To: Said Amali, IRZ Consulting LLC	
From: Bryan Black, P.E Anna Zaklikowski, P.E.	Project: Umatilla Recharge Project
CC:	
Date: January 27, 2009	Job No: 86502
Re: Task 1.H – Cost for Municipal-Type ASR Source Water Treatment Systems	

The Oregon Water Resources Department (OWRD) designated four groundwater aquifers within the Umatilla Basin as Critical Groundwater Areas (CGAs) due to their documented overdraft (OWRD 2003). As a result, use of additional groundwater for irrigation in the CGAs has been curtailed causing adverse impact to the economies of Umatilla and Morrow counties. To increase water availability in the CGAs, OWRD has begun a technical assessment of the feasibility of storing water from Columbia River and other surface sources during high flow periods in shallow sediment and deeper basalt aquifers for subsequent recovery and use during the irrigation season. The project has been divided into several tasks. This technical memorandum includes a summary of information regarding the cost for municipal-type water treatment systems, as they may be utilized to treat water prior to injection into basalt aquifer.

EXECUTIVE SUMMARY

Three Supply, Storage, Recovery, and Distribution (SSRD) systems have been proposed that would service areas within the Butter Creek, Ordnance Gravel, and Stage Gulch CGAs. The SSRD systems will include recharge of shallow alluvial aquifers in the County Line and Echo Meadows areas with Columbia River water, and potentially from Umatilla River. Groundwater from these aquifers would be withdrawn and injected into the basalt aquifer through an ASR system for later recovery. Aquifer Storage and Recovery (ASR) regulations require source water that is injected into the Columbia River Basalt Group aquifer (basalt aquifer) to meet standards for water quality and treatment, if applicable. The level of treatment required is dependent on the source water classification: surface water, groundwater, or groundwater under the direct influence of surface water (GWUDI).

A review of the available technologies shows that slow sand filtration and chlorine disinfection were the least costly surface water treatment technologies for this project. If the SSRD systems are designed so that the groundwater in the shallow aquifers meets certain criteria, the pumped water will be classified as groundwater and not require treatment prior to injection into the basalt aquifer. If the groundwater is subsequently found to contain microbial contamination, disinfection could be required with capital and operation and maintenance (O&M) costs for chlorination facilities ranging from $240,000 to $700,000 ($30 to $21 per acre foot), and $60,000 to $160,000 ($8 to $5 per acre foot), respectively.

If the recharged groundwater does not meet the criteria, the pumped water may be classified as GWUDI. The GWUDI designation would require disinfection and, potentially, engineered filtration if natural filtration credit is not obtained. For GWUDI as source water, the approximate capital cost of a disinfection system with maximum natural filtration credit ranges from $2.2 to $10 million ($270 to $300 per acre foot), with a corresponding annual O&M cost range of $100,000 to $300,000 ($12 to $9 per acre foot).

If Columbia or Umatilla River water were to be directly injected into the basalt aquifer, the approximate capital cost of treatment would range from $13 to $55 million ($1,600 to $1,650 per acre foot) for the treatment capacities required under the three SSRDs. The corresponding annual O&M cost would range from $210,000 to $610,000 ($26 to $18 per acre foot).

OBJECTIVES

This memorandum provides descriptions and planning-level cost estimates for potential technologies to treat surface water or groundwater in County Line and Echo Meadows alluvial aquifers to drinking water standards to comply with regulations governing injection of such waters as ASR source water into basalt aquifer.

INTRODUCTION

This project includes percolation of imported surface water from Columbia River, and potentially from Umatilla River, through surficial alluvial aquifers in the County Line and ~~Eco~~ Meadows areas, respectively. The percolated water recharges alluvial aquifer groundwater in the CGAs. Groundwater will be withdrawn from the alluvial aquifers to provide source water for injection into the basalt aquifer ASR system. As described in a separate memorandum (HDR 2009), the SSRD systems proposed in this project will be designed so that the groundwater pumped out of the alluvial aquifers will be classified as groundwater and not GWUDI (based on the distance criteria specified in OAR 333-061-0032(7)). Groundwater requires less treatment against microbial pathogens since it is typically less vulnerable to microbial contamination than surface water. Depending on the degree to which this goal can be accomplished, the project will take advantage of reduced treatment requirements for groundwater compared with surface water. Treatment costs were nevertheless estimated for systems that would use GWUDI or surface water from the Columbia or Umatilla Rivers as ASR source water so that the importance of natural filtration afforded by alluvial aquifer storage is clarified.

The following two options are available depending on whether ASR source water is groundwater or GWUDI:

- Groundwater - Filtration is not required and disinfection is not required unless the well is found to be susceptible to microbial contamination as indicated through coliform sampling.

- GWUDI - Required treatment includes filtration and disinfection. Potentially eligible for up to 2-log inactivation/removal credits for *Giardia* and *Cryptosporidium,* if criteria for natural filtration are met.

TOTAL TREATMENT REQUIREMENTS

Treatment of surface water must include filtration and inactivation (by disinfection) of specific pathogenic microorganisms. If natural filtration criteria are met for water categorized as GWUDI, the source water must only be disinfected. If not, engineered filtration will be required prior to disinfection. Treatment of groundwater, ~~if~~ required by ~~the~~ Oregon Department of Human Services (DHS) would consist of disinfection for virus inactivation only.

Inactivation (or removal) is typically expressed using logarithmic form based on percent reduction of microorganisms across the treatment process, as listed in Table 1 below.

Table 1. Converting Log Removal / Inactivation to Percent Reduction.

Log Removal and/or inactivation	Percent Reduction
0.5-log	68.4
1-log	90
2-log	99
3-log	99.9
4-log	99.99

OAR 333-061-0032(5) requires that surface water treatment facilities remove and / or inactivate specific pathogenic microorganisms that could be present in the raw surface water, as listed in Table 2 below.

