Consistent with provisions of the Utah Open and Public Meetings Act, Utah Code Ann. § 54-2-207(4), the Water Conservation and Drought Management Advisory Board Chair has issued written determinations supporting the decision to convene electronic meetings of the Board without a physical anchor location. Due to the health and safety risks related to the ongoing COVID-19 pandemic and considering public health orders limiting in-person gatherings, the Water Conservation and Drought Management Advisory Board will continue to hold meetings by electronic means. The public is invited and encouraged to view the Board’s electronic meetings by viewing the City’s YouTube channel: https://www.youtube.com/channel/UCl0o0z0Zgdmz4y1FoIo17CJA.

1. Written Determination To Convene Electronic Meetings

2. Call To Order

3. Approval Of Minutes

   3.I. Minutes: August 12, 2020, Regular Meeting

   Documents:

   WB-MIN-2020-08-12 DRAFT.PDF

4. Board And Staff Reports

5. Discussion Of The Hydrologic And Hydrogeologic Assessment Of The Surface Water And Groundwater Resources Affecting The Moab Springs And Wells: Phases 3 And 4

   Documents:

   2020 HSA HHI CITY OF MOAB PHASE 3 FINAL REPORT.PDF
   2020 HSA HHI CITY OF MOAB PHASE IV REPORT [MARCH 2020 FINAL].PDF

6. Water Conservation Plan Update

   1. Discussion about numeric goals and context regarding conservation measures in Moab - Arne Hultquist
   2. Discussion of stormwater management strategies - Jeremy Lynch
   3. Update on water trend analysis, demand projections, and water use - City
7. Adjournment

Special Accommodations:
In compliance with the Americans with Disabilities Act, individuals needing special accommodations during this meeting should notify the Recorder’s Office at 217 East Center Street, Moab, Utah 84532; or phone (435) 259-5121 at least three (3) working days prior to the meeting.
Check our website for updates at: www.moabcity.org
The Water Conservation and Drought Management Advisory Board held its regular meeting on August 12, 2020. Per Executive Order 2020-5 issued by Governor Gary R. Herbert on March 18, 2020, this meeting was conducted electronically. An anchor location was not provided. An audio recording of the meeting is archived at http://www.utah.gov/pmn/index.html. A video recording is archived at https://www.youtube.com/watch?v=vwhYyvDOj-ck.

Regular Meeting—Call to Order and Attendance:
Water Board Chair Kara Dohrenwend called the meeting to order at 2:07 pm. Participating remotely were Water Board Members Kyle Bailey and Mike Duncan. Water Board Member Arne Hultquist had technical difficulties and joined the meeting at 2:11 PM and at 3:22 PM. Water Board Members John Gould, Denver Perkins, and Jeremy Lynch were absent. City staff in attendance were Assistant City Manager Carly Castle, City Engineer Chuck Williams, Recorder Sommar Johnson, and Deputy Recorder Kerri Kirk.

Approval of Minutes: June 10, 2020 & July 8, 2020 – Postponed to the end of the meeting
Board Chair Dohrenwend moved this agenda item to the end of the meeting.

Board and Staff Reports
There were no board and staff reports.

Board Vacancy
Board Chair Dohrenwend stated Board Member Perkins resigned. There was discussion about postponing filling the vacancy. Board Member Dohrenwend requested Assistant City Manager Castle research if the Board must consist of 7 members. Assistant City Manager Castle clarified the process for appointing Board Members. Board Member Duncan suggested candidates should focus on both the state-mandated water conservation effort and the amount of water available in the valley. Assistant City Manager Castle said a 6-member board would require 4 members in attendance for a quorum.

Presentation of the Hydrologic and Hydrogeologic Assessment of the Surface Water and Groundwater Resources Affecting the Moab Springs and Wells: Phases 3 and 4 – Ken Kolm
Hydrologic Systems Analysis Senior Hydrogeologist Kenneth Kolm presented Phases 3 and 4 of the Hydrologic and Hydrogeologic Assessment of the Surface Water and Groundwater Resources Affecting the Moab Springs and Wells. Board Chair Dohrenwend confirmed that phase 3 is not available on the City website because it has sensitive information regarding well and spring locations. City Engineer Williams said phases 1, 2, and 4 are on the City website. Board Chair Dohrenwend requested a safe yield percentage for the groundwater that is released from storage. She also requested clarification on the protection zones. Board Member Duncan inquired about the protection zone around the Lionsback development. City Engineer Williams stated the developer will include protection measures in the development design. He said the updated protection zones will be shared with Grand County, and education will be needed for people who reside in protection zones.

