MEMORANDUM

Project No.: 180249

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To: Mike Hermanson – Spokane County Environmental Services, Lead Agency
WRIA 55 Planning Unit Members

From:

Hydrogeologist
1100
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Re: **Managed Aquifer Recharge Site Optimization and Selection**
WRIA 55 ESSB 6091/RCW 90.94 Watershed Plan Update

Background

The passage of Engrossed Substitute Senate Bill (ESSB) 6091, as codified by RCW 90.94, requires that an update to the existing Watershed Plan for Water Resource Inventory Area (WRIA) 55, the Little Spokane Watershed, be approved by the Washington Department of Ecology (Ecology) by February 1, 2021. Spokane County Environmental Services is serving as the lead agency for this process. The WRIA 55 Initiating Governments for the watershed planning process are Spokane County, Stevens County, Pend Oreille County, the City of Spokane, and Whitworth Water District. The process is supported by convening the WRIA 55 Planning Unit to review technical tasks and memorandums, policy decisions, and the pending watershed plan update. Aspect Consulting, LLC (Aspect) has been contracted by Spokane County to facilitate planning unit meetings, conduct supporting technical tasks, and prepare the Watershed Plan update.

Spokane County previously received a grant from the Bureau of Reclamation's Drought Resiliency grant program to develop modeling tools to identify and quantify projects aimed at enhancing streamflows. Through that project, a transient integrated surface and groundwater model was developed for WRIA 55 by EarthFX, a consulting group specializing in groundwater modeling, using the USGS modeling package GSFLOW. EarthFX is supporting Aspect and Spokane County in conducting modeling and analysis specific to the Watershed Plan update.

The model is an ideal tool to identify and optimize selection of potential water offset project sites, given that it has been calibrated to surface water flows and groundwater conditions in the basin and can model the predicted effects of proposed projects. Model results have been combined with GIS analysis to evaluation potentially suitable managed aquifer recharge (MAR) locations within WRIA 55. Based on the screening criteria discussed in this memorandum, 18 sites were targeted for additional GSFLOW modeling, to evaluate the response of streamflows to induced recharge at the target sites. This memorandum summarizes the evaluation of those 18 sites.

Approach

There are several site-specific criteria that control the suitability of a particular area for a MAR facility. The suitability of a site for an MAR project is based on a number of factors that have been considered in this analysis. The screening approach for this investigation has been conducted, in essence, as a process of elimination of areas of WRIA 55 based on consideration of key factors discussed below:

Availability of Water Rights for Purchase

A portion of the WRIA 55 watershed within the Dragoon and Beaver Creek subbasins was excluded from the study area based on the availability of water rights that were either already purchased by the County for the WRIA 55 Water Bank or are identified as target water rights for future purchase based on interested water right sellers. **The study area covers the portions of WRIA 55 where no clear water right purchase targets have been identified.**

Infiltration Capacity and Available Water Table Rise

MAR projects can be implemented with either infiltration ponds or subsurface drainfield piping (similar to a septic field). In both cases, near surface soils with suitable hydraulic conductivity are needed to allow for adequate infiltration rates. One concern is that under certain geologic conditions, the water table beneath the basin may rise rapidly and thereby affect the efficiency of the recharge operations. This is likely to occur in areas with shallow depth to the water-table and/or a surficial aquifer with low to moderate permeability. The rise of the water table beneath a recharge basin face depends on several factors including the rate of infiltration, the hydraulic conductivity and thickness of the surficial aquifer, proximity to aquifer boundaries, and the area and shape of the recharge basin.

Several analytical solutions (simple groundwater models) have been developed that can be used to estimate the rise of the water table beneath a rectangular or circular recharge basin. These models can be applied in situations where the aquifer geometry and properties are relatively uniform over reasonably large distances. Analytical solutions were used in this phase of the study as a screening tool to identify areas where water table rise could pose a limit to the effectiveness of aquifer recharge operations. An analytical solution for water table rise was developed by Hantush (1966) for rectangular and circular basins. This solution was integrated with data from the WRIA 55 GSFLOW model to estimate the available water table rise in target WRIA 55.

The solution for the maximum rise of the water table at the center of a circular basin is given as:

$$s^2 = h^2 - h_i^2 = \frac{NR^2}{2K}[W(u_0) + (1 - exp(-u_0)/u_0)]$$

where:

s is the maximum increase in head (height of water table) below the basin at a given time;

h is the head (height of the water table) at a given time;

$\mathrm{h_i}$ is the initial head;

N is the infiltration rate;

R is the radius of the basin;

$\mathrm{W(u_0)}$ is the well function for non-leaky aquifers;

$\mathrm{u_0} = \frac{\mathrm{R^2S}}{4\mathrm{K\bar{b}t}}$; where:

S is the storage coefficient of the aquifer (specific yield);

K is the hydraulic conductivity of the surficial aquifer;

$\bar{\mathrm{b}}$ is the average saturated thickness of the surficial aquifer; and;

t is time measured from the start of recharge.

