November 21, 2016

Steven Patten
Senior Environmental Scientist
Walla Walla Basin Watershed Council
810 S. Main
Milton-Freewater, OR 97862

RE: Walla Walla Basin Integrated Water Flow Model: Piping and MAR Alternatives Management Scenarios Report

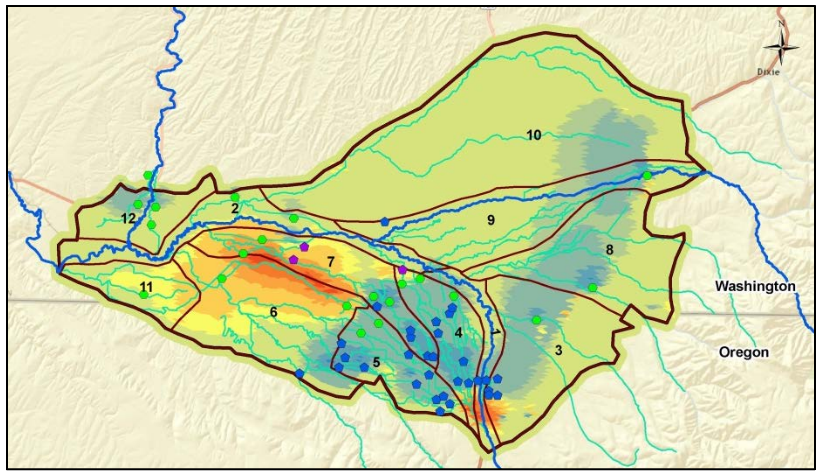
Dear Steven,

Enclosed please find the Walla Walla Basin Integrated Water Flow Model canal piping and managed aquifer recharge management scenarios report. This report incorporates the “No MAR-Piped” scenario and results from corrected inputs for urban water supplies and treated wastewater return flows. Should you have any questions, please do not hesitate to give us a call.

Sincerely,

Jason Keller, R.G.
Senior Hydrogeologist

1412 13th St., Suite 200
Hood River, Oregon 97031
phone: 541-716-4167
fax: 206-338-3058
WWW.GEOSYSTEMSANALYSIS.COM



Walla Walla Basin Integrated Water Flow Model: Piping and MAR Alternatives Management Scenarios Report

Prepared for:
Walla Walla Basin Watershed Council
810 S. Main St.
Milton-Freewater, OR 97862

Prepared by:
GeoSystems Analysis
1412 13th St., Suite 200
Hood River, OR 97031
www.gsanalysis.com

Walla Walla Basin Integrated Water Flow Model:

Piping and MAR Alternatives Management Scenarios Report

Citation

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MAJOR REVISIONS FROM DECEMBER 2015 REPORT ISSUE

- Urban water supply for Walla Walla, College Place, and Milton-Freewater is corrected in the Baseline Forward Model and “Current MAR-Piped” scenarios.
- Treated wastewater return flows routed to irrigation districts (in summer and fall) is corrected in the Baseline Forward Model and “Current MAR-Piped” scenarios.
- An additional scenario, “No MAR-Piped”, is added to the report and incorporated into the analysis of scenario results.
- Nomenclature used to reference scenarios has been revised, with “-Piped” added to the “Maximum MAR” and “Increased MAR” scenario titles and the “Pipe Installation” scenario renamed “Current MAR-Piped” scenario.

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EXECUTIVE SUMMARY

The Walla Walla Basin Watershed Council and Walla Walla Watershed Management Partnership have initiated the Walla Walla Basin Integrated Flow Enhancement Study, which seeks to enhance stream flows in the basin while maintaining the long-term viability of water supplies for irrigated agriculture, residential, and urban use. Through the study, water management scenarios are being evaluated to meet established streamflow and water supply goals.

In support of the Walla Walla Basin Integrated Flow Enhancement Study, GeoSystems Analysis, Inc. applied the calibrated surface water - groundwater numerical finite element model for the Walla Walla Basin to evaluate the potential impacts of proposed water management scenarios on hydrological conditions in the basin. The basin model utilizes the code Integrated Water Flow Model (IWFM), developed by the California Department of Water Resources Bay-Delta Office.

Four alternative management scenarios as well as the continuation of current management practices (i.e. baseline scenario) were evaluated. The scenarios were designed to evaluate the impact of converting canals into pipelines to eliminate canal seepage losses, which is coupled with the reduction of diversions from the Walla Walla River into irrigation networks; a practice referred to as water savings. In addition, the scenarios are designed to assess varying quantities of Managed Aquifer Recharge (MAR). The specific management alternatives evaluated were:

1) **Baseline Forward Model:** MAR applied at the 7 currently active sites within the basin at the current average rate of 9,014 acre-feet per year. No additional canals are replaced with pipelines.
2) **No MAR-Piped:** No MAR is applied. Gardena Farms Canal, White Canal, Lowden #2 Canal, and Garden City Canal are converted into pipelines.
3) **Current MAR-Piped:** MAR applied at the 7 currently active sites within the basin at current average rate of 9,014 acre-feet per year. Gardena Farms Canal, White Canal, Lowden #2 Canal, and Garden City Canal are converted into pipelines.
4) **Increased MAR-Piped:** MAR applied at 22 locations within the basin at the proposed rates, totaling 14,566 acre-feet per year. Gardena Farms Canal, White Canal, Lowden #2 Canal, and Garden City Canal are converted into pipelines.
5) **Maximum MAR-Piped:** MAR applied at 60 locations within the basin at the proposed rates totaling 24,201 acre-feet per year. Gardena Farms Canal, White Canal, Lowden #2 Canal, and Garden City Canal are converted into pipelines.

Model results for alternative management scenarios indicate that relative to the Baseline Forward Model, Walla Walla River flows at Nursery Bridge and Pepper Bridge would increase due to reduced diversions from the Walla Walla River into piped canals. MAR had a negligible effect on river flows at these locations. Walla Walla River flows at Beet Road increased under all management scenarios due to reduced diversions from the Walla Walla River, with greater flows predicted as MAR was increased. MAR was predicted to have the greatest influence at the two lower reference locations, McDonald Bridge and Touchet WA. Greater river flows were predicted with increasing levels of MAR. At the McDonald Bridge reference location the Maximum MAR-Piped and Increased MAR-Piped scenarios were predicted to produce respective flows averaging 12.6 and 10.1 cfs greater than the Baseline Forward Model from July through October. At the Touchet reference location simulated flows for the Maximum MAR-Piped and Increased MAR-Piped scenarios over the same time period were predicted to be, on average, 9.1 and 5.7 cfs greater than for the Baseline Forward Model, respectively.

The portion of the predicted flow increase that is due to in stream water savings is given by comparing the Current MAR-Piped scenario to the Baseline Forward Model. This difference peaks at the Beet Road reference location, where water saving have been applied for the White and Garden Farms canals but upstream of several diversions taken directly from the main channel. At this location the predicted increase in flow in the Current MAR-Piped scenario for July through September is 10.0 cfs. At the McDonald Road and Touchet reference locations the predicted increase in flow in the Current MAR-Piped scenario is 9.3 and 4.4 cfs, respectively.

The No MAR-Piped scenario can be compared to the other scenarios to determine how much of the predicted flow increase is a direct result of MAR. The difference between predicted flows in alternative management scenarios at the two upstream reference locations was negligible. At the Beet Road reference location the Maximum MAR-Piped, Increased MAR-Piped, and current MAR-Piped scenarios resulted in, on average, 4.0, 2.2, and 1.7 cfs more predicted flow than the No MAR-Piped scenario from July through October due solely to MAR. At the McDonald Road reference location the Maximum MAR-Piped, Increased MAR-Piped, and current MAR-Piped scenarios resulted in, on average, 6.0, 3.5, and 2.7 cfs more predicted flow than the No MAR-Piped scenario from July through October. At the Touchet reference location (furthest downstream) the Maximum MAR-Piped, Increased MAR-Piped, and Current MAR-Piped scenarios are predicted to yield on average 7.8, 4.2, and 3.1 cfs more flow than predicted in the No MAR-Piped scenario for the period from July through October.

The No MAR-Piped scenario was predicted to have lower flow than the Baseline Forward Model at the Touchet reference location by 2.1 and 0.8 cfs for August and September, respectively. This indicates that reduced groundwater return flows resulting from canal piping exceed in stream water savings for these months.

Management scenarios had a strong impact on predicted groundwater-surface water interactions in the model area. Conversion of canals to pipelines eliminated an important source of aquifer recharge and was predicted to lead to lower groundwater elevations and decreased groundwater return flows to streams. Groundwater elevation was predicted to increase with increased MAR, particularly in the areas where MAR sites were concentrated and increase groundwater return flows in both the Walla Walla River and off-channel tributaries. Groundwater return flows have potential ecological benefits in the form of increased summer flow rates, lower stream temperature, and improved riparian habitat.

Model area wide groundwater storage was predicted to decrease as a result of pipe installation in all but the Maximum MAR-Piped scenario as canal seepage was eliminated as an aquifer recharge source. The loss of groundwater recharge was increasingly compensated for as MAR increased, being 24,631, 8,900, and 5,117 acre-feet less than the Baseline Forward Model for No MAR-Piped, Current MAR-Piped, and Increased MAR-Piped scenarios, respectively. Under the Maximum MAR-Piped scenario the predicted groundwater storage was 7,260 acre-feet greater than the Baseline Forward Model. Maximum MAR-Piped scenario predicted increases in groundwater storage were in areas where MAR sites are most heavily concentrated; however declines in groundwater storage were predicted in the vicinity of the piped Gardena Farms Canal.

Management scenario results indicate that converting canals into pipelines is likely to have a negative impact on groundwater resources and limit the benefit of instream water savings if not combined with the increased application of MAR to enhance groundwater storage. Significant declines in groundwater and surface water resources are predicted if MAR were to be eliminated. Increasing MAR to include the currently proposed recharge sites (Increased MAR-Piped scenario) is predicted to approximately mitigate the impact of the simulated canal piping. Greater increases in MAR to incorporate 60 sites (Maximum MAR-Piped scenario) is predicted to provide more widespread benefits to both fish habitat and groundwater resources by allowing for significantly increased summer flows in the Walla Walla River and some tributaries while stabilizing aquifer storage. The use of MAR in the Walla Walla Basin is an opportunity to practice conjunctive management of groundwater and surface water resources to meet conflicting water demands in the basin.

1.0 INTRODUCTION

The Walla Walla Basin is located in a semi-arid region of Eastern Washington and Oregon (Figure 1), receiving an average of 17 inches of annual rainfall, primarily over the winter and spring months. Low summer flows in the Walla Walla River are known to be limiting to fish passage and are associated with seasonally high stream temperatures that degrade fish habitat (Mendel et al., 2005). An agreement between local irrigation districts and federal regulators in 2000 established a minimum flow of 25 cubic feet per second (cfs) in the Walla Walla River below the Nursery Bridge, with the objective of promoting viable habitat for endangered fisheries (Mahoney et al., 2011). However, flows below 10 cfs have been recorded at gauges downstream of this point.

The Walla Walla Basin Watershed Council (WWBWC) and Walla Walla Watershed Management Partnership have initiated the Walla Walla Basin Integrated Flow Enhancement Study, which seeks to enhance stream flows in the basin while maintaining the long-term viability of water supplies for irrigated agriculture, residential, and urban use. Through the study, water management scenarios are being evaluated to meet established streamflow and water supply goals.

In support of the Walla Walla Basin Integrated Flow Enhancement Study, GeoSystems Analysis, Inc. (GSA), in a collaborative effort with the Walla Walla Basin Watershed Council (WWBWC), developed a calibrated surface water - groundwater numerical finite element model for the Walla Walla Basin as a tool for evaluating the potential impacts of proposed water management scenarios on hydrological conditions in the basin. The basin model was developed utilizing data sources to define basin geology, precipitation, groundwater and surface water conditions, land use classification, agricultural and urban demand, and soil properties. The model boundary (Figure 1) was defined by the areal extent of the alluvial basin deposits and encompasses the land surface and five sedimentary geologic units that overlay the Columbia River Basalt formation within the Walla Walla Basin. Overall, the model encompasses 239 mi^2 and extends to a maximum depth of 940 ft below ground surface. The model area was divided into 12 sub-regions based on physical characteristics or management entities, allowing for focused evaluation of water use and available resources for a sub-region. The model sub-regions are each assigned a name and number for reference purposes and are presented in Table 1 and Figure 1. A detailed description of the Walla Walla Basin model, including model development and calibration, is provided in GSA (2015).

This report presents model predicted surface water and groundwater conditions in the basin resulting from three alternative management scenarios as well as the continuation of current management practices (i.e. baseline scenario). The scenarios are designed to evaluate the impact of converting canals into pipelines to eliminate canal seepage losses, which is coupled with the reduction of diversions from the Walla Walla River into irrigation networks; a practice referred to as water savings. In addition, the scenarios are designed to assess increasing quantities of Managed Aquifer Recharge (MAR). MAR is currently applied in the basin to enhance groundwater resources in the underlying alluvial aquifer. Each model scenario is feasible given the water resources within the basin (Henry et al, 2013). A full description of the alternative management scenarios is provided in Section 2.0. A comparative review of alternative management scenarios predicted influence on surface water flows and groundwater storage are provided in Section 3.0.