Table 2. Microbial Treatment Requirements for Surface Water and GWUDI

Organism	Log Removal and /or Inactivation
Cryptosporidium	2-log
Giardia	3-log
Viruses	4-log

The treatment requirement listed in Table 2 must come from a combination of filtration and disinfection. Based on OAR 333-061-0032 a combination of filtration and disinfection is required for surface water to provide a multiple treatment barrier for enhanced reliability in preventing water borne disease outbreaks. Under OAR 333-061-0032(2), systems may be able to avoid filtration if the surface water source meets strict criteria for coliform bacteria counts, turbidity levels, and watershed control / protection, which are not currently met by the Columbia and Umatilla Rivers in the area of the project.

FILTRATION SYSTEMS CONSIDERED

The Surface Water Treatment Rule Guidance Manual issued by the U.S. Environmental Protection Agency (EPA 1991) outlines filtration technologies suitable for use in surface water treatment. Table 3 presents four filtration technologies listed by EPA that would be applicable to a large range of system sizes.

Table 3. Primary And Alternative Filtration Technologies For Surface Water ~~Treatment~~

Primary Filtration Technologies	Alternative Filtration Technologies
Conventional Treatment Direct Filtration Slow Sand Filtration	Membrane Filtration

A number of the above ~~treatment~~ systems are in use by municipalities to treat Columbia and Umatilla River waters, as summarized in Table 4 below.

Table 4. Partial List Of Municipal Treatment Systems Using Columbia Or Umatilla River Sources

Municipality	Filtration Technology	Disinfection Technology	Size (mgd)(AFD)*	Source River
Richland, WA	Direct Filtration	Chlorine	15 (5)	Columbia
Richland, WA	Slow Sand Filtration	Ultraviolet light	15 (5)	Columbia
Kennewick, WA	Sedimentation, membrane filtration	Chlorine	15 (5)	Columbia
Kennewick, WA	Bank filtration	Ultraviolet light	15 (5)	Columbia
Pendleton, OR	Membrane filtration	Chlorine	6 (2)	Umatilla
St Helens, OR	Bank filtration, membrane filtration	Chlorine	8 (2.6)	Columbia

*mgd = million gallons per day; AFD = acre feet per day

Certain filtration treatment processes are "credited" with removal capabilities provided they are properly engineered and operated. The filtration "credit" is subtracted from the overall treatment requirement in Table 2 to yield the inactivation target for disinfection. Based on OAR 333-061-0050(4)(c)(D) a minimum of 0.5 log reduction of *Giardia* and 1.0 log reduction of viruses must be provided from disinfection alone after filtration. Table 5 presents filtration credits and disinfection requirements associated with different filtration technologies deemed suitable for treating raw Columbia or Umatilla River surface waters.

Table 5. Filtration Credits And Remaining Disinfection Requirements

	Credited Log Removals		Required Disinfection (Log inactivation)	
Filtration	**Giardia**	**Viruses**	**Giardia**	**Viruses**
Conventional	2.5	2.0	0.5	2.0
Direct	2.0	1.0	1.0	3.0
Slow Sand	2.0	2.0	1.0	2.0
Membrane	2.5	0 – 3	0.5	1 – 4
Natural	2.0	2.0	1.0	4.0

FILTRATION SYSTEM COST ESTIMATES

Cost estimates were prepared for the technologies listed in Table 3 based on the unit processes listed in Table 6 below.

Table 6. Unit Processes Considered For Filtration Cost Estimating

Conventional Treatment	**Direct Filtration**	**Membrane Filtration**	**Slow Sand Filtration**
Chemical feed (alum, polymer) Rapid mix Flocculation Sedimentation Gravity filtration (mixed media) Backwashing with washwater surge basins In-plant pumping and sludge pumping Clearwell storage Solids handling	Chemical feed (alum, polymer) Rapid mix Flocculation Sedimentation Gravity filtration (mixed media) Backwashing with washwater surge basins In-plant pumping and sludge pumping Clearwell storage Solids handling	Chemical feed (alum) Rapid mix Flocculation Membrane Filtration	Covered concrete filters (small) Membrane-lined earthen berm filters (large)

Anticipated capital, and operations and maintenance (O&M) costs of filtration for the four filtration technologies in Table 6 are graphically shown on Figures 1 and 2 below. The figures are intended to allow a comparison between the technologies. Based on the estimated cost values, slow sand filtration appears to be the technology with the lowest capital and O&M cost. Slow sand filtration also offers the benefit of simplicity of operation since chemicals are not required.

The cost estimates shown on Figures 1 and 2 are "planning level" values and are intended to provide relative comparison between major alternatives. Costs for the process groups were developed using information presented by US EPA (1988), except membrane filtration costs which were developed using information presented by US EPA in the *Technologies and Costs for Removal of Arsenic from Drinking Water* (2000). The Engineering News Record (ENR) Construction Cost Index was used to adjust costs to October 2008. Detailed cost tables are presented in Appendix A. All filtration options include appropriate backwashing and waste handling facilities, but exclude cost for land.

