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February 8, 2023

Washington County Water Conservancy District
Attn: Zach Renstrom, P.E.
533 East Waterworks Drive
Saint George, Utah 84770

RE: Review of USGS Report for Sand Hollow Reservoir
Washington County, Utah

Dear Mr. Renstrom,

We are pleased to present you with this summary for our review of U.S. Geological Survey (USGS) Scientific Investigations Report 2012-5236 for the Sand Hollow Reservoir Managed Aquifer Recharge (MAR) project, Washington County, Utah (Marston and Heilweil, 2012).

SCOPE OF WORK

We understand that Washington County Water Conservancy District (the District) is assessing whether the USGS Sand Hollow groundwater model presented in Marston and Heilweil (2012) properly accounts for water resources in the Hurricane Bench. By understanding the Sand Hollow groundwater model and its limitations will allow the District to make informed decisions about how groundwater resources in the Hurricane Bench should be managed in the future.

We reviewed Marston and Heilweil (2012) and also the following supplemental reports and maps:

- The geology of the central Virgin River basin, southwestern Utah, and its relation to ground-water conditions (Hurlow, 1998);
- Geohydrology and numerical simulation of ground-water flow in the central Virgin River basin or Iron and Washington Counties, Utah (Heilweil and others, 2000);
- Assessment of managed aquifer recharge at Sand Hollow Reservoir, Washington County, Utah, updated to conditions through 2016 (Marston and Nelson, 2018);

- Geologic map of the St. George and east part of the Clover Mountains 30' x 60' quadrangles, Washington and Iron Counties, Utah (Biek and others, 2010).

We spoke on the phone with:

- Tom Marston, USGS (verbal communication, January 20, 2023);
- Ken Richins, Hurricane City Water Department Superintendent (verbal communication, January 23, 2023); and
- Brent Gardner, Alpha Engineering, Hurricane City water system engineer (verbal communication, January 25, 2023).

Brent Gardner provided the following materials, which we also reviewed:

- Safe Yield – Navajo Sandstone – Hurricane Valley Area; Memo to Thomas Marston and Brie Thompson, dated May 30, 2022 (Alpha Engineering, written communication, January 25, 2023); and
- Hydrogeologic Report of Hurricane Basin prepared for Creamer and Noble, Inc. and Hurricane City (Montgomery, 1978).

We summarize our findings in this letter report.

USGS SAND HOLLOW MODEL

Marston and Heilweil (2012) summarize a numerical groundwater-flow model that was developed by the USGS to simulate groundwater movement in the Hurricane Bench area and groundwater recharge from Sand Hollow Reservoir (the Sand Hollow model). The purpose of Marston and Heilweil (2012) is to describe the groundwater hydrology of the Hurricane Bench area and to present the construction, calibration, and projected results of the groundwater-flow model, including recharge from Sand Hollow Reservoir. Marston and Heilweil (2012) is the culmination of numerous other studies conducted by the USGS and others to characterize the geologic, hydrologic and groundwater conditions in the Hurricane Bench area.

In general, based on available data, the Sand Hollow model accurately simulates recharge from Sand Hollow Reservoir and movement of groundwater through the Hurricane Bench area. However, we believe that some aspects of the natural system are not accounted for in the model, which we present in the following sections.

Model Framework

The Sand Hollow groundwater model was discretized to account for the Navajo Sandstone and the underlying Kayenta Formation in the Hurricane Bench area. All natural recharge and MAR from Sand Hollow Reservoir is assumed to flow into the Navajo Sandstone. Quaternary-age volcanic units and related alluvial deposits from erosion of the volcanics are not considered in the model even though these units overlie Navajo Sandstone throughout a significant portion of the east side of Hurricane Bench. The volcanics may have localized physical and recharge impacts to the Navajo Sandstone and are not addressed. It is likely that the volcanic necks that intruded through the Navajo Sandstone altered the sandstone and affected the hydraulic conductivity of the sandstone in these localized areas.

