PACIFIC groundwater GROUP

Aquifer Recharge Feasibility Study for the Dungeness Peninsula

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1 INTRODUCTION

This study evaluates the feasibility of performing aquifer recharge (AR) and aquifer storage and recovery (ASR) on the Dungeness Peninsula in Clallam County, Washington. The study area, shown on **Figure 1-1**, is within Water Resource Inventory Area (WRIA) 18. Groundwater availability and stream baseflows within the study area have been significantly affected by human activities. Irrigation diversions from the Dungeness River began in the late 19th century, and have reduced irrigation-season baseflows in the river. Groundwater recharge from leaky irrigation ditches has increased groundwater occurrence and the ability of the uppermost ("shallow") aquifer to support baseflows in small streams and saturation in groundwater-supported wetlands. More recently, movements towards restoring summer flows in the Dungeness River by irrigation conservation (such as piping of irrigation ditches to reduce river diversions) has led to reduced groundwater recharge and has likely caused some decline in groundwater levels. While the reduced diversions have benefited Dungeness River streamflows overall, the associated groundwater level declines have likely caused minor reductions in river baseflow during some portions of the year. In addition, population growth and increased consumption of groundwater for residential/ commercial uses has further stressed study-area aquifers and contributed to the observed declines (PGG, 2002). As many of the small streams and river tributaries are fed by groundwater, groundwater level declines will ultimately cause baseflow reductions below the historic rates from times of open (leaky) irrigation ditches and lower population density.[1]

The Dungeness River Management Team (DRMT) and the Technical Advisory Group (TAG) formed for Artificial Recharge studies by the County have long discussed the possibility of maintaining the benefits of irrigation conservation on Dungeness River flows while considering the shallow groundwater system and associated surface-water features. AR and ASR are strategies discussed for diverting a portion of flow in the Dungeness River during periods of relative availability and re-directing this water to the groundwater system. This additional recharge could support baseflows in the Dungeness River during other times of the year as subsurface "return flow", could support baseflows in small streams and water levels in wetlands year-round, and could offset groundwater level declines due to ditch piping and increased well withdrawals. Dungeness River diversions for AR/ASR would likely be limited to periods when instream flow (ISF) rule requirements are met. ISF recommendations in the 2005 Elwha/ Dungeness Watershed Plan are currently under discussion in the instream flow and water management rule-making process for the Dungeness watershed planning area. The preliminary draft rule (under development) proposes closure of the Dungeness mainstem to new unmitigated withdrawals from July 15th until November 15th. Aquifer recharge projects could access flows higher than the adopted instream flow levels from November 16 through July 15 under the rule's provisions. In addition, AR could be sourced with reclaimed water which is currently generated

[1] It is beyond the scope of this study to evaluate whether reduced diversions from the Dungeness River outside the irrigation season (i.e. during fall low flows) are significantly offset by reduced subsurface returns originating from leaky irrigation ditches or other unconsumed irrigation water.

by the City of Sequim and may be generated in the Carlsborg area by the Clallam PUD in the near future.

The DRMT and TAG have pursued studies and tools to assess the effectiveness of AR and ASR. A groundwater model commissioned in 2001 to assess effects of irrigation conservation and efficiency measures on the Dungeness system was previously used to perform preliminary evaluation of AR scenarios as part of watershed planning (TTFW, 2003). As preparation for this feasibility study (FS), the "2003 groundwater flow model" was reviewed, updated, refined and renamed as the "2008 groundwater flow model" (PGG, 2009). The latter model was used under this project to evaluate 14 scenarios for AR/ASR on the Dungeness Peninsula, three of which were selected for detailed analysis in this FS by the TAG in October 2008.

While properly designed AR/ASR projects can benefit the hydrologic system as described above, the magnitude of these benefits must justify the financial and environmental costs. In addition to estimating the hydrologic effects of the three preferred AR/ASR scenarios, this FS addresses water-quality, habitat, engineering, financial, permitting, and monitoring considerations.

1.1 Objectives for AR/ASR on the Dungeness Peninsula

Design, construction, operation and maintenance of an AR/ASR project can require a substantial financial investment. It is important to define both the objectives of AR/ASR and the value of meeting those objectives. On February 6, 2008, the TAG defined the following main objectives for an AR/ASR project, without prioritizing them:

- Improve Dungeness Low Flows (including some benefit to side channels)
- Support Small Streams & Wetlands
- Provide for or mitigate new water development in place of exempt wells
- Reduce potential for seawater intrusion

Many stakeholders agree that improvement of Dungeness River streamflow is a top priority objective. The Public Utility District No. 1 of Clallam County expressed interest in using AR/ASR as mitigation for various future public water-supply strategies. The Jamestown S'Klallam Tribe expressed interest in studying whether AR/ASR is a feasible option for water supply either in place of or to provide mitigation for new exempt wells.

1.2 Project Description and Associated Deliverables

In late 2006 Clallam County hired Pacific Groundwater Group (PGG) and its consultant team to perform this AR/ASR feasibility study. PGG's team includes: R2 Resource Consultants (R2) for their expertise in Dungeness River habitat; Anchor Environmental (now Anchor QEA [AQ]) (AE) for their expertise in Dungeness Peninsula irrigation, ditch losses; Brown & Caldwell (BC) for their expertise in design/construction of infiltration facilities; and GSI Water Solutions (GSI) for their expertise in design/construction of aquifer storage and recovery facilities.

The project included the following major tasks:

- Peer review of the 2003 Groundwater Flow Model (ESI, 2007, including PGG, 2007a);
- Evaluation of effects on habitat from baseflow changes associated with AR/ASR diversions;
- Assistance with site-selection, design, implementation and interpretation of AR infiltration pilot tests by AQ and PGG;
- Evaluation of "preliminary considerations" for selection of AR/ASR scenarios (PGG, GSI and BC) and assisting the TAG in selecting scenarios to be evaluated with the updated model;
- Supplementary hydrogeologic investigations and model refinement for development of the 2008 Groundwater Flow Model;
- Calibration of the 2008 Groundwater Flow Model;
- Model simulation of AR/ASR scenarios;
- Model training for project partners; and,
- Preparation of this feasibility study.

Associated project deliverables include:

- Dungeness River Aquifer Recharge Habitat Technical Memorandum (Presentation on April 25, 2007 and R2 Resources memorandum dated May 31, 2007);
- Groundwater Considerations for Carlsborg Pilot Test Design (PGG memorandum dated March 4, 2007 and presentation on March 23, 2007);
- Operations Plan for Ditch Recharge (AQ memorandum dated May 11, 2007);
- Hydrogeologic Screening for Sequim Pilot Infiltration Test (PGG memorandum dated August 21, 2007 and phone participation at TAG meeting on August 29, 2007);
- Assessment of Baseflow in Small Streams of the Dungeness Watershed (TAG workshop on January 4, 2008 and PGG memorandum dated January 14, 2008);
- Preliminary Considerations for Aquifer Recharge (PGG/BC/GSI memorandum dated January 30, 2008 and presentation on February 6, 2008);
- PGG presentation on design and calibration of 2008 Groundwater Model (September 16, 2008);
- PGG presentation on results of first group of predictive model scenarios (October 8, 2008);
- PGG/AQ/BC/GSI presentation on results of second group of predictive model scenarios and scenario selection for feasibility study (October 22, 2008);
- PGG/AQ technical input regarding interpretation of pilot infiltration testing from the Jakeway and ODT ditches, incorporated into technical summary by Clallam County (2009);

- PGG documentation of the groundwater flow model (PGG, 2009) and model training (provided January 15, 2009); and,
- PGG/AQ/BC/GSI/R2 draft and final versions of this feasibility study.

1.3 AR/ASR Scenarios Considered

PGG worked with the TAG to identify preferred AR/ASR scenarios for the FS during the course of several presentations. During the "Preliminary Considerations" presentation, in February 2008, TAG members identified several sites of interest for model simulation of AR. After PGG presented the results of this first group of model scenarios (October 8, 2008), the TAG identified other AR and ASR scenarios of interest. The results of this second group of scenarios were presented on October 22, 2008 and at this time the TAG selected preferred scenarios for the FS. Over the subsequent several weeks, PGG worked with Clallam County to adjust these scenarios based on input from stakeholders and supplemental hydrogeologic screening. The final three FS scenarios are described below, and associated sites are shown on **Figure 1-1**. A summary of the three scenarios and their intended benefits is provided on **Table 1-1**.

Scenario A - Infiltration of Dungeness River water west of the Dungeness River

In this scenario, water available from the Dungeness River would be conveyed via piped irrigation ditches to two abandoned ditch reaches. The ditches would be maintained to facilitate infiltration to the underlying shallow aquifer. Water would be available for AR on a seasonal basis subject to instream flow requirements and available capacity in the irrigation lines. The most reliable period of availability occurs during the spring snowmelt ("freshet"), which typically ranges from May 15 through July 15. Water may also be available during the preceding winter months (e.g. November through May); however, winter runoff events are episodic rather than continuous and prolonged. Scenario A assumes 2-month availability of 2 to 10 cfs during the freshet months. In addition, Scenario A explores a hypothetical situation in which streamflow is also made available for diversion during the 4 months preceding the freshet in order to perform AR for 6 months (January 15 through July 15) and thereby increase augmentation during the late-summer period of low Dungeness River baseflow.

Scenario B - Infiltration of reclaimed water east of the Dungeness River

In this scenario, reclaimed water would be recharged in infiltration basins. Water would be piped from the City of Sequim treatment plant to a location outside (northwest of) the city limits. The City plans to generate as much as 2.0 mgd (3.1 cfs) of reclaimed water annually (Gray & Osborne, 2007), but would likely allocate at least part of this water for irrigation during the growing season (May through September). This feasibility scenario assumes that reclaimed water would be available for infiltration eight months per year (October through May) at a maximum rate of 3.1 cfs[2].

[2] During model simulation of FS scenarios, information from the City indicated a maximum generation of 3.1 cfs.

A specific site has not yet been identified for this scenario; however, a general area with the potential for supporting one or more sites has been considered. The City of Sequim plans to consider other sites, located within the city limits, under a separate study being performed directly for the City.

Scenario C – Aquifer storage and recovery west of the Dungeness River

In this scenario, water available from the Dungeness River would be extracted from shallow wells adjacent to the river (thus obtaining "bank filtration" through the alluvial sediments) and injected and recovered from either the lower aquifer or aquifer materials encountered in the undifferentiated deposits (heretofore called the "deep aquifer"). (A conceptual illustration of aquifers and aquitards beneath the Sequim-Dungeness Peninsula is presented in **Figure 1-2.**) About 2 cfs of Dungeness River water is assumed available for ASR injection during the spring freshet (May 15 – July 15). Recovery could occur immediately after the injection period during the peak demand season (July 15 – September 15) or could be distributed outside the freshet period according to demand[3]. Because suitable sites have not been identified for this scenario, the FS addresses the scenario in general terms.

1.4 Organization of this Report

An executive summary of FS findings and recommendations is presented in Section 2. Sections 3 through 5 describe scenarios A through C (respectively), and address the conceptual project designs, hydrogeologic settings, AR/ASR sources, fate of AR/ASR water, environmental impacts (including water quality and habitat), engineering/design considerations, permitting considerations, project implementation (tasks, schedule, costs), and overall summaries of project costs, benefits and concerns. Section 6 discusses how the lessons learned from evaluation of FS scenarios A through C and modeling simulations for other locations can be applied to alternative sites for AR/ASR. Section 7 discusses new water supply development and compares how various AR/ASR strategies can be used to mitigate associated hydrologic impacts. Section 8 discusses financing options for AR/ASR projects, and Section 9 provides recommendations for selecting AR/ASR projects, further studies, and funding opportunities. References are presented in Section 10, and a glossary of key terms is presented in Section 11.

1.5 Authorization and Warrantee

This project is funded under grant number G0600342, issued to Clallam County by Washington Department of Ecology (Ecology). PGG and its consultant team were authorized to perform the work discussed above (Section 1.2) by Clallam County under the following contracts and amendments: 53118-06-PGG, 100511-06-PGG, 100511-06-PGG, 100511-07-PGG, 100511-06-PGG2-Amend 1, 100511-06-PGG2-Amend2, and 100511-06-PGG2-Amend3.

[3] If the net impact of the ASR operation caused streamflow depletion during portions of the year, mitigation would be required. Net depletion could be avoided by reducing recovery volumes relative to injection volumes.

This work was performed, our findings obtained, and this report prepared, using generally accepted hydrogeologic practices used at this time and in this vicinity, for exclusive application to this feasibility study, and for the exclusive use of Clallam County and Ecology. This is in lieu of other warranties, express or implied.

1.6 Acknowledgements

This project was performed based on significant participation from the TAG, as listed below:

Clallam County	Ann Soule, Andy Brastad
WA Dept. of Ecology	Cynthia Nelson, Dave Nazy, John Pearch
Jamestown S'Klallam Tribe	Shawn Hines, Scott Chitwood
City of Sequim	Frank Needham
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[Volunteer]	Mark Hannah
Note taker	Debra Danielson

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2 EXECUTIVE SUMMARY

The following bullets provide a broad overview of the findings of this feasibility study (FS) for aquifer recharge in the Dungeness watershed:

1. After consideration of modeling and pilot test results as well as comprehensive input from water supply/storage professionals, three scenarios were selected by the project Technical Advisory Group (TAG) and evaluated for feasibility:

   A) Aquifer recharge (AR) of Dungeness River water to the shallow aquifer via abandoned leaky irrigation ditches on the west side of the river;

   B) AR of Class A reclaimed water to the shallow aquifer via an infiltration basin to be constructed on the east side of the river; and

   C) Aquifer storage and recovery (ASR) through injection of Dungeness River water into a well to be constructed in the lower or deep aquifer on the west side of the river.

2. FS scenarios can be compared based on key elements of the feasibility evaluation: effects on streamflow; effects on habitat; project cost and project risk.

3. Estimated costs for implementation of the FS scenarios cover a wide range. Scenario A (AR through leaky ditches) is least expensive, costing between $137,000 to $155,000 in fixed costs and about $15,000 per year for operation and maintenance (O&M). Scenario B (AR of reclaimed water) has an estimated capital cost of $4,100,000 to $8,300,000, and an O&M cost of $60,000 to $70,000 annually. Relative to Scenario B, Scenario C (ASR) has a (smaller) estimated capital cost of $2,600,000 to $5,700,000 but a (larger) estimated O&M cost of $120,000 to 200,000 annually.

4. The 2008 Dungeness Groundwater Flow Model (PGG, 2009) was used to estimate effects on flows in the Dungeness River and small streams associated with the three scenarios. Model predictions should be considered approximate, and have some degree of uncertainty, but should provide reasonable estimates of the magnitude of effects on flow. AR scenarios A and B are predicted to provide maximum Dungeness River flow augmentation on the order of several cfs[4]. Scenario B is also predicted to provide between 0.3 and 0.6 cfs flow augmentation to both Cassalery and Gierin Creeks. Scenario C is predicted to provide both flow augmentation and depletion, associated with the injection and recovery phases of ASR. Streamflow impacts predicted for ASR are more uncertain because the hydraulic connection between shallow and deep portions of the groundwater flow system is less well understood. Predicted impacts of ASR on the Dungeness River generally range from +0.13 to –0.08 cfs; although a "sensitivity analysis" model run suggested an "upper limit" ranging from +0.4 to -0.3 cfs. Significantly smaller effects are predicted for the small streams. During periods of Dungeness River diversion under Scenarios A and C, rates of diversion generally

[4] Measurement accuracy of streamflow gauges range from +/- 5 to 10 percent. Dungeness River low flows are typically on the order of 100 cfs. Hence streamflow augmentation (or depletion) of less than 5 to 10 cfs would not be accurately measured.

overshadow augmentation achieved by the AR/ASR activity. However, diversions are expected to occur during periods of high flow (e.g. spring freshet).

5. Dungeness River flow augmentations associated with the three scenarios individually provide non-measurable benefit to stream habitat. Multiple or larger (and carefully sited) AR projects would likely be needed to achieve measurable benefit to Dungeness River habitat. Benefits to some small streams associated with Scenario B could be significant, due to the already low baseflows observed in these streams.

6. AR (Scenarios A and B) may also be suitable as mitigation to offset effects of new groundwater development in deeper aquifers, as deep pumping has a reduced effect on streamflows, and AR to the shallow aquifer can efficiently deliver water to streams. ASR (Scenario C) is inherently more oriented towards new water-supply development, and has significantly smaller streamflow capture than conventional groundwater withdrawals (i.e. without associated injection/storage). Mitigation of streamflow capture from any groundwater withdrawal (including ASR) may face the challenging task of offsetting flow impacts on multiple streams.

The following bullets summarize the findings of each AR/ASR scenario:

7. Scenario A: Recharge of Dungeness River water in abandoned irrigation ditches provides the most benefit per unit cost and has a relatively high likelihood of success, provided that water can be supplied either through existing conveyances.

    a. Source water availability would likely be limited to 2 months per year during the spring freshet. Although a scenario was considered where river water is diverted for 6 months per year, such a scenario would require a special water right or would need to be sourced by a legal transfer of existing water rights senior to instream flow requirements. Current rule-making proposes specific quantities of water above instream flow levels for allocation to storage and environmentally beneficial projects. A new water right issued subject to instream flow levels being met would be interruptible and not a reliable source of supply[5].

    b. Source water would be delivered to the site using irrigation pipes operated by the Clallam Ditch Company and Cline Irrigation District. No quantity for excess pipe capacity has been established to deliver the source water during periods of availability, and use of the pipes would require the cooperation of the District.

    c. The proposed infiltration site has an estimated maximum capacity of 5 to 7 cfs. Aquifer recharge (AR) at a rate of 7 cfs over 2 months is predicted to provide between 0.2 to 3.1 cfs flow augmentation to the Dungeness River, about 0.01 to 0.2 cfs augmentation to Matriotti Creek, and insignificant amounts of augmentation to small streams within the study area. During the September-October low flows, this schedule of AR infiltration is predicted to provide between 0.7 to 1.6 cfs

[5] Although a request could conceivably be made to Ecology for a new water right based on overriding considerations of the public interest (OCPI), this is not currently contemplated in the rule.

augmentation to the Dungeness River and about 0.1 cfs augmentation to Matriotti Creek[6].

d. If 7 cfs were infiltrated over a 6-month period (mid-January thru mid-July) at the project site, predicted Dungeness River augmentation would increase to between 0.7 and 4.7 cfs (1.4 to 2.8 cfs during the low-flow season) and predicted Matriotti Creek augmentation would increase to between 0.1 to 0.4 cfs (about 0.2 cfs during the low-flow season).

e. During periods of diversion for AR the Dungeness River would experience reduced flows. Rates of augmentation via subsurface return flows are insufficient to fully offset rates of diversion, and the subsurface return flows enter the River downstream of point of diversion.

f. While the AR operation would *increase* Dungeness River flow *outside* periods of diversion for AR, associated changes in habitat are considered to be small and likely non-measurable. For instance, the 2-month diversion scenario is estimated to provide about 2 percent increase in Chinook salmon spawning WUA (weighted usable area) during the fall low-flow period, and the 6-month diversion option is estimated to provide about a 3 percent increase in WUA. Measurable changes to habitat are estimated to be on the order of 10 percent of WUA.

g. The habitat impacts of reduced streamflows due to diversions during the spring freshet are also non-measurable, but occur in the direction of habitat improvement. Similarly, if the AR source water were diverted in winter months *during high-flow events,* some minor habitat improvement is expected. However, qualitative assessment of habitat impacts from diversions during periods of winter baseflow suggests that the impacts are more likely to be adverse.

h. Development of the AR Scenario A is expected to cost about $137,000 to $155,000 and require less than a year to put into operation (barring delayed water rights negotiations and conveyance arrangements with irrigation entities). Once developed, ongoing costs are approximately $15,000 per year for the 2-month infiltration scenario.

i. Concerns associated with Scenario A are primarily related to source availability. Conveyance of the AR water requires cooperation and agreements with the irrigators, and it is not yet clear whether their pipes can accommodate delivery of AR water during the spring freshet. In addition, the impacts of climate change on the timing and magnitude of the freshet could influence source availability as instream flow requirements must be met before flows are available for new water rights.

8. Scenario B: Surface infiltration of Class A reclaimed water has a good likelihood for success, either within the area considered under this scenario or at other sites to be

[6] As indicated in the main body of this report, Matriotti Creek predictions have some additional degree of uncertainty due to complex hydrogeologic conditions along the creek.

considered by the City of Sequim or the Clallam PUD. Scenario B is more costly than Scenario A because it requires construction of a new infiltration facility, additional or new conveyance, and because management of reclaimed water requires more monitoring, permitting and overall attention.

a. Under hypothetical Scenario B, source water would be obtained from the City of Sequim's Class A treatment facility. The City will soon be investigating other alternatives for using a portion of its Class A water for aquifer recharge. The efficacy of AR in the area considered under Scenario B will likely be compared to the efficacy offered by sites in other areas, and the City will decide which location(s) best meet its recharge objectives (if any). The area considered for Scenario B would require construction of about 2 to 3 miles of piped conveyance from the terminus of the City's existing reclaimed water line.

b. Scenario B assumes that the Class A reclaimed water would be available 8 months out of the year (October through May), and that the City would find other uses for most of its reclaimed water during the irrigation season (June through September). The scenario assumes a maximum source availability of 3.1 cfs.

c. Scenario B specified a general area where AR activities would occur (northwest of downtown Sequim), but did not specify a unique site. A preliminary review of hydrogeologic conditions in the area under consideration suggests hydrogeologic variability and notes that some sites may be incapable of infiltrating the targeted recharge rate (3.1 cfs). Field investigation would need to be performed to look for an adequate site, and more than one facility may be required to infiltrate the desired recharge rate.

d. AR within the area selected for Scenario B is predicted to enhance streamflows in the Dungeness River, Cassalery Creek, and Gierin Creek. Model simulations from an arbitrary location within this area suggest that Dungeness River baseflows could be augmented by between 0.7 and 1.1 cfs, baseflows in Cassalery Creek could be enhanced by between 0.3 and 0.5 cfs, and Gierin Creek could be enhanced by between 0.5 to 0.6 cfs. Seasonal variations are relatively minor, with maximum enhancement generally predicted to occur in July and August. The distribution of augmentation among streams is dependent on the ultimate location in which AR is conducted.

e. Habitat evaluation suggests that the year-round augmentation of Dungeness River flows would cause minor and non-measurable changes in habitat (e.g. about 1 percent increase in Chinook salmon spawning WUA), but could cause significant benefits to habitat in Cassalery Creek (due to about 50 percent of predicted baseflow increase compared to recorded low flows) and to Gierin Creek (due to between 25 percent and 50 percent of predicted increased baseflow compared to recorded low flows).

f. Scenario B capital costs are estimated to range between $4,000,000 and $8,300,000 depending upon the number of sites characterized for selection, the scale of investigations required on each characterized site, the infiltration capacity encountered at the final site (thus affecting the site size), and how the site location affects the required length of transmission pipe. Operating costs are expected to be on the order of $60,000 to $70,000 per year. The project is expected to require about 2 years to complete pilot testing and design and an additional year for construction.

g. Although performing AR with reclaimed water is relatively insensitive to climate change, the main concern about source availability would be if new uses are developed for the reclaimed water. Use of reclaimed water is a highly regulated program and subject to changing rules; changing regulations could increase future operating and capital costs. Recent attention has focused on water quality considerations associated with anthropogenic residual compounds (e.g. personal care products and pharmaceuticals).

9. Scenario C: ASR on the west side of the Dungeness River is oriented to developing a new source of water supply, but may also result in augmented streamflows. Scenario C is the most costly of the three scenarios and has the highest risk of incurring significant additional costs to achieve success.

    a. The source for ASR would be Dungeness River water diverted over approximately 2 months per year during the spring freshet. A diversion quantity of 2 cfs was assumed, and is likely consistent with aquifer properties for injection under best-case conditions. The Dungeness River can exhibit high turbidity during periods of high flow, and some means of filtration is required to prevent clogging of ASR wells during injection. Riverbank filtration (RBF) would use wells or trenches along the Dungeness River to achieve natural filtration, and is the most cost effective technique. However, sediments along the Dungeness River may prove to be too coarse to sufficiently filter out turbidity, and zones of clay-bound sediments may require over-sized RBF facilities. If RBF does not provide sufficient filtration, more expensive above-ground technologies would be required.

    b. Two ASR target aquifers were considered. A *limited* review of the small number of well logs from the "lower aquifer" west of the Dungeness area did not reveal very promising locations, although 2 cfs of ASR might be accommodated with multiple wells, and other (unexplored) aquifer locations might exhibit sufficient ASR capacity. The "deep aquifer" was encountered in several wells and suggested potentially better ASR capacity. The geographic occurrence and ASR capacity distribution is not well known for either aquifer. Exploratory drilling would be needed to identify suitable sites for ASR.

    c. The 2008 groundwater flow model was used to simulate the effects of ASR operations on the Dungeness River and small streams. ASR injection was assumed to occur for 2 months during the spring freshet, and ASR recovery was assumed to occur for 2 months soon thereafter to provide a source of peaking supply. Both injection and recovery were assumed to occur at an arbitrary location west of the Dungeness River. Because there is less confidence that the model accurately characterizes the degree of hydraulic connection between the shallow and deep portions of the groundwater flow system (PGG, 2009), a series of model scenarios were run to estimate effects on streamflows over a range of uncertainty, and model results for Scenario C should be considered preliminary.

d. The injection/recovery cycle inherent in ASR is predicted to cause periods of both streamflow augmentation and streamflow depletion. PGG has the most confidence in model runs that predict impacts to the Dungeness River ranging from +0.05 to -0.03 cfs and +0.13 to –0.08 cfs; and a "sensitivity analysis" run suggested an "upper limit" ranging from +0.4 to -0.3 cfs. Predicted impacts to small streams are considerably smaller, but are spread out among multiple streams. Note that if ASR were used to generate new water supply, then the associated additional wastewater (if treated to Class A standards and recharged into the shallow aquifer) would likely be sufficient to offset the magnitude of predicted seasonal streamflow depletion. Because ASR withdrawals from the deeper aquifers tend to cause a wide distribution of (relatively small) impacts to streams, distributing the reclaimed water for mitigation purposes may prove challenging.

e. Development of the AR Scenario C is expected to cost between approximately \$2,600,000 and \$5,700,000 and require about 2.5 years to put into operation under pilot conditions and up to 5 additional years of running under pilot operation. Costs may increase if additional filtration of water from the RBF facility is required. Once developed, ongoing costs are approximately \$135,000 to \$200,000 per year.

f. The main concerns identified for Scenario C include hydrogeologic uncertainties (number of sites to be investigated, number of RBF facilities and ASR wells, ASR well depths and potential need for RBF filtration to remove turbidity) and possible changes in source availability due to climate change (earlier, shorter and lower-volume spring freshet). Because subsurface explorations (wells) are more costly than surface explorations (infiltration basins and ditches), and because subsurface conditions are less well known, Scenario C poses more risk for budget overruns than Scenarios A and B.

The following bullets present findings from supplemental analysis provided in this FS:

10. Although this FS evaluates how AR would be conducted for only two alternatives (A & B), elements of the evaluations can be applied to consideration of other AR sites. Conversely, simulation of 11 AR sites during model development suggested that site location relative to the Dungeness River and other small streams can have a significant impact on the geographic distribution and timing of streamflow augmentation associated with AR.

11. New water-supply development could make use of a variety of AR approaches to offset associated impacts to streams. This FS compared several water-supply strategies using AR for mitigation, with the following findings:

    a. For all strategies, providing streamflow augmentation that matches the geographic distribution of streamflow depletion may be difficult to achieve. Mitigation requirements will depend on the streamflow protections adopted during rulemaking. Mitigation sources, whether from the river (during the spring freshet) or from Class A reclaimed wastewater, have some potential for interruption or changes in availability.

b. Among the five water-supply strategies considered, the least expensive likely include: 1) conventional withdrawals with mitigation from river water, 2) conventional withdrawals with mitigation from reclaimed water, and 3) ASR with mitigation from river water; and the most expensive likely include: 4) conventional withdrawals with mitigation from reclaimed water and a newly constructed river-water infiltration facility, and 5) ASR with mitigation from reclaimed water. While not performed in this FS, ultimately, all strategies should be considered on a cost-per-gallon basis.

c. Mitigation of conventional groundwater withdrawals with reclaimed water may be insufficient to offset streamflow depletion (depending on the source aquifer), and could require supplemental mitigation with river water. Mitigation with river water alone could be feasible if the rate of withdrawal was sufficiently small relative to the available rate of river-water infiltration during the freshet. Additional model calibration focusing on deeper portions of the groundwater flow system would be valuable towards providing better predictions of streamflow depletion associated with pumping in the middle, lower and deep aquifers – and thereby improving estimates of mitigation requirements.

d. New water-supply development from ASR is typically limited to the source quantity available for injection and the system capacity for injection/recovery. The ASR approach also requires more investment for hydrogeologic characterization, site selection, and overcoming technical obstacles such as turbidity in the source water. Mitigation of seasonal ASR streamflow capture with infiltration of the reclaimed water generated by ASR-enabled residential development might provide excess mitigation due to ASR (deep) withdrawal's relatively low percentage of streamflow capture. Mitigating ASR with infiltration of river water may be sufficient if streamflow depletion associated with recovery pumping is relatively small and does not exceed the quantity of river water available for mitigation.

3 SCENARIO A: DUNGENESS RIVER AR IN ABANDONED IRRIGATION DITCHES WEST OF DUNGENESS RIVER

3.1 Conceptual Project Design

Clallam County has performed pilot infiltration tests on two abandoned irrigation ditches located west of the Dungeness River. **Figure 3-1** shows the two ditch sites, labeled as Jakeway (#1) and Olympic Discovery Trail NW (#2). The Jakeway site provides approximately 2,650 feet of ditch in which to infiltrate water and the Olympic Discovery Trail (ODT) site provides approximately 1,600 feet. PGG performed an initial evaluation of the two sites prior to pilot testing (PGG, 2009b) and AQ provided an operations plan for implementing the pilot test. More recently PGG and AQ, together with the County, analyzed the infiltration test results (Clallam County et al, 2009). PGG and AQ estimate that the entire 4,250 feet of ditch should be able to infiltrate approximately 2.5 cfs under current conditions, and that further conditioning of the ditch bottoms and installation of additional check dams in the ditches could increase the infiltration rate to as much as 7 cfs.

Water would be sourced from the Dungeness River during the spring freshet, when available as per instream flows requirements, and conveyed to the infiltration ditches via existing irrigation pipes operated by the Clallam Ditch Company and the Cline Irrigation District. The Clallam-Cline irrigation system main line consists of 24-inch and 27-inch PVC pipe with capacity to convey approximately 15 cfs from the Dungeness River to the proposed recharge sites. During the irrigation season (April 15 – September 15), most of that capacity is used to convey water from the Dungeness River to water users for irrigation.

PGG used the 2008 Dungeness groundwater model (PGG, 2009) to analyze two scenarios at these sites. In the first scenario water from the spring freshet was available for AR for 2 months out of the year (May 15 – July 15). The 2-month period of AR would be followed by a 10-month period without AR (heretofore called the "period of dormancy"). In the second scenario, water was assumed available for 6 continuous months, including a portion of the winter (January 15 – July 15). The second scenario is purely hypothetical at this time. A continuous winter diversion would likely violate instream flow requirements because winter flows typically exceed ISF requirements only during isolated runoff events. However, the TAG agreed to consider this scenario to assess how it might improve augmentation during lowest (late summer) flows in the Dungeness River.

3.2 Hydrogeologic Setting of Project Sites

PGG evaluated surficial soils in the vicinity of the sites as mapped by the NRCS (PGG, 2007b). **Figure 3-1** shows that the Jakeway site is underlain by Carlsborg gravelly sandy loam. This soil occurs on alluvial terraces and fans, is derived from alluvium, is somewhat excessively drained, and is highly permeable. The hydraulic conductivity of the most restrictive layer (uppermost 9 inches) is estimated to be 4 -12 feet/day, and the hydraulic conductivity of deeper soils within a typical 5-foot profile is estimated to range from 12-40 feet/day. Due to its coarse texture, the Carlsborg gravelly sandy loam has very low moisture storage potential ("available water capacity"). Whereas sand and gravel are common components of this soil type, silt is not reported in significant quantities.

Figure 3-1 shows that the ODT site is partially underlain by Carlsborg gravelly sandy loam and partially underlain by Dungeness silt loam. The Dungeness silt loam is similarly derived from alluvium, is well drained, but has a slightly lower hydraulic conductivity throughout the soil profile (1.1 – 4 feet/day). As it has a higher silt content, it tends to store more moisture and is considered to have a moderate available water capacity.

Surficial geology has been mapped by WDNR (Schasse & Wegmann, 2000), and is shown as Quaternary alluvium (Qa) under both ditch sites. Qa is described as follows (ibid):

> "Qa - Alluvium(Holocene) – Generally well stratified and well sorted deposits of rounded, cobble and pebble gravel, sandy gravel, gravelly sand, silt, clay and peat; brown to gray, depending on composition and weathering; deposited in and along present streams. Cobbly sands, silts and clays are deposited in a flood plain environment. Grain size varies both laterally and vertically due to stream migration. Thickness of alluvium varies; a maximum thickness of 40 ft was estimated from water-well data collected from the Dungeness River flood pain. Unit Qa overlies older alluvium (unit Qoa), Vashon glaciomarine drift (unit Qgdm), recessional outwash deposits (unit Qgo), and ice-contact deposits (unit Qgo_i) in the lower alluvial valley of the Dungeness River… The Dungeness has migrated over time, leaving behind alluvial terraces that mark previous higher flood plains."

PGG reviewed 104 drillers' logs obtained from the Ecology website for the immediate vicinity of the Jakeway and ODT sites (PGG, 2007b). Most of the wells are shallower than 75 feet and are completed in the shallow unconfined aquifer defined by the USGS (Thomas et al, 1999). Wells in the area are predominantly shallow because sufficient well yield can be achieved for domestic purposes from the unconfined aquifer in this vicinity. The distribution of well yields reported from testing performed by drillers shows that most wells can provide between 20-60 gallons per minute (gpm).

PGG's review of the local well logs suggests a relatively high-energy alluvial environment of deposition, as evidenced by the common occurrence of gravels and cobbles. However, these coarse-grained sediments often occur in a fine-grained matrix typically described by drillers as clay. A 75-foot well log will typically penetrate zones of clay-bound (or more likely silt-bound) gravels and cobbles alternating with clean sand, gravels and cobbles. Finer-grained zones of clay, silt and silty sand are noted, but are less common in this environment. Drillers sometimes report cementation of the sediments, which may lead to the description of "hardpan".

For wells not otherwise studied by the County or other agencies, PGG did not attempt to locate logs beyond their reported quarter-quarter (QQ) section; however, QQ-section groupings did not reveal consistent depths to silt-bound deposits between wells. Preliminary interpretation suggests a heterogeneous distribution of silt-bound zones, which is consistent with the lateral and vertical variability associated with stream channel migration in alluvial environments (Schasse & Wegmann, 2000).

Clallam County compiled drillers logs from 25 wells monitored during pilot infiltration testing at the Carlsborg and ODT ditches, with good location information. The County summarized textural descriptions of the subsurface sediments and found that most logs mentioned some occurrence of clay in the upper 25 feet of the boring. Interpolation of clay occurrence between logs appeared to be impossible, and considerable heterogeneity was noted (Soule, 2008). Field investigations would be required to further ascertain whether the silt-bound materials demonstrate any significant degree of lateral continuity.

The maximum thickness of Qa is estimated to be 40 feet in the Carlsborg quadrangle (Schasse & Wegmann 2000). Near the two sites, water-bearing sediments sufficient for completing a domestic well are typically encountered within the uppermost 60 feet. Conditions below the ODT site in Section 14-SWNW show slightly deeper completion depths. The shallow aquifer includes alluvium and other sediments that may underlie the alluvium and is estimated to be about 100 to 150 feet thick in the site vicinity based on USGS analysis (Thomas et al, 1999). Thus, local wells may be completed in water-bearing sediments that differ in origin from the alluvial sediments described above. Specifically, the USGS describe the shallow aquifer occurring over the entire Dungeness Peninsula as follows:

> "(The shallow aquifer) contains alluvium, older alluvium, Everson sand, Everson glaciomarine drift, Vashon recessional ice-contact and recessional outwash deposits, Vashon till, Vashon reworked till, and Vashon advance outwash. Because of the complex and discontinuous nature of the surficial deposits, the shallow aquifer was not delineated into individual coarse- and fine-grained deposits".

Moderate reported well yields combined with the limited available drawdowns of shallow wells suggest moderately permeable aquifer materials. USGS mapping of hydraulic conductivity (K) in the shallow aquifer suggest values on the order of 150 ft/day beneath the Jakeway and ODT sites, although the ODT site immediately borders a 38 ft/day zone to the east (Thomas et al, 1999). The USGS values were based on specific capacities observed in wells. PGG's model calibration estimated K on the order of 400 ft/d at both sites, with associated transmissivity (T) values ranging from 35,000-55,000 ft^2/day. The USGS assumed specific yield (S_y) values of 0.12 for the shallow aquifer, which is reasonable for unconfined conditions. PGG performed transient model simulations using S_y values ranging from 0.1 to 0.2.

The difference between K values estimated during model calibration and those estimated by the USGS based on specific capacities, the likely textural differences between the shallow Qa sediments and those occupying deeper portions of the "shallow aquifer", and heterogeneity *within* the Qa sediments all indicate that site investigations and/or pilot testing would be needed to obtain best-estimate local values of T and K. In any case, moderate to high values of horizontal hydraulic conductivity (Kh) and T are expected. The abundance of silt-bound sediments will likely impose greater restriction on K in the vertical direction (K_v). As groundwater recharge moves downward towards the water table, it will likely encounter silt-bound zones of lower permeability. If silt-bound sediments exhibit significant lateral continuity, zones of restricted downward flow are likely. Lower K values in the vertical direction relative to the horizontal direction is a form of "anisotropy". Data collected during pilot testing at the Jakeway and ODT ditches showed unsubstantial groundwater level responses to infiltration in monitoring wells, which may indicate relatively high aquifer Kh values and/or anisotropy and heterogeneity that distributes portions of the infiltrated water through zones that overlie the well completions.

Groundwater levels in the area are also relatively shallow. Most wells completed within 75 feet of land surface show static water levels (at time of drilling) between 0-30 feet. (Shallow clay and silt observed in well logs may provide some local confinement.) There is little correspondence between the depths of shallow wells and the associated water level, but the timing of drilling (pre- vs. post-piping, and mid- vs. post-irrigation season) may also need to be considered. PGG reviewed hydraulic gradients described in the USGS publication (Thomas et al, 1999). Horizontal gradients near the two sites are relatively gentle at approximately 0.01 ft/ft. These gradients are among the gentlest observed in the shallow aquifer, thus suggesting relatively transmissive sediments. USGS piezometric surface maps show little difference in water-level elevations between the shallow aquifer and the underlying middle aquifer in the project vicinity (ibid). This suggests relatively mild vertical gradients between these aquifers. Site-specific characterization would be needed to better understand vertical hydraulic gradients in the vicinity.

One factor influencing groundwater in the Dungeness Peninsula is the ongoing effort by the Sequim Dungeness Water Users Association to improve irrigation conveyance efficiencies and reduce diversions by piping unlined irrigation ditches. Most of the active, unlined irrigation ditches in the vicinity of the two sites have been piped over the past 15 years. The Clallam-Cline irrigation system, which would supply water for recharge at the two recharge sites, is now almost entirely piped. More than half of the pipe in the Clallam-Cline system has been installed since the fall of 2006, including portions of the main transmission line that would deliver water to the abandoned ditches for recharge

3.3 AR Source: Dungeness River

Dungeness River water would be the source of infiltration water. The river water would be conveyed through the existing network of piped irrigation ditches to the infiltration ditches. The Clallam, Cline and Dungeness irrigation companies share a diversion and fish screen on the west side of the Dungeness River at about River Mile 8.0. Analysis of previous pilot testing by PGG and AQ suggests that at least 2.5 cfs could be infiltrated into the ditches, and with proper ditch preparation/maintenance, as much as 7 cfs might be infiltrated.

3.3.1 Timing and Magnitude of Streamflow Availability

The availability for future diversions from the Dungeness River will depend on instream flow requirements adopted into rule, natural flows in the river, and diversions under existing water rights. Ecology's gauging station at the Schoolhouse Bridge (RM 0.8) will likely be the measurement point for future compliance with the instream flow (ISF) requirements. Water is diverted for irrigation purposes upstream of this station between RM 11.0 and 6.9, and the City of Sequim operates an infiltration gallery also near RM 11. Irrigation diversions occur between April 15 and September 15; whereas diversions can occur year-round for municipal and stock-watering purposes. Instream flow recommendations based on the IFIM study results are 575 cfs from November through March, 475 cfs April through July and 180 cfs August through October, although NOAA Fisheries determined 105 cfs as a target flow for late summer. The IFIM-based flows are currently proposed in Ecology's instream flow and water management rule.