Table 1. Walla Walla Basin model sub-region name and number

Sub-region Number	Name
1	Upper Walla Walla River
2	Lower Walla Walla River
3	Birch Creek Drainage-Eastside Pipeline
4	Walla Walla River Irrigation District
5	HBDIC Irrigation District
6	Pine Creek Drainage-Gardena-HBDIC
7	Mud Creek-Lowden
8	Yellowhawk Creek Drainage
9	Walla Walla-College Place
10	Dry Creek (WA) Drainage
11	Gardena Farms
12	Lower Touchet River

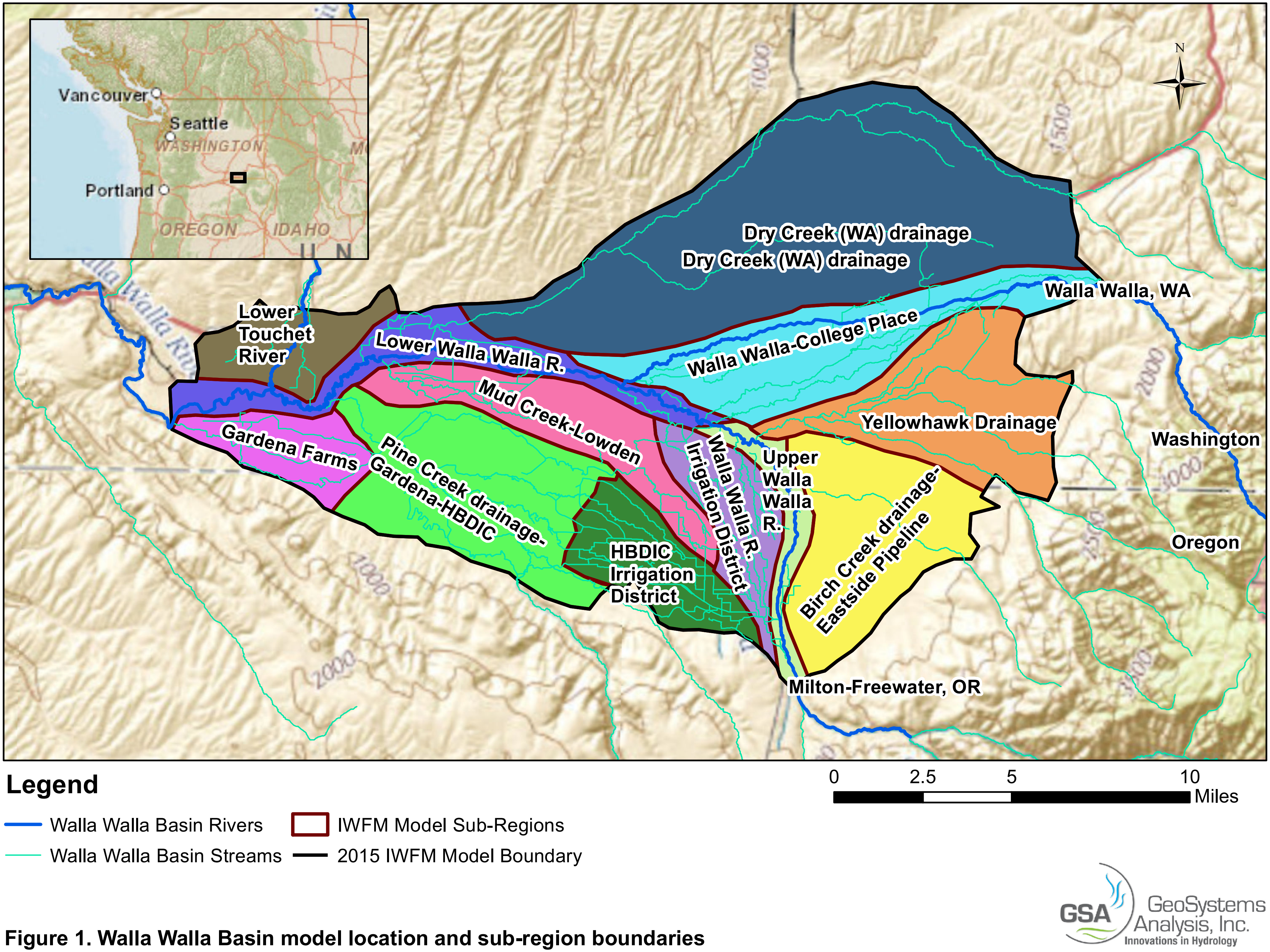

Figure 1. Walla Walla Basin model location and sub-region boundaries

2.0 MODEL SCENARIOS

Five management scenarios were incorporated into the Walla Wall Basin model, representing a range of MAR applications and the conversion of unlined canals into pipelines. Each model scenario was simulated for ten years using a daily time step. A ten year model period was selected based on the model attaining equilibrium conditions over this period. Model initial conditions were taken to be the simulated conditions at the end of the last day of the calibration model (end of December 31, 2014).

Daily variable conditions such as precipitation, evapotranspiration (ET), stream inflows, groundwater boundary conditions, and urban water requirements were taken to be the daily average of the calibrated model inputs for each day of the year. The daily average model inputs were applied over the ten year forward model as an annually repeating cycle of daily data. The four model scenarios used the same daily variable inputs, allowing for simulated differences in scenario results to be solely attributable to management practices under scenario conditions.

MAR is currently applied at seven locations in the basin. These are collectively referred to as the ‘Active MAR Locations’. An additional fifteen locations have been selected for MAR development with licensing applications that are currently in the review process. These are collectively referred to as the ‘Proposed MAR Locations’. An additional 38 locations have been identified as having potential for MAR development based on location and current land use. There are no current efforts to develop MAR at these locations. These are collectively referred to as ‘Potenitial MAR Locations’. Table 2 shows MAR sites used in each of the model scenarios, the operational time period for each site, and total amount of water applied annually.

Table 2. Active MAR sites and recharge volumes applied in the baseline and management alternatives models

Site	Recharge Volume (acre-feet per year)			
	Current MAR	Increased MAR	Maximum MAR	Operational Time Period
Total MAR	**9013.8**	**14566.2**	**24200.9**	**Annually**
Anspach	1005.1	1005.1	1005.1	11/1 - 1/31 & 3/1 - 5/15
Barrett	1005.1	1005.1	1005.1	11/1 - 1/31 & 3/1 - 5/15
Birch Creek	0.0	0.0	342.4	12/1 - 4/15
Chuckhole	0.0	183.9	183.9	11/1 - 11/30 & 3/15 - 5/15
Chuckhole North	0.0	0.0	503.4	11/1 - 1/31 & 3/1 - 5/15
County Road	0.0	841.6	841.6	11/1 - 1/31 & 3/1 - 5/15
Detour	0.0	211.6	273.7	12/1 - 4/15
East Locust	0.0	183.9	183.9	11/1 - 11/30 & 3/15 - 5/15
East Touchet	0.0	0.0	273.7	12/1 - 4/15
Eastside Field	0.0	0.0	183.9	11/1 - 11/30 & 3/15 - 5/15
Eastside Pit	0.0	0.0	183.9	11/1 - 11/30 & 3/15 - 5/15
Frog Hollow	0.0	0.0	183.9	3/1 - 5/30
Fruitvale Rd	0.0	183.9	183.9	11/1 - 11/30 & 3/15 - 5/15
Gallagher	0.0	1340.1	1340.1	11/1 - 1/31 & 3/1 - 5/15
Garden City	0.0	0.0	273.7	12/1 - 4/15
Gardena Ditch	0.0	0.0	183.9	3/1 - 5/30
Grant Road	0.0	0.0	183.9	11/1 - 11/30 & 3/15 - 5/15
Hall-Wentland (HW)	183.9	0.0	183.9	11/1 - 11/30 & 3/15 - 5/15
Huffman	0.0	0.0	183.9	11/1 - 11/30 & 3/15 - 5/15
Hwy 11	0.0	0.0	276.2	11/1 - 11/30 & 3/15 - 5/15
Hyline	0.0	0.0	183.9	11/1 - 11/30 & 3/15 - 5/15
Johnson	5033.5	5033.5	5033.5	11/1 - 1/31 & 3/1 - 5/15
Last Chance Road	0.0	363.6	363.6	11/1 - 4/30
LeFore	0.0	183.9	183.9	11/1 - 11/30 & 3/15 - 5/15
Locher North	0.0	0.0	183.9	3/1 - 5/30
Locher Rd	735.4	735.4	735.4	3/1 - 5/30
Lowden Gardena Road	0.0	0.0	273.7	12/1 - 4/15
Lower Hyline	0.0	0.0	183.9	11/1 - 11/30 & 3/15 - 5/15
Lower Touchet	0.0	0.0	273.7	12/1 - 4/15
McDonald Rd	0.0	238.6	545.8	11/1 - 4/30

Table 2. Active MAR sites and recharge volumes applied in the baseline and management alternatives models (continued)

Site	Recharge Volume (acre-feet per year)			
	Current MAR	Increased MAR	Maximum MAR	Operational Time Period
Mill Creek	0.0	0.0	273.7	12/1 - 4/15
Mud Creek	0.0	183.9	183.9	11/1 - 11/30 & 3/15 - 5/15
Mud Creek Stateline	0.0	0.0	731.3	11/1 - 4/30
Nibler	0.0	0.0	183.9	3/1 - 5/30
NW Umapine[1]	0.0	841.6	841.6	11/1 - 1/31 & 3/1 - 5/15
Old Milton Hwy	0.0	0.0	276.2	11/1 - 11/30 & 3/15 - 5/15
Pine Creek	0.0	0.0	183.9	3/1 - 5/30
Rainville	0.0	0.0	367.7	3/1 - 5/30
Ruby	0.0	0.0	138.1	11/1 - 11/30 & 3/15 - 5/15
SE Umapine	0.0	0.0	167.5	11/1 - 1/31 & 3/1 - 5/15
Stateline	0.0	0.0	183.9	11/1 - 11/30 & 3/15 - 5/15
Stiller Pond	547.5	547.5	547.5	12/1 - 4/15
Sunquist	0.0	183.9	183.9	11/1 - 11/30 & 3/15 - 5/15
SW Umapine	0.0	0.0	503.4	11/1 - 1/31 & 3/1 - 5/15
Triangle Road	0.0	183.9	183.9	11/1 - 11/30 & 3/15 - 5/15
Triangle Station	0.0	92.3	92.3	11/1 - 11/30 & 3/15 - 5/15
Trolley Lane	0.0	183.9	183.9	11/1 - 11/30 & 3/15 - 5/15
Trumbull	503.4	503.4	503.4	11/1 - 1/31 & 3/1 - 5/15
Upper Cottonwood	0.0	0.0	273.7	12/1 - 4/15
Upper Eastside	0.0	0.0	276.2	11/1 - 11/30 & 3/15 - 5/15
Upper Fruitvale	0.0	0.0	183.9	11/1 - 11/30 & 3/15 - 5/15
Upper Pine Creek	0.0	0.0	183.9	11/1 - 11/30 & 3/15 - 5/15
Upper Touchet	0.0	0.0	273.7	12/1 - 4/15
Walsh Creek	0.0	0.0	183.9	3/1 - 5/30
West Locust	0.0	0.0	183.9	11/1 - 11/30 & 3/15 - 5/15
West Ringer Road	0.0	335.8	335.8	11/1 - 1/31 & 3/1 - 5/15
West Touchet	0.0	0.0	273.7	12/1 - 4/15
WLWW	0.0	0.0	183.9	11/1 - 11/30 & 3/15 - 5/15
Woodward	0.0	0.0	183.9	3/1 - 5/30

[1] The NW Umapine MAR site was activated in 2014, after the model development period used for the Current MAR scenario.

2.1 Baseline Forward Model

The baseline forward model scenario is a forward projection of current basin management practices as implemented in the calibration model (GSA, 2015). This scenario provides the baseline to which other scenarios can be compared to evaluate the impact of alternative management practices. Canals that are currently unlined remain unlined and the current minimum flow target of 25 cfs in the Walla Walla River is maintained. Water deliveries to the seven active MAR sites (Table 2) are at rates provided by the WWBWC and are based on current practices. For this scenario the total annual allocation of MAR was 9,014 acre-feet.

2.2 No MAR-Piped

Channel seepage over much of the canal network causes inefficiency in the delivery of irrigation water. Ongoing efforts to convert permeable canals into pipelines have improved irrigation efficiency by eliminating canal seepage losses. The eliminated canal seepage water volumes (i.e. seepage water savings) are left in the Walla Walla River to enhance summer flows. However, the reduction in channel seepage deprives the underlying aquifers of an important source of recharge. Previous studies predicted that large scale conversion from permeable canals to pipelines resulted in reduced groundwater storage within the alluvial aquifer system (Scherberg, 2012; Scherberg et al., 2014).

The No MAR-Piped scenario predicts groundwater and surface water conditions within the model area in response to conversion of canals to pipelines in the absence of MAR. Figure 2 shows the location of existing canals and pipelines in the model area, and highlights the canals that are converted into pipelines in this and the following three model scenarios. Canals converted to pipelines include the Gardena Farms Canal, White Canal, Lowden #2 Canal, and Garden City Canal.

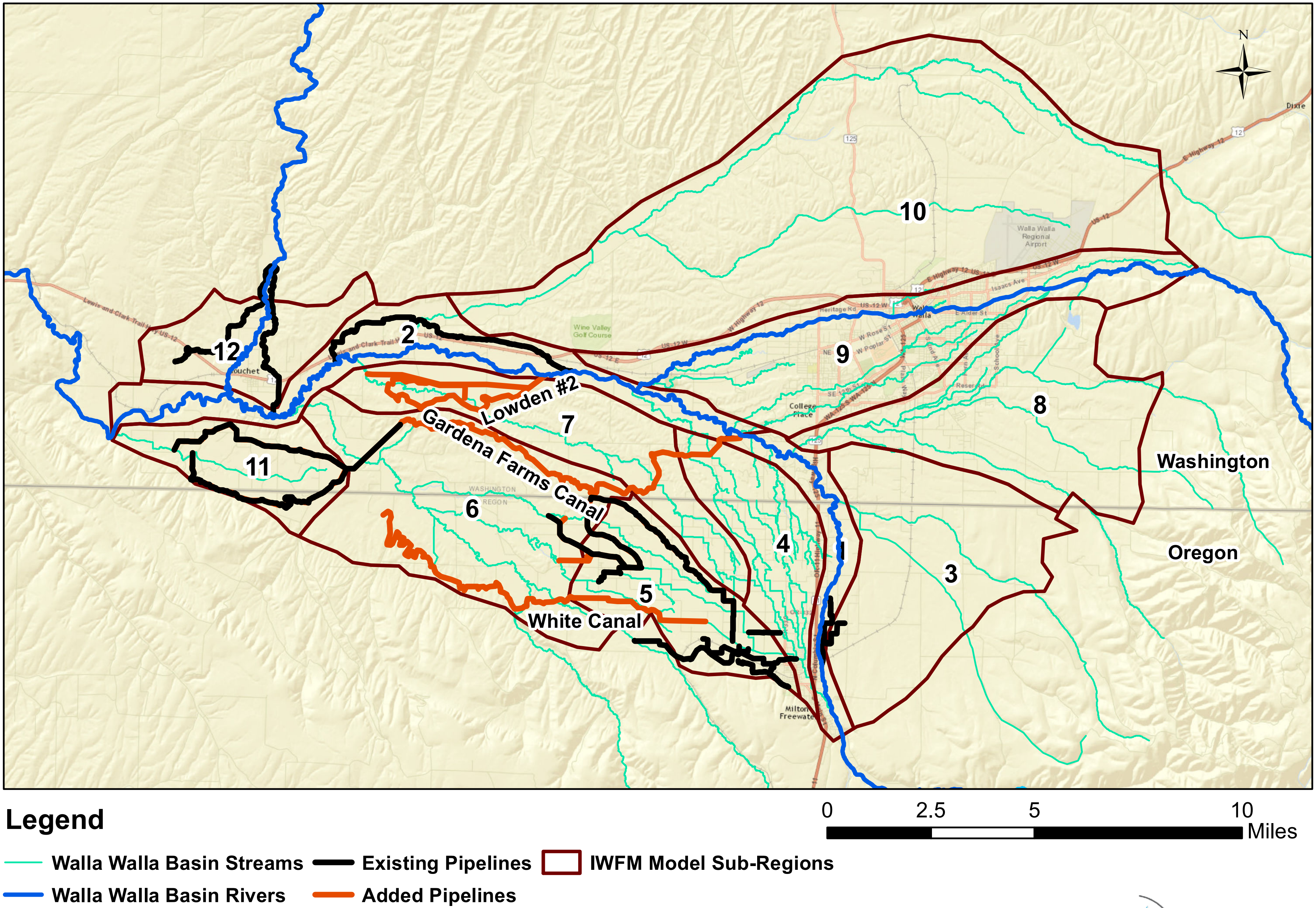

Figure 2. Existing pipelines within the model area and canals that are converted into pipelines in the Pipe Installation scenario

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Two of the primary canal systems in the model area, the White Canal operated by the Hudson Bay District Improvement Company (HBDIC) and the Gardena Farms Canal operated by the Gardena Farms Irrigation District (GFID), are known to lose significant quantities of water due to channel seepage. The impact of converting these canals into pipelines is evaluated in this scenario. Surface water left instream as a result of seepage water savings was determined from the relationship between canal flow rate and seepage losses.