Board Member Hultquist requested time to digest the information prior to asking questions.
about the presentation. Board Chair Dohrenwend suggested adding an agenda item to the next meeting for follow up discussion.

**Approval of Minutes: June 10, 2020 & July 8, 2020—Approved**

**Discussion:** Board Chair Dohrenwend inquired about postponing approval of the minutes until the next meeting. She said there was one correction needed to change MOPS to MAWP.

**Motion:** Board Member Hultquist moved to approve the minutes from June 10 and July 8. Board Member Duncan seconded the motion.

**Vote:** The motion passed 4-0 with Board Members Duncan, Hultquist, Dohrenwend, and Bailey voting aye.

**Water Conservation Plan Update—All items postponed until the next meeting**

Board Chair Dohrenwend postponed the water conservation plan updates until the next meeting. Board Member Hultquist requested clarification on the plan’s due date. Board Chair Dohrenwend said the plan is due in 2022.

- **Discussion About Numeric Goals and Context Regarding Conservation Measures in Moab** – Arne Hultquist
- **Discussion of Stormwater Management Strategies** – Jeremy Lynch
- **Update on Water Trend Analysis, Demand Projections, and Water Use** – City Engineering
- **Questions About the City’s Leak Detection Efforts**

**Adjournment:** Board Chair Dohrenwend adjourned the meeting at 3:56 PM.
HYDROLOGIC AND HYDROGEOLOGIC ASSESSMENT OF THE SURFACE WATER AND GROUNDWATER RESOURCES AFFECTING THE MOAB CITY SPRINGS AND WELLS, MOAB, UTAH:
PHASE 3:
PROPOSED UPDATED DRINKING WATER SOURCE PROTECTION (DWSP) ZONE DELINEATIONS AND PROPOSED MONITORING PLAN

Authors:
Dr. Kenneth E. Kolm, Hydrologic Systems Analysis, LLC., Golden, Colorado
and
Paul K.M. van der Heijde, Heath Hydrology, Inc., Boulder, Colorado

Prepared For:
City of Moab, Utah

Final Report July 2020
Front Page: View of fenced off DWSP Zone 1 for City of Moab’s Skakel Spring. Skakel Spring discharges at the base of the Wingate Sandstone and its water is collected in the spring box shown.
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HYDROLOGIC AND HYDROGEOLOGIC ASSESSMENT OF THE SURFACE WATER AND GROUNDWATER RESOURCES AFFECTING THE MOAB CITY SPRINGS AND WELLS, MOAB, UTAH:
PHASE 3: UPDATED PROPOSED DRINKING WATER SOURCE PROTECTION ZONE (DWSP) DELINEATIONS AND PRELIMINARY MONITORING PLAN

Report prepared for City of Moab, Utah, May 2020
by
Dr. Kenneth E. Kolm, Hydrologic Systems Analysis, LLC., Golden, Colorado
and
Paul K.M. van der Heijde, Heath Hydrology, Inc., Boulder, Colorado

Abstract

Under an agreement with City of Moab, Utah, Hydrologic Systems Analysis LLC (HSA) of Golden, Colorado, in conjunction with Heath Hydrology, Inc. (HHI) of Boulder, Colorado, was tasked to complete Phase 3: Review three existing drinking water source protection plans (DWSPP) and update the delineations of the drinking water source protection (DWSP) zones, one for the City's Skakel Spring, one for the City's Springs 1, 2, and 3 near the golf course (referred to as "City of Moab Springs"), and one for the City's wells (Wells 4, 5, 6, 7, and 10), also near the golf course. This Phase 3 report contains the proposed expanded delineations of the DWSPs for the Skakel Spring and the Moab City’s Springs 1, 2, and 3, and adds a comprehensive preliminary water monitoring plan for the combined GCMC/PCLA hydrologic systems as a new deliverable.