PGG has developed an initial estimate of synthetic flows at the Schoolhouse Bridge under half buildout of the Sequim-Dungeness Water Users Association Comprehensive Water Conservation Plan[7] based on: 1) correlations between flows at the USGS gage and the sum of flows at the Schoolhouse Bridge and irrigation diversions between 1999 and 2004; and 2**)** 35 years of flow data from the USGS gage. Synthetic flows at the Schoolhouse Bridge were then compared to proposed instream flow requirements to calculate associated flows above the ISF requirements. **Figure 3-2** shows the exceedance probabilities above the recommended ISF requirements, and **Table 3-1** presents the percent of days per month during which flows would be above ISF requirements. Flow availability is most consistent during the spring freshet (typically May through July). Winter runoff events are more sporadic but can occur at higher rates. Use of sporadic, instantaneous flows during winter would require capability to control the short-term timing and rate of diversions.

Actual availability of Dungeness River water relative to ISF requirements can be estimated for various means of capture and conveyance. The simplest estimation assumes that flows above the ISF requirements (up to a certain upper limit) can be captured instantaneously when ISF requirements are met (e.g. automated valving system) and that available flows are always greater than the conveyance capacity for AR deliveries[8]. If these assumptions are met, estimating flow availability is as simple as multiplying the percent of days that ISF requirements are exceeded by the conveyance capacity of the system. For instance, the high-availability month of June has an average of 68 percent exceedance-days of the 35-year record. A system capacity of 10 cfs would deliver an average diversion of 6.8 cfs for the month of June.

3.3.2 Timing and Magnitude of Conveyance Capacity

As noted previously, water would be conveyed to the proposed recharge site through the Clallam-Cline irrigation system main line pipes. These pipes have the capacity to convey approximately 15 cfs from the Dungeness River to the proposed recharge site. However, during the irrigation season (April 15 – September 15), that capacity is used to varying degree to convey water from the Dungeness River to water users for irrigation. Further discussions are needed to address this potential limitation to operating the proposed AR facility for Scenario A, including

[7] For the purpose of this analysis, PGG assumed that half buildout of the conservation plan includes a savings of 19 cfs when diversions exceed 60 cfs; zero savings when diversions fall below 10 cfs; and linear interpolation between these two values. Minimum diversions outside the irrigation season were assumed to be 10 cfs.

[8] Prior analysis suggests that flows above the ISF requirements will likely meet an AR conveyance capacity of 10 cfs the vast majority of the time (PGG, 200Xx). Additional analysis would be required to assess flow availability at higher conveyance capacities.

whether operational changes might increase the overall pipe capacity available during the irrigation season for conveyance of water to the proposed AR sites for infiltration. An agreement will need to be reached with Clallam Ditch Company and Cline Irrigation District to ensure that capacity is available.

3.4 Predicted Fate of Recharged Water

PGG used the 2008 groundwater flow model to estimate the extent to which the infiltrated water would discharge to nearby streams, thus augmenting baseflows. Model predictions should be considered approximate, but provide reasonable indication of the general magnitudes of streamflow augmentation. The model predicts that the infiltrated water will augment baseflows in both the Dungeness River and Matriotti Creek, with minimal (less than 0.5 percent of the AR infiltration rate, "Q_{ar}") augmentation in other nearby streams. Development of the model raised questions about the nature of the hydraulic connection between the shallow regional aquifer and Matriotti Creek. The lower reach of the creek (below RM 0.7) gains baseflow from groundwater, as documented in PGG's "Small Streams Analysis" (PGG, 2008a). However, model calibration to heads in nearby wells suggests that water levels in the aquifer are below the streambed along reaches of Matriotti Creek. The apparent inconsistency between these observations suggests that Matriotti Creek may be gaining water from shallow perched conditions along its lower reach. The complexity associated with possible perched conditions could not be realistically represented by the model, in which the shallow aquifer system was represented with a single model layer. Thus, there is some uncertainty in the model-predicted distribution of streamflow augmentation between the Dungeness River and Matriotti Creek. The model predictions discussed below assume that:

- AR is infiltrated into the main water-bearing body of the shallow aquifer rather than into an overlying perched water-bearing zone.
- The Dungeness River is connected to the main water-bearing body of the shallow aquifer.
- Matriotti Creek is connected to the main water-bearing body of the shallow aquifer over limited reaches (e.g. immediately northwest of the infiltration ditches). Matriotti Creek may be connected to shallow perched groundwater in other locations (e.g. below RM 0.7), but is not connected to the main water-bearing portion of the shallow aquifer in these locations.

AR likely does reach the regional water-table aquifer; however, its flowpath may be partially impeded by shallow, fine-grained sediments. Clallam County reviewed logs of monitoring wells located near the two ditches and found common occurrence of shallow clayey and silty sediments (Section 3.2). The logs did not suggest occurrence of perching near the land surface; however, shallow saturation is rarely reported by drillers. While clayey and silty materials may cause infiltrated water to take a circuitous path as it disperses into the subsurface, occurrence of these materials does not dictate development of perched conditions unless they are laterally continuous over extensive areas. Given the heterogeneity observed between driller's logs, it is more likely that the occurrence of fine-grained materials is discontinuous and water can make its way downwards through the vadose zone to the regional water table. However, data collected during the pilot testing does not aid in interpreting the hydraulic role of shallow, fine-grained materials because groundwater level responses to pilot infiltration testing at the two ditches were generally indistinguishable from regional rises. Formation of perched conditions was not observed during infiltration testing at a combined rate of 1.5 cfs between the two ditches. The testing is further described in Section 3.6.1.

Characterization by the USGS indicates that the Dungeness River is generally connected to the shallow water-table aquifer (Simonds & Sinclair, 2002). The actual geographic distribution and degree of the hydraulic connection between Matriotti Creek's downstream reaches (prior to its confluence with the Dungeness) and the shallow aquifer will require further hydrogeologic characterization. Expansion of the connection beyond the current model representation would result in additional water captured by Matriotti Creek and delivered downstream to the Dungeness River, and a possible reduction in the water captured directly by the River.

Figure 3-3 shows the model prediction of augmented flow in the Dungeness River expressed as percent of AR infiltration rate (Q_{ar}), when AR is infiltrated for periods of 2 months and 6 months. The model was run for two values of specific yield (S_y): 0.1 and 0.2. For the 2-month simulation, the model predicts that the rate of Dungeness River augmentation ranges from 4.6 percent to 33.2 percent of Q_{ar} ($S_y = 0.2$) and from 2.4 percent to 44.4 percent of Q_{ar} ($S_y = 0.1$). In both cases, the annual average rate of streamflow augmentation is predicted to be 13 percent of Q_{ar}, and the annual volume of streamflow augmentation is predicted to be 78 percent of the volume infiltrated (V_{ar}).

If source water were infiltrated for 6 months rather than the 2 months assumed for the spring freshet, model predictions show higher rates of streamflow augmentation. In this case, the model predicts that the rate of Dungeness River augmentation ranges from 17.9 percent to 59.9 percent of Q_{ar} ($S_y = 0.2$) and from 10.7 percent to 67.1 percent of Q_{ar} ($S_y = 0.1$). In both cases, the predicted annual average rate of streamflow augmentation is increased to 39 percent of Q_{ar}, and the annual volume of streamflow augmentation remains at 78 percent of the volume infiltrated (V_{ar})[9].

In order to estimate the net impact to the Dungeness River from the AR scheme proposed under Scenario A, one must deduct the source water diverted from the Dungeness River from the AR augmentation to the river. The source water would likely be diverted from the Clallam-Cline out-take, located upstream of the ODT and Jakeway ditches at RM 8.0. **Figure 3-4** shows the predicted net flow impact at the mouth of the Dungeness River associated with Scenario A. The predicted net impact is negative (reduced flow) during times of diversion and positive (increased flow) outside the AR diversion period. **Figure 3-5** shows the model-predicted spatial distribution of Dungeness River flow augmentation associated with steady-state (continuous)

[9] The increase in rate is due to the fact that water is infiltrated for more of the year, thus providing a greater volume to be distributed over the year as streamflow augmentation.

infiltration at the Scenario-A site[10]. While this figure gives a reasonable idea of the spatial distribution of streamflow augmentation, the modeled distribution is expected to vary during the annual cycle of AR infiltration and dormancy. During periods of diversion, the maximum streamflow reduction would occur at the point of diversion, and this impact would be diminished in a downstream direction as Scenario-A infiltration reaches the stream. Outside the diversion period, streamflow augmentation would roughly follow the steady-state modeled distribution shown on **Figure 3-5** (with some degree of seasonal variation superimposed).

Figure 3-6 shows the model prediction of augmented flow in the Matriotti Creek expressed as percent of AR infiltration rate (Q_{ar}), when AR is infiltrated for periods of 2 months and 6 months. The 2-month AR simulations predict that flow in Matriotti creek will be augmented by between 0.4 percent and 2.5 percent of Q_{ar} ($S_y = 0.2$) and from 0.2 percent to 3.5 percent of Q_{ar} ($S_y = 0.1$). Average annual augmentation rate for the 2-month AR prediction is 1.1 percent of Q_{ar}, and the associated annual augmentation volume is about 7 percent of V_{ar}. The 6-month AR simulations predict that Matriotti Creek will be augmented by between 1.8 percent and 5.2 percent of Q_{ar} ($S_y = 0.2$) and from 1.1 percent to 6.0 percent of Q_{ar} ($S_y = 0.1$). Average annual augmentation rate for the 6-month AR prediction is about 3.5 percent of Q_{ar}, and the associated annual augmentation volume remains approximately 7 percent of V_{ar}. Predicted augmentation to Matriotti Creek is subject to the uncertainty discussed above. It is not negatively affected by the Dungeness River diversions.

PGG expressed model predictions of streamflow impact (above) as percent of Q_{ar} because the ultimate AR rate is unknown and will vary with Dungeness River flows, available transmission capacity in existing irrigation pipes, and ditch infiltration capacity (to be determined through further testing and operations). The predicted percentages can be applied within the Q_{ar} range from 2 to 10 cfs (and somewhat beyond that range in either direction) without any significant loss of accuracy. This is because the model behaves in a linear manner over this range of rates (PGG, 2009). The streamflow impact curves provided on **Figures 3-3, 3-4** and **3-6** are specific to 2-month and 6-month periods of steady AR infiltration – other infiltration schedules would require additional model runs. Impacts to the Dungeness River over time are estimated by multiplying the 2-month or 6-month infiltration rate by the percent Q_{ar} augmentation schedule calculated by the model. This "percent multiplier" approach allows flexible estimation of the benefits of AR Scenario A.

Net impacts of AR to the Dungeness River can be estimated based on **Figure 3-4**. For example, if 4 cfs were diverted and infiltrated for two months during the spring freshet, streamflow reductions are estimated to occur during the diversion period of about 60 percent to almost 100 percent of the diversion rate (e.g. 2.4 to 4 cfs). As discussed in Section 3.6.1, these impacts would likely be acceptable during the high flows of the freshet. Immediately after the AR diversion ends, estimated stream baseflows would be augmented by about 33 percent to 44

[10] The spatial distribution of Dungeness River augmentation is annualized and presented as percent annual AR infiltration volume (Var).

percent of Q_{ar} (1.3 to 1.8 cfs). Estimated augmentation would decline until the next period of AR infiltration. During the critical low-flow months of September and October, estimated AR flow augmentation would range from about 10 percent to 20 percent of Q_{ar} (0.4 to 0.8 cfs). By increasing the AR infiltration period to 6 months, predicted augmentation during the critical low-flow period would range from about 20 percent to 40 percent of Q_{ar} (0.8 to 1.6 cfs); however, flow reductions from streamflow diversion would occur over a 6-month period (e.g. mid January through mid July) ranging from 40 percent to 90 percent of the diversion rate (1.6 to 3.6 cfs).

Water infiltrated at the ODT-NW and Jakeway ditches will flow downgradient within the shallow aquifer. PGG used the 2008 Groundwater Flow Model and the USGS particle tracking software "MODPATH" to evaluate the likely flowpath for the infiltrated water. Particles were introduced at the top of the water table within the model cells that contain the AR ditches, and the model was run assuming constant (steady-state) AR infiltration. As shown in **Figure 3-7**, the water is predicted to follow a north-northeast flowpath on a swath that falls between Matriotti Creek and the Dungeness River. Direct interactions with surface-water bodies are expected to be minimal, as the particle traces do not reach the Dungeness River and the model does not predict a direct hydraulic connection between the shallow aquifer and lower Matriotti Creek. However, due to existing uncertainty about the hydraulic connection between the shallow aquifer and Matriotti Creek, localized hydrogeologic characterization would be necessary to better estimate whether a portion of the AR water would directly discharge to the creek. Because the AR water is introduced at the top of the shallow aquifer (i.e. the water table), the model predicts that it generally remains within the shallow aquifer rather than migrating downward to underlying water-bearing units. Augmentation to local streams occurs because the infiltrated AR water displaces existing groundwater, in effect "pushing it" towards the Dungeness River and Matriotti Creek, thus increasing groundwater heads near these streams and increasing associated baseflow.

3.5 Environmental Impacts

3.5.1 Water Quality Considerations

PGG's consulting team previously evaluated Dungeness River water quality considerations for AR/ASR (PGG, 2008b). Our assessment noted that data set for the Dungeness River provided to us is limited and does not contain several parameters needed to fully evaluate suitability for recharge. Available data from the City of Sequim's Dungeness Collector Site suggest that the raw water quality is generally very good. However, personal communication with the City of Sequim indicates that high turbidity is observed in the collector during the spring runoff and other high flow events. During pilot testing at the ODT and Jakeway ditches, source water from the Dungeness River (conveyed through Clallam-Cline pipes) was turbid during periods of high river flow; but was often visually clear during other flows (personal communication, Ann Soule, Clallam County). The source water was not measured for turbidity.

Water delivered to infiltration ditches and/or basins does not require pre-treatment for regulatory water quality purposes, however, the presence of fine particulates, nutrients and carbon (particulate, dissolved, and organic) may cause operational challenges, as the water is filtered naturally as it infiltrates at the surface. Suspended sediment in the recharge water will eventually clog infiltration facilities and periodic maintenance will be required to restore the permeability. Further, the presence of nutrients and carbon will result in a biological growth forming at the liquid soil interface.

Water quality data submitted to the Washington State Department of Health for the City of Sequim Collector well meets all drinking water standards and so this source should be an acceptable source of water for infiltration assuming that turbidity is effectively removed during infiltration. Native groundwater quality data provided to PGG for the study area were limited to select inorganic parameters (conductivity, turbidity, arsenic, iron, manganese, nitrate, chloride, sulfate). The limited available data indicate that native groundwater quality is good and that parameter values for the Dungeness River Collector are better or equal to the native groundwater quality (**Table 3-12**). On the basis of these limited data (and the understanding that microbes are typically filtered out in the subsurface and that historic infiltration of river water from leaky irrigation ditches has not been associated with significant groundwater quality problems), it is most likely that the Dungeness source water, whether derived from the collector or directly from the river, should not degrade native groundwater quality and satisfy the Groundwater Antidegradation Policy set forth in WAC 173-200.

3.5.2 Net Effect on Habitat

The effects of diversion and streamflow augmentation through AR are discussed below. Analysis presented in Section 3.4 shows that streamflows would be reduced during the periods of AR diversion and augmented outside these diversion periods (**Figure 3-4**). Streamflow reductions are limited to the spring freshet for the 2-month AR scenario, whereas they extend through much of the winter and early spring for the (more hypothetical) 6-month AR scenario. Thus, these two scenarios differ markedly in the associated timing of reduced streamflows. As habitat also varies between the winter months and the spring freshet, habitat impacts are evaluated separately for the 2-month and the 6-month AR scenarios.

The net flow changes discussed in Section 3.4 were used to evaluate effects on habitat primarily based on the habitat assessment summarized in the project technical memo (TM) entitled: *Dungeness River Aquifer Recharge Habitat Technical Memorandum* (R2, 2007). Information related to the six-month AR scenario (between January 15 and July 15th) is extrapolated from the TM since the months of February, March and April were not addressed in the original memorandum. Habitat effects were evaluated for both the period of diversion (reduced streamflows) and the period of dormancy (augmented streamflows). As noted in the TM, habitat impacts on the mainstem Dungeness River and associated flow regimes are assessed at the upper IFIM study location (RM 4.2). During the period of diversion, the maximum streamflow reduction is experienced at the point of diversion (RM 8.0 at the Clallam-Cline out-take). Much of the streamflow augmentation re-enters the mainstem river between RM 3.3 and RM 5.5 (**Figure 3-5**). For the purpose of this analysis, the reach between RM 8.0 and RM 5.5 is referred to as the “bypass reach”, because streamflow reductions show little offset from AR augmentation. During the period of diversion, streamflow reductions are cumulatively diminished downstream of RM 5.5, but remain as reductions because the AR diversion exceeds the augmentation. During the period of dormancy, Dungeness River flows are solely augmented by AR (primarily downstream of RM 5.5). For the purpose of this analysis, this dormant period will be called the "period of augmentation".

This section is organized in a manner that discusses habitat impacts for both the period of diversion and the period of augmentation for each diversion option (2-month and 6-month) in Scenario A. This discussion is applied to both the Dungeness River and its side channels. Discussion of habitat impacts to small streams solely references a period of augmentation because diversion does not impact flows in small streams.

3.5.2.1 Habitat Effects from 2-Month AR Scenario

Effects on the Mainstem Dungeness River During Diversion

Under this option, water for infiltration would be withdrawn from the mainstem Dungeness River between May 15 and July 15 at RM 8.0. This water would be conveyed in existing pipelines to the two infiltration ditches west of the Dungeness River. For the purposes of this analysis, the withdrawal amount is assumed to lie between 2 and 10 cfs. Although the maximum infiltration capacity of the ditches is estimated to be 7 cfs, diversions of 2, 5, and 10 cfs were assessed in the TM and a maximum diversion of 10 cfs is discussed herein as the upper bound.

As described in the TM, the anticipated habitat impacts of an AR diversion between 2 and 10 cfs, based on the instream flow model (Hiss 1993a,b), are a function of the shape of the weighted usable area (WUA) vs flow (Q) curve for various life stages of the species of interest (TM Figures 4a-f). A typical curve will exhibit increasing WUA with increasing Q ("ascending curve") up to an optimal Q (maximum WUA), followed by decreasing WUA with further increases in Q ("descending curve"). AR diversions during the 2-month diversion period provide both increases and decreases in habitat levels for all life history stages. Indices of habitat area increase as a result of AR diversions along descending portions of the curves. Conversely, habitat is projected to decrease with mainstem flow reductions along ascending portions of the curves.

In this section, the maximum beneficial or adverse impacts during the period of diversion are assessed in the river as a worst-case situation at the point of diversion RM 8.0 in the bypass reach. Overall impacts downstream in the Dungeness River would be reduced due to the inflow of AR augmentation as described in Section 3-4.

The overall anticipated habitat change as a result of the 2-month AR diversion during the spring freshet, across all mainstem flows between 475 and 750 cfs, averages between a 0.5 percent improvement in rearing habitat indices for juvenile Chinook salmon and a 0.5 percent decrease for juvenile native char (**Table 3-2**). There is no change in habitat levels for steelhead trout spawning under this scenario for any of the diversion rates. Habitat changes for the balance of the species and life stages fall in between these levels.

All life history stages show improvements in habitat with the 2-month AR diversion at some point across the range of modeled flows (**Table 3-3**). The largest increases occur with the 10 cfs withdrawal rate. The life stages benefiting the most include: (1) coho, steelhead and Chinook rearing, with 1.2, 1.3, and 2.6 percent improvements in WUA indices, respectively. Cumulatively, over the 2.5 miles of the bypass reach in the mainstem Dungeness River, these maximum increases in habitat indices are equivalent to less than 0.005 acres to 0.07 acres of rearing and spawning habitat during the May 15 to July 15 diversion period (**Table 3-3).**

Conversely, all species and life stages show habitat decreases at some point across the modeled flow range during the diversion period (**Table 3-4**). The largest instantaneous decreases occurring during the May 15 to July 15 period fall between 1.1 and 1.8 percent for Chinook salmon and native char rearing, and for steelhead trout spawning.

Over the 2.5 miles of the bypass reach in the mainstem Dungeness River, these decreases are equivalent to approximately 0.005 acres to 0.18 acres of rearing and spawning habitat during the May 15 to July 15 diversion period, depending upon the species, the life history stage and the existing mainstem flow rate (**Table 3-4**).

Effects on the Mainstem Dungeness River During Augmentation

The fate of aquifer recharge is anticipated to augment mainstem Dungeness River flows in a cumulative fashion, primarily downstream of RM 5.5 (**Figure 3-5**). The instantaneous peak net augmentation will likely occur in July with diminishing augmentation to very low levels from December through April (**Figure 3-4**). For example, at a maximum Q_{ar} of 10 cfs, the mainstem flow net augmentation is anticipated to be in the neighborhood of 3.5 cfs in July, 2.0 cfs in August, 1.5 cfs in September and 1.3 cfs in October, with lower quantities November through April (**Table 3-5**).

Flow augmentation from less than 1 cfs up to 3 cfs between RM 3.3 and RM 5.5 is anticipated under the two-month AR option in Scenario A. Augmentation during the lowest flow period of the year (September – October) is expected to range between 1.1 and 1.5 cfs with a Q_{ar} of 10 cfs for the 2-month option. Augmentation at a Q_{ar} of 2 cfs would likely range in the neighborhood of 0.3 cfs for these two months. The 90 percent exceedance flow during this period at the upper IFIM study site at RM 4.2 is on the order of 82 cfs as extrapolated from England (1999) using current levels of irrigation withdrawals. The maximum anticipated augmentation with AR for the 10 cfs, 2-month AR option is less than a 2 percent increase in mainstem river flow and less than a 2 percent increase in Chinook salmon spawning WUA (the most critical life history stage during this time period) at the 90 percent exceedance flow level of 82 cfs. Such increases are minor and likely do not offer measurable changes in either habitat characteristics or species abundance/ productivity. Based on best professional judgment and given the variability in the ability to measure habitat attributes and fish population responses, it is anticipated that a minimum detectable change in mainstem habitat might be on the order of a 10 percent change in WUA.

Effects on Side Channels During Diversion

The work of Daraio et al. (2003) is used to assess flow and habitat conditions for the various side channels downstream of RM 8.0, when each of the channels is connected to the mainstem river. This Bureau of Reclamation study offers flow/habitat relationships in selected key side channels in the lower river for various fish species, including all of the species evaluated in the IFIM study. The surface water-connected side channels with developed habitat/flow relationships downstream of RM 8.0 include Dawley, Lower East Railroad Bridge, Stevens/Savage and Anderson side channels. The anticipated mainstem flow range that preferred habitat is available in the side channels is calculated for each of the identified rates of diversion. Although river flow and habitat characteristics for individual side channels are dynamic in nature, it is assumed for the purposes of this analysis that the observed habitat trends in the Daraio et al (2003) study are representative of the other side channels in the lower watershed and that similar habitat conditions with mainstem river flow will be maintained on average, over time, across the many side channels downstream of RM 8.0.

Findings from the TM indicate that the maximum estimated decreases in physical habitat attribute values in side channels of the Dungeness River with AR diversion up to 50 cfs are too small to identify potential changes in preferred fish habitat conditions. The side channel assessment suggests diversions between 2 to 50 cfs during high stream flows in the Dungeness River are not sufficient to predict changes in side channel features important for fish habitat. Cumulative availability of preferred physical habitat attributes across all of the measured surface water-connected side channels for priority life stages at various mainstem river flow levels suggest reductions of high river flows during the 2-month evaluation period would enhance habitat conditions for salmonid fishes in Dungeness River side channels.

Effects on Side Channels During Augmentation

Daraio et al. (2003) modeled the characteristics of four side channels in the flow augmentation area between RM 3.3 and 5.5 including: the E. (Lower) Railroad Bridge, Stevens/Savage, Gagnon E. and Anderson channels. The Gagnon and Anderson side channel lost their surface water connection with the mainstem Dungeness River at discharges below 200 and 160 cfs, respectively, in the summer of 2002. According to Daraio et al. (2003), habitat suitability was not attainable in either of these channels at the flows surveyed or modeled. A maximum of 2 to 4 cfs augmentation in the mainstem will have little to no influence on the suitability of habitat conditions in either the RR Bridge or Stevens/Savage side channels (Daraio et al. 2003, R2 2007). For example, as shown in the TM, a 5 cfs incremental increase in mainstem flows would have less than 1 percent change in key physical habitat parameters of side channel width, discharge, depth, or velocity (**Table 3-6**). These small changes are insufficient to alter the suitability of habitat conditions for various life histories of salmonid fishes as described in the TM (R2 2007). A minimum detectable habitat change might be on the order of a 30 percent increase in mean mainstem river flow conditions.

Effects on Small Streams

The 2008 groundwater model predicted minor flow augmentation in Matriotti Creek, with minimal (less than 0.5 percent) augmentation in other nearby streams (Section 3.4). Matriotti Creek is one of the largest lowland tributaries to the Dungeness River, entering the river at RM 1.9.

Ecology operated a stand-alone stream flow gauge on Matriotti Creek at the Olympic Game Farm from November 1999 to November 2000. The information is available in their River and Stream Flow Monitoring database as gauge 18D060. Daily stream flows were recorded between the range of 10 and 50 cfs, but normally occurred around 15 cfs during that time period. Miscellaneous flows recorded near the Dungeness River confluence between 2002 and 2007 typically ranged from 7 to 15 cfs (PGG, 2008a). The percent of Q_{ar} surfacing in Matriotti Creek is predicted to be between 0.2 and 3.5 percent of Q_{ar} or less than 0.35 cfs at all times for the 2-month 10 cfs AR scenario. Some uncertainty is noted in the model predictions for Matriotti Creek because the model cannot simulate some of the hydrogeologic complexities believed to occur in the vicinity of the creek. Matriotti Creek supports runs of coho salmon, steelhead and cutthroat trout. No quantitative habitat/flow modeling effort has been completed for this tributary, but based on the side channel assessment effort discussed above, it is logical that less than a 0.35 cfs change in discharge conditions would be insufficient to alter habitat conditions in a manner offering a measurable change in productivity of various life history stages of the fish present. A minimum detectable habitat change might be on the order of a 20 percent increase in mean flow conditions, or roughly 3 cfs relative to conditions at the confluence.

3.5.2.2 Habitat Effects from 6-Month AR Scenario

Effects on the Mainstem Dungeness River During Diversion

Under this option, water for infiltration would be withdrawn from the mainstem Dungeness River between January 15 and July 15 at RM 8.0. Withdrawal rates of 2, 5 and 10 cfs were assessed in the TM for river flows in excess of the ISF level during January under the rain-dominated winter season and again between May and July for the spring snow melt season (R2, 2007). Extrapolations of the initial assessment to the winter and early spring months of February through April are included, herein. Since this AR option consists of continuous withdrawal, a two-tiered assessment is included in this section, one for river flows above the ISF level that is consistent with the TM and one for river flows below the ISF level. For this portion of the assessment, the period between January 15 and May 15 is summarized. The information presented above for the 2-month infiltration period still applies to the time frame between May 15 and July 15 under this option. Estimates of habitat modifications for withdrawals under this

AR option at river flow levels below the ISF are qualitatively addressed at the end of this section.

Effects at River Flows in Excess of ISF levels (January 15 – May 15): The overall anticipated habitat change as a result of a 10 cfs AR diversion, across all mainstem flows above the ISF and 750 cfs, average between a 0.2 percent improvement in rearing habitat indices for juvenile steelhead trout and a 0.2 percent decrease for juvenile native char, (**Table 3-7**). There is a 0.7 percent increase in spawning habitat levels for coho salmon during the month of January under this scenario. Habitat changes for the balance of the species and life stages fall in between these levels.

Similar to the two-month infiltration results, all life history stages show improvements in habitat with AR diversions at some point across the range of modeled flows (**Table 3-8**). The life stages benefiting the most include: (1) coho and steelhead rearing and (2) coho and steelhead spawning with 0.6, 0.5, 1.2, and 1.3 percent improvements in WUA indices, respectively. Cumulatively, over the 2.5 miles of the bypass reach in the mainstem Dungeness River, these maximum increases are equivalent to approximately 0.005 acres to 0.07 acres of rearing and spawning habitat during the January 15 to May 15 diversion period (**Table 3-8**).

Conversely, all species and life stages also show habitat decreases at some point across the modeled flow range (**Table 3-9**). The largest instantaneous decreases occurring during the January 15 to May 15 period fall between 0.7 and 1.1 percent for coho salmon and native char rearing, and for steelhead trout spawning. Over the 2.5 miles of the bypass reach in the mainstem Dungeness River, these decreases are equivalent to approximately 0.005 acres to 0.08 acres of rearing and spawning habitat during the May 15 to July 15 diversion period, depending upon the species, the life history stage and the existing mainstem flow rate (**Table 3-9**).

Given the shape of the habitat versus flow curve, juvenile native char were also the most sensitive life stage to flow reductions in winter and early spring, with an average WUA loss and an instantaneous WUA loss across the modeled flow ranges of 0.2 and 1.1 percent, respectively. However, since the amount of suitable habitat in the mainstem river for native char is low, the potential equivalent number of productive acres lost is less than for steelhead spawning and coho rearing (**Table 3-9**).

Effects at River Flows Lower than ISF levels (January 15 – May 15): Detailed analysis was not performed in the TM for diversions when winter flows were below ISF levels. In a generic sense, the general shapes of the WUA v Q curves for various species present during the 6-month AR diversion period suggest AR withdrawals will generate more adverse effects on habitat at flow levels below the ISF than above the ISF. The most sensitive species and life history stage during this time period is steelhead trout spawning (Hiss 1993b). As a worst-case example, a maximum instantaneous reduction in steelhead spawning habitat of 6 percent WUA occurs with the maximum 10 cfs withdrawal rate, when the river is flowing at 170 cfs and again at river discharges between 240 and 260 cfs (TM Figure 4a). The anticipated reduction in steelhead spawning when river levels were less than the ISF would always remain below percent a 6 percent change in the WUA index. Such a decrease remains relative minor and likely does not offer measurable changes in either habitat characteristics or species abundance and productivity estimates. Given the variability in the ability to measure habitat attributes and fish population responses, it is anticipated a minimum detectable change in mainstem habitat might be on the order of a 10 percent change in WUA.

Effects on the Mainstem Dungeness River During Augmentation

The fate of aquifer recharge is anticipated to augment mainstem Dungeness River flows in a cumulative fashion, primarily downstream of RM 5.5 (**Figure 3-5**). The instantaneous peak net augmentation will likely occur in July with diminishing augmentation to very low levels from December through April, annually (**Figure 3-4**). For example, at a maximum Q_{ar} of 10 cfs, the mainstem flow net augmentation is anticipated to be in the neighborhood of 5.5 cfs in July, 4.0 cfs in August, 2.8 cfs in September and 2.3 cfs in October, with lower quantities November through December (**Table 3-10**).

Flow augmentation from less than 2 cfs up to 6 cfs below RM 5.5 is anticipated under the six-month AR option in Scenario A. Augmentation during the lowest flow period of the year (September – October) is expected to range between 2.3 and 2.8 cfs with a Q_{ar} of 10 cfs for the 6-month option. For comparison, augmentation at a Q_{ar} of 2 cfs would like range in the neighborhood of 0.5 to 0.6 cfs for these two months. The 90 percent exceedance flow during this period at the upper IFIM study site at RM 4.2 is on the order of 82 cfs as extrapolated from England (1999) using current levels of irrigation withdrawals. The maximum anticipated augmentation with AR for the 6-month option is less than a 4 percent increase in mainstem river flow and a 3 percent increase in Chinook salmon spawning WUA (the most critical life history stage during this time period, Hiss 1993b) at the 90 percent exceedance flow level. Such increases are small and offer indistinguishable changes in either habitat characteristics or species abundance/productivity characteristics. Given the variability in the ability to measure habitat attributes and fish population responses, it is anticipated a minimum detectable change in mainstem habitat might be on the order of a 10 percent change in WUA. Approximately 10 cfs of flow augmentation would be needed to measure a 10 percent change in WUA at lowest flow period of the year.

Effects on Side Channels During Diversion

Effects at Mainstem River Flows in excess of ISF levels: Findings from the TM indicate the maximum estimated decreases in physical habitat attribute values in side channels of the Dungeness River with AR diversion up to 50 cfs are too small to identify potential changes in preferred fish habitat conditions. The side channel assessment suggests diversions between 2 to 50 cfs during high stream flows in the Dungeness River are not sufficient to predict changes in side channel features important for fish habitat. Cumulative availability of preferred physical habitat attributes across all of the measured surface water-connected side channels for priority life stages at various mainstem river flow levels, suggest reductions of high river flows during the 6-month evaluation period would enhance habitat conditions for salmonid fishes in Dungeness River side channels.

Effects at Mainstem River Flows lower than of ISF levels: Detailed analysis was not performed in the TM for side channel influences at these river flow levels. However, using rating curve coefficients for mainstem channel depths at the mouths of Dawley, the Lower E. Railroad Bridge and Stevens/Savage side channels, it can be determined that a 10 cfs reduction in mainstem discharge (6 percent) at a river flow level representative of the 90 percent exceedance flow for the late winter and early spring period of approximately 170 cfs would result in minor changes in habitat conditions in these side channels, as shown **Table 3-11**.

These habitat attribute changes are small and, by themselves, do not likely represent measurable changes in habitat conditions for salmonid fishes present during this period. However, if flow levels decrease to a point below the lower threshold that offers suitable habitat to fish in these side channels, then suitable habitat conditions for a given life history stage will cease to exist. As shown in TM Figure 5, side channel habitat for spawning and rearing steelhead trout the most sensitive life history stages present during the late winter, early spring period is available in moderate levels for the modeled side channels downstream of RM 8.0 at mainstem river flows between 360 and 480 cfs, and again between 180 and 190 cfs. So, if the mainstem river is flowing at levels less than 180 cfs or between 190 and 350 cfs, AR diversions could adversely impact available steelhead trout spawning and rearing habitat in the side channels. Thus, potential adverse effects on habitat in side channels are dependent upon mainstem river discharges at flows below the ISF levels.

Effects on Side Channels During Augmentation

Daraio et al. (2003) modeled the characteristics of four side channels in the flow augmentation area between RM 3.3 and 5.5 including: the E. (Lower) RailRoad Bridge, Stevens/Savage, Gagnon E. and Anderson channels. According to Daraio et al. (2003) habitat suitability was not attainable in either the Gagnon E. or the Anderson side channels at the flows surveyed or modeled. A maximum of 2 to 6 cfs augmentation in the mainstem river will have little to no influence on the suitability of habitat conditions in either the RR Bridge or Stevens/Savage side channels (Daraio et al. 2003, R2 2007). For example, as shown in the initial AR Task 4 TM, a 5 cfs incremental increase in mainstem flows would have less than 1 percent change in key physical habitat parameters of side channel width, discharge, depth, or velocity (Table 3-5).

Changes in habitat attribute values of 1 percent or less are insufficient to alter the suitability of habitat conditions for various life histories of salmonid fishes as described in R2 Resource Consultants (2007). A minimum detectable habitat change might be on the order of a 30 percent increase in mean mainstem river flow conditions.

Effects on Small Streams

The 2008 groundwater model predicted minor flow augmentation in Matriotti Creek, with minimal (less than 0.5 percent) augmentation in other nearby streams (Section 3.4). Matriotti Creek is one of the largest lowland tributaries to the Dungeness River, entering the river at RM 1.9.

As previously noted, miscellaneous Matriotti Creek flows ranged from about 7 to 15 cfs at the confluence with the Dungeness River between 2002 and 2007 (PGG, 2008a). The percent of Q_{ar} surfacing in Matriotti Creek is predicted to be between 1.8 and 6.0 percent of Q_{ar} or approximately 0.2 to 0.6 cfs for the upper bound of AR at 10 cfs for the 6-month AR option. Some uncertainty is noted in the model predictions for Matriotti Creek because the model cannot simulate some of the hydrogeologic complexities believed to occur in the vicinity of the creek. Matriotti Creek supports runs of coho salmon, steelhead and cutthroat trout. No quantitative habitat/flow modeling effort has been completed for this tributary, but based on the side channel assessment effort discussed above, it is logical that less than 0.6 cfs change in discharge conditions would be insufficient to alter habitat conditions in a manner offering a measurable change in productivity of various life history stages of the fish present. A minimum detectable habitat change might be on the order of a 20 percent increase in mean flow conditions or roughly 3 cfs.

3.5.2.3 Habitat Impact Summary for Scenario A

WUA indices, as derived from the IFIM instream flow studies (Hiss 1993a,b), are a surrogate for suitable fish habitat characteristics in a river that can be quantitatively assessed relative to incremental changes in river discharge. The indices are one tool that fish managers use to approximate habitat characteristics. The approach fits the purpose of this assessment well. However, WUA indices are not an exact measure of habitat, as habitat is comprised by a complex interaction of a myriad of physical, chemical and biological stream variables.

The IFIM assessment of proposed AR diversions suggests mainstem Dungeness River habitat levels for any life stage, on average, are not sensitive (< 0.5 percent decrease in WUA indices; < 0.7 percent increase in WUA) to diversion rates of equal to or less than 10 cfs (**Tables 3-2** and **3-7**). Per the original TM, diversions of 30 to 50 cfs would be needed prior to recording an average decrease in WUA indices of 1 percent or more across either of the 2-month or 6-month time periods (R2 2007). Peak instantaneous adverse influences on WUA for any single life stage are on the order of 2 percent or less for withdrawal rates of 10 cfs any time between January 15 and July 15 (**Tables 3-4** and **3-9**). Instantaneous increases in WUA up to a maximum near 3 percent are generally more prevalent than reductions as a result of AR diversions for all species and life history stages modeled with the exception of habitat for juvenile native char (**Table 3-3** and **3-8**). Unlike other life stages, the shape of the habitat versus flow curve for native char continues to rise until approximately 650 cfs. The overall conclusion is habitat for more species is potentially increased than decreased at flow levels ranging between the ISF and 750 cfs in the mainstem Dungeness River with AR diversions of 2 to10 cfs during the spring freshet as well as the late winter and early spring period under either of the AR options. The 2-month AR option would support half the augmentation of the 6-month option in terms of mainstem discharge and Chinook spawning WUA increases.

Neither habitat decreases during diversion nor increases during augmentation are sufficient to influence habitat characteristics in a material way in modeled side channels downstream of RM 8.0 in the Dungeness basin, with the exception of diversions during river flows below 190 cfs and between 205 and 240 cfs for the 6-month continuous AR diversion option. Similarly, habitat changes in Matriotti Creek at forecasted flow increases of less than 6 percent during periods of base stream discharge are likely not detectable.

3.5.3 Shallow Groundwater / Flooding

Sufficient freeboard is required to accommodate groundwater mounding in the vicinity of the infiltration ditches without causing the water table to intersect (and thereby flood) the land surface. The thickness of the unsaturated zone (vadose zone) dictates the freeboard between the land surface and the shallow water table. The general vicinity of the ODT and Jakeway sites historically contained multiple unlined irrigation ditches. As shown on **Figure 3-1**, most of these ditches have been converted to pipes over the past two decades. Historically, total recharge from the unlined ditches likely far exceeded the ditch recharge possible from the ODT-NW and Jakeway sites. Groundwater flooding over the *general* site vicinity is therefore not considered to be a concern.

If recharge from the ODT-NW and Jakeway ditches is increased beyond historical rates, groundwater mounding in the immediate vicinity of these ditches may increase beyond historic levels. PGG examined select wells near the ODT and Jakeway ditches during analysis of 2008 pilot test results. Wells near the ODT ditch exhibited minimum depths to water of at least 35 feet. Wells near the Jakeway ditch exhibited minimum depths to water of at least 18 feet. Water-level rises during infiltration testing ranged from about 0.3 to 0.8 feet, and may not have been fully attributable to the ditch infiltration. The subsurface pathway of infiltrated water is not well documented. Assuming that depths to water in wells represent the maximum height of the regional water table and that infiltrated water reaches the regional water table, there appears to be plenty of freeboard for anticipated rates of infiltration. However, if silty zones, heterogeneity and anisotropy cause infiltrated water to disperse into more shallow portions of the subsurface, the response to higher rates of infiltration will be difficult to predict. Given the historical operation of these ditches, it would be worthwhile to review accounts of historic conditions to assess whether operation at fully wetted capacity was associated with shallow standing groundwater, or to consider further testing at maximum infiltration rates.

The maximum infiltration capacity of the two ditches may reach as much as 7 cfs, as discussed in Section 3.6.1. Because pilot testing was not performed at such rates, definitive determination of sufficient freeboard can only be determined with testing at the final capacity of the ditches. If such local flooding were to occur, it could be controlled by reducing the inflow rate.

3.6 Engineering Considerations

3.6.1 Pilot vs. Full Scale Project

Pilot testing on the Jakeway and ODT ditches was conducted during the summers of 2007 and 2008. PGG and AQ recently evaluated the results of the 2008 pilot test, and AQ developed recommendations for increasing infiltration from the two ditches, as summarized below. If these recommendations are followed, additional testing could be conducted to confirm predicted increases in infiltration rate or the full-scale project could be initiated directly.