Two wells drilled near the eastern boundary of the Sand Hollow model at the base of the Hurricane Cliffs in Grass Valley penetrated volcanic sedimentary deposits and volcanic bedrock to approximate depths of 500 feet (Well Identification Numbers 8174 and 9455) with static water levels of approximately 465 feet measured in 1972 and 1981. It appears that these hydrogeologic conditions are not represented in the model. The geologic and potentiometric surface map presented in Montgomery (1978) indicate that this area is trough shaped and groundwater flows to the southeast towards the Hurricane Fault then south into Warner Valley. This potential diversion from the groundwater system will need future analysis.

The Springdale Sandstone geologic unit is not accounted for in the Sand Hollow model. The Springdale Sandstone is stratigraphically located at the base of the Kayenta Formation with a reported thickness of 90 to 150 feet. The unit has a similar lithology to the Navajo Sandstone. Hurlow (1998) and Heilweil and others (2000) state that the Springdale Sandstone is a member of the Moenave Formation; however, Biek and others (2010) indicate the Springdale Sandstone is a member of the Kayenta Formation. Omission of the Springdale Sandstone in the Sand Hollow model may underestimate groundwater storage capacity in the Hurricane Bench. The Springdale Sandstone is a potential aquifer in the area that may be underutilized and collecting additional hydrogeologic data from the unit can help evaluate this possibility and expand groundwater supply potential. Groundwater in the Springdale Sandstone may also be under confined conditions in certain areas, which adds complexity to the hydrogeologic conditions in the Hurricane Bench.

Model Boundaries

The perimeter of the Sand Hollow model is assumed to be a no flow boundary, with the exception of where the Virgin River crosses the model domain. The Virgin River is modeled as a head-dependent boundary to allow groundwater to discharge to the river. The Sand Hollow model assumes that groundwater in the Navajo and Kayenta formations flows towards the Virgin River and is withdrawn from wells or discharges to the Virgin River. There are several springs located along the west side of the Hurricane Bench (Willow Spring, Sand Mountain Spring, Sand Spring, Warner Spring, Berry Spring) that discharge from the either the Navajo Sandstone or the Springdale Sandstone. Although the total discharge of the springs may not be significant the underlying assumption of the boundary condition is not accurately portrayed. The groundwater flow model presented in Heilweil and others (2000) for the main part of the Navajo and Kayenta aquifers, which includes the area in question, utilized drain cells for western portion of Hurricane Bench in the model. Tom Marston communicated to LRE that model drain cells for this area have been incorporated into an updated Sand Hollow model which is currently still under review by the USGS.

The eastern boundary of the model does not extend to the Hurricane Fault. Normal faults, like the Hurricane Fault, are often characterized as a barrier to groundwater flow across the fault and a conduit to flow parallel to the fault. The hydrogeologic conditions along the Hurricane Fault are likely complex and poorly understood, due to a lack of data. Therefore, it is understandable why the Sand Hollow model boundary does not extend to the Hurricane Fault. However, omission of the sliver of the Hurricane Bench between the model boundary and the Hurricane Fault does not account for potential recharge in this area.

Hydraulic Conductivity

The hydraulic conductivity values of the Navajo Sandstone in the vicinity of Sand Hollow Reservoir are well constrained and are within reported value ranges for the formation. However, the uncertainty in model parameters increases with distance from the reservoir due to a lack of data from wells that penetrate the Navajo Sandstone, especially in the eastern portion of the Hurricane Bench.

Recharge

The Sand Hollow model does not account for recharge of unconsumed irrigation water. Irrigation occurs in the northeast portion of the Hurricane Bench and Heilweil and others (2000) estimate that up to 4400 acre-feet per year (ac-ft/yr) of recharge to the Navajo

Sandstone in the Hurricane Bench occurs from unconsumed irrigation water. The groundwater flow model presented in Heilweil and others (2000) for the main part of the Navajo and Kayenta aquifers used a recharge rate of 1050 ac-ft/yr for unconsumed irrigation water in this portion of the Hurricane Bench.