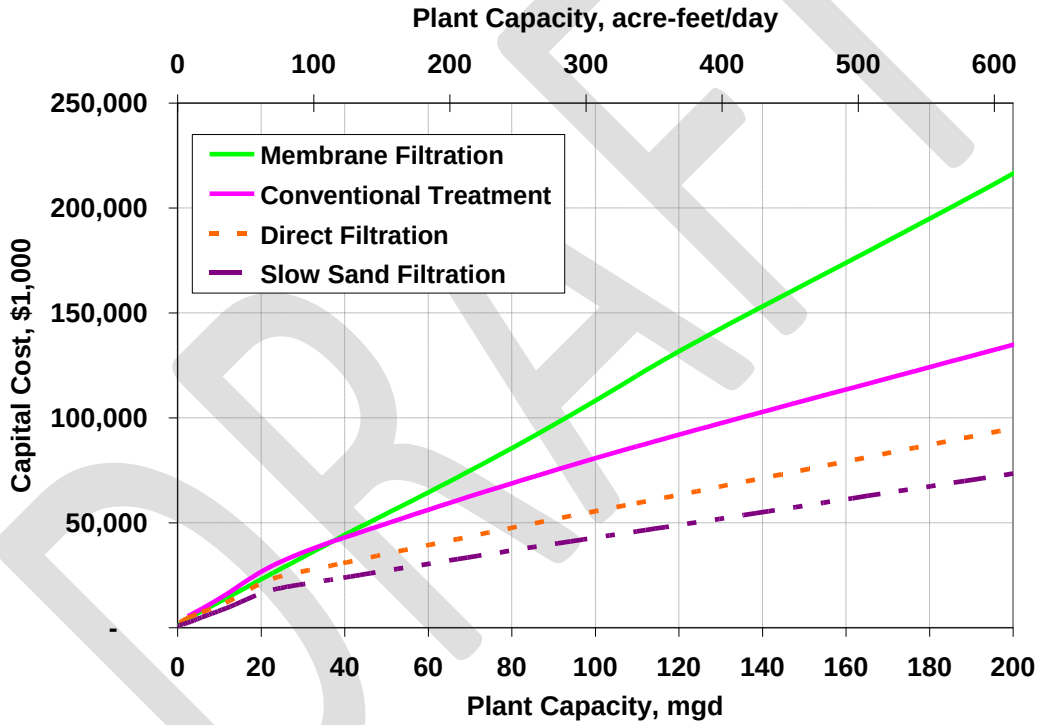

Figure 1. Filtration System Capital Costs

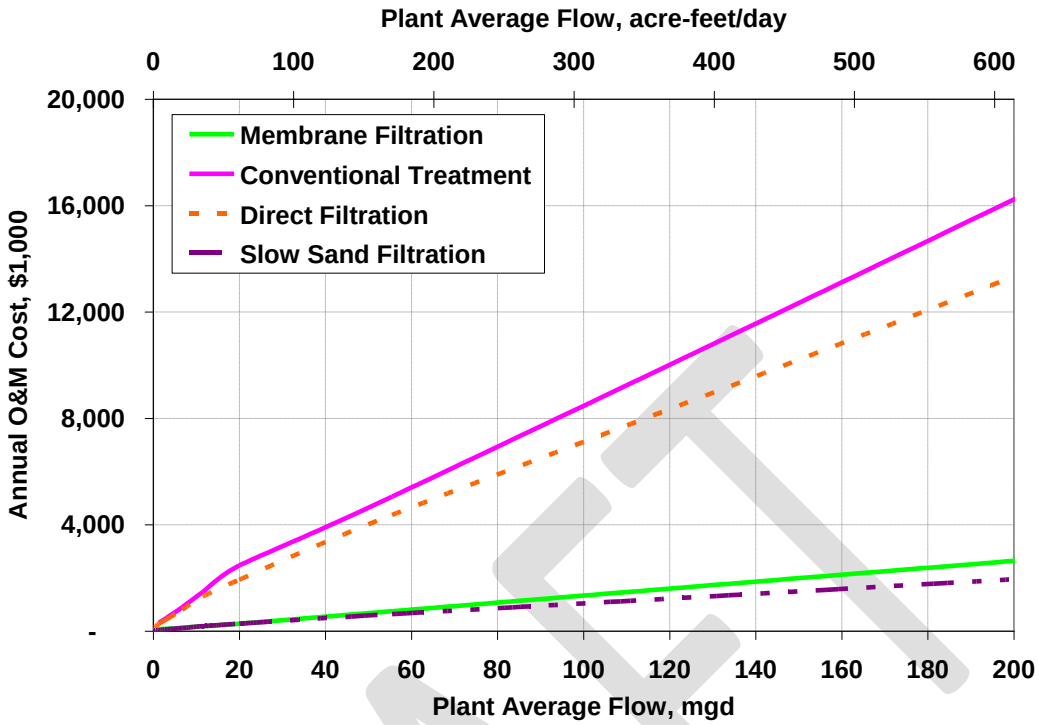

Figure 2. Filtration System Annual O&M Costs
(based on 365 day/year plant operation at average flow)

DISINFECTION SYSTEMS CONSIDERED

The most widely used forms of disinfection for Columbia River water are chlorine and ultraviolet (UV) light, as summarized in Table 4. Use of chlorine to provide inactivation of *Giardia* and viruses after filtration requires adequate contact time, in the range of 45 to 90 minutes for winter Columbia River water, before disinfection is complete. This is typically provided in a storage tank. The amount of contact time, and therefore the size of tank, depends on the required disinfection as shown in Table 5. For example, since direct filtration plants have a 1-log Giardia disinfection requirement, they would need to be provided with a larger chlorine contact tank than conventional filtration facilities (0.5-log requirement).

~~The~~ UV light is an alternative to disinfection with chlorine. ~~The~~ UV light can be operated under pressure, potentially eliminating the need for additional pumping and reducing the volume of water storage needed for contact time. As UV light is typically used only for the inactivation of *Giardia* and *Cryptosporidium*, chlorination is still used to achieve the required inactivation of viruses. However, the contact time needed to provide inactivation of viruses using chlorination is significantly less than required for protozoan pathogens and should be adequate in the pipeline that conveys water from the well collection point to the deep basalt (no storage tank will be needed). The final design of a disinfection system should plan for a combination of contact time and chlorine feed concentration to achieve the required inactivation rates.

DISINFECTION SYSTEM COST ESTIMATES

Capital and O&M costs are provided for chlorination and UV light disinfection options. Similar to cost estimates for filtration technologies, the estimates for the disinfection alternatives are "planning level" values and are intended to provide relative comparison between the two alternatives. For each technology, costs were developed for the treatment processes listed in Table 7 below using information contained in US EPA (1988) for chlorination and information published in the Journal AWWA (Cotton et al, 2001) for UV light technology. The Engineering News Record (ENR) Construction Cost Index was used to adjust costs to October 2008. Detailed cost tables are presented in Appendix A.

Table 7. Unit Processes Considered For Disinfection System Cost Estimates

Chlorination	**UV Light**
Chlorine feed and cylinder storage	UV disinfection system
Chlorine Contact Tanks	Valves and flow metering
Effluent Pump Station	Chlorine feed facilities (for virus inactivation)*

*Chlorine facilities are added to the UV disinfection system for the purpose of fulfilling the remaining inactivation/removal requirement for viruses. At this time, the majority of UV reactors have not been validated for virus inactivation as it has not been found to be cost-effective. Chlorine contact tanks are not included as the contact time for virus inactivation is assumed to be minimal and provided during transmission of water to injection wells.