For 2008, pilot testing of infiltration in the abandoned irrigation ditch at the Jakeway site occurred between June 16 and July 8. Pilot testing of infiltration at the ODT site occurred between May 16 and July 8, 2008. Before the 2007 pilot tests were conducted, a contractor was hired to prepare the ditches (May 2007). The contractor cleared and grubbed portions of the existing ditches by excavating approximately one foot below the existing grade to remove organic material and top soil and expose the underlying sand and gravel formation. The contractor did not clear and excavate segments where established trees and foliage lined the banks. The cleared sections of ditch were reshaped to provide a specified bottom width and side slopes to match the existing ground alongside each ditch. Two steel flumes were installed to measure flow in each ditch during pilot testing; one at the upstream end and another approximately halfway down the length of the ditch. The flumes were designed to measure flows up to 3.5 cfs. A tap with a valve and a discharge assembly were installed to deliver water from the piped irrigation system to the upstream end of each ditch. The pilot tests were then carried out by filling each ditch with water from the pressurized irrigation system. Flows were monitored by reading each flume; periodic manual flow measurements were made to check flume readings. Tailwater was also monitored to ensure that the inflow at each ditch did not exceed the infiltration capacity of the ditch.

Key observations and results from the 2008 pilot testing at the Jakeway site include the following:

- Flow was initially discharged into the ditch at an average daily rate of about 0.3 cfs. The flow rate was increased to an average daily rate of 1 cfs after approximately 12 days.
- During the 3-week test, the wetted front barely reached the second flume at the half-way point of the 2,650 feet of ditch. During the period when the average inflow was 1 cfs, the wetted length of ditch ranged from 890 feet to 1,250 feet.
- Before, during and following the 3-week test, nearby wells were monitored in an effort to determine the impact of the pilot tests on groundwater levels. Water level rises in nearby wells from about 0.3 to 0.75 feet occurred in nearby wells during the period of infiltration. However, it was not clear whether infiltration was the principal cause of the rise in groundwater level. The comparison between groundwater levels, infiltration rates, precipitation and Dungeness River levels suggests that river levels (and associated infiltration) may have been the primary influence on groundwater levels during pilot tests

- Calculations suggest that evapotranspiration (ET) of water occupying the ditch was likely insignificant during testing. For each 1000 feet of 2-foot-wide ditch, an assumed ET rate of 4 feet of water over the 120-day growing season translates to only 0.0008 cfs.
- Instantaneous inflow rates and observed wetted ditch areas were used to estimate the rate of infiltration in the ditch during the pilot test. Estimated infiltration rates ranged from approximately 7 feet/day to as much as 21 feet/day. Infiltration rates greater than 21 feet/day were estimated from measurements taken early in the test period. However, the higher rates occurred early in the testing period in conditions where the wetted area had not yet stabilized, and do not represent long-term seepage conditions. Estimated infiltration rates after the first day of testing were more typically within the range of 7-15 feet/day and likely represent more steady conditions. Only one infiltration rate was estimated from measurements taken after the average inflow was increased to 1 cfs. That estimated rate was approximately 21 feet/day. It should be noted that the wetted length of the ditch never extended beyond the second flume, so the infiltration capacity of the downstream half of the ditch was not estimated.

Key observations and results from the pilot testing at the ODT site include the following:

- Flow was discharged into the ditch at an average daily rate of 0.4-0.5 cfs.
- During the 8-week test, the maximum wetted length of ditch included the entire length (1,600 feet). The median wetted length of ditch was approximately 1,350 feet.
- During the 8-week test, nearby wells were monitored in an effort to understand the potential impact of the pilot tests on groundwater levels. Water level rises in nearby wells from about 0.4 to 0.6 feet occurred during the period of infiltration. However, the small rises and falls in regional groundwater level did not correlate well with infiltration, which suggests that other influences, such as water levels in the Dungeness River, may have also influenced the water level in these wells.
- As was noted for the Jakeway site, calculations suggest that evapotranspiration (ET) of water occupying the ditch was likely insignificant during testing.
- Instantaneous inflow rates and observed wetted ditch areas were used to estimate the rate of infiltration in the ditch during the pilot test. Estimated infiltration rates in the upstream reach of the ditch between flumes 1 and 2 were generally in the range of 15-20 feet/day, with estimates as low as 12 feet/day. Estimated infiltration rates for the reach of the ditch downstream of flume 2 typically ranged from 5-10 feet/day, with estimates as low as 2.5 feet/day. Similar to the results from the Jakeway site, initial infiltration rates at the ODT site were highly variable, suggesting unsteady conditions during the initial week of testing. Unsteady conditions include increases in the wetted area that occurred as water filled the ditch. Infiltration rates estimated from measurements taken after the early testing period were generally more consistent as conditions became more uniform. It should be noted that the upstream half of the ditch was not excavated, cleared or grubbed in order to protect trees and brush lining the ditch.

The results of the pilot test at both sites indicate that the ditches infiltrated an average combined flow rate of approximately 1.4 cfs while only wetting an average of about 55 percent of the total length of the ditch available. The results suggest that an inflow rate nearly double what was pilot tested could have been infiltrated had the full length of ditch available been filled. As was noted previously, the Jakeway ditch overlies Carlsborg gravelly sandy loam, with a predicted permeability of 12-40 feet/day. The ODT ditch occurs along the transition between Carlsborg gravelly sandy loam and Dungeness silt loam, which is moderately permeable (1-4 feet/day). The lower reach of the ODT ditch is more likely to overlie the Dungeness silt loam, which may partly explain why the infiltrations rates for that reach of the ODT ditch were lower.

While the results of the pilot test are promising, the following measures could be implemented as part of continued pilot testing or a full scale project to increase infiltration:

- Provide additional ditch treatment by clearing and grubbing all sections of the ditch, including those sections that were not cleared before pilot testing, to remove organic material, top soil, vegetation (including trees, if optimal infiltration is desired) and fine sediment, thus more effectively exposing the underlying sand and gravel materials. Additional clearing and excavation will ensure that, infiltration rates remain within the range of expected soil permeability, when flow is available, and maximize the potential wetted surface area of the ditch.
- Install check dams at additional locations along each ditch. Clallam County indicated that two check dams were installed at the ODT site (both in the lower reach) and three check dams were installed at the Jakeway site (at roughly equal distances) as part of the initial pilot testing done in 2007. In 2008, the first check dam at the Jakeway site was removed. Installation of additional check dams at regular spacing would help maximize infiltration by increasing the average depth of flow through the ditch and increasing the wetted area of the ditch. For example, if a ditch section includes a 2-foot bottom width and 2H:1V side slopes, increasing the average depth of flow in the ditch from 6 inches to 18 inches would approximately double the wetted area of the ditch. Check dams also help maximize infiltration by increasing the head in the ditch. According to Darcy's Law, which estimates the movement of water through saturated soils, the rate at which water moves through soil is directly proportional to hydraulic gradient. Increasing the depth of water in the canal will increase the hydraulic gradient, thereby increasing the rate of infiltration.
- Coordinate with irrigators and manage inflow rates to maximize use of available ditch. On average only about 55 percent of the full length of available ditch (for both sites combined) was utilized during the 2008 pilot test due to water availability and flow measurement issues. Additional planning, coordination, and advance agreements with irrigation managers may facilitate achievement of desired AR flows. Careful operation and monitoring of flows and tailwater depths throughout an AR period will be key in knowing how much water on any given day can be discharged to the ditches without overflowing the ditches. Also, trenching to connect the Jakeway and ODT ditches

would provide more available ditch length (up to approximately 5,000 total feet), which would increase infiltration potential and decrease the likelihood of the ditches overflowing.

- Regularly clean and maintain the ditches. As was indicated by pilot testing, there is potential for sediment carried in the ditches to clog the underlying soils and reduce infiltration rates. The ditches should be scraped to remove sediment, organic material, vegetation and debris at least once a year.

As was noted previously, specifications were provided prior to the pilot tests regarding ditch cleaning and excavation, and placement of check dams. These specifications were achieved for the 2007 testing, but were not repeated prior to the 2008 testing due to budget and time constraints. In addition, recommendations regarding wetting of the ditches could not be fully achieved due to limitations on available time (AR diversions were limited to days the Dungeness flow was above a minimum level), available water (AR diversions were limited to times when irrigators' demand was less than the pipe conveyance capacity), and flow measurement requirements (irrigation managers required a flow meter to be installed at Jakeway).

It is AQ’s estimation that the total potential infiltration capacity for the ditches is within the range of 4 to 7 cfs, as outlined in the table below, assuming that the following conditions are met:

- The entire length of both ditches are cleaned, excavated and maintained to match the geometry shown below.
- Check dams are placed regularly to maintain the average flow depths shown below.
- The surface of the ditch is conditioned to maintain infiltration rates (in feet/day) within the ranges shown.
- The flows to the ditches from the Clallam-Cline irrigation pipeline are sufficient to maintain the projected infiltration rates.

Estimated Infiltration Potential of Jakeway and ODT Ditches

	Jakeway Ditch			ODT Ditch		
	US Reach	DS Reach	Total	US Reach	DS Reach	Total
UPSTREAM FEATURE	Flume 1	Flume 2		Flume 1	Flume 2	
DOWNSTREAM FEATURE	Flume 2	End		Flume 2	End	
TOTAL LENGTH (feet)	1,260	1,390		800	800	
AVE. DEPTH OF FLOW (inches)	18	9		18	9	
BASE WIDTH (feet)	4	3		2	2	
AVE. SIDE SLOPES (__H:1V)	2	2		2	2	
TOTAL WETTED AREA (feet^2)	13,492	8,832		6,967	4,283	
MIN. INFILTRATION (feet/day)	10	10		10	4	

MIN. INFILTRATION RATE (cfs)	1.6	1.0	2.6	0.8	0.2	1.0
MAX. INFILTRATION (feet/day)	20	20		20	10	
MAX. INFILTRATION RATE (cfs)	3.1	2.0	5.1	1.6	0.5	2.1

It should be noted that the four flumes installed for the pilot test had capacities of 0-3.5 cfs each. If the full scale project is designed to infiltrate more than 3-3.5 cfs in either ditch, the flumes would have to be replaced.

3.6.2 Land Acquisition

The Jakeway ditch and ODT ditch were previously owned and operated by the Clallam Ditch Company. The ditch easements are still owned by Clallam Ditch Company and an arrangement would need to be made with Clallam Ditch Company to use this easement to operate the recharge sites on a permanent basis. The property needed to adequately operate the recharge facilities would be roughly equal to the width of the ditch easement times the length of the abandoned ditches, or approximately 2 acres (assuming a 20-foot wide easement). An additional 0.4-acre easement would be required to install a ditch to connect the two sites.

3.6.3 Transmission

As was noted previously, water would be discharged at the proposed recharge sites from an irrigation main owned and operated by Clallam Ditch Company and Cline Irrigation District. The Clallam Ditch Company shares a diversion on the west side of the Dungeness River at River Mile 8.0 with Cline Irrigation District and Dungeness Irrigation Company. Almost all of the Clallam-Cline irrigation system has been piped within the last few years. The system consists of pressurized irrigation laterals and mains ranging in size from 4-inch diameter to 27-inch diameter. The main transmission line between the diversion and the Jakeway and ODT recharge sites consists of 24-inch and 27-inch PVC irrigation pipe rated for pressures up to 125 psi. The 24-inch main was tapped at the upstream end of each abandoned ditch as part of the preparation for the pilot tests. The tap at each location includes an 8-inch gate valve, pipe, and fittings designed to discharge water to the surface at the upstream end of the ditch.

It is estimated that the transmission capacity of the 27-inch and 24-inch transmission line upstream of the Jakeway and ODT recharge sites is approximately 15 cfs. The capacity was estimated based on limiting pipe velocities to 5 fps and headloss to 5 feet/1,000 feet of pipe. Actual operation of the transmission line may allow for higher velocities and headloss.

It is assumed that during the irrigation season (April 15 – September 15) most of the transmission capacity is needed to deliver irrigation flows to Clallam-Cline water users. Recharging water during the spring freshet would require careful coordination and agreement with Clallam Ditch Company and Cline Irrigation District to determine the flow rate that could be discharged for recharge purposes without negatively impacting delivery pressures and flow rates to irrigators.

If recharge occurred during the 6-month period, the early recharge period would occur before the irrigation season; however, operation of the diversion and transmission line outside the irrigation season to deliver water for recharge to the site would also require coordination and agreement with the irrigators, especially since periods of this season may be needed for pipe maintenance.

3.6.4 Construction/Design

Construction and design of a full scale facility at the Jakeway and ODT ditch sites would mostly expand on preliminary design work and ditch excavation that was done in preparation for the pilot tests. Design work would include preparation of a scope of work to develop the full-scale project, any details, and specifications needed to complete permanent ditch treatments and install check dams within the ditches. Construction work would include re-scraping portions of the ditch that were previously cleared and grubbed for the pilot test, clearing and grubbing of ditch sections that were not treated previous to the pilot tests, installation of permanent check dams, and re-installation of the flume at the Jakeway site. If AR flows are expected to exceed 3.5 cfs at either site, the first flumes at least would need to be replaced. If irrigation managers require different flow measurement methods, flumes will need to be reconsidered.

It is anticipated that the system would be operated manually. Valves would be opened and adjusted manually with a valve wrench. However, manual operation will require daily monitoring and adjustment to ensure that inflows are balanced with infiltration. As an option, the system could be installed with level sensors and an automatic valve actuator that would close or open the valve based on the level of water in the ditch. The system could be configured so that levels and flows would be monitored remotely, which would reduce the time and effort required to monitor the system. Remote control of flows to the ditches for recharge would also enable remote coordination with river gauge readings to ensure that water is not diverted for infiltration when in-stream flow requirements are not being met. However, automatic valves, level sensors, and telemetry for remote monitoring would be expensive and more difficult to maintain.

3.6.5 Operation & Maintenance

As was noted previously, successful operation and maintenance of a permanent ditch recharge facility would include the following:

- Regular monitoring of flow rates and tailwater during operation to ensure that the ditches do not overflow and flood adjacent property;
- Regular operation of the valves at taps to the 24-inch main;
- Flushing and cleaning of the discharge assembly at the upstream end of the ditch; and,
- Scraping of the ditches to remove sediment, organic material, vegetation and debris, when monitoring indicates a consistent decline in infiltration rates

3.6.6 Monitoring Recommendations

Similar start-up and monitoring procedures are recommended for annual operation of a permanent ditch recharge facility as were implemented during the pilot test. The following is recommended for monitoring ditch conditions on the initial day of start-up each year:

- Open valve at the mainline to discharge water into the ditch early in the morning to maximize the daylight available to visually monitor the system and adjust the system until it has reached a steady condition.
- Starting at a flow of 0.5 cfs, as measured at the upstream flume, gradually increase inflow by 0.5 cfs increments until inflow is balanced with infiltration.
- Monitor spill at the end of each reach to ensure that overflow does not occur.
- Record flow at the upper and lower flumes every 1-2 hours for the first day (or every 2-4 hours if it takes several days) until the flow is stabilized.

The following daily monitoring is recommended for monitoring ditch conditions during continued operation of the recharge facility:

- Record flows at the flumes 2-3 times a day during the first week of recharge and at least daily after that, and record wetted ditch lengths when flows are recorded to ensure that flows are continually balanced with infiltration.
- Monitor tailwater at end of each infiltration reach daily when flows are recorded. If tailwater exists, estimate flow and note changes. Adjust inflow as needed to eliminate tailwater while maximizing AR flow.
- Visually check water levels in the ditch and flow over check dams.

In addition, continued monitoring of precipitation, Matriotti Creek stage, and water-levels in nearby wells is recommended to develop a better understanding of how ditch recharge affects the groundwater flow system. As discussed in Section 3.6.1, groundwater monitoring during pilot testing was somewhat inconclusive regarding the relative effects of ditch recharge, water levels in the Dungeness River and Matriotti Creek and precipitation on groundwater level trends. Clallam County has developed a network of monitoring wells near the ditches, and monitoring should continue in a subset of 6-10 of these wells as the rate and duration of infiltration from the ditches is increased. Monitoring is best conducted with dedicated transducers and data loggers, as manual monitoring may fail to capture key characteristics of water-level responses at previous pilot test (weekly) measurement frequencies. Monitoring should continue until groundwater level responses associated with operational rates and durations of infiltration are reasonably understood.

Monitoring of source-water and groundwater quality is not an agency requirement in this scenario. Infiltration of Dungeness River water has been occurring through ditches in the study area for over a century without causing water quality problems according to ambient monitoring

(Soule, pers. com., 3/18/09). However, Clallam County notes the importance of continued ambient monitoring to detect changes in water quality and groundwater levels associated with overall changes in land use and ditch recharge over time.

3.7 Permitting Considerations

The availability of river water for AR will also depend on the availability of water rights. A water right application would need to be submitted to specify the period for which use of the water is desired. Both 2-month and 6-month continuous recharge periods were analyzed. If the application were approved, a water right permit would be issued by Ecology that would specify the instantaneous and annual diversion rates, diversion period, location, purpose of use, and other conditions. A new water right would likely be subject to ISF requirements, once rule making is complete in the watershed. The water right would likely be conditioned to instream flows, causing the right to be interruptible when ISF requirements are not met. Purchase and transfer of existing water rights (e.g. irrigation and stock water rights) may represent a second option.

The project will need to be reviewed by Clallam County to ensure that the county's permitting requirements are met. Permitting requirements will include application for a right-of-way permit for any work done within or adjacent to county roadways. In addition, permitting activities will need to address facility ownership, land use, environmental documentation (SEPA), construction and operations.

3.8 Project Implementation

Project implementation would follow a decision to proceed and acquisition of sufficient funding. The following sections describe key elements of project implementation.

3.8.1 Project Approach by Tasks

The following tasks are recommended, in order of priority, to implement a full scale recharge project at the Jakeway and ODT sites:

1. Amend the existing agreement with the Clallam Ditch Company and Cline Irrigation District to deliver flows for recharge at the Jakeway and ODT sites. As was noted previously, the source water for recharge at the Jakeway and ODT will be Dungeness River water diverted at a facility shared by Clallam Ditch Company, Cline Irrigation District, and Dungeness Irrigation Company. The water will be conveyed from the Dungeness River to the site via a transmission line that is the backbone of the Clallam-Cline irrigation system. Delivery of water for recharge will need to be negotiated with, agreed to, and managed by the irrigators so that irrigators are not negatively impacted by the project.

2. Negotiate agreement to use the ditch easement with the Clallam Ditch Company, rights of way with affected property owners along the ditch, and continued access to monitored wells from well owners.

3. Prepare plans, specifications, and a final description of the work to be completed to treat the ditches, install check dams and upgrade appurtenances needed to establish a permanent recharge facility at the Jakeway and ODT sites.
4. Complete the required permit applications and secure permits for the project, as outlined in Section 3.7.
5. Prepare and document a formal monitoring plan for the project to include yearly start-up procedures, daily ditch flow monitoring requirements, groundwater level monitoring, and Matriotti Creek monitoring (in addition to existing monitoring of precipitation and Dungeness River flow).
6. Prepare and document a formal operations and maintenance plan, including valve operations and maintenance, discharge assembly operations and maintenance, ditch maintenance, flume operations and maintenance, and check dam maintenance.
7. Advertise, bid and construct the improvements needed to establish a permanent recharge facility at the Jakeway and ODT sites.

It is assumed that the tasks listed in this section would be completed prior to Ecology making a decision on issuing a temporary water right for the full-scale recharge facility.

3.8.2 Project Schedule

It is anticipated that if funding is made available, a full scale recharge facility could be operating at the Jakeway and ODT sites in time to capture the spring freshet in 2010. It is anticipated that plans, specifications, a final description of work to be completed, a monitoring plan, an operations and maintenance plan, and permitting documentations could be prepared within two-to-four months of a decision to proceed with the project. Assuming that an agreement has been reached with the irrigators regarding delivery of water and use of the ditch easement by that time, permitting can proceed. Because construction work will build on work that was done in preparation for the pilot tests, it is anticipated that construction work can be completed in 1 month. The most significant variable in development of a schedule for implementation of a full scale recharge project at this site will be the time required for negotiations with irrigators, and permitting and securing a water right to operate a long-term recharge project. Ecology may choose to wait to issue a new water right until instream flow requirements have been formalized (expected after the 2009 irrigation season), but may issue temporary water rights until such time.

3.8.3 Project Cost Estimate

A summary of estimated costs associated with implementation of a full scale recharge project at the Jakeway and ODT sites is presented in the table below. The costs provided include a range defined by a low and high estimate. The total estimated cost, in 2009 dollars, for completing the planning, design, permitting and construction of the project is estimated to be in the range of $136,500 to $154,700. Additional costs will be incurred through regular monitoring, operation, and maintenance of the recharge facility. Costs will be incurred each spring for cleaning and scraping the ditches to remove sediment and debris. Costs will include a day of start-up, and daily monitoring and maintenance during recharge operations. Assuming that these tasks are handled locally and over a 2-month operating period, it is estimated that these costs will be approximately $15,000 annually. Operations and maintenance costs would be much higher if the recharge site was operated continuously for 6-months each year. In addition, technical review of groundwater level monitoring data is recommended until groundwater level responses to enhanced rates of infiltration are well documented and understood. This would likely occur over one or two seasons, at an estimated contracted cost of up to $8,000 per season. Optional project costs may include constructing a connection between the Jakeway and ODT ditch sites and installing valve actuators and telemetry for remote control of the project. The cost of planning, design, and installation of a connection between the Jakeway and ODT ditch sites is estimated to be in the range of $35,000 to $45,000. The cost of valve control instrumentation and telemetry could vary significantly depending on what is installed. A system that includes valve actuators, level sensors, and telemetry units set up for remote control of the system will likely be at least $25,000 and may be as much as $50,000.

PRELIMINARY COST ESTIMATE FOR SCENARIO A

ITEM	Lower End	Upper End	Notes
Construction – Ditch Upgrades, Jakeway Flume Replacement, Check Dams	$50,000	$56,500	
Planning, Engineering and Construction Administration	$20,000	$22,500	
Water Rights and Permitting	$25,000	$28,000	
Generation of Agreement with Irrigators	$10,000	$12,000	
SUBTOTAL – FIXED COSTS	$105,000	$119,000	
Planning Contingency (30%)	$31,500	$35,700	
ESTIMATED TOTAL – FIXED COSTS	**$136,500**	**$154,700**	
ESTIMATED ANNUAL COSTS	**$23,000**	**$31,000**	AR assumed 2 months/year
OPTIONAL COSTS			
Connecting ODT and Jakeway Ditches	$35,000	$45,000	
Automatic Valves and Telemetry	$25,000	$50,000	

3.9 Summary of Costs, Benefits and Concerns

As was outlined in Section 3.8.3, implementing a full-scale recharge project using abandoned ditches at the Jakeway and ODT sites for recharge will cost an estimated $136,500 to $154,700. It is estimated that it will cost an additional $15,000 annually to operate and maintain the facilities based on a 2-month recharge schedule (the annual O&M cost would be proportionally higher for a 6-month recharge schedule), and another $8,000 to $16,000 for contracted analysis of groundwater response to AR infiltration.

The major benefit of the project is that it will provide a site to infiltrate up to 7 cfs during the spring runoff (with some upward adjustments possible if the two ditches were connected). If the recharge project were operated for two months during the spring freshet each year, that water would recharge the shallow aquifer and augment flows in the Dungeness River during the low flow period by approximately 0.7 to 1.4 cfs, according to modeling analyses performed for this project. The analyses indicate that the increase and duration of Dungeness River flow augmentation would be greater (1.4 to 2.8 cfs in the low-flow season) if recharge at 7 cfs was continuous for 6 months each year (Jan.-July).

Associated changes in Dungeness River habitat are estimated to be small and likely non-measurable. While the predicted flow augmentation could provide significant mitigation for offsetting impacts of water-supply development, multiple such AR projects (possibly combined with other measures) would be needed to provide significant habitat benefit. It should be noted that additional locations could be considered for similar AR projects. Sites closer to the irrigation diversions will have better flow availability due to higher conveyance capacities. Pond sites may also be considered, however, the cost to purchase land for an infiltration pond (including overflow area) is likely higher than the cost of a ditch easement.

Concerns associated with Scenario A are primarily related to source availability. Conveyance of the AR water requires cooperation and agreements with the irrigators, and it is not yet clear whether their pipes can accommodate delivery of 7 cfs or more to the AR project during the spring freshet window of opportunity prior to July 15. Streamflows available for diversion under a new water right would be subject to ISF requirements, and availability could be variable from year to year. Climate change predictions for the Pacific Northwest include earlier and reduced spring freshets, which may affect overall source availability during the freshet period. However, the extent to which reduced freshet flows would affect source availability into the future has not been evaluated at the scale of this project.

4 SCENARIO B: RECLAIMED WATER AR IN INFILTRATION POND EAST OF DUNGENESS RIVER

4.1 Conceptual Project Design

Preliminary assessments of AR feasibility have been performed for several sites east of the Dungeness River (PGG, 2007b). Several of these sites have reasonable potential for AR operations; however, these sites are within the Sequim city limits, and Sequim will be performing its own site-specific analyses of AR feasibility in the near future. For this reason, City staff requested that this FS evaluate sites outside the city limits, and the County selected a general area of undeveloped property northwest of the city limits shown on **Figure 1-1**. At the County's request, PGG performed a general evaluation of AR feasibility within this area. We expect that site selection for reclaimed-water AR would ultimately include consideration of the existing preliminary assessments, the area evaluation included in this FS, and any future site assessments performed by the City.

Under Scenario B, an infiltration basin would be constructed on the selected site, and Class A reclaimed water generated by the City of Sequim would be piped to the site. The quantity of reclaimed water delivered to the site would depend both on site infiltration capacity and source availability. Current generation of reclaimed water is on the order of about 0.5 mgd (0.8 cfs); however, Sequim expects to produce an annual average of 2.0 mgd (3.1 cfs) by 2025 *Gray & Osborne, 2007). Reclaimed water would be available for AR outside the growing season, when the City is not making use of the water for irrigation. Scenario B assumes that reclaimed water would be available from October through May. (It should be noted, however, that the City is in the early stages of planning their reclaimed water management, and the actual timing and magnitude of reclaimed water availability for AR has not been determined.) According to modeling conducted for this study, infiltrated water would move through the subsurface to augment flows in the Dungeness River, Cassalery Creek and Gierin Creek/Graysmarsh.

4.2 Hydrogeologic Setting of Project Site

NRCS soil mapping shows that surficial soils in the area considered are comprised of Carlsborg gravelly sandy loam (map unit 6) and Carlsborg-Dungeness complex (map unit 7), as shown on **Figure 4-1.** Carlsborg gravelly sandy loam (map unit 6) occurs on alluvial fans and terraces, is derived from alluvium, is somewhat excessively drained, and is moderately permeable. NRCS estimates that saturated hydraulic conductivity values for a typical soil profile range from 4 to 12 feet/day. Gravelly and cobbly sand are common components of this soil type; the NRCS do not report silt in significant quantities. Carlsborg-Dungeness complex occurs in river valleys and is reportedly comprised of about 50 percent Carlsborg soils (described above) and 30 percent Dungeness soils. Similar to the Carlsborg soils, Dungeness soils are derived from alluvium and occur on river terraces and in floodplains. They are well drained and slightly less permeable than the Carlsborg soils (NRCS estimates hydraulic conductivity values between 1 to 4 feet/day). NRCS report a silt component to these loamy soils.

The surficial geology in the site vicinity is comprised of "older alluvium" (Qoa) and alluvium (Qa) as mapped by Schasse and Logan (1998) (**Figure 4-2**). Within the area considered, Qa coincides with the Carlsborg-Dungeness soils, and has been described above in Section 3.2. Within the area considered, Qoa is coincident with the Carlsborg soils, and is described by Schasse and Logan as follows:

> "Stratified cobbly gravel, sand and gravel, sand, silt, and clay; brown to dark reddish brown; consists of cobble gravels near Sequim and upslope to the southwest to progressively finer grain sizes downslope to the northeast, following the underfit streams, Cassalery, Gierin and Bell Creeks. These exposures are flood-plain terrace deposits of an ancestral Dungeness River whose current channel and flood plain have moved west; this alluvium probably represents older deposition by an early Dungeness River (Othberg and Palmer, 1970).
>
> The unit is mapped on the basis of geomorphology and texture. Thickness is varied and ranges from a few feet to more than 70 feet near the centers of former floodplain channels now occupied by these deposits. On aerial photographs, unit Qoa has an anastomosing appearance that strongly resembles a braided stream pattern.
>
> Unit Qoa overlies till and ice-contact deposits of the Vashon glacial stade (units Qgt_v and Qgo_{vi}); at shallow depth it may locally lie disconformably on glaciomarine drift of the Everson Insterstade (unit $Qgdm_e$). Water well logs indicate that the unit overlies older nonglacial fluvial channel sands and gravels, overbank silts, and estuarine silty clay deposits in the lower drainage of present-day Bell Creek. These deposits can be seen in the bluff exposures at nearby Washington Harbor."

The Qa and the Qoa sediments are both included in the shallow aquifer. The USGS describe the shallow aquifer as composed of a variety of geologic materials, including: stream alluvium, glaciomarine drift, glacial outwash, ice contact deposits, and glacial till (Thomas et al, 1999). Given the range of geologic materials present, the texture of the shallow aquifer can vary from fine-grained, to coarse-grained, to heterogeneous (locally variable). The thickness of the shallow aquifer beneath the area under consideration is mapped as ranging from about 50 to 250 feet (ibid.). These estimated thicknesses suggest that the USGS included various geologic units that underlie the Qoa and Qa in their definition of the shallow aquifer. The USGS note that the shallow aquifer is regionally unconfined, but can exhibit some local confinement and shallow perching with the occurrence of glaciomarine drift or till.

PGG performed a review of 38 well logs in the vicinity of the study area ranging in depth from 18 to 217 feet. The majority of wells (63 percent) were completed between 50 to 100 feet below land surface, and only 13 percent were completed within 50 feet of the land surface. Our review indicated that the upper portions of the shallow aquifer generally contain coarse-grained sediments, but also exhibit variable contents of clay binder and cementation. Well logs report zones of clean sands, gravels, cobbles and boulders interfingered with zones containing clay-binder or cementation and with finer-grained zones such as those described as "sandy clay". This variable distribution of clay-bound zones is consistent with the lateral and vertical variability associated with stream channel migration in alluvial environments. Some driller's logs mention shallow "hardpan", which may be indicative of cemented alluvial deposits. Glacial till (Qgt) is unlikely to be present in the alluvial Qoa deposits, although it may underlie the Qoa.

Given the variable (but common) occurrence of clay and cemented zones, the ability to infiltrate water at any particular site will depend on local conditions. If the lower-permeability clay and cemented zones are local and not well connected over large areas, the infiltrated water will be able to make its way through the highly permeable zones of clean gravel and cobbles and diffuse through the groundwater flow system. If the clay/cemented zones are extensive and well connected, they will inhibit downward infiltration of the AR water. Because the shallow aquifer may include multiple sedimentary units with varying hydraulic properties, it is possible that deeper portions of the shallow aquifer that underlie the Qa and Qoa sediments may be hydraulically removed from water infiltrated at the land surface, and therefore may not participate much in diffusion of the infiltration mound. Field investigation would be needed to assess the capability of a particular site to diffuse infiltrated water, and whether this water moves through all or just parts of the shallow aquifer.

PGG's calibrated model suggests that sites within the area under consideration fall within hydraulic conductivity zones of 15 or 100 ft/d in the shallow aquifer. Although the model has distinct boundaries for these zones, their simulated distribution must not be considered exact and only site investigations can determine actual aquifer properties. Modeled transmissivity values range from about 1,500 to 10,000 ft^2/day. Because portions of the shallow aquifer may not be accessible for diffusion of the infiltrated water, effective transmissivity values for diffusing the infiltrated water may be lower. Again, field investigation is required to refine model predictions of transmissivity to local site conditions.

PGG's review of local well logs shows that groundwater levels in the area generally range from 10 to 60 feet, with 30 percent of wells showing depths-to-water between 10 and 20 feet. The distribution of depth-to-water among the 38 reviewed wells suggests that some sites may have ample freeboard to accommodate mounding (assuming that the sediments above the water table have sufficient permeability), whereas other sites may have limited freeboard.

PGG reviewed local hydraulic gradients described in the USGS publication (Thomas et al, 1999). Horizontal gradients in the area under consideration are relatively gentle at approximately 0.013 to 0.017 ft/ft in a northeastern direction. USGS piezometric surface maps suggest that local heads in the shallow aquifer are about 40 to 50 feet higher than heads in the middle aquifer (PGG's 2008 groundwater model shows head differences of about 40 to 45 feet). Thus, downward gradients occur across the upper confining bed in this area. Assuming a local aquitard thickness of around 75 feet (Thomas et al, 1999), travel time through the aquitard is estimated to range from about 9 to 85 years[11].

[11] Travel time can be estimated as $b^2n/Kz*\Delta h$ where b is the thickness of the aquitard, n is the aquitard porosity (20%), Kz is the aquitard vertical horizontal conductivity (0.0008 ft/d or 0.008 ft/d for uncertainty analysis), and Δh is the head difference across the aquitard.

4.3 AR Source (Reclaimed Water)

The City of Sequim operates a sewage treatment plant adjacent to Sequim Bay that is currently capable of producing about 0.5 mgd (0.8 cfs) of Class A reclaimed water. Sequim expects to produce as much as 2.0 mgd[12] (3.1 cfs) by 2025 based on growth projections and treatment plant capacity. Monthly variation in reclaimed water generation is fairly insignificant. However, during the growing season (June through September), the City expects to use the majority of its reclaimed water for irrigation. Therefore, reclaimed water is expected to be available for AR over an 8-month period from October through May.

The City currently has a transmission pipeline running from the treatment plant up to Carrie Blake Park (near Bell Creek), and further inland to beyond the City Shop (**Figure 1-1**).

4.4 Predicted Fate of Recharged Water

PGG used the 2008 groundwater flow model to evaluate the fate of water infiltrated over an 8-month period. Model predictions should be considered approximate, but provide reasonable indication of the general magnitudes of streamflow augmentation. The model was run with S_y values of both 0.1 and 0.2. Because FS Scenario B specifies only a general area for AR (as opposed to a unique site), PGG chose a site within this area for model simulation. **Figures 4-3** and **4-4** show model predictions of augmented flow in the Dungeness River, Cassalery Creek, and Gierin Creek. For the S_y = 0.2 simulation, the model predicts rates of augmentation (as percent Q_{ar}) ranging from 29 percent to 33 percent for the Dungeness River, 12 percent to 13 percent for Cassalery Creek, and 14 percent to 15 percent for Gierin Creek. For the S_y = 0.1 simulation, the model predicts rates of augmentation (as percent Q_{ar}) ranging from 24 percent to 37 percent for the Dungeness River, 21 percent to 30 percent for Cassalery Creek, and 12 percent to 16 percent for Gierin Creek. In both cases, the annual volume of streamflow augmentation (relative to V_{ar}) is predicted to be 47 percent for the Dungeness River, 19 percent for Cassalery Creek, and 21 percent for Geirin Creek. These higher values are due to the fact that the AR volume is based on infiltration for only 2/3 of the annual cycle (8 of 12 months).

Bell Creek was predicted to receive a minor portion (about 2.4 percent) of the AR infiltrated in the area under consideration. However, given that portions of lower Bell Creek appear to be hydraulically connected to shallow perched groundwater (PGG, 2000), this estimate may be too high. All other streams simulated by the model received insignificant portions of the AR infiltrated (e.g. <0.3 percent).

PGG ran the 2008 groundwater flow model in steady-state mode to estimate the spatial distribution of augmentation to the Dungeness River. **Figure 4-5** shows the distribution of augmentation per model cell, expressed as percent of the annual V_{ar}. Previous model analysis suggests that the Var is distributed similarly between steady-state (year round) and transient (partial year) AR simulations. The relative spatial distribution of V_{ar} may also roughly

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[12] Maximum treatment capacity 2.23 mgd.

approximate the average spatial distribution of instantaneous augmentation from transient AR – at least on a regional scale. However, departures from the relative V_{ar} distribution are expected as mounding from the AR operation expands and contracts over the AR cycle. As noted above, instantaneous augmentation rates (expressed as percent Q_{ar}) will be lower than annual augmentation (expressed as percent V_{ar}) because AR infiltration occurs during only a portion of the year.

Infiltration of reclaimed water requires consideration of source water quality and the downgradient hydrologic features (wells, streams, wetlands) that receive a portion of the infiltrated water. An exact site is not yet selected for Scenario B; however, model-predicted groundwater flow directions, counts of domestic wells per quarter-quarter section, and streams are shown on **Figure 4-2**. Groundwater flow is predicted to occur in a north-northeast direction, and flow velocities in the area under consideration are predicted to range from about 2 to 5 ft/d (under 1995-1997 calibration conditions). Counts of well logs range from 3 to 27 per quarter-quarter section within and downgradient of the area under consideration. Water quality and downgradient wells are further discussed in Section 4.5.1.

4.5 Environmental Impacts

4.5.1 Water Quality Considerations

The state requires all reclaimed water to be used for groundwater recharge through surface percolation to be at least Class A (highest level of treatment). The applicant will also need to demonstrate that percolated reclaimed water will meet state groundwater quality requirements so the resource can continue to be used as a drinking water source[13]. According to the state's Water Reclamation and Reuse Standards, Class A Reclaimed Water is defined as:

> "Reclaimed water that, at a minimum, is at all times an oxidized, coagulated, filtered, disinfected wastewater. The wastewater shall be considered adequately disinfected if the median number of total coliform organisms in the wastewater after disinfection does not exceed 2.2 per 100 milliliters, as determined from bacteriological results of the last 7 days for which analyses have been completed, and the number of total coliform organisms does not exceed 23 per 100 milliliters in any sample." (Washington State Departments of Health and Ecology, September 1997)

Class A Reclaimed Water is clean enough for public contact and any use except direct consumption.

Recharge from the land surface relies upon the ability to infiltrate the water into the soil strata and finally into the aquifer. The source water characteristics that most affect the operational capacity of infiltration basins are total suspended solids (i.e. turbidity), dissolved nutrients,

[13] Recharged reclaimed water has to meet drinking water standards as it reaches the groundwater table. This may or may not meet antidegradation criteria in WAC 173-200, but reclaimed water is not required to meet this requirement. The local health department will likely decide on the level of treatment and acceptability.

biochemical oxygen demand, microorganisms, dissolved gasses and disinfection byproducts (DBP's).

Data from 2007 at the Sequim wastewater treatment plant contained in their daily monitoring summary suggests total nitrogen levels vary seasonally between 1.5 and 7.5 mg/l with the higher levels being present during the cooler months (November – April) and the lower values during warmer months. This is due to the effectiveness of the biological treatment process as it responds to temperature. BOD and TSS values range between 3-10 mg/l and 1-2 mg/l respectively (not as temperature dependent as nitrogen). Based on this data, nitrogen concentration in the recharge water is likely to exceed the groundwater background levels during the active recharge period (outside the growing period). Pilot testing and modeling may be needed to determine changes to nitrogen levels.

Although reclaimed water may not meet the standards of the antidegradation policy (Ch. 173-200 WAC), the groundwater (at the negotiated point of compliance) must still meet the drinking water requirement of 10 mg/l nitrate. At a total nitrogen level of up to 7.5 mg/l in the source water, the nitrate fraction will likely not exceed 5-6 mg/l. Because nitrates are highly mobile in groundwater, downgradient potable wells in close proximity to the recharge basin could see a change in water quality. Depending upon the scale of the impact, these wells may require mitigation and/or monitoring. This will be an issue to discuss and resolve with the local and state health departments and well owners prior to implementation.

The potential for DBP's will be controlled, in large part, by reclaimed water total organic carbon (TOC) concentration and chlorine residual dosage. Controlling DBP formation can be accomplished through careful control of the chlorine addition to assure excess chlorine is not present at the recharge site. The DBP compounds also break down when exposed to sunlight in the recharge basins and generally are not an groundwater quality compliance (WAC 173-200) issue. This issue is more often a controlling factor important with reclaimed water and injection wells. In these cases, an AKART (all known and reasonable treatment) assessment would be necessary.

It is anticipated that haloacetic acids (HAA) concentrations will dissipate quickly (within days of storage) in the vadose zone or the aquifer (in the immediate vicinity of application) as a result of aerobic microbial degradation. Trihalomehane (THM) concentrations may increase slightly after injection as a result of the reaction between the TOC present in the recharge water and any residual chlorine; however, THM concentrations should decrease with time (within weeks of storage) due to anaerobic microbial activity in the subsurface once introduced oxygen is depleted. Dilution caused by mixing between recharge water and native groundwater is also expected to reduce DBP concentrations.

An emerging area of consideration associated with groundwater recharge using reclaimed water is the fate of pharmaceutical, personal care products, metals, and other endocrine-disrupting compounds (EDCs). The Department of Ecology recently completed an assessment of these compounds from Lower Dungeness reclaimed water facilities. The recommendations from this 2004 Ecology study suggests additional monitoring for pharmaceuticals and personal care products (PPCPs) is a low priority in connection with the Sequim and Sunland wastewater treatment plants (Johnson et al, 2004). Based upon this report it appears the concentration of these compounds in receiving waters appears to be below levels to be hazardous for human health. However, PCPPs and other EDCs will continue to be a public concern and managed to properly represent the environmental and human health risks.

Washington Department of Health may require that Class A reclaimed water infiltration facilities be sited at least a 1-year travel-time from public supply wells unless mitigation and monitoring are performed[14]. Based on model-predicted groundwater velocities of as much as 5 feet/day, a 1-year travel time distance is estimated to be about 0.35 miles. The counts of well logs per quarter-quarter section shown on **Figure 4-2** do not distinguish between domestic wells and small (Group B) water systems. The City of Sequim's wellfields are far from the area under consideration. If an AR site were selected within the area of interest, additional investigation would be needed to identify public supply wells within the 1-year travel time. As site specific hydrogeologic information is collected, the 1-year travel time distance may be further refined. Consideration of downgradient domestic wells would likely be dictated by the County Health Department.

