in Kienle (1995) and Jervey (1996). The glaciofluvial deposits are absent in up-slope areas of the Orchards Tract and areas to the south.
- Well diameter of 6 or 8 inches, which are the most common well diameters in the Orchards Area (Table 3-1).
- The Priest Rapids basalt aquifer is the assumed target aquifer for well repairs and new well construction.
- Casing and sealing to a depth of 300 feet is assumed for new well construction, which approximates the depth to the top of the Priest Rapids basalt in the Orchards Area based on data in Kienle (1995) and Jervey (1996).

- Pump removal and installation costs are included in the total cost.
- A conservative cost range for new pump systems also is provided. The costs for new pumping systems are highly dependent on the well diameter, desired pumping rate, pumping lift and pump setting and thus will vary greatly.
- Costs reflect understanding of market conditions in spring 2011 based on polling drilling contractors in the Willamette Valley, Oregon and Columbia Gorge areas. Actual costs at the time of repair or replacement is conducted would depend on current economic conditions which are sensitive to market demand, labor, fuel and materials costs.
- A 15% cost contingency is included in all costs presented.

Based on these assumptions the following table summarizes costs for well repair options and well replacement. Individual well repair and/or replacement costs could vary significantly depending on well contractor, market conditions and individual well characteristics.

Table 3-5. Summary of Well Repair and Replacement Cost Estimates

Well Repair Types	Cost Range
Well Type 1A	$32,000 - 37,000
Well Type 1B	$36,000 - $47,000
[1]Well Type 2A or Well Type 3A	$29,000 - $33,000
[1]Well Type 2B or Well Type 3B	$35,000 - $42,000
Well Replacement	**Cost Range**
Well Abandonment	$12,000 – $20,000
New Well Construction	$27,000 – $46,000
Total Well Replacement Cost	$39,000 – $66,000
Pump System Replacement	**Cost Range**
Pump/Motor/Plumbing/Electrical/Controls	$4,000 - $16,000

Notes: [1] Steps necessary to repair Well Types 2 and 3 are identical, and as such, costs are presented together for each of these types.

For repair of deeper wells, more common in up-slope areas of the Orchards Tract and beyond, a 10 to 20% contingency for each additional 100 feet of borehole should be assumed, depending on which aquifer is selected for production. The actual cost of repairing a deeper well will depend on the length of casing and seal beyond the base assumptions listed above.

Abandonment costs vary primarily due to the depth of the well and potential volume of cement needed. Some boreholes may require greater volumes of cement to seal off highly-permeable zones, which would significantly increase the cost. A pre-repair video should be used to identify potentially permeable zones and design a decommissioning program that will minimize cement loss, including such measures as pre-conditioning to reduce the borehole wall permeability, and cementing in lifts.

As shown in Table 3-5, the costs to complete most well repair options are somewhat greater than well replacement costs for smaller diameter wells and in most cases, it may not be feasible to repair 6-inch wells. Furthermore, while the well repair approach outlined above was selected to provide the greatest level of certainty of effectiveness, there is a higher overall risk with attempting a well repair than

replacing the well. Failure of a repair may necessitate replacement, adding to the overall cost of remediating the commingling at that location. These risks should be assessed on a case-by-case basis.

3.8 Prioritization and Assessment

This section outlines a process for prioritizing the repair or replacement of commingling wells and summarizes methods for identifying and quantifying commingling in individual wells.

Prioritization Process

A technical approach for prioritizing wells for repair or replacement was developed on the basis of the premise that it likely is impractical to test all wells throughout the watershed or Orchard Tract for the occurrence of commingling, and evaluation and repair of commingling wells likely would occur individually or in small increments because of funding and/or access limitations. The technical process for prioritizing wells for repair or replacement involves two general steps: (1) an initial screening to identify areas where wells may present a higher risk for commingling, followed by (2) testing of individual wells within higher risk areas to verify commingling and evaluate well repair feasibility. Wells having a high potential for commingling would be identified on the basis of completion in two or more aquifers and location within an area of high commingling potential based on past and present groundwater level elevation differences, and water level declines. Individual wells considered to be a high risk for commingling would then be targeted for individual well assessment to verify commingling and evaluate repair feasibility on a case-by-case basis as access and funding opportunities arose. The initial screening and well assessment steps to the prioritization scheme are described in the following sections.

Initial Screening

The screening process is designed to yield information for prioritizing individual wells for assessment of repair feasibility as funding and access opportunities arise in the future. The screening involves a two-step process including (1) developing commingling potential maps using existing information, and (2) completing limited field testing of select wells to validate the mapped commingling potential. The commingling potential maps would identify where a potential for commingling exists between two aquifers if a well open to both is present. A summary of the elements of the initial screening process include:

1. Develop maps of the general distribution of hydraulic heads in aquifers under present and past conditions to identify the general areas where head differences exist and map whether the gradients are downward or upward. The distribution of head differences could be supplemented by an overlay of the spatial distribution of groundwater level decline rates for each aquifer. Present day head condition maps would provide a snapshot of current commingling potential. Map overlays of past conditions could provide valuable information regarding where significant commingling has occurred in the past, and could identify future higher priority areas for well remediation as commingling well repair and/or recharge increase aquifer water levels. While few wells are completed within single aquifers, the groundwater elevation maps by Lite and Grondin (1988) provide a starting place for evaluating past commingling risk, and ongoing monitoring in the basin by OWRD may provide sufficient

information to map areas with current head differentials between aquifers even if the absolute water level within each aquifer may not be known. The existing information could be supplemented by new water level data from well drillers who may be working in the area.

2. A second verification step in the initial screening process involves completing field measurements using one or more of the methods outlined below at several select wells that are completed in two or more aquifers and provide spatially representative coverage. The purpose of the field measurement survey would be to verify the presence of commingling and quantify rates where possible to confirm commingling potential.

Individual Well Assessment

The initial screening process summarized above would be used to prioritize subsequent field testing of individual wells using methods described in the following section to confirm the presence and/or magnitude of commingling, and determine well repair feasibility as funding and access opportunities arose. The priority of a well for further assessment for repair or replacement would be determined on the basis of whether well construction information is available that indicates the well likely cross-connects two or more aquifers, and the location of the well relative to the areas of relative commingling potential determined in the initial screening.

Well Assessment Methods

A variety of well testing methods are available for use in assessing whether wells are commingling, measuring the rates of vertical borehole flow between aquifers and evaluating the feasibility of well repair. Each method has certain limitations regarding accessibility and the types and potential reliability of information that can be derived. Thus, selection of a method and well(s) to be assessed should be made on a case-by-case basis, according to the objectives of the survey and specific well conditions. Information derived from methods identified for testing individual wells could include:

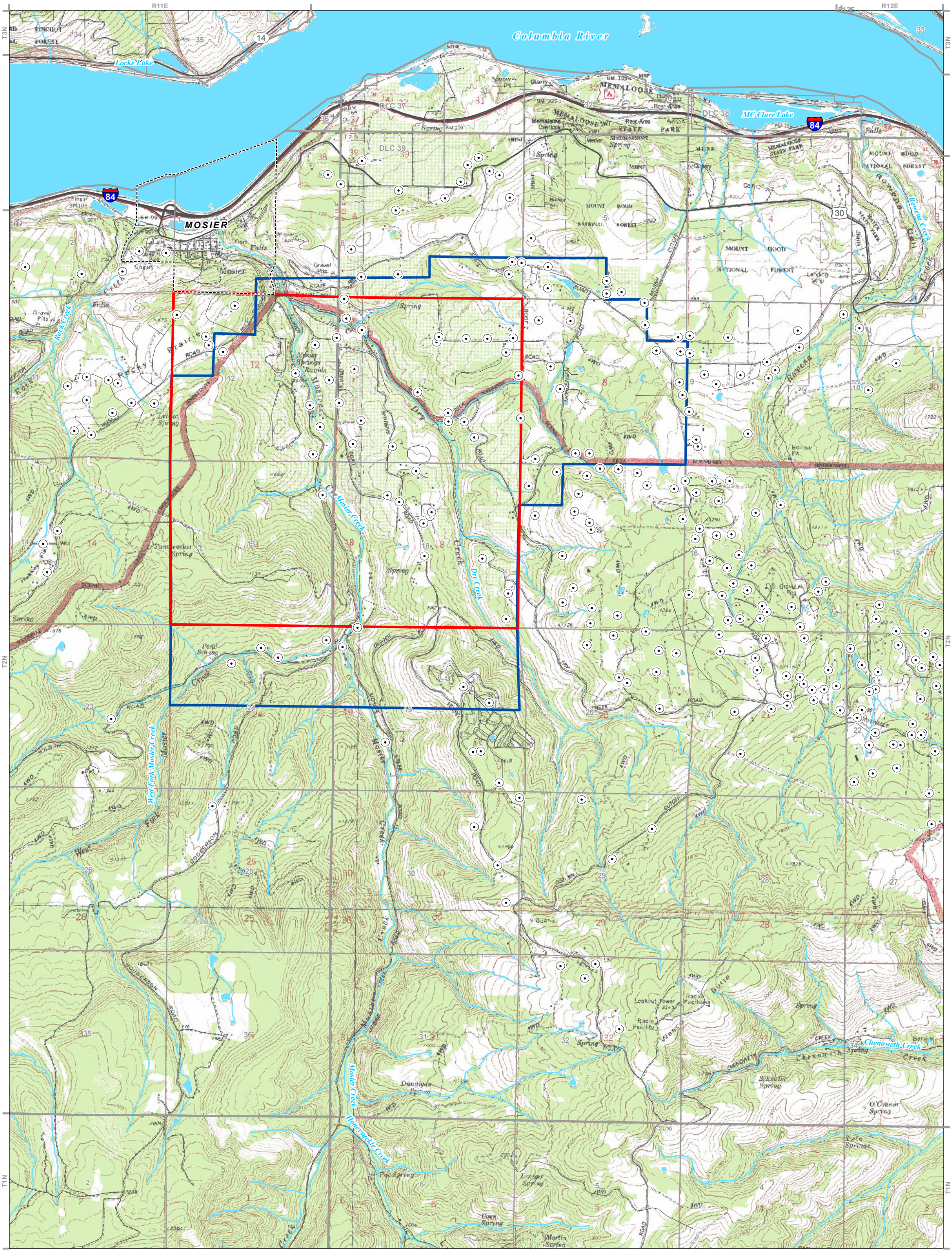
- Verifying the Presence of Commingling: Identification of the current occurrence of commingling may be sufficient in many cases to elevate the priority of a well for repair or replacement since it confirms that the well is currently contributing to water level declines in the aquifer of higher head. Also, the current occurrence of commingling would generally imply that vertical borehole flow within the well likely used to be more pronounced, and that that the rate of commingling within the well likely would increase with recovery of aquifer levels due to commingling well remediation or artificial recharge. Verification could be done qualitatively by several techniques, including a few potentially without removing the pump.
- Quantifying the Severity of Commingling: Measurement of vertical borehole flow rates between aquifers would quantify the severity of commingling at each borehole measured. Borehole flow data from a representative group of wells would verify assumptions regarding the contribution of commingling to overall water level declines, as well as provide a quantitative basis for prioritizing areas for commingling well remediation. Several types of tools are designed to measure vertical flow within a borehole, three of which are likely applicable to wells in the Mosier area. Two of these require removal of the pump to utilize, and a third is designed for use without removing the pump if an access port is present at the wellhead and obstructions are not present.