Seepage losses through the Gardena Farms Canal channel bed are more than 20 cfs when the canal is operating near its peak flow rate (Baker, 2014). Measured seepage rates as a function of Gardena Farms Canal flow are presented in Figure 3 (Patten, 2015) along with the regression equation describing this relationship. Water left in stream as a result of Gardena Farms Canal seepage water savings was estimated by the fitted regression equation:

$$Seepage\ Water\ Savings = 7.1678 \times e^{0.0092 \times Gardena\ Canal\ Flow} \qquad \text{Equation 1}$$

Where Gardena Farms Canal flow is the baseline model canal flow, as determined by daily average flow over the model development period (2007-2013).

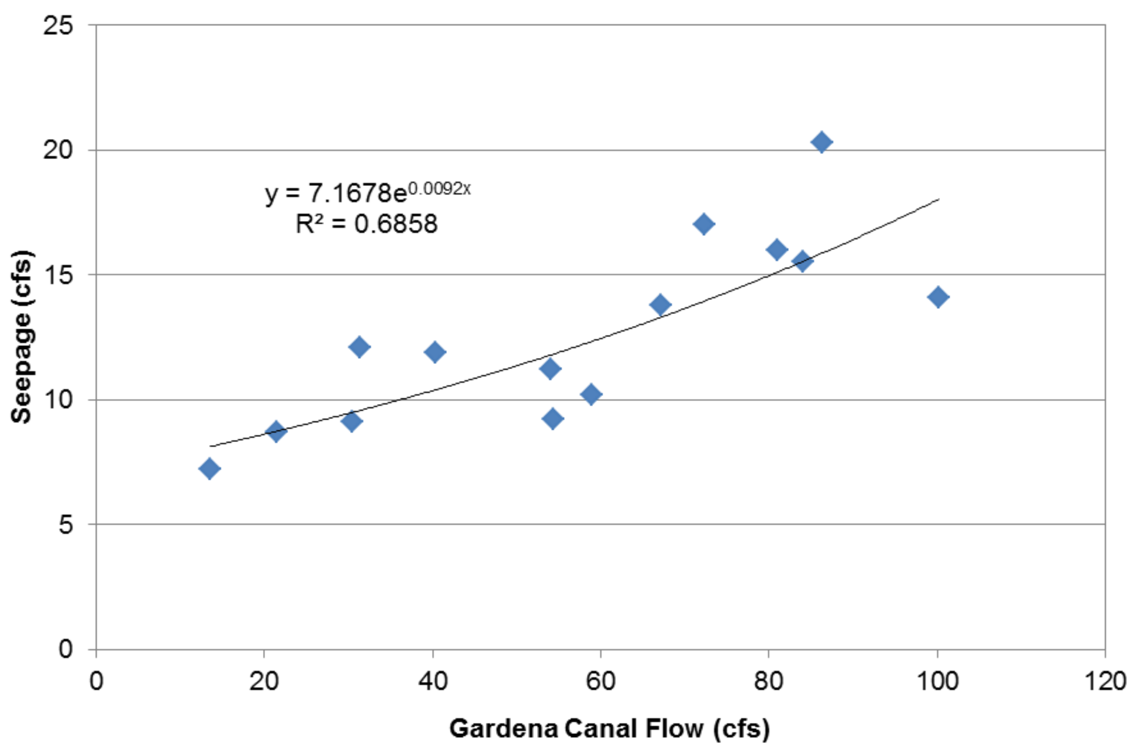

Figure 3. Flow rate versus seepage in the Gardena Farms Canal

Seepage for the White Canal was calculated between gauge s-401 at the head of the canal and the downstream gauge s-413. This canal segment represents 1.1 miles of the total 10.7 mile canal length and is in a relatively high seepage loss area. Downstream of gauge s-413 the White Canal is estimated to lose approximately one cfs per mile (personal communication, Jon Brough, 7/9/2015). Total White Canal seepage losses are estimated to be approximately 11.6 cfs when flow rates are near their maximum levels (personal communication, Jon Brough, 7/9/2015). Seepage was estimated for the White Canal by averaging the measured losses between s-401 and s-413 for 10 cfs flow increments and multiplying by a factor of 1.5 to account for the full canal length, while factoring for a lower loss rate in the downstream portion of the canal. Water left in stream as a result of White Canal seepage water savings was estimated as a function of baseline model White Canal flow in accordance with Table 3.

Table 3. White Canal seepage water savings applied in model scenarios that include pipe installation

White Canal Flow Range in Baseline Model (cfs)	Seepage Water Savings (cfs)
0 to 5	0.0
5 to 20	3.3
20 to 30	6.2
30 to 40	9.7
40 to 50	12.0

The Lowden #2 Canal is smaller than the Gardena and White Canals. To account for seepage water savings from this canal as a result of piping, the simulated withdrawals from the Walla Walla River into Lowden #2 were reduced by 15 percent. The resulting reductions are in line with the 0.5 to 3.3 cfs seepage losses reported by Patten (2014). The Garden City Canal, which branches off of Lowden #2, is also proposed to be piped; however WWBWC seepage analyses have not found that this canal loses significant amounts water to seepage on a net basis (Patten, 2014). As such, no water savings are applied for piping the Garden City canal.

2.3 Current MAR-Piped

The WWBWC MAR program began in 2004 and since that time has gradually expanded in the number of MAR sites and the amount of water allocated for MAR. MAR has been demonstrated to increase groundwater storage, thereby increasing groundwater available to irrigators while also increasing groundwater return flows to some streams (Scherberg, 2012). The Current MAR-Piped scenario maintains current MAR operations as they are applied in the Baseline Forward Model. Canals converted to pipelines in this model scenario are the same as in the No MAR-Piped scenario, and are highlighted in Figure 2. The Current MAR-Piped scenario predicts groundwater and surface water conditions within the model area in response to conversion of canals to pipelines while maintaining MAR at its current level.

2.4 Increased MAR-Piped

The impact of the current MAR program is primarily observed in the proximity of the recharge sites (Patten and Keller, 2015). It is hypothesized that more widely distributed MAR sites will have a more widespread effect on the groundwater resources, and possibly surface water resources, in the basin (Scherberg et al., 2014).

The Increased MAR-Piped scenario uses the same scheme as previous piped scenarios for flow reductions into the Gardena, White, and Lowden #2 canals due to conversion of canals into pipelines. In the increased MAR-Piped scenario the seven active MAR sites from the Current MAR-Piped scenario continue at their current operational scheme in addition to water being delivered to the fifteen proposed recharge sites shown in Figure 4. Water delivery rates to the MAR sites used in this scenario were specified by WWBWC personnel and are provided in Table 2. Under this scenario the total annual allocation of water applied to the MAR sites was 14,566 acre-feet.

2.5 Maximum MAR-Piped

The Maximum MAR scenario uses the same assumptions about pipe installation and diversion rates into the Gardena Farms Canal, White Canal, and Lowden #2 as previous piped scenarios; however water is delivered to all 60 MAR sites (active, proposed, and potential) that are shown in Figure 4 at the rates specified in Table 2. Potential MAR sites are locations that have been identified by the WWBWC where MAR is likely to be feasible and beneficial. This scenario is conceived as a means of predicting the outcome of a fully realized MAR development. In this scenario the total annual application of MAR for all 60 sites was 24,201 acre-feet.

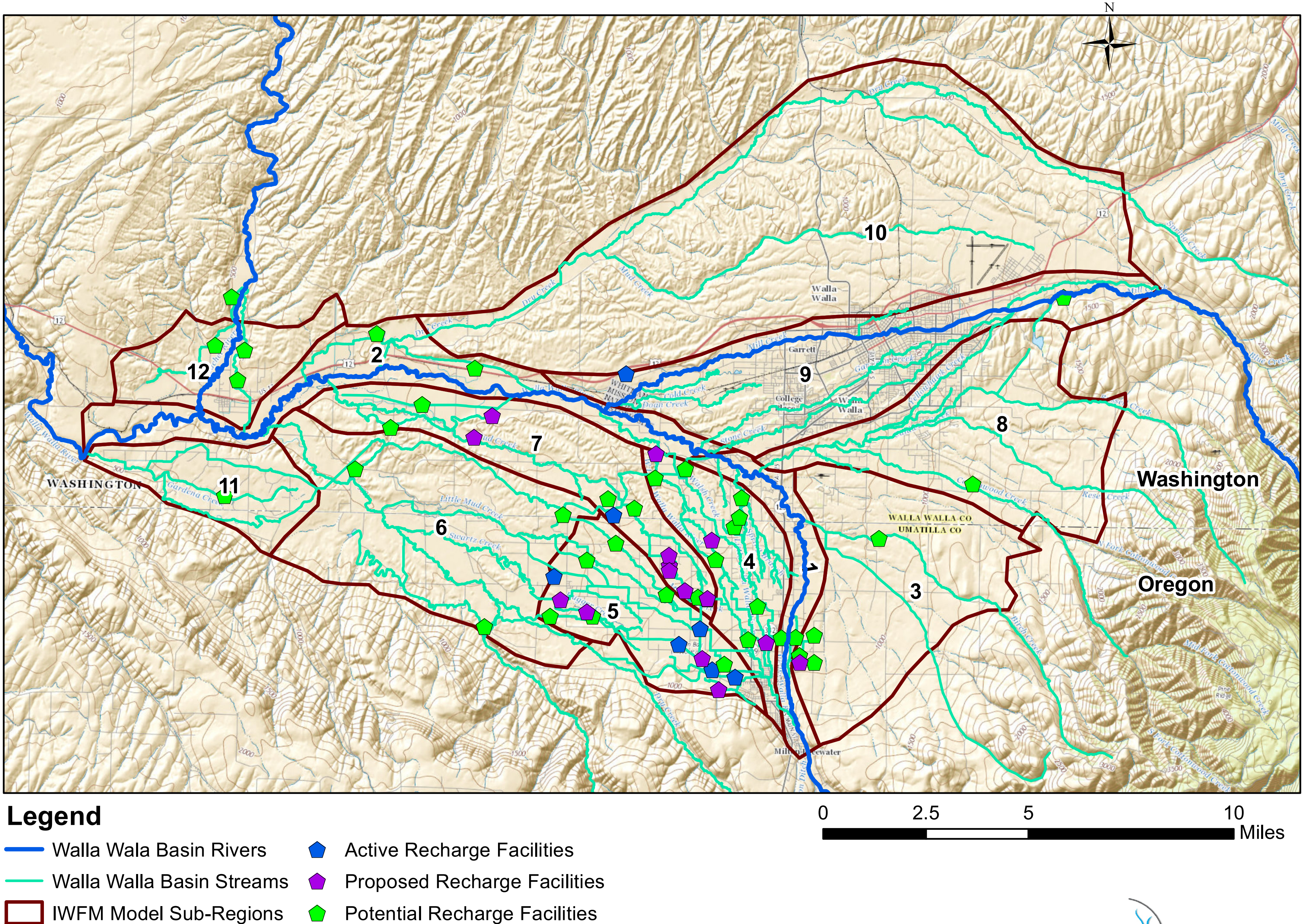

Figure 4. Locations of active, proposed, and potential MAR sites within the Walla Walla Basin model area

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3.0 RESULTS

The results of the Baseline Forward Model and the four alternative management scenarios described in the preceding section are presented below with focus on low flow conditions in the Walla Walla River, groundwater storage for agricultural and ecological benefits, and how available resources can be used to meet agricultural water requirements. Scenario results were evaluated in comparison to the Baseline Forward Model, and in terms of changes in resource distribution that are predicted to occur. Simulation results were evaluated for the twelve individual sub-regions shown in Figure 1 and for the model area as a whole.

3.1 Surface Water

3.1.1 Walla Walla River Flows

Five locations along the Walla Walla River were selected by the WWBWC as reference points for simulated surface water flows and are shown in Figure 5. These reference locations were chosen in part because at each location there is a stream gauge that allows managers to determine if flow targets are being met.