In addition, it does not appear that recharge from ephemeral streams is accounted for in the Sand Hollow model. The Gould Wash drainage area discharges onto the eastern side of the Hurricane Bench and may provide a source of recharge. Heilweil and others (2000) estimate 13 to 220 ac-ft/yr of water recharges the Navajo Sandstone along Gould Wash. Frog Hollow is another area that may provide additional recharge to the Navajo Sandstone.

Recharge from underlying geologic units are not accounted for in the Sand Hollow model. Heilweil and others (2000) also show an area in the northwest portion of the Hurricane Bench area where recharge from underlying geologic units may occur, which is estimated to be approximately 1085 ac-ft/yr based on a solute mass balance approach. We assume that recharge from underlying geologic units occurred by groundwater in the Springdale Sandstone flowing upward through the Kayenta Formation and into the Navajo Sandstone.

Irrigation of golf courses is also not addressed in the model. Given the basement flooding issues that occurred to homes at the Sand Hollow Resort, recharge to the Navajo Sandstone likely occurs from irrigation of golf courses in the area.

We believe that groundwater recharge in the Hurricane Bench may be underestimated in Marston and Heilweil (2012) based on the reasons explained above.

Discharge

Herbert and others (1995) estimated that there is a gain of 7.2 cubic feet per second (cfs) in the Virgin River downstream of Hurricane based on a seepage study conducted during November 1994. Marston and Heilweil (2012) assume that the contribution of this gain in flow to the Virgin River from groundwater discharge from the Hurricane Bench is about half the total gain in flow. Under steady-state conditions (average conditions for 1975) discharge to the Virgin River equals recharge from precipitation, which was estimated to be 2100 ac-ft/yr. Conducting an additional seepage study of this section of the Virgin River could provide additional data to further constrain the groundwater budget for the Hurricane Bench.

SAFE YIELD

LRE understands that one of the critical questions that the District and Hurricane City is seeking is what is the safe yield of the Navajo Sandstone in the Hurricane Bench. Evaluating the safe yield of an aquifer can be difficult because it depends upon several factors, but is ultimately based on what is an acceptable impact to an aquifer. Therefore, before a constructive dialogue about safe yield can begin it needs to be explicitly defined. Another term that is often synonymous with safe yield is sustainable groundwater use. Safe yield of an aquifer, or sustainable groundwater use, can be defined as any of the following:

- Groundwater withdrawals that do not exceed natural recharge to an aquifer;
- Groundwater withdrawals that do not exceed what is artificially recharged to an aquifer; and
- Groundwater withdrawals that do not exceed a certain pre-determined threshold that represents the maximum allowable impact to an aquifer.

One complicating factor in many areas is that groundwater pumping has already depleted the local aquifer and a return to pre-pumping conditions is nearly impossible to achieve (i.e. mining of groundwater). Another factor that complicates safe yield determination is local hydrogeologic conditions. MAR typically does not reach the entire aquifer, so there could be an abundant groundwater supply in one portion of the aquifer and a declining groundwater supply in another portion. Changes in land use must also be considered when evaluating safe yield. Groundwater recharge of unconsumed irrigation water can be significant, and if this recharge component will be eliminated through a change in land use, then it must be factored into the groundwater budget and safe yield of the aquifer.

Based on our review of the groundwater conditions in the Hurricane Bench area, the recharge components and quantities are summarized as follows:

Recharge Component	**Quantity (ac-ft/yr)**	**Reference**
Infiltration of precipitation	2100	Marston and Heilweil (2012)
Unconsumed irrigation water	< 4400	Heilweil and others (2000); 1050 acre-ft/yr in their model
Seepage from ephemeral streams	13 to 220	Heilweil and others (2000)

Recharge Component	Quantity (ac-ft/yr)	Reference
Upwelling from underlying formations	1085	Heilweil and others (2000)
Sand Hollow MAR	8000 to 9000	Verbal communication from the District
Total Potential Recharge	**11,200 to 16,500** (rounded)	

The most conservative estimate of safe yield for the Hurricane Bench is 2100 ac-ft/yr. Alternatively, the safe yield may be as great as approximately 11,000 ac-ft/yr. The most recent (2021) water use data from the Utah Division of Water Rights (DWRi) indicates that well withdrawals in the Hurricane Bench totaled approximately 6100 acre-feet (approximately 2100 and 4000 acre-ft for Hurricane City and the District, respectively). Therefore, it is possible that the safe yield of the Navajo Sandstone in the Hurricane Bench is already being exceeded.