- Assessment of Borehole Conditions: several of the assessment tools used to develop information summarized in prior bullets, in conjunction with a borehole camera survey would be used to identify depths and locations of aquifers, and borehole conditions for repair design and implementation. A borehole camera survey would be mandatory for development of a repair design, regardless of whether verification and/or quantification of vertical borehole flow was evaluated.

The types of tools for assessing whether wells are commingling, measuring commingling rates and evaluating borehole conditions are summarized in Table 3-6, with the limitations and approximate costs for employing each tool.

Table 3-6. Well Assessment Methods

Method	Information Derived from Testing	Limitations	Costs
Temperature Probe	Qualitative evidence of commingling	Access into well and around pump may be difficult. Hoist to move pump during survey can greatly increase success rate	The MWC has been supplied a basic temperature logging tool that is employed manually. Cost for use of the tool consists primarily of MWC staff labor, assuming that access is adequate. To assure access, a pump hoist may be required for some wells. The costs for a pump hoist are summarized below Pump hoist: $600 - $1,000/well, if needed
Standard Borehole Camera with Flag	Qualitative evidence of commingling from flag movement Well construction and borehole conditions for assessment of repair feasibility and methodology	Pump must be removed	Camera Survey: $1,200 - $2,000/well Pump Removal: $2,000 - $4000/well Total Costs: $3,200 - $6,000/well
Spinner Log or Induction Flow Log	Quantify rate of vertical borehole flow	Pump must be removed	Logging (USGS or Private): $4,000 - $7,000/well Pump Removal: $2,000 - $4000/well Total Costs: $6,000 - $11,000/well
Dye Fluorescence Flow Profiling (BESST)	Quantify rate and direction of vertical borehole flow	Small diameter tooling can fit by pump in many applications, but tight borehole constraints can prevent access. Accessibility more reliable with hoist to move pump. Survey is run with miniature borehole camera which may provide sufficient information for a repair assessment and design.	BESST: $8,500 - $10,000/well Pump hoist: $1,000 - $2,000/well Total Cost: $9,500 - $12,000/well



LEGEND

- Wells
- Orchards_Tract
- Groundwater Withdrawal Area
- Cities
- Highways
- Roads
- Watercourses
- Waterbodies

MAP NOTES:
Date: April 25, 2011
Data Sources: DOGAMI, USGS, OGIC, ESRI

N

0 1,500 3,000 4,500
Feet

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FIGURE 3-1

Wells and Locations

Wasco SWCD: Mosier AR Feasibility Study

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FIGURE 3-2

Orchard Tract Well Types

Mosier AR Feasibility Study

LEGEND

Geologic Information

- Glaciofluvial Deposits/Dalles Formation
- Pomona Basalt
- Selah Interbed
- Priest Rapids Basalt
- Frenchman Springs Basalt

Well Construction/Repair Information

- Grout Seal
- Casing
- Open Borehole

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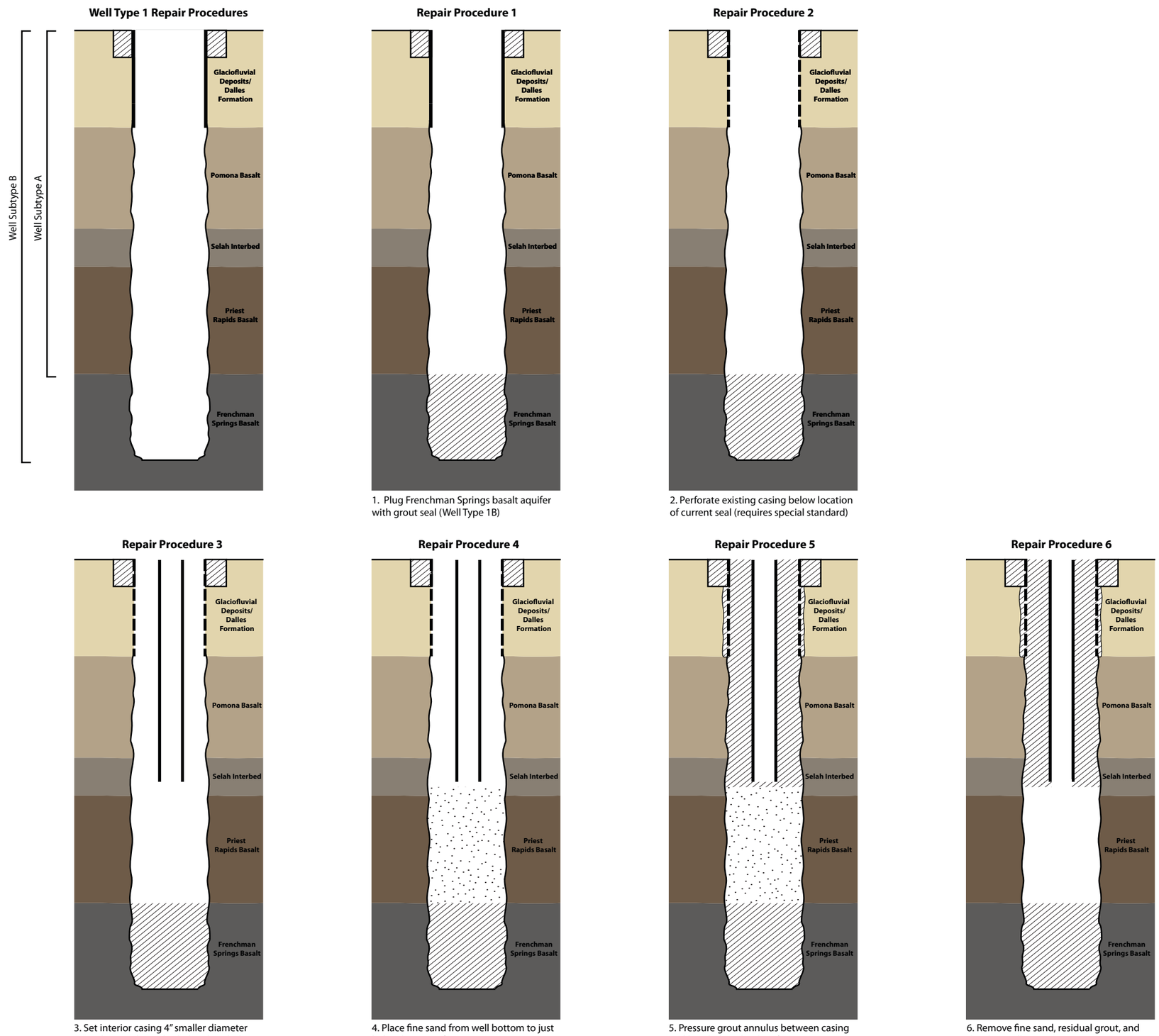
FIGURE 3-3A

Well Type 1
Commingling Repair Procedures
Mosier AR Feasibility Study



LEGEND

Geologic Information

- Glaciofluvial Deposits/Dalles Formation
- Pomona Basalt
- Selah Interbed
- Priest Rapids Basalt
- Frenchman Springs Basalt

Well Construction/Repair Information

- Grout Seal
- Fine Sand
- Casing
- Per forated Casing
- Open Borehole

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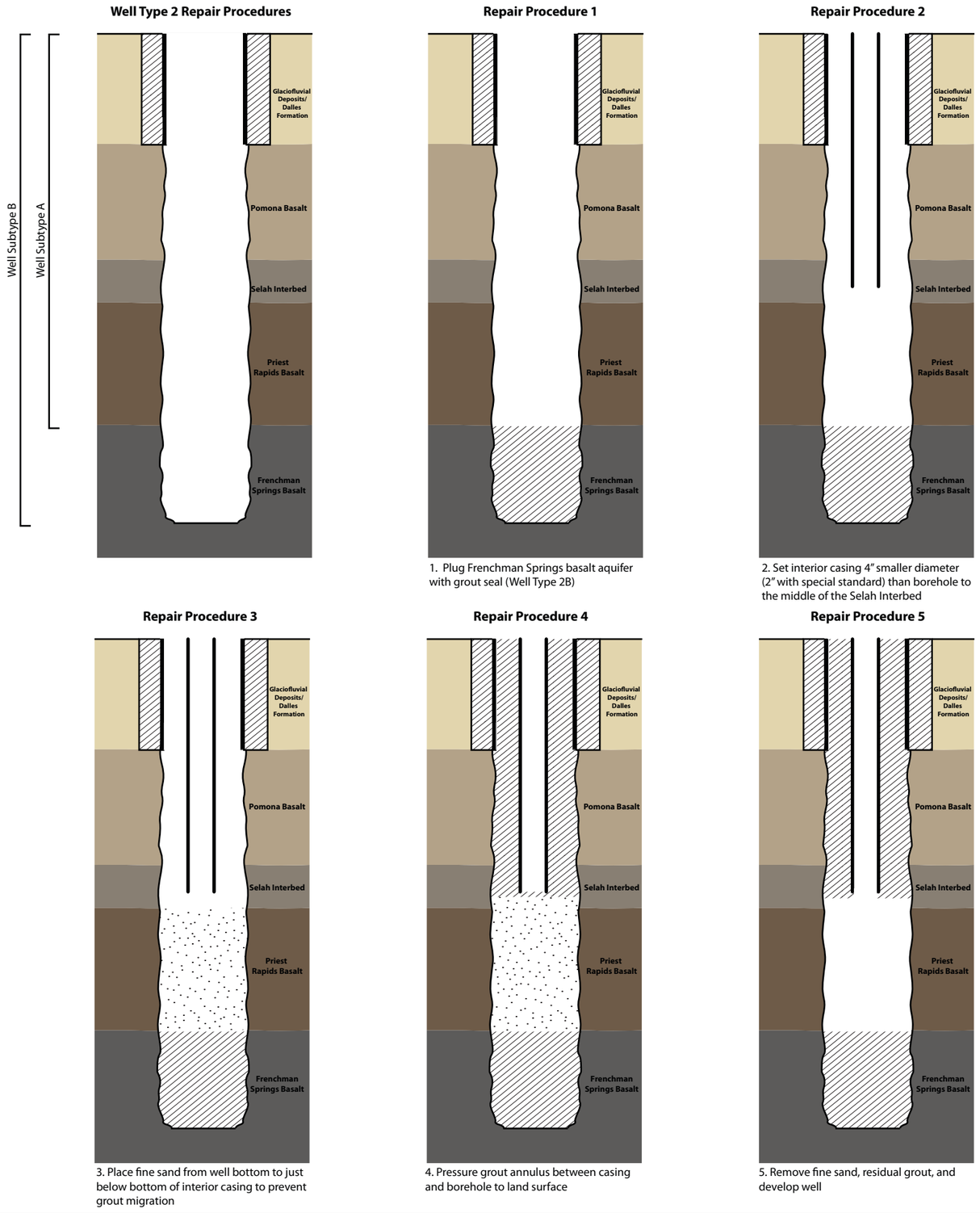
FIGURE 3-3B