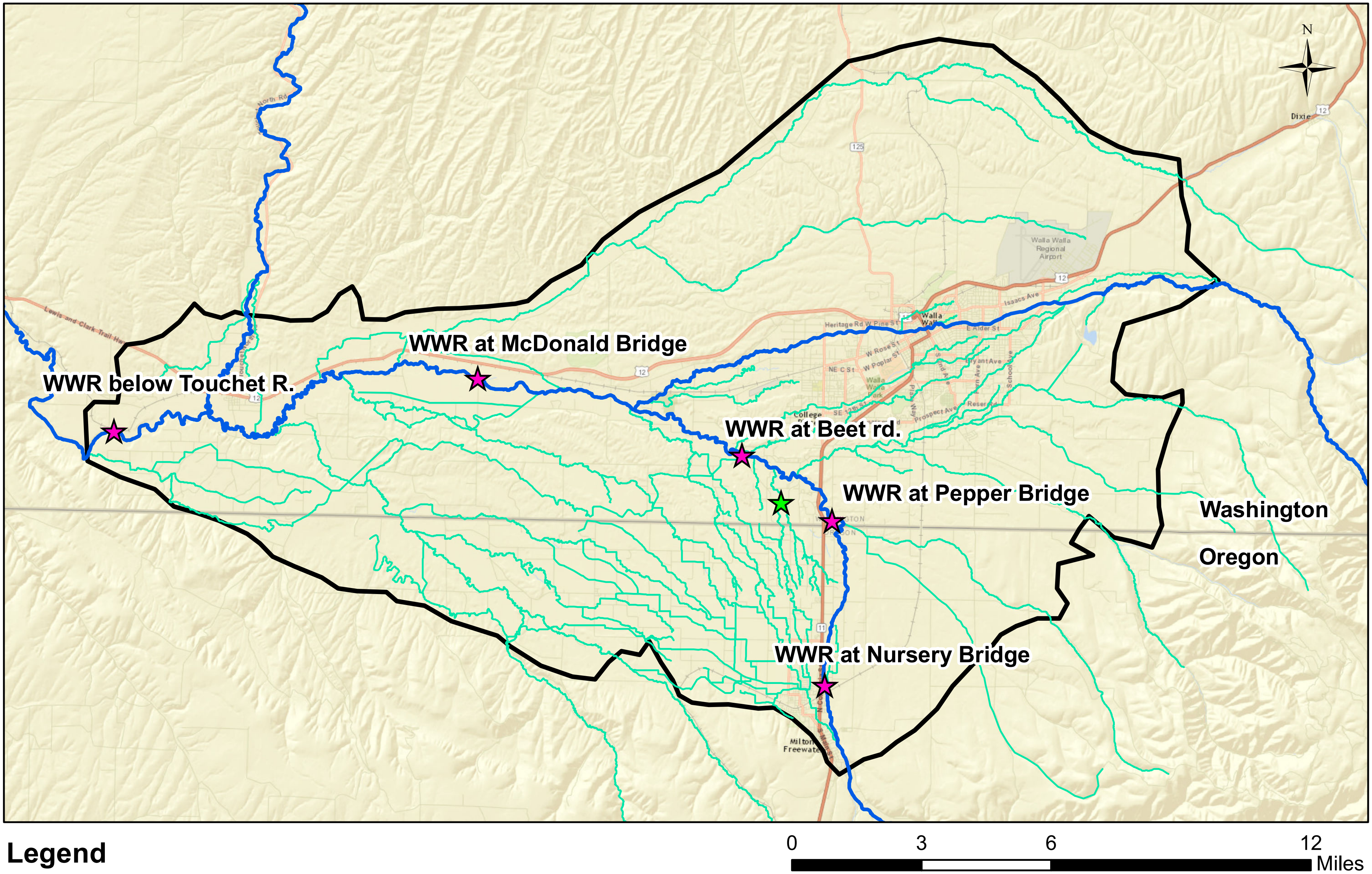
Figure 6 through Figure 10 show predicted flows at the reference locations from July through October in order of the upper stream location at Nursery Bridge, to the furthest downstream location at the USGS gauge near Touchet WA. The latter of these, referred to as the Touchet reference location, is located on the Walla Walla River a short distance downstream from its confluence with the Touchet River. Discussion of predicted flows at these locations is focused on the July through October time period because it encompasses the low flow portion of the year when habitat may be imperiled and irrigation supply is limited.

Hydrographs for predicted flows for management scenarios with pipe installation were generally greater than those for the baseline forward model due to water savings applied as diversions from the Walla Walla River were decreased (Figure 6 through Figure 10). There was negligible difference in predicted flow at Nursery Bridge for the piped scenarios because the effect of MAR was not apparent at the upstream extent of the model area (Figure 6). Predicted flows at Nursery Bridge ranges from 2.8 cfs to 11.5 cfs greater than the Baseline Forward Model from July through October. Predicted flows at Pepper Bridge ranged from 2.1 cfs to 12.5 cfs greater than the Baseline Forward Model from July through October, with flow predicted to increase slightly with increasing MAR (Figure 7). .

At Beet Road the impact of water saving was at its peak among the reference locations because it is downstream from the diversions for the White and Gardena Farms canals but upstream from several irrigation diversion from the mainstem river that increase when more water is available above the minimum flow threshold. The influence of increased MAR becomes more pronounced, with greater predicted flow as MAR increases (Figure 8). Predicted flows for the Increase MAR-Piped and Maximum MAR-Piped scenarios ranged from 3.3 cfs to 25.7 cfs greater than the Baseline Forward Model scenario from July through October. Current MAR-Piped scenario predicted flows were between 2.9 cfs and 22.9 cfs greater than flow predicted for the Baseline Forward Model scenario, the increase in this case being due to water savings alone. No MAR-Piped scenario predicted flows ranged from 1.5 cfs to 20.1 cfs greater than flow predicted for the Baseline Forward Model scenario. The predicted increase in flow with increased MAR is due to increased groundwater return flow to rivers and streams resulting from increase groundwater elevations.

Predicted summer flows at McDonald Bridge (Figure 9) for the Maximum MAR-Piped scenario were between 5.3 cfs and 26.7 cfs greater than the Baseline Forward Model. The Increased MAR-Piped scenario simulated flow rates were between 3.1 cfs and 23.7 cfs greater than the Baseline Forward Model over the July through October time period. Current MAR-Piped scenario predicted flows were between 2.5 cfs and 22.6 cfs greater than flow predicted for the Baseline Forward Model scenario. No MAR-Piped scenario predicted flows ranged from being similar to Baseline Forward Model predicted flows to 18.6 cfs greater than flow predicted for the Baseline Forward Model scenario The similar flow predictions for the No MAR-Piped scenario and the Baseline Forward Model indicate that without MAR late summer water savings from pipe installation are offset by reduced groundwater return flows following piping.

The Touchet reference point is also subject to low summer flows. Predicted summer flows at this location are significantly influenced by increasing MAR volume (Figure 10). Due to higher October flows at this location Figure 10 does not include October in order to highlight differences in simulated flows when flows are at their lowest levels. The greatest flows were predicted for the Maximum MAR-Piped scenario. with flow rates between 3.5 cfs and 16.1 cfs greater than the Baseline Forward Model over the July through September time period. Predicted flow rates for the Increased MAR scenario ranged from 0.7 cfs to 11.9 cfs greater than the Baseline Forward Model for the same time period. Current MAR-Piped scenario predicted flows ranged from 0.2 cfs less to 10.5 cfs greater than predicted flows for the Baseline Forward Model scenario over this time period. In the No MAR-Piped scenario, model predicted flows were, on average, 1.5 cfs greater than predicted flows in Baseline Forward Model for July; however in August and September predicted flows at the Touchet reference location were on average 1.2 cfs lower than in the Baseline Forward Model. Model results indicate that in the lower model area the loss of recharge through unlined canals due to piping, and resulting reduced groundwater return flows to the Walla Walla River and its tributaries, exceeds pipeline water savings for much of the critical low flow period. The application of MAR is predicted to compensate for lost groundwater recharge from canal seepage.



Legend

- Walla Walla Basin Rivers
- Walla Walla Basin Streams
- Walla Walla River Gauges
- East Little Walla Walla Gauge
- IWFM Model Boundary

Figure 5. Locations within the model area used for analyzing simulated flow conditions in the Walla Walla River

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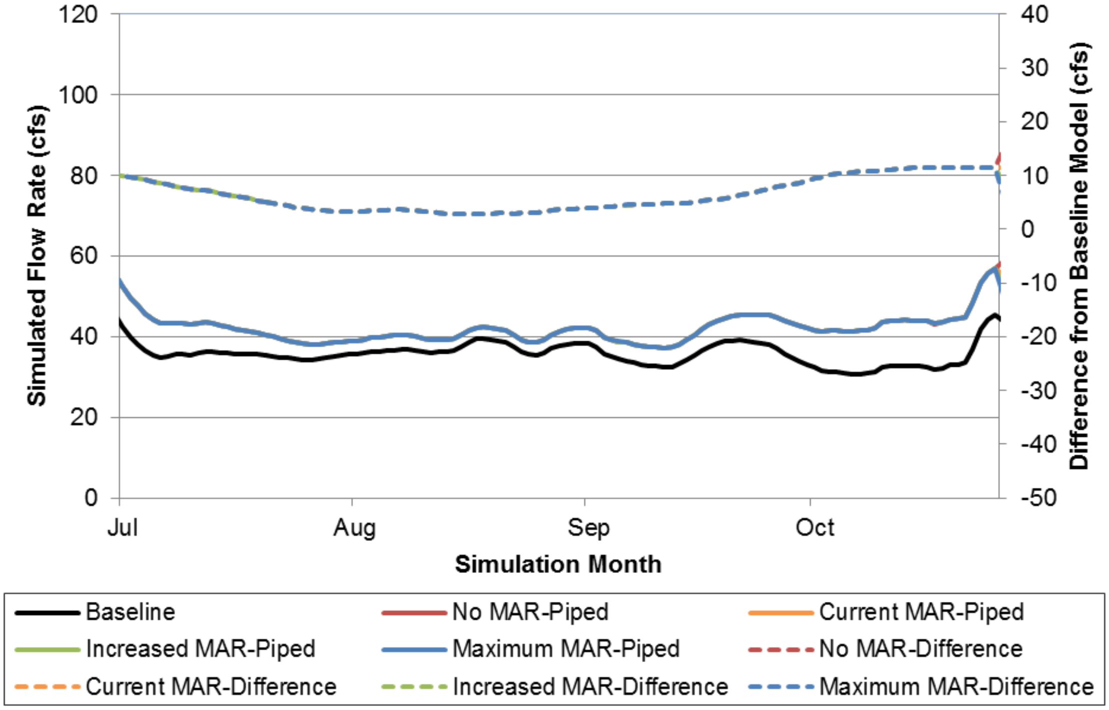

Figure 6. Simulated Walla Walla River flow rates at Nursery Bridge and difference from the Baseline Forward Model scenario for July through October (Dashed lines are plotted on top of each other at this location)

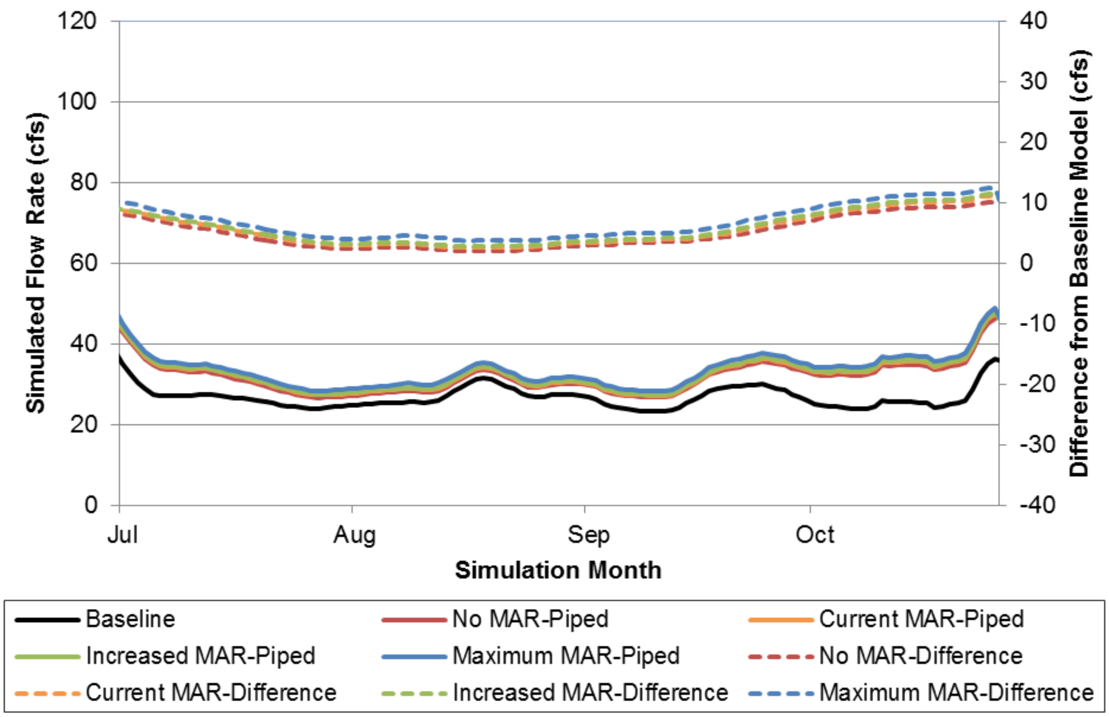

Figure 7. Simulated Walla Walla River flow rates at Pepper Bridge and difference from the Baseline Forward Model scenario for July through October

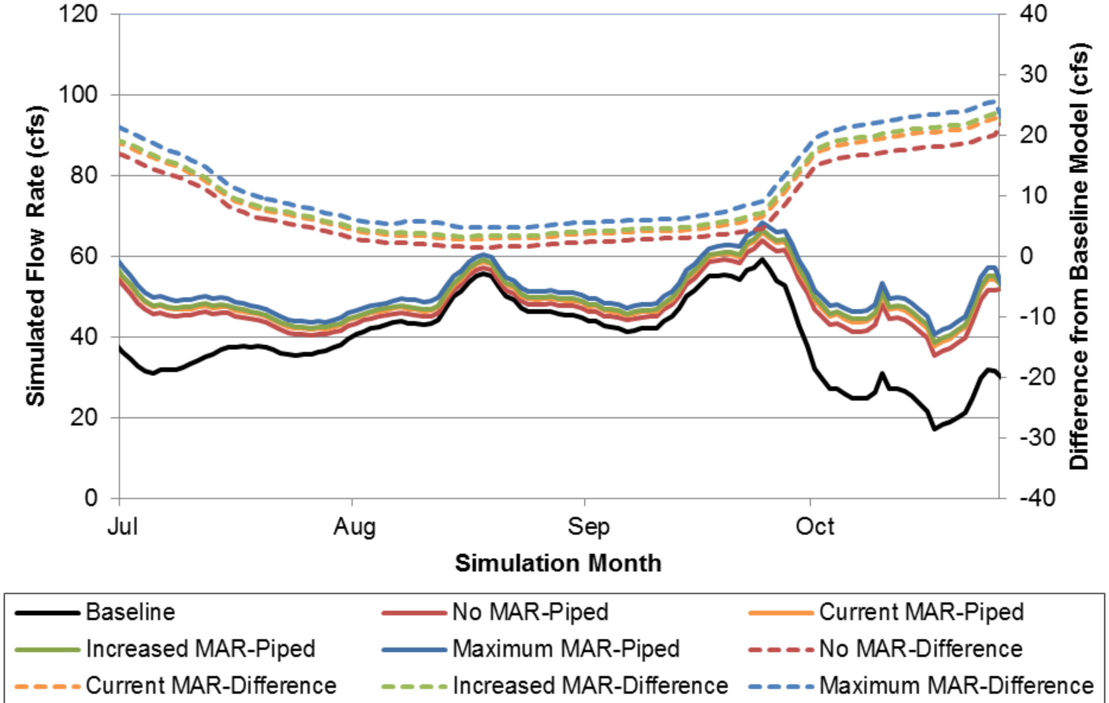

Figure 8. Simulated Walla Walla River flow rates at Beet Road and difference from the Baseline Forward Model scenario for July through October

