PEER REVIEW OF HYDROGEOLOGIC PUBLICATIONS RELATED TO THE
GROUNDWATER CONDITIONS IN THE MOAB-SPANISH VALLEY AREA,
GRAND AND SAN JUAN COUNTIES, UTAH

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1. INTRODUCTION

The groundwater resources in the Moab-Spanish Valley area (see Figure 1) have been the subject of scientific investigations ever since the publication of the first study of these resources in 1971 (Sumison, 1971). More recently, increased usage due to development combined with decreased recharge due to climate change have compelled several of the various agencies concerned with water supply issues in the area to invest in supporting additional investigations to determine whether the Utah Division of Water Rights (UDWRi) should be approached to request that the groundwater resources in the area be closed to further appropriations.

Because of the rather large number of documents on the subject of the groundwater resources in the Moab-Spanish Valley area and their technical nature, a need for a peer review of them became apparent, as well as the preparation of a summary of each one in relatively non-technical terms for the various stakeholders involved in managing the water resources in the area. Of particular interest to the stakeholders are the series of four reports prepared by Dr Kenneth E Kolm of Hydrologic Systems Analysis, LLC, and Paul K M van der Heijde of Heath Hydrology, Inc (Kolm and van der Heijde, 2018; 2019; 2020a; 2020b) for the City of Moab, as well as a report prepared contemporaneously but independently by the USGS (Masbruch, Gardner, Nelson, Heilweil, Solder, Hess, McKinney, Briggs and Solomon, 2019), which subsequently was published in a well-respected, peer-reviewed scientific journal (Gardner, Nelson, Heilweil, Solder and Solomon, 2020).

It has been decided that a peer review of the many documents pertaining to the groundwater resources in the Moab-Spanish Valley area will be an excellent next step in protecting these resources. Utah State University (USU) has been selected to perform the peer review and prepare a non-technical summary of the many documents for several reasons, including: (1) USU is the State Land Grant University, and is respected by state agencies, including the State Engineers Office (UDWRi) and the Utah Geological Survey (UGS); (2) no one at USU has been involved in any of the previous investigations, as has Dr D Kip Solomon, who is a professor at the University of Utah; (3) the USU Moab campus will be a new user of the water resources of the area and will impose a significant new load on the water system.

This report is the result of the peer review of the many documents related to the groundwater resources in the Moab-Spanish Valley area, and contains relatively non-technical summaries of each document. The individual summaries are presented in chronological order based on publication date in the next section (Section 2). Section 3 presents an overall summary (Subsection 3.1) of the various documents, as well as the most important conclusions (Subsection 3.2) deduced and the most important recommendations (Subsection 3.3) made by them. Finally, complete citations of all of the documents are listed in alphabetical order based on the first author’s last name in Section 4 (References).
Figure 1. Location map of the Spanish Valley study area, and the Moab-Spanish Valley watershed, Grand and San Juan Counties, Utah (Masbruch, Gardner, Nelson, Heilweil, Solder, Hess, McKinney, Briggs and Solomon, 2019).
2. INDIVIDUAL REPORT SUMMARIES

2.1 Sumison (1971)

This is the seminal work on the groundwater resources of the Moab-Spanish Valley area. It is cited, as well as expounded upon, by most, if not all, of the subsequent investigations.

Sumison identified the two principal aquifer systems, the Wingate and Navajo Sandstones of the Glen Canyon Group, and the Quaternary deposits of the Spanish Valley area. He also characterized the hydraulic properties and chemical quality of these two aquifer systems.

Perhaps most importantly, though, he created the first “Hydrologic Balance” for the groundwater basin in Spanish Valley and for the Spanish Valley area (Table 3), which is reproduced on the following page.

Finally, he created an electric analog model (a precursor of digital computer models) to predict the effects of both continued and increased withdrawals of groundwater on water levels. The model results indicated that an estimated 190 acre-feet per year of additional groundwater could be diverted for beneficial use, and that it would have the least effect on water levels if it was diverted at the northwest end of the valley.
Table 1. Sumison (1971) hydrologic balance.

<table>
<thead>
<tr>
<th>Groundwater basin in Spanish Valley:</th>
<th>Acre-feet per year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recharge</td>
<td>14,000¹</td>
</tr>
<tr>
<td>Discharge</td>
<td></td>
</tr>
<tr>
<td>Groundwater outflow</td>
<td>8,000</td>
</tr>
<tr>
<td>Net groundwater withdrawal use</td>
<td>6,300</td>
</tr>
<tr>
<td>Total discharge (rounded)</td>
<td>14,000</td>
</tr>
</tbody>
</table>

**Spanish Valley area:**

| Inflow                              |                    |
| Weighted mean precipitation (15 in.)| 115,000             |

| Outflow                             |                    |
| Water yield                         |                    |
| Surface runoff                      | 14,000²             |
| Groundwater discharge from Spanish Valley (includes base flow) | 14,000 |
| Subtotal (3.6 in.)                  | 28,000              |

| Water loss                          |                    |
| Consumptive use (11.4 in.)         | 87,000³             |
| Total (15 in.)                      | 115,000             |

¹Assumed equal to the total discharge.
²Average discharge of Mill Creek and Pack Creek plus gain of Mill Creek from the gaging sites to the confluence of Mill Creek with the Colorado River.
³Assumed equal to difference between inflow and outflow.
2.2 Eychaner (1977)

Six years after Sumison’s publication, the results of a “modern” digital computer model were published. It is important to note that Eychaner’s model was prepared and adjusted based largely on data presented in Sumison’s earlier publication.

Eychaner’s model was used to predict the effects of a proposed annual diversion of 3,200 acre-feet from Mill Creek through a new tunnel near Sheley Tunnel into the channel of Pack Creek near the head of Spanish Valley. The diverted water would seep into the subsurface and recharge the Quaternary valley fill deposits, and permit increased withdrawals from wells for irrigation lower in the valley.