Well Type 2
Commingling Repair Procedures
Mosier AR Feasibility Study



LEGEND

Geologic Information

- Glaciofluvial Deposits/Dalles Formation
- Pomona Basalt
- Selah Interbed
- Priest Rapids Basalt
- Frenchman Springs Basalt

Well Construction/Repair Information

- Grout Seal
- Fine Sand
- Casing
- Open Borehole

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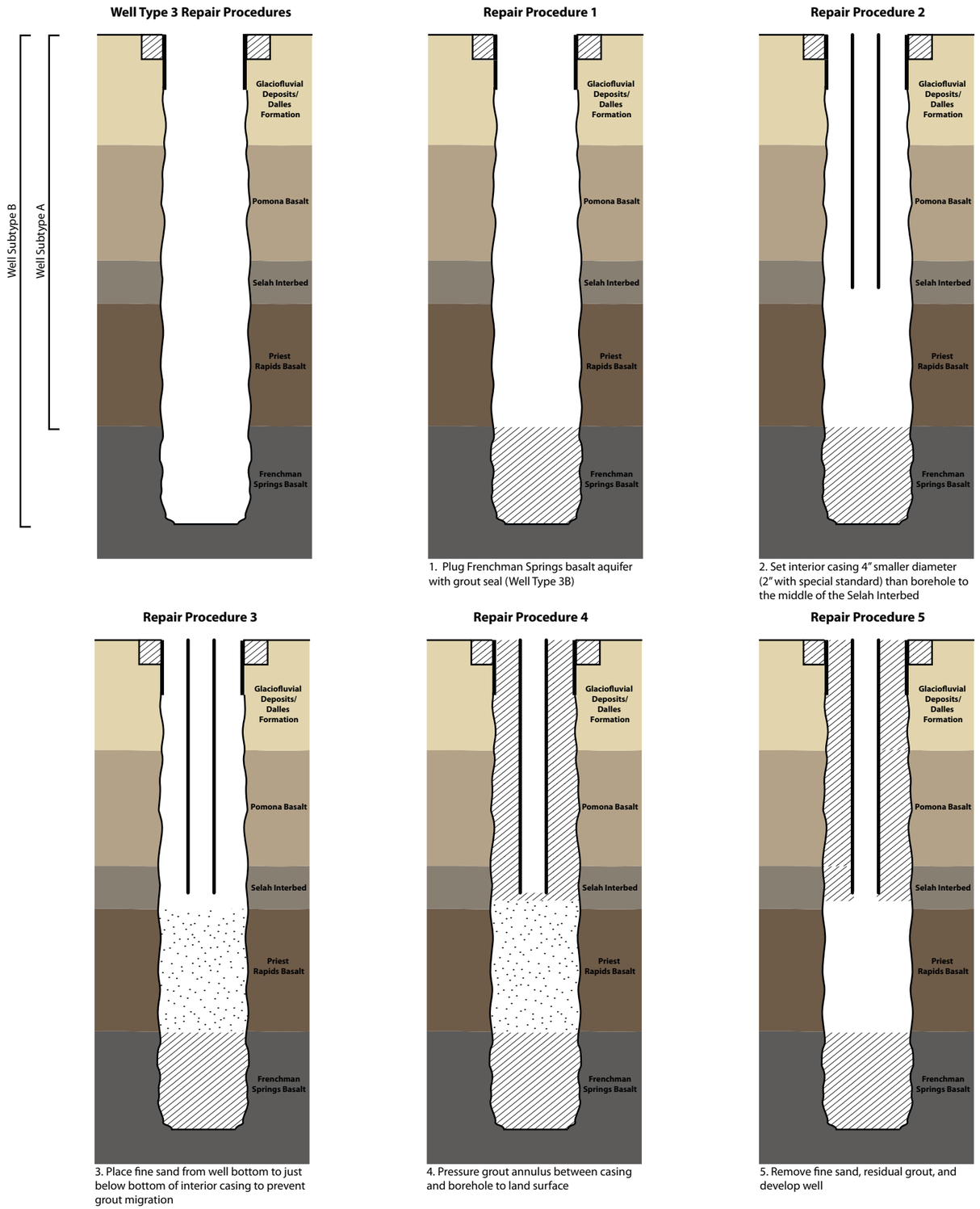
FIGURE 3-3C

Well Type 3
Commingling Repair Procedures
Mosier AR Feasibility Study



LEGEND

Geologic Information

- Glaciofluvial Deposits/Dalles Formation
- Pomona Basalt
- Selah Interbed
- Priest Rapids Basalt
- Frenchman Springs Basalt

Well Construction/Repair Information

- Grout Seal
- Fine Sand
- Casing
- Open Borehole

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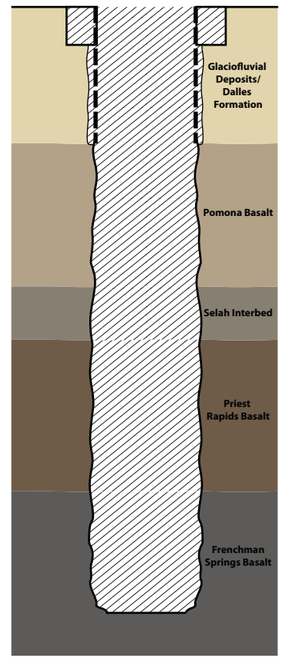
FIGURE 3-4

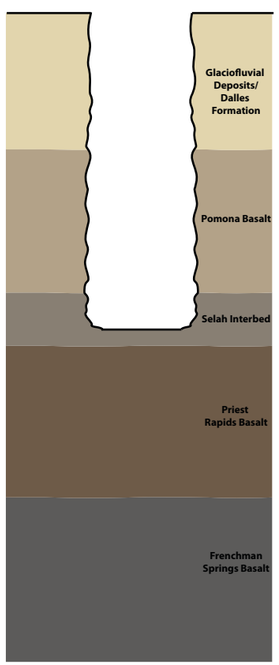
Well Decommissioning and Replacement

Mosier AR Feasibility Study

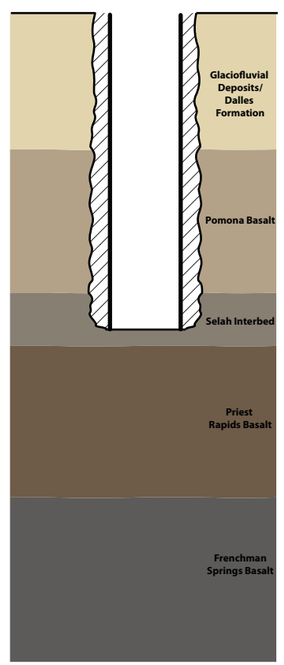
1. Perforate existing casing below existing seal



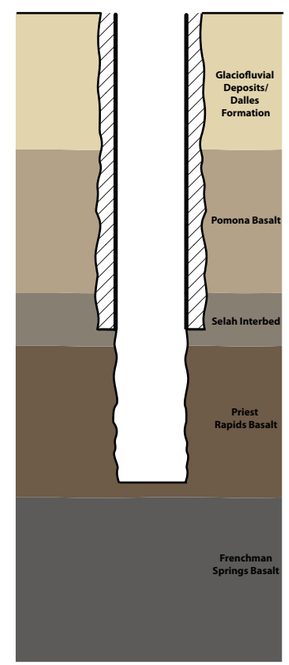
2. Fill borehole with cement grout. Pre-condition permeable zones to minimize grout loss



1. Drill borehole to Selah interbed



2. Install casing and full length grout seal



3. Drill through the bottom of Selah and into Priest Rapids Aquifer and complete well

LEGEND

Geologic Information

- Glaciofluvial Deposits/Dalles Formation
- Pomona Basalt
- Selah Interbed
- Priest Rapids Basalt
- Frenchman Springs Basalt

Well Construction/Repair Information

- Grout Seal
- Casing
- Open Borehole

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4.0 Water Conservation Strategies

The Mosier area relies on groundwater to irrigate approximately 900 acres of land, with the bulk of groundwater withdrawals for irrigation occurring in the Orchard Tract. Over the past decade many Mosier area growers have considerably reduced their irrigation water use by installing more efficient irrigation systems (e.g. micro-sprinklers and drip systems) and improving irrigation practices (e.g. soil moisture based irrigation scheduling). Several groundwater conservation projects were supported through financial assistance provided by the Wasco County Soil and Water Conservation District (SWCD), the Oregon Watershed Enhancement Board (OWEB), and the USDA Natural Resources Conservation Service (NRCS). Examples of such efforts include:

- In 2005, NRCS provided cost-share to an orchardist to install more efficient micro-sprinklers.
- In 2005, the SWCD assisted an orchardist in securing an OWEB grant to install more efficient drip irrigation and to experiment with different types of mulch in tree rows to reduce evaporation and further reduce irrigation water use.
- Through an OWEB grant, in 2006, the SWCD assisted five Mosier irrigators in upgrading to more efficient sprinkler systems on a combined acreage of 97.2 acres.
- The SWCD provided a grant for installation of a rainwater harvesting system to reduce groundwater pumping by providing an alternate source of irrigation water for a small nursery in Mosier.
- Funds from OWEB and the SWCD have also helped fund soil moisture monitoring in Mosier orchards to refine irrigation scheduling and further reduce overall water use.