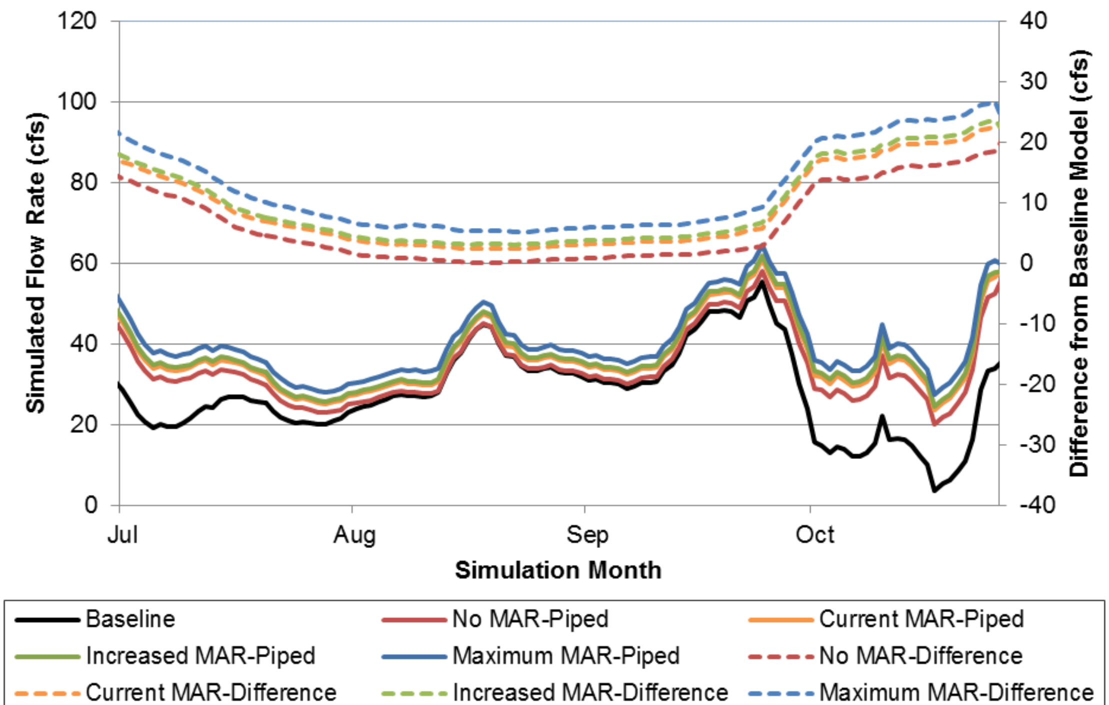

Figure 9. Simulated Walla Walla River flow rates at McDonald Bridge and difference from the Baseline Forward Model scenario for July through October

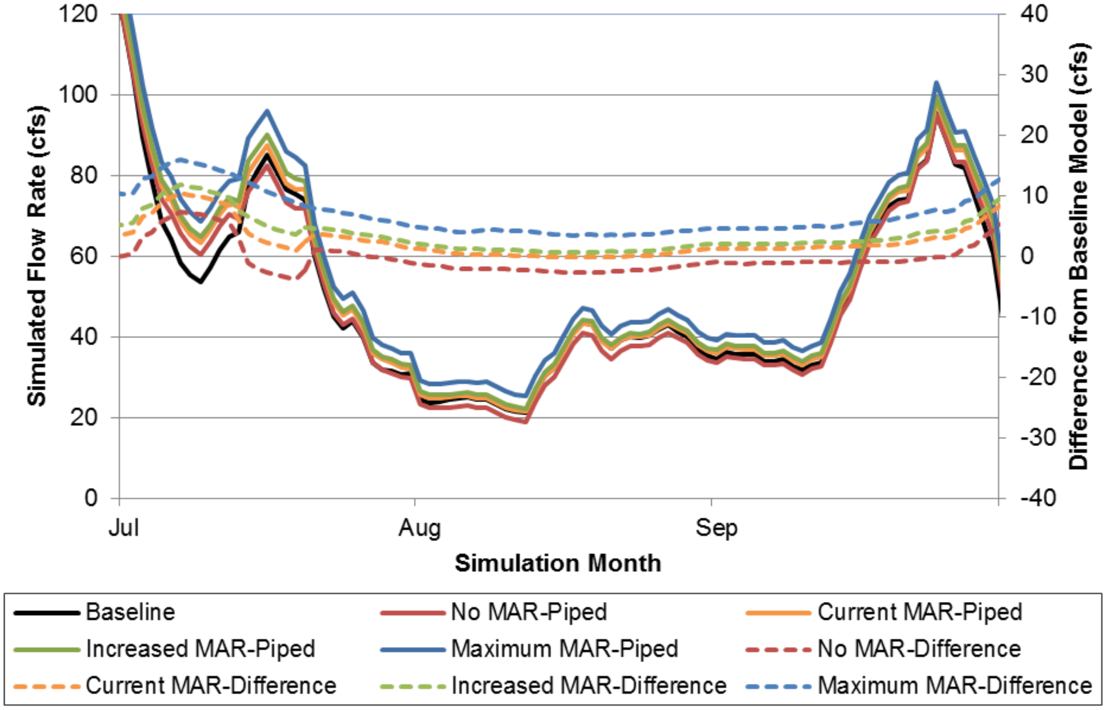

Figure 10. Simulated Walla Walla River flow rates downstream of the confluence with the Touchet River and difference from the Baseline Forward Model scenario for July through September

Figure 11 summarizes management scenario differences in monthly average flow relative to the Baseline Forward Model during the low flow season (July through October). Positive value indicates flow that is greater than predicted in the Baseline Forward Model. Predicted flows under all management scenarios were greater than those in the Baseline Forward Model, with the exception of the No MAR-Piped scenario in August and September. The change in flow at the two upstream reference locations, Nursery Bridge and Pepper Bridge, was similar between the four alternative management scenarios, reflecting instream water savings associated with pipe installation. Greater differences in flow rates were predicted between the four alternative management scenarios moving downstream, with the greatest flow consistently predicted for the Maximum MAR-Piped scenario.

The No MAR-Piped scenario can be compared to the other piped scenarios to determine how much of the predicted flow increase is a direct result of MAR. The difference in predicted flows between the No MAR-Piped scenario and other piped scenarios was negligible at the two upstream reference locations (Nursery Bridge and Pepper Bridge). At the Beet Road reference location the Maximum MAR-Piped, Increased MAR-Piped, and Current MAR-Piped scenarios resulted in, on average, 4.0, 2.2, and 1.7 cfs more predicted flow than the No MAR-Piped scenario from July through October. At the McDonald Road reference location the Maximum MAR-Piped, Increased MAR-Piped, and Current MAR-Piped scenarios resulted in, on average, 6.0, 3.5, and 2.7 cfs more predicted flow than the No MAR-Piped scenario from July through October. At the Touchet reference location (furthest downstream) the Maximum MAR-Piped, Increased MAR-Piped, and Current MAR-Piped scenarios were predicted to yield on average 7.8, 4.2, and 3.1 cfs more flow than predicted in the No MAR-Piped scenario for the period from July through October. Overall, the influence of MAR on flows increased from the furthest upstream (Nursery Bridge) to the furthest downstream (Touchet) location.

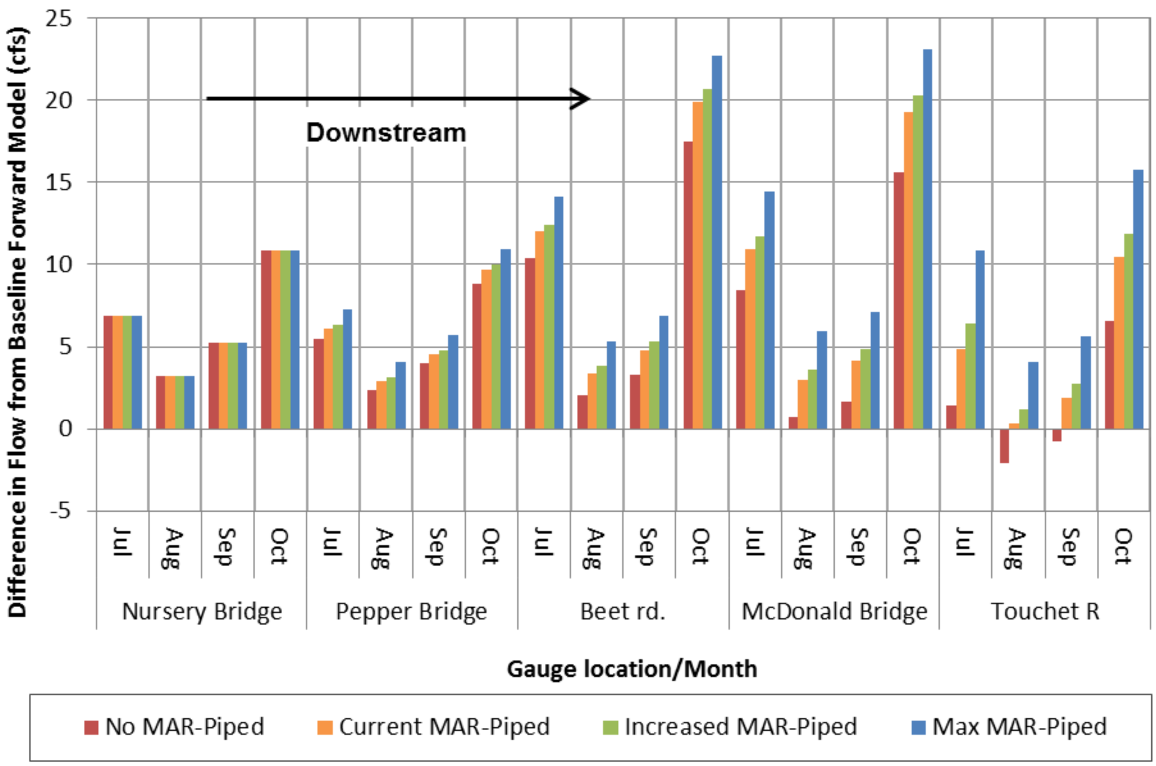

Figure 11. Management scenario predicted monthly average flows from July through October relative to the Baseline Forward Model

3.1.2 Tributary Channel Flow Example

Small channels that contribute flow to the Walla Walla River provide important off channel habitat and cold water refuge for salmonids residing in the Walla Walla River system (Wolcott, 2010). In many cases, the flow rates in small tributaries are more difficult to predict with certainty compared to flow in the mainstem Walla Walla River (GSA, 2015). Reasons for this include that low flow rates can magnify relative error in flow predictions and that upstream flows are often managed based on irrigation demand with little or no record keeping. It is still informative to evaluate predicted trends in stream flows with scenario conditions relative to the Baseline Forward Model. In the East Little Walla Walla River, below its confluence with Big Spring (Figure 5), summer flow rates, shown in Figure 12, were shown to be sensitive to the amount of MAR applied in model scenarios. Predicted flows in the Maximum MAR-Piped scenario were, on average, 56.2 percent greater than in the Baseline Forward Model; whereas in the Current MAR-Piped scenario flows were predicted to be only 1.0 percent greater than baseline conditions. For the No MAR-Piped scenario, summer flows were predicted to decline by an average of 47.3 percent compared to the Baseline Forward Model. Figure 12 illustrates that Maximum and Increased MAR yield consistently higher flows in the East Little Walla Walla River over the summer months relative to the Baseline Forward Model and that without MAR stream flow is predicted to decline significantly in late summer. These results indicate the importance of MAR for maintaining flow in the East Little Walla Walla River and the potential for MAR to increase groundwater return flows that in turn flow into the Walla Walla River and improve summer flow conditions. This predicted trend was observed for many of the small tributaries south of the Walla Walla River.

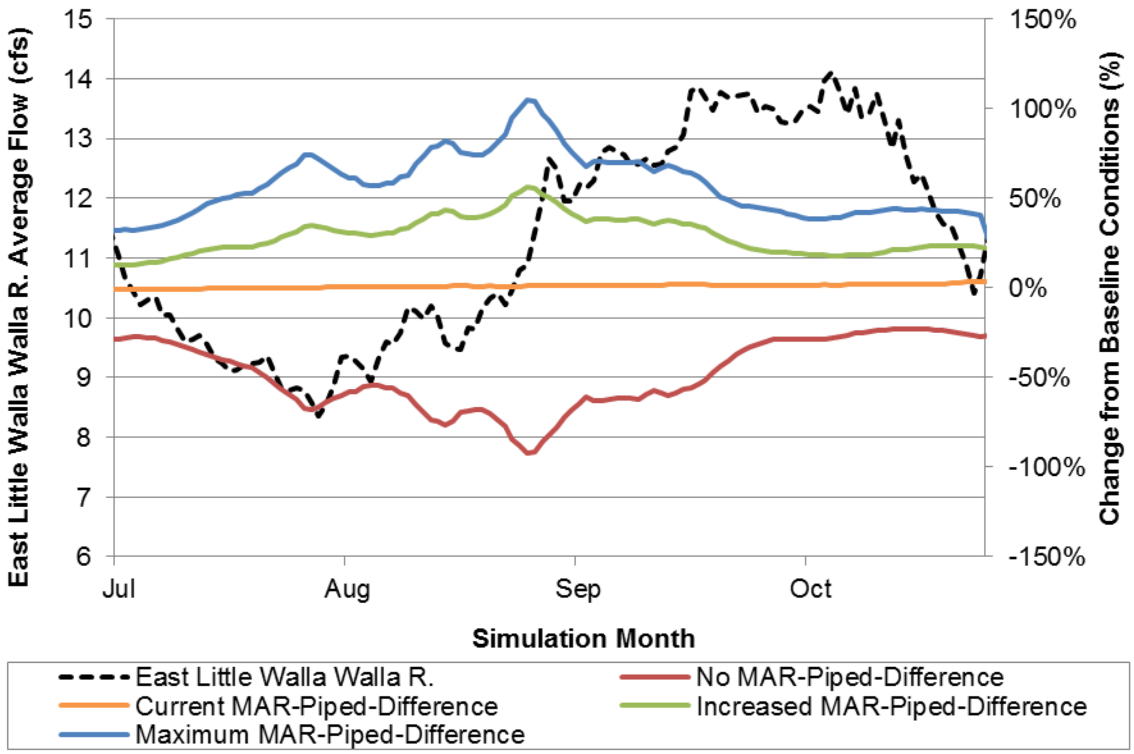

Figure 12. Average monthly flow in the East Little Walla Walla River over the model development period (2007-2013) and model predicted change in flow

3.2 Groundwater

3.2.1 Groundwater Storage

Total groundwater storage for the Baseline Forward Model and the four alternative management scenarios is shown in Figure 13. Figure 13 also shows the difference between groundwater storage in the Baseline Forward Model and under the four alternative management scenarios. The Maximum MAR-Piped scenario was predicted to yield 5.3 to 9.7 thousand acre-feet (average of 7.3 thousand acre-feet) more groundwater storage than the Baseline Forward Model, with the greatest difference predicted to occur in mid-May at the end of the recharge season. The other three alternative management scenarios were all predicted to yield less groundwater storage than the Baseline Forward Model, with predicted storage declining as MAR was decreased. In the No MAR-Piped, Current MAR-Piped, and Increased MAR-Piped scenarios, groundwater storage was predicted to be on average 5.1, 8.9, and 24.6 thousand acre-feet less than in the Baseline Forward Model. Only in the Maximum MAR-Piped scenario was MAR predicted to fully compensate for the loss of aquifer recharge from canal leakage following conversion to pipelines.