The analytical solution can be easily evaluated if the aquifer properties (hydraulic conductivity and storage coefficient) are known. One small complication is that the average saturated thickness, $\bar{\mathrm{b}}$, is unknown because it depends on the water table rise. An iterative technique can be used where the starting saturated thickness is substituted in the equation as an initial guess. The calculated rise is then used to update the average saturated thickness and the process repeated until $\bar{\mathrm{b}}$ ceases to change.

A Visual Basic code program was written to evaluate the analytical solution at the center of every cell in the numerical model grid. The aquifer properties were determined from the calibrated model parameters. The average hydraulic conductivity was determined by summing the transmissivities of the underlying model layers and divided by the total thickness.

The suitability for recharge was measured in terms of the "percent of available rise" (PAR), where:

$$PAR = \left(1 - \frac{s}{available\ rise}\right)\ x\ 100$$

The available rise was determined in each cell as the average topographic elevation minus the average head for March in Model Layer 1 (as averaged over the 15-year numerical model simulation period). March was selected because it would be the start of a typical 3-month recharge period, assumed to extend from March through May where flows in the streams would accommodate the diversion of water needed for recharge. An injection rate of 1 cubic foot per second (cfs) was selected and the radius of the recharge basin was assumed to be 165 ft (equivalent to a two-acre site). Large PAR values (e.g., 90 percent) would indicate that the expected rise in the water table uses a small portion of the total available. **Percent available rise of less than 50 percent was considered unsuitable for recharge sites in the screening process**, to provide a safety factor given the uncertainty typically associated with subsurface conditions.

Figure 1 shows the computed percent available rise for each cell in the model. A geologic section through some of the suitable areas is provided in Figure 2 (section line shown on Figure 1) that also shows the March water levels. Results show that the suitability is strongly dependent on (1) the presence of sandy materials in the shallow subsurface, and (2) the presence of a relatively deep water table.

Stream Augmentation Factor (SAR)

In addition to being able to accept the infiltrated water, another consideration is the time it takes for the recharge to affect flow in the nearest stream. If the facility is located too close to the stream, recharge from the basin could cause an increase in streamflow during the diversion period. Ideally, the streamflow should be augmented starting after the diversion period and extending through the period of typically low stream flow.

Early studies of streamflow depletion (i.e., loss of streamflow to the aquifer caused by pumping a well adjacent to a stream) identified a "Stream Depletion Factor" used to determine when a stream will first show the influence of the nearby pumping (Jenkins, 1968). This same factor, in reverse, can be used to identify when augmentation of streamflow due to aquifer recharge will first be detected. This streamflow augmentation factor (SAF) is a measure of how rapidly the pressure increase caused by the increased heads beneath the recharge facility propagates through the aquifer and depends on the aquifer storage and transmissivity values. It differs from the actual arrival time of the injected water because the pressure increase will typically move through the aquifer much faster than the water itself.

The Streamflow Augmentation Factor (SAF) is given by:

$$SAF = \frac{L^2 S_y}{T}$$

where:

L is the length of the flowpath between the recharge facility and the stream;

S_y is the specific yield of the surficial aquifer;

T is the transmissivity of the aquifer.

A Visual Basic code program was written to evaluate the SAF at the center of every cell in the numerical model grid. Flowpaths from each cell were determined by analyzing the average March water table. This code started at a cell and analyzed heads in each adjacent cell do determine the path with the steepest gradient. The search continued until a stream segment was intersected. Average transmissivity and specific yields were computed by keeping a running average of the transmissivity and specific yield of all model cells encountered along the flowpath. The SAF factor was computed and the process was repeated for each cell in the model grid

A small SAF means small lag between start of recharge and start of stream response. **Areas with SAF less than 90 days were excluded from the selection process.** Large SAF factors would indicate that a measurable response to recharge would not be detected for a long period. Accordingly, SAF factors greater than 5 years were also excluded. Figure 3 the SAF values within the study area. The SAF value grows quickly as the length of the flowpath increases.

Distance from Surface Water Sources

Another consideration in siting MAR projects is access to a suitable water source to provide water for infiltration and recharge. **For this investigation, areas further than one mile from a surface water source were eliminated from consideration,** given the high cost of infrastructure and conveyance costs expected to be associated with developing an MAR site at further distances from a water source than this. Figure 4 shows the areas excluded based on distance for surface water sources.