In addition to these examples, other Mosier orchardists have upgraded their irrigation systems independently. The details of these upgrades, such as timing, acreage, and water savings, are not available; however, observations from the SWCD and local orchardists suggest that approximately 95 percent of orchard acreage uses some form of micro-sprinkler or drip irrigation and the majority of irrigators use less water now than they did 20 years ago. Water rights have historically allowed Mosier orchardists to apply three acre-feet of water per acre, but current estimates from a United States Geological Service 2006 groundwater use study indicates that irrigators have reduced their usage to approximately one acre-foot per acre (Jonathan Haynes, USGS, personal communication, March 31, 2011).

The City of Mosier has also reduced its groundwater pumping. The average city water use from 1989 through 2005 was 97 acre-feet per year (afy). Following repairs to the city water distribution system and installation of meters at homes, the average groundwater pumping for 2008 through 2009 decreased to 71 afy.

While great efforts have been made by irrigators and the City of Mosier to decrease groundwater withdrawals, the conservation measures have not produced a noticeable decrease in groundwater level declines of the Priest Rapids or Pomona aquifers. This is consistent with

the premise that commingling wells are the primary cause for the observed groundwater declines.

Although groundwater conservation alone will not provide a long-term, sustainable water supply for the Mosier area, the Mosier Watershed Council and Wasco County SWCD continue to enthusiastically promote increased water conservation and irrigation efficiency through various forms of technical and financial assistance. Furthermore, as groundwater levels decline, the increased energy costs associated with extracting groundwater from deeper depths serves as a strong incentive for Mosier area irrigators to use water conservation and irrigation efficiency practices. As a result, water conservation and water use efficiency is expected to continue to improve in the Mosier area.

5.0 SB 1069 Grant Requirements

5.1 Ecological and Peak Flow Analysis Road Map

A condition of the Oregon Water Resources Department's (OWRD) SB-1069 grant requires an analysis of the potential impacts of a water storage project on peak and ecological flows in Mosier Creek. The objective of this memo is to provide a road map for how to conduct an ecological and peak flow analysis for Mosier Creek, rather than actually carry out the analysis. The methodologies presented in this memo are largely guided by Oregon Water Resources Department's (OWRD) *White Paper: Peak and Ecological Flow; a Scientific Framework for Implementing Oregon HB 3369* (Norris, 2010), published December 2010. The White Paper presents approaches for determining peak and ecological flows. GSI discussed the use of this approach with ODFW's Instream Flow specialist, Tim Hardin, who indicated that the approach is likely to be applied over other methods. He also provided additional guidance and explained that the process for evaluating peak and ecological flows is still evolving.

Peak and Ecological Flows

The White Paper describes peak flows as peak or elevated streamflows needed by fish and wildlife and describes ecological flows as "flows needed to sustain ecosystem functions that native fish and wildlife species require to survive and flourish." Ecosystem functions of different flows include: stimulating biological life stages, forming habitat (pools, riffles, gravel bars, etc), cycling nutrients, providing for basic habitat needs, and replenishing riparian vegetation. Ecological flows can be categorized by the ecological function that a type of streamflow provides. These functions include baseflow functions, biological triggering flows, and channel habitat maintenance flows. For example, baseflows are flows that provide minimal or optimum habitat for aquatic species. Biological triggering flows are elevated flows that initiate and facilitate aquatic species life stage behaviors, such as migration and spawning of fish. Channel and habitat maintenance flows are elevated flows that maintain and create habitat (instream, riparian, and floodplain), such as pools and gravel beds.

Geomorphology and Hydrology

An analysis of ecological flows in Mosier Creek requires information on its geomorphology and hydrology, which is presented in some detail in the 2002 Mosier Watershed Assessment (Clark and Loop, 2002). Mosier Creek originates in Mt. Hood National Forest then flows north through forested lands and fruit orchards before emptying into the Columbia River at the town of Mosier, experiencing a 3,300 foot elevation change along its course. Figure 5-1 shows a topographic map of Mosier Creek and identifies the focus area of the water storage project. The creek is largely confined to a single, narrow channel due to hill slopes, terraces, and bedrock canyons restricting lateral movement of the stream channel and preventing wide floodplains. To assess habitat conditions and productive potential of streams, the Oregon Watershed Assessment Manual presents a classification system that describes "channel habitat types" along the length of a stream (Watershed Professionals Network, 1999). The channel habitat in the mid to upper Mosier Creek watershed is largely characterized as SV (steep headwater, confined) and MV (moderately steep, narrow valley), having steep to moderately steep, narrow valley terrain with large to small cobbles and bedrock. The mid to lower channel is largely

characterized as MC (moderate gradient, confined) and MM (moderate gradient, moderately confined), having a moderate gradient and moderate to considerable confinement and containing gravel to small boulders. MC and MM channels likely serve as important spawning and rearing habitat. The channel in the lower reaches of the Mosier Creek watershed is primarily characterized as BC (bedrock canyon), LM (low gradient, moderately confined), and LC (low gradient, confined), having a low gradient with moderate confinement to bedrock canyon and having substrate ranging from fine gravel to large boulders and bedrock. All of the anadromous spawning in Mosier Creek occurs in these habitats in the lower reaches due to a waterfall that creates a fish passage barrier. The watershed transports sediment fairly rapidly, resulting in an alluvial fan at the mouth of Mosier Creek. The channel habitats described are typical of many streams draining uplands in Columbia River Basalt bedrock.

As far as hydrology, the Mosier Creek watershed is located in the rain-on-snow runoff zone, such that its highest peak flows typically occur during or after rain-on-snow events in mid-to late winter. A US Geological Survey streamflow gage near the mouth of Mosier Creek recorded flow from 1963 to 1981 and the highest flows recorded were peak winter flows that exceeded 1600 cfs in 1964, 1974, and 1978. Mosier Creek is also affected by surface water and groundwater use in the watershed. Streamflow is diverted for irrigation and domestic use, and the Oregon Department of Agriculture has reserved water rights for storage in reservoirs for future economic development (See OAR 690-504-0100 and OAR 690-504-0140). Mosier Creek currently has no instream water rights. Groundwater from the aquifer underlying the watershed is used for commercial irrigation and drinking water. The majority of the wells tap into one of three basalt layers that create distinct aquifers: Pomona, Priest Rapids, and Frenchman Springs. The top two aquifers, Pomona and Priest Rapids, are considered overallocated and have declined substantially in the orchard area of the Mosier Valley. OWRD staff commented that Mosier Creek has generally gone from a gaining reach to a losing reach due to groundwater level declines affecting the creek. OWRD also suggested that water rights on Mosier Creek and/or associated springs could be researched to determine the amount of water that water right holders are presently getting as a way to better understand where and how Mosier Creek has been affected by groundwater withdrawals.

Evaluating Peak and Ecological Flows

To determine how water diversions for a storage project may affect peak and ecological flows, the White Paper recommends evaluating whether Regionally Protective Criteria (RPC) are met, which integrates information on hydrology and the anticipated effects of hydrology on channel habitat. The RPC considers the season that storage of water could occur (season of use), water availability, and peak flows. Whether or not the RPC are met indicates the extent of impact (low to high) a project would have on Mosier Creek and what conditions or additional analysis may be required for higher impact projects. The White Paper suggests that proposed storage projects could be evaluated in terms of three tiers of analysis based on the size and likely impact of the project. This would relate the complexity of the method needed for determination of ecological flows to the anticipated impact of the project.

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<u>Tier 1.</u> A project could be considered Tier 1, or low impact, if the project falls within the RPC and the project diverts water to a location not influenced by streamflow, meaning the project is not in the main

channel. To fall within the RPC, the project would only require water during the storage season, the needed amount of water would be available during the storage season requested at the 50 percent exceedance flow criteria, and the amount of water desired to be stored would likely not exceed 5 percent of the 2-year peak flow threshold. If the project falls within Tier 1, then no further analysis would probably be needed. The proposed storage project on Mosier Creek is likely to fall within Tier 1, because the project would be designed to only divert during the storage season, the diverted streamflow (approximately 2 cfs) would likely fall within the net water available during the storage season after accounting for instream flows needed for fish protection, and the diverted streamflow would likely fall below the threshold cumulative flow established to protect channel habitat and maintenance flow. The type of storage project used would be off-stream, as well.

Tier 2. If a project exceeds the RPC or the diversion would involve a main channel dam or structure, then the project would be considered a Tier 2 project. When applying for a water right for an aquifer storage and recharge or artificial recharge project, the RPC and other information already collected could be used by OWRD, ODFW, and DEQ to develop conditions of use to protect channel and habitat maintenance flow. Conditions could include storage season restrictions, planned releases, and trigger flow shut-offs. OWRD requires a pre-application conference, which can include DEQ, to discuss the application and potential conditions or constraints on the project.

Tier 3. If a project is a major storage project on a high value stream with target species of concern, then the project would fall within Tier 3, or high impact. Projects in the Tier 3 category require additional peak and ecological flow analyses, such as new baseflow studies, new modeling studies of the effects of flow changes on channel and riparian habitat maintenance, and behavioral studies of fish species related to biological triggering flows. The additional analysis required under Tier 3 would involve effort and costs several times greater than Tier 1 and Tier 2 projects.

Mosier Creek Road Map

The RPC evaluation for Mosier Creek would likely include analyses of the storage season, water availability, and peak flows. This information would then be considered in determining which evaluation Tier the project would fall within. Each is described below with respect to Mosier Creek.