Figures 3 and 4 include summaries of the anticipated capital and O&M costs for chlorine and UV disinfection. For systems exceeding a capacity of 10 mgd (approximately 30 acre feet per day), chlorine has the lowest capital cost value, while for systems with a smaller capacity UV disinfection provides the lowest cost option. O&M costs for chlorine are lower than for UV disinfection for surface water plants with average flows less than 15 mgd. For the SSRD systems under consideration, which range in daily flows from 15 mgd to 122 mgd, UV disinfection has lower O&M costs compared with chlorine within a margin of 5 to 15%.

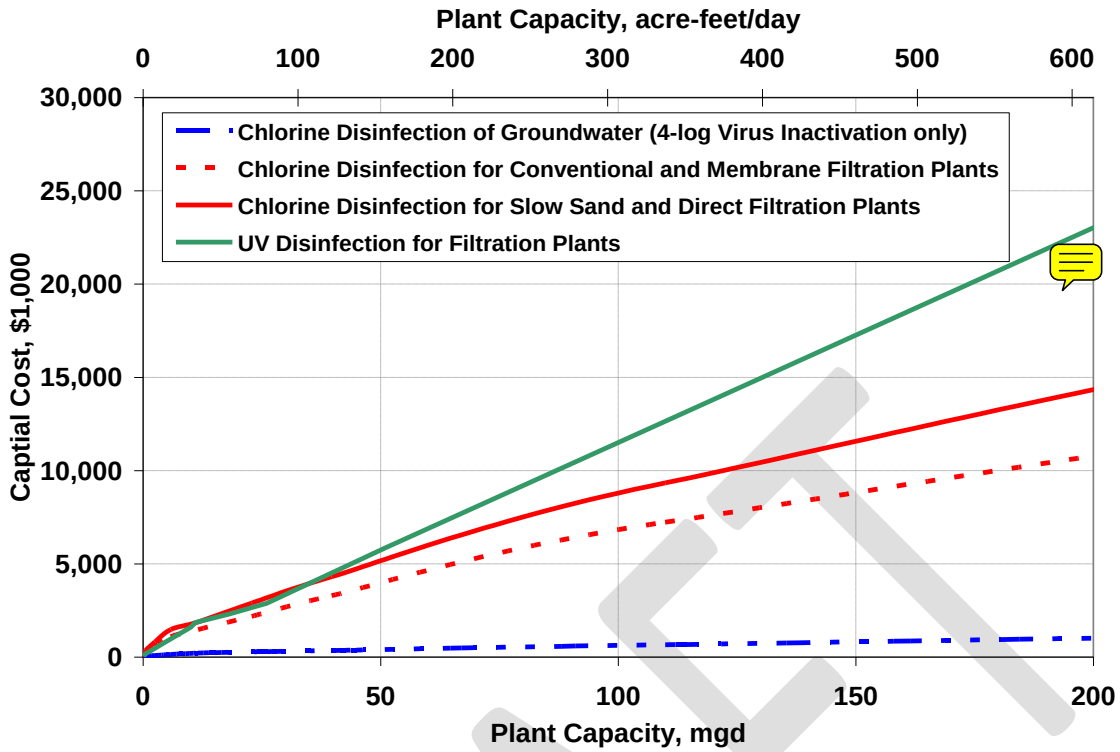

Figure 3. Disinfection Capital Costs

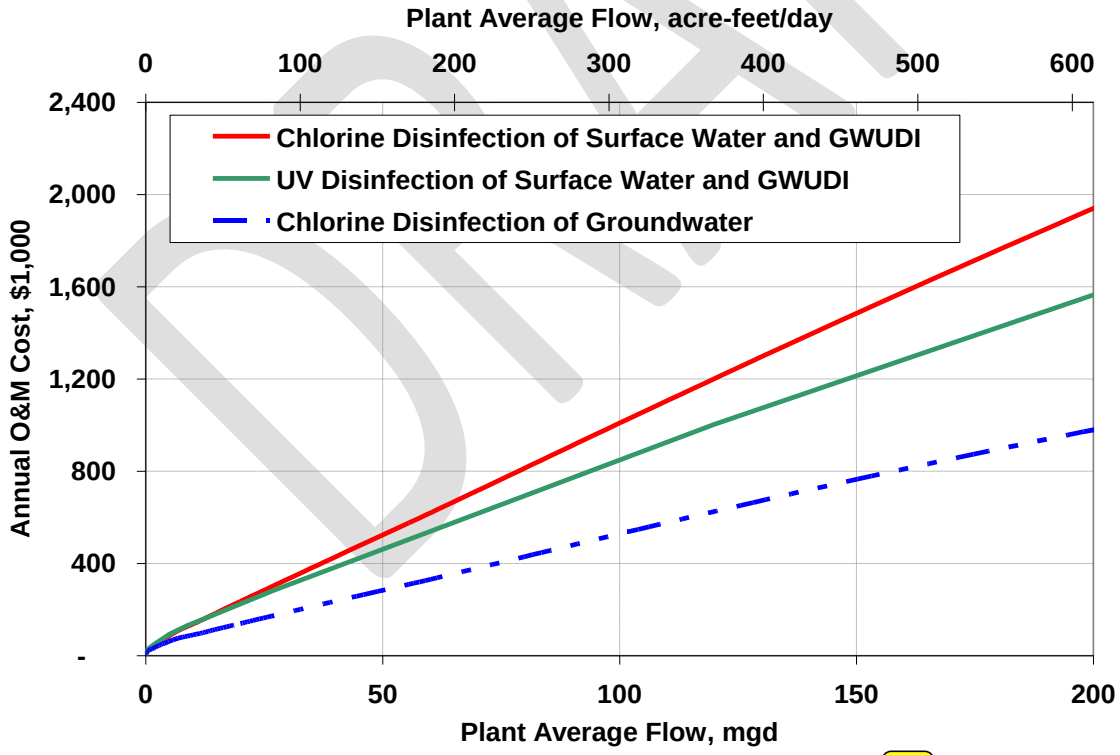

Figure 4. Disinfection Annual O&M Costs

SUMMARY OF TOTAL TREATMENT COSTS FOR THE PROPOSED SSRD SYSTEMS

Three Supply, Storage, Recovery, and Distribution (SSRD) systems have been proposed to bring surface water from the Umatilla and Columbia rivers into the project area. The treatment capacities associated with these SSRD systems and options are indicated in Table 8. The capacities are the volumes projected for each system to be injected into the basalt aquifer (not the total volume of river water diverted). The SSRD1 system will serve the areas in the Butter Creek and Ordnance Gravel CGAs. The SSRD2 system will serve the areas within Stage Gulch CGA Sub-Area G and the portion of Sub-Area A south of Umatilla River. The SSRD3 system will serve the remaining sub-areas in the Stage Gulch CGA.

Table 8: SSRD System Options and Treatment Capacities

SSRD System/ Duration of Operation	Options	Total Capacity		
		Acre-feet per year	AFD	MGD
SSRD 1 (6 months operation)	Options 1&2	8,100	45	15
	Options 3&4	15,000	85	28
	Options 5&6	18,000	100	33
	Option 7	34,000	190	62
SSRD 2 (90 days operation)		22,000	245	80
SSRD 3 (90 days operation)		33,500	375	122