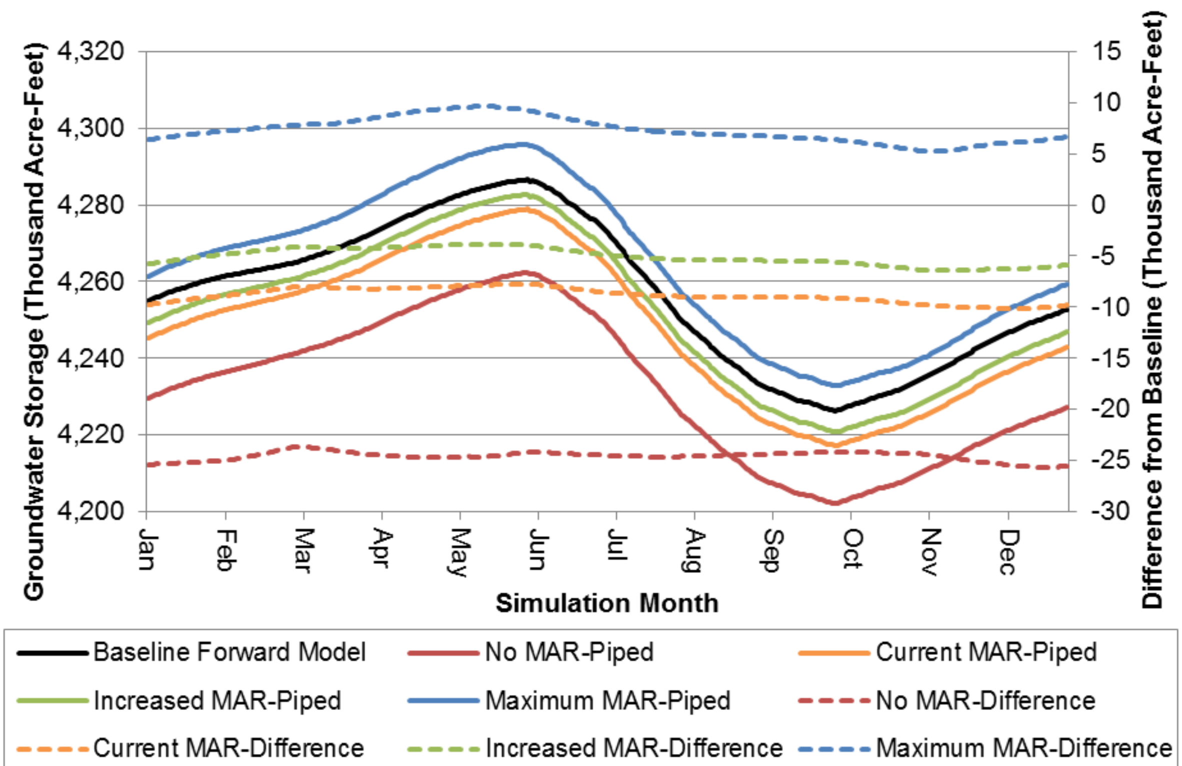

Figure 13. Simulated groundwater storage and difference from the Baseline Forward Model scenario for January through December

3.2.2 Groundwater-Surface Water Interactions

Model results indicate that as MAR is increased, groundwater return flow to streams and rivers will also increase. This limits the potential for using MAR to increase groundwater storage on a large scale because a proportion of recharge water becomes baseflow and is not retained in the aquifer. However, increased baseflow from MAR provides several important ecological benefits by supporting riparian vegetation, adding cooler water to stream channels, and directly increasing surface flows. Figure 14 shows model sub-region change in groundwater return flow for each management scenario relative to the Baseline Forward Model. Positive values represent increased groundwater return flows and negative values indicate increased net seepage out of the streams.

Sub-region one (Upper Walla Walla River) includes the Tum-a-Lum reach of the Walla Walla River, where a significant portion of river flow is lost to seepage due to high stream bed permeability (Baker, 2014). Mean annual net groundwater return flows in this sub-region were predicted to increase by nearly 0.2 acre-feet per acre for the Maximum MAR-Piped scenario. The Increased MAR-Piped and Current MAR-Piped scenarios were predicted to have a 0.1 and 0.2 acre-feet per acre less net groundwater return flow, respectively, through the river bed than was predicted for the Baseline Forward Model. This is due to water savings from pipe installation increasing the amount of water left in stream resulting in more water being available to seep out through the channel in this reach. In the No MAR-Piped scenario there are no diversions from the river for MAR, in addition to water savings from piping. The water table in the No MAR-Piped scenario is also lower than in the Baseline Forward Model, resulting in an increased vertical hydraulic gradient through the stream bed. These combined factors lead to the No MAR-Piped scenario predicting a nearly 0.5 acre foot per acre predicted net decline in groundwater return flows relative to the Baseline Forward Model in this region.

Sub-region two (Lower Walla Walla River) net groundwater return flows in the Maximum MAR-Piped scenario were predicted to be approximately equal to those in the Baseline Forward Model, while decreasing relative to the Baseline Forward Model in the other three alternative management scenarios. Gaining conditions were predicted to increase in sub-region four (Walla Walla River Irrigation District) under all management scenarios where MAR was applied. Gaining conditions in sub-region four are attributable to seepage losses from the Walla Walla River (sub-region one) and MAR, particularly in the Maximum MAR-Piped scenario where several MAR sites in sub-region four are activated leading to the greatest increase in predicted groundwater return flows.

Sub-region five represents a portion of the HBDIC Irrigation District that includes the White Canal, one of the canals converted into a pipeline under the management scenarios. The model predicted lower net groundwater return flows in this sub-region for all alternative management scenarios relative to the Baseline Forward Model. Decreased net groundwater return flows are due to lower groundwater elevations resulting from the loss of recharge in the form of seepage through the bed of the White Canal. The decrease in net groundwater return flows is primarily a function of the elimination of gaining conditions that are predicted for the White Canal over the winter months in the Baseline Forward Model. It should be noted that stream-groundwater interactions occur year round while the majority of lined canals operate during the irrigation season only (except when they are used to supply MAR sites). Water savings during irrigation season are more important than lost flow in the winter months due to water scarcity and high demand during irrigation season.

In sub-region six (Gardena Farms Irrigation District-Pine Creek Drainage), the Gardena Farms Canal has been reported to lose over 20 cfs when operating at full capacity (Patten, 2015) and is among the canals that are converted into a pipeline in the alternative management scenarios. The model predicted an increase in net groundwater return flow relative to the Baseline Forward model in sub-region six for all four alternative management scenarios as a direct result of lining the Gardena Farms Canal. Greater net groundwater return flow was due to seepage losses eliminated by piping the Gardena Farms Canal exceeding the predicted decline in groundwater return flows into Pine Creek, reflected by the positive change in net groundwater return flow relative to the Baseline Forward Model for sub-region six (Figure 14). The figure also shows that the amount of predicted groundwater return flows increased with greater MAR application.

Pipe installation on the Gardena Farms Canal reduced seepage as a source of groundwater recharge for much of sub-regions six and seven. This resulted in decreased groundwater elevations and reduced groundwater return flows being predicted for sub-region seven (Mud Creek-Lowden) because it is down-gradient of the Gardena Farms Canal. As MAR was increased the loss of recharge from the Gardena Farms Canal is partially mitigated; however, even under the Maximum MAR-Piped scenario groundwater return flows were predicted to be lower than in the Baseline Forward Model by over 0.3 acre-feet per acre. Predicted changes in net groundwater return flows for all other sub-regions were small (< 0.1 acre-feet per acre) because pipes were not installed in these areas and there were few MAR sites. The predicted change in net groundwater return flows for the entire model area was 0.04, 0.00, -0.02, and -0.04 acre-feet per acre for the Maximum MAR-Piped, Increased MAR-Piped, Current MAR-Piped, and No MAR-Piped scenarios, respectively.

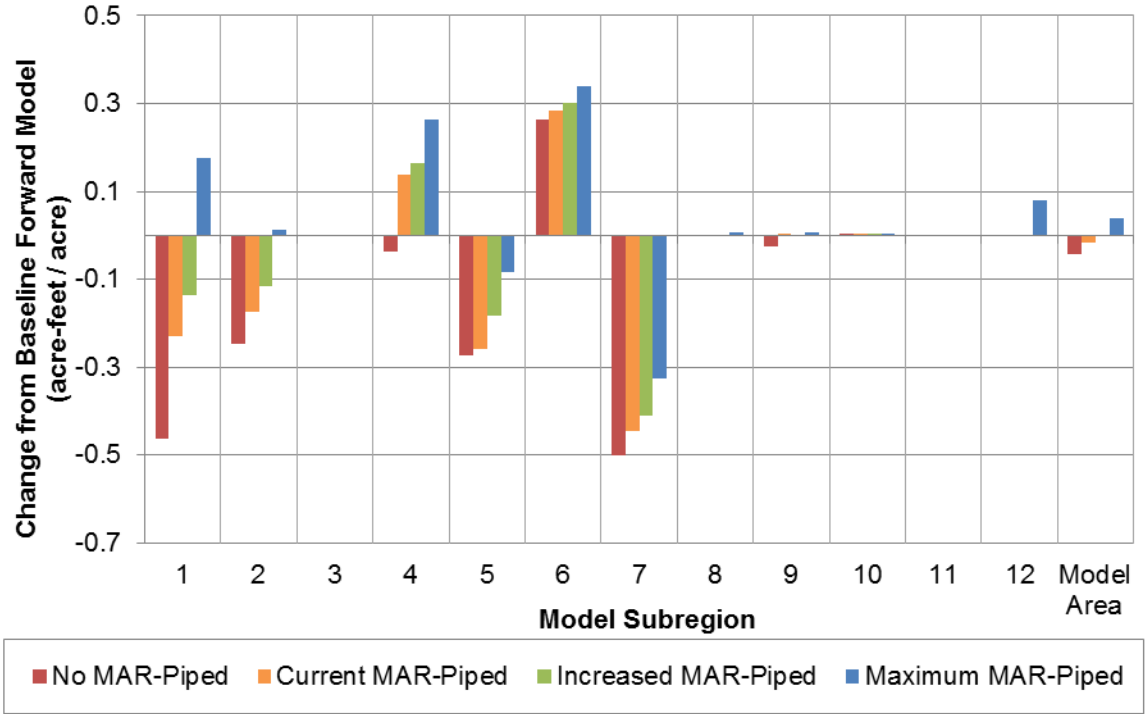

Figure 14. Management scenario simulated change in net seepage through stream beds and canals relative to the Baseline Forward Model. Positive values represent increased groundwater return flows and negative values indicate increased net seepage out of streams.

3.2.3 Groundwater Elevations

Figure 15 shows the predicted change in annual average groundwater elevation resulting from the No MAR-Piped scenario relative to the Baseline Forward Model. The groundwater elevation was predicted to be similar to the Baseline Forward Model over most of the northern portion of the model area but decrease more than four feet over most of the area south of the Walla Walla River channel. Groundwater declines of 10 to nearly 24 feet were predicted adjacent to MAR sites and canals that served as recharge sources in the Baseline model.

Figure 16 shows the predicted change in annual average groundwater elevation resulting from the Current MAR-Piped scenario relative to the Baseline Forward Model. The groundwater elevation was predicted to be similar over most of the northern portion of the model area and decreased by four to ten feet in the areas adjacent to the Gardena, Lowden, and Garden City canals due to loss of seepage from pipeline installation. An increase of groundwater elevation of up to four feet was predicted in the area immediately down gradient from the active recharge sites. This is due to improved conveyance efficiency through piping increasing the proportion of water allocated for

MAR that reaches the intended MAR site (though the seepage losses also contribute to aquifer recharge).

Figure 17 shows the predicted change in annual average groundwater elevation resulting from the Increased MAR-Piped scenario relative to the Baseline Forward Model. The groundwater elevation was predicted to increase from four to seven feet in the vicinity of the MAR sites in the central portion of the model area as a result of aquifer recharge and to be primarily unchanged over most of the northern portion of the model area. Similar to the Current MAR-Piped scenario, water table elevations around the Gardena, Lowden, and Garden City canals were predicted to be four to ten feet below levels predicted by the Baseline Forward Model.

Figure 18 shows the predicted change in annual average groundwater elevation resulting from the Maximum MAR-Piped scenario relative the Baseline Forward Model. A widespread increase in groundwater elevation of four to ten feet higher than the Baseline Forward Model was predicted in the central portion of the model area where MAR sites are concentrated. Little change was predicted in the northern portion of the model area. The water table was predicted to decrease one to ten feet around the Gardena, Lowden, and Garden City canals as a result of pipe installation. This predicted groundwater decline was less extensive than predicted for the other three alternative management scenarios and reflects a more broadly distributed benefit of increased groundwater storage in the Maximum MAR-Piped scenario, partially offsetting the impact of lost aquifer recharge in areas adjacent to pipe installation.