Storage Season

The period of time when streamflows are sufficient to provide water for storage needs to be determined. In most watersheds, this corresponds to the non-irrigation season. The Mosier Creek Decree (1928) set the irrigation season for decreed surface water rights as March 1st to October 1st, making the storage season for those water rights October 1st to February 28th. However, OWRD's regional Watermaster explained that the storage season established by Oregon Administration Rules (OAR) Division 33 applies to applicants of proposed new appropriations in the Hood Basin, where Mosier Creek is located. OAR Division 33 states that no new appropriations will be allowed during the irrigation season of April 15 to September 30 which makes the storage season from October 1st to April 14th. The rules also state that exceptions can be made for some storage projects. Specifically, OAR 690-033-0120(2)(a) and (b) states that applicants need to show compliance with the following permit conditions related to periods of use:

1) "The proposed use does not involve appropriation of direct streamflow from April 15 to September 30, except as provided in OAR 690-033-0140," and
2) "The proposed use does not involve hydraulically connected groundwater with potential for substantial interference as listed in Division 9 of this chapter during the time period of April 15 to September 30, except that which is artificially recharged or as otherwise provided in OAR 690-033-0140."

OAR 690-033-0140 states that OWRD may approve a water right permit for "multipurpose storage projects or other projects with measurable public benefits" during the April 15 to September 30 time period. This rule indicates that OWRD may consider a storage season that extends into the April 15 to September 30 time period if the storage project augments instream flow for fish during that period. The OWRD regional Watermaster also suggested that storage may be not be approved until November or December due to the limited amount of net water available during those months (See Table 5-1). ODFW does not yet have a storage season in mind for Mosier Creek. Determining the storage season would require further discussions with ODFW and OWRD.

Water Availability

The objective of a water availability analysis is to determine whether instream and out of stream water rights can be protected while water is withdrawn in the storage season for storage. As described in the Legal Process section, OWRD's Water Availability Basin reports indicate that water is available at 50 percent exceedance (water is available 50 percent of the time) during an assumed storage season between October 1 and April 14 (Table 5-1). The report indicates that Mosier Creek has consumptive use and storage water rights, as well as reserved streamflow. OAR 690-504 outlines Hood Basin Program rules and states that 6,400 acre-feet of unappropriated water of Mosier Creek or its tributaries are reserved for storage in multipurpose reservoirs. The OWRD regional Watermaster explained that an aquifer storage project could potentially utilize the reserved water during the storage season, and that the reserved water program may sunset in the future for unused reserved water. The report also indicates that Mosier Creek has no instream water rights, such that a storage project would need to leave a certain amount of the "available" water instream to protect fish and wildlife.

Table 5-1. Mosier Creek (ID#: 30410527) Water Availability Basin Report, using OWRD'S Water Availability Analysis tool.

Month	Natural Stream Flow (cfs)	Consumptive Use & Storages (cfs)	Expected Stream Flow (cfs)	Reserved Stream Flow (cfs)	Instream Flow Requirement (cfs)	Net Water Available (cfs)	Water Available
Jan	38.3	0.56	37.7	17.3	0	20.5	Y
Feb	64	0.66	63.3	29	0	34.3	Y
Mar	62.8	0.74	62.1	28.5	0	33.6	Y
Apr	36.6	1.66	34.9	16	0	18.9	Y
May	11.3	3.66	7.64	3.5	0	4.14	Y
Jun	5.01	3.11	1.9	0.87	0	1.03	Y
Jul	2.41	1.24	1.17	0.54	0	0.64	Y
Aug	2	0.85	1.15	0.53	0	0.62	Y
Sep	2.3	0.86	1.44	0.66	0	0.78	Y
Oct	3.2	0.48	2.82	1.29	0	1.53	Y
Nov	5.82	0.48	5.34	2.44	0	2.9	Y
Dec	15.1	0.52	14.6	6.68	0	7.91	Y

Due to the lack of an instream water right on Mosier Creek, ODFW indicated that an analysis would need to be done to determine flows necessary to support fish species. Mosier Creek has Coho and listed anadromous Winter Steelhead below the waterfalls near the mouth of the creek and cutthroat trout and redband trout above the falls. Analyses often utilize Basin Investigation Reports, PHABSIM (Physical Habitat Simulation System), or 50 percent exceedance flow. ODFW indicated that the Hood River Basin Investigation report (OSGC, 1963 and Smith, 1973) mentioned Mosier Creek, but does not provide guidance on minimum flows that are protective of aquatic species. PHABSIM is a method that predicts physical microhabitat changes associated with alterations in streamflow and then relates physical habitat to fish production and life stages, thereby indicating instream flow needs of fish. ODFW suggested that an abbreviated PHABSIM analysis could be conducted for Mosier Creek for small storage projects. The 50 percent exceedance flow may be considered for establishing minimum flow requirements and may be considered equivalent to an instream water right in small watersheds. According to ODFW, 50 percent exceedance flows are sometimes multiplied by a factor to provide adequate flows that are protective of fish species. If this method was chosen for Mosier Creek, ODFW indicated that a factor would not likely be applied, but rather the Natural Streamflow at 50 percent exceedance would be considered equivalent to the instream minimum flow requirement. Consequently, water available for storage would be any streamflow above the Natural Stream Flow at 50 percent exceedance. For example, if 38.3 cfs is the Natural Streamflow at 50 percent exceedance in January, then flows for storage could be removed whenever the flow is over 38.3 cfs Natural Streamflow. However, the amount of diversion for storage has a limit, or threshold, due to the need to protect peak flows and other water rights (Consumptive Use Flows, Instream Flows, and possibly Reserved Flows), which will be described in the next sections.

ODFW indicated that the type of analysis required would be related to the size of the storage project, where and when the water would discharge back into the creek, and how much would discharge.

Channel and Habitat Maintenance Threshold Criteria (Peak Flow Analysis)

Peak flows play a significant role in channel and habitat maintenance. The objective of the Peak Flow Analysis is to determine a threshold at which the total rate of diversion for out of stream uses and storage projects during the storage season is less than a percentage of a peak flow, thereby still supporting channel and habitat maintenance flows.

OWRD provides a model that estimates peak flows for 2-year, 5-year, and less frequent events. However, ODFW indicated that historical streamflow data from the Mosier Creek gage should be used rather than the OWRD model, since approximately 20 years of data is available for Mosier Creek. ODFW is currently discussing internally whether 1-year, 1.5-year, or 2-year peak flows should be used for peak flow analysis. Given the geomorphology of Mosier Creek, ODFW indicated that a 1-year or 2-year peak flow event would likely be considered the channel and habitat maintenance flow. ODFW estimated that the 2-year peak flow in Mosier Creek is 686 cfs.

ODFW also mentioned that another method of determining channel and habitat maintenance flows is to identify the channel bed type (sand bed, gravel bed, or course bed) and then estimate the flows needed to move the bed substrate, which is explained in the 2007 ODFW guidance document *Calculating Channel Maintenance and Elevated Flows*. The document suggests several books that explain how to conduct a substrate movement study, which would involve an analysis using cross-sectional and substrate data to estimate what critical velocity or shear stress would be needed to initiate bed movement. ODFW indicated that this method would be more appropriate for streams that are considered "high value" and/or have major storage projects instream, such that use of this method is unlikely to be required on Mosier Creek.

Once the peak flow is established, the percent of that peak flow that can be diverted for storage needs to be set. The total rate of diversion for storage projects during the storage season is typically 5 percent of the peak flow, but can range from 5 to 10 percent. ODFW indicated that a 5 percent threshold would be likely for a project on Mosier Creek. Using ODFW's 686 cfs 2-year peak flow, 5 percent of the peak flow would be 34.3 cfs. The 34.3 cfs is considered the threshold cumulative flow.

Integrating Analyses

The amount of water that can be diverted for storage is determined by subtracting consumptive uses, instream uses, and potentially reserved flow from the threshold cumulative flow, thereby protecting both approved uses and peak flows. For example, the amount of storage allowed in January is 16.44 cfs, or the 34.3 cfs threshold cumulative flow minus the Consumptive Use (0.56 cfs), Instream Flow (0 cfs), and Reserved Streamflow (17.3 cfs). Examples of the amount of storage allowed every month are shown in Table 5-2.

Table 5-2. Example analysis integrating the Water Availability Basin report and Peak Flow Analysis.

Month	Natural Stream Flow (cfs)	Consumptive Uses + Reserved Streamflow + Instream Flow (cfs)	Threshold Cumulative Flow (cfs)	Amount of storage allowed (cfs)
Jan	38.3	17.86	34.3	16.44
Feb	64	29.66	34.3	4.64
Mar	62.8	29.24	34.3	5.06
Apr	36.6	17.66	34.3	16.64
May	11.3	7.16	-	0
Jun	5.01	3.98	-	0
Jul	2.41	1.78	-	0
Aug	2	1.38	-	0
Sep	2.3	1.52	-	0
Oct	3.2	1.77	34.3	32.53
Nov	5.82	2.92	34.3	31.38
Dec	15.1	7.2	34.3	27.1

Thus, the amount of water that can ultimately be diverted for storage is equal to the flow above the Natural Streamflow at 50 percent exceedance up to the threshold cumulative flow with adjustment for Consumptive Uses, Instream Flows, and possibly Reserved Streamflow. For example, in January, storage of up to 16.44 cfs can occur when streamflows exceed 38.3 cfs (the Natural Flow at 50 percent exceedance flow). The possibility exists that the Reserved Streamflow for multipurpose storage could be used for an aquifer storage project, in which case part or all of the Reserved Streamflow may not have to be subtracted from the threshold cumulative flow.

The RPC evaluation would possibly need to be conducted at several locations downstream of the project, particularly where major tributaries join Mosier Creek, at diversion locations for off-stream allocations, and where other Water Availability Basin reports exist.

5.2 Environmental Impact

Introduction

Aquifer recovery alternatives under consideration in the Mosier area include recharge of the aquifer under Oregon AR rules using Mosier Creek (via a well or infiltration gallery) for source water and the Columbia River Basalt Group aquifers for storage. This section outlines the results of an initial review of the potential environmental harm and/or impacts that may result within the study area from a recharge project. It is assumed that repair of commingling wells and additional conservation measures would have no environmental impacts and that this evaluation thus focuses on potential impacts from development of an aquifer recharge project (see Figure 5-1).