4.5.2 Net Effect on Habitat

There is no diversion from the mainstem Dungeness River under Scenario B. As such, there are only net flow increases in the mainstem and some small independent streams on the east side of the Dungeness River. As discussed in Section 4.4, the 2008 groundwater model predicted flow augmentation in the Dungeness River, Cassalery Creek, and the Gierin Creek/Graysmarsh complex with minor flow increases in other nearby streams.

4.5.2.1 Effects on the Mainstem Dungeness River

AR infiltration is anticipated to augment mainstem Dungeness River flows primarily below RM 7.2, with most of the groundwater return flow between RM 3.8 and RM 7.2 (**Figure 4-5**). Flow augmentation occurs year-round at average rates of around 30 percent of Q_{ar}, with less annual variation when $S_y = 0.2$ (**Figure 4-3**) versus when $S_y = 0.1$ (**Figure 4.4**). The instantaneous peak augmentation is projected to occur in late June in the model run using $S_y = 0.1$; compared to early August using the $S_y = 0.2$ assumption. The current available amount of reclaimed water is 0.8 cfs, with a maximum projected 3.1 cfs in 2025.

The results of anticipated mainstem flow augmentation for these two AR rates are shown in **Table 4-1**. Augmentation is predicted to range from about 0.2 to 0.3 cfs for a Q_{ar} of 0.8 cfs, and between 0.7 to 1.1 cfs for a Q_{ar} of 3.1 cfs. Augmentation during the lowest flow period of the year (September – October) is predicted to be about 0.2 cfs (Q_{ar} – 0.8 cfs) and 1.0 cfs (Q_{ar} = 3.1

[14] WDOH has not established regulatory guidelines for consideration of Group A or Group B public supply wells.

cfs). The 90 percent exceedance flow between August and October at the upper IFIM study site at RM 4.2 is on the order of 82 cfs as extrapolated from England (1999) using current levels of irrigation withdrawals. The maximum anticipated AR augmentation during this period, assuming a Q_{ar} of 3.1 cfs, is about a 4.0 percent increase in mainstem river flow and a 1 percent increase in Chinook salmon spawning WUA (the most critical life history stage during this time period) at the 90 percent exceedance flow level. The minimum flow augmentation during this period, assuming the existing amount of reclaimed water available for AR (0.8 cfs) is immeasurable in terms of mainstem discharge and Chinook spawning WUA increases. In accordance with the IFIM/PHABSIM model, a flow increase of 10 cfs would be needed to provide a 10 percent improvement in Chinook spawning habitat during this low flow period (Hiss 1993a, b).

4.5.2.2 Effects on Side Channels

Daraio et al. (2003) modeled the characteristics of three surface water side channels in the flow augmentation area between RM 3.8 and 7.2 including: Dawley, the E. (Lower) Railroad Bridge, and Stevens/Savage. A maximum of 1 cfs augmentation in the mainstem will have little to no influence on the suitability of habitat conditions in any of these side channels (Daraio et al. 2003, R2 2007). For example, as shown in the habitat technical memo (TM) (R2, 2007), a 2 cfs incremental increase in mainstem flows would have less than 0.4 percent change in key physical habitat parameters of side channel width, discharge, depth, or velocity (**Table 4-2**).

These small changes are insufficient to alter the suitability of habitat conditions for various life histories of salmonid fishes as described in the TM. A minimum detectable habitat change might be on the order of a 30 percent increase in mean mainstem river flow conditions.

4.5.2.3 Effects on Small Streams

The 2008 groundwater model predicted flow augmentation in Cassalery Creek and Gierin Creel, with minimal augmentation in other nearby streams (Section 4.4). Cassalery Creek and Gierin Creek are independent drainages discharging to Strait of Juan de Fuca east of the Dungeness River. Cassalery Creek has a bankfull width and depth of approximately 20 feet and 1.3 feet respectively. Springtime discharges run between 2 and 6 cfs. Summer low flows typically range from 1 to 2.5 cfs, although higher low flows were noted prior to 1999 (PGG, 2008a). Flows in the lower reaches of Gierin Creek (above Graysmarsh) typically range from 0.2 to 1.5 cfs, although flows as high as 3.5 cfs have been noted (ibid).

The percent of Q_{ar} augmenting flow in Cassalery Creek in estimated to range between 10 and 15 percent for the 8-month AR option under Scenario B, depending upon the specific yield assumption used in the model. Estimated augmentation rates in Cassalery Creek range between 0.1 and 0.5 cfs. Using the best-case assumptions of S_y = 0.1 and a Q_{ar} of 3.1 cfs suggests a maximum augmentation of 0.5 cfs would be available in Cassalery Creek during the month of July. This volume could increase the lowest baseflows in the creek by about 50 percent. Although no quantitative habitat/flow modeling effort has been completed for this stream, a 50 percent increase in baseflow could support enhanced rearing productivity of coho salmon, steelhead and cutthroat trout.

The percent of Q_{ar} forecasted to surface in Gierin Creek ranged between 12 and 16 percent for the 8-month AR options under Scenario B. Thus, the anticipated augmentation rates in Gierin Creek range between about 0.1 cfs for a Q_{ar} of 0.8 cfs and 0.4 cfs for a Q_{ar} of 3.1 cfs. Using the best case assumptions of $S_y = 0.1$ and a Q_{ar} of 3.1 cfs suggests a maximum augmentation of 0.4 cfs would be available in Gierin Creek during the months of July and August in 2025. Relative to baseflows ranging from 0.2 to 1.5 cfs, a 0.4 cfs increase could support enhanced rearing productivity of coho salmon, steelhead and cutthroat trout.

4.5.3 Shallow Groundwater / Flooding

Sufficient freeboard is required to allow groundwater mounding beneath in the vicinity of an infiltration basin without causing the water table to intersect (and thereby flood) the land surface. The thickness of the unsaturated zone (vadose zone) dictates the freeboard between the land surface and the shallow water table. The shallow water table is defined as the uppermost occurrence of seasonal saturation beneath the land surface. However, it should be noted that a new shallow water table can form if the sediments that overlie the historic shallow water table cannot accommodate the rate of recharge associated with the infiltration basin. The duration and extent of groundwater mounding is dependent on such factors as:

- Rate and duration of recharge application;
- Aerial extent of the application;
- Aquifer thickness, horizontal and vertical hydraulic conductivity
- Proximity of discharge features or hydraulically connected surface-water bodies.

A specific site has not been identified for AR Scenario B; however, PGG has reviewed well logs in the area under consideration. As noted above, groundwater levels in local wells generally range from 10 to 60 feet, with 30 percent of wells showing depths-to-water between 10 and 20 feet. If the sediments between the land surface and the intakes of shallow wells are reasonably permeable, freeboard is expected to be similar to the depth to groundwater measured in these wells. However, it is important to note that although the upper portions of the shallow aquifer contain coarse-grained sediments, they also exhibit variable contents of clay binder and cementation. Shallow occurrence of clay binder or cementation can impede the downward flow of recharge, and thus cause shallow water-table conditions above the water levels observed in wells. Actual freeboard must be evaluated on a site specific basis, and could range from local depths-to-water observed in shallow wells to perched water tables above shallow lower permeability sediments.

The groundwater flow model was used to estimate mounding in the vicinity of an infiltration basin based on 8 months of reclaimed water recharge at 2 cfs spread out over a model cell (1320 x 660 feet). While the model predicts that the maximum mounding associated with this recharge would range from 14 to 15 feet, it includes several assumptions that may alter the estimated mounding if not locally applicable. Specifically,

- Mounding is assumed to be distributed over a larger area than typically attributed to an infiltration basin (i.e. the model cell is considerably larger than a typical infiltration basin). In actuality, concentrating the recharge rate over a smaller area would cause additional mounding in the immediate vicinity of the infiltration basin.

- The shallow aquifer is simulated as a single layer with no discrete low permeability units. Local occurrence of low-permeability silt-bound or cemented sediments could impede the flow of infiltrated AR into portions of the aquifer, thus causing higher mounding.

- The site simulated by the model is close to an estimated region of low aquifer hydraulic conductivity (Section 4.2). If the actual site is farther from this region, mounding will be less than predicted. However, if the actual site is within this region, mounding will be greater than predicted.

- The model does not represent local variations in aquifer hydraulic conductivity ("local heterogeneity"). Areas of locally high permeability may have less mounding than predicted by the model, whereas areas of locally low permeability will have more mounding.

The potential for groundwater flooding at the infiltration basin and in nearby areas will ultimately depend on local site conditions. Several factors could cause actual mounding to exceed model estimates, and the combination of this increased mounding along with the possible occurrence of shallow (low permeability) perching layers, could disqualify some of the sites. Site investigations and pilot testing will ultimately be needed to evaluate whether specific sites within the area under consideration can accommodate the assumed rate and duration of reclaimed water AR (2 cfs for 8 months). Alternative infiltration-basin designs and/or multiple locations may also be necessary to maximize recharge rates if freeboard is locally limited.

4.6 Engineering Considerations

4.6.1 Pilot vs. Full Scale Project

Pilot testing is used to better calibrate numerical models, estimate impacts from long-term AR activities, and establish defendable design criteria. The actual results and impacts of long-term AR activities will ultimately be determined by long-term operating data. The degree of pilot testing required prior to full scale implementation will depend on the extent to which key project outcomes (e.g. infiltration capacity, mounding, groundwater quality, time of travel and permitting) are critical to project success. This is a function of both acceptable risk to the project proponent and regulatory needs.

Estimating long term operational impacts is a combination of science and art; however, increasing levels of pilot testing can better approximate full-scale results to satisfy public and regulatory concerns. It is not uncommon that pilot testing at up to one-quarter scale over a four to six month period may be necessary to address potential issues. Pilot scale testing at up to 0.2 cfs can exceed several hundred thousand dollars and also satisfy the preliminary design reporting requirements. The scale of pilot testing should be discussed early in the project implementation to meet schedule, budget, and regulatory needs based on the project proponent's acceptable risk level.

Pilot tests may need to be conduced on multiple properties depending on the test results. Pilot testing would ideally be conducted prior to property purchase; however, the site modification required for testing usually precludes this. For any given site, if preliminary AR feasibility investigations suggest favorable surficial soil characteristics and hydrogeologic conditions, pilot testing should be performed prior to planning and design for full-scale operation. The purpose of the pilot study is to evaluate the following full-scale design issues:

- Surface soil characteristics, infiltration rate, and type of imported sand for the basin floor.
- Hydrogeologic conditions and potential for excessive water-level mounding in the vadose zone due to perching of recharge water.
- Shallow aquifer flow parameters and observed response to recharge mounding.
- Operation characteristics and equipment performance.
- Design features for project facilities and maintenance requirements.

The capacity of the groundwater recharge basin is limited by the surface recharge rate and the ability of the aquifer to transmit water away from the recharge basin (minimize flooding). As part of the recharge basin pilot test, monitoring wells should be installed to evaluate hydrogeologic conditions at the site, to estimate shallow aquifer flow parameters (aquifer thickness, hydraulic conductivity), and to monitor the mounding response in the aquifer during recharge. The wells will also be used to evaluate seasonal variation in water-level elevations and evaluate water quality. Based on the results of the aquifer testing and mounding response during pilot testing, the predicted response to full-scale recharge operations can be calculated using groundwater flow models such as a modified version of the 2008 Dungeness Model (PGG, 2009) or other types of mathematical models.

The capacity of a recharge basin is also affected by clogging as the ponding period increases. During pilot testing, drying cycles and various ponding/drying cycle frequencies can be evaluated to optimize basin performance and clogging mitigation techniques if the project proponent is willing to perform testing for sufficient periods (e.g. a minimum of several months). The pilot test will additionally allow testing of various basin scraping devices to understand which devices are effective at removing the clogging material with the minimal amount of disturbance to the basin floor. A goal of the testing is to select the optimal equipment for basin maintenance and accurately project the long-term operation costs.

After the pilot test is complete, the data will be used to assimilate the design criteria required for the successful construction and operation of the full-scale groundwater recharge facility. The design features that need to be resolved during the pilot test are:

1. Existing groundwater levels and seasonal variations at the proposed site.
2. Aquifer properties (hydraulic conductivity, transmissivity, storage coefficient) that affect hydrologic responses to AR.
3. The expected amount of groundwater mounding (height, elevation, and lateral dimensions).
4. The final area required for the groundwater recharge basins, based on soil and aquifer properties, water levels, and expected mounding.
5. The hydraulic residence time in the aquifer and travel time to nearby wells.
6. The site background water quality and expected water-quality impacts;
7. The type, grade and depth/quantity of imported sand used in the groundwater recharge basins.
8. The number of basins needed to accommodate the ponding/drying schedule determined during the pilot test.
9. The required basin maintenance and frequency.
10. Equipment required for operation and maintenance.

4.6.2 Land Acquisition

Land acquisition represents substantial financial and policy commitments and must be balanced with the risk tolerance of the owner. Unfortunately for these types of facilities, the information necessary to make an informed decision can only be obtained from the site itself. This will require purchasing, environmental documentation, and technical assessment approaches to be coordinated to enable purchasing decisions to meet the needs of the lead agency. There are many strategies to accomplish this sort of purchase, but they can increase the ultimate cost of purchase and the implementation time period.

As previously stated, a general area northwest of Sequim city limits has been identified as a potential area for infiltration basin construction. Preliminary factors to consider when evaluating land for purchase within this general area include the following:

- Proximity of the site to the existing wastewater conveyance system and other utilities.
- Zoning and preferences for undeveloped properties and willing sellers.
- Proximity and potential impacts to streams, rivers, irrigation ditches and other surface-water bodies.
- Proximity and potential impacts to neighboring wells.

- Proximity and potential impacts to environmentally sensitive areas (e.g., wetlands, areas prone to flooding, or slope instability)

Preliminary AR feasibility investigations can be performed prior to purchase, but can only address these considerations to a limited degree. Such investigations are typically based on readily available (pre-existing) data, and include a survey of existing neighboring well logs, soil surveys, hydrogeologic investigations, and other background data to evaluate whether local hydrogeology would likely support surface infiltration basins. It is worthwhile to note that PGG has performed preliminary investigations for a number of proposed sites in the Carlsborg and Sequim vicinities (PGG, 2007a,b), and that actual field investigations (including pilot testing) were recommended to further address these considerations. Prior to pilot testing, the 2008 Groundwater Model (PGG, 2009) can be used to simulate a hypothetical infiltration facility; but such predictions are highly preliminary and should be updated based on pilot test results.

Depending on agreements negotiated with a land owner, additional investigations could potentially be performed prior to purchase of the site in order to confirm and/or supplement preliminary investigations. If allowed by the owner, such investigations could include: a Phase I Environmental Site Assessment (ESA); general environmental screening for SEPA compliance; installation of monitoring wells to assess actual hydrostratigraphy and groundwater levels; monitoring of groundwater levels over time; and groundwater sampling (to establish a background water-quality baseline). Data from these field investigations can be used to further update both the conceptual hydrogeologic model of the site and the 2008 Groundwater Model, and thereby revise preliminary assessment of AR feasibility. If the site assessment remains favorable, it should be considered for conceptual design and pilot test studies (see Section 4.8).

Depending on the proximity of the source of reclaimed water supply to the recharge basin, a routing analysis and land (easement) acquisition services may be required. For this evaluation we have assumed all pipelines would be located in existing rights-of-way and/or purchased private easements (i.e. land acquisition is not required).

4.6.3 Transmission

Potential pipeline alignment corridors to the discharge site should be identified and evaluated from a review of background data, including:

- Geotechnical investigation based largely on existing data. Compile existing geotechnical and geologic data, including Ecology well records and WSDOT drilling records (as readily available), geologic maps, hazard maps and City records.
- Potential right-of-way easements, including costs and timeframes for contracting.
- Utility routes and infrastructure specifications (water, sewer, stormwater, power, irrigation, railroads, etc.)

- Construction feasibility considerations, including potential construction difficulties (e.g. utility conflicts, creek crossings, land use/sensitive areas regulations) and opportunities for reducing costs by coordinating construction with road improvement projects.
- Natural resource considerations, including: wetlands, plants and animals, and cultural resources.

The City of Sequim Public Works Department owns and operates a reclaimed water distribution system that includes the following:

- Pumps at the Sequim Wastewater Treatment Plant capable of delivering the effluent from the plant to the reclaimed water distribution system
- Approximately 3.7 miles of reclaimed water mains and laterals, ranging in size from 18-inches to 2-inches in diameter.

An 18-inch reclaimed water transmission main extends from the Sequim Wastewater Treatment Plant to the city shop, near the intersection of Sequim Avenue and West Hemlock Street (**Figure 1-1**). Primary laterals in the system include a 14-inch lateral that extends from West Sequim Bay Road south to a transportation facility near U.S. Highway 101 and a 14-inch lateral that extends north from West Sequim Bay Road to the water reuse facility near North Rhodefer Road. The City of Sequim Public Works Department indicated that the system is designed to maintain 30 psi at the highest point in the system.

Delivery of water to a proposed recharge site northwest of the City limits would require extension of the City's reclaimed water transmission main from the City Shop to the recharge site. The transmission line would likely need to follow an east-west route for most of its length in a roadway that is not overly congested with utilities. The alignment would need to meet Ecology's requirements for separation from potable waterlines and other utilities. Possible routes might include Prairie Street or Fir Street. It is anticipated that the City will want to coordinate extension of reclaimed water service to a recharge site with other planned improvements. Planned improvements for the reclaimed water system are outlined in the most recently amended version of the *City of Sequim, Reclaimed Water 100% Upland Reuse Plan* (Gray and Osborne, 2003).

The length of the pipeline required to extend the City's reclaimed water transmission line from the city shop to a recharge site northwest of the city limits would be on the order of 10,000-15,000 feet. The size of pipeline required to deliver 3.1 cfs (the expected 2025 average annual reclaimed water generation capacity) or 3.5 cfs (the expected 2025 reclaimed maximum monoth water generation capacity), would be 14-inch diameter. The required pipe size was estimated based on providing the assumed flow while limiting velocities to 5 feet per second and the headloss to 3 feet per thousand feet of pipe.

4.6.4 Construction/Design

Once a site has been selected for further testing, the procedures for designing the groundwater recharge basins are as follows:

1. Pilot test basins will be installed on the site to calculate the infiltration rate of the surrounding soils. If possible, a similar water type to that which will be used long term should be used.
2. Site investigation and monitoring wells will be used to measure the pathway and depth to groundwater.
3. The hydraulic loading rate will be calculated based on the infiltration rate and the preliminary flooding/drying time period ratio and the depth to groundwater.
4. Based on the hydraulic loading rate, the land requirement for the full-scale system will then be calculated.
5. The basin loading cycles and the total number of basins required will be calculated.
6. Final source and groundwater monitoring equipment requirements will then be assessed.

The parameters used for the design of the groundwater recharge basins are outlined in the following paragraphs.

Square or rectangular shaped areas are preferred to facilitate operation and maintenance with imported sand base material. Multiple basins will be needed to provide rotation for flooding and drying of each basin. Based on typical site layouts, the length to width ratio can range from 1:1 up to 3:1 with the discharge header pipe placed on the longest side of the basin.

The land required for the groundwater recharge basins is a function of the average design flow to the basins, the infiltration rate of the soils, and the area needed for berming, access roads, and storage areas. The final area needed for the recharge basins will be calculated after the pilot testing has been performed. The number of basins required is a function of the flooding and drying cycles. It is estimated that a flooding period of 3 to 7 days and a drying period of 4 to 10 days may be required.

Due to the importance of preserving the quality of the aquifers, security of the groundwater recharge basins is an utmost priority. Landscaping around the basins can be incorporated into the overall security of the recharge basin site. Native plants and trees could be used in conjunction with a screen wall/fence to maintain the integrity of the basins. Native plants with deterring characteristics (i.e. thorns or spines) can also be used to enhance the security.

Construction of the final installation is a relatively straightforward process compared to the site selection, capacity validation, and permitting efforts. Most construction activities are considered general civil site work and general contractors can complete work in several months. Since construction will involve mostly earthmoving it would be best completed during drier periods to increase efficiency and limit stormwater control costs.

4.6.5 Operation & Maintenance

Maintaining basin recharge performance will be the most critical aspect of the long-term success of a groundwater recharge site. Therefore, developing a reliable operation and maintenance plan will be necessary prior to implementing full-scale recharge basin design. Using ponding and drying cycles with periodic removal of clogging material is the best management practice for maintaining recharge performance. Therefore, controlling clogging agents that enter the basin will reduce required maintenance. Clogging agents can enter the basin from erosion of basin side slopes, wave action erosion, biomass, algae growth, bacteriological clogging, and suspended solids. The primary clogging agents that may originate from the basin are sidewall erosion due to precipitation or wave action and water inlet velocities. The pilot test will focus on mitigating formation of clogging agents from the recharge basin. Great care must be taken to insure that the basins are graded level. Low spots tend to clog quickly and decrease the capacity of the basin. Care should be taken each time maintenance is performed to ensure that the basins slope away from the discharge header pipe and water is able to reach the entire basin.

Under Scenario B, the site could be remotely operated and monitored from the Sequim Treatment Plant using its SCADA (Supervisory Control and Data Acquisition) system. Weekly visits to the site should be conducted for general maintenance and to maintain security. If the site is designed with landscaping and vegetation, seasonal landscape maintenance may also be required.

General recharge basin maintenance will consist of cleaning and scraping the top sand layer in the basins, general landscape maintenance and thorough checking of the site for erosion, low spots, and other potential clogging mechanisms. Before the winter season, the entire system should be thoroughly checked with attention to the basin surface, berms, and piping. A summary of the approximate hours required for operation and maintenance of the site is provided below:

Estimated Operation and Maintenance Labor Requirements[a]

Unit process	Labor needs, hours/year
Disking or Scraping of Basin	120
General Basin Maintenance	400
Landscape Maintenance	300
Total	820

[a]Includes labor for operation, maintenance, process, and lab analysis associated the facilities.

Clogging is the single most detrimental problem that decreases recharge basin performance and life. Without proper drying and maintenance the basins can quickly clog and become ineffective at infiltrating the water. It is important to develop a recharge basin maintenance schedule based on the results of the pilot test and based on monitoring of actual performance. Even with proper drying, the basins will accumulate material over time decreasing the basin recharge rate. The basins will then need to be more aggressively cleaned by disking or scraping to breakup the top layer. Each basin will need to be thoroughly cleaned at least once a year, at which time the basin will be dried, disked, or the top layer of sand will be scraped and removed. A front-end loader or similar equipment can be used to remove the top ½ to 1-inch of material, thereby, restoring the basin to its original capacity. Monitoring of recharge rate over time should be used to identify when basin maintenance is required.

Basin maintenance cannot begin until the cell is completely dry. To speed up the drying process, cell outlet controls (mechanical drains or gates) may be added to help drain the basin more quickly. It is important to stop the flow of water to the basin prior to point when infiltration rates have reached extremely low values. This will again help in drying the basin more quickly.

4.6.6 Monitoring Recommendations

To assess the performance of the recharge basins, basin water-level sensors and flow meters should be used to monitor and record the infiltration rate compared to the hydraulic loading rate. This can be used to determine when a basin needs to be restored via disking or scraping. In addition, water-level monitoring should be performed in monitoring wells to record and evaluate groundwater level responses over various rates of infiltration along with seasonal water-level variations arising from climatic factors.

Monitoring wells are used not only as a tool to assess basin performance, but are also required by the Washington Department of Ecology (Ecology) to evaluate the groundwater quality beneath the recharge basins after infiltration. Water-quality monitoring is an important aspect of the project and performs two primary functions: it provides an indication of basin performance against groundwater quality criteria and the surrounding groundwater system's response to infiltration activities.

State standards for the protection of groundwater specify that for groundwater recharge, sampling must occur in the groundwater and it is recommended for the vadose zone, soil strata, and effluent. The areas are described as follows:

1. Groundwater- Monitoring will occur in the uppermost saturated zone in addition to any other zone that may be affected by groundwater recharge. Water quality parameters are listed on **Table 4-3**.
2. Vadose Zone- A lysimeter can provide a reliable way to measure the quality of effluent after it has received treatment and is not diluted by the lower aquifer. Although vadose zone testing is not required by Ecology for monitoring of groundwater recharge basins, it permits the ability to record and analyze changes in the water quality below the recharge basins for use during future permitting and approval.
3. Soils- Soil sampling is not required by Ecology but is recommended for determination of constituent concentration that has been adsorbed by soil particles.

4. Effluent- The final effluent discharged to the groundwater recharge basins should be sampled quarterly for the parameters listed in **Table 4-4.** WDOH and Ecology require sampling of the groundwater for compounds highlighted in Table 4-4 (Ecology, 1996).

Ecology must approve the number and location of groundwater monitoring wells prior to construction of the recharge facility. Generally, the number of wells required is a function of the volume and quality of recharge water, the affected area, site hydrology, and the groundwater gradient. At a minimum, at least one monitoring well is required up gradient to characterize the background water quality, and at least two wells are required down gradient. In most cases, the monitoring wells shall be located 100 feet from the edge of the groundwater recharge basins and in areas that are not subject to frequent flooding.

In addition to the monitoring requirements that occur after infiltration basin operation, prior to basin construction the background groundwater quality must be measured for an area representative of the anticipated impacted area. A complete chemical characterization (eight background water quality samples are considered a minimum number to statistically evaluate existing conditions) of the existing groundwater quality must be performed including the concentrations of the anions; chloride, sulfate, nitrate, fluoride, carbonate, and bicarbonate, and the cations; calcium, magnesium, potassium, sodium, iron, and manganese.

4.7 Permitting Considerations

Reclaimed water is treated differently than other 'waters of the state' in Washington State. In the State of Washington, when utilities produce reclaimed water that would otherwise have been discharged to marine waters (i.e., unappropriated to other beneficial uses), the reclaimed water becomes the property of the Producer and therefore can be used (or sold) without an additional water right. The Producer still must obtain a Reclaimed Water Permit in addition to a NPDES permit which specifies this use and describes the intent. It can include the names of the recipients of reclaimed water, a description of the application area/uses, application rate, timeframes, etc. The state generally administers the permit and the Producer maintains a list of recipients which is updated annually. Water that can no longer be accounted for becomes a 'water of the state'.

In addition, permitting activities will need to address facility ownership, land use, environmental documentation (SEPA), construction and operations. Public involvement is mandatory as part of SEPA and will need to be carefully administered throughout the project to assure the project moves forward. Thoughtful consideration should be given to the long-term use of the City's reclaimed water with respect to ownership, jurisdiction, and application. This will affect which regulatory agencies may have authority. Failure to account for this in advance can potentially result in loss in the intended use and benefit. For cases where reclaimed water is recharged, the applicant should declare the use of the recharged water (i.e., instream flow augmentation for Dungeness River, habitat mitigation, water source development, etc.) prior to commencing permitting to retain the intended use.

4.8 Project Implementation

4.8.1 Project Approach by Tasks

The general project approach described below encompasses the initial phases of the project, beginning with the preliminary AR feasibility investigation, extending through pilot-scale testing, modeling, and permitting of the site for ultimate development. Given that Scenario B identifies a project area rather than a specific site and that portions of this area may not be suitable for the full quantity of reclaimed water, one or more sites may be investigated. The tasks for site development are summarized below.

Groundwater recharge project implementation generally goes through several phases of development to quantify and manage risks with respect to technical feasibility, financial investment, and environmental process. Similarly there will be technical, legal (including land purchase), and environmental activities that will need to be undertaken to support these actions. These activities may occur sequentially, in concurrence, or some combination depending upon the needs and financial tolerance of the owner. Each phase represents an increasing level of financial commitment to reduce the uncertainty associated with the technical feasibility of a specific site. These phases include:

- Phase 1 - General hydrogeologic screening: Using existing data to understand the potential viability and target areas with the greatest potential for success.
- Phase 2 - Site specific characterization: Verify hydrogeologic characterization through limited on-site investigations (wells, test pits, etc.) to estimate the potential capacity of the site. May involve model development.
- Phase 3 – Pilot testing: Conduct pilot scale testing appropriate to the potential risks to establish final design criteria and initiate regulatory applications.
- Phase 4 – Final design, permitting and construction: Develop final plans, obtain permit approvals, advertise for bidding and construct the final basins based on the pilot scale results.

Note, property purchase can occur at any time during the first three phases and the environmental documentation (SEPA) process can begin in Phase 2 or 3 depending upon the preferred distribution of risks.

4.8.1.1 Phase 1 Activities

Phase 1 provides key information for the preliminary AR feasibility assessment, which is based on readily available (pre-existing) information. Phase 1 can be conducted for one or more sites, depending on the preferences of the project proponent and the potential for success for each site investigated.

Task 1: Conduct Background Hydrogeologic Investigation

Compile preliminary basemap information on: soils, surficial geology, topography, existing parcels, wells, streams, wetlands, irrigation ditches, stormwater facilities, contaminated site listings, aquifer protection zones. Compile and review available hydrogeologic reports, site investigations, water-level data, and water-quality data. Review well logs and develop a conceptual model of the groundwater flow system beneath the site(s). Assess available information regarding: aquifer properties, groundwater flow directions, depths to groundwater, seasonal groundwater level variations. Based on aquifer and soil properties, develop preliminary estimates of potential infiltration rates.

The background investigation should also incorporate some non-hydrogeologic information that may influence development of the site. Such information could include:

- Land use regulations/sensitive areas considerations
- Natural resources, including wetlands, plants and animals (fish and wildlife)
- Cultural resources
- Aesthetics
- Community considerations, including traffic, noise, and public health

In addition, potential costs associated with impacts should be estimated. Examples include: costs of mitigation needed to achieve compliance with land use or sensitive areas codes, and/or anticipated costs of traffic mitigation.

Task 2: Groundwater Quality Characterization

Establish baseline groundwater and source water characteristics from existing data (regular well water quality reports) to allow characterization of groundwater targeted for reclaimed water infiltration. Water-quality characterization will likely be used in Phase 3 for development of a simulation model, regulatory negotiations and preparation of a Basis of Design Report. If data are not available for the parameters listed in **Tables 4-3** and **4-4**, sampling and laboratory testing of nearby (i.e. readily accessible wells) is recommended. If not wells are available, water-quality characterization would need to be conducted under phase 2.

4.8.1.2 Phase 2 Activities

Phase 2 activities are conducted in the field, and will likely be repeated for more than one site, depending on the conditions encountered). The cost of this activity will be dependent upon the purchasing strategy and level of effort required to make the purchasing / leasing determination.

Task 1: Site Specific Hydrogeologic Field Investigations

Based on the background hydrogeologic investigations performed, it is assumed that there will be one or more sites where field investigations will be necessary to refine the information gathered. Field investigations should be performed preferentially on the highest ranked sites identified under Phase 1. Field investigations will include test drilling to verify subsurface conditions, including the presence or absence of aquitards and depth to the water table. For analysis of aquifer hydraulic properties, typically one eight-inch diameter test well will be drilled at each site and used to conduct aquifer tests of the uppermost aquifer. The scope of work for this task for each site to be evaluated may be assumed to include:

- Installation of several (e.g. 3 to 5) 2-inch diameter monitoring wells;
- Installation of an 8-inch diameter test well;
- An aquifer (pumping) test;
- Background water quality baseline;
- Estimation of groundwater mounding; and,
- Ranking of sites with respect to infiltration capacity.

Task 2: Alternative Development and Analysis

If more than one site has been investigated under Task 1, the activities in this task include developing site and design alternatives for AR and summarizing/comparing costs, benefits, and risks for each site alternative. The benefits and risks of considered alternative pipeline alignments should be evaluated in this task. Criteria for evaluating benefits and risks may include environmental, community, cultural, and political factors using life-cycle costs. This information will be used in the environmental documentation (SEPA) process. Note, final site implementation cannot be made until SEPA is complete.

4.8.1.3 Phase 3 Activities

Pilot testing and associated analyses may be conducted on multiple properties. It is likely that prior to commencing this work phase, property acquisition will need to occur. It should be noted, however, that pilot testing results may indicate that the level of financial investment required and estimated AR capacity may not meet project objectives, and the property may be abandoned for other purposes / resale.

Task 1: Pilot Testing

The goal of pilot testing is to develop groundwater recharge basin operating criteria at a suitable scale to secure operating permits and establish final system design criteria. The recharge basin used for pilot testing will likely be smaller than the final design, but large enough to provide a basis for the design. During the pilot test, data should be collected on groundwater levels and groundwater quality using the monitoring wells on the site installed during phase 2 (and possibly supplemental monitoring wells). Monitoring should also include flow rates of water source, flooding times and drying times. The duration of pilot testing could range from weeks to months, depending on the level of risk and confidence desired in predictions that will be based on the pilot test results.

The pilot test results should be used to estimate the capacity and efficiency of the recharge basins site to infiltrate up to 2-mgd of reclaimed water, and the optimal final basin configuration. This will allow estimation of capital investment risks prior to committing resources for full development. To mitigate sunk costs, pilot-scale infiltration basins can be designed and constructed to allow incorporation into the full scale development of the site.

Task 2: Groundwater Modeling

This task includes utilization of a numerical groundwater flow model to estimate groundwater mounding beneath the infiltration basins and the flowpath and rate of the recharged water away from the selected infiltration basins. The model would be calibrated using data collected during the pilot basin testing. The model would also be used to quantify potential impacts to adjacent properties and surface-water bodies. A modified version of the 2008 Groundwater Model (possibly including recalibration) could be used for this purpose, as could other model configurations developed specifically for this purpose. The required degree of model complexity would depend on hydrogeologic conditions and the desired level of prediction accuracy. .

Task 3: Basis of Design Report

Prepare a Basis of Design Report for the recharge basins to document the capacity and efficiency of the selected project site to infiltrate reclaimed water as well as fulfill requirements for state and local agency permitting and funding. The Basis of Design Report should meet the following objectives:

- Identify site selection, preliminary testing criteria, and proposed site characteristics;
- Document design standards and criteria for the design and construction of the recharge basins;
- Summarize pilot testing results and modeling performed for the recharge basins;
- Discuss the configuration and construction of the proposed recharge basins;
- Describe operational and maintenance protocols, security, and water quality monitoring programs for the recharge basins;
- Comply with the Washington State Department of Ecology Criteria for Sewage Works Design (Ecology Publication #98-37) for groundwater recharge;
- Complete Engineering Report requirements for the proposed recharge basins in accordance with the Washington Department of Health (Health) and Ecology (WAC 173-240-050); and,
- Demonstrate compliance with Washington State Water Reclamation and Water Reuse Standard (Ecology Publication #96-02) for groundwater recharge as developed by Health and Ecology.
- In general, the report would provide assistance in obtaining permits required for continued groundwater recharge with Class A Reclaimed Water at full scale development; early versions would also assist with pilot-scale recharge basin construction permits.

4.8.1.4 Phase 4 Activities

Phase 4 activities are to be completed once final site(s) are purchased and permitted.

Task 1: Identify and Design Potential Pipeline Alignments

Determine potential pipeline alignment corridors to the discharge sites. Additional background data, including existing geotechnical data, Right-of-Way easements, utility data, and proposed road improvement projects should also be reviewed when identifying potential pipeline alignments.

Task 2: Prepare Final Design Documents and Obtain Permits

Prepare engineering plans and specifications for public bidding and construction of transmission and infiltration facilities. Complete permit applications and conduct final SEPA documentation and public processes. This can include water right considerations and modification of NPDES permits.

Task 3: Cost Estimates and Construction Schedule Preparation

Prepare project construction costs and schedule in accordance with the selected alternatives, and prepare draft review cost estimates and final design total construction cost for the project.

Task 4: Construction

Bid and construct the infiltration basins. Since this involves mostly earthmoving, it is usually best conducted during periods with less precipitation.

4.8.2 Project Schedule

A suggested project schedule for the tasks developed above is shown in **Table 4-5**. It is estimated that the preliminary engineering and pilot-scale testing could be completed in approximately two years from the time of initial project planning. Completion of final design and permitting are estimated within 2.5 years, and completion of construction is estimated within 3 years of project initiation.

4.8.3 Project Cost Estimate

The cost of constructing infiltration basins is greatly influenced by the size of the required infiltration basins, which depends on such factors as local geography and the infiltration capacity of the site (dictated by soils and hydrogeology). As noted in Section XX, the general area identified for AR under Scenario B lies in an area where aquifer hydraulic conductivity is believed to transition from low-moderate (15 ft/d) to moderate-high (100 ft/d). USGS review of well performance (Thomas et al, 1999) and model calibration (PGG, 2009) provide the basis for this hydraulic conductivity distribution; however, actual hydraulic conductivities would need to be determined via field investigations. Optimally, an infiltration site would be selected in an area of higher hydraulic conductivity, at some distance from areas of lower hydraulic conductivity. The ultimate size required for infiltration basins is so dependent on soil/aquifer properties encountered during field investigation that it is difficult to predict the required infiltration area based on available information. For the purpose of this cost estimate, we assume lower-end and upper-end infiltration areas of 5 and 10 acres, as summarized on **Table 4-6.** Respective costs for construction of 5- and 10-acre infiltration basin complexes are about $924,000 and $1,567,000.

If more favorable sites were identified in the Sequim vicinity, costs could be proportionally reduced.

For the purpose of this analysis, the estimated cost of developable land in the Sequim area is assumed to be approximately $100,000 per acre. Higher prices may be encountered depending on location and zoning, and prices may differ depending on the timing of project implementation. Nevertheless, based on this estimate and the reasonable assumption that the area of the complete AR facility is likely to be twice the area of the infiltration basins, the estimated land costs for 10- and 20-acre facilities range from $1,000,000 to $2,000,000. If the facility can be located on a public property, such as a park, the cost for land may be lower.

Land costs would also require an agreement for use of a public right-of-way for installation of a transmission line. Assuming that an appropriate right-of-way or easement is available, the cost of the agreement should be relatively low (less than $10,000). However, if an easement has to be secured from private property owners for a transmission line, the cost may be much higher. For the purpose of this analysis, lower-end easement costs are assumed to be $10,000 and upper-end easement costs are assumed to be $60,000, based on the assumption that private easements would be required for no more than 5,000 feet of transmission line, at a cost of $10 per foot.

Costs for implementation of this scenario will include the cost of installing a transmission main that extends from the City's reclaimed water system to the recharge site. As was noted previously, a 14-inch pipe should have sufficient capacity to convey up to 3.9 cfs for recharge under this scenario. The cost of installing a14-inch PVC transmission line rated for pressures up to 125 psi is estimated at approximately $95 to $120 per foot of pipe installed. The cost to plan, design and permit the reclaimed water transmission line would likely be around 15 percent of the construction cost. A transmission line would need to be approximately 10,000 to 15,000 feet long to connect the existing reclaimed water transmission line at the city shop to a proposed recharge area. Depending on the length required and the per-foot cost, the total cost of the transmission line would be in the range of $1,093,000 to $2,070,000.

This estimate does not include a cost for the actual reclaimed water. It is most reasonable to assume that a reclaimed water infiltration facility would be owned and operated by the City of Sequim. However, if the reclaimed water had to be purchased from the City, a 4-month supply at 3 cfs (totaling 725 acre-feet/year) might range from zero (if the generator was motivated to dispose of the water) to about 50 percent-70 percent of typical costs for irrigation water.

Operating and maintenance activities include: maintaining the infiltration basins (cleaning and scraping infiltration surface), periodically replacing surface sand, gathering water quality data, monitoring water levels and controlling inflows, yard maintenance, associated equipment. These activities typically require about 1/3 to ½ FTE. Average annual costs, including equipment and materials, are estimate to be about $60,000 to $70,000.

Total capital costs include allied cost (engineering, administration, permitting and legal), pilot testing, and land acquisition as shown below:

PRELIMINARY COST ESTIMATE FOR SCENARIO B

Item	Lower End		Upper End		Notes
	Quantity	Value	Quantity	Value	
Phase 1	1	$ 50,000	1	$ 50,000	
Phase 2 – Preliminary Site Investigation (per site cost)	1 site	$ 45,000	2 sites	$ 170,000	Range $45,000 to 85,000 per site.
Phase 3 – Pilot Testing, Modeling and Preliminary Design (per site cost)	1 site	$ 200,000	2 sites	$ 800,000	Range $200,000 to 400,000 per site.
Phase 4 – Final Design, Permitting and Construction	1 site		1 site		
- Recharge Basins	5 acres	$ 924,402	10 acres	$ 1,566,800	See Table 4-6
- Pipelines (14-inch pipe)	10,000 ft	$1,092,500	15,000 ft	$ 2,070,000	Ranges: 10,000-15,000 ft; $95-$120/ft. Plus 15% for design & permitting
- Allied Costs*	35%	$ 791,666	35%	$ 1,612,380	Engineering, legal and administration
- Land Purchase for AR Facility (per acre)	10	$1,000,000	20	$ 2,000,000	Uniform assumption of $100k/acre.
- Easements for Conveyance		$ 10,000		$ 60,000	
LIKELY TOTAL CAPITAL COST		**$4,063,568**		**$ 8,279,180**	
Annual Operating Costs (labor, monitoring and equipment)	Per site / year	$60-70,000	Per site / year	$60-70,000	

4.9 Summary of Costs, Benefits and Concerns

Scenario B capital costs are estimated to range between $4,000,000 and $8,300,000 million depending upon the number of sites characterized for selection, the scale of investigations required on each characterized site, the infiltration capacity encountered at the final site (thus affecting the site size), and how the site location affects the required length of transmission pipe. Operating costs are expected to be on the order of $60,000 to $70,000 per year.