The model was run for a simulated time of two years with increased recharge but without increased withdrawal followed by five years of both. The model predicted there would be a maximum water-level rise of about 28 feet in the recharge area and a maximum decline of about five feet in part of the irrigated area. Eychaner also speculated there likely would be a gradual improvement in the chemical quality of groundwater in Spanish Valley because the recharge water was of better quality than the existing groundwater in the Quaternary valley fill deposits.
2.3 Blanchard (1990)

Nearly twenty years after Sumison’s publication, an updated report on the groundwater conditions in the (Moab/Mill Creek-) Spanish Valley area was published. The area of Blanchard’s investigation included all of Grand County, plus the Mill Creek and Pack Creek drainages in San Juan County, as well as the area between the Colorado and Green Rivers in San Juan County. However, his study was concentrated in the Mill Creek-Spanish Valley area because it was the area where most groundwater development was expected to occur. Also, his investigation focused exclusively on the bedrock aquifers of the Glen Canyon Group, ignoring the Quaternary valley fill deposits in Spanish Valley itself. He included the Entrada Sandstone as a third important water-bearing formation within the Glen Canyon Group, along with the Navajo and Wingate Sandstones.

From April 1985 through October 1986, Blanchard collected much new data, consisting of an inventory of wells and springs, monthly measurements of water levels in wells, a streamflow gain-loss study in the Mill Creek and North Fork Mill Creek drainages, and an 8-day, multiple-well pumping test in the Moab City well field. In addition to water-level measurements, the well and spring inventory included discharge measurements, measurements of field water-quality parameters, and collection of water samples for chemical analysis.

Blanchard noted that water levels in the Glen Canyon aquifer declined until about 1979, and then rose as much as 39.5 feet from 1979 to 1987. He attributed the rise to above-average precipitation that began in 1977.

Blanchard stated that discharges from wells in the Glen Canyon aquifer ranged from less than 10 up to a maximum of 2,000 gallons per minute reported for one of the wells in the Moab City well field. Spring discharges ranged from 15 to 390 gallons per minute. He noted that the larger discharges occurred where the formations in the Glen Canyon Group were fractured and/or faulted.

As for water quality, Blanchard noted that concentrations of dissolved solids and sulfate increased south and west of the Moab City well field because a smaller proportion of the groundwater is supplied by the Glen Canyon aquifer while a larger proportion is supplied by the Quaternary valley fill deposits. He also noted that dissolved solids concentrations in the Navajo aquifer are higher along the Moab fault.

Finally, Blanchard also reported on other consolidated rock aquifers in the larger area beyond Mill Creek-Spanish Valley, including the Cedar Mountain Formation, the Brushy Basin Shale and Salt Wash Sandstone Members of the Morrison Formation, the White Rim Sandstone Member of the Cutler Formation, as well as the undifferentiated Cutler Formation.
2.4 Steiger and Susong (1997)

The report authored by Steiger and Susong follows in the proverbial footsteps of Sumison and Blanchard. Their investigation focused primarily on the quality of groundwater in the Glen Canyon and valley-fill aquifers, and included the results of 141 chemical analyses of water collected from 57 wells and springs. These chemical data included analyses of groundwater samples from both Sumison’s and Blanchard’s studies, and were augmented with data from Utah Division of Water Quality files, as well as with either 30 or 33 samples (the number is reported inconsistently within the document) collected in December 1995 as part of this investigation.

The stated purpose of the report was to provide “… hydrologic data and information to support Grand County commissioners and city of Moab officials in preparing and implementing a plan for managing ground-water quality for the Spanish Valley area.” The report also states that, in response to “… a rapid increase in development of residential and business property …”, the Grand County commissioners would like to classify the groundwater system in accordance with the State’s administrative rules to establish groundwater protection levels used to regulate existing and potential sources of groundwater contamination from new and existing facilities within the classified area.

The report identifies and provides maps of primary recharge areas for the Glen Canyon and valley-fill aquifers, and water-quality characteristics in each of the two aquifers. Regarding the latter, concentrations of trace metals and organic constituents were less than State of Utah standards, except for one well that had a lead concentration equal to the standard of 15 μg/L. One well completed in sandstone older than the formations comprising the Glen Canyon aquifer exceeded the State standard for nitrate plus nitrite. In addition, an area in the central part of Spanish Valley had nitrate plus nitrite concentrations that exceeded 3.0 mg/L, which the authors speculated possibly was the result of human activities.
2.5 Eisinger and Lowe (1999)

Eisinger and Lowe examined in detail all of the geologic units in Grand County, with an emphasis on each unit’s hydrologic characteristics and significance. For the most part, this report relies on data presented in previous investigations, particularly those by Sumison and Blanchard, with little or no new data collected by the authors themselves. The information is presented in summary form in a five-page table (Table 1) and then discussed in some detail in the text of the report.

Eisinger and Lowe subdivided the many and various geologic units in Grand County into nine fractured rock aquifers, consisting of, from oldest to youngest, the: (1) Lower Paleozoic aquifer, (2) Cutler aquifer, (3) Wingate aquifer, (4) Navajo aquifer, (5) Entrada aquifer, (6) Morrison aquifer, (7) Dakota aquifer, (8) Wasatch aquifer, and (9) Parachute Creek aquifer. Unconsolidated deposits comprise the other type of aquifer. The hydrologic characteristics of each of these ten aquifers are discussed first, followed by their water quality characteristics, with a section inserted between them that discusses recharge and discharge, as well as groundwater flow direction.

Eisinger and Lowe emphasized the importance of the unconsolidated aquifers and especially the Navajo Sandstone because it is one of the shallowest and most permeable formations, generally producing water with low concentrations of total dissolved solids. Therefore, it is the target for most bedrock wells and the principal source of drinking water in southern Grand County.
2.6 Kovacs (2000)

Kovacs prepared this report to document the project he conducted as part of the Master of Science degree in Civil and Environmental Engineering he earned at Brigham Young University. His project consisted of developing a three-dimensional, finite-difference digital computer model of the Spanish Valley area using MODFLOW and GMS. He also developed a particle-tracking model using MODPATH and GMS.