Surface Slope Limitations on Conveyance

In addition to distance from a surface water source, another factor that can affect infrastructure and conveyance costs is the elevation difference between a water source and the site targeted for MAR. this both complicates a conveyance alignment and adds significantly to pumping costs to the MAR project site. **For this investigation, areas with slopes great than 25 percent were eliminated from consideration,** given the high cost of infrastructure and conveyance costs expected to be associated with developing an MAR site in this circumstance. Figure 5 shows the areas excluded based on this factor.

Availability of Public Versus Private Land for Project Access

While not an exclusionary factor, emphasis was placed on availability of public lands for target site selection for additional investigation, with particular emphasis on county lands within WRIA 55. This focus was based on the relative ease of securing assess to these lands, versus privately held lands. Figure 6 shows the distribution of public lands within the study area.

Distribution of Target Sites Based on Instream Flow Needs

A final factor considered in selecting target sites focused on identifying a distribution of sites for further analysis that were spread through all the key subbasins needing water offset projects.

Selection of Sites for GSFLOW Modeling of MAR

In summary, the exclusionary factors considered in this analysis are:

- Areas within WRIA 55 where water right purchases have been made or are considered likely.
- The estimated percent available water table rise is less than 50 percent.
- The Stream Augmentation Factors is less than 90 days.
- Areas further than one mile from a surface water source.
- Areas with slopes great than 25 percent were eliminated from consideration,

Figure 7 shows the 18 site locations that were selected for additional GSFLOW modeling investigation. The modeling was conducted with the following assumptions:

- 1 cubic foot per second (cfs) was recharged (when available in the water source) at the modeled MAR site over the period March, April, and May.
- Streamflow was calculated at the nearest surface water discharge point from recharge site.

- Modeling was done over a multi-year period to provide an indication of longer term response of groundwater discharge to the recharge process.

MAR Modeling Results

A summary of the GSFLOW modeling results for each tested MAR site is presented below. The graphs discussed in this section present monthly averages of flow differences induced by the simulated MAR projects. Negative cfs values are indicative of recharge to the project site (reflected as decreases in streamflow from the diversions to the project sites), while positive cfs values show the benefits to streamflow from the MAR project.

Site #1 Milan Road/Bear Creek

This site responded well to the MAR modeling simulation (Figure 8). Suitable March to May streamflow was generally available for infiltration, and associated increases in nearby streamflows of up to 0.2+ cfs were apparent over the modeled period, including during critical low streamflow periods. This site was selected for field investigations, including infiltration testing. The field investigations will be summarized in a separate memorandum to be completed after field work is complete.

Site #2 Otter Creek 1

This site responded somewhat poorly to the MAR modeling simulation. Instream flow benefits were inconsistent, with poor timing of release to nearby surface water. Based on these results, it does not appear that this specific site warrants further consideration as an MAR site; however, other sites may exist in the Otter Creek area where the timing of release of recharged water back to surface water would be more suitable. Based on these results, it does not appear that this site warrants further consideration as an MAR site. Given the poor response, a figure with the modeling results was excluded from this memorandum.

Site #3 Feryn/Deadman

This site responded well to the MAR modeling simulation (Figure 9). Suitable March to May streamflow was available for infiltration, although with gaps. Associated increases in nearby streamflows of up to 0.4 cfs were apparent during portions of the modeled period, including during some, but not all critical low streamflow periods. This site was selected for field investigations, including infiltration testing. The field investigations will be summarized in a separate memorandum to be completed after field work is complete.

Site #4 Dartford 1

This site responded very poorly to the MAR modeling simulation due to insufficient streamflow availability for recharge. Based on these results, it does not appear that this site warrants further consideration as an MAR site. Given the poor response, a figure with the modeling results was excluded from this memorandum.

Site #5 Chattaroy – Deer Creek

This site responded very poorly to the MAR modeling simulation due to insufficient streamflow availability for recharge. Based on these results, it does not appear that this site warrants further consideration as an MAR site. Given the poor response, a figure with the modeling results was excluded from this memorandum.

Site #6 Deer Creek – Fire District

This site responded very poorly to the MAR modeling simulation due to insufficient streamflow availability for recharge. Based on these results, it does not appear that this site warrants further consideration as an MAR site. Given the poor response, a figure with the modeling results was excluded from this memorandum.

Site #7 Dry Creek 1

This site responded well to the MAR modeling simulation (Figure 10). Suitable March to May streamflow was generally available for infiltration, and associated increases in nearby streamflows of up to 0.2+ cfs were apparent over the modeled period, including during critical low streamflow periods. This site was selected for field investigations, including infiltration testing. The field investigations will be summarized in a separate memorandum to be completed after field work is complete.

Site #8 County Park/Last Chance Road

This site responded well to the MAR modeling simulation (Figure 11). Suitable March to May streamflow was available for infiltration during many, but not all periods, and associated increases in nearby streamflows of up to 0.2+ cfs were apparent over the modeled period, including during many critical low streamflow periods. We recommend that this site continue to be considered for a MAR project.