The major benefit of the project is that it will provide a site to infiltrate up to 3.1 cfs of reclaimed water over the majority of the year (the duration and volume of reclaimed water available would ultimately be determined by the City of Sequim). If the recharge project described here were operated for eight months per year, that water would recharge the shallow aquifer and augment flows in the Dungeness River during the low flow period by approximately 1.0 cfs, according to modeling analyses performed for this project. The analyses also estimate that flows in Cassalery Creek could be augmented by as much as 0.5 cfs (during the month of July) and flows in Gierin Creek could be augmented by as much as 0.4 cfs (during the months of July and August).

Associated changes in Dungeness River habitat are estimated to be small and likely non-measurable; however, changes in Cassalery and Gierin creeks could be significant and enhance rearing productivity of coho salmon, steelhead and cutthroat trout. Flow augmentation could also provide mitigation to offset baseflow impacts associated with groundwater development.

One benefit of performing AR with reclaimed water is the relative insensitivity of source availability to climate change. However, one possible concern would be changes in availability if new uses are developed for the reclaimed water.

Recycling water through reclamation and groundwater recharge is a long-practiced and sustainable practice. It preserves higher quality water for higher quality purposes, and extends existing water supplies. Recycling reclaimed verses disposing wastewater effluent is also an environmental benefit as it buffers receiving waters from direct release of anthropogenic residual compounds (i.e., PCCPs and EDCs) by enabling further degradation in the subsurface near the point of release.

Use of reclaimed water is a highly regulated program and subject to changing rules. These can increase future operating and capital costs.

5 SCENARIO C: DUNGENESS RIVER ASR WEST OF DUNGENESS RIVER

5.1 Conceptual Project Design

An ASR system under Scenario C consists of a surface water diversion that would divert ASR source water during high flow periods, a filtration system to remove turbidity, a piping system from the source water diversion site to the ASR well site(s), and ASR wells that would inject water during periods of diversion and recover water for use during the peak season summer months. The water could be used to meet public peak-season water demands, late season irrigation, or other purposes in areas west of the Dungeness River. ASR and injection-only wells could be used in deeper portions of the groundwater flow system as mitigation for new water rights. Such a scenario was proposed by the PUD, assuming that 2 cfs would be injected during the spring freshet and recovered as needed during the summer. Based on limited data for deep wells in the area, we have assumed that as many as two ASR wells would be needed to inject and recover the 2 cfs. The following discussion for Scenario C is presented in general terms (non site-specific), as preliminary analysis and project budget limitations did not confirm specific sites particularly well suited for obtaining the ASR source water and performing the injection/recovery.

The source water for ASR storage would come from the Dungeness River or irrigation ditches that come off of the Dungeness or its tributaries. This water would require filtration due to turbidity present in the water. In order to avoid clogging of the ASR well, the turbidity would need to be less than 1 nephlometric turbidity unit (NTU) before the water is directed into the well. Several options are available for filtering the water to reduce turbidity including conventional mechanical treatment (used commonly for drinking water systems, e.g., flocculation and sedimentation systems, slow sand filters, or membrane filtration systems) or "riverbank filtration" (RBF) systems. As discussed in the preliminary considerations memorandum (PGG, 2008b), conventional water treatment technologies would be prohibitively expensive and so we have focused on using RBF, if feasible, to provide the needed filtration. The RBF system would consist of a series of shallow wells or an infiltration gallery located adjacent to the Dungeness River (or irrigation ditches if specific hydrologic conditions are met) that would be designed to capture the surface water by filtration through aquifer materials. PGG reviewed two sites along the Dungeness River and found sub-optimal conditions for RBF at one site and an existing collector system susceptible to turbid water at the other. However, RBF remains the most cost effective solution to filtering Dungeness River water, so Scenario C includes general discussion of riverbank filtration along the Dungeness River.

Site(s) for the injection/recovery well(s) are also not specifically identified, and are handled in a general manner. PGG reviewed several sites west of the Dungeness River and found that the thickness, texture and/or hydraulic conductivity of the lower aquifer did not suggest sufficient capacity for 2 cfs of injection using a single well (Section 5.2.2). Additional analysis would be required to determine whether these sites could accommodate 2 cfs of injection with multiple wells. Other locations, however, may reveal more capacity in the lower aquifer. Several wells were completed in a deep aquifer in the undifferentiated sediments which underlie the lower aquifer (see conceptual diagram of hydrostratigraphy on **Figure 1-2**). Preliminary consideration of these well yields and well completions suggests that the "deep aquifer" may be able to accommodate 2 cfs with a single injection well, but confirmation would require additional testing. If injection is performed in the lower aquifer, recovery volumes may need to be reduced and recovery schedules optimized so as to avoid impacting stream baseflows (the model predicts limited connection between the lower and shallow aquifers). These concerns would likely be substantially reduced by performing injection and recovery in the deep aquifer.

If ASR were used as a means to facilitate new residential development in the area west of the Dungeness River, there would be a commensurate increase in the amount of wastewater generated. Scenario C explores the possibility that wastewater would recharge the shallow aquifer through infiltration of Class A reclaimed water. Section 7 describes how a portion of the infiltrated wastewater could augment flows in the Dungeness River and other streams, thus potentially providing some offset or mitigation for streamflow capture associated with ASR recovery and possibly providing a net increase in streamflows during portions of the year when injection water is not withdrawn from the river. (In the absence of such mitigation, recovery pumping volumes would need to be reduced to below injection volumes to avoid net streamflow depletion.) It is also worthwhile to note that while infiltration from septic tanks associated with new development would also offset streamflow impacts from recovery pumping, Ecology has indicated that they typically would not accept septic return flows as a mitigation. Section 7 also compares the ASR approach to various other strategies for development/mitigation of new water supplies.

5.2 Hydrogeologic Setting of Project Site(s)

The general hydrogeology of the Sequim-Dungeness area is described by Thomas et al (1999). Specific sites are not identified for Scenario C; however, PGG did evaluate several proposed sites in the early stages of evaluating this Scenario. The following sections describe both USGS regional hydrogeologic characterization (ibid) and PGG's observations during early site evaluations.

5.2.1 Hydrogeologic Conditions for Source-Water Bank Filtration

Bank filtration of source water would likely occur within the floodplain of the Dungeness River, and would therefore draw water from the Dungeness River alluvium. As noted above, Schasse & Wegmann (2000) describe the alluvium as:

> "Generally well stratified and well sorted deposits of rounded, cobble and pebble gravel, sandy gravel, gravelly sand, silt, clay and peat; brown to gray, depending on composition and weathering; deposited in and along present streams. Cobbly sands, silts and clays are deposited in a flood plain environment. Grain size varies both laterally and vertically due to stream migration. Thickness of alluvium varies; a maximum thickness of 40 ft was estimated from water-well data collected from the Dungeness River flood pain.... The Dungeness has migrated over time, leaving behind alluvial terraces that mark previous higher flood plains."

PGG has reviewed drillers logs of wells penetrating the alluvium near West Washington Street (immediately east of the Dungeness River) and from other sites where wells penetrate the "older alluvium" of the Dungeness River (Qoa described in Section 4.2). Driller's descriptions of both the Qa and Qoa are similar in that they both include coarse-grained materials (e.g. gravels and cobbles) with variable contents of clay binder and cementation. The descriptions suggest zones of clean coarse-grained sediments interfingered with zones of silt-bound or cemented gravels/cobbles. "Clean" gravel/cobbles (without silt or cementation) should transmit substantial quantities of water. Zones of fine-grained sediments (such as "silty sand") are also mentioned. Although Schasse & Wegmann suggest well sorted deposits, the silt-bound gravels/cobbles described by drillers must be considered poorly sorted, and would likely exhibit low hydraulic conductivity (and therefore have limited water production capacity). Cemented zones also tend to exhibit low hydraulic conductivity. A discussion of the suitability of these deposits for constructing a riverbank filtration system is presented in Section 5.3.

The City of Sequim has an infiltration gallery adjacent to the Dungeness River that provides an indication of the feasibility of using RBF for diverting ASR source water. The infiltration gallery was installed in the early 1960s and collects water from both a 10-inch diameter perforated PVC pipe and an 18-inch diameter perforated concrete pipe Both run parallel to the river over a 360-foot length, about 120 feet from the channel (Tjemsland, 2008). The perforated pipes are set within a ditch that was excavated 20 feet deep and 4 feet wide. A perpendicular discharge pipe is connected at roughly the midpoint of the 360-foot length. The City's schematics indicated the following sequence of materials in the ditch, from land surface to ditch bottom:

- 5 feet of natural soil
- A "vapor barrier"
- 5 feet of washed gravel
- The 10-inch PVC perforated pipe
- 5 feet of washed gravel
- The 18-inch concrete perforated pipe
- 6 inches of washed gravel

The City's water right provides a maximum instantaneous allocation (Qi) of 718 gpm from the infiltration gallery. Excessive turbidity has been measured at the infiltration gallery during high river flows associated with the spring freshet. When turbidity measured in the infiltration gallery reaches 15 NTU, the City temporarily suspends use of the infiltration gallery. Available information about the construction of the gallery is insufficient to conclude that the turbidity problems are a result of the infiltration gallery design. There is also no available information regarding the likelihood that high entrance velocities caused by over pumping is causing the turbidity problem. Given the distance between the river and the infiltration gallery, it appears that the alluvial aquifer materials at this location are exceedingly permeable and lack sufficient filtration capacity to remove turbidity. While modification of the existing design to provide more filtration around the perforated pipe (i.e. use of finer materials for backfill, such as sand rather than gravel) may reduce turbidity, it could also reduce the yield of such a design.

5.2.2 Hydrogeologic Conditions for Injection/Recovery (ASR Wells)

Injection/recovery could occur in the lower aquifer or within underlying deep aquifer(s) encountered at two locations in the deep undifferentiated deposits on the west side of the Dungeness River. Thomas et al (1999) describe the lower aquifer as:

> "…composed of sand with thin lenses of sand and gravel, silt, and clay. Few wells are completed in this aquifer, so meager data are available. The aquifer is present in the northern and eastern parts of the study area where the unconsolidated deposits are thick and is absent in the southern and southwestern parts of the study area where unconsolidated deposits are thin. The typical thickness is about 90 ft, with a range from about 10 to 180 feet. Six percent of the study wells (44) were completed in the lower aquifer"

USGS cross sections west of the Dungeness River show 13 wells that penetrate the lower aquifer. Early in the FS investigation, PGG was provided several locations west of the river for possible ASR injection/recovery to review. These locations included: West Washington Street, Idea Place, Sequim Prairie Grange, and the Weyerhaeuser Seed Orchard. Deep wells were generally absent near West Washington Street, so the local occurrence of deep aquifers could not be evaluated. A deep well was noted at the Dungeness Golf Course, about a mile north of the Grange. Both the Golf Course and Weyerhaeuser wells penetrated the lower aquifer, but evidently could not obtain sufficient yield from this unit and continued drilling downward[15]. Specifically, the Golf Course Well encountered the lower aquifer as 25 feet of coarse sand and gravel (425-450 feet below land surface, "bls") and the Weyerhaeuser Well encountered minor water-bearing zones between 400-500 feet bls interpreted to be marginal for water production (Robison & Noble, 1974). Ecology's monitoring well at Idea Place encountered only 21 feet of lower aquifer comprised of mostly sand with some silt and some gravel. The Idea Place well log also described the overlying (lower) confining unit as 69 feet of brown to greenish gray silty very fine to fine sand and sandy silt with some gravel[16]. Such materials provide less hydraulic isolation to overlying portions of the groundwater flow system than do silts and clays. The upper confining unit, while siltier in description, was only 10 feet thick at the Idea Place site.

While none of the three well logs reviewed suggest adequate capacity in the lower aquifer to accommodate 2 cfs of injection/recovery with a single well, multi-well sites or other locations west of the river may provide such capacity. Additional investigation would be required to identify acceptable locations.

Deeper aquifers were encountered in the Golf Course and Weyerhaeuser wells. Along with its completion in the lower aquifer (425-450 feet bls), the Golf Course well is completed in coarse sand and gravel from 521 to 565 feet bls and produces about 550 gpm[17]. The Weyerhauser Well

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[15] The Golf Course Well is completed in both the lower aquifer and underlying aquifer materials.

[16] Grab samples taken from air-rotary drilling cuttings were used to characterize the lower confining unit. The presence of clay in this unit may have been obscured due to the drilling and sampling technique

[17] Drawdown and specific capacity were not recorded for the pumping test at the Golf Course Well.

is completed in a water bearing zone between 790-837 feet bls and was pumped for 5 hours at 715 gpm. PGG's interpretation of the pumping test data indicated a moderate-high transmissivity (T=89,000 gpd/ft) and substantial isolation from other portions of the flow system (i.e. incomplete recovery from pumping). The yields of these "deep aquifer" wells and the hydraulic isolation observed in the Weyerhaeuser Well suggest that the deep aquifer may be a good candidate for ASR. Additional testing would be required to evaluate the storage capacity of the aquifer relative to source availability, and exploratory drilling may be needed to identify whether deep aquifer units occur beneath preferred locations.

FS Scenario C does not specify whether the injection/recovery well(s) are completed in the lower aquifer or the "deep aquifer". The costs of siting and developing successful wells in both units are discussed in Section 5.8.3. If the deep aquifer has sufficient transmissivity and storage, its increased hydraulic isolation from shallower portions of the groundwater flow system may offer the advantage of less interaction with surficial streams. Section 5.4 discusses predicted effects of lower-aquifer ASR on streams, and Sections 5.4 and 7 discuss whether mitigation for streamflow impacts would be needed if treated wastewater were used to recharge the shallow aquifer.

5.3 AR Source: Bank Filtration from Dungeness River

This section discusses the suitability of riverbank filtration (RBF) along the Dungeness River or associated irrigation ditch systems as source water for ASR. Source availability from the river is discussed above in Section 3.3. Scenario C assumes that 2 cfs of flow would be available from the river during a 2-month period corresponding to the spring freshet. The suitability of Dungeness River alluvium for bank filtration will depend on site specific conditions. Shallow source water extraction wells (or ditches) must intercept sufficiently permeable materials (i.e. absent significant silt binder or cementation) to obtain the requisite quantities of water. These "clean" zones, however, must have enough medium-grained materials (e.g. sand) to filter turbidity out of the river water intercepted by pumping. The West Washington Street location evaluated by PGG showed a significant occurrence of clay-bound materials interbedded with "clean" zones, and would likely require a high number of wells or a longer collection gallery to achieve the desired 2 cfs yield. The City of Sequim's infiltration gallery apparently does not provide sufficient filtration to reduce turbidity in the Dungeness River during high flow periods. Both of these conditions are sub-optimal for riverbank filtration.

Table 3-12 presents a summary of available water quality data for the City of Sequim's Dungeness River collector (infiltration gallery). For the purposes of this study, we have assumed that these data sources are representative of the source water (Dungeness River). The data set for the Dungeness River provided to us is limited and does not contain several parameters needed to fully evaluate suitability for recharge. The available data from the City's infiltration gallery site suggest that the raw water quality is generally very good. However, personal communication with the City of Sequim indicates that high turbidity is observed in the gallery during the spring runoff and other high flow events. Water quality data submitted to the Washington State Department of Health for the City of Sequim Collector well meets all drinking water standards and so this source should be an acceptable source of water for ASR, except possibly during times when turbidity levels exceed 1 NTU in the collector well.

As noted previously, it is beyond the scope of this study to evaluate all potential RBF sites in the study area; however, we believe, based on our observations of well logs in the area, that the shallow alluvial materials in the area are highly variable and that finding suitable locations for developing ASR source water through RBF will be difficult. In addition, based on the City of Sequim's experience with RBF, it is possible that additional filtration may still be needed during high flow periods.

We conclude from these observations that it is not possible to generalize about the feasibility of using bank filtration to produce sufficient quantities (2 cfs) of high quality source water. Additional site specific investigation would be required, including drilling, trenching, and/or hydraulic testing, in order to determine if riverbank filtration is a feasible method for developing ASR source water. These additional field investigations would cost on the order of $25K to $35K per site. The overall costs for developing an RBF system is discussed in Section 5.8.3.

5.4 Hydrologic Responses to ASR Operations

PGG used the 2008 groundwater flow model (PGG, 2009) to evaluate how ASR operations are likely to affect stream baseflows. The model simulated an ASR cycle of 2 months injection followed by 1 month dormancy followed by 2 months recovery from a lower-aquifer ASR site west of the Dungeness River (**Figure 1-1**). Although the model employed an ASR rate of 2 cfs on both injection and recovery, model-predicted effects on surficial streams are expressed as percent of the 2-month ASR rate (percent Q_{asr}) and are applicable to any rate between 2 and 10 cfs (and a bit beyond these two endpoints) due to the linearity of the model.

PGG estimated effects on surficial streams using three model configurations with different values of aquitard vertical hydraulic conductivity (K_v):

- the "best estimate" version of the model where both the upper and lower confining beds were assigned K_v values of 0.0008 ft/d
- an "alternate" version of the model where the upper confining bed was assigned a K_v of 0.008 ft/d and the lower confining bed was assigned a K_v of 0.0008 ft/d; and
- a "sensitivity analysis" version of the model where both aquitards were assigned a K_v value of 0.008 ft/d.

Our experience with calibrating the 2008 model leads us to believe that assigning *both* aquitards a value of 0.008 ft/d provides too much hydraulic connection between the lower aquifer and the shallow aquifer; however, these simulations were included to represent an "upper end" in the sensitivity analysis.

PGG also performed a steady-state simulation using the "best-estimate" model where 2 cfs was injected *year-round* to the ASR site west of the river. Simulating year-round injection (without recovery) predicts much more effect on local streams and is not representative of the effects of ASR; however, the steady-state simulation serves to illustrate which streams will be most affected by ASR in the transient simulations. **Table 5-1a** summarizes the results of the steady-state and transient ASR simulations, and **Figures 5-1b** shows how the simulated ASR cycle is predicted to affect Dungeness River baseflows. While instantaneous effects are presented as percent Qasr, year-round impacts are summarized as percent of the ASR volume (Vasr).

The steady-state injection simulation shows that the Dungeness River is predicted to be most affected by the lower-aquifer injection (**Table 5-1a**). Whereas the Dungeness River was predicted to receive about 18 percent of a year-round injection, smaller streams such as Matriotti Creek, Cassalery Creek, Gierin Creek, and Bell Creek were predicted to receive smaller amounts (between 0.8 and 2.4 percent of the injection rate) and other streams were predicted to receive less than 0.5 percent of injection. As noted in the model documentation (PGG, 2009), predictions for both Matriotti Creek and Bell Creek are associated with some degree of uncertainty, as the model's single-layer representation of the shallow aquifer does not simulate some of the hydrogeologic complexities believed to occur in the vicinity of these creeks.

The transient simulations of ASR injection followed by recovery, summarized on **Table 5-1b**, show lesser impacts to surficial streams. Predicted instantaneous ASR impacts to the Dungeness River range from +2.5/-1.3 percent Qasr ("Best Estimate" model"), to +6.6/-4.2 percent Qasr ("alternative" model), to +20.1/-15.2 percent Qasr ("sensitivity analysis" model). As noted above, the "sensitivity analysis" model is believed to simulate too much connection between shallow and deep portions of the flow system, and therefore may over estimate ASR impacts on baseflows. The timing of predicted ASR impacts to the Dungeness River baseflow is shown on **Figure 5-1**. A positive impact (increased baseflow) is established soon after ASR injection begins and persists until partway through the recovery phase. A negative impact (reduced baseflow) begins during the recovery phase and persists until soon after ASR injection is commenced.

Estimation of net impact to the Dungeness River must also take into account the ASR source diversion. A 2 cfs diversion during the spring freshet (e.g. May 15 – July 15) causes a relatively large negative impact to river flow compared to the small positive flow impact associated with simultaneous ASR injection. Towards the end of the ASR injection period, the 2 cfs diversion impact on river flows could be reduced by maximum values of 2.5 percent, 6.6 percent, or 20.1 percent (as discussed above). Thus, the 2 cfs diversion is the dominant ASR impact on river flow during the ASR injection period. The net impact of ASR diversion and subsurface return flow is small relative to typical flows during the spring freshet.

As noted by the PUD, if ASR is used for water-supply development, the non-consumptive portion of the new residential water use enabled by an ASR water right would be re-infiltrated into the ground to recharge the shallow aquifer. Whereas historic decisions including case law at the Pollution Control Hearings Board (PCHB) indicate that septic return flow is unlikely to be considered acceptable mitigation for water rights (Nazy, pers. com., 2009), recharge could be introduced at a Class A reclaimed water infiltration facility. Estimates presented in Section 7 suggest that about 46 percent of the new annual water use would be available to recharge the shallow aquifer in a steady, year-round manner. Streamflow augmentation associated with this recharge would depend on the location(s) and/or distribution of infiltration. The reclaimed water recharge would not be sufficient to offset the impact on the Dungeness River diversion during period of ASR injection; however, it appears to be sufficient to offset ASR (recovery pumping) impacts during the rest of the year assuming a favorable geographic distribution of recharge. The septic/reclaimed water recharge must also be sufficient to offset ASR recovery pumping impacts on small streams.

Predictions of impacts to small streams within the model domain are relatively low (**Table 5-1b**). All predicted negative impacts are less than 0.5 percent of Qasr, with the maximum impact predicted to Cassalery Creek. Predicted impacts for Matriotti Creek, which is closer to the modeled ASR site, include some uncertainty as the model does not reflect hydrogeologic complexities that may be influencing its baseflow regime. While **Table 5-1b** only provides documentation of model-predicted impacts to *a subset* of the small streams, it does establish that the typical magnitude of such impacts would likely be relatively small.

PGG did not attempt to simulate ASR in the deep aquifer (where present) with the 2008 groundwater model. The fact that aquitard materials are typically encountered between the lower aquifer and the deep aquifer suggests that impacts to surficial streams from deep-aquifer ASR will be reduced relative to impacts estimated for ASR in the lower aquifer. Therefore, if the deep aquifer has sufficient capacity to accommodate the ASR infiltration volume, its use would require less mitigation than the lower aquifer. Further evaluation of the thickness and texture of the low permeability materials between the two aquifers is recommended prior to performing model simulations of ASR in the deep aquifer.

5.5 Environmental Impacts

5.5.1 Water Quality Considerations

The state's antidegradation policy requires that existing and future groundwater quality and beneficial uses be protected. Contaminants that will reduce the existing quality are normally not allowed to be introduced into an aquifer, except in those instances where it can be demonstrated to the Department of Ecology's satisfaction that an overriding consideration of the public interest (OCPI) will be served and all introduced contaminants are provided with all known, available, and reasonable methods of prevention, control, and treatment ("AKART") prior to introduction to the aquifer. Based on GSI's experience, this is an issue commonly encountered with ASR projects within the USA, and Ecology is currently formulating policy on how to approach this issue.

Native groundwater quality data provided to PGG were limited for the study area. Selected data for two City of Sequim wellfields (shallow and deep) are presented in **Table 3-12**. Available data indicate that native groundwater quality is good and that the Dungeness River Collector water quality is equal to or better than native groundwater quality for the following parameters: conductivity, arsenic, iron, manganese, nitrate, chloride, and sulfate. On the basis of these limited data, the Dungeness source water (assumed to be derived through RBF) should not degrade native groundwater quality. However, additional water quality characterization will be needed to confirm this and will be required by Ecology as part of the permitting process.

Data are insufficient to assess whether turbidity will be a concern with regards to injection well clogging. If the raw river water contains a significant amount of turbidity, it first must be removed prior to delivery to an injection well (turbidity of water delivered to an injection well should be less than 1 NTU). Possible methods for removal include RBF, settling or flocculation basins, rapid sand filtration and/or membrane filtration. If the water source is obtained via RBF, additional filtration may or may not be necessary. If it comes from a direct diversion on the river, filtration will be necessary. If the source water for the project is derived from a public water system that is chlorinated then an AKART (All Known, Available, and Reasonable Treatments) evaluation will be required to address possible chlorine residuals.

If the Scenario C moves forward to further planning, we recommend collecting samples of native groundwater from the target storage zone and river source water samples from the river and the City of Sequim's infiltration gallery. Samples should be analyzed for all Safe Drinking Water Act parameters, iron and manganese, cations, anions, total dissolved solids, disinfection byproducts, total organic carbon, total and fecal coliform, radon, dissolved oxygen, turbidity, oxidation-reduction potential (field measurement), and pH (field measurement).

5.5.2 Net Effect on Habitat

The source for lower aquifer ASR would be Dungeness River water extracted using RBF during the spring freshet under a new water right subject to instream flow requirements (Section 5.3). This extraction is designed with the intent of a 1:1 ratio between RBF pumping and streamflow depletion. Scenario C withdrawal and injection of Qasr of 2 cfs was simulated between May 15 – July 15. As discussed in Section 3.6.1, direct diversions of 2 to 10 cfs were not of sufficient magnitude to illicit a measurable change in habitat conditions. Per the TM, diversions of 30 to 50 cfs would be needed prior to recording an average decrease in WUA indices of 1 percent or more in the mainstem river and more than 50 cfs to alter habitat attributes in the modeled side channels (Daraio et al. 2003, R2 2007).

During the remaining 10 months of the year, when the ASR source is not pumped from the RBF facility, impacts to the Dungeness River and small streams from ASR recovery pumping are expected to be relatively small (Section 5.4). Assuming that impacts could be offset by by infiltration of Class A reclaimed water **),** resulting streamflows might be increased. It is beyond the scope of this general analysis for ASR to provide a detailed discussion of habitat impacts associated with Scenario C.

5.5.3 Other Potential Environmental Impacts

Other potential environmental impacts sometimes associated with ASR that were not mentioned previously are listed below. While many of these are not applicable to this project, Ecology ASR rules require that they be considered.

- Slope instability caused by increasing water levels and pore pressures.
- Ground deformation caused by ASR injection and recovery.
- Impacts to spring flow due to water level changes.
- Reduction in stream maintenance functions resulting from peak flow diversions.
- Decrease in groundwater levels in nearby wells during seasonal recovery pumping.
- Changes in water quality resulting from stored water discharge to nearby streams.
- Reduction in overall groundwater levels resulting from loss of stored water.

These issues must be evaluated on a site-specific basis. Ecology's ASR rules require these issues to be assessed in an Environmental Assessment report and that a SEPA analysis be conducted as part of the ASR permitting process. We believe these issues will not be a significant concern in the Dungeness area and can be dealt with during the ASR permitting process.

5.6 Engineering Considerations

This section discusses significant engineering elements of the project.

5.6.1 Pilot vs. Full Scale Project

Ecology's ASR rules require that a pilot project be performed to evaluate aquifer response to injection and pumping, assess water quality changes and compatibility, and identify potential impacts. In addition, pilot testing provides important information concerning the ability to divert sufficient quantities of high quality source water to meet project needs, target injection and recovery rates, target storage volume, ASR well performance, recovery percentage, water quality compatibility and treatment needs, and other operational parameters of the system. In most cases, facilities used for pilot projects (e.g., wells) are constructed and tested at full scale. Some projects retrofit existing wells and facilities to reduce costs, particularly for the first project. If existing wells are used for ASR, they must meet today's well construction standards, be constructed so that they are completed within the target aquifer, have a well seal that can maintain integrity during injection, have a screen and filter pack design suitable for injection, and must have suitable diameter to allow for installation of necessary water level monitoring equipment. Existing facilities may or may not allow operation at full scale.

If an existing water-supply well is not retrofitted for ASR in the Dungeness area, we anticipate that it will be necessary to drill a test well that is large enough diameter to permit pumping prior to drilling a full-size ASR well because there is insufficient subsurface information about the deeper aquifers in most areas. If the hydraulic and water quality testing at the test well indicates ASR is feasible, the test well would be converted to a monitoring well and a full-scale ASR well would be drilled. If not, an alternate site could be selected for exploration, at additional cost. The test well approach provides additional assurance that the full-scale ASR well will be a success.

Source water is required for the pilot testing, and developing facilities to obtain low turbidity source water has large cost implications. As the City of Sequim has the only RBF facility in the area, and this facility is both already in use and produces water with too much turbidity for ASR, either a new facility would need to be constructed or pilot testing could be performed with existing sources of water supply (if sufficient rates are available). To construct a new infiltration gallery or shallow extraction wells near the river (or near irrigation ditches), additional siting and characterization work would be required as discussed previously. Testing with existing water-supply sources includes the risk of investing in a test well and injection testing without certainty that an adequate source is available at reasonable cost. If a new RBF facility produces turbid water during high flow events, additional filtration would need to be added at a potentially prohibitive cost.

5.6.2 Land Acquisition

Land for an ASR well site generally must accommodate the well, wellhouse, piping manifold and electrical systems. If needed, a filtration facility can also be included on the ASR well site. The State Department of Health requires that the well owner have a 100 foot radius of control, which results in a site that is roughly 200 feet by 200 feet, or slightly less than 1 acre.

The land area required for an infiltration gallery or a series of extraction wells depends on what length of infiltration gallery is needed or how many extraction wells are required to achieve the desired yield. For planning purposes, we assume that a 400 foot by 100 foot land area would be required.

A 20-foot wide easement would be required for a transmission main needed to deliver water from shallow extraction wells or an infiltration gallery to the recharge facility, unless the transmission main can be located in an existing public right-of-way or irrigation ditch easement. It should be noted that several irrigation districts in the area are in the process of installing pipe in existing irrigation ditches and there may be an opportunity to coordinate with an irrigation district to combine installation of the transmission line with a ditch piping project to reduce expenses, or use an existing irrigation pipeline for transmission.

Acquisition of land, particularly along a water course, can be a very time consuming and expensive process. Therefore, it is generally advantageous to look for property owned by local governments, including parks, schools, and rights of way.

5.6.3 Transmission

A transmission main would be required to deliver 2 cfs of water from the RBF shallow extraction wells or infiltration gallery to the injection facility. Criteria used for preliminary sizing of a transmission main included limiting velocities in the pipeline to 3 feet per second and limiting head loss to 5 feet per thousand feet of pipe. Based on those criteria, a 10-inch diameter transmission main would be required to deliver water from the source to injection wells for recharge. The main could be constructed of pressure rated PVC pipe.

5.6.4 Construction/Design

Components of the ASR system described in this report include a source water diversion along the Dungeness River (or a different surface water feature if suitable conditions are encountered), treatment to remove turbidity as needed, transmission piping from the diversion to the ASR well site, and the ASR well and wellhead system. A conceptual description of each of these components and associated design and construction related issues is presented below.

Diversion System

The conceptual plan for the diversion system for ASR source water consists of an infiltration gallery located adjacent to the Dungeness River[18]. Other surface-water features, such as irrigation ditches, could be considered if sufficient flow capacity, aquifer transmissivity, and groundwater/surface-water connection were available. In order to produce enough water to meet the target (2 cfs) flow rate and acceptable turbidity (<1 NTU), the gallery must be completed in permeable sand and gravel material that is hydraulically connected to the surface-water feature. Ideally, the shallow aquifer materials are laterally extensive, connected with the surface water, are at least 20 feet thick, and contain a high percentage of sand that can provide for adequate filtration. Another key to the success of an infiltration system is that the entrance velocities through the screen must be low to prevent clogging and minimize turbidity. The infiltration gallery should be located as close as possible to the surface water, but no closer than 50 feet away to ensure adequate filtration through natural aquifer materials and to prevent damage from flood events. The conceptual design of the system consists of the following:

- 400-foot long trench, four feet wide
- 6-inch diameter (min) wire-wrapped well screen with slot openings that retain 95 percent of the backfill material
- Course sand backfill around the screen that is sized to retain the aquifer matrix
- Course washed gravel backfill above and below the sand backfill

[18] Ranney collectors were not considered for this analysis because they are quite expensive relative to infiltration galleries and are generally used in situations where a much higher yield is needed.

- Concrete caisson pump chamber on one end of the screen that is approximately 3-feet in diameter and 20-feet deep
- Concrete pipe on the other end of the screen assembly to allow for periodic maintenance.
- Submersible pumps mounted in the concrete pump chamber with control units placed at higher elevation

Treatment

Ideally, water produced by the infiltration gallery will have turbidity that is less than 1 NTU in order to prevent clogging of the ASR well. If it is not possible to produce this quality of water, a filtration system will be needed. Typical filter systems capable of treating 2 cfs generally consist of one of the following technologies:

Slow sand filter beds – generally require large land area, may not function at high turbidity levels, and are maintenance intensive.

High pressure filtration media vessels with pretreatment – smaller footprint but energy intensive and has high O&M costs.

Membranes – small foot print but expensive and energy intensive. Also requires significant O&M.

We have not considered treatment in the cost estimates because if it is required, the cost and feasibility of the overall project would come into question. Because of the importance of this issue, we have included significant characterization and testing work related to RBF feasibility in the early phases of the project.

Conveyance Piping

Conveyance piping from the infiltration gallery to the ASR well site should be sized to accommodate 2 cfs (assume 10-inch diameter). The piping would be installed along existing rights of way to the extent possible.

ASR Well

ASR well(s) would be completed in the lower aquifer or the deep aquifer and are constructed in a manner similar to conventional production wells, except that they are usually larger diameter to accommodate water level access tubes and a down-hole flow control valve, have carefully placed well seals that are capable of handling injection under pressure, have screens that are heavy duty to accommodate periodic aggressive redevelopment, and have filter packs that are generally courser grained and placed so that changes in down-hole pressure due to pumping and injection do not promote sand pumping. The conceptual design for the ASR well(s) for this project is as follows:

- 20-inch min diameter borehole to between 400 and 700 feet depth into the lower or deep aquifer (respectively)

- 16-inch diameter steel casing, sealed into a confining layer above the target aquifer
- 16-inch pipe size (or 12-inch telescoping) heavy duty stainless steel well screen (assume at least 20 – 40 feet long)
- Sand filter pack appropriately sized for the formation

Wellhead and Pumping Facility

An ASR wellhead and pump assembly is similar to a conventional pumping well except that it has an injection loop that by-passes the backflow prevention valve, has a bidirectional flow meter, a flow control valve or down-hole flow control valve to regulate injection, and pump to waste discharge piping to accommodate periodic backflushing (pumping) to remove sediment that has entered the well during injection. Automatic turbidity monitoring systems with auto injection shutoff are recommended. Most ASR well systems utilize a line shaft turbine pump and motor because these can be locked to prevent the impellers from spinning backwards. The specific size and number of impellers must be selected to create enough head loss during injection so that the pump column remains full during injection and no air is allowed to enter the well. An interesting new development is that there are now electrical generating systems being developed to generate electricity during ASR injection. The pump house building is similar to a conventional wellhouse, except that they are usually somewhat larger to accommodate additional wellhead piping. The conceptual design for the ASR well and pumping facility envisioned for this project is summarized below:

- Line shaft turbine pump and motor assembly with locking ratchet
- Two PVC water level access tubes (one for a transducer with datalogger)
- Injection bypass loop
- Bidirectional flow meter
- Flow control valve installed inline or a down hole flow control valve to control injection
- Pump to waste piping and discharge
- Backflow prevention valve
- Manual flow control valve
- Air relief valve
- Sampling port
- Telemetry system to monitor control valve position, flow meter, system pressure (the entire system operation can be automated)

5.6.5 Operation & Maintenance

The initial piloting phase of an ASR project can last 5 or more years depending upon how quickly required data can be collected and evaluated. Operation and maintenance (O&M) effort and associated cost is higher during the pilot phase due to more intensive monitoring requirements and laboratory testing that is required by Ecology. O&M for an ASR project, both during pilot and full-scale phases, typically consists of the following activities:

- Maintenance of the water source diversion facility and transmission lines
- Monitoring flows to the ASR well
- Source water quality testing during injection
- Recovered water quality testing
- Monitoring or water levels in the ASR well and observation wells
- Monitoring ASR well performance during injection and pumping
- Periodic back-flushing of the ASR well if clogging is observed
- Maintenance of disinfection systems (if required)
- Data recording and annual reporting

Based on GSI's experience, one or two well ASR systems require approximately 0.5 FTE of staff support during the pilot phase. Most ASR projects also utilize consultants to assist with data collection and interpretation during the pilot phase. These consulting costs could be $20K - $30K annually depending on how much support the project owner can provide. Laboratory costs are variable but they may be as high as $25K per year during the piloting phase. O&M costs would decrease significantly after the piloting phase is complete. Staff support needed to operate an ASR well system once the pilot phase is completed is slightly greater (+0.25 FTE) than what is needed to operate a typical water supply production well (assuming 1 FTE for a 3 – 4 well system) because injection efficiency must be monitored to ensure that clogging is not occurring. Ideally, consulting costs would be reduced or eliminated as operations staff takes responsibility for monitoring, evaluation, and reporting. Likewise, laboratory costs should be reduced to less than one half of costs for pilot testing (e.g. $12K per year).

5.6.6 Monitoring and Data Needs

Section 5.6.5 outlines the monitoring that is typically required. If the ASR project proceeds, the following items require additional information and/or consideration by project partners:

- Define the pilot project elements including the type and location of the desired ASR source water diversion (bank filtration, shallow extraction wells), location of the desired pilot ASR well site, and approach to conveyance of ASR source water to the ASR well site (e.g., if and how much existing piping can be used). The location and type of source water diversion system would be decided upon first because the ASR well site will likely be determined based on this location. Given the lack of information about deep aquifers, the site for the exploration test well may be selected on the basis of land availability and ownership, proximity to infrastructure including source water diversion, and proximity to where the water is needed.

- Once the ASR source water diversion approach/location and pilot ASR sites are identified, additional site characterization data is needed that includes the following:

  Source Water Diversion

  - Assess shallow aquifer stratigraphy, thickness and extent of high permeability zones, relationship to surface water and degree of connection between surface water and groundwater. Drill shallow test well(s) and dig test pits. Conduct hydraulic testing.
  - For RBF facilities near irrigation ditches, estimate infiltration rates along selected irrigation ditch lengths.
  - Assess Dungeness River water quality during the time of year that water would typically be diverted and recharged. Turbidity of the source water over time is particularly important in order to determine if additional treatment is required for use with injection wells.

  ASR Well Site

  - Drill exploratory test well and conduct aquifer tests at the priority ASR well site. Identify the target aquifer zone (lower or deep aquifer), measure hydraulic characteristics of the target zone, estimate injection and recovery rates, assess boundary conditions to estimate size of storage zone and water level response during ASR. Depending on the results of testing, it may be necessary to drill additional exploratory test wells.
  - Identify the location of nearby existing wells in the target and overlying aquifers so that a monitoring network can be established for future identification of ASR impacts. Measure wellhead elevations and begin collecting baseline water levels. Conduct short term specific capacity tests in target-aquifer wells (if available) and further estimate aquifer transmissivity.
  - Assess native groundwater quality in target aquifer. Collect samples from the exploratory test well and analyze for all Safe Drinking Water Act parameters, iron and manganese, cations, anions, total dissolved solids, total organic carbon, total and fecal coliform, radon, dissolved oxygen, oxidation-reduction potential (field measurement), and pH (field measurement).

Although hydrogeologic conditions have been defined based on available data and estimates derived from the 2008 model, these estimates should be updated as more information becomes available or as pilot ASR sites are considered. Recommendations for further refinement of the 2008 model are included in the model report (PGG, 2009). In addition, the following recommendations pertain to the information gathered during ASR site investigation:

- Aquifer property estimates can be updated and the model recalibrated to both water-level elevations and pilot-test aquifer responses. If ASR is to be conducted in the deep aquifer, approaches as to how to represent this aquifer in the model must be explored.
- Utilize site specific aquifer data and rerun the model to estimate updated stream depletion impacts.

5.7 Permitting Considerations

This section summarizes the permitting process for an ASR project in accordance with the ASR rules (WAC 173-157). Permitting steps include the following elements:

- Pre-application meeting with Ecology
- Reservoir Permit Application to collect and store water
- Preliminary permit for a test well (assuming one is needed)
- Water rights to the source water (diversion and stored water use)
- Secondary permit (needed to recover the water)
- Underground Injection Control (UIC) registration
- NPDES permit for discharges from the ASR system to surface water during short-term redevelopment periods or well flushing

As part of the permitting process, the applicant would also provide the following information:

- Quality assurance project plan (QAPP) for water quality monitoring and any other data collection activities
- Project operation plan (WAC 173-157-130)
- Hydrogeologic assessment report
- Legal framework (WAC 173-157-140),
- Environmental assessment and analysis, including a SEPA determination (WAC 173-157-150), and if necessary,
- Project mitigation plan (WAC 173-157-160).

At this time, there are a number of ASR projects in Washington that are in the permitting and pilot testing phase, but none have been granted a final reservoir permit to conduct full-scale ASR.

5.8 Project Implementation

This section presents an approach to implementing an ASR project, including tasks, schedule, and planning level costs.

5.8.1 Project Approach by Tasks

The approach to the project will depend on several factors including the method and location for diverting ASR source water, location and target aquifer of ASR well(s), and approach for conveying ASR source water to the ASR well(s). Once these factors have been defined and determined, the following are typical tasks that would be conducted:

- Site characterization and monitoring studies as described in Section 5.6.6, and preparation of a site-specific ASR feasibility study.
- Project permitting as described in Section 5.7
- Pre- and final design, bidding, and contractor selection
- Project construction
- Pilot testing
- Final permitting and project documentation

5.8.2 Project Schedule

As discussed previously, several elements of the project require further definition in order for the schedule to be determined. In general, the following schedule can be assumed once the project definition has been completed.