Capital costs for a treatment plant that would include slow sand filtration and either chlorine or UV light disinfection technologies over a wide range of treatment capacities are shown in Figure 5. Capital costs are generally similar between the two disinfection options for the SSRD systems considered in this project within a margin of approximately 10%.

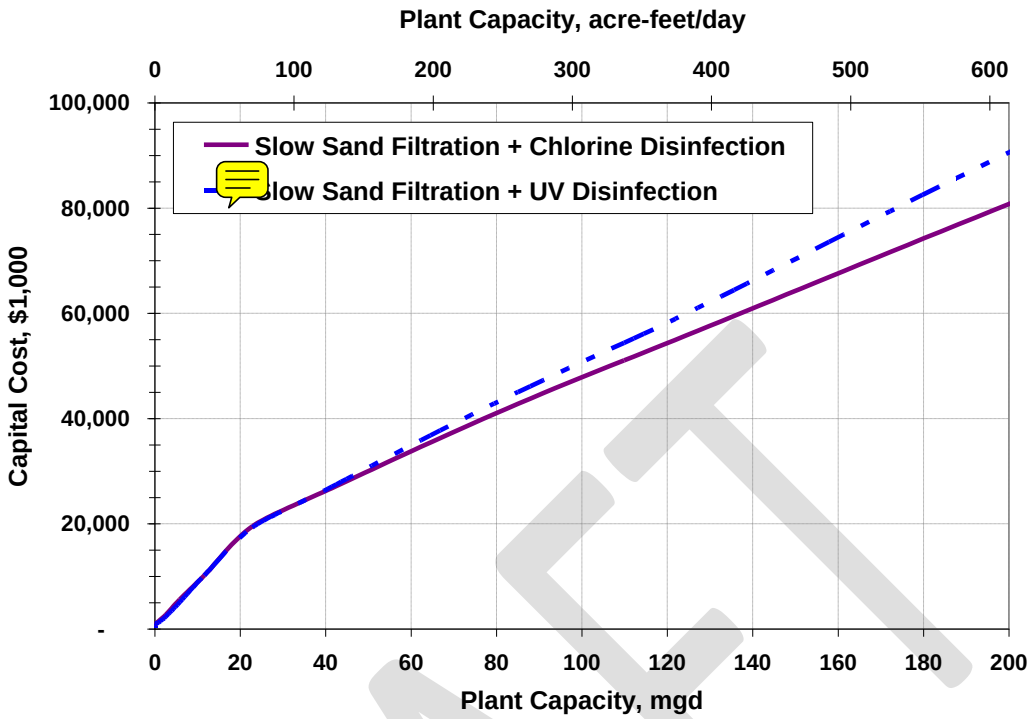

Figure 5: Capital Costs For Filtration Facilities With Chlorine Or UV Light Disinfection

Figure 6 includes a summary of the anticipated capital cost of treatment for the three SSRD Systems. Capital costs are compared for three water source classifications: 1) groundwater systems that provide 4-log disinfection of viruses, 2) GWUDI systems that qualify for 2-log natural filtration credit and 3) surface water (or GWUDI systems not receiving 2 log credit) with slow sand filtration. Costs are based on using slow sand filters for filtration systems and chlorine for disinfection systems. SSRD system costs are not presented for UV disinfection systems. As the capital and O&M costs for chlorine and UV disinfection systems varied by less than 15% for the range of SSRD systems under consideration, the decision to use UV or chlorine should be evaluated in greater detail during facility design.

Approximate costs to build treatment systems that include filtration and disinfection vary from $13 to $55 million for capital and $210,000 to $610,000 for annual O&M costs, depending on the treatment capacity. If the water source is credited for natural filtration, disinfection facilities would vary from $2.2 to $10 million in capital and $100,000 to $300,000 in O&M costs, depending on system size. For groundwater systems providing 4-log inactivation of viruses, capital costs vary from $240,000 to $700,000 and from $60,000 to $160,000 for O&M costs, with increasing system size. If the water is classified as groundwater and further sampling does not reveal evidence of microbial contamination, filtration and disinfection would not be required and there would be no cost associated with treatment.