Site #9 Little Deep Creek 1

This site responded well to the MAR modeling simulation (Figure 12). Suitable March to May streamflow was available for infiltration during many, but not all periods, and associated increases in nearby streamflows of up to 0.3+ cfs were apparent over the modeled period, including during many critical low streamflow periods. We recommend that this site continue to be considered for a MAR project.

Site #10 Deadman

This site responded well to the MAR modeling simulation (Figure 13). Suitable March to May streamflow was available for infiltration during many, but not all periods, and associated increases in nearby streamflows of up to 0.2+ cfs were apparent early in the modeled period, including during many critical low streamflow periods. Additional increases in streamflow were predicted in later years of the modeling simulation. We recommend that this site continue to be considered for a MAR project.

Site #11 Little Deep Creek 2

This site responded poorly to the MAR modeling simulation due to insufficient streamflow during most periods, and limited streamflow benefits. Based on these results, it does not appear that this site warrants further consideration as an MAR site. Given the poor response, a figure with the modeling results was excluded from this memorandum.

Site #12 Deer Creek

This site responded poorly to the MAR modeling simulation due to insufficient streamflow during most periods, and limited streamflow benefits. Based on these results, it does not appear that this site warrants further consideration as an MAR site. Given the poor response, a figure with the modeling results was excluded from this memorandum.

Site #13 Dry Creek 2

This site responded well to the MAR modeling simulation (Figure 14). Suitable March to May streamflow was generally available for infiltration, and associated increases in nearby streamflows of up to 0.2+ cfs were apparent over the modeled period, including during critical low streamflow periods. We recommend that this site continue to be considered for a MAR project..

Site #14 Otter Creek 2

This site responded somewhat poorly to the MAR modeling simulation due to inconsistent streamflow availability for recharge and corresponding inconsistent streamflow benefits. Based on these results, it does not appear that this site warrants further consideration as an MAR site. Given the poor response, a figure with the modeling results was excluded from this memorandum.

Site #15 Dragoon DNR

This site was located outside of the original study area but was added later in the study. It responded well to the MAR modeling simulation (Figure 15). Suitable March to May streamflow was available for infiltration during many, but not all periods, and associated increases in nearby streamflows of up to 0.2+ cfs were apparent over the modeled period, including during many critical low streamflow periods. We recommend that this site continue to be considered for a MAR project.

Site #16 Dartford 2

This site responded poorly to the MAR modeling simulation due to insufficient streamflow during most periods, and limited streamflow benefits. Based on these results, it does not appear that this site warrants further consideration as an MAR site. Given the poor response, a figure with the modeling results was excluded from this memorandum.

Site #17 Bear Creek

This site responded well to the MAR modeling simulation (Figure 16). Suitable March to May streamflow was generally available for infiltration, and associated increases in nearby streamflows of up to 0.2+ cfs were apparent over the modeled period, including during critical low streamflow periods. We recommend that this site continue to be considered for a MAR project.

Site #18 Otter Creek 3

This site was modeled as an early test case during development of the GSFLOW model. Variable recharge rates ranging from 1 to 3 cfs were tested. Suitable March to May streamflow was generally available for infiltration, and associated increases in nearby streamflows were predicted. We recommend that this site continue to be considered for an MAR project.

References

Jenkins, C.T., 1968, Computation of rate and volume of stream depletion by wells: U.S. Geological Survey Techniques of Water-Resources Investigations, Book 4, chap. D1, 17 p.

Hantush, M.S., 1967, Growth and decay of groundwater mounds in response to uniform percolation: Water Resources Research, v. 3, p. 227–234.

Attachments
Figure 1 – Percent Available Rise in Cell, Circular Basin at 1 cfs for 3 months
Figure 2 – Geologic Section Showing Areas with Percent Available Rise Greater than 50%
Figure 3 - Stream Augmentation Factor
Figure 4 – Area Beyond One Mile From Stream
Figure 5 - Surface Slope
Figure 6 – Public Lands
Figure 7 - Modeled Site Locations
Figure 8 - Site #1 Modeled Streamflow Differences, Milan Road/Bear Creek
Figure 9 - Site #3 Modeled Streamflow Differences, Feryn/Deadman
Figure 10 - Site #7 Modeled Streamflow Differences, Dry Creek 1
Figure 11 - Site #8 Modeled Streamflow Differences, County Park/Last Chance Road
Figure 12 - Site #9 Modeled Streamflow Differences, Little Deep Creek 1
Figure 13 - Site #14 Modeled Streamflow Differences, Deadman
Figure 14 - Site #13 Modeled Streamflow Differences, Dry Creek 2
Figure 15 - Site #15 Modeled Streamflow Differences, Dragoon DNR
Figure 16 - Site #17 Modeled Streamflow Differences, Bear Creek

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