- Site characterization and monitoring studies - 6 months
- Project permitting as described in Section 5.7 – 6 months to 1 year concurrent with other tasks
- Pre- and final design, bidding, and contractor selection - 6 months
- Project construction – 6 months
- Pilot testing – 6 month duration each year for up to 5 years
- Final permitting and project documentation – 3 months

The timing of when recharge water will be available will drive the schedule during the pilot testing phase of the project.

5.8.3 Project Cost Estimate

The preliminary cost estimates presented below are based on our experience with other projects and are not developed for the specific needs of this project. A contingency of 25 percent has been added to capital cost items to account for uncertainties associated with project specific conditions.

Additional Site Characterization Costs

As discussed in Section 5.6.6, additional site specific characterization information is needed to evaluate ASR project feasibility and cost, and is also needed for the ASR permitting process. This information includes investigation of RBF feasibility, project definition and cost, further characterization of source water and native groundwater quality, development of a groundwater monitoring network, and characterization of the target storage zone.

Contractor costs for investigating RBF feasibility, assuming two shallow (25 foot deep) test wells, aquifer testing at the test wells, four shallow trenches, infiltration tests at the trenches, and water quality characterization are on the order of $30,000. Outside consultant costs associated with overseeing the RBF feasibility characterization, collecting water samples, and analyzing the data would be on the order of $30,000. Assuming a 25 percent contingency, the total RBF site characterization costs would be approximately $75,000. It should be noted that characterization of more than one RBF site may be required.

For the ASR site investigation, contractor costs for drilling and testing a deep exploratory well to 400 to 700 feet are approximately $300/foot or between $120,000 and $210,000. Outside consultant costs associated with development of the ASR monitoring well network, overseeing the ASR characterization work, collecting water samples, and analyzing the data would be on the order of $50,000. Assuming a 25 percent contingency, the total ASR site characterization costs would range from about $212,000 to $325,000. It should be noted that characterization of more than one ASR site may be required.

Capital Costs for Construction

Capital costs for ASR wells vary depending upon well depth, diameter, and injection rates. Drilling and well construction costs would be similar to conventional production wells except that they may include additional features as described in Section 5.6.1. Assuming injection/pumping rates of approximately 900 gpm, drilling, well construction, and aquifer test costs for a 400 to 700 foot deep ASR well would be on the order of $350 per foot or $140,000 to $245,000.

Capital costs for above-ground injection facilities (concrete pad, near-well piping, control valve, metering, monitoring equipment, and down-hole injection tube) are typically on the order of $300,000. However, as previously noted, wells typically require back-flushing (pumping to remove entrained sediment) in addition to injection. Therefore, dual-purpose (injection and back-flushing) facilities are typically recommended. Capital costs for a dual-purpose ASR station to support pumping and injection (including the pump, pumphouse, telemetry and disinfection) are on the order of $1,000,000.

Capital costs for construction of an RBF intake facility capable of producing up to 2 cfs are based on the conceptual design described in Section 5.6.4 and are estimated to be approximately $250,000. This cost includes site preparation, installation of the collection screen and pump chamber, installation of three submersible pumps and pump control systems, meters, valves and appurtenances. Available monthly production data from the City of Sequim's infiltration gallery indicates that it is capable of producing up to 1 million gallons per day or 1.6 cfs (700 gpm). The conceptual RBF system we have described in this report is somewhat larger and so we have assumed that it would be capable of producing the target 2 cfs. The yield of the system will be dependent on the permeability of subsurface materials and the degree of hydraulic connection with surface water. Given the apparent variability of the shallow geologic materials in the area, it is possible that a second RBF system may be needed to achieve the target production rate.

If the ASR well testing results indicate that an additional ASR well is needed to inject and store the desired source water diversion rate of 2 cfs (900 gpm), capital costs for the additional ASR well and above-ground facilities would be added to the total project cost. Capital costs for land and conveyance piping would also increase proportionately.

Design and Permitting

Costs of design (excluding piping because the distances are unknown, land purchase, and source water diversion system), construction oversight, and permitting the ASR well program are assumed to be approximately 20 percent of the capital costs for the ASR well system, or $250,000. Consultant costs for conducting and evaluating pilot tests (approximately $50,000) and laboratory costs (approximately $25,000) would be approximately $75,000.

Transmission

Costs for implementation of this scenario will include the cost of installing a transmission main from the RBF source to the injection wells. As was noted previously, a 10-inch pipe should have sufficient capacity to convey 2 cfs for recharge under this scenario. The cost of installing a 10-inch PVC transmission line rated for pressures up to 125 psi is estimated at approximately $55 to $80 per foot of pipe installed. Design and permitting costs will likely be approximately 15 percent of the construction cost, or $8 to $12 per foot of pipe installed. Although the required length of transmission line is unknown, for the purposes of comparison with other projects this cost estimate assumes low-end and high-end lengths of 1 and 2 miles (respectively).

Land Acquisition

Additional costs will be incurred for the purchase of land for the extraction and recharge facilities. As indicated in Section 5.6.2, approximately 1.8 acres of land will be required for these facilities. The estimated cost of developable land in the Sequim area is approximately $100,000 per acre. As a result, the estimated land costs for the extraction and recharge facilities is $180,000 per facility (note that two facilities could be required depending on the facility yields and aquifer properties encountered). If these facilities can be located on a public property, such as a park, school, or right-of-way can be found, the cost for land may be lower.

In addition, an agreement will be needed for use of a public right-of-way or ditch easement for installation of a transmission line. Assuming that an appropriate right-of-way or easement is available, the cost of the agreement should be relatively low (less than $10,000). However, if an easement has to be secured from private property owners for a transmission line, the cost may be much higher. For the purpose of this analysis, lower-end easement costs are assumed to be $10,000 and upper-end easement costs are assumed to be $60,000, based on the assumption that private easements would be required for no more than 5,000 feet of transmission line, at a cost of $10 per foot.

Maintenance and Monitoring Costs

Ongoing operation and maintenance costs for ASR and injection wells can vary greatly depending upon Ecology monitoring requirements (refer to Section 5.6.5), staff availability versus hiring consultants to perform the monitoring, and source water quality and the degree of clogging that will be experienced. Dedicated pumps should be installed in injection wells to allow for back-flushing of the wells to remove injected sediment. In addition to maintaining the injection well system, water quality and water level monitoring will be required by Ecology as part of the recharge permit. It is difficult to estimate operation and maintenance costs at this time because we have limited information on source water quality (particularly turbidity), number of injection wells, susceptibility of injection wells in this area to clogging, and monitoring requirements. This information is typically developed later as part of a pilot project. For preliminary cost estimating purposes, we can envision that it may be necessary to spend on the order of $100,000 per year for operation, maintenance, and monitoring of the injection system.

Operation and maintenance costs for an RBF system generally consist of electrical costs for pumping, periodic monitoring of flow and produced water quality and turbidity (this can be automated), and periodic pump maintenance. Assuming that the system is operated for 2 or 3 months per year, annual operating costs are estimated to be approximately $25,000. Infiltration galleries that are not properly designed for the site setting (e.g., improper sizing of the filter media and screen) or are over-pumped have a tendency to clog, requiring potentially significant effort to maintain production rates. For cost estimating purposes, we have assumed that the infiltration gallery will have to be cleaned out and redeveloped every two years at a cost of $20,000. The total annualized O&M cost would then be approximately $35,000.

Summary of Total Project Costs

Based on the estimates discussed above, the following table summarizes the range of estimated project costs. Note that the lower-end estimate assumes just one RBF and ASR site investigation needs to be performed and one of each facility needs to be constructed, whereas the upper-end estimate assumes two.

PRELIMINARY COST ESTIMATE FOR SCENARIO C

Fixed Costs	Lower End		Upper End		Notes
	Units	Costs	Units	Costs	
RBF Site Characterization	1 site	$ 75,000	2 Sites	$ 150,000	
ASR Site Characterization	1 site	$ 212,500	2 Sites	$ 650,000	Includes test well(s) @$300/ft, 400 to 700 feet deep.
ASR Wells	1	$ 140,000	2	$ 490,000	ASR wells @$350/ft, 400 to 700 feet deep.
Above Ground ASR Facilities	1	$ 1,000,000	2	$ 2,000,000	
RBF Facility	1	$ 250,000	2	$ 500,000	
Design Costs	1 site	$ 250,000	2 Sites	$ 500,000	
Pilot Testing	1 site	$ 50,000	2 Sites	$ 100,000	

Laboratory Fees During Pilot Testing	1 site	$ 25,000	2 Sites	$ 50,000	
Transmission (10-inch pipe)	5,280 feet	$ 485,760	10,560 feet	$ 971,520	Ranges: 1 mile - 2 miles; $63-$92/ft. Plus 15% for design & permitting.
Land for Facilities (acres)	1.8	$ 180,000	3.6	$ 360,000	Assumed $100,000/acre
Easements for Transmission		$ 10,000		$ 60,000	
Total Fixed Costs	1 site	**$ 2,603,260**	2 Sites	**$ 5,681,520**	
Maintenance/Monitoring Costs (per year)	1 site	$ 135,000	2 Sites	$ 202,500	O&M for ASR and RBF sites combined

5.9 Summary of Costs, Benefits and Concerns

Scenario C capital costs are estimated to range between $2,600,000 and $5,700,000 million depending upon the number of locations characterized for RBF and ASR sites, the number of RBF collectors and ASR wells required to achieve the desired system capacity, the depth to the targeted ASR aquifer, and how the site locations affect the required length of transmission pipe. Operating costs are expected to be on the order of $135,000 to $200,000 per year.

Because ASR is conducted in deeper portions of the groundwater flow system, an ASR project by itself would have little direct benefit to either streamflows or habitat. However, use of ASR could significantly reduce the streamflow impacts of new water-supply development, particularly if the ASR is conducted as deep as possible in the groundwater flow system. In addition, if ASR is used to support new residential development, infiltration of Class A reclaimed wastewater from the new development could cause net streamflow augmentation in a manner similar to the mechanisms described above for Scenario B. The benefits of infiltrating reclaimed water associated with ASR-based groundwater development are further discussed in Section 7.

Conceptually, ASR could also be used solely to augment streamflows by storing river flows when available (i.e. during the freshet) and recovering the stored water when needed (during the low flow season). Only a portion of the injected ASR water could be retrieved during the low flow season, because a portion is expected to be lost as increased groundwater discharge to marine and surface-water features. Although the cost of injecting the target volume (2 cfs over a 2-month period) is relatively high, the ASR approach provides more control over the recovered water for direction to specific habitat enhancement projects. As noted above, up to 2 cfs of Dungeness-River flow enhancement during the low-flow season is expected to provide small or immeasurable habitat benefit; however, such flow enhancement could be significant for the small, independent streams.

The main concerns identified for Scenario C include hydrogeologic uncertainties (number of sites to be investigated, number of RBF facilities and ASR wells, ASR well depths and potential need for RBF filtration to remove turbidity) and possible changes in source availability due to climate change (earlier, shorter and lower-volume spring freshets).

6 TRANSFERABILITY OF FS FINDINGS TO ALTERNATIVE SITES

The level of location specificity in this FS varies from a designated site (Scenario A), to a designated area (Scenario B), to general concepts for ASR in deeper portions of the groundwater flow system (Scenario C). Similarly, the level of specificity for various FS findings ranges from site-specific to general. While only two AR scenarios (A and B) were selected for this FS, many additional scenarios were evaluated during the modeling exercise (PGG, 2009), and over time, interest may form for performing AR at other sites. As noted in Section 2, the benefits of AR vary from site to site, and while AR benefits from any one single site may be relatively small, greater cumulative benefit can be achieved by performing AR at multiple sites. Thus, consideration of additional AR sites and/or site combinations may be required at a later time. While a site-specific FS (similar to Scenario A) is recommended for any site under consideration, portions of the content of this FS may be helpful in performing back-of-the-envelope assessments of the costs and benefits of performing AR at alternative sites.

Concepts on the transferability of FS elements are presented below. These concepts focus mainly on the transferability of components of an AR project, because the ASR discussion is already general enough to remain transferable to multiple sites.

- Conceptual Project Design – While project design will vary from site to site, common elements remain. AR sources are generally either river water or reclaimed water (although groundwater from deeper aquifers could conceivably be transferred to the shallow aquifer). The timing and quantity of sources will be dictated by either natural river flows and instream flow requirements, or production from wastewater treatment plants along with other competing uses for reclaimed water. AR is typically accomplished in infiltration basins or ditches (whether constructed or existing. abandoned and leaky ditches), and ASR is typically accomplished with dedicated wells.
- Hydrogeologic Setting of Project Site – Hydrogeologic setting can vary significantly between locations and should not be generalized between sites. Hydrogeologic conditions control the infiltration capacity of an AR site, thus the sizing, design and cost of an infiltration facility will depend largely on site conditions.
- Hydrologic Responses to AR Operations – PGG used the 2008 Groundwater Model to evaluate hydrologic responses to AR operations at 11 sites, under a variety of model assumptions (PGG, 2009). Hydrologic responses, expressed as net impact to Dungeness Peninsula streams, varied significantly as a function of the magnitude and timing of AR infiltration and the location of the AR site relative to various surface-water bodies. While the 2008 Model report can be used to reference predicted AR responses for the remaining sites considered, additional model simulations are recommended to obtain model predictions for sites with much different locations or associated aquifer properties.
- Water Quality Considerations – These considerations are largely dependent on the source (river water vs. reclaimed water) and can be generalized between sites. However, the number of downgradient wells (and other groundwater receptors) can vary between sites, and

are a consideration in maintaining sufficient subsurface travel times when AR is performed with reclaimed water.

- Net Effect on Habitat – Habitat effects depend on hydrologic responses to AR operations, which are very site-specific (see above).
- Other Potential Environmental Impacts – These impacts are largely site-specific.
- Engineering and Cost Considerations – Engineering considerations are largely transferable between sites. Distinctions between the pilot-scale and full-scale project are similar among AR projects. Costs and considerations for land acquisition and transmission are comparable, but may be influenced by differences in local property values and terrain. Construction/design concepts are also transferable among similar projects (e.g. infiltration via ditches and infiltration via basins); however the scale of a facility will be dependent on the site hydrogeologic setting and the desired recharge rate – and scale can influence the costs of construction. Similarly, while operation and maintenance approaches may be similar for similar projects (ditches or basins), the cost of O&M will depend on scale. Monitoring approaches will also be similar between similar projects; however, larger scale projects may require more monitoring points.
- Permitting Considerations – Permitting is expected to be similar for AR projects with similar sources. However, permitting requirements are site specific and may vary depending on the conditions at each site.

7 COMPARING STRATEGIES FOR NEW WATER SUPPLY DEVELOPMENT

Projected population growth in the study area continues to drive planning for new water-supply development. Water purveyors generally target the middle and lower aquifers for new sources of groundwater supply, as the shallow aquifer is more vulnerable to contamination from the land surface and may have insufficient available drawdown for high capacity production wells. Furthermore, because the shallow aquifer is more hydraulically connected to surface water features, new water rights would require more mitigation. Pumping from the deeper aquifers has less impact on surficial streams because the aquifers are less hydraulically connected to these streams, and because deeper withdrawals capture a higher portion of groundwater that would have otherwise discharged to marine bodies. However, pumping from deeper portions of the groundwater flow system tends to cause more widespread drawdown (both in the pumped aquifer and in overlying aquifers), so streamflow impacts (while greatly reduced) occur over a wider area.

The Elwha/Dungeness Watershed Plan (2005) included recommendations for rulemaking for instream flow protection, which will affect strategies for new water supply. The rulemaking has not yet been completed, but includes instream flow requirements on the Dungeness River, its tributaries, and independent streams; and will include mitigation requirements and/or reservations to protect streamflows. Mitigation requirements typically necessitate that potential effects of new withdrawals on streamflow is offset. Proposals for new groundwater supply development will be faced with the challenge of meeting mitigation requirements for streamflow capture associated with pumping. The details regarding mitigation requirements are yet to be determined but will dictate the complexity and expense of new water-resource development strategies, and water purveyors will need to plan accordingly.

This section was prepared based on interest expressed by TAG members. It explores some of the options available to water purveyors under the assumption that mitigation will be required for flow depletion to the Dungeness River and (at least some) small streams. As illustrated in Section 5.4, pumping from the middle and lower aquifers (and presumably the deep aquifer) are expected to cause *some* reduction in baseflow in streams with hydraulic connections to the shallow aquifer. Purveyors will need to decide which aquifer to target for new supply. This decision includes considerations of available yield per aquifer along with the geographic distribution and quantity of likely mitigation requirements. While streamflow capture from pumping in the middle aquifer will likely remain somewhat more local to the point of withdrawal, quantities of streamflow capture will be greater than for pumping from the lower aquifer. Conversely, pumping from the lower aquifer is expected to cause less overall streamflow capture, but would likely affect streams over a larger area. Because small streams occur throughout the peninsula, flow protections on these streams and the availability of local mitigation will likely affect a purveyor's choice of source aquifer and point of withdrawal.

A third possible source of groundwater supply – the "deep aquifer" discussed in Section 5.2.2 – would likely cause similar impacts as pumping from the lower aquifer. The deep aquifer occurs beneath limited portions of the peninsula, and its full geographic extent is unknown. Impacts from pumping in the deep aquifer could be more dispersed and slightly smaller than pumping in the lower aquifer, but more hydrogeologic characterization would be required to make this prediction. Hydraulic isolation between the deep aquifer and overlying portions of the groundwater flow system may impose some limitation on recharge available to the deep aquifer. If this is so, the deep aquifer may be better suited for ASR than the year-round withdrawals typical of public water supply.

Assuming that mitigation would be required for potential impact to small streams, the following five strategies for developing new groundwater supplies are considered:

1. Conventional withdrawals from the middle or lower aquifer with mitigation from infiltration of reclaimed water;
2. Conventional withdrawals from the middle or lower aquifer with mitigation from infiltration of reclaimed water plus supplemental AR with infiltration of river water;
3. Conventional withdrawals from the middle or lower aquifer with mitigation from infiltration of river water;
4. ASR conducted within the lower or deep aquifer with mitigation from infiltration of reclaimed water; and,
5. ASR conducted within the lower or deep aquifer with mitigation from infiltration of river water.

As mentioned above, if future groundwater-sourced residential development relies upon septic systems, a portion of the new pumping would be recharged into the shallow aquifer via septic effluent and would therefore provide some baseflow increase in nearby streams. Such a baseflow increase would provide some offset to streamflow capture associated with pumping; however, Ecology does not usually accept septic return flows as mitigation for pumping impacts (in part, based on decisions by the PCHB). The geographic distribution and water quality associated with septic recharge is less controlled than for infiltration of reclaimed water, as is the ability to account for the quantity recharged and enforce water quality standards. Furthermore, future conversions of septic systems to sewers could result in loss of recharge unless the sewer systems are *required* to infiltrate the reclaimed water. While it may be possible to stipulate conditions (and legal agreements) under which septic recharge would provide acceptable mitigation, such conditions may be complex and are beyond the scope of this analysis. For the purpose of this discussion, all potential mitigation associated with wastewater management is assumed to occur through infiltration of Class A reclaimed water from a centralized facility.

Conventional Withdrawals with Reclaimed Water Mitigation

Infiltration of reclaimed water could provide mitigation for groundwater withdrawals from the deeper aquifers. PGG has reviewed a number of estimates for the annual average consumptive and non-consumptive portions of water use. Based on the assumptions outlined on **Table 7-1**, a reasonable estimate might suggest that year-round wastewater generation from indoor use represents about 50 percent of the annual volume pumped to supply a domestic residence with a small lawn or garden (e.g. about 0.1 acre)[19].

If Class A reclaimed wastewater were used to mitigate groundwater withdrawals, it is reasonable to assume that about 50 percent of the annual withdrawal volume could be available to recharge the shallow aquifer at a steady rate through infiltration of Class A reclaimed water in an AR facility. If reclaimed water were infiltrated at a single facility close to the Dungeness River, model simulations suggest augmentation rates of over 90 percent Q_{ar} can be achieved (PGG, 2009). Augmentation would be steady throughout the year because the reclaimed water has a steady source of supply. If augmentation of smaller streams is also desired (as determined by biological and other considerations), the AR infiltration facility would need to be moved away from the Dungeness River towards the targeted streams. Small streams located farther from a single AR facility receive less benefit. For example, model scenarios suggest that AR infiltration on one side of the Dungeness River has significantly lower benefit to small streams on the other side of the river (ibid). Among 11 AR scenarios simulated by the model, all showed that at least 79 percent of the AR volume discharges to the Dungeness River and other streams, as opposed to marine discharge[20].

Designing a mitigation approach based on wastewater infiltration would need to consider the impacts of pumping from the new groundwater source and the streamflow mitigation requirements generated through rule making. For example, PGG simulated steady-state pumping from two locations (east and west of the Dungeness River) from the middle and lower aquifers with varying assumptions regarding aquitard permeability (K_v) (ibid). For these two locations, the "best estimate" model (K_v = 0.0008 ft/d) estimated that about 27 percent of pumping from the lower aquifer would impact streams and about 55 percent of pumping from the middle aquifer would impact streams. Middle aquifer pumping simulated with the "alternative model" (K_v of the upper confining bed increased to 0.008 ft/d) increased estimated stream capture from 55 percent to between 75 percent and 85 percent. Lower aquifer pumping simulated with the "sensitivity analysis" model (K_v of both confining beds increased to 0.008 ft/d) west of the river suggested that that the impact on streams would increase from about 27 percent of pumping to about 64 percent of pumping. Given PGG's prior observation that the "sensitivity analysis" model likely over-estimates the hydraulic connection between the lower aquifer and the shallow aquifer, a range of 27 percent to 50 percent may be more reasonable. It should be re-stated that model predictions are considered approximate, and multiple model "realizations" along with sensitivity analyses were used to address uncertainties associated with pumping predictions from the middle and lower aquifers. Additional model calibration (and potentially hydrogeologic characterization) would be needed to improve the accuracy of this range.

[19] It is also worthwhile to note that annualized recharge associated with inefficiencies in irrigation applications is estimated to be about 13% of domestic water use. Although this recharge is not considered as a mitigation source in the analysis below, a portion would likely augment baseflows in local streams.

[20] A facility close to the coast would likely exhibit a much smaller portion of discharge to streams.

It is also important to note that steady-state model simulations do not portray seasonal variations in pumping, which will also cause seasonal variations in streamflow depletion above and below the average values described above. However, for the purpose of this analysis, assuming that streamflow capture from lower-aquifer pumping is on the order of 27 percent to 50 percent of the annual volume pumped and that 50 percent of the volume pumped is available for generation of reclaimed water, this quantity of reclaimed water may be sufficient to mitigate for a new groundwater source. However, this general observation is subject to several specific qualifications. First and foremost, Ecology may require that the reclaimed water available for augmentation would need to provide benefits to streams in accordance with the peninsula-wide distribution of estimated streamflow depletion. Depending on the ultimate mitigation requirements, suitable distribution of mitigation water could be a challenging and expensive endeavor. Also, as noted above, depending on the temporal pattern of withdrawal, pumping impacts could seasonally exceed wastewater generation. Finally, estimates of streamflow capture may also vary somewhat with the location of pumping, particularly if local aquitard K_v varies from the regional values used to calibrate the model. Nevertheless, this analysis suggests that infiltration of reclaimed water alone could provide the bulk of the mitigation volume associated with new pumping from the lower aquifer. Supplemental mitigation might be needed during portions of the year, and yet more supplemental mitigation would be needed if groundwater was withdrawn from the middle aquifer due to greater capture from streams.

Conventional Withdrawals with Reclaimed and River Water Mitigation

If mitigation with reclaimed water alone proved to be insufficient during portions of the year, the Dungeness River could be used as a supplemental source to meet a portion of the mitigation conditions. As described in Scenario A, water would likely be available during the spring freshet to be used as a source for AR infiltration. PGG performed a variety of model simulations to estimate how 2 months of AR infiltration would augment flows in the Dungeness River and other small streams throughout the year (PGG, 2009). Infiltration sites near the river were predicted to deliver relatively high rates of augmentation to the Dungeness River both during and immediately after infiltration (e.g. up to 70 percent of Q_{ar}); however, these rates were predicted to decline quickly after cessation of infiltration and provide little benefit to surrounding small streams. Infiltration sites farther from the river were predicted to provide lower but more consistent rates of Dungeness River augmentation over the course of the year (e.g. 5 percent to 15 percent of Q_{ar}) and increased benefit to nearby small streams.

An AR program using Dungeness River water would provide additional water to the groundwater flow system – most of which is predicted to augment flows in the river and small streams. Designing a mitigation program using both reclaimed water *and* Dungeness River water would require analysis of the magnitude and timing of mitigation benefits at specific (and multiple) locations, and the quantity and timing of Dungeness River water availability. If a new groundwater supply is developed and Dungeness River water is used *purely* for supplemental mitigation of pumping impacts, the net effect of the project could be habitat neutral. If more water is infiltrated than is required for mitigation, streamflows will be increased outside the period of AR diversion and the net project effect on habitat may be more positive.

Conventional Withdrawals with River Water Mitigation

Mitigation of new groundwater withdrawals with river water only might be considered when the quantity of new withdrawal is small relative to the available mitigation volume. Such a high ratio of mitigation water to groundwater withdrawal would be needed because pumping impacts are year-round and the year-round portion of streamflow augmentation from AR infiltration during the 2-month spring freshet is relatively low. For example, model predictions of the year-round impact of a constant groundwater withdrawal from the middle and lower aquifers on flows in the Dungeness River range from about 20 to 70 percent of the pumping rate (PGG, 2009). As noted above, the year-round component of Dungeness River augmentation from AR of river water infiltrated during the freshet is predicted to range from 5 to 15 percent of Q_{ar}. Assuming a year-round impact of 50 percent of the pumping withdrawal and a year-round mitigation of 5 percent Q_{ar}, mitigating flow depletion on the Dungeness River would require a Q_{ar} during the freshet 10 times greater than the rate of groundwater withdrawal[21]. If a new groundwater development from the lower aquifer is associated with septic return flows (i.e., no wastewater treatment plant is constructed) and if Ecology does not accept septic return flows as mitigation to streamflow impacts, then infiltration of river water alone could possibly meet mitigation requirements. As with all mitigation strategies relying on shallow aquifer AR, this mitigation strategy would also need to address mitigation requirements in other streams on the peninsula, which could be relatively widespread.

ASR with Reclaimed Water Mitigation

A different approach to gaining new water supply and simultaneously benefiting streamflows uses ASR as the source of supply, rather than a conventional groundwater withdrawal. As discussed under Scenario C, ASR water sourced from the Dungeness River could be injected into the lower aquifer or the deep aquifer during the spring freshet and recovered during remaining portions of the year. Greater recovery efficiencies can be achieved by withdrawing the water soon after injection (e.g. inject for two months during the freshet and recover for two months during the summer peak demand); however, the injected water could also be recovered year round. Class A reclaimed wastewater from the residential development associated with ASR could then be infiltrated to offset impacts to streams associated with ASR recovery pumping. In effect, the ASR water is used twice: first it is injected into the target aquifer and pulled back out to supply new homes, and then the non-consumptive portion of the associated residential use (e.g. 50 percent) is used to recharge the aquifer and augment streamflows.

In the ASR scenario, instantaneous impacts to streams are smaller than conventional withdrawals due to the period of recharge (injection) prior to recovery. The ASR activity itself can cause periods of streamflow augmentation *and* depletion (respectively associated with injection and recovery) and nearly negligible net annual impacts (if properly designed). For example, model simulation of ASR in the lower aquifer assuming 2 months injection followed by 1 month

[21] For instance, a groundwater withdrawal of 1 mgd (1.55 cfs) would be required to mitigate for 0.5 mgd, which could be accomplished by infiltrating 10 mgd (15.5 cfs) during the freshet.

dormancy and 2 months recovery (at the same rate as injection) suggested that maximum seasonal depletion in the Dungeness River could range from 1.3 percent, to 4.2 percent, to as much as 15.2 percent of the ASR injection rate depending on assumptions regarding the hydraulic conductivity of the aquitards that separate the major aquifers (Section 5.4). The upper value is derived from sensitivity analysis rather than a calibrated version of the model; and the range suggests that further model calibration would help to constrain seasonal streamflow depletion impacts. Predicted seasonal depletion of other small streams is small relative to the Dungeness River (**Table 5-2b**). Seasonal streamflow depletion could be further reduced by lowering the recovery volume relative to the injection volume. Finally, if hydrogeologic investigations show that the deep aquifer is relatively isolated and suitable for ASR, seasonal depletion estimates would likely be significantly lower for ASR within the deep aquifer.

Because model simulations predict that seasonal streamflow depletion is less than the reclaimed water availability (assumed to be 50 percent of the annual pumped volume), sufficient reclaimed water should be available to provide mitigation as well as net streamflow augmentation year-round (except for during the period of diversion - spring freshet). As discussed above, mitigation may include the requirement to distribute streamflow augmentation among multiple streams based on the predicted geographic distribution of depletion. The feasibility of this strategy for new water supply development will be affected by the mitigation requirements developed during rulemaking for the Dungeness watershed.

In many ASR applications, recovery is limited to only a portion of the quantity injected, because a small portion of the injected water migrates away from ASR well and is generally not available for recovery by the ASR well. Any water left in the aquifer ultimately offsets pumping impacts to streams from other wells, or eventually discharges to streams or the marine environment. The above analysis suggests that, ASR conducted in the deeper aquifers coupled with shallow groundwater recharge of reclaimed water could provide a net positive impact to streamflows (outside the period of ASR diversion). Furthermore, if reclaimed water return flow to streams significantly exceeds the estimated streamflow capture associated with ASR recovery withdrawals (when recovery equals injection), it may be possible for the withdrawal quantity to exceed the injection quantity in a typical ASR injection/recovery cycle. Such a groundwater development scenario could be considered a hybrid between traditional ASR (recovery ≤ injection) and conventional groundwater withdrawal.

ASR with River Mitigation

Development of new water supply using ASR along with mitigation from infiltration of river water could also work if the streamflow augmentation from infiltration exceeds seasonal streamflow depletion from ASR. Whereas mitigation from reclaimed water infiltration could have a year-round source, mitigation from the river flows is largely limited to the spring freshet, and flow availability would likely vary from year-to-year. Nevertheless, if additional studies and/or use of the deeper aquifer for ASR predict that associated streamflow depletion will be very low (e.g. less than several percent of Q_{asr}), then the availability and timing of a river source may be sufficient to offset this small seasonal depletion. As noted above, model predictions suggest that infiltration sites farther from the Dungeness River can provide low (e.g. 5 percent to 15 percent of Q_{ar}) but consistent rates of river augmentation over the course of the year along with flow benefits to nearby small streams. As with all the strategies discussed in this section, mitigation water would need to be distributed to streams according to mitigation criteria established in the Rule.

Comparison of Water-Supply Development Strategies Using AR or ASR

The following summary compares the strengths and weaknesses of the four water-resource development strategies described above:

1. For all strategies, providing streamflow augmentation that matches the geographic distribution of streamflow depletion may be difficult to achieve. The quantity and timing of streamflow augmentation is controlled both by the AR source availability and the location of the AR mitigation site(s). The possibility of mitigation success will partially depend on the streamflow protections adopted during rulemaking.
2. The costs of both conventional groundwater withdrawals and infiltrating river water using existing facilities (e.g. ditches) are relatively low compared to the costs of infiltrating reclaimed water and ASR. Both the latter activities require construction of new facilities and require considerably more monitoring and regulation. Infiltration of river water using newly constructed facilities falls within this cost continuum. Among the five strategies described above, the least expensive likely include: 1) conventional withdrawals with mitigation of river water in existing facilities, 2) conventional withdrawals with mitigation from reclaimed water, and 3) ASR with mitigation from river water in existing facilities; and the most expensive likely include: 4) conventional withdrawals with mitigation from reclaimed water *and* a new river-water infiltration facility, and 5) ASR with mitigation from reclaimed water. Construction of *new* river-water infiltration facilities would increase costs for the approaches relying on river-water infiltration. While not performed in this FS, ultimately, all strategies should be considered on a cost-per-gallon basis.
3. Mitigation sources, whether from the river during the spring freshet or from Class A reclaimed wastewater, have some potential for interruption. Interruptions in the operation of a full-time reclaimed wastewater facility are possible, as are affects on Dungeness River flows due to normal climatic variability and long-term climate change.
4. Additional model calibration would be valuable towards providing better predictions of streamflow depletion associated with pumping in the middle, lower and deep aquifers. These predictions include a significant range of uncertainty, and dictate the required rates of streamflow augmentation as mitigation.
5. Mitigation of conventional groundwater withdrawals with reclaimed water depends on the water-supply source aquifer. Streamflow depletion associated with withdrawals from the middle aquifer may exceed the availability of reclaimed water for mitigation, whereas withdrawals from the lower aquifer are far less likely to have this effect.

6. Mitigation of conventional groundwater withdrawals with reclaimed infiltration *and* Dungeness River AR infiltration might offset impacts of middle-aquifer pumping that could not be mitigated with wastewater infiltration alone, and might also increase the available quantity of groundwater development. Additional costs would be incurred for AR infiltration of river water.
7. Mitigation of conventional groundwater withdrawals from deeper portions of the groundwater flow system with river water alone (assuming river water is available only during the 2-month spring freshet) would require a relatively high ratio of mitigation rate to the annual rate of withdrawal, but should not be dismissed if available river flows combined with the infiltration capacity of the AR site could mitigate the desired new groundwater withdrawal.
8. New water-supply development from ASR is typically limited to the source quantity available for injection. With this limitation on how much water can be injected (e.g., site injection capacity over the maximum 2-month long spring freshet period when flows in the river exceed the minimum stream flow), new water supply derived from ASR may be less than with conventional withdrawals mitigated by reclaimed and river infiltration. The ASR approach also requires more investment for hydrogeologic characterization, site selection, and overcoming technical obstacles such as turbidity in the source water.
9. If the ASR source quantity were sufficient to satisfy new development, mitigation of ASR with reclaimed water infiltration might provide a higher percentage of streamflow augmentation due to its relatively low percentage of streamflow capture[22]. Consequently, a hybrid approach that combines conventional withdrawals from new production wells and ASR (both in the lower or deep aquifers) with mitigation via reclaimed infiltration could be used to increase the available quantity for water supply development beyond ASR source availability.
10. Mitigating ASR with infiltration of river water may be sufficient if streamflow depletion associated with recovery pumping is relatively small and does not exceed the quantity of river water available for mitigation. Mitigation requirements can be further reduced by reducing the quantity recovered relative to the quantity stored in the aquifer. Additional analysis would be required to evaluate how the ratio of injected vs. recovered ASR water influences mitigation requirements.

[22] As noted in Section 4, net streamflow augmentation associated with reclaimed water recharge remains small relative to the flow magnitudes required for significant improvements to habitat.

8 FINANCING OPTIONS

There are a myriad of potential funding sources for the recharge project. A few options summarized here are recommended to pursue initially because of greater funding availability and fewer strings attached to the funding.

8.1 Direct Legislative Appropriations

The first potential source of funding is direct legislative appropriations from Congress or the State Legislature. Senators Cantwell and Murray have in the past been successful in obtaining appropriations for numerous projects in Washington State with similar purposes such as flood control, water resource management, and aquifer storage and recovery. The State Legislature has also provided direct appropriations for similar projects. The key to obtaining funding for projects through this approach is to have a defined project with a good estimate of costs, demonstrate widespread local and partner acceptance of the project, demonstrate regional benefits, and meet directly with the legislators to convey the importance of the project

8.2 Other State and Federal Programs

Table 8-1 presents a list of selected state and federal grant and loan funding programs that may be suitable for the projects. Each program has unique requirements and funding applications that would need to be tailored to the type of benefits the funding program is looking for. For example, the Centennial Clean Water Fund (administered by WA Dept. of Ecology) is looking for projects with a water quality benefit, while the Salmon Recovery Funding Board grant programs (with the WA Recreation and Conservation Office) are for projects that benefit salmon habitat. Most of the funding programs listed in Table 12 will require participation from Clallam County, either as a partner or as a lead agency.

8.3 Local Stakeholders

Major local stakeholders in water management include Clallam County, the City of Sequim, the Jamestown S'Klallam Tribe, the Clallam PUD, and irrigators. Consideration should be given to funding from existing programs that are already focused on improving low flows in the lower Dungeness River and augmenting groundwater resources.

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TABLES

Table 1-1 Summary of FS Simulations

	A	B	C
Primary Purpose	Benefit Dungeness River flows	Benefit small streams as well as River	Mitigate for new water rights
Zone of recharge	Shallow aquifer	Shallow aquifer	Lower confined aquifer (a.k.a. "deep aquifer"; model layer 5, or potentially layer 6)
Source water	River	Reclaimed	River via bank filtration
Type of recharge	Infiltration via unused irrigation ditches	Infiltration via infiltration pond/basin	Separate injection and pumping wells
Location	West of River at modeled site #9 (pilot-tested ditches in Carlsborg area)	East of River near modeled site #6, north of City	"Diversion" from shallow wells next to River; injection to deep aquifer either near shallow wells or near extraction well; extraction from deep aquifer – all at unidentified sites
Recharge rate	2-10 cfs (depends on results of recharge test data; likely <10)	Up to 3 cfs	2 cfs considered a reasonable maximum at this time
Recharge timing	2 months (mid-May – mid-July) and 6 months (throughout year)	8 months (Oct. – May)	2 months (freshet, mid-May – mid-July)
Extent of analysis	Comprehensive, site-specific	Comprehensive, multi-site-specific	General, including multiple sites

Table 3-1 Summary of Estimated Monthly Flow Availability at Conservation Plan Half Buildout

Year	*Percent days in month in exceedance of IFIM flows*												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Avg
1970	16%	0%	0%	7%	35%	97%	23%	26%	3%	0%	3%	3%	18%
1971	16%	29%	6%	0%	81%	100%	100%	100%	47%	10%	3%	3%	41%
1972	10%	14%	74%	17%	81%	100%	100%	100%	53%	0%	0%	39%	49%
1973	19%	0%	0%	0%	48%	57%	3%	48%	7%	29%	17%	35%	22%
1974	39%	0%	19%	0%	48%	100%	100%	100%	63%	3%	0%	10%	40%
1975	6%	0%	0%	0%	39%	83%	42%	100%	37%	94%	50%	55%	42%
1976	29%	0%	0%	7%	77%	60%	81%	97%	37%	0%	0%	0%	32%
1977	3%	0%	0%	7%	0%	17%	0%	13%	13%	29%	20%	32%	11%
1978	0%	4%	0%	0%	10%	93%	45%	77%	100%	3%	3%	0%	28%
1979	0%	4%	13%	0%	52%	27%	0%	0%	17%	29%	0%	52%	16%
1980	10%	11%	16%	53%	84%	87%	71%	71%	23%	0%	27%	29%	40%
1981	32%	39%	0%	7%	26%	10%	0%	0%	13%	77%	33%	65%	25%
1982	16%	36%	0%	0%	58%	100%	100%	100%	30%	32%	0%	29%	42%
1983	42%	61%	29%	0%	58%	100%	94%	100%	63%	3%	63%	0%	51%
1984	39%	7%	3%	0%	6%	57%	52%	71%	10%	52%	10%	0%	26%
1985	0%	0%	0%	0%	42%	73%	0%	10%	0%	39%	7%	0%	14%
1986	16%	18%	13%	0%	32%	50%	0%	0%	0%	16%	27%	3%	15%
1987	10%	7%	23%	10%	58%	63%	6%	6%	0%		0%	19%	18%
1988	6%	0%	3%	40%	65%	80%	42%	68%	10%	16%	7%	3%	28%
1989	0%	0%	0%	33%	23%	50%	0%	6%	0%	23%	10%	23%	14%
1990	16%	0%	0%	33%	39%	83%	0%	26%	0%	35%	60%	42%	28%
1991	13%	79%	6%	17%	19%	63%	58%	77%	30%	0%	13%	10%	32%
1992	23%	50%	0%	20%	65%	27%	0%	0%	3%	0%	0%	0%	16%
1993	6%	0%	6%	0%	71%	60%	0%	26%	0%	6%	0%	6%	15%
1994	0%	0%	16%	3%	23%	3%	0%	0%	0%	10%	3%	42%	8%
1995	23%	61%	19%	0%	58%	83%	39%	48%	0%	45%	67%	77%	43%
1996	55%	50%	0%	33%	19%	40%	10%	10%	0%	39%	7%	6%	22%
1997	48%	11%	23%	37%	74%	97%	55%	84%	47%	100%	27%	13%	51%
1998	45%	0%	3%	3%	87%	100%	48%	52%	0%	10%	47%	35%	36%
1999	45%	36%	32%	47%	65%	100%	100%	100%	100%	39%	70%	45%	65%
2000	0%	7%	0%	0%	39%	100%	13%	77%	3%	32%	0%	0%	23%
2001	3%	0%	0%	0%	19%	7%	0%	13%	0%	6%	30%	19%	8%
2002	42%	18%	0%	20%	29%	100%	48%	68%	0%	0%	0%	13%	28%
2003	48%	4%	26%	0%	26%	87%	16%	39%	0%	58%	27%	26%	30%
2004	13%	0%	0%	0%	35%	43%	0%	16%	7%	0%	0%	0%	10%
IFIM Flow (cfs)	575	575	575	475	475	475	475	180	180	180	575	575	n/a
10th Percentile	*0%*	*0%*	*0%*	*0%*	*19%*	*21%*	*0%*	*0%*	*0%*	*0%*	*0%*	*0%*	*12%*
Median	*16%*	*4%*	*3%*	*3%*	*42%*	*80%*	*23%*	*48%*	*7%*	*16%*	*7%*	*13%*	*28%*
Average	*20%*	*16%*	*9%*	*11%*	*45%*	*68%*	*36%*	*49%*	*20%*	*25%*	*18%*	*21%*	*28%*
Monthly % of Total	*6%*	*5%*	*3%*	*3%*	*13%*	*20%*	*10%*	*15%*	*6%*	*7%*	*5%*	*6%*	*n/a*
90th Percentile	*45%*	*50%*	*25%*	*35%*	*79%*	*100%*	*100%*	*100%*	*59%*	*56%*	*56%*	*49%*	*47%*
Standard Deviation	*17%*	*22%*	*15%*	*16%*	*24%*	*31%*	*38%*	*38%*	*28%*	*27%*	*22%*	*21%*	*14%*

Table 3-2. Average Percent Change[1/] in Habitat (WUA Index) for Various Life Stages with AR Diversions During Spring Snowmelt Period (May – July)

AR Diversion (cfs)	Spawning	Rearing			
	Steelhead (%)	Steelhead (%)	Coho (%)	Chinook (%)	Dolly Varden (%)
2	0.0	0.0	0.0	0.1	-0.1
5	0.0	0.1	0.0	0.2	-0.2
10	0.0	0.2	0.0	0.5	-0.5

1) Positive numbers imply an improvement and negative numbers imply a reduction in habitat indices.