Evaluating the water budget and safe yield of an aquifer is a constructive exercise because it can lead to identification of MAR, water-use and conservation objectives, which are often achieved through a phased approach that scales recharge and conservation efforts upward and water-use downward overtime.

We understand that the District desires that the DWRi establish a groundwater management plan for the Hurricane Bench area. It will likely be up to the local water users (stakeholders) to create a vision of what sustainable groundwater use looks like and to determine what a groundwater management plan entails. We offer some considerations about the groundwater management plan.

A groundwater management plan should provide the administrative framework that informs upgradient and downgradient water users (stakeholders) of what measures will be executed at defined threshold events. The goal of the groundwater management plan is to promote regional cooperation for the appropriate management of groundwater in the area. The groundwater management plan should also be flexible so that the executed measures can be modified as conditions change or new data is gathered. This can be accomplished by taking a tiered approach to the plan. Such a plan will allow stakeholders (1) to see current conditions so that proactive measures can be planned accordingly, (2) devise metrics for success/progress, and (3) execute measures.

An appropriate monitoring network of groundwater levels throughout the Navajo Sandstone aquifer will be important for transparent sharing of data among the stakeholders. Investment in the monitoring network by the stakeholders will help build collaboration between stakeholders and help distribute the cost of managing the network.

Because safe yield of the aquifer is a dynamic quantity, the plan could initially set limits on pumping based on current or near-term water use demands and focus on the collection of important (pumping and water level) data. If water levels in the aquifer reach a certain pre-determined criteria, tiered actions could be implemented, which likely involve reductions to pumping and certain water uses and possibly increases to recharge operations. If water levels in the aquifer continue to decline to another pre-determined criteria, additional tiered actions could be implemented, which would require that the stakeholders agree on appropriate measures to execute.

CONCLUSIONS

The primary objective of the Sand Hollow model is to simulate MAR from Sand Hollow Reservoir and the subsequent movement of groundwater through the Hurricane Bench area. We believe that the model achieves this objective at a regional scale, but local areas of excessive pumping will require additional monitoring. However, the hydrogeologic system is more complicated than what is presented in the model especially along the east side of Hurricane Bench and along the Hurricane Fault. Because some recharge (unconsumed irrigation water, ephemeral stream, subsurface geologic units) and discharge (springs and Virgin River discharge) was not accounted for in the model or is poorly constrained, the underlying water budget of the model may be underestimated. However, the quantity of water recharged from Sand Hollow Reservoir is significantly greater than any of these components and is the predominant factor driving the groundwater system in the area. The collection of additional data in areas with limited data can help refine and update the model in the future.

The safe yield of the Navajo Sandstone in the Hurricane Bench is an uncertain number that may be as low as 2100 ac-ft/yr or as high as 11,000 ac-ft/yr depending on how safe yield and sustainable groundwater use are defined. A groundwater management plan for the Hurricane Bench can establish an administrative framework for groundwater use in the area while additional data is collected and evaluated prior to the determination of the safe yield. A successful groundwater management plan will likely involve:

- Identification and engagement of stakeholders to build consensus toward a proposed plan.

- Development of a monitoring network with stakeholder investment to provide the transparent sharing of data.
- Ongoing stakeholder engagement to promote understanding of collected data and delineation of how metrics will be used to demonstrate proper groundwater resource management in the aquifer.
- A tiered approach with flexible action items, which will likely be easier to implement and also provide more stakeholder involvement and collaboration.

If you have any questions about this letter report, please contact me at (801) 541-4426 (mobile) or neil.burk@LREwater.com.

Sincerely,

LRE WATER

Neil I. Burk, P.G.
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