The purpose Kovacs stated for conducting his project was to estimate how much additional groundwater could be withdrawn without affecting water quality in the area. The motivation for his project came from the Grand County Water and Sewer Service Agency (GCWSSA), which had acquired rights for an additional 4,234 acre-feet of water per year. The GCWSSA, which supplies water to the unincorporated area of Spanish Valley southeast of Moab, intended to use the additional rights to meet future demand for water as development increased.

Kovacs relied heavily on the data collected and compiled by the five earlier reports for his model. The results showed that the entire 4,234 acre-feet per year could be withdrawn from groundwater without adversely affecting water quality in the area. His particle-tracking analysis showed that the water withdrawn from wells along the east side of the valley would be supplied by the Glen Canyon Group or by leakage from Ken’s Lake, and that lower quality water from the western side of the valley would not be drawn into the capture zones of the wells. The model also showed that nearly half of the leakage from Ken’s Lake would end up being withdrawn by the proposed new wells.
Solomon’s first project related to the groundwater conditions in the Moab-Spanish Valley area was performed at the request of the Moab Mesa Land Company, LLC. Solomon stated that the objective of his study was to evaluate the age, and the temperature and elevation of groundwater recharge based on analyses of water samples collected from three springs and two wells. The samples were analyzed for stable isotopes of oxygen and hydrogen, tritium, and dissolved noble gases (his specialty).

Solomon’s results suggest that the groundwater in the three springs and two wells was recharged at high elevations (circa 2,000 to 2,500 meters), and was recharged prior to the peak of thermo-nuclear weapons testing in the early 1960s, and possibly before 1,000 A.D. However, he cautioned that, due to the very limited number of samples, the results of his reconnaissance study should be used mainly as a guide to the general nature of the groundwater flow system.
These two documents were prepared as part of the same investigation but for different purposes. The first (in time) is a report that appears to have been written for an unspecified entity that presumably funded the study. The authors are a former University of Utah graduate student and his advisor. The second is the thesis that the graduate student wrote as part of the Master of Science degree in Geology that he earned from the University of Utah.

This investigation is concerned with the subsurface hydrologic connection between the Moab Mill Tailings, to the west, and the Matheson Wetland Preserve, to the east, which are located on opposite sides of the Colorado River. It was suspected that channel gravels may have been allowing contaminated groundwater from the Mill Tailings to pass beneath the river toward the Wetland Preserve.

Three new boreholes were drilled and logged on the Wetland Preserve to define more clearly the extent of the channel gravels. In addition, water samples were collected and analyzed for uranium, as well as for stable isotopes of oxygen and hydrogen, tritium, and dissolved noble gases in order to understand their ages and sources of recharge.

The lithologic logs from the three new boreholes showed that channel gravels exist at a depth of around 18 feet below the ground surface across the northwestern portion of the Matheson Wetland Preserve, and that they extend into the Wetland Preserve more than 2,300 feet from the Colorado River. The chemical data indicated the existence of a shallow, fresh groundwater system recharged by irrigation return flows and local groundwater of the valley-fill aquifer. This system was underlain by denser, contaminated brine, suggesting that contamination from the Moab Mill Tailings had indeed migrated beneath the Colorado River in the channel gravels.

In addition to these two documents, there are two others that appear to be Microsoft PowerPoint presentations containing virtually the same information. One is entitled “Hydrogeologic investigation of the Scott M. Matheson Wetland Preserve in Moab, Utah.” The only other identifying information is that the first slide states it was funded by The Nature Conservancy and the State of Utah Department of Environmental Quality. The other document is entitled “Hydrologic evaluation of Matheson Wetland Preserve.” It contains no other information that might be used to identify who prepared it or when, or who might have funded it.
Crowley’s project focused on quantifying the overall contribution of evapotranspiration on the water budget for the Matheson Wetland Preserve. His project was performed to inform the Nature Conservancy, which jointly manages the wetland preserve with the Utah Department of Wildlife, as to whether increased use of groundwater from the Glen Canyon Group aquifer (GCGA) would have a detrimental effect on water levels.

I was not familiar previously with the methods Crowley used for estimating evapotranspiration. However, the explanations in his report were clear and thorough, and his methods seemed sound and justified to me.

Crowley employed the Penmann-Monteith equation to calculate estimates of evapotranspiration. First, he divided the wetland preserve into five vegetation zones: (1) healthy native vegetation, (2) unhealthy native vegetation, (3) healthy tamarix, (4) unhealthy tamarix, and (5) open water and open water plants. Then he estimated the acreage of each zone. Finally, he used values from the literature for the “average crop factor” parameter required for calculating evapotranspiration using the Penmann-Monteith equation for each zone.

Crowley’s final estimate for wetland evapotranspiration was 3,200 acre-feet per year. This is remarkably close to the value of 3,000 acre-feet per year Sumison estimated using a far less sophisticated approach. This unexpected agreement appears to lend more credence to Sumison’s “Hydrologic Balance,” the first of its kind for the Moab-Spanish Valley area, which has been reproduced in Table 1 on page 4.

In addition to Crowley’s report, there is a second document entitled “Ecohydrology in a Colorado River riparian forest: Implications for the decline of *Populus fremontii*,” by D.E. Pataki, S.E. Bush, P. Gardner, D.K. Solomon and J.R. Ehleringer. It appears to be a manuscript written for a scientific journal entitled “Ecological Applications.” However, it is not dated and contains no other information that might be used to identify it. Because it pertains to the decline of *Populus fremontii* (Fremont cottonwood) along the Colorado River in the Moab area, it contains information that is beyond my area of expertise. Consequently, I did not read it in its entirety because I could not understand it, nor will I attempt to summarize it here.
2.10 Lowe, Wallace, Kirby and Bishop (2007)

The authors of this report state that the purpose of their investigation is to provide tools for water-resource management and land-use planning in the Moab-Spanish Valley area. To accomplish this purpose they: (1) characterized the relationship of geology to groundwater conditions in the Glen Canyon and unconsolidated valley-fill aquifers, (2) classified the groundwater quality of the Glen Canyon (east of the valley only) and valley-fill aquifers, and (3) applied a groundwater flow model to determine the potential impact on water quality in the valley-fill aquifer of a projected increase in the number of septic-tank systems in the San Juan County portion of the valley, in order to recommend appropriate septic-system density requirements to limit water-quality degradation.