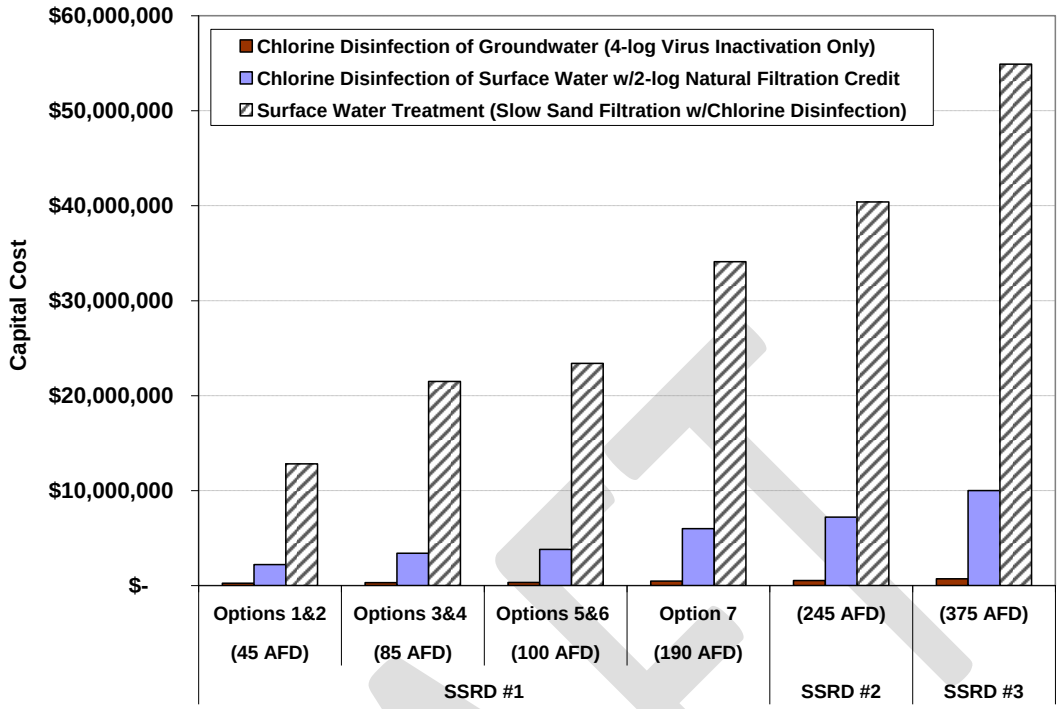

Figure 6: Capital Costs For SSRD Treatment Facilities

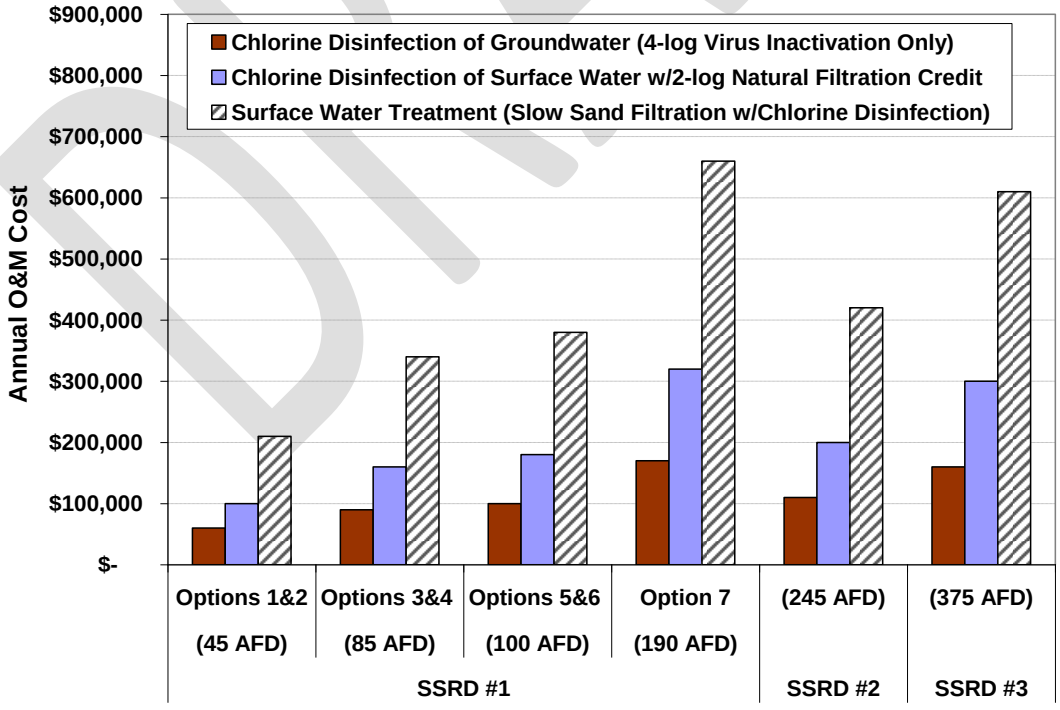

Figure 7: Annual O&M Costs For SSRD Treatment Facilities (based on O&M duration in Table 8)

Table 9 summarizes the proposed levels of treatment for each source water category and their associated range of treatment cost.

Table 9: Summary of Treatment Needs and Cost

Source Water Classification	Filtration	Disinfection Requirement	Capital Cost ($Million) ($ per acre foot treated)	Annual O&M Cost ($) ($ per acre foot treated)
Surface water GWUDI with no natural filtration credit	Slow Sand Filtration	1-log *Giardia* 2-log viruses	13 to 55 (1,600 to 1,650)	210,000 to 610,000 (26 to 18)
GWUDI with 2-log natural filtration credit	None	1-log *Giardia* 4-log viruses	2.2 to 10 (270 to 300)	100,000 to 300,000 (12 to 9)
Ground water	None	None or 4-log virus*	0.24 to 0.7 (30 to 21)	60,000 to 160,000 (8 to 5)

* 4-log virus inactivation required if determined necessary by DHS. Costs are for disinfection facilities to provide 4-log virus inactivation.

REFERENCES

Cotton, CA; Owen, DM; Cline, GC; Brodeur, TP. *UV Disinfection Costs for Inactivating Cryptosporidium*, Journal AWWA, June 2001.

HDR, Inc. 2009. Task 1.H Assess Water Treatment Needs, Alternatives, and Regulatory Approach. Draft Technical Memorandum. *In Preparation*.

Oregon Water Resources Department. 2003. *Groundwater Supplies in the Umatilla Basin.* OWRD Groundwater Section, Pendleton, Oregon. April.