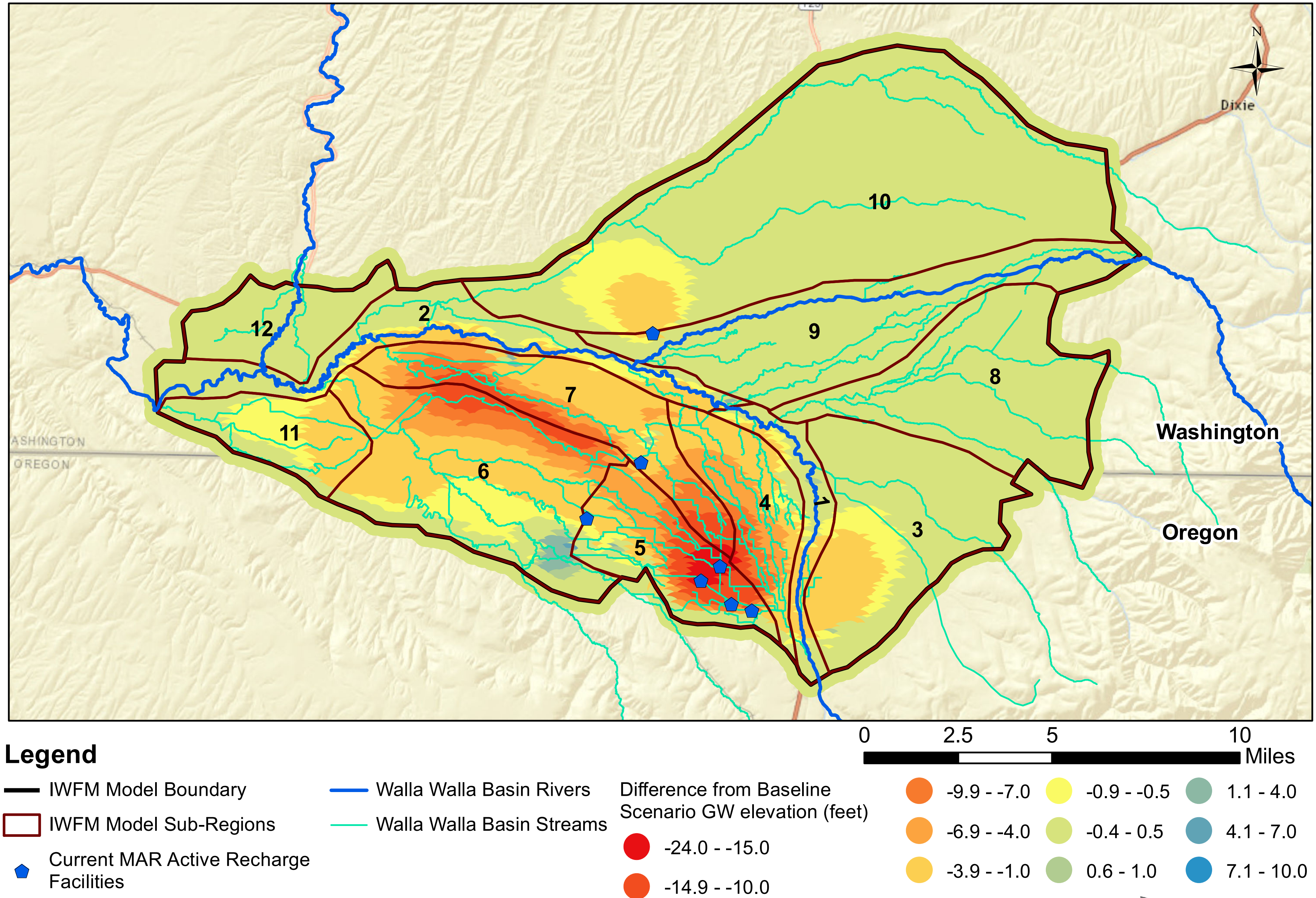

Figure 15. No MAR-Piped scenario predicted change in groundwater elevation relative to the Baseline Forward Model

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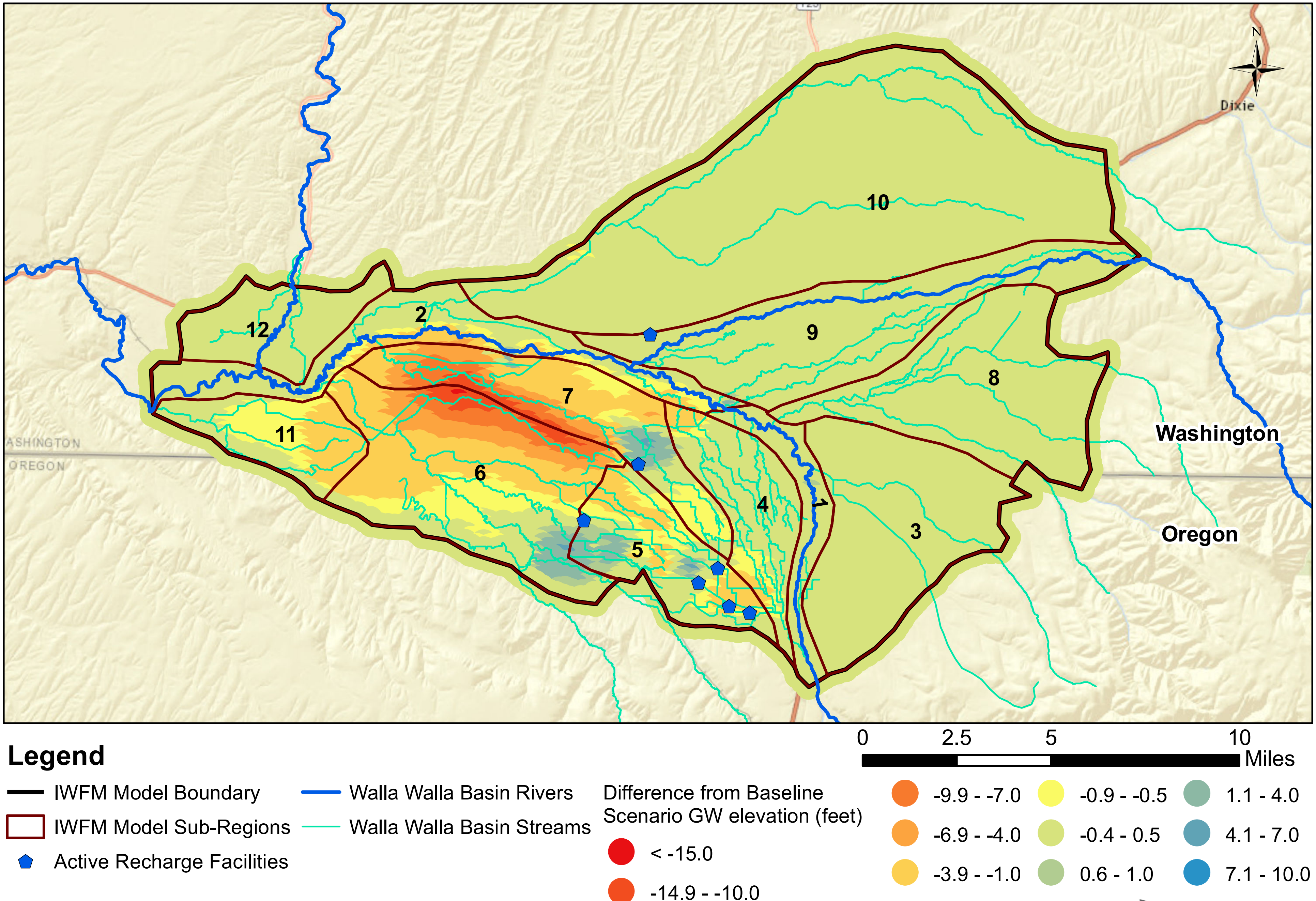

Figure 16. Current MAR-Piped scenario predicted change in groundwater elevation relative to the Baseline Forward Model

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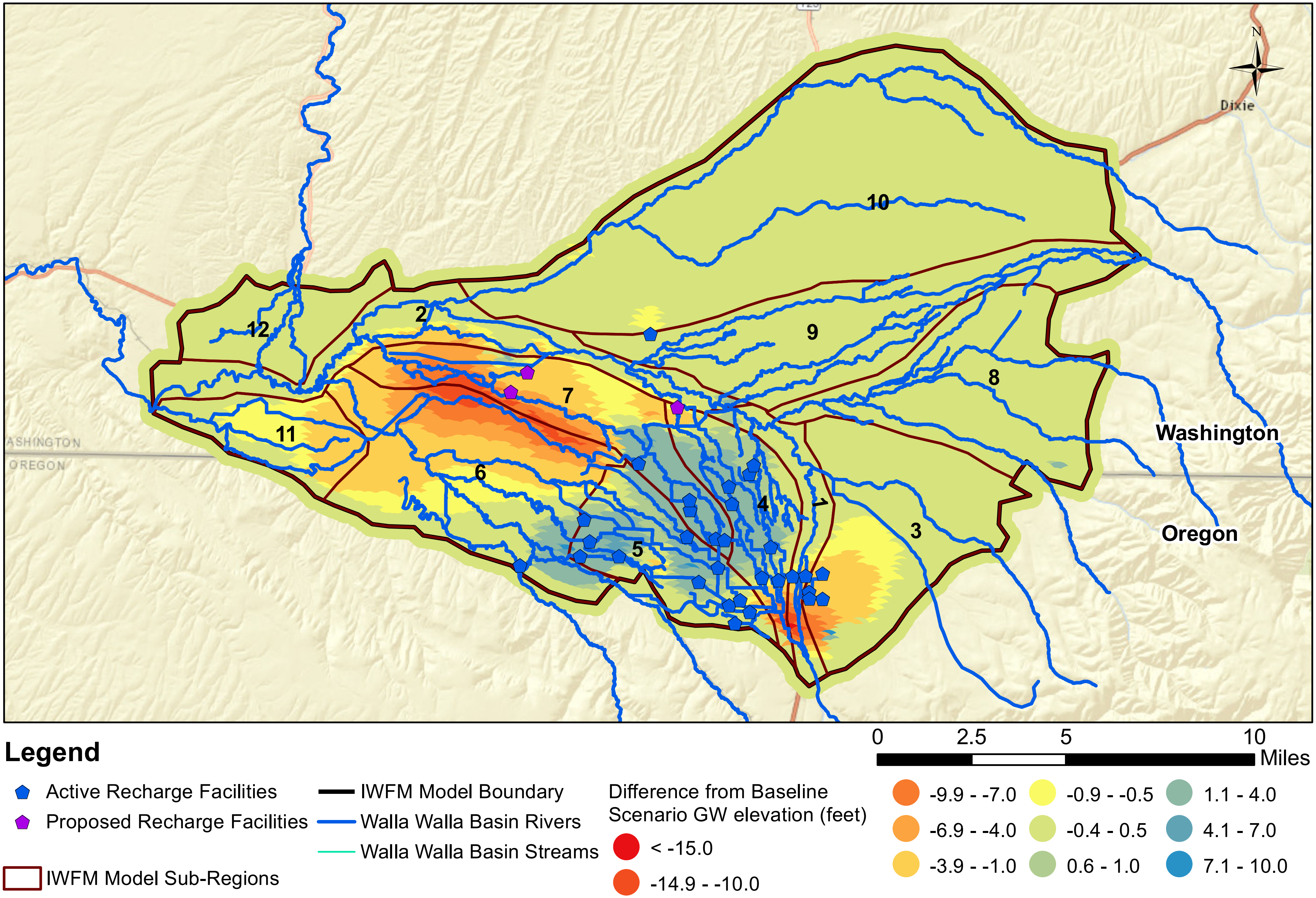

Figure 17. Increased MAR-Piped scenario predicted change in groundwater elevation relative to the Baseline Forward Model

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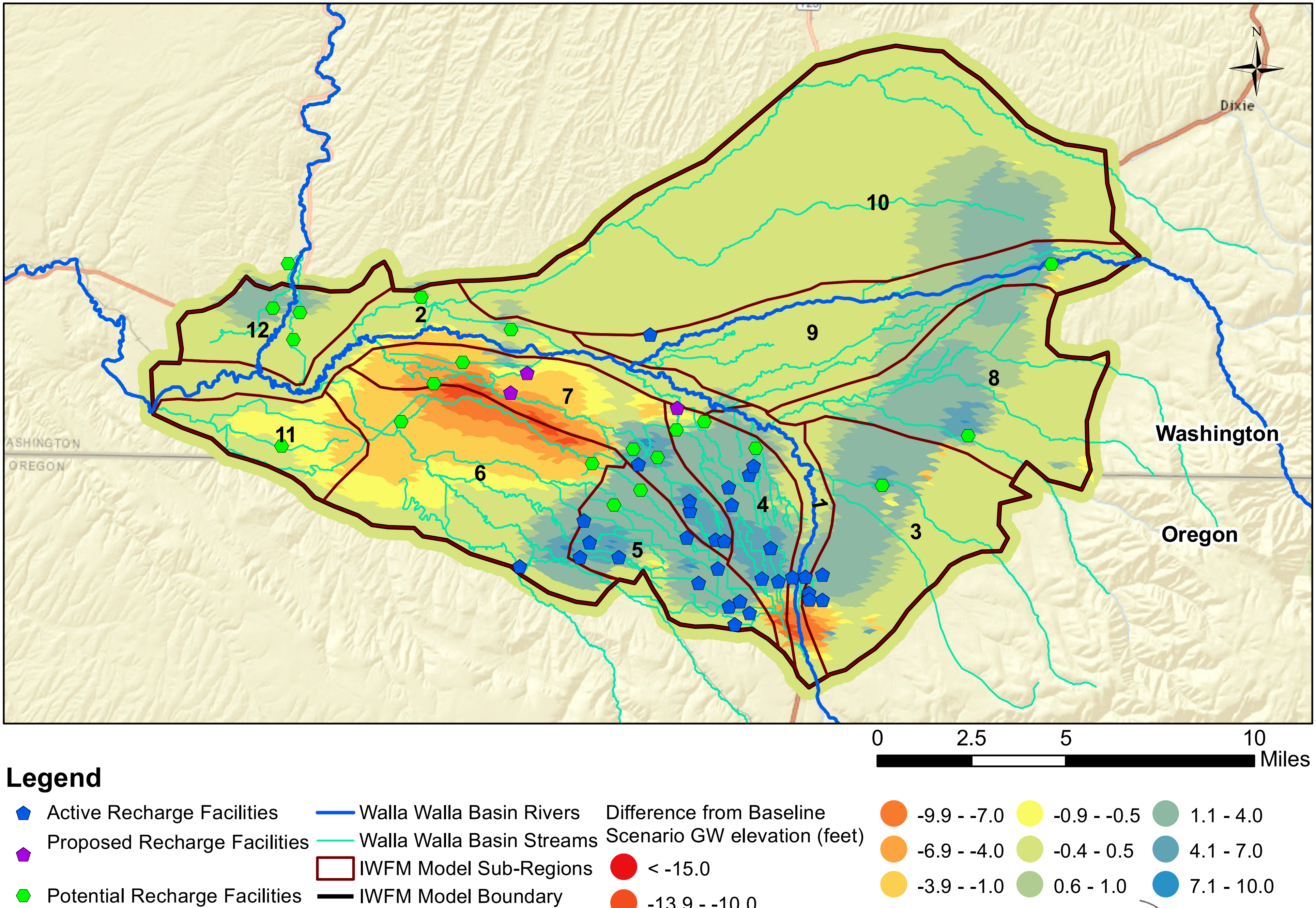

Figure 18. Maximum MAR-Piped scenario predicted change in groundwater elevation relative to the Baseline Forward Model

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3.3 Model Water Balance

The impact of management scenarios on the total model area water balance relative to the Baseline Forward Model is presented in Figure 19. Alternative management scenarios were predicted to have the largest impact on net groundwater discharge relative to other fluxes. Compared to the Baseline Forward Model, the total net discharge from groundwater to surface water was predicted to increase by 9.2 percent for the Maximum MAR-Piped scenario; however it was predicted to decrease by 0.4, 4.0, and 10.8 percent for the Increased MAR-Piped, Current MAR-Piped, and No MAR-Piped scenarios, respectively. Declines in groundwater elevation are predicted to occur with conversion from earthen canal beds to pipelines, reducing groundwater contributions to many surface streams. In the Maximum MAR-Piped scenario, additional groundwater recharge from MAR is predicted to exceed the lost groundwater recharge from canal seepage and result in increased groundwater discharge to streams. In the case of the Increased MAR-Piped scenario, MAR is predicted to nearly mitigate the lost canal seepage inputs, as is evident by the negligible change in groundwater storage relative to the Baseline Forward Model.