This report draws heavily on the previous studies performed by Sumison, Blanchard, Steiger and Susong, Eisinger and Lowe, and (Downs and) Kovacs. The authors state that Steiger and Susong’s study was conducted specifically to provide data needed for groundwater quality classification. Furthermore, the authors used the three-dimensional, finite-difference digital computer model of (Downs and) Kovacs for the Spanish Valley area using MODFLOW and GMS, as well as the particle-tracking model using MODPATH and GMS. Finally, this report relies upon information presented in Table 1 in Eisinger and Lowe, which is presented as Table 4 in this report.

The authors’ groundwater flow analysis using a regional, three-dimensional, steady-state computer model indicated that two categories of recommended maximum septic-system densities were appropriate. In the central portion of the valley, the recommended minimum lot size was 10 acres, due to the greater amount of groundwater available for mixing per acre. In the southeastern portion and along the outer margins of the valley, the recommended minimum lot size was 20 acres.
2.11 Kolm and van der Heijde (2018; 2019)

These are the first two of four hydrogeologic assessment reports prepared by Kolm and van der Heijde for the City of Moab. They were prepared as phases of the same project. Phases 1, 2 and 4 all were related to the same goals; namely, developing a conceptual model of the hydrogeology of the Moab-Spanish Valley area, and creating an updated water budget for the area. Unfortunately, though, these three reports relied on data collected previously by others, and did not collect any additional field data to guide or supplement the authors’ assessment of the hydrogeology of the area.

The first (Phase 1) report introduces what the authors refer to as the Moab City Springs and Wells (MCSW) study area. Despite its name, the MCSW area is essentially the same as the Moab-Spanish Valley area, as it is located between the La Sal Mountains to the southeast, the Colorado River to the northwest, the Porcupine Rim to the northeast, and the Moab Rim to the southwest.

The Phase 1 report also introduces a concept that the authors refer to as a Hydrologic and Environmental System Analysis (HESA). This first report contains the results of the HESA for the MCSW area.

In developing their conceptual model, the authors divided the MCSW area into five Hydrogeologic Subsystems. They consist of: (1) two La Sal Mountain Upper Alluvium Subsystems, the Mill Creek headwaters and the Pack Creek headwaters (LSMA-M and LSMA-P); (2) the Wilson Mesa and South Mesa Alluvial Fan Subsystems (WMAF and SMAF); (3) the Glen Canyon Group Mill Creek Subsystem (GCMC); (4) the Glen Canyon Group Grandstaff Creek Subsystem (GCGC); (5) the Pack Creek Lower Alluvium Subsystem (PCLA).

The Phase 2 report presents the first water budget created by Kolm and van der Heijde. The water budget is only for the GCMC because it is the source of water for the springs and wells supplying the City of Moab. This report actually contains four water budgets (Tables 1a, 1b, 2a and 2b), one each for pre- and post-development using low and high estimates for consumptive use by phreatophytes. These four water budgets are reproduced in the table on the following page.
Table 2. Kolm and van der Heijde (2019) water budgets.

<table>
<thead>
<tr>
<th>WATER BUDGET COMPONENT</th>
<th>IN¹</th>
<th>OUT¹</th>
<th>IN²</th>
<th>OUT²</th>
<th>IN³</th>
<th>OUT³</th>
<th>IN⁴</th>
<th>OUT⁴</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recharge from precipitation</td>
<td>9155</td>
<td>-</td>
<td>9155</td>
<td>-</td>
<td>11339</td>
<td>-</td>
<td>11339</td>
<td>-</td>
</tr>
<tr>
<td>Groundwater underflow at upper Mill Creek boundary</td>
<td>4</td>
<td>0</td>
<td>4</td>
<td>0</td>
<td>4</td>
<td>0</td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>Direct runoff from precipitation to streams from storms + local snowmelt within budget area</td>
<td>0</td>
<td>-</td>
<td>0</td>
<td>-</td>
<td>0</td>
<td>-</td>
<td>0</td>
<td>-</td>
</tr>
<tr>
<td>Mill Creek inflow above later location of Sheley diversion</td>
<td>7546</td>
<td>-</td>
<td>6814</td>
<td>-</td>
<td>7546</td>
<td>-</td>
<td>6814</td>
<td>-</td>
</tr>
<tr>
<td>Irrigation return flow + septic tank infiltration</td>
<td>0</td>
<td>-</td>
<td>0</td>
<td>-</td>
<td>0</td>
<td>-</td>
<td>0</td>
<td>-</td>
</tr>
<tr>
<td>Consumptive use crops</td>
<td>-</td>
<td>0</td>
<td>-</td>
<td>0</td>
<td>-</td>
<td>0</td>
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<td>0</td>
</tr>
<tr>
<td>Consumptive use riparian vegetation</td>
<td>-</td>
<td>4009</td>
<td>-</td>
<td>4009</td>
<td>-</td>
<td>6193</td>
<td>-</td>
<td>6193</td>
</tr>
<tr>
<td>Springs (including Skakel)</td>
<td>-</td>
<td>2325</td>
<td>-</td>
<td>1860</td>
<td>-</td>
<td>2325</td>
<td>-</td>
<td>1860</td>
</tr>
<tr>
<td>Municipal use</td>
<td>-</td>
<td>1364</td>
<td>-</td>
<td>1875</td>
<td>-</td>
<td>1364</td>
<td>-</td>
<td>1875</td>
</tr>
<tr>
<td>Domestic consumptive use</td>
<td>-</td>
<td>80</td>
<td>-</td>
<td>120</td>
<td>-</td>
<td>80</td>
<td>-</td>
<td>120</td>
</tr>
<tr>
<td>Sheley diversion</td>
<td>-</td>
<td>0</td>
<td>-</td>
<td>3665</td>
<td>-</td>
<td>0</td>
<td>-</td>
<td>3665</td>
</tr>
<tr>
<td>Mill Creek outflow at delta</td>
<td>-</td>
<td>8927</td>
<td>-</td>
<td>5317</td>
<td>-</td>
<td>8927</td>
<td>-</td>
<td>5317</td>
</tr>
<tr>
<td>Change of storage</td>
<td>-</td>
<td>873</td>
<td>-</td>
<td>-</td>
<td>873</td>
<td>-</td>
<td>-</td>
<td>-</td>
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<tr>
<td>TOTALS</td>
<td>16705</td>
<td>16705</td>
<td>16846</td>
<td>16846</td>
<td>18889</td>
<td>18889</td>
<td>19030</td>
<td>19030</td>
</tr>
</tbody>
</table>