US Environmental Protection Agency, October 1988. *Technologies and Costs for the Treatment of Microbial Contaminants in Potable Water Supplies*, Science and Technology Branch.

US Environmental Protection Agency, 1991. *Guidance Manual for Compliance with the Filtration and Disinfection Requirements for Public Water Systems Using Surface Water Sources (SWTR Guidance Manual)*, Washington DC.

US Environmental Protection Agency, December 2000. *Technologies and Costs for Removal of Arsenic from Drinking Water*, Targeting and Analysis Branch.

Appendix A
Cost Tables

Table A-1. Estimated cost for surface water treatment by conventional complete treatment (2008 Cost basis)

				Operation and Maintenance Cost		
Category	Plant Capacity, mgd	Average Flow, mgd	Capital Cost, $1,000	$1,000/yr	$/1,000 gal	Total Cost, $/1,000 gal
5	2.5	1.3	5,379	310	0.65	1.99
6	5.9	3.3	9,098	523	0.44	1.34
7	11.6	6.8	15,750	905	0.37	1.12
8	22.9	11.5	29,640	1,475	0.35	1.18
9	39.7	20.0	42,731	2,469	0.34	1.03
10	109.9	55.5	86,356	5,061	0.25	0.75
11	404.0	205.0	247,545	16,628	0.22	0.61
12	1275.0	650.0	754,779	51,587	0.22	0.59

Notes:
See text for complete process description
0.1177 Amortization Factor
8623.22 ENR Construction Cost Index

Table A-2. Estimated cost for surface water treatment by direct filtration (2008 Cost basis)

				Operation and Maintenance Cost		
Category	Plant Capacity, mgd	Average Flow, mgd	Capital Cost, $1,000	$1,000/yr	$/1,000 gal	Total Cost, $/1,000 gal
4	0.5	0.4	2,416	135	0.92	2.87
5	2.5	1.3	4,656	273	0.58	1.73
6	5.9	3.3	7,356	458	0.39	1.12
7	11.6	6.8	11,812	811	0.33	0.89
8	22.9	11.5	23,364	1,298	0.31	0.96
9	39.7	20.0	30,802	1,935	0.27	0.76
10	109.9	55.5	59,355	4,368	0.22	0.56
11	404.0	205.0	170,533	13,646	0.18	0.45
12	1275.0	650.0	463,221	42,000	0.18	0.41

Notes:
See text for complete process description
0.1177 Amortization Factor
8623.22 ENR Construction Cost Index

Table A-3. Estimated Cost for Surface Water Disinfection Using Membrane Filtration (2008 Cost Basis)

				Operation and Maintenance Cost		
Category	Plant Capacity, mgd	Average Flow, mgd	Capital Cost, $1,000	$1,000/yr	$/1,000 gal	Total Cost, $/1,000 gal
1	0.026	0.013	239	29	6.12	12.05
2	0.068	0.045	421	36	2.20	5.22
3	0.166	0.13	653	41	0.87	2.49
4	0.5	0.4	1,461	65	0.45	1.63
5	2.5	1.3	4,172	76	0.16	1.20
6	5.9	3.3	7,910	91	0.08	0.86
7	11.6	6.8	3,956	129	0.05	0.72
8	22.9	11.5	6,128	186	0.04	0.78
9	39.7	20.0	3,836	282	0.04	0.75
10	109.9	55.5	19,929	753	0.04	0.73
11	404.0	205.0	88,221	2,708	0.04	0.80
12	1275.0	650.0	2,020,229	8,460	0.04	1.04

Notes:
See text for complete process description
0.1177 Amortization Factor
8623.22 ENR Construction Cost Index

Table A-4. Estimated Cost for Surface Water Treatment by Slow-Sand Filtration (2008 Cost Basis)

				Operation and Maintenance Cost		
Category	Plant Capacity, mgd	Average Flow, mgd	Capital Cost, $1,000	$1,000/yr	$/1,000 gal	Total Cost, $/1,000 gal
1	0.026	0.013	277	2	0.32	7.19
2	0.068	0.045	521	3	0.19	3.92
3	0.166	0.13	969	10	0.21	2.61
4	0.5	0.4	1151	17	0.12	1.05
5	2.5	1.3	2315	39	0.08	0.66
6	5.9	3.3	4910	73	0.06	0.55
7	11.6	6.8	9125	119	0.05	0.48
8	22.9	11.5	18,050	190	0.05	0.55
9	39.7	20.0	23,796	284	0.04	0.42
10	109.9	55.5	45,854	640	0.03	0.30
11	404.0	205.0	131,743	2,000	0.03	0.23
12	1275.0	650.0	357,855	6,157	0.03	0.20

Notes:
See text for complete process description
0.1177 Amortization Factor
8623.22 ENR Construction Cost Index

Table A-5. Estimated Cost for Surface Water Disinfection Using Chlorine (2008 Cost Basis)

Category	Plant Capacity, mgd	Average Flow, mgd	Capital Cost, $1,000	Annual Operation and Maintenance Cost		Total Cost, $/1,000 gal	Storage Volume, gal		Storage Unit Cost, $/gal	Storage Cost, $1,000		Pumping Capital Cost, $1000	Total Chlorine Disinfection Capital Cost, $1,000		Plant Capacity, acre-feet	Annual Pumping Cost ($1,000/yr)	Total Annual O&M
				$1,000/yr	$/1,000 gal		0.5-log	1.0-log		0.5-log	1.0-log		0.5-log	1.0-log			
1	0.026	0.013	12	5	0.97	1.25	794	1,625	18.0	14	29	3	29	44	0.08	0	5
2	0.068	0.045	23	5	0.29	0.45	2,078	4,250	15.0	31	64	7	61	94	0.21	0	5
3	0.166	0.13	34	11	0.23	0.31	5,072	10,375	12.0	61	125	17	112	175	0.51	1	11
4	0.5	0.4	58	20	0.14	0.18	15,278	31,250	7.5	115	234	50	223	342	1.53	2	22
5	2.5	1.3	87	29	0.06	0.08	76,389	156,250	3.0	229	469	252	568	808	7.67	6	35
6	5.9	3.3	135	48	0.04	0.05	178,750	365,625	2.1	369	755	590	1,094	1,480	17.95	16	63
7	11.6	6.8	218	75	0.03	0.04	354,139	724,375	1.1	400	819	847	1,465	1,883	35.57	32	108
8	22.9	11.5	273	96	0.02	0.03	698,500	1,428,750	1.0	678	1,386	1,234	2,184	2,893	70.15	55	151
9	39.7	20.0	355	139	0.02	0.02	1,212,444	2,480,000	0.8	982	2,009	1,949	3,286	4,312	121.77	96	235
10	109.9	55.5	658	309	0.02	0.02	3,358,056	6,868,750	0.6	2,015	4,121	4,563	7,236	9,342	337.27	266	576
11	404.0	205.0	1574	1000	0.01	0.02	12,344,444	25,250,000	0.5	6,172	12,625	8,992	16,739	23,191	1239.83	984	1,984
12	1275.0	650.0	2582	2717	0.01	0.01	38,958,333	79,687,500	0.4	15,583	31,875	13,377	31,542	47,834	3912.83	3,120	5,838