Land Use/Important Farmland/Formally Classified Lands

The study area location is in northwest Wasco County, Oregon. Land in the vicinity is privately owned. Located at elevations of approximately 200 to 800 feet above mean sea level, the study area is situated along Mosier Creek just upstream of the City of Mosier.

The study area is predominately private land within the A1-Exclusive Farm Use Zone. The most southern extent of the study area is within the F2-Forest Zone of Wasco County (WCPDO, 1985). Construction activities will require excavation of the soil and possibly in-water work. The impacts of construction will be minimal and temporary. There will be no long-term, permanent impacts as a result of this project. A Land Use Compatibility Statement from Wasco County may be required for this project.

Important Farmland

There are two dominant soil types in the study area: cobbly complexes and loams (NRCS, 2011). Cobbly soils occur in the upper reaches of the study area while loams persist in the lower reaches. The loam soils, including Van Horn and Wamic loam, are listed as Farmland of Statewide Importance. Thus, if federal funding is accepted for this project, the action area may be subject to review under the Farmland Protection Policy Act. Soils listed as Prime Farmland do not exist in the project area. With the exception of pump facilities, disturbed areas will be restored to pre-construction condition and no permanent conversion activity will take place.

Formally Classified Lands

Formally classified lands are lands designated by federal, state, and local governments for special purposes. These include parks, monuments, landmarks, historic trails, wild and scenic areas, wilderness areas, Native American-owned lands, etc.

The lower reach of the study area is located adjacent to the southern boundary of the Columbia River Gorge National Scenic Area. The study area is 12 miles northeast of the Mt. Hood National Forest. The proposed actions would have no impact on formally classified lands.

Wild and Scenic Rivers

No portions of Mosier Creek are classified as wild and scenic. Thus, this project would have no effect on wild and scenic rivers (NWSRS, 2011).

Floodplain

The lower Mosier Creek subbasin is located in north-central Oregon. The study area is located adjacent to Mosier Creek, in 5th Field HUC 1707010506.

According to the Federal Emergency Management Agency (FEMA) Map Service Center (FEMA, 2011), FEMA Flood Insurance Rate Map Panel Number 410229B (05), Zone C, Area of Minimal Flooding has been assigned to the project area. The floodplain of Mosier Creek would be temporarily disturbed by excavation to install buried main line and collection structures (either in stream or buried); however, there would be no permanent impacts to the floodplain. No existing aboveground structures would be impacted as a result of the project.

Wetlands

The National Wetlands Inventory map identifies areas of freshwater forested/ shrub wetlands along the riparian area in the study area (USFWS, 2011a). To the extent possible, efforts would be made to locate construction away from wetland areas. Potential impacts to wetlands would be minor and temporary. If wetlands cannot be avoided, a Fill/Removal Permit from the Oregon Department of State Lands and a Section 404 Permit from the U.S. Army Corps of Engineers would be obtained.

A site visit to scope for wetlands would be conducted prior to finalizing project design and location.

Historic Properties

A search of the National Register of Historic Places (Register) was conducted and there are no listings on the Register within the study area (NPS, 2011). The Jefferson House, 1 mile from the study area within the City of Mosier, is listed on the Register. The selected site would have no impact on historical resources associated with the Jefferson House.

Once the project is designed, a pedestrian survey would be conducted to evaluate the potential for impacts to cultural resources if required by the Oregon State Historic Preservation Office (SHPO). No impacts to cultural resources are anticipated. However, excavation associated with the proposed conveyance line, diversion facilities (infiltration gallery or well), and injection/recovery well would involve ground disturbance and could affect unknown cultural resources.

If additional work is required beyond the pedestrian survey, it would be completed prior to project construction. Project specifications would include an *Unanticipated Discovery Clause* for cultural resources.

In the event that an archaeological resource is discovered during project operations, work would cease in that area and an archaeologist would be contacted to assess the discovery. SHPO and the appropriate tribes would be notified to be made aware of the discovery.

Biological Resources

A list of federally listed species was obtained from the U.S. Fish and Wildlife Service and National Marine Fisheries Service on March 31, 2011 (USFWS, 2011b; NMFS, 2011). The following Table 5-3 identifies the threatened or endangered species that may occur within Wasco County, as well as designated critical habitat.

Table 5-3. ESA Listed and Proposed Species in Wasco County

Common Name	Scientific Name	Federal ESA Status	Critical Habitat Designated
Chinook Salmon	*Oncorhynchus tshawytscha*	Threatened	Yes
Steelhead	*Oncorhynchus mykiss*	Threatened	Yes
Coho Salmon	*Oncorhynchus kisutch*	Threatened	Yes
Bull Trout	*Salvelinus confluentus*	Threatened	Yes
Northern Spotted Owl	*Strix occidentalis caurina*	Threatened	No

Waterfalls in the lower reaches of Mosier Creek, below the study area, create an impassable barrier and restrict the range of anadromous species. Winter steelhead (*Oncorhynchus mykiss*) and coho salmon (*O. kisutch*) spawn below the impassable waterfalls on Mosier Creek (SWCD, 2002). Resident fish, including cutthroat trout (*Oncorhynchus clarki clarki*), exist in Mosier Creek above the falls (SWCD, 2002). Neither bull trout nor critical habitat exist within Mosier Creek (USFWS, 2011c).

The northern spotted owl is not likely to be found in the project area. Lack of habitat and disturbance limit owl distribution in the watershed. Critical habitat for the northern spotted owl is located over 10 miles away in the heavily wooded portions of the Mt. Hood National Forest.

To avoid impacts to resident species, any in-stream work would occur within the Oregon Department of Fish and Wildlife preferred in-water work window from July 15 to September 30 and Best Management Practices would be followed to avoid any stream degradation. Prior to construction, a permit would be obtained and necessary environmental documents completed.

Water Quality

Mosier Creek is water quality limited; habitat modification (limited, not needing a total maximum daily load [TMDL]), flow modification (limited, not needing a TMDL), and temperature (303(d) list, TMDL approved) are the listed parameters.

Some treatment of source water to reduce turbidity and remove biological contaminants to water quality standards may be needed. Comprehensive sampling and analysis of source water and native groundwater are needed to further evaluate compliance with water quality standards, potential treatment requirements, and geochemical compatibility between source water and native groundwater.

Coastal Resources

The proposed project is not located within a coastal zone. Thus, the proposed project would have no environmental consequences on coastal resources.

Miscellaneous Issues (Air, Noise, Transportation, Visual Aesthetics)

Air Quality

The affected environment would include the entire project area and immediate surrounding vicinity. The Clean Air Act and Amendments of 1990 define a "non-attainment area" as a locality where air pollution levels persistently exceed National Ambient Air Quality Standards or that contribute to ambient air quality in a nearby area that fails to meet standards (DEQ, 2011).

The portion of Wasco County identified as the proposed study area has not been classified by the Oregon Department of Environmental Quality as a non-attainment area and does not have an air quality maintenance plan or program.

The project has the potential to temporarily affect air quality at the local level. Short-term impacts would include emissions from equipment operation and dust generated from construction activities.

No substantial particulate matter or detrimental emissions would be released as a result of the project. Fugitive dust control measures, such as spraying water in work areas and applying mulch to disturbed ground, would be implemented as necessary during and following construction.

Noise

The affected environment for noise generated as a result of the project would include the project area and immediate surrounding vicinity. Noise is defined as unwanted sound that interferes with the normal activities of humans and the natural environment. The Oregon Department of Energy regulates noise levels through the Site Certification process.

The proposed project is located outside any city limits or urban growth boundaries, and Wasco County does not have a noise ordinance. Local law enforcement agencies provide noise regulation within the County.

All noise created by the project would be intermittent and temporary in nature and confined to the project area during daylight hours for the duration of construction. No long-term noise impacts would occur.

Transportation

Mosier Creek Road is the only access to the study area. Temporary impacts to traffic congestion could occur during construction of the proposed project as more equipment is entering and exiting the road. No permanent or long-term impacts to transportation are anticipated as a result of the proposed project.

There are no scenic byways in the project area.

Visual Aesthetics

Temporary impacts to visual aesthetics would occur during construction; however, the project area would be reshaped, reseeded, and returned to pre-construction conditions. A pump facility would be installed along with a fence around a one-quarter to one-half acre area to protect the site. Efforts will be made to locate the project area away from the road to avoid visual impairment.

Erosion/Slope Stability

The predominant soils in the study area have a relatively low "K" factor, which indicates the susceptibility of a soil to sheet and rill erosion (NRCS, 2011). The soil's "K" factor is 0.24 on a range of 0.02 to 0.69. Any construction impacts will be temporary and will not increase erosion potential.

The slopes adjacent to the stream tend to be somewhat steep, ranging from 12 to 35 percent with flatter areas occurring at the southern extent of the study area. Work on slopes is not anticipated; however, once a final project area is determined, slope stability will be evaluated and measures taken to prevent destabilization.

5.3 Streamflow Augmentation with Stored Water

One stipulation of the SB 1069 grant funding is that the project must evaluate the need for and feasibility of using stored water to augment in-stream flows for ecological benefits.

Although the present relationship between Mosier Creek and the Pomona and Priest Rapids aquifers remains to be clarified, some evidence suggests that the creek is losing to the aquifers in the vicinity of 2N/12E sections 18 and 19 (K. Lite, OWRD, pers comm., 2011.). Previous investigations indicate that Mosier Creek gained from approximately 0.5 cfs of discharge from the Pomona aquifer in 2N/12E

Section 18 during the 1980s (Lite and Grondin, 1988) and Newcomb (1969) suggested that the Priest Rapids aquifer also discharged to the creek in 2N/12E Section 19. Although still speculative, this implies that depressurization of the basalt aquifers has caused a reach of Mosier Creek at the southern end of the Orchard Tract to transition from gaining to losing.

Strategies that could halt and reverse water level declines in the Pomona and Priest Rapids aquifers at a minimum could prevent additional stream losses during summer base flow periods on Mosier Creek. Restoration of water levels in the basalt aquifers would further serve to reduce current stream losses. If water levels were restored to levels above the stream at the location of the aquifer/stream connection, renewed discharge of groundwater to the stream would add to summer base flows. The degree of connection between the aquifers and stream, as well as the direction of exchange is still uncertain. OWRD and Portland State University are currently implementing a research project to evaluate this connection, which could provide valuable information from which to quantify potential benefits to streamflow from aquifer recovery strategies.