Lower groundwater elevations predicted in the No MAR-Piped scenario increased the groundwater gradient along the model boundary, inducing an increase of groundwater inflow into the model area. The opposite was predicted in both scenarios where MAR was increased from the baseline conditions (i.e. Increased MAR-Piped, Maximum MAR-Piped) (Figure 19).

Surface water diversions were predicted to be 3.4 percent lower in the Current MAR-Piped scenario compared to the Baseline Forward Model, a result of the decreased withdrawals from the Walla Walla River into the piped irrigation networks (Figure 19). As MAR was increased more water was available for surface water diversions because less water in the irrigation canals was lost to seepage due to decreased groundwater gradient below the canals.

Groundwater pumping is calculated by the model based on the difference between agricultural demand and surface water applications. Agricultural water demand was unchanged in all scenarios therefore groundwater pumping directly reflects the change in available surface water. The No MAR-Piped scenario predicted a groundwater pumping increase of 2.1 percent relative to the Baseline Forward Model. As MAR was increased, slightly less pumping was predicted relative to the Baseline Forward Model because of the additional water available in streams and canals after pipe installation and in some cases, increased groundwater return flow.

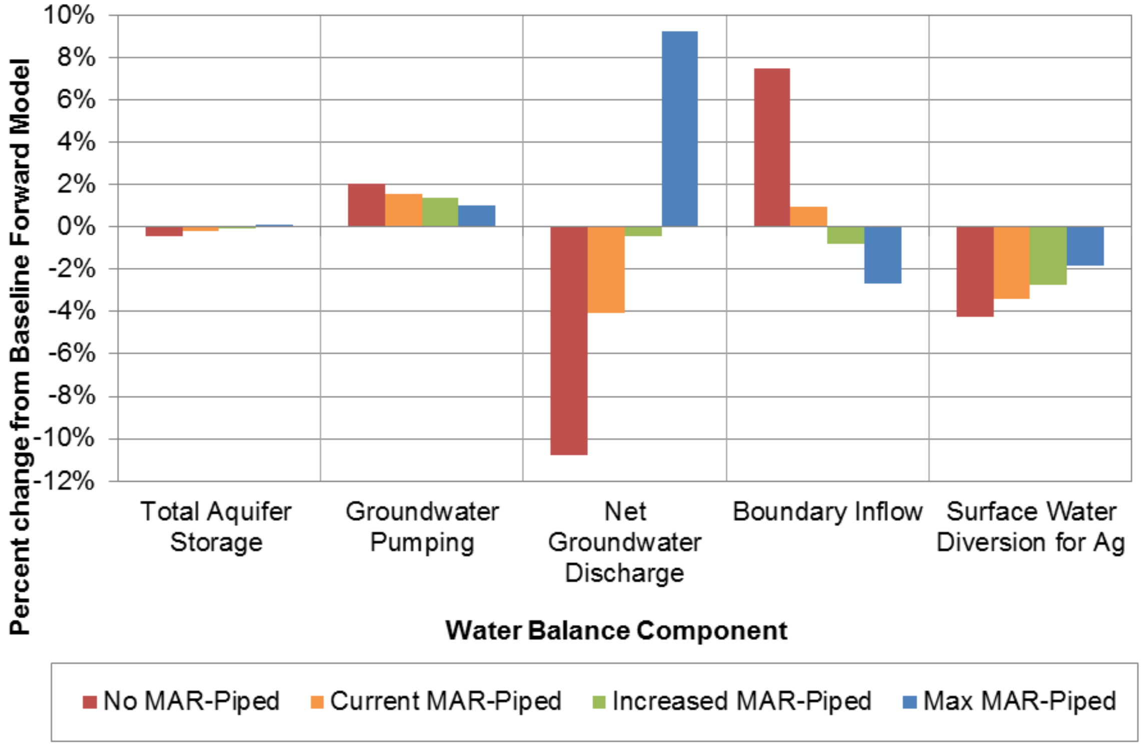

Figure 19. Management scenario simulated water budget changes relative to the Baseline Forward Model

Changes in management scenario predicted water balance relative to the Baseline Forward Model for each model sub-region are presented in Table 4. Positive changes are highlighted green and negative changes are highlighted red, with shades becoming darker as changes increase. Sub-regions four and five, where MAR sites are most heavily concentrated, were predicted to see the greatest groundwater storage increases resulting from MAR and the greatest declines with no MAR. Sub-region six, seven, and eleven were predicted to see declines in groundwater storage resulting from the loss of recharge with pipe installation; though this loss was minimal in sub-region seven in the case of the Maximum MAR-Piped scenario. Groundwater storage over the model area as a whole was predicted to increase by 0.03 acre feet per acre in the Maximum MAR-Piped scenario and decrease in the three other alternative management scenarios, with the greatest decline, 0.13 acre feet per acre, predicted in the No MAR-Piped scenario. In sub-region six the elimination of White Canal and Gardena Farms Canal seepage losses resulting from their conversion into pipelines was predicted to translate into an increase in surface flows in all scenarios. The opposite was predicted for sub-region seven, where in Mud Creek groundwater return flow was predicted to decline from the elimination of aquifer recharge following the piping of the Gardena Farms Canal (Table 4).

Sub-region eleven, which has a particularly thick soil profile (personal communication with Mike Ingham, GFID) was predicted to experience a large decline in soil water storage with pipe installation as a result of lining the Gardena Farms Canal. Soil water storage was minimally affected by scenario conditions in the other sub-regions.

Table 4. Management scenario simulated sub-region water budget changes relative to the Baseline Forward Model. Green shading indicates increase, red shading indicate decrease.

Subregion	Total GW Storage (acre ft/acre)				Groundwater Pumping (acre ft/acre)				Net Groundwater Discharge (acre ft/acre)			
	No MAR-Piped	Current MAR-Piped	Increased MAR-Piped	Maximum MAR-Piped	No MAR-Piped	Current MAR-Piped	Increased MAR-Piped	Maximum MAR-Piped	No MAR-Piped	Current MAR-Piped	Increased MAR-Piped	Maximum MAR-Piped
1	-0.05	0.01	0.03	0.11	0.00	0.00	0.00	0.00	-0.46	-0.23	-0.14	0.18
2	-0.01	-0.01	0.00	0.00	0.00	0.00	0.00	0.00	-0.25	-0.18	-0.12	0.01
3	-0.03	0.00	0.02	0.15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4	-0.50	-0.04	0.08	0.30	0.04	0.00	-0.01	-0.03	-0.04	0.14	0.17	0.26
5	-0.88	-0.06	0.09	0.22	0.14	0.14	0.13	0.12	-0.27	-0.26	-0.18	-0.08
6	-0.29	-0.27	-0.25	-0.20	0.00	0.00	0.00	0.00	0.26	0.28	0.30	0.34
7	-0.37	-0.15	-0.08	0.01	0.04	0.02	0.02	0.02	-0.50	-0.45	-0.41	-0.33
8	0.00	0.00	0.00	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
9	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.00	-0.02	0.00	0.00	0.01
10	-0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
11	-0.08	-0.08	-0.08	-0.05	0.04	0.04	0.04	0.03	0.00	0.00	0.00	0.00
12	0.00	0.00	0.00	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.08
Model Area	-0.13	-0.05	-0.03	0.03	0.01	0.01	0.01	0.01	-0.04	-0.02	0.00	0.04

Table 4. Management scenario simulated sub-region water budget changes relative to the Baseline Forward Model. Green shading indicates increase, red shading indicate decrease (continued).

Subregion	Boundary Inflow (acre ft/ft)				Surface Water Diversions (acre ft/acre)				Soil Water Storage (acre ft/acre)			
	No MAR-Piped	Current MAR-Piped	Increased MAR-Piped	Maximum MAR-Piped	No MAR-Piped	Current MAR-Piped	Increased MAR-Piped	Maximum MAR-Piped	No MAR-Piped	Current MAR-Piped	Increased MAR-Piped	Maximum MAR-Piped
1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	0.00	0.00	0.00	0.00	0.01	0.02	0.02	0.03	0.00	0.00	0.00	0.00
3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00
4	0.00	0.00	0.00	0.00	-0.05	0.00	0.03	0.08	0.00	0.00	0.00	0.00
5	0.12	0.01	-0.02	-0.03	-0.56	-0.50	-0.44	-0.39	0.00	0.00	0.00	0.00
6	0.01	0.00	0.00	-0.01	-0.09	-0.06	-0.05	-0.03	-0.01	0.00	0.00	0.00
7	0.00	0.00	0.00	0.00	-0.19	-0.16	-0.12	-0.09	0.00	0.00	0.00	0.00
8	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
11	0.00	0.00	0.00	0.00	-0.09	-0.09	-0.09	-0.07	-0.02	-0.02	-0.02	-0.01
12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.00
Model Area	0.03	0.00	0.00	-0.01	-0.05	-0.04	-0.03	-0.02	0.00	0.00	0.00	0.00

4.0 CONCLUSION

Model results for all management scenarios indicate that Walla Walla River flows at Nursery Bridge and Pepper Bridge would increase relative to the Baseline Forward Model due to reduced diversions from the Walla Walla River following pipe installation. MAR had a negligible effect on river flows at these locations. Walla Walla River flows at Beet Road also increased under all management scenarios due to reduced diversions from the Walla Walla River, with greater flows predicted as MAR was increased.

River flows at the two lower reference locations, McDonald Bridge and Touchet, increased under all management scenarios due to water savings in the Walla Walla River; with the exception of less flow predicted in August and September at the Touchet location in the No MAR-Piped scenario. At the McDonald Bridge reference location the Maximum MAR-Piped and Increased MAR-Piped scenarios were predicted to produce respective flows averaging 12.6 and 10.1 cfs greater than the Baseline Forward Model from July through October. At the Touchet reference location simulated flows for the Maximum MAR-Piped and Increased MAR-Piped scenarios over the same time period were predicted to be, on average, 9.1 and 5.7 cfs greater than for the Baseline Forward Model, respectively.

The portion of predicted flow increase that is directly due to in stream water savings (i.e. piping) is given by comparing the Current MAR-Piped scenario to the Baseline Forward Model. The difference in predicted flow between these two scenarios peaks at the Beet Road reference location, where water saving have been applied for the White and Garden Farms canals but upstream of several diversions taken directly from the main channel. At the Beet Road reference location the July through September predicted increase in flow in the Current MAR-Piped scenario was 10.0 cfs. At the McDonald Road and Touchet reference locations the predicted increase in flow in the Current MAR-Piped scenario was 9.3 and 4.4 cfs, respectively. Lower predicted increased flow at McDonald Road and Touchet location was due to water savings being used to satisfy diversion water demands located between these locations and the upstream Beet Road reference location.

The No MAR-Piped scenario can be compared to the other piped scenarios to determine how much of the predicted flow increase is a direct result of MAR. The difference in predicted flows between the No MAR-Piped scenario and other piped scenarios was negligible at the two upstream reference locations (Nursery Bridge and Pepper Bridge). At the Beet Road reference location the Maximum MAR-Piped, Increased MAR-Piped, and Current MAR-Piped scenarios resulted in, on average, 4.0, 2.2, and 1.7 cfs more predicted flow than the No MAR-Piped scenario from July through October. At the McDonald Road reference location the Maximum MAR-Piped, Increased MAR-Piped, and Current MAR-Piped scenarios resulted in, on average, 6.0, 3.5, and 2.7 cfs more predicted flow than the No MAR-Piped scenario from July through October. At the Touchet reference location (furthest downstream) the Maximum MAR-Piped, Increased MAR-Piped, and Current MAR-Piped scenarios were predicted to yield on average 7.8, 4.2, and 3.1 cfs more flow than predicted in the No MAR-Piped scenario for the period from July through October. Overall, the influence of MAR on flows increased from the furthest upstream (Nursery Bridge) to the furthest downstream (Touchet) location.

At the Touchet reference location the No MAR-Piped scenario was predicted to have 2.1 and 0.8 cfs lower flow than the Baseline Forward Model for August and September, respectively. This indicates that reduced groundwater return flows in the Walla Walla River, a result of lost groundwater recharge following canal piping, exceed in stream water savings for these months, producing a predicted decline in flow despite reduced diversions into the piped canals.

Management scenarios had a strong impact on predicted groundwater-surface water interactions in the model area. Conversion of canals to pipelines eliminated the aquifer recharge that occurred within those canals and was predicted to lower groundwater elevations, decreasing groundwater return flows to streams as a result. Groundwater elevation was predicted to increase in areas where MAR sites were concentrated; in turn increasing groundwater return flows in down gradient portions of the Walla Walla River and off-channel tributaries. Increased groundwater return flows have potential ecological benefits in the form of increased summer flow rates, increased cold water inflows, and improved riparian habitat.

Model area wide groundwater storage was predicted to decrease as a result of pipe installation in all but the Maximum MAR-Piped scenario as canal seepage was eliminated as an aquifer recharge source. The loss of groundwater recharge was increasingly compensated for as MAR increased, being 24,631, 8,900, and 5,117 acre-feet less than the Baseline Forward Model for No MAR-Piped, Current MAR-Piped, and Increased MAR-Piped scenarios, respectively. Under the Maximum MAR-Piped scenario the predicted groundwater storage was 7,260 acre-feet greater than the Baseline Forward Model. Maximum MAR-Piped scenario predicted increases in groundwater storage were in areas where MAR sites are most heavily concentrated; however declines in groundwater storage were predicted in the vicinity of the piped Gardena Farms Canal.

Management scenario results indicate that converting canals into pipelines is likely to have a negative impact on groundwater resources and limit the benefit of instream water savings if not combined with the increased application of MAR to enhance groundwater storage. Increasing MAR to include the currently proposed recharge sites (Increased MAR-Piped scenario) is predicted to mitigate the impact of the simulated canal piping. Greater increases in MAR to incorporate 60 sites (Maximum MAR-Piped scenario) is predicted to provide more widespread benefits to both fish habitat and groundwater resources by allowing for significantly increased summer flows in the Walla Walla River and some tributaries while stabilizing aquifer storage. Conversely, eliminating MAR (No MAR-Piped scenario) would lead to a significant decline in groundwater and surface water resources relative to current conditions. The use of MAR in the Walla Walla Basin is an opportunity to practice conjunctive management of groundwater and surface water resources to meet conflicting water demands in the basin.

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