Notes/Assumptions:
See text for complete process description
0.1177 Amortization Factor
8623.22 ENR Construction Cost Index
22 CT (mg-min/L): 0.5-log, 10C, pH 7.5
45 CT (mg-min/L): 1.0-log, 10C, pH 7.5
50% Baffling Factor
Annual Pumping Energy Costs calculated based on 100 ft TDH, 80% efficiency (water-to-wire), and $0.08/kWh

Table A-6. Estimated Cost for Surface Water Disinfection Using Ultraviolet Light (2008 Cost Basis)

Category	Plant Capacity, mgd	Average Flow, mgd	Capital Cost, $1,000	Operation and Maintenance Cost		Total Cost w/Chlorine Feed, $1,000	Annual O&M Cost with Chlorine
				$1,000/yr	$/1,000 gal		
1	0.024	0.0056	44	2	0.80	55	6
2	0.087	0.024	51	2	0.26	76	7
3	0.1	0.031	52	2	0.22	78	7
4	0.3	0.1	70	4	0.12	111	11
5	0.5	0.1	96	5	0.10	150	16
6	0.7	0.2	127	6	0.07	187	20
7	0.8	0.3	164	7	0.06	226	23
8	1.0	0.4	177	7	0.05	242	26
9	1.8	0.7	287	9	0.03	363	32
10	4.8	2.1	696	16	0.02	816	53
11	10.0	4.5	1406	29	0.02	1600	86
12	11.0	5.0	1638	31	0.02	1847	93
13	18.0	8.8	2047	46	0.01	2296	131
14	26.0	13.0	2593	61	0.01	2881	165
15	51.0	27.0	5459	111	0.01	5863	283
16	210.0	120.0	23203	396	0.01	24173	1003
17	430.0	270.0	39581	805	0.01	41185	2056

Notes:
See text for complete process description
0.1177 Amortization Factor
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Table A-7. Estimated Cost for Surface Water Treatment by Slow-Sand Filtration with Disinfection (2008 Cost Basis)

Category	Plant Capacity, mgd	Average Flow, mgd	Capital Cost, $1,000	O&M Cost		Total SSF Cost, $/1,000 gal	Total System Capital Cost, $1,000		Annual O&M Cost for Complete System
				$1,000/yr	$/1,000 gal		with Cl2 Disinfection	with UV Disinfection	
1	0.026	0.013	277	2	0.32	7.19	291	303	6
2	0.068	0.045	521	3	0.19	3.92	551	527	8
3	0.166	0.13	969	10	0.21	2.61	1,020	936	21
4	0.5	0.4	1151	17	0.12	1.05	1,259	1075	39
5	2.5	1.3	2315	39	0.08	0.66	2,653	2315	74
6	5.9	3.3	4910	73	0.06	0.55	5,635	5129	136
7	11.6	6.8	9125	119	0.05	0.48	10,190	10191	226
8	22.9	11.5	18,050	190	0.05	0.55	19,557	19316	342
9	39.7	20.0	23,796	284	0.04	0.42	26,099	26300	519
10	109.9	55.5	45,854	640	0.03	0.30	51,075	54379	1216
11	404.0	205.0	131,743	2000	0.03	0.23	142,310	158293	3984
12	1275.0	650.0	357,855	6157	0.03	0.20	373,814	367165	11994

Notes:
See text for complete process description
0.1177 Amortization Factor
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Table A-8. Capital and O&M Cost Estimates for Treatment Facilities for Proposed SSRD Systems (2008 Cost Basis)

SSRD System	SSRD Option	System Capacity			Capital Cost			Annual O&M Costs		
		AF per year	AF per day	MGD	Chlorine Disinfection w/Filtration (Surface Water or GWUDI)	Chlorine Disinfection and No Filtration (Surface Water or GWUDI)	Chlorine Disinfection for 4-log Virus Only (Groundwater)	Chlorine Disinfection w/Filtration (Surface Water or GWUDI)	Chlorine Disinfection and No Filtration (Surface Water or GWUDI)	Chlorine Disinfection for 4-log Virus Only (Groundwater)
	Options 1 & 2	8,100	45	15	$ 12,800,000	$ 2,200,000	$ 240,000	$ 210,000	$ 100,000	$ 60,000
	Options 3 &4	15,000	85	28	$ 21,500,000	$ 3,400,000	$ 300,000	$ 340,000	$ 160,000	$ 90,000
	Options 5 & 6	18,000	100	33	$ 23,400,000	$ 3,800,000	$ 330,000	$ 380,000	$ 180,000	$ 100,000
SSRD #1	Option 7	34,000	190	62	$ 34,100,000	$ 6,000,000	$ 460,000	$ 660,000	$ 320,000	$ 170,000
SSRD #2		22,000	245	80	$ 40,400,000	$ 7,200,000	$ 530,000	$ 420,000	$ 200,000	$ 110,000
SSRD #3		33,500	375	122	$ 54,900,000	$ 10,000,000	$ 700,000	$ 610,000	$ 300,000	$ 160,000