5.4 Comparative Analysis of Alternatives

A comparative analysis of aquifer recovery alternatives was developed on the basis of the evaluation summarized in this report. The comparative analysis considered positive and negative aspects of feasibility criteria including: infrastructure requirements, physical feasibility, costs and environmental and ecological impacts. Each criterion was assigned a numerical score that reflects an assessment of how each attribute affects feasibility. The criterion scores were combined to provide a numerical ranking of each alternative. A matrix comparing the aquifer recover alternatives is presented in Table 5-4 and the numerical rankings of the alternatives are presented in Table 5-5. A summary of the conclusions from the alternative analysis is provided below:

- Commingling well remediation receives the highest ranking of the alternatives because the effectiveness of other alternatives is predicated on reducing or eliminating commingling between aquifers. Further, commingling well remediation has the least amount of uncertainty with regard to physical feasibility. The one significant disadvantage of remediation of commingling wells in the ranking is cost. The cost ranking for this strategy was assigned assuming that most or all of the commingling wells within the Orchard Tract would be repaired or replaced; however, substantial benefit may be realized by remediation of fewer, select wells, which would significantly reduce the overall cost and increase the ranking of this strategy.
- The two aquifer recovery strategies, surface recharge and well recharge scored equivalently. However, we would anticipate that well recharge would score higher for effectiveness in the event that (1) commingling wells were remediated, and (2) cost-effective treatment using an infiltration gallery is feasible.
- The conservation strategy was deemed to be not effective on the basis of data showing that conservation measures largely have been implemented by irrigators, but have not demonstrably reduced groundwater level declines in the basin.

Table 5-4. Comparative Analysis of Aquifer Recovery Alternatives

Aquifer Recovery Strategy		Description	Infrastructure Requirements	Physical Feasibility: Hydrogeology	Physical Feasibility: Potential Effectiveness	Key Uncertainties (data needs)	Costs: Capital Cost	Costs: O & M	Environmental and Ecological Impacts*
Aquifer Recharge	*Surface Recharge*	**Description** • Ponding and enhanced surface infiltration of water diverted from Mosier Creek into target basalt aquifer interflow zone(s). Infiltration basin located in connection with interflow zone or within overlying permeable soils. Infiltrated water percolates downward through soil material and recharges interflow zone of target basalt aquifer. **Assumptions** • Strategy could only be employed where Priest Rapids and Pomona aquifer crop out in valley bottom, near stream. Pumping lifts, topography and likely lower permeability of interflow zones in highlands preclude surface recharge in these locations. • Replace annual groundwater withdrawals from the basin Volumes of up to 1,000 AF/yr over 5 to 7 month recharge period	• Diversion on Mosier Creek: gravity diversion or pump to remove water from Creek if incised below grade. • Conveyance (piping) • Engineered surface spreading basin (0.3 to 24.6 acres to recharge 1,000 AF over 5 month period, depending on soil and interflow zone permeabilities).	**Positives** • Permeable soil layers present that readily percolate water. • Sufficient water available in Mosier Cr. For AR. • Locally unconfined permeable flow layer in Priest Rapids or Pomona may be present in suitable areas near the Orchard Tract. Suitability likely increases nearer the axis of Mosier syncline (north). • Pre-treatment of source water likely not necessary. **Negatives** • Limited land availability for spreading basin. • Locally unconfined permeable flow layer in Priest Rapids or Pomona may not be present in suitable areas.	**Positives** • Effective if hydraulic connectivity exists between recharge area and Orchard tract. • Restoration of aquifer levels to those in Mosier Creek would reverse stream losses to aquifers. **Negatives** • Accounting of where recharged water goes made difficult by spatially heterogeneous and comingled basalt aquifer system. • Benefit of surface recharge tied to commingling well repair/replacement. • Magnitude of aquifer recovery limited to elevation of stream connection with aquifer. Surface recharge not feasible where basalt aquifers discharge to stream.	• Presence of locally unconfined Priest Rapids or Pomona permeable zones (Geologic investigation including mapping and drilling or trenching required to determine existence and hydraulic connectivity with Orchard Tract). • Soil permeability key factor in recharge basin design (Site specific characterization of soil permeability). • Gradient between aquifer(s) and Mosier Creek in potential area for surface recharge (Stream seepage runs and shallow piezometers needed to verify that aquifer will accept recharge at these locations). **Overall** High uncertainty whether right combination of conditions are present. Significant exploration required to determine.	Total: $520,000 - $710,000 **Assumptions**: • 2.5 acre spreading basin. • Excavate 7 ft bgs, short haul offsite. • Conveyance distance of 100 ft • Includes land acquisition, diversion, conveyance and investigation and engineering design	Total: $10,000/yr to $20,000/yr **Assumptions**: • Removal of clogging layer: $3,000/yr to $6,000/yr • Site Maintenance: $5,000/yr to $10,000/yr (basic grounds maintenance, checking of system when running) • Electrical:$2,000/yr to $4,000/yr (pumped diversion)	**Advantages:** • Net benefit to summertime streamflows from reduction and ultimately potential for reversal of stream losses below USGS gauge **Disadvantages** • Potential visual impairment from a pump facility and fence around the site. • Streamflow will be reduced during the storage season, but peak flows will be maintained and an instream minimum flow requirement for fish will be adhered to.
	Direct Well Recharge	**Description** • Direct Injection of water diverted from Mosier Creek into one or more wells within the Orchard Tract. Total injection rates of 2 to 3 MGD (1,400 to 2,100 gpm) for 5 to 7 months would be necessary to replace entire annual pumped volume of 1,000 AF in basin. Actual recharge volumes necessary for given aquifer recovery benefit unclear. **Assumption** • Strategy would only be employed near stream and diversion to reduce pumping lifts and conveyance/easement costs.	• 1 or more dedicated injection wells designed for injection under pressure. Existing wells generally not available or suitable for use. • Diversion on Mosier Cr., utilizing natural filtration though alluvial sediments to remove suspended solids and biological contaminants. • Booster pump(s) to transmit water to wellheads at sufficient pressure to overcome potential artesian pressures at well head • Conveyance (piping) • Treatment necessary if sufficient filtration not achievable at diversion. Disinfection or wellhead treatment potentially needed if potential for bio-fouling of injection wells is identified.	**Positives** • Priest Rapids aquifer(s) appears to have suitable characteristics within the Orchards Tract area for potential injection rates of up to 1 to 1.5 mgd (700 – 1,000 gpm). • The Pomona aquifer also appears to be locally suitable within sections 7 and 12. **Negatives** • Aquifer suitability generally diminishes up-dip (south), away from axis of Mosier syncline.	**Positives** • Direct well injection effective in targeting benefit to area of greatest need. Benefits would be direct, instantaneous and measurable. • Restoration of aquifer levels to those in Mosier Creek would reverse stream losses to aquifers. **Negatives** • Benefit of direct well injection tied to commingling well repair/replacement. Commingling wells would limit or negate benefits of direct well injection, particularly within Orchards Tract. • Recharge wells should be located away from connection between aquifer and Mosier Creek to maximize aquifer recovery before discharge of water to stream.	• Achievable diversion rates and filtration – need saturated thickness and connection of alluvial sediments with creek (alluvial sediment investigation, including drilling, hydraulic testing and filtration analysis). • Achievable recharge rates and volumes in basalt aquifer including aquifer and injection well capacities (test well drilling and testing). • Incremental benefit that would be derived from each unit of recharge volume (injection pilot testing).	**Without Treatment** $1,004,000 to $1,374,000 **With Treatment** $3,500,000 to $3,800,000 **Assumptions**: • 100 feet of collection pipe. ($30 - $40/ft) • One or two 400 - 500 foot deep injection wells. • Injection under 200 feet of artesian pressure. • Investigation, design and permitting costs included.	**Without Treatment** Total: $35,000 - $70,000/yr Pumping Costs:$20,000 - $40,000/yr General maintenance:$10,000 – 20,000/yr Injection well rehabilitation:$20,000 – $40,000/3 to 5 years **With Treatment** Total: $65,000 – $100,000/yr • Pumping and general maintenance additional costs $30,000/yr	**Advantages:** • Net benefit to summertime streamflows by reducing and potentially reversing stream losses to aquifers below USGS gauge **Disadvantages** • Potential visual impairment from a pump facility and fence around the site. • Streamflow will be reduced during the storage season, but peak flows will be maintained and an instream minimum flow requirement for fish will be adhered to.

Aquifer Recovery Strategy	Description	Infrastructure Requirements	Physical Feasibility			Costs		Environmental and Ecological Impacts
			Hydrogeology	Potential Effectiveness	Key Uncertainties (data needs)	Capital Cost	O & M	
Commingling Well Remediation (Repair/Replacement)	• Repair or replacement of commingling wells to reduce flow between aquifers • Focus on Orchard Tract (area of greatest vulnerability to commingling effects), starting nearest to synclinal axis and working up-dip • Prioritize based on testing to confirm and quantify commingling in individual wells. • Evaluate incremental response to commingling repairs in Pomona and Priest Rapids aquifers. **Repair** • Install inner casing and fully penetrating seal, and perforate existing casing to ensure seal integrity. • Owner would need to choose single aquifer (Tpr, Tf or Tp) and choice would affect repair sequencing, resulting water level within well and potentially the well capacity.. ***Replacement*** • Decommission existing commingling well and install new well in single aquifer. Choice of aquifer would affect cost, resulting water level and potentially the well capacity.	**Repair** • Potential need to replace pump to accommodate reduced diameter of repaired well. **Replacement** • New well and potentially new pump/motor and minor distribution piping to connect to new well location.	**Repair** • Understanding of nature and location of strata in which seal will be placed is important. • Selah Interbed generally suitable to seal placement to prevent Priest Rapids -> Pomona commingling.	**Repair/Replacement Overall** • Available information indicates that could be highly effective in arresting water level declines and aquifer recovery. Overall effectiveness uncertain and would depend on location and number of repairs. Maximum benefit achieved by focus near synclinal axis and working up-dip to progressively eliminate lowest drainage points. **Repair** • Fully penetrating seal with casing generally effective and reliable if carefully placed. • Zonal/split seal less expensive but has lower reliability and effectiveness, and needs variance. • Repairs may be limited to 8-inch wells and greater. • Repairs may be prevented by crooked boreholes or other conditions. **Replacement** • Highly effective and reliable. Will reliably eliminate effects of commingling at well location.	**Repair** • Owner would need to choose single aquifer (Tpr, Tf or Tp) and choice would affect repair sequencing, resulting water level within well and potentially the well capacity. • Somewhat greater uncertainty associated with repair. • OWRD variance for installation of 6-inch casing in 8-inch borehole uncertain, though more likely. • OWRD variance for installation of 4-inch casing in 6-inch borehole unlikely. **Replacement** • Owner would need to choose single aquifer (Tpr, Tf or Tp) and choice would affect repair sequencing, resulting water level within well and potentially the well capacity. • Minimal uncertainty with regard to effectiveness.	**Repair** • $29,000 - $47,000/well • Depends on type of well and which aquifers commingling **Replacement** • $35,000 - $47,000/well **Pump System Replacement** • $5,000 - $16,000 **Prioritization** $2,000 to $10,000/well	**N/A**	**Advantages:** • Net benefit to summertime streamflows from reduction and ultimately potential for reversal of stream losses below USGS gauge • May preclude need for additional measures such as aquifer recharge **Disadvantages** • None identified