All units in acre-feet per year.
¹Pre-development using low estimate for consumptive use by phreatophytes.
²Post-development using low estimate for consumptive use by phreatophytes.
³Pre-development using high estimate for consumptive use by phreatophytes.
⁴Post-development using high estimate for consumptive use by phreatophytes.
2.12 Kolm and van der Heijde (2020a)

The focus of the Phase 3 report is the three drinking water source protection plans and drinking water source protection (DWSP) zones for: (1) Moab City’s Skakel Spring; (2) the City’s Springs 1, 2 and 3 near the golf course (“City of Moab Springs”); (3) the City’s wells (Wells 4, 5, 6, 7 and 10), also near the golf course. The report proposes to expand the delineations of the DWSP zones for Skakel Spring and the City of Moab Springs. The report also verifies that the existing delineations for the City’s wells are reasonably accurate and do not need adjustments at this time.

The Phase 3 report also provides a preliminary monitoring plan (PMP) containing guidance on source protection as it relates to the interaction between groundwater and surface water systems within the DWSP zones, and the continuation of the groundwater system and interacting streams beyond the DWSP zones. The PMP is intended to help protect Moab City’s water supply and water quality at Skakel Spring, and at the City of Moab Springs and wells.
2.13 Kolm and van der Heijde (2020b)

This is the fourth and final hydrogeologic assessment report prepared by Kolm and van der Heijde for the City of Moab. This report states that Phase 4 was added to the project in July of 2019 with the expressed purpose of creating an expanded water budget of the Spanish Valley, including a combined water budget for the Pack Creek Lower Alluvium (PCLA) and the GCMC hydrologic subsystems of the MCSW area. As with the four water budgets created for Phase 2, both pre- and post-development budgets were estimated. However, only two budgets were created, as they did not include low and high estimates for consumptive use by phreatophytes. The two water budgets (Tables 5 and 6) are reproduced in the table below.

Table 3. Kolm and van der Heijde (2020b) water budgets.

<table>
<thead>
<tr>
<th>WATER BUDGET COMPONENT</th>
<th>IN(^1)</th>
<th>OUT(^1)</th>
<th>IN(^2)</th>
<th>OUT(^2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direct runoff to streams</td>
<td>5925</td>
<td>-</td>
<td>5950</td>
<td>-</td>
</tr>
<tr>
<td>Recharge</td>
<td>8410</td>
<td>-</td>
<td>8050</td>
<td>-</td>
</tr>
<tr>
<td>Groundwater underflow at upper Mill Creek boundary</td>
<td>900</td>
<td>-</td>
<td>900</td>
<td>-</td>
</tr>
<tr>
<td>Groundwater underflow at upper Pack Creek boundary</td>
<td>100</td>
<td>-</td>
<td>100</td>
<td>-</td>
</tr>
<tr>
<td>Groundwater underflow at Brumley Creek</td>
<td>25</td>
<td>-</td>
<td>25</td>
<td>-</td>
</tr>
<tr>
<td>Mill Creek inflow above later location of Sheley diversion</td>
<td>7545</td>
<td>-</td>
<td>6815</td>
<td>-</td>
</tr>
<tr>
<td>Upper North Fork Creek and Burkholder Draw inflow from mesa’s (sic)</td>
<td>minor</td>
<td>-</td>
<td>Minor</td>
<td>-</td>
</tr>
<tr>
<td>Pack Creek inflow above later ditch diversion</td>
<td>1845</td>
<td>-</td>
<td>1755</td>
<td>-</td>
</tr>
<tr>
<td>Brumley Creek flow into Pack Creek</td>
<td>1100</td>
<td>-</td>
<td>1100</td>
<td>-</td>
</tr>
<tr>
<td>Consumptive use crops</td>
<td>-</td>
<td>0</td>
<td>-</td>
<td>3600</td>
</tr>
<tr>
<td>Consumptive use riparian vegetation</td>
<td>-</td>
<td>11190</td>
<td>-</td>
<td>8845</td>
</tr>
<tr>
<td>Evaporative loss open water</td>
<td>-</td>
<td>1460</td>
<td>-</td>
<td>1460</td>
</tr>
<tr>
<td>Municipal use (City of Moab and GWSSA)</td>
<td>-</td>
<td>0</td>
<td>-</td>
<td>2855</td>
</tr>
<tr>
<td>Domestic consumptive use</td>
<td>-</td>
<td>0</td>
<td>-</td>
<td>350</td>
</tr>
<tr>
<td>Groundwater discharge to Colorado River</td>
<td>-</td>
<td>750</td>
<td>-</td>
<td>750</td>
</tr>
<tr>
<td>Mill Creek outflow to Colorado River</td>
<td>-</td>
<td>12450</td>
<td>-</td>
<td>10830</td>
</tr>
<tr>
<td>Release from storage</td>
<td>-</td>
<td>0</td>
<td>3995</td>
<td></td>
</tr>
<tr>
<td>TOTALS</td>
<td>25850</td>
<td>25850</td>
<td>28690</td>
<td>28690</td>
</tr>
</tbody>
</table>

All units in acre-feet per year.