Table 3-3. Maximum Instantaneous Percent *Increase* in Habitat (WUA Index) for Various Life Stages with AR Diversions During Spring Snowmelt Period (May – July)

AR Diversion (cfs)	Spawning	Rearing			
	Steelhead (%)	Steelhead (%)	Coho (%)	Chinook (%)	Dolly Varden (%)
2	0.1	0.3	0.2	0.5	0.0
5	0.3	0.7	0.6	1.3	0.1
10	0.5	1.3	1.2	2.6	0.2
Equivalent Acres of Increased Habitat[1/].	0.05	0.01	0.07	0.02	0.005

1) Maximum instantaneous increase in WUA indices at 10 cfs withdrawal; extended across the bypass reach between RM 8.0 and RM 5.5.

Table 3-4. Maximum Instantaneous Percent *Decrease* in Habitat (WUA Index) for Various Life Stages with AR Diversions During Spring Snowmelt Period (May – July)

AR Diversion (cfs)	Spawning	Rearing			
	Steelhead (%)	Steelhead (%)	Coho (%)	Chinook (%)	Dolly Varden (%)
2	0.4	0.1	0.1	0.2	0.3
5	0.9	0.2	0.4	0.6	0.8
10	1.8	0.4	0.7	1.1	1.5
Equivalent Acres of Decreased Habitat[1/].	0.18	0.005	0.04	0.01	0.03

1) Maximum instantaneous decrease in WUA indices at 10 cfs withdrawal; extended across the bypass reach between RM 8.0 and RM 5.5.

Table 3-5. Estimate of the Average Monthly Net Flow Augmentation in the Dungeness River Based on the 2008 Groundwater Model Results at Average Monthly S_y for the 2-Month AR Option Under Scenario A

	2-Month AR		
Month	Mean Monthly Surface Water Flow Augmentation as % of Q_{ar}	Discharge (cfs at Q_{ar} =2)	Discharge (cfs at Q_{ar} =10)
January			
February			
March			
April			
May			
June			
July	35	0.7	3.5
August	20	0.4	2.0
September	15	0.3	1.5
October	13	0.3	1.3
November	10	0.2	1.0
December	8	0.2	0.8

Table 3-6. Percent Change (%) in Side Channel Physical Features with Anticipated Flow Augmentation of 5 Cubic Feet Per Second

Physical Metric	RR Bridge	Stevens/Savage
Discharge (Q, cfs)	0.7	0.9
Velocity (fps)	0.5	0.6
Depth (ft)	0.3	0.1
Width (ft)	0.1	0.0

Table 3-7. Average Percent Change[1/] in Habitat (WUA Index) for Various Life Stages with AR Diversions During the Winter and Early Spring Rainfall Period (January – April)

AR Diversion (cfs)	Spawning		Rearing		
	Steelhead	Coho (%)	Steelhead (%)	Coho (%)	Dolly Varden (%)
2	0.0	0.1	0.0	0.0	0.0
5	0.1	0.3	0.1	0.1	-0.1
10	0.2	0.7	0.2	0.1	-0.2

1) Positive numbers imply an improvement and negative numbers imply a reduction in habitat indices.

Table 3-8. Maximum Instantaneous Percent *Increase* in Habitat (WUA Index) for Various Life Stages with AR Diversions During Winter/Early Spring Rainfall Period (January - April)

AR Diversion (cfs)	Spawning		Rearing		
	Steelhead (%)	Coho (%)	Steelhead (%)	Coho (%)	Dolly Varden (%)
2	0.1	0.2	0.1	0.1	0.0
5	0.3	0.6	0.3	0.3	0.1
10	0.5	1.2	1.3	0.6	0.2
Equivalent Acres of Increased Habitat[1/].	0.05	0.07	0.01	0.03	0.005

2) Maximum instantaneous increase in WUA indices at 10 cfs withdrawal; extended across the bypass reach between RM 8.0 and RM 5.5.

Table 3-9. Maximum Instantaneous Percent *Decrease* in Habitat (WUA Index) for Various Life Stages with AR Diversions During Winter/Early Spring Rainfall Period (January - April)

AR Diversion (cfs)	Spawning		Rearing		
	Steelhead (%)	Coho (%)	Steelhead (%)	Coho (%)	Dolly Varden (%)
2	0.2	0.0	0.1	0.0	0.1
5	0.4	0.0	0.2	0.4	0.5
10	0.8	0.1	0.4	0.7	1.1
Equivalent Acres of Decreased Habitat[1/].	0.08	0.005	0.005	0.04	0.02

1) Maximum instantaneous decrease in WUA indices at 10 cfs withdrawal; extended across the bypass reach between RM 8.0 and RM 5.5.

Table 3-10. Estimate of the Average Monthly Net Flow Augmentation in the Dungeness River Based on the 2008 Groundwater Model Results at Average S_y for the 6-Month AR Option Under Scenario A

Month	Mean Monthly Surface Water Flow Augmentation as % of Q_{ar}	Discharge (cfs at Q_{ar} =2)	Discharge (cfs at Q_{ar} =10)
January-June	n/a	n/a	n/a
July	55	1.1	5.5
August	40	0.8	4.0
September	28	0.6	2.8
October	23	0.5	2.3
November	19	0.4	1.9
December	16	0.3	1.6

Table 3-11. Change in Side Channel Physical Features with Anticipated AR Flow Diversion of 10 Cubic Feet Per Second when Mainstem River Discharges are Less than the MISF During Late Winter and Early Spring.

Change in Habitat Attribute	Dawley	Lower (e) RR Bridge	Stevens/Savage
Discharge (cfs)	1.3	3.8	0.7
Velocity (fps)	-	0.1	-
Depth (ft)	-	-	-
Channel Width (ft)	-	-	-

Table 3-12 City of Sequim Sources: Selected Water Quality Parameters

Parameter	Units	Dungeness River Collector*	Silberhorn Well (shallow)*	Pt. Williams Well (deep)**
Conductivity	Umhos/cm	130	249	340
Turbidity	NTU	0.1	-	0.7
Arsenic	Mg/L	0.002	0.002	0.01
Iron	Mg/L	0.1	0.1	0.2
Manganese	Mg/L	0.01	0.01	0.01
Nitrate- N	Mg/L	0.5	1.38	0.6
Chloride	Mg/L	5.0	5.0	20.0
Sulfate	Mg/L	10.0	10.0	10.0

* Samples collected on 2/10/06
** Sample collected on 12/30/98

Table 4-1. Estimate of the Average Monthly Flow Augmentation in the Dungeness River Based on the 2008 Groundwater Model Results at Variable S_y

	8-Month AR, S_y = 10%			8-Month AR, S_y =20%		
Month	Mean Monthly Surface Water Flow Augmentation as % of Q_{ar}	Discharge (cfs at Q_{ar} =0.8)	Discharge (cfs at Qar =3.1)	Mean Monthly Surface Water Flow Augmentation as % of Q_{ar}	Discharge (cfs at Q_{ar} =0.8)	Discharge (cfs at Q_{ar} =3.1)
January	27	0.2	0.8	29	0.2	0.9
February	30	0.2	0.9	29	0.2	0.9
March	32	0.3	1.0	30	0.2	0.9
April	34	0.3	1.1	31	0.2	1.0
May	36	0.3	1.1	31	0.2	1.0
June	37	0.3	1.1	32	0.3	1.0
July	36	0.3	1.1	33	0.3	1.0
August	34	0.3	1.1	33	0.3	1.0
September	30	0.2	0.9	32	0.3	1.0
October	26	0.2	0.8	32	0.3	1.0
November	24	0.2	0.7	31	0.2	1.0
December	25	0.2	0.8	29	0.2	0.9

Table 4-2. Percent Change (%) in Side Channel Physical Features with Anticipated Flow Augmentation of 2 Cubic Feet Per Second

Physical Metric	Dawley	RR Bridge	Stevens/Savage
Discharge (Q, cfs)	0.3	0.3	0.4
Velocity (fps)	0.2	0.2	0.3
Depth (ft)	0.1	0.1	0.1
Width (ft)	0.1	0.0	0.0

Table 4-3. Washington State Department of Health and Ecology Groundwater Sampling Requirements for Surface Infiltration of Class A Reclaimed Water

Parameter	Units	Minimum Sampling Frequency	Sample Type
Static well water elevation	Feet above sea level	Quarterly[a]	Measurement
Temperature	^oC	Quarterly[a]	Measurement
Dissolved Oxygen	mg/L	Quarterly[a]	Grab
PH	Standard Units	Quarterly[a]	Measurement
Conductivity	umhos/cm	Quarterly[a]	Grab
Nitrate NO_3 (as N)	mg/L	Quarterly[a]	Grab
Nitrite NO_2 (as N)	mg/L	Quarterly[a]	Grab
TKN (as N)	mg/L	Quarterly[a]	Grab
Total Dissolved Solids	mg/L	Quarterly[a]	Grab
Total Coliform Bacteria	cfu/100mL	Quarterly[a]	Grab
Chloride	mg/L	Quarterly[a]	Grab
Cations/Anions: Calcium, Magnesium, Potassium, Sodium, Bicarbonate, Carbonate, Fluoride, Sulfate	mg/L	Yearly[b]	Grab
Total Metals: Arsenic, Cadmium, Chromium, Copper, Lead, Mercury, Nickel, Silver, Zinc[c]	ug/L	Yearly[b]	Grab
Total Trihalomethanes	mg/L	Quarterly[a]	Grab

[a] Quarterly is defined as: March, June, September, and December.
[b] Yearly is defined as March.
[c] Analytical method: Arsenic, EPA 206.3 or 206.2; Cadmium, EPA 2007.7 or 213.2; Chromium, EPA 200.7 or 218.2; Copper, EPA 200.7 or 220.2; Lead, EPA 239.2; Mercury, EPA 245.1 or 245.2; Nickel, EPA 249.2; Silver, EPA 272.2; Zinc, EPA 200.7 or 289.1.

From Ecology Publication 96-02 "*Implementation Guidance for the Ground Water Quality Standards*" Originally published in April 1996 and revised on October 2005

Table 4-4: Recommended Parameters for Source Water Characterization

Aluminum (Al)	Copper (Cu)	pH
Arsenic (As)	Dissolved Oxygen (02)	Phosphate (PO4)
Barium (Ba)	Fluoride (F)	Potassium (K)
Bicarbonate (HCO3)	Ion Balance	Redox Potential (Eh)
Bisulfide (HS-)	Iron (Fe)	Selenium (Se)
Cadmium (Cd)	Langlier Index	Silica (aqueous) (SiO2)
Calcium (Ca)	Lead (Pb)	Silver (Ag)
Carbonate(CO3)	Manganese (Mn)	Sodium (Na)
Chloride (Cl)	Magnesium (Mg)	Sulfate (SO4)
Chromium (Cr)	Mercury (Hg)	Zinc (Zn)
Conductivity	Nitrate-Nitrogen (NO3 -N)	
Total Dissolved Solids (TDS)		
Total Suspended Solids (TSS)		
Biochemical Oxygen Demand (BOD)		

Table 4-5. Suggested Project Schedule for Scenario B

Task Description		**Project Schedule (months)**										
		Effort (months)	1-3	4-6	7-9	10-12	13-15	16-18	19-21	22-24	24-30	30-36
Phase 1												
Background Hydrogeologic Investigation		**2**	X									
Recharge Source Water Characterization		**1**		X								
Phase 2 *(may be repeated)*												
Field Hydrogeologic Investigation		**4**	X	X								
Development and Analysis of Alternatives		**2**		X								
Phase 3 *(may be repeated)*												
Pilot Test	Design	**3**			X	X						
	Construction Phase	**3**				X	X					
	Operation and Maintenance	**6**					X	X				X
Groundwater Modeling		**2**							X			
Design Report (30% design)		**2**							X			
Phase 4												
Final Design (100% Design)		**6**								X	X	
Permitting, Reclaimed Water Negotiations & SEPA		**3**			X	X				X	X	
Construction		**6**									X	X

NOTES:

Level of effort for tasks are typically spread over longer durations.

Breaks for decision making (e.g. after Phase 2) also typically occur.

Permitting includes early SEPA checklist for pilot testing.

Table 4-6 – Construction Cost Estimate for 5-acre and 10-acre Recharge Basins

Item		5-Acre Basin	10-Acre Basin
Site Clearing		$1,550	$3,100
Haul Off and Disposal		$27,050	$54,100
Excavation of Basins		$94,050	$188,100
Hauling of Excavation Off Site		$46,750	$93,500
Grading and Compaction		$70,100	$140,200
Sand Bedding		$100,450	$200,900
PVC Discharge Header Pipe		$50,200	$50,200
PVC Conveyance Pipe		$40,900	$40,900
Valving		$8,800	$8,800
Flow Meters		$4,600	$4,600
Sampling		$3,500	$3,500
Ground Water Monitoring Wells		$25,200	$25,200
Fencing		$43,416.00	$64,800
Landscaping		$11,658.00	$17,400
Subtotal Base Cost		$528,224	$895,300
Mobilization/Demobilization	5%	$26,411	$44,770
Overhead and Profit	18%	$99,834	$169,210
Bonds	1.50%	$9,817	$16,640
Permits	0.75%	$4,982	$8,440
Liability Insurance	1.50%	$10,039	$17,020
Contractors Contingency	5.00%	$33,965	$57,570
Engineer Contingency	20.00%	$142,655	$241,790
Sales Tax	8.00%	$68,474	$116,060
Total Construction Cost		$924,402	$1,566,800

ASSUMPTIONS

1. Haul Off Volume = 4050 cubic yards (5 acres) and 8100 cubic yards (10 acres)
2. Excavation Volume = 27,500 cubic yards (5 acres) and 55,000 cubic yards (10 acres)
3. Bedding Volume = 6,500 cubic yards (5 acres) and 13,000 cubic yards (10 acres)
4. Labor Rates=$35/hour
5. ENR CCI=8551

TABLE 5-1a
SCENARIO C - STREAM AUGMENTATION BASED ON STEADY-STATE INJECTION USING "BEST ESTIMATE" MODEL

STREAM	%Var
Dungeness	17.92%
Morse	0.01%
Siebert	0.04%
Bagley	0.03%
McDonald	0.47%
Matriotti	0.81%
Meadowbrook	0.26%
Cassalery	2.44%
Gierin	2.04%
Bell	0.98%
Johnson	0.03%
Total to Streams	26.33%

Note: results do not include augmentation to Graysmarsh.

TABLE 5-1b
SCENARIO C - SUMMARY OF MODEL PREDICTED EFFECTS ON STREAM BASEFLOW

RUN NAME	BASE MODEL	Transient or SS	Sy	S	Description	AR Cell Maximum Head Rise (ft)	Matriotti Creek	Dungeness River	Cassalery Creek	Gierin Creek
W-5-7e	Dung-7e	SS	n/a	n/a	Best Estimate Model, Steady State	40.5	0.8%	17.9%	2.4%	3.3%
P-W-5a	Dung-7e	Tran	0.2	0.0002	Best Estimate Model, Lower Kz in Both Confining Beds, Sy=0.2	34.7	0.04%, -0.03%	2.5%, -1.3%	0.18%, -0.09%	0.10%, -0.04%
P-W-5b	Dung-7e	Tran	0.1	0.0002	Best Estimate Model, Lower Kz in Both Confining Beds, Sy=0.1	34.7	0.08%, -0.04%	3.6%, -1.9%,	0.33%, -0.14%	0.17%, -0.05%
P-W-5e	Dung-7g	Tran	0.2	0.0002	Higher Kz in Upper Confining Bed, Sy=0.2	34.6	0.06%, -0.02%	5.0%, -2.6%	0.50%, -0.15%	0.22%, -0.05%
P-W-5f	Dung-7g	Tran	0.1	0.0002	Higher Kz in Upper Confining Bed, Sy=0.1	34.6	0.10%, -0.05%	6.9%, -4.2%	0.81%, -0.36%	0.24%, -0.09%
P-W-5c	Dung-7i	Tran	0.2	0.0002	Higher Kz in Both Confining Beds, Sy=0.2	26.4	0.14%, -0.06%	14.2%, -10.2%	0.51%, -0.19%	0.17%, -0.12%
P-W-5d	Dung-7i	Tran	0.1	0.0002	Higher Kz in Both Confining Beds, Sy=0.1	26.4	0.30%, -0.13%,	20.1%, -15.2%,	0.88%, -0.44%	0.20%, -0.14%

Notes:
ASR assumed to occur in May and June. Recovery Assumed to Occur in August and September. Modeled ASR and recovery rates were 2 cfs.
Transient results are reported as Min % Qasr, Max % Qasr where Qasr = the ASR rate.
Steady state results are reported as Net Annual % Vasr - where Vasr = the ASR volume.
n/a = not applicable. n/c = not calculated
Steady state simulation (W-5-7e) represents year-round injection (no recovery).
Results do not include effects on Graysmarsh.
Dung-7i is merely a version of Dung-7g with both aquitards set to Kv = 0.008 ft/d.

Table 7-1. Water Use Assumptions for New Development

Parameter	Amount
Domestic Use	
Wastewater Generation from Domestic Use (%)	87%
Domestic Consumptive Use (%)	13%
Domestic Use Per Hookup (gpd)	170
Domestic Wastewater Generation (gpd)	**148**
Irrigation Use	
Irrigation Acres per Hookup (acres)	0.1
Irrigation Consumptive Demand (in/yr)	15.5
Irrigation Application Per Hookup (gal/yr)	42,086
Irrigation Consumptive Demand Per Hookup Over 120-day Growing Season (gpd)	351
Annualized Irrigation Consumptive Demand Per Hookup (gpd)	115
Irrigation Efficiency for Sprinklers (%)	75%
Irrigation Application Over 4-Month Growing Season to Meet Efficiency (gpd)	468
Irrigation Local Recharge from Inefficiency Over 4-Month Growing Season (gpd)	117
Annualized Irrigation Local Recharge from Inefficiency (gpd)	38
Summary Totals (Annualized)	
Amount Withdrawn per hookup (gpd)	302
Wastewater Generation per Hookup (gpd)	148
Wastewater Generation as Percent of Annual Use	49%
Annual Irrigation Recharge as Percent of Annual Use	13%
Annualized Percent Non-Consumptive Use	62%
Annualized Percent Consumptive Use	38%

Table 8-1
Selected State and Federal Funding Programs for Recharge Projects

State and Federal Funding Program Name and Agency Contacts	Programs Funded	Eligible Recipients	Financing Information
Centennial Clean Water Fund, State Revolving Fund, and Federal Nonpoint-Source Management grants Kim McKee Washington Department of Ecology Box 47600 Olympia, WA 98504-7600 Phone: (360) 407-6566 e-mail: kmck461@ecy.wa.gov	These three funding programs provide low-interest loans and grants for projects that protect and improve water quality. Low-interest loans are available for site-specific water, stormwater, or sewer project design and construction.	Any public body and certain non-profit groups	Application occurs during September and October every year.
Salmon Recovery Funding Board Grant Programs Tara Galuska P.O. Box 40917 Olympia, Washington 98504-0917 Phone: (360) 902-2953 Email: tarag@rco.wa.gov	The Salmon Recovery Funding Board administers programs that that provide grants for projects that protect and restore salmon habitat.	Any public body and certain non-profit groups	Applications due in September.
Farmland Preservation Program P.O. Box 40917 Olympia, Washington 98504-0917 Phone: (360) 902-3000 info@rco.wa.gov	This funding program provides grants for projects that preserve viable farmland, enhance agricultural production, and improve ecological functions of the farmland.	Cities, Counties	Applications for recent funding cycle due May 1.
Public Works Trust Fund, Construction Loan Program Public Works Board Cecilia Gardner Marketing and Information Phone: (360) 725-5006 E-mail: cecilia.gardener@pwb.wa.gov	Funds can be used for water distribution, stormwater collection, or sewer systems and other infrastructure projects.	Loans are available for counties, cities, and towns, and special purpose districts meeting certain requirements	Ten million dollars is available per jurisdiction, per biennium; the interest rate is linked to the percentage of local match. Applications are accepted every June.

State and Federal Funding Program Name and Agency Contacts	Programs Funded	Eligible Recipients	Financing Information
Public Works Trust Fund, Pre-Construction Loan Program Public Works Board Cecilia Gardner Marketing and Information Phone: (360) 725-5006 E-mail: cecilia.gardener@pwb.wa.gov	Low-interest loans for the pre-construction phase of infrastructure projects including water, sewer and stormwater facilities or projects that include repair, replacement, rehabilitation, reconstruction, or improvement of eligible public works systems to meet current standards for existing users.	Counties, cities towns, and special purpose districts	One million dollars is available per jurisdiction, per biennium; the interest rate is linked to the percentage of local match. Applications are available on an open cycle, as funds are available.
Watershed Protection and Flood Prevention Larry Johnson U.S. Department of Agriculture Natural Resources and Conservation Service West 316 Boone, Suite 450 Rock Pointe Tower II Spokane, WA 99201-2348 Phone: (509) 323-2955 E-mail: larry.johnson@wa.usda.gov	This program provides assistance in planning and implementing watershed projects for: flood prevention, water quality improvement, agricultural water management, water-based recreation, municipal and industrial water supplies, and fish and wildlife habit.	Any particular or group of local or tribal governments, soil and water conservation district, flood prevention or flood control district, or any other nonprofit agency with authority under state law to carry out, maintain, and operate watershed works of improvement	Check with the NRCS office for the application period

FIGURES

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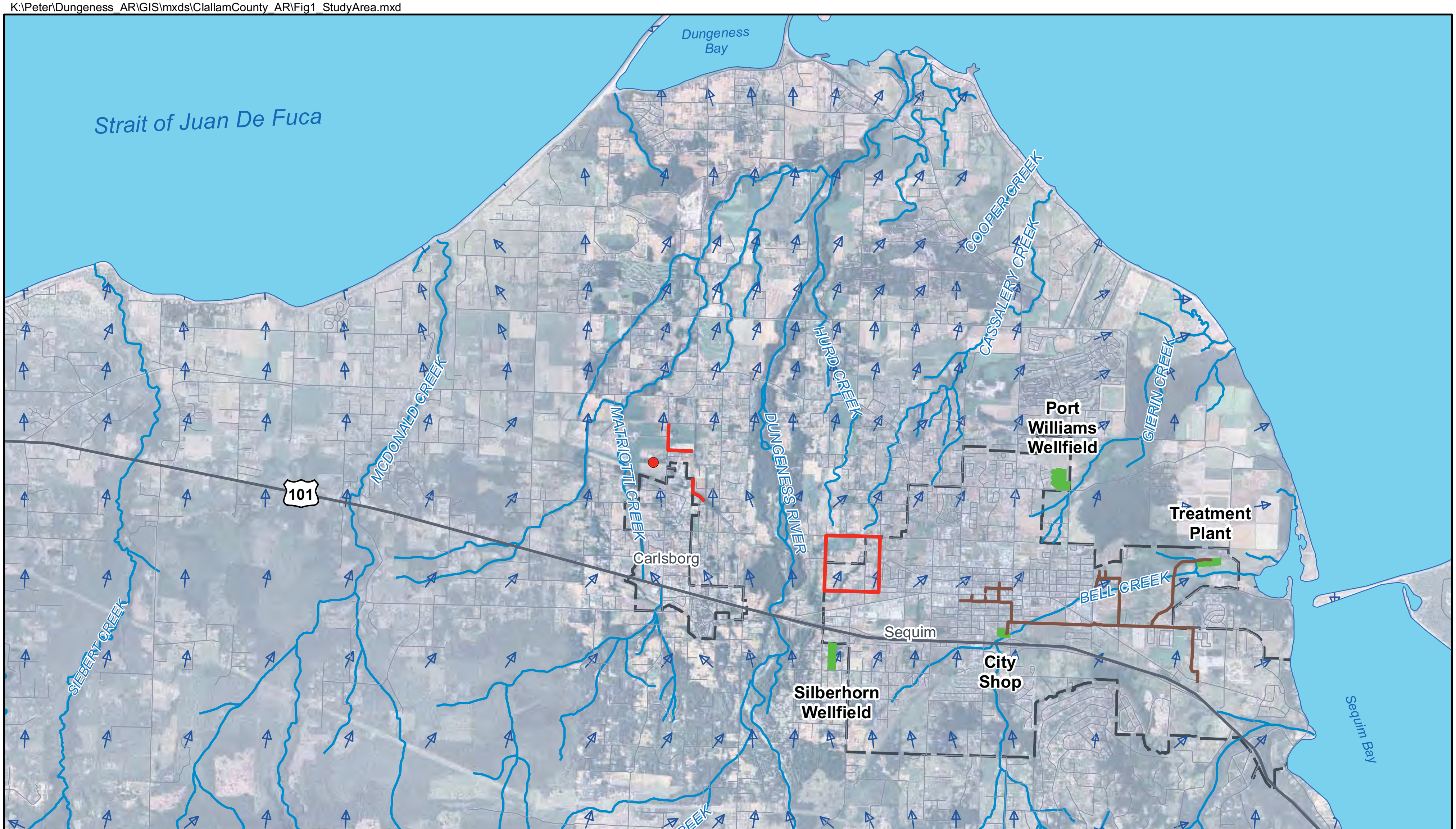

FS Sites/Areas
Scenario A
Scenario B
Scenario C

Reuse Water Distribution Lines
Model Estimated Groundwater Flow Direction
Urban Growth Areas
Sequim Facilities

N

0 Miles 2

Figure 1-1

Study Area Map

Clallam County
AR/ASR Feasibility Study

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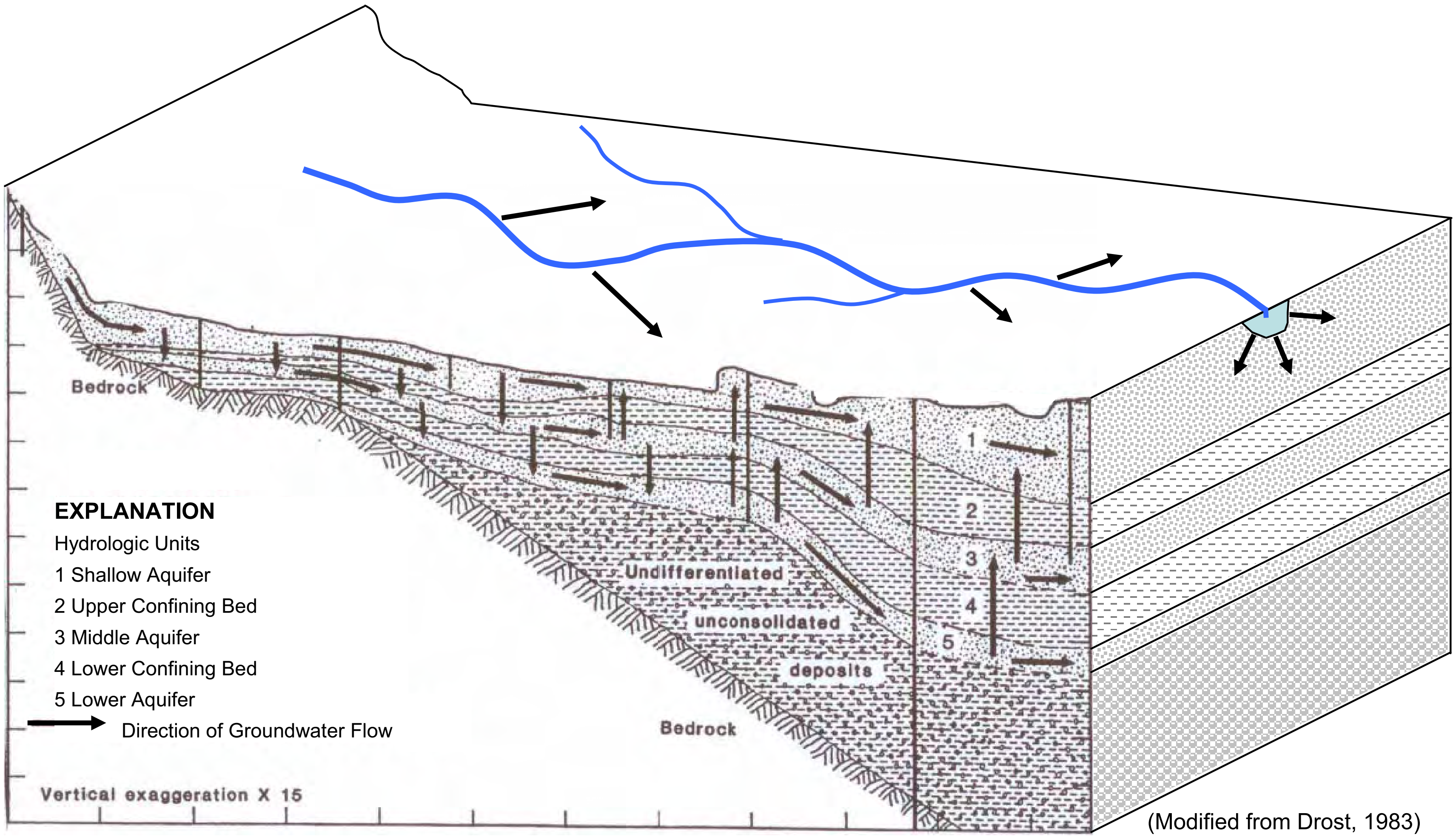

Figure 1-2
Conceptual Diagram of Groundwater Flow System

Clallam County
AR/ASR Feasibility Study

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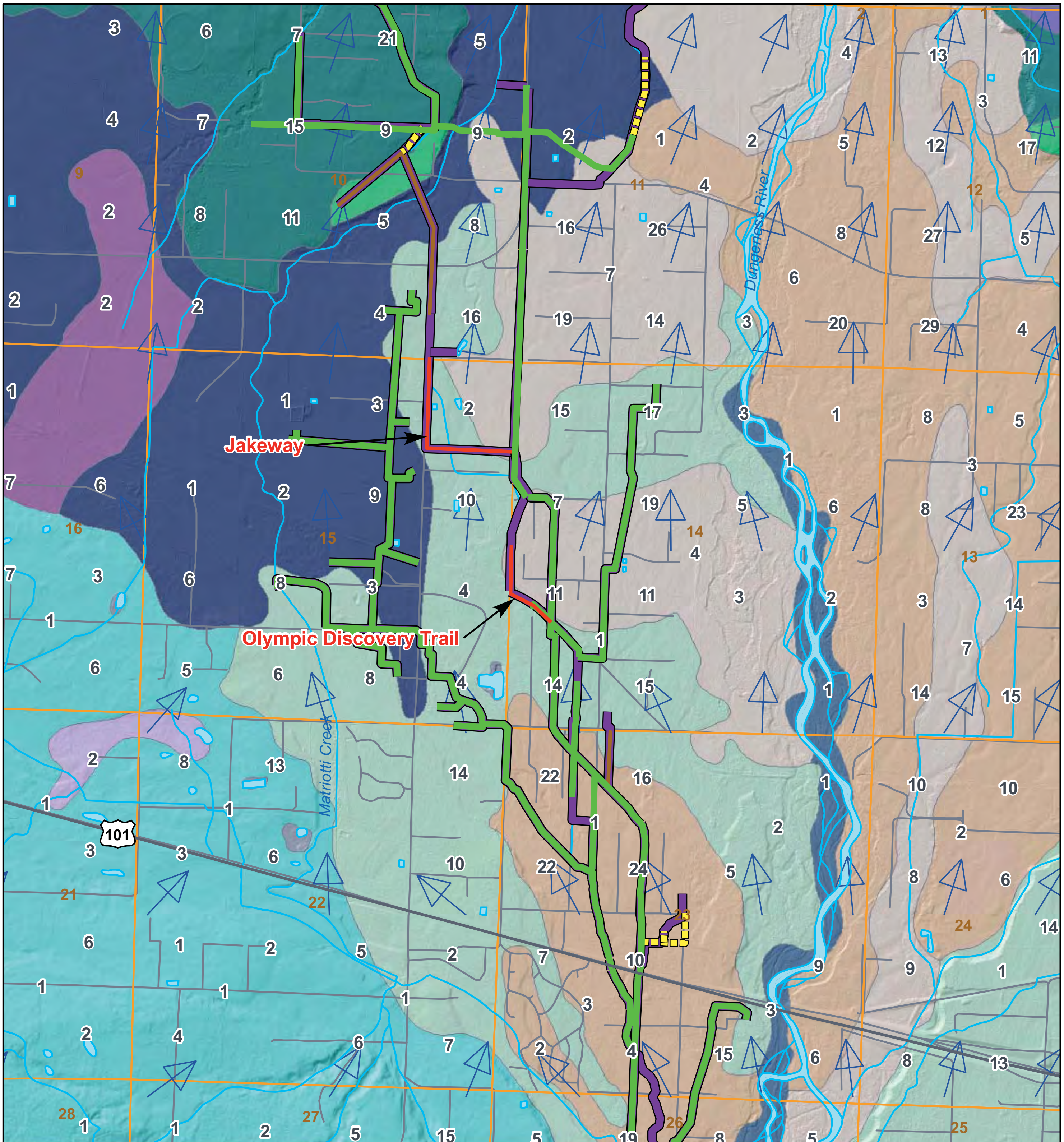

Scenario A Ditches
Abandoned Pipe
Existing Pipe
Will be Piped
Existing Ditches
(Ditch Designation by Clallam Conservation District (12/2007))

4 Number of Well logs by Quarter-Quarter Section
(No value indicates zero reported wells)

Model Estimated Groundwater Flow Direction

NRCS Soils

- Agnew silt loam, 0 to 8 percent slopes
- Carlsborg gravelly sandy loam, 0 to 5 percent slopes
- Dick loamy sand, 0 to 15 percent slopes
- Hoypus gravelly sandy loam, 0 to 15 percent slopes
- Carlsborg-Dungeness complex, 0 to 5 percent slopes
- Dungeness silt loam
- Bellingham silty clay loam
- Clallam gravelly sandy loam, 0 to 15 percent slopes
- McKenna gravelly silt loam
- Puget silt loam
- Riverwash

0 Feet 2,000

N

Figure 3-1
Scenario A - Soils, Irrigation and Wells

Clallam County
AR/ASR Feasibility Study

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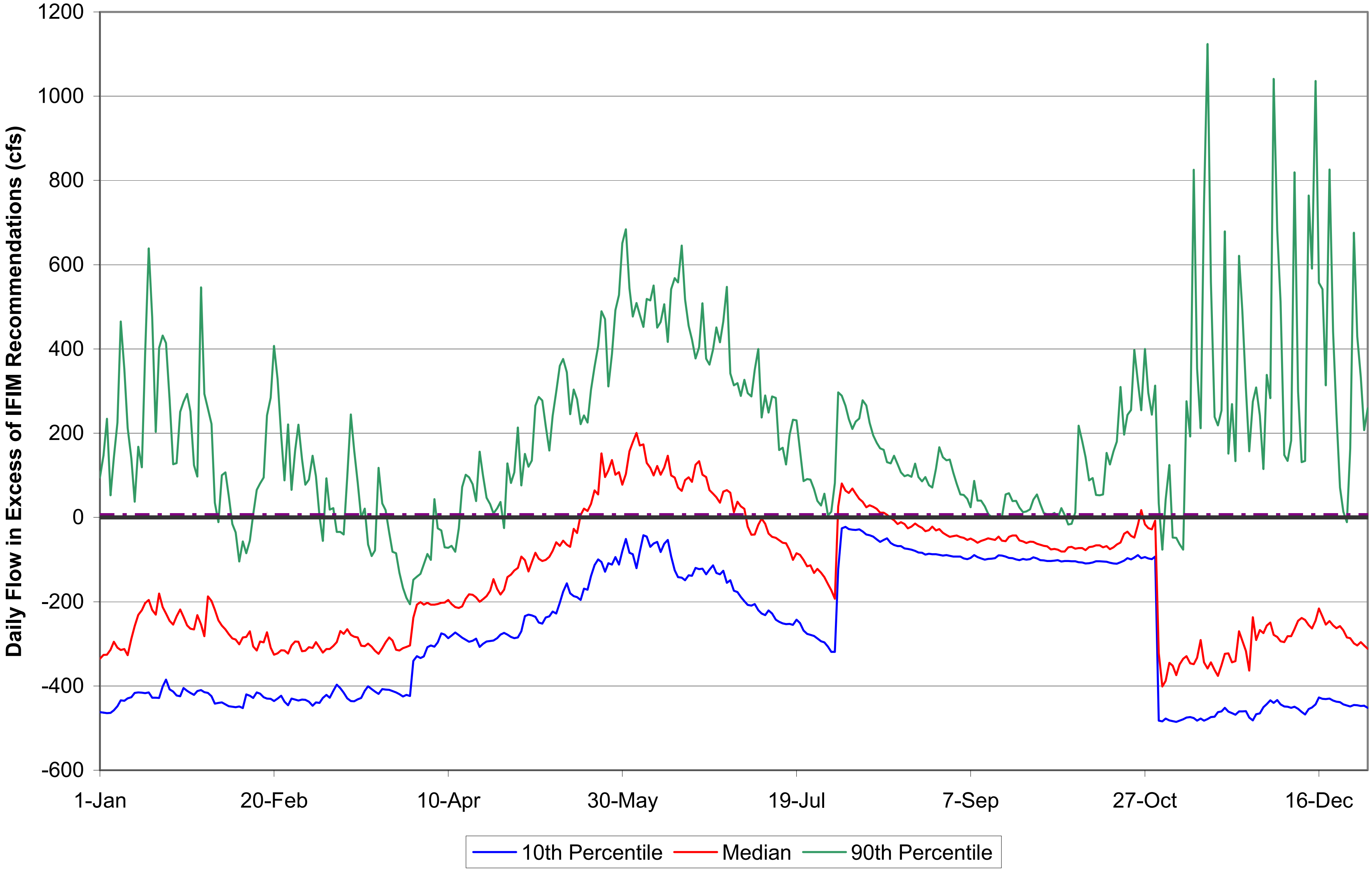
Figure 3-2   Daily Flow Exceedance Probabilities at Half Conservation Plan Buildout