Aquifer Recovery Strategy	Description	Infrastructure Requirements	Physical Feasibility Hydrogeology	Physical Feasibility Potential Effectiveness	Physical Feasibility Key Uncertainties (data needs)	Costs Capital Cost	Costs O & M	Environmental and Ecological Impacts
Commingling Well Remediation and Aquifer Recharge	• Repair or replace commingling wells based on prioritization scheme above • Implement either surface or well recharge project to augment recovery of aquifer levels, as needed	• See recharge and well repair/replacement alternatives.	• See recharge and well repair/replacement alternatives.	• Effectiveness of adding recharge depends on number and priority of commingling wells repaired or replaced. • Repair/replacement of significant number of high priority wells likely required before benefits justify expense of recharge project in lieu of additional well repair/replacement. • Repair/replacement of all and possibly most of commingling wells in Orchard Tract coupled with recharge would achieve the maximum water level recovery.	• See uncertainties under recharge and well repair/replacement alternatives. • The point at which recharge would provide significant benefit is currently unknown. • Available information indicates that the objective of arresting water level decline and at least some water level recovery likely could be achieved through commingling well repair/replacement alone.	**Commingling Well Repair/Replacement** **Repair/Replacement:** $29,000 - $47,000/well **New Pumping System (as needed):** $5,000 - $16,000/well **Recharge** • Surface Recharge: $520,000 - $710,000 • Well Recharge w/o Treatment: $980,000 - $1,350,000 • Well Recharge w/ Treatment: $3,500,000 - $3,800,000	**Commingling Well Repair/Replacement** • **N/A** **Recharge** Surface Recharge: $10,000 – $20,000 Well Recharge without Treatment: $35,000 - $70,000 Well Recharge with Treatment: $65,000 - $100,000 Total: $10,000 - $100,000	**Advantages:** • Net benefit to summertime streamflows from reduction and ultimately potential for reversal of stream losses below USGS gauge **Disadvantages** • Potential visual impairment from a pump facility and fence around the site. • Streamflow will be reduced during the storage season, but peak flows will be maintained and an instream minimum flow requirement for fish will be respected.
Conservation	Reduction in irrigation water use by installation of more efficient irrigation systems and improving irrigation practices.	Examples are: Micro-sprinklers, drip irrigation system, soil moisture monitoring sensors.	NA	Implementation of conservation measures in the Mosier basin have been effective in reducing average irrigation water use from approximately 3 acre-feet/acre to one acre-foot/acre. Although this reduction in water use has not had a noticeable influence on reducing groundwater declines in the Priest Rapids aquifer, conservation could play a significant role in maintaining aquifer levels if aquifer commingling is remediated. This is particularly relevant for the Pomona aquifer if used in the future for irrigation supply since historical data indicate that the Pomona is vulnerable to over-pumping.	None. Irrigation and monitoring technologies are well developed and have been implemented in the Mosier Basin for over a decade.	Approximately $1,000/acre	Minimal	**Advantages:** • Potential to achieve minor reduction in withdrawals, which would reduce net stream losses to aquifer; however, benefits likely minor unless aquifer commingling is remediated. Conservation measures may be particularly beneficial for users of the Pomona aquifer. **Disadvantages** • None.

Table 5-5. Numerical Ranking of Aquifer Recovery Alternatives

Aquifer Recovery Strategy		Physical Feasibility: Hydrogeology	Physical Feasibility: Potential Effectiveness	Physical Feasibility: Key Uncertainties	Physical Feasibility: Average	Physical Feasibility: Weighted Average (WF = 1.5)*	Costs	Environmental and Ecological Impacts	Total Numerical Rating
Aquifer Recharge	***Surface Recharge***	2	1	1	1.3	**2**	2	3	7
	Direct Well Recharge	3	1	2	2	**3**	1	3	7
Commingling Well Repair/Replacement		3	3	3	3	**4.5**	1**	3	8.5
Commingling Well Remediation and Aquifer Recharge		3	3	2	2.7	**4.1**	1	3	8.1
Conservation		NA	0***	3	NA	**0*** **	2	3	NA – Demonstrated Not Effective

Notes:

Ranking System

0 = Fatal Flaw

1 = unsuitable or significant uncertainty

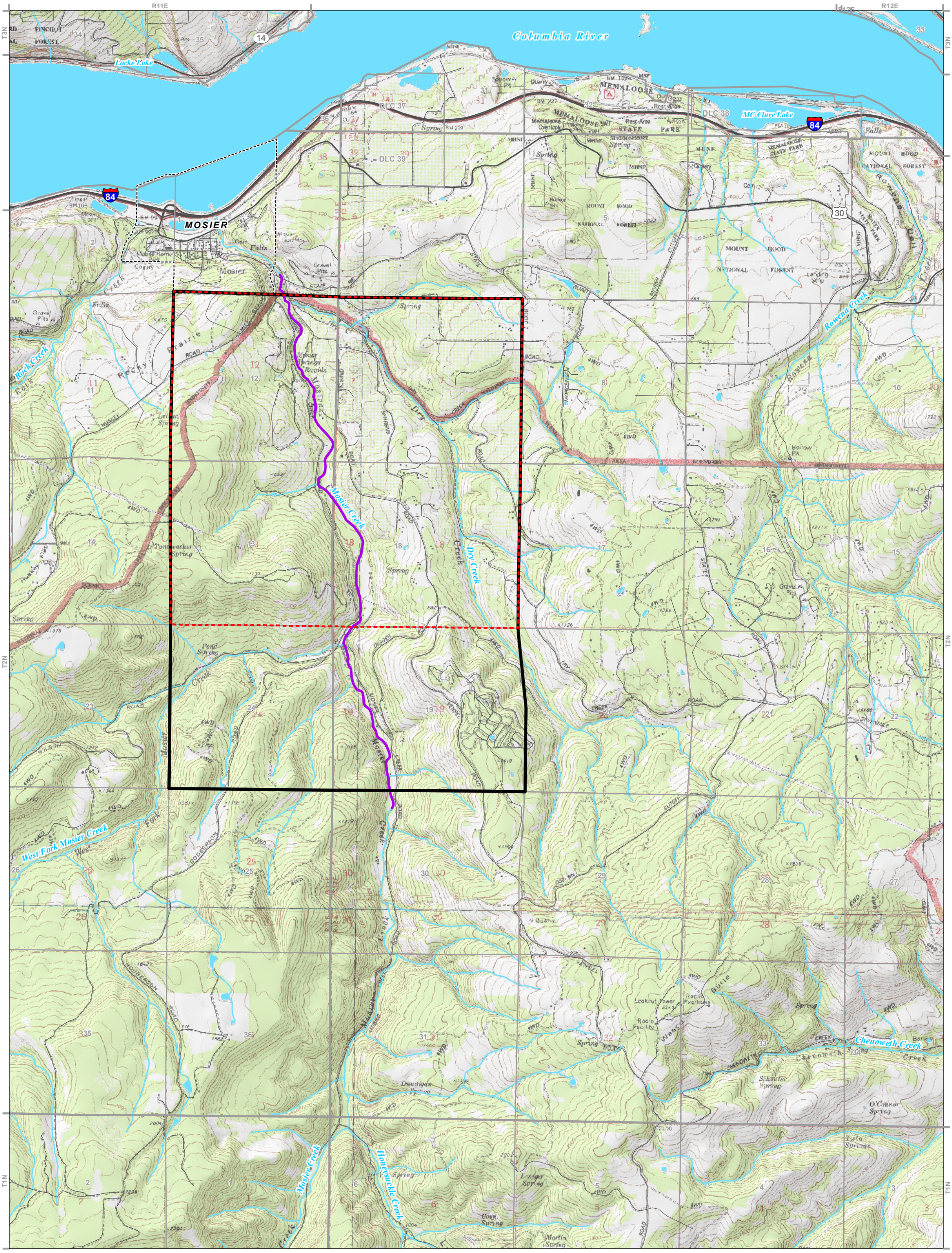
2 = somewhat suitable or moderate uncertainty

3 = suitable or minimal uncertainty

* Weighting factor of 1.5 applied to physical feasibility (fatal flaw) average because the physical feasibility criteria define whether any fatal flaws exist

**Cost ranking based on total estimate cost to repair/replace majority of commingling wells in Orchard Tract. Potentially significant benefit to repairing select wells for much less cost

***Conservation measures largely implemented among irrigators without noticeable effects on water level declines



LEGEND

- Aquifer Recharge Focus Area
- Area Considered for Well Recharge and Commingling Well Repair
- Reach of Mosier Creek for Potential Diversion

All Other Data

- Cities
- Highways
- Roads
- Watercourses
- Waterbodies

FIGURE 5-1

Aquifer Recovery Focus Area

Wasco SWCD: Mosier Aquifer Recovery Feasibility Study

N

0 1,500 3,000 4,500

Feet

GSI Water Solutions, Inc.

MAP NOTES:

Date: April 5, 2011

Data Sources: DOGAMI, USGS, OGIC, ESRI

File Path: P:\Portland\397-Wasco_Cty_SWCD\001-Mosier_AR_Feas_Study\Project_GIS\Project_mxds\FigureX_Project_Focus_Area_topo.mxd, Date: January 28, 2011 11:39:32 AM

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