\(^1\) Pre-development.

\(^2\) Post-development.
These two documents present the results of the same investigation. The first document is a report published by the United States Geological Survey (USGS). It has nine co-authors. The second is a paper published in a well-respected, peer-reviewed scientific journal by five of the nine co-authors of the USGS report.

The most important accomplishment of this investigation probably is the authors’ updated (ground)water budget for the combined Glen Canyon Group aquifer (GCGA) and the valley-fill aquifer (VFA). Besides Crowley’s estimate of wetland evapotranspiration, none of the other components of Sumison’s water budget had been re-estimated prior to the Kolm and van der Heidje reports. Because their reports were contemporaneous with this investigation, presumably the authors of these two documents were unaware of the water budgets prepared by Kolm and van der Heidje.

The most important difference between this investigation and the Kolm and van der Heidje reports is that these authors collected much valuable new data, including: (1) water samples from 41 wells, 9 springs and 18 surface water sites (the 2020 paper only included samples from 38 wells and 4 streams, plus the 9 springs, for a total of 51 sites); (2) vadose-zone pore-water samples from cores retrieved from four borehole sites along Sand Flats Road; (3) stream and spring discharge measurements; (4) a geophysical survey measuring electrical conductivity, and the drilling, installation and aquifer testing of twelve new observation wells in the Matheson Wetland Preserve.

The 68 (51) water samples were analyzed for: (1) field parameters (specific conductance, pH, temperature, dissolved oxygen and total dissolved-gas pressure); (2) major ions (Ca, Mg, Na, K, alkalinity, SO₄, Cl, SiO₂, F, Br, Fe, Mn and NO₃ plus NO₂); (3) stable isotopes of oxygen (¹⁸O) and hydrogen (²H); (3) tritium (³H) and helium isotopes (³He and ⁴He); (4) noble gases (²⁰Ne, ⁴₀Ar, ⁶⁴Kr and ¹²⁹Xe); (5) chlorofluorocarbons (CFC-11, CFC-12 and CFC-113) and sulfur hexafluoride (SF₆); (6) carbon isotopes (¹³C and ¹⁴C).

Sixteen core samples from the four borehole sites were analyzed for vadose-zone Cl, ³H, and ¹⁸O and ²H. Vadose-zone Br also was analyzed for a subset of ten core samples.

The results of the authors’ analyses of the new data they collected led them to arrive at the following conclusions: (1) recharge to the deeper part of the GCGA only occurs at high altitudes in the La Sal Mountains; (2) recharge to the shallower part of the GCGA likely occurs at middle altitudes along the mountain front, with relatively small amounts as infiltration of precipitation at the lower-altitude Sand Flats area; (3) recharge to the VFA occurs from subsurface groundwater inflow from the upper Pack Creek drainage and loss from Pack Creek; (4) subsurface outflow from the lower Moab-Spanish Valley to the Colorado River is much smaller than previously estimated; (5) the overall groundwater budget is much less than previous estimates.

The greatly revised (reduced) annual 2014, 2015 and 2016, and average annual groundwater budgets for the Moab-Spanish Valley area (Table 11 in Masbruch, Gardner, Nelson, Heilweil, Solder, Hess, McKinney, Briggs and Solomon, 2019) is reproduced in the table below.
Table 4. USGS groundwater budget.

<table>
<thead>
<tr>
<th></th>
<th>2014</th>
<th>2015</th>
<th>2016</th>
<th>Average annual</th>
<th>Uncertainty (percent)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Recharge</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Direct infiltration of precipitation (in-place recharge)(^1)</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>9,000 to 27,000</td>
<td>50</td>
</tr>
<tr>
<td>Infiltration of runoff (includes recharge from losing reaches of streams and unconsumed surface-water irrigation)(^1)</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>510 to 2,550</td>
<td>50</td>
</tr>
<tr>
<td>Unconsumed irrigation from well withdrawals</td>
<td>25 to 125</td>
<td>8 to 40</td>
<td>9 to 45</td>
<td>N/A</td>
<td>unknown</td>
</tr>
<tr>
<td><strong>Total:</strong></td>
<td></td>
<td></td>
<td></td>
<td>9,550 to 30,000</td>
<td></td>
</tr>
<tr>
<td><strong>Discharge</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Streams and springs (base flow)</td>
<td>10,600</td>
<td>11,700</td>
<td>10,200</td>
<td>N/A</td>
<td>5</td>
</tr>
<tr>
<td>Springs and well withdrawals for culinary use</td>
<td>2,400</td>
<td>3,000</td>
<td>3,300</td>
<td>N/A</td>
<td>unknown</td>
</tr>
<tr>
<td>Well withdrawals for irrigation (net depletion)</td>
<td>250</td>
<td>80</td>
<td>89</td>
<td>N/A</td>
<td>unknown</td>
</tr>
<tr>
<td>Subsurface outflow</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>300 to 1,000</td>
<td>40-50</td>
</tr>
<tr>
<td><strong>Total:</strong></td>
<td></td>
<td></td>
<td></td>
<td>14,000 to 16,000</td>
<td></td>
</tr>
</tbody>
</table>

\(^1\)Represents average annual values of in-place recharge and recharge from runoff from 1940-2012 from the Basin Characterization Model.

\(^2\)Based on sensitivity analysis of the Basin Characterization Model documented in Flint and others (2011) and Masbruch and others (2011).

\(^3\)Average of assumed measurement error.