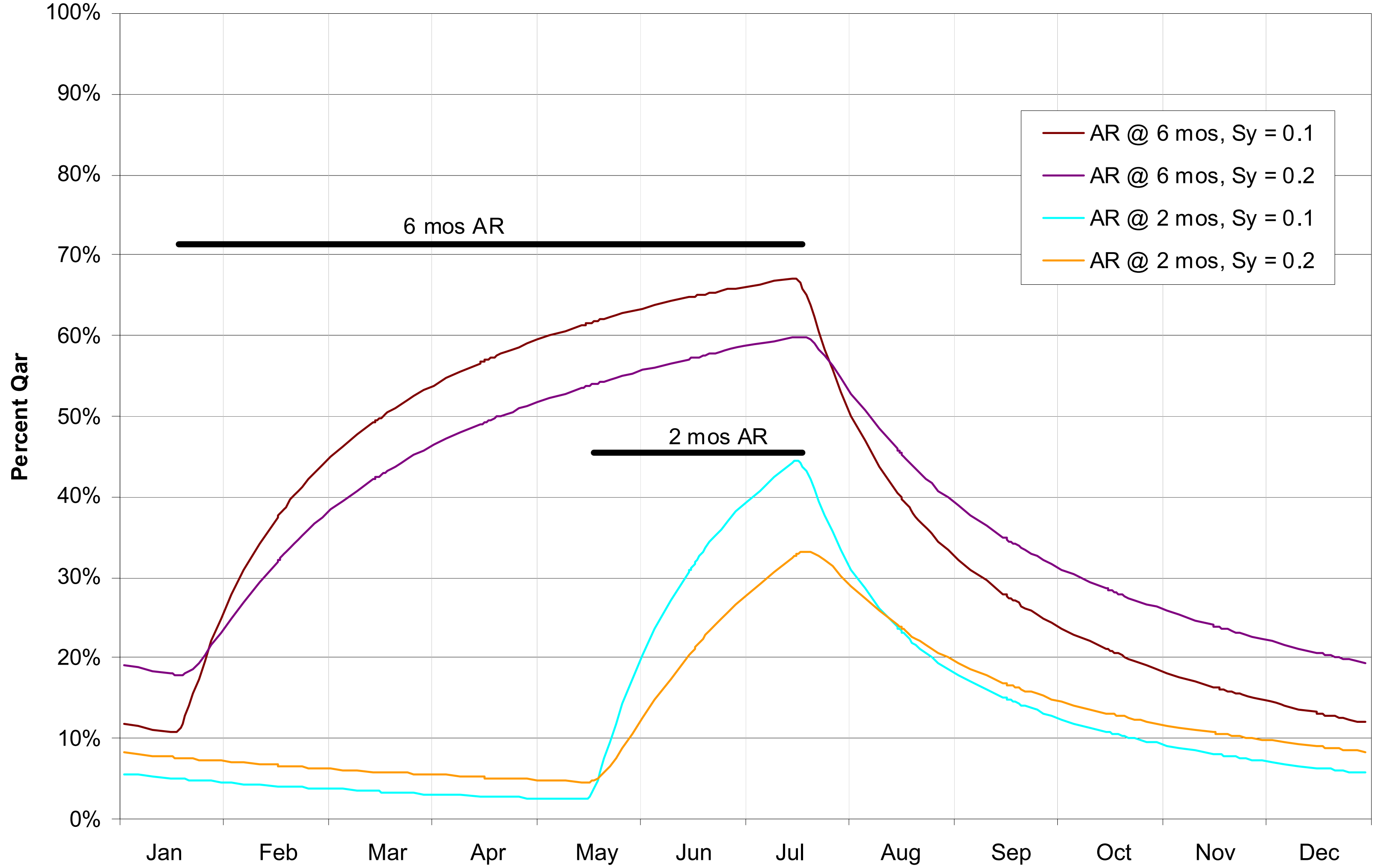


Figure 3-3
Scenario A - Dungeness River Gross Streamflow Augmentation as Percent Q_{ar}

Clallam County
AR/ASR Feasibility Study

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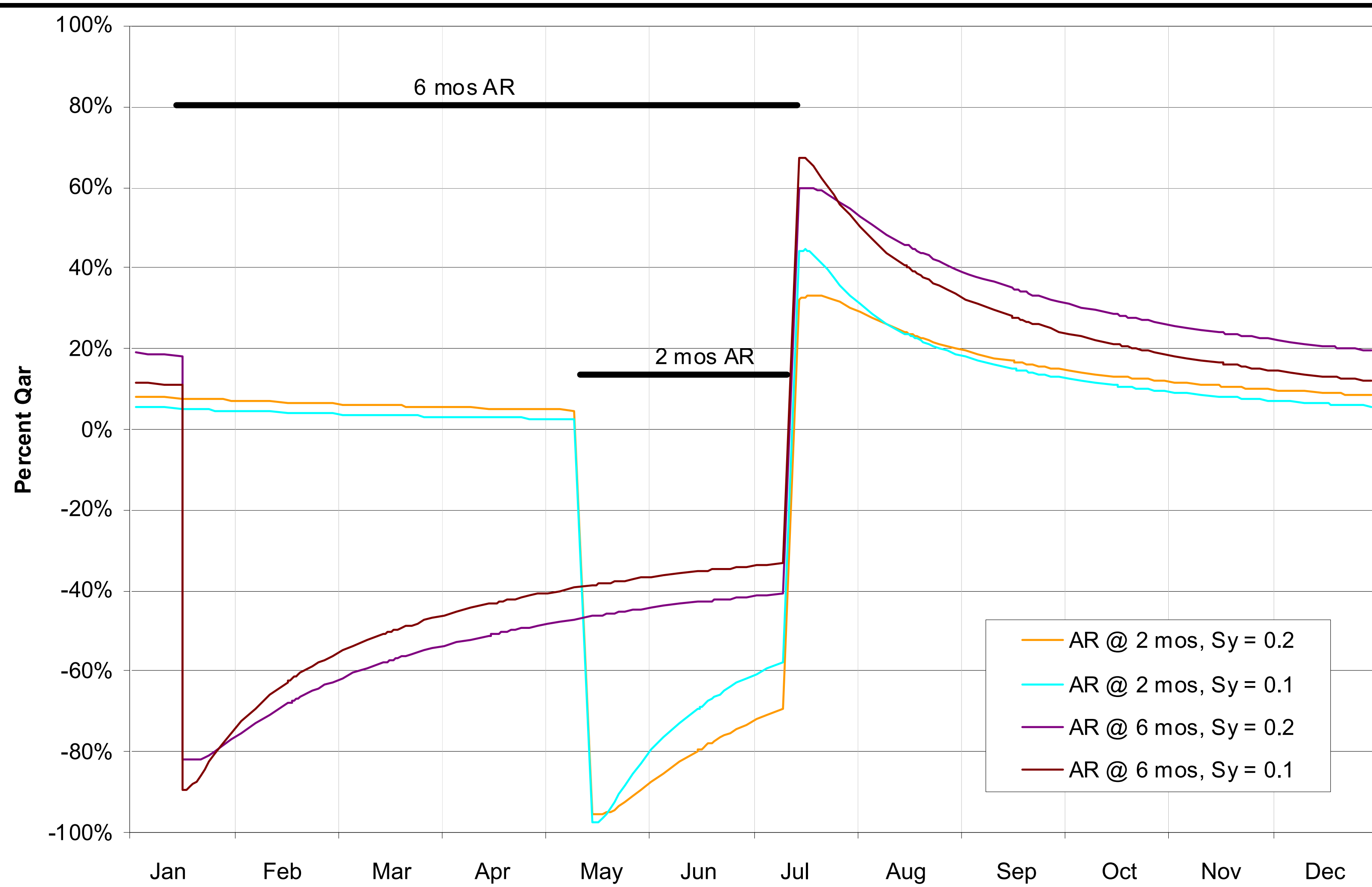

Figure 3-4
Scenario A - Dungeness River Net Streamflow Impact as Percent Q_{ar}

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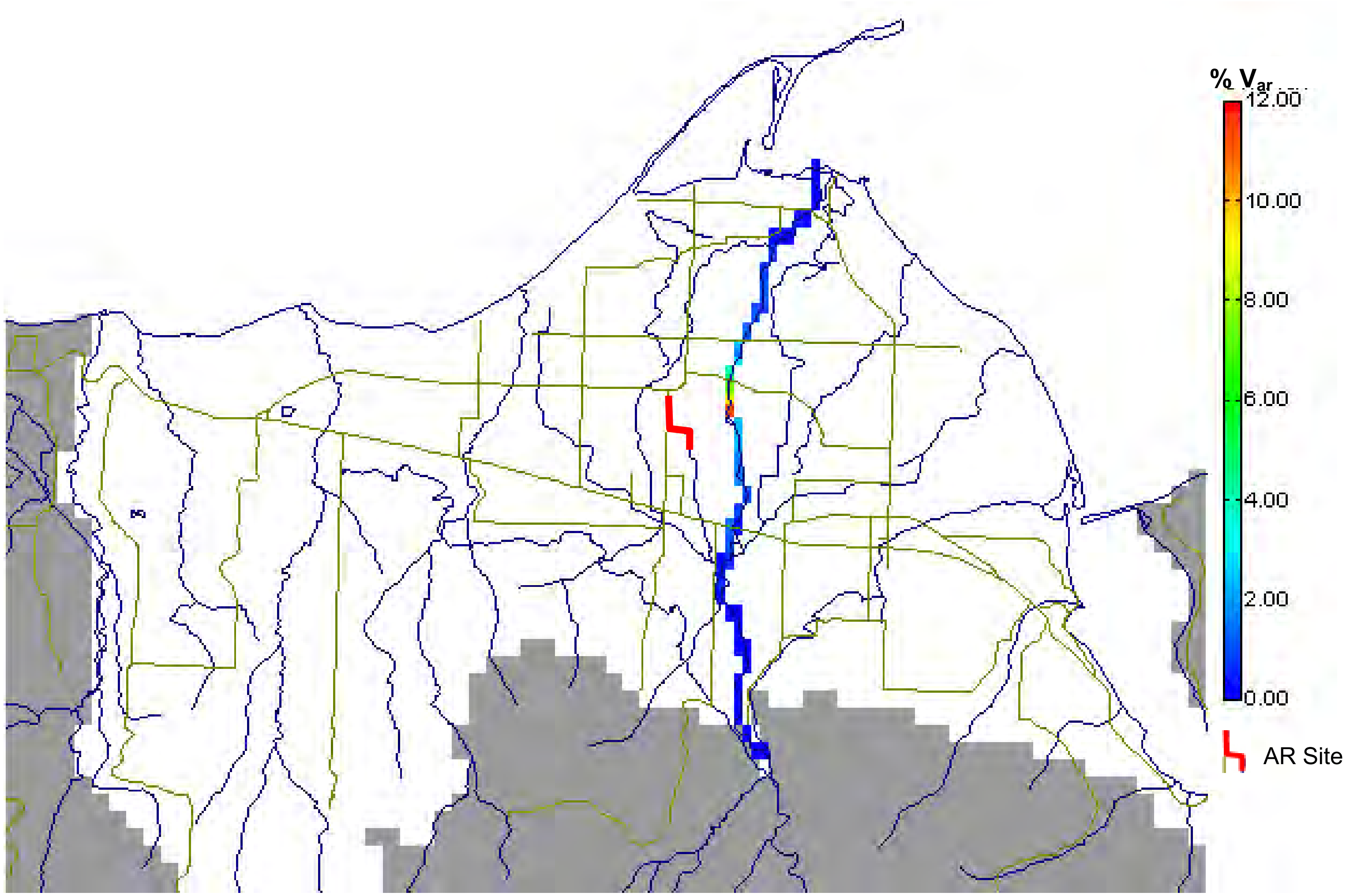

Figure 3-5
Scenario A -Dungeness River Steady-State Augmentation per Model Cell as Percent V_{ar}

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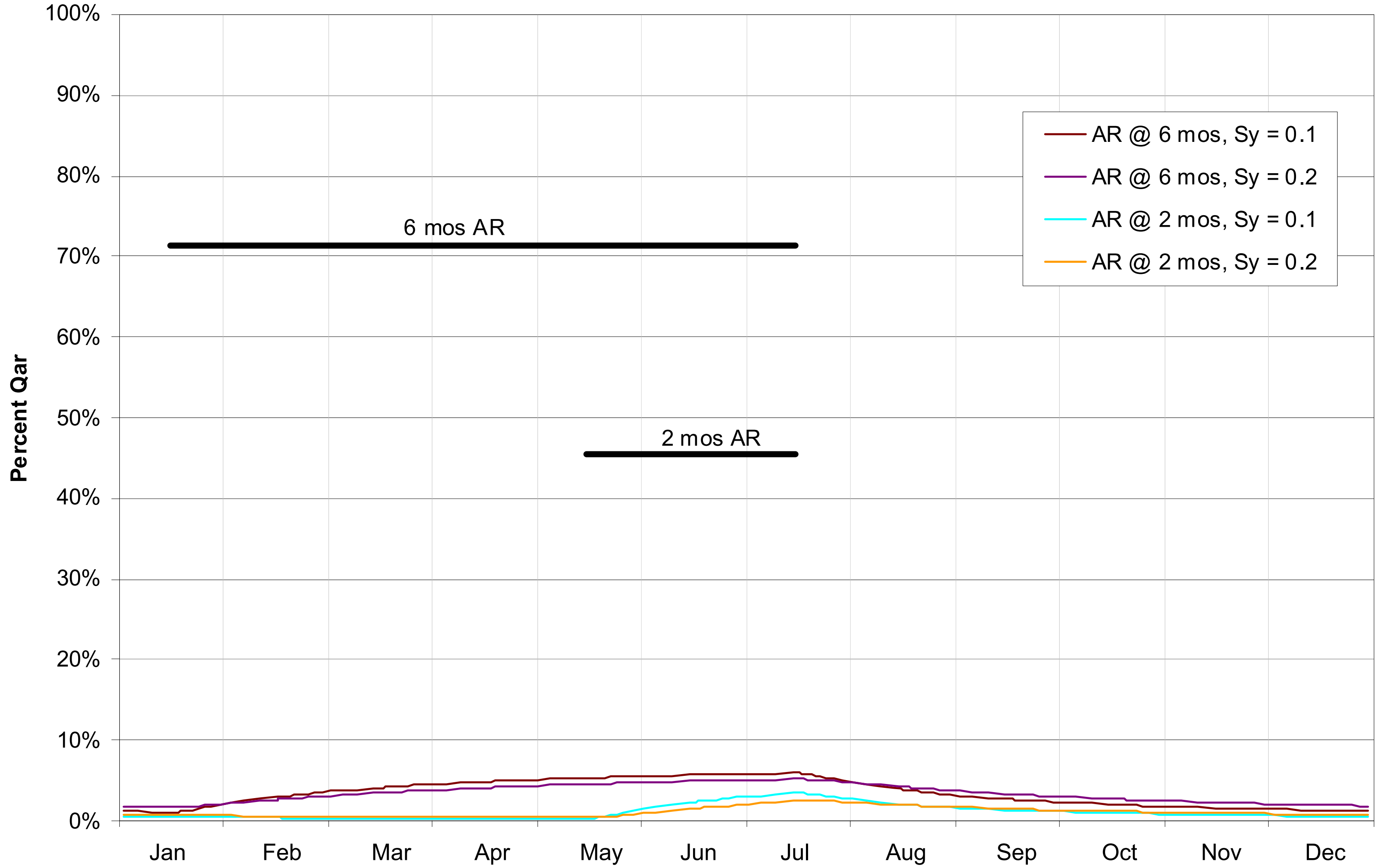

Figure 3-6
Scenario A - Matriotti Creek Net Streamflow Augmentation as Percent Q_{ar}

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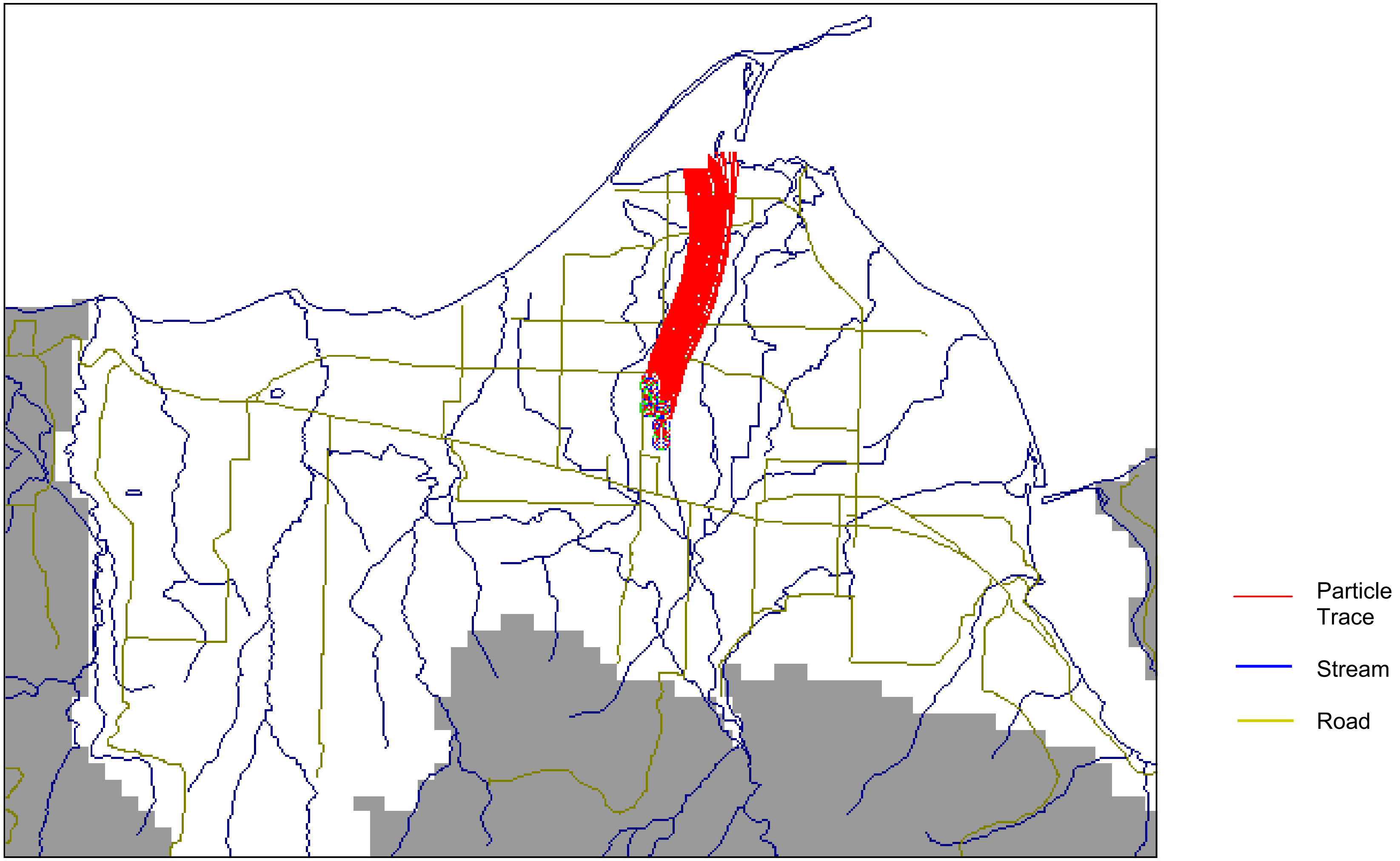

Figure 3-7
Scenario A - Predicted Groundwater Flow Path from Infiltration Site

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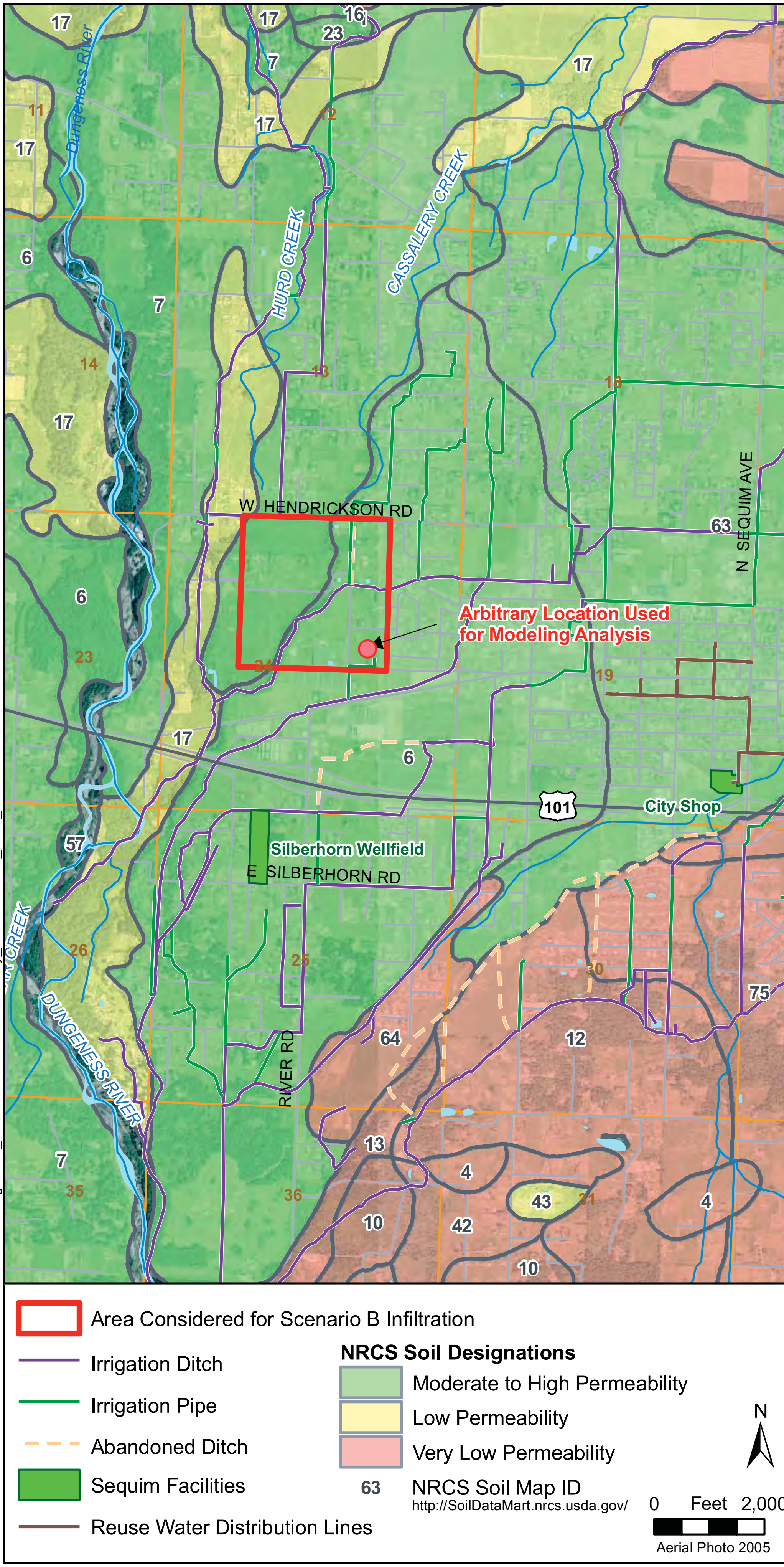

Figure 4-1

Scenario B - Soils and Irrigation Features

Clallam County AR/ASR Feasibility Study

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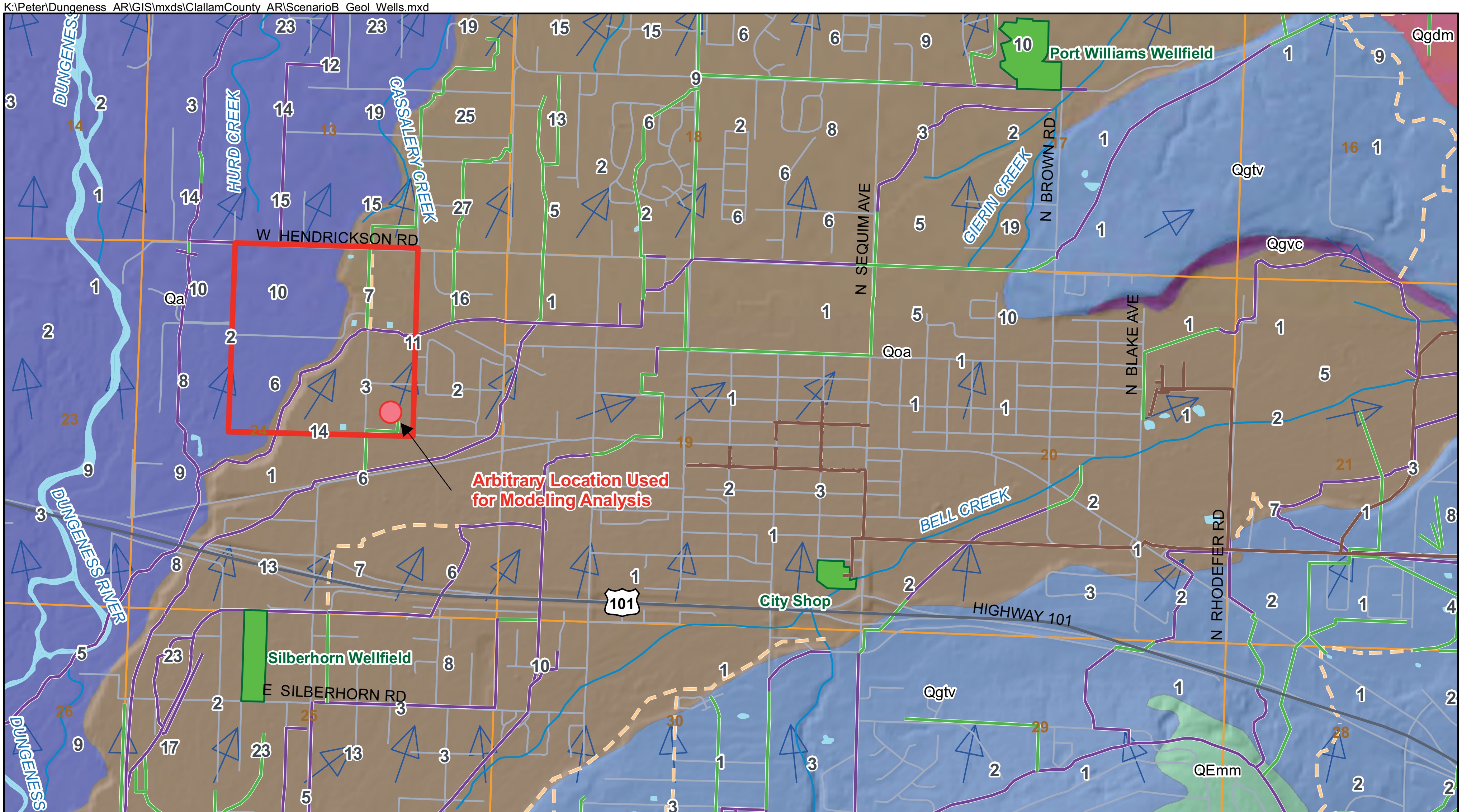

4 Number of Well logs by Quarter-Quarter Section (No value indicates zero reported wells)

Area Considered for Scenario B Infiltration

Irrigation Ditch

Irrigation Pipe

Abandoned Ditch

Reuse Water Distribution Lines

(Ditch Designation by Clallam Conservation District (12/2007))

Sequim Facilities

Streams

Model Estimated Groundwater Flow Direction

Surficial Geology (Shasse & Logan, 1998)

- QEmm
- Qa
- Qgdm
- Qgtv
- Qgvc
- Qoa

N

0 Feet 2,000

Figure 4-2

Scenario B - Surficial Geology, Wells and Groundwater Flow Directions

Clallam County AR/ASR Feasibility Study

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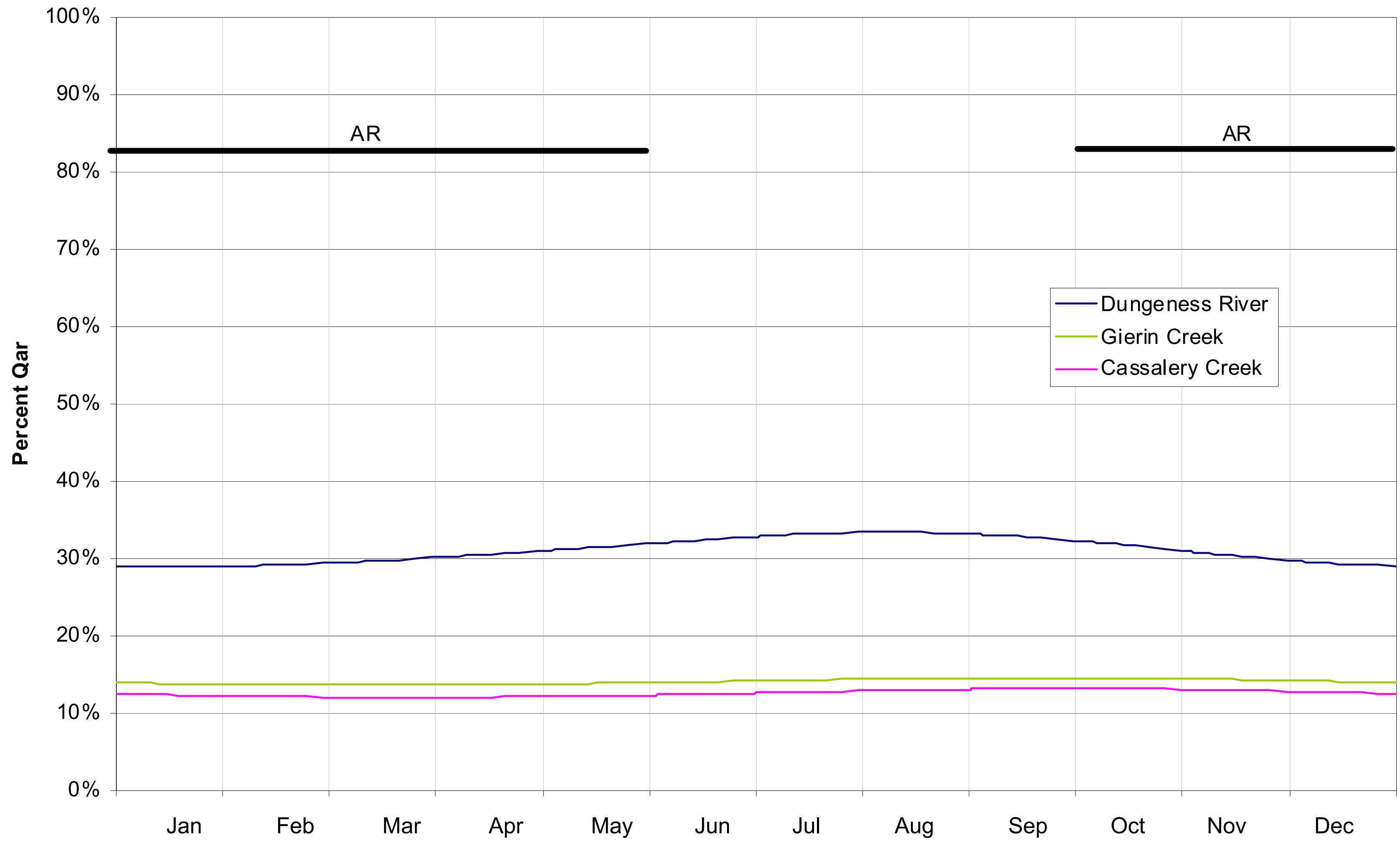

Figure 4-3
Scenario B - Streamflow Augmentation as Percent Q_{ar} (S_y = 20%)

Clallam County
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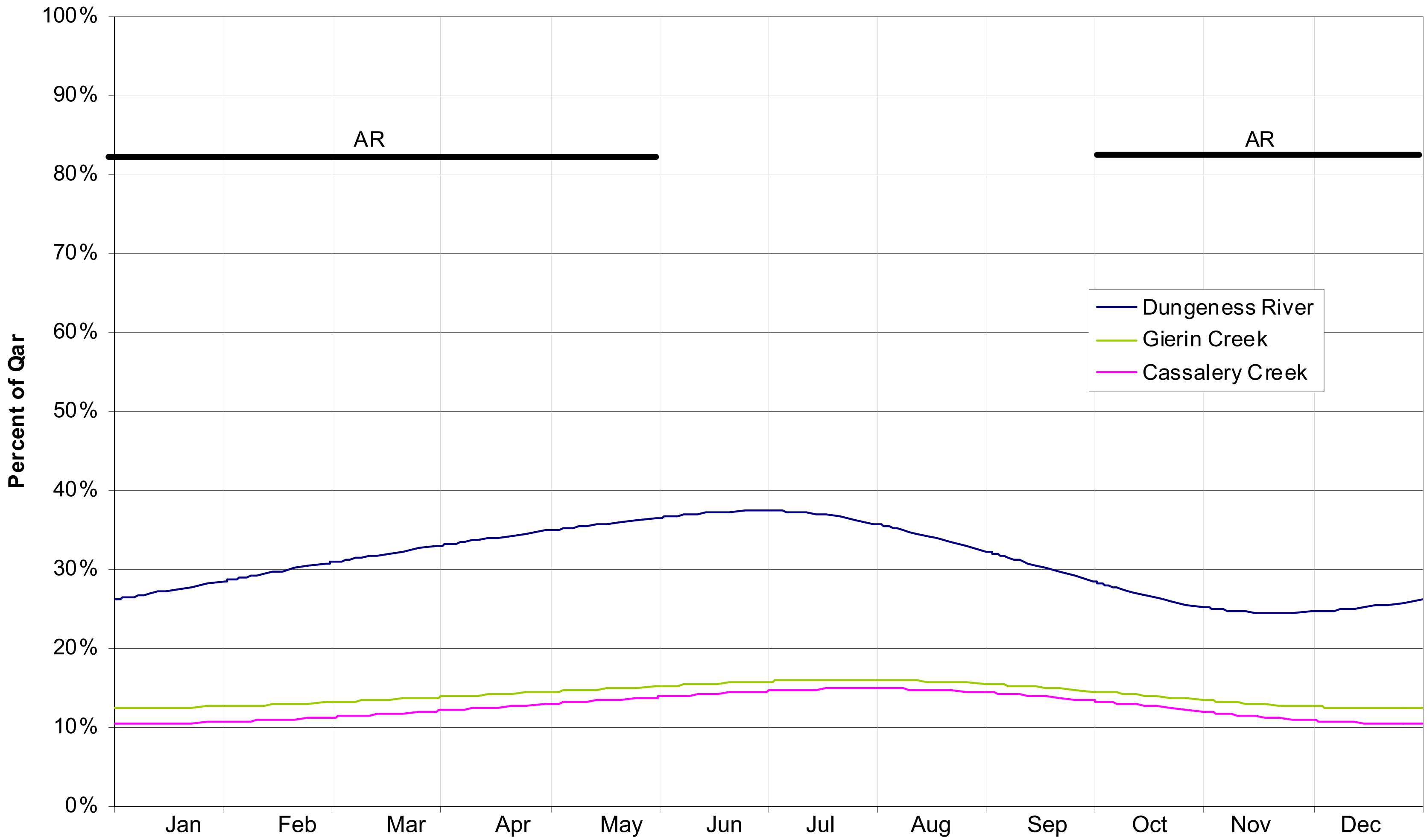

Figure 4-4
Scenario B - Streamflow Augmentation as Percent Q_{ar} (S_y = 10%)

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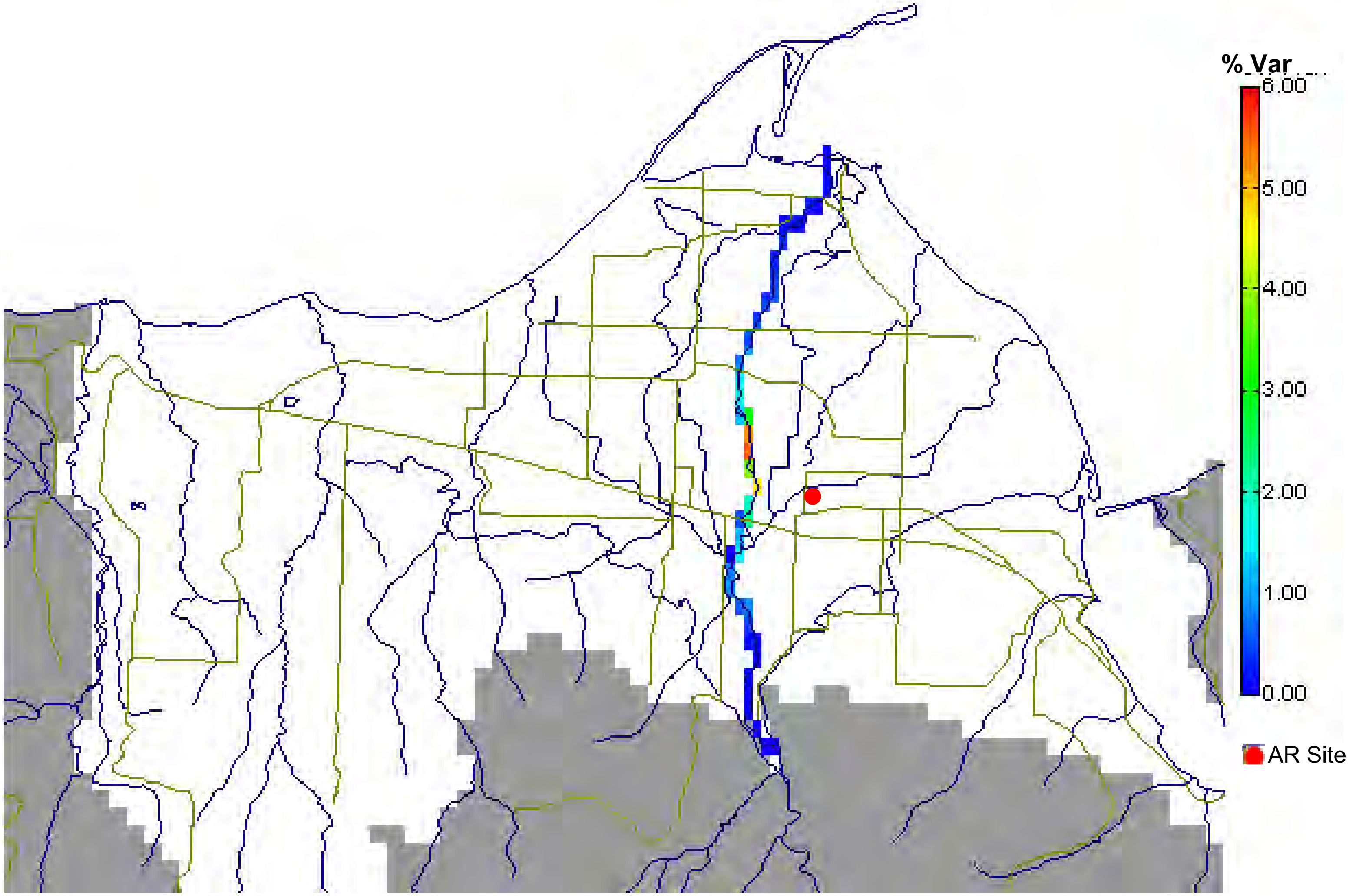

Figure 4-5
Scenario B - Dungeness River Steady-State Augmentation per Model Cell as Percent V_{ar}

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AR/ASR Feasibility Study

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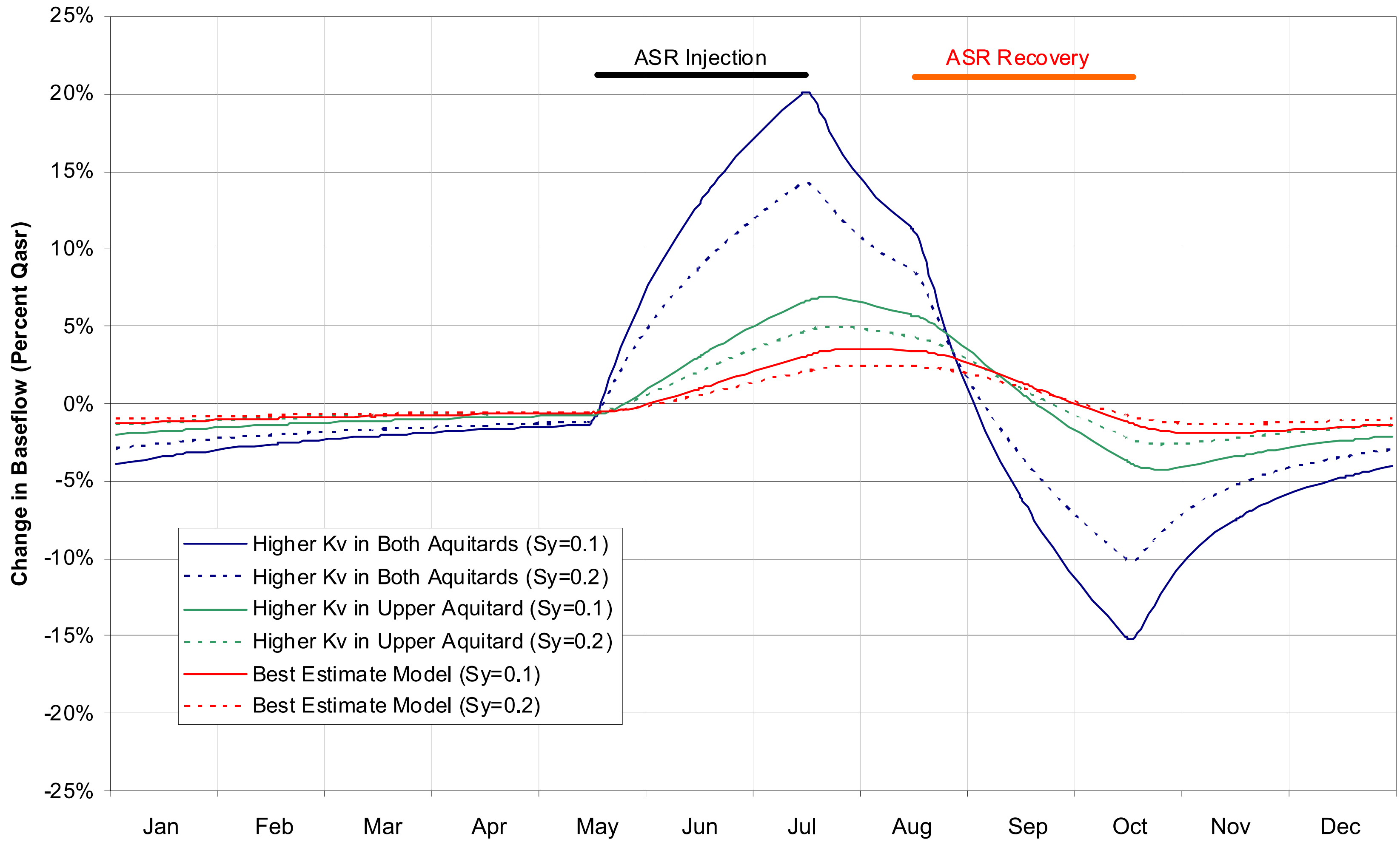

Figure 5-1
FS Scenario C - Change in Dungeness River Baseflow from ASR in Lower Aquifer

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