\(^4\)Based on average error of transmissivity estimates for the hydraulic-gradient method, and errors in age difference and distance for the age-gradient method.
This is a short (4-1/2 pages) “report” prepared by six USGS hydrologists and professor D Kip Solomon from the University of Utah. It was written in response to a request by the State of Utah’s Division of Water Rights (UDWRi) for suggestions for additional groundwater monitoring to aid the UDWRi in making future decisions on well withdrawals in Spanish Valley, and contains a prioritized list of seven monitoring suggestions for consideration by the UDWRi. The seven suggestions, in order of priority from highest to lowest, are:

Continuous spring discharge measurements: The authors strongly urge that the City of Moab undertake an effort to permit the continuous measurement of the total discharge from all springs used as culinary water resources, and not just the portion that is diverted for use. The authors recommend measuring the discharge before any diversions into their water-supply system. The authors also recommend continuous monitoring of one or more other Glen Canyon Group aquifer (GCGA) springs, such as Old City Park spring and/or Water Park North spring.

Continuous groundwater-level monitoring using dedicated submersible pressure transducers: The authors emphasize the importance of monitoring groundwater levels in the GCGA. Two options are presented: (1) drilling a new multi-level monitoring well completed in both the shallower valley-fill aquifer (VFA) and the deeper GCGA, and (2) identifying an existing unused (abandoned) well that is screened in the GCGA. The former is preferred, but is the more expensive option. If the latter option is pursued, the authors also state that it would be useful to identify a separate abandoned well nearby that is screened in the VFA.

Stream gage on upper Pack Creek: The authors state that continuous year-round measured streamflow in upper Pack Creek (perhaps at the Pack Creek road bridge) would help constrain recharge to the VFA, because streamflow losses from Pack Creek likely are the main source of recharge to the VFA.

Water-quality sampling: The authors suggest sampling for: (1) stable oxygen/deuterium isotopes of newly developed wells or springs; (2) major ions and selected trace elements (e.g., bromide) at existing GCGA wells or springs on a quarterly or annual basis; (3) annual vertical profiling of specific conductance in existing monitor wells in the Matheson Wetlands Preserve. This sampling can serve as an early warning against groundwater quality degradation from sources of poorer-quality water.

Continuous water-quality monitoring: Monitoring temperature and specific conductance of wells or springs in the GCGA can be used to evaluate changes in water quality caused by natural processes (e.g., droughts) or development (e.g., increased well withdrawals). Once again, this monitoring could serve as an early warning system for protection of the quality and quantity of water derived from the GCGA.

Data to support future numerical groundwater flow modeling: The authors recommend that a numerical groundwater flow model be developed to: (1) test recently updated hypotheses regarding aquifer connections, recharge zones and flow directions; (2) assess the recently revised (decreased) groundwater budget estimates; (3) optimize locations of additional groundwater
monitoring sites; (4) simulate changes to the groundwater system based on potential future changes in groundwater development and/or climate.

Utilize the USGS “Furnished Data” program to publish water-level data collected by other agencies: The authors encourage the use of data collected by other agencies (e.g., Utah Division of Water Resources, Moab Area Watershed Partnership, Moab City, Grand Water and Sewer Service Agency) that is approved after review for quality assurance by USGS personnel.
2.16 Western Water Assessment (2019); Arens (2021)

These two documents are concerned with the possible impacts of climate change on groundwater in Spanish Valley.

The first document presents the results of a workshop consisting of two half-day meetings attended by the City of Moab, Grand Water and Sewer Service Agency, San Juan Spanish Valley Special Service District and other key water supply stakeholders. The workshop reviewed data on: (1) the water budget and drought; (2) observed precipitation (high variability, no long-term trend); (3) observed temperatures (strong recent warming trend); (4) observed snowpack and streamflow (a little earlier, a little less). The workshop also presented possible future trends in: (1) temperatures (even warmer); (2) precipitation (large variability continues). The workshop participants then discussed a drought and reduced water supply scenario, including: (1) groundwater depletion; (2) extreme precipitation; (3) wildfire risk; (4) flora and wildlife risk; (5) water quality and extreme heat.

The second document appears to be from a Microsoft PowerPoint presentation, and contains an introductory slide and seven additional slides. The seven substantive slides consist of: (1) recharge is likely to decrease and water demand is likely to increase; (2) temperature should continue to increase and precipitation may decrease slightly but with increased variability; (3) snow-water equivalent and soil moisture will decrease, decreasing aquifer recharge; (4) extreme precipitation is likely to increase, increasing runoff and decreasing recharge; (5) potential evapotranspiration is likely to increase, which will reduce recharge and may lead to increased water use; (6) summary slide; (7) historical context displaying long-term water table decline due to increased water withdrawal and decreased aquifer recharge, and historical temperature anomalies and precipitation.
These appear to be two Microsoft PowerPoint presentations that address two different aspects of the groundwater system in the Moab-Spanish Valley area.

The PowerPoint presentation by Gardner, Solomon and Heilweil consists of twelve slides, plus an introductory slide and a fourteenth concluding slide. The second through sixth slides present the estimated annual discharge from each of three aquifers: (1) the valley-fill aquifer (VFA = 2,600 acre-feet per year); (2) the deep Glen Canyon Group aquifer (DGCGA = 3,600 acre-feet per year); (3) the shallow Glen Canyon Group aquifer (SGCGA), which the authors divide into two because they reside in different watersheds, the Moab (= 7,400 acre-feet per year) and the Grandstaff (= 1,100 acre-feet per year). The seventh slide presents a hydrogeologic cross section. The eighth and eleventh slides are plots of stable isotope data for the three aquifers (slide eight) and the three aquifers and Sand Flats pore water (slide eleven). The ninth slide displays major ion chemistry for the three aquifers. The tenth, twelfth and thirteenth slides present results for the SGCGA (tenth), VFA (twelfth) and DGCGA (thirteenth) aquifers. The fourteenth and final slide presents six conclusions, specifically: (1) all of the methods employed are in relatively good agreement; (2) groundwater clearly can be separated into the three distinct aquifers; (3) the source of recharge to the VFA is primarily Pack Creek stream loss, (4) Sand Flats is not a source of recharge to DGCGA wells and springs, (5) there is less flow through the VFA than previously estimated, and nearly all VFA groundwater is consumed by evapotranspiration in the Matheson Wetland; (6) the various methods are consistent with a DGCGA discharge of 3,600 acre-feet per year, indicating a low likelihood of additional undiscovered water.

The PowerPoint presentation by Wilkowske consists of nine slides, including: (1) graphs of three water levels in the VFA and four in the GCGA with time (slides three and four); (2) a graph of discharge versus time for Mill Creek below Pack Creek near Moab (slide five), (3) a histogram of annual baseflow discharge from Pack Creek (slide six); (4) graphs of salinity for the Colorado River (slides seven and eight). In addition, there are two introductory slides (one and two) and a concluding slide (nine) containing no technical information.
3. SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

3.1 Summary

Utah State University (USU) has been selected to perform a peer review and a relatively non-technical summary of each of the many documents that have been prepared as part of scientific investigations related to the groundwater resources of the Moab-Spanish Valley area. The individual summaries have been presented in the previous section (Section 2).

Sumison (1971) identified two principal aquifer systems, the Glen Canyon Group, consisting of the Wingate and Navajo Sandstones, and the Quaternary deposits of the Spanish Valley area. All of the subsequent investigators accepted these two principal aquifer systems, albeit with some modifications. Blanchard (1990) added the Entrada Sandstone to the Glen Canyon Group aquifer. Steiger and Susong (1997) were the first to refer to the Quaternary deposits as the valley-fill aquifer. Once again, both of these modifications were accepted and used by all of the subsequent investigators.

Sumison (1971) also noted that the groundwater quality differed between the two aquifers, with the Glen Canyon Group having lower total dissolved solids than the Quaternary deposits. This was confirmed by Blanchard (1990), who collected additional water samples for chemical analysis. Many of the subsequent investigators also collected water samples that were analyzed for an even wider suite of chemical parameters, including stable isotopes of oxygen and hydrogen, tritium and helium isotopes, carbon isotopes, noble gases, chlorofluorocarbons and sulfur hexafluoride. These analyses confirmed the distinct differences in chemistry between the higher-quality Glen Canyon Group aquifer and the lower-quality valley-fill aquifer, and have provided some of the most valuable and insightful data related to the hydrogeology of the Moab-Spanish Valley area.

3.2 Conclusions

Although the very first study published (Sumison, 1971) was a remarkable early attempt to characterize the water resources of the area, its conclusions were constrained by the limited field data that had been collected up to that time. The subsequent investigations prepared prior to the Kolm and van der Heijde (2018; 2019; 2020a; 2020b) and the USGS (Masbruch, Gardner, Nelson, Heilweil, Solder, Hess, McKinney, Briggs and Solomon, 2019; Gardner, Nelson, Heilweil, Solder and Solomon, 2020) reports also only are of limited value, even those for which additional field data were collected. Of these two studies, the USGS report stands out as being superior because it is based on an extensive amount of new field data which were collected expressly for that investigation. The Kolm and van der Heijde reports, on the other hand, relied exclusively on data collected previously, primarily from the older studies. Nonetheless, the methods employed by Kolm and van der Heijde are sound, and the results and conclusions are credible and consistent with the data they used.

However, despite the critical value of the USGS report, perhaps the most important document is the “report” prepared by Heilweil, Masbruch, Gardner, Nelson, O’Leary, Solomon and Wilkowske (2020), as it contains a prioritized list of seven suggestions for additional
groundwater monitoring to aid the Utah Division of Water Rights (UDWRi) in making future decisions on well withdrawals in Spanish Valley. It seems safe to assume that collecting most, if not all, of the suggested additional data will be essential in convincing the UDWRi to close the groundwater resources in the Moab-Spanish Valley area to further appropriations. Furthermore, such additional data also will serve the equally important function of acting as an early warning system for protection of the quantity and quality of water derived from springs and wells in the area.

3.3 Recommendations

In my professional opinion, implementing the additional groundwater monitoring suggested by Heilweil, Masbruch, Gardner, Nelson, O’Leary, Solomon and Wilkowske (2020) should be given the highest priority by any and all stakeholders interested in the management of the water resources in the Moab-Spanish Valley area. Once again, the seven suggestions, in order of priority from highest to lowest, are: (1) continuous spring discharge measurements; (2) continuous groundwater-level monitoring using dedicated submersible pressure transducers; (3) stream gage on upper Pack Creek; (4) water-quality sampling; (5) continuous water-quality monitoring; (6) data to support future numerical groundwater flow modeling; (7) utilize the USGS “Furnished Data” program to publish water-level data collected by other agencies.

I agree that the first two items on the list should be the highest, and of equal, priority. Documenting any decreases in spring discharges or water-level declines in wells will be critical in convincing the UDWRi that it should consider closing the area to further groundwater appropriations. Furthermore, such documentation will ensure that any reductions in the quantity of groundwater available from springs and wells are noted just as soon as possible, allowing for the maximum amount of time to take any steps needed to address such a serious problem. However, in my opinion the sixth item should be the second priority (again, I think the first two should be combined into one, as they are of equal importance). In all likelihood, the UDWRi will rely on the results of a numerical groundwater flow model to justify its decision to close the area to future appropriations.

One of the most critical first steps in creating a numerical groundwater flow model is to develop a groundwater budget. Fortunately, the budget developed by Masbruch, Gardner, Nelson, Heilweil, Solder, Hess, McKinney Briggs and Solomon (2019) and Gardner, Nelson, Heilweil, Solder and Solomon (2020) appears to be nearly ideal for groundwater modeling. As noted by Heilweil, Masbruch, Gardner, Nelson, O’Leary, Solomon and Wilkowske (2020), such modeling can be used to: (1) test recently updated hypotheses regarding aquifer connections, recharge zones and flow directions; (2) assess the recently revised (decreased) groundwater budget estimates; (3) optimize the locations of additional groundwater monitoring sites; (4) simulate changes to the groundwater system based on potential future changes in groundwater development and/or climate. The last item is the one that the UDWRi probably will be most interested in as it considers whether to close the area to future groundwater appropriations.
4. REFERENCES


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