The updated DWSP zones for springs were derived using the same methods for calculating catchment areas as employed in delineating the existing spring DWSP zones, but with updated and refined recharge rates and adhering to new insights in spatial variability of recharge based on the presence of high hydraulic conductivity fracture zones derived from findings on Phases 1, 2, and 4 of this project. These new calculations resulted in updated and extended protection zones for Skakel Spring, and City Springs # 1, #2, and #3 to include additional areas of the Kayenta Heights Fault and Fracture Zone, parts of the North Fork Mill Creek and Mill Creek groundwater basins, the Spring Fork/Mill Creek groundwater region, the City Springs and Wells Fracture Zone, and the Mill Creek Fracture Zone. The Phase 3 evaluations also verify that the existing DWSP delineations for City of Moab Wells #4, #5, #6, #7, and #10 are reasonably accurate and do not need adjustments at this time.

As the focus of the DWSPP is the protection of the groundwater systems that function as a source for drinking water supplies, it does not provide 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. Therefore, it is important to have an adequate monitoring system in place that collects essential climatic, hydrologic, and water quality data within and beyond the DWSP zones. To provide guidance in developing such a data collection network, a preliminary monitoring plan (PMP) is provided to help protect the City of Moab water supply and water quality at Skakel Spring, and Moab City golf course springs and wells.
1. INTRODUCTION

Under an agreement with City of Moab, Utah, Hydrologic Systems Analysis LLC (HSA) of Golden, Colorado, in conjunction with Heath Hydrology, Inc. (HHI) of Boulder, Colorado, was tasked to: 1) Perform a Hydrologic and Environmental System Analysis (HESA) of the Moab City Springs and Wells (MCSW) area, supported by GIS databases and maps, to develop a comprehensive and updated understanding of hydrogeologic and hydrologic characteristics of the groundwater system, using currently available data and published analyses; 2) Collect hydrological, hydrogeological and other data, and develop an as-accurate-as-possible water budget for the segment of the MCSW area affecting the City’s springs and wells; and 3) Review three existing drinking water source protection plans (DWSPP) and update the delineations of the drinking water source protection (DWSP) zones, one for the City’s Skakel Spring, one for the City’s Springs 1, 2, and 3 near the golf course (referred to as "City of Moab Springs", and one for the City’s wells (Wells 4, 5, 6, 7, and 10), also near the golf course. (See Figure 1 for the location of these springs and wells and the current delineation of the Moab drinking water source protection zones for the wells and springs). In July, 2019, the agreement was expanded to include Task 4: Perform a Hydrogeologic and Environmental Systems (HESA) Analysis (including an expanded water budget and storage analysis) of the Spanish Valley as part of protecting its remaining wells and for water management and water rights purposes, and a combined water budget analysis for the combined Pack Creek Lower Alluvium (PCLA) and Glen Canyon Mill Creek (GCMC) hydrologic subsystems of the MCSW hydrologic system. It was agreed that Task 4 would be completed before starting Task 3 and that Task 3 would include the development of a water resources monitoring plan. Each of these tasks constitutes a phase of the project. This report contains the results of Phase 3: Updates of the delineations of the City’s drinking water source protection zones and a comprehensive water resources monitoring plan for the City of Moab. The results of the HESA of the entire MCSW area performed in Phase 1 are documented in Kolm and van der Heijde (2018). The results of the study of the GCMC area performed in Phase 2 are documented in Kolm and van der Heijde (2019). The results of the study of the PCLA and the combined GCMC/PCLA water budgets and storage performed in Phase 4 are documented in Kolm and van der Heijde (2020).

The Phase 1 study area 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 (Figure 1) and includes the Mill Creek, Pack Creek and Grandstaff Creek watersheds. Based on the results of Phase 1, the Glen Canyon aquifer and Mill Creek Watershed (GCMC) underlying the Sand Flats region was chosen as the setting for the water budget developed in Phase 2 of this project, and the Pack Creek Watershed and the Quaternary unconsolidated alluvium (PCLA) in the Spanish Valley was chosen as the setting for the water budget developed in Phase 4 of this project. The combined GCMC/PCLA conceptual models, water budgets, and storage calculations of Phases 1, 2, and 4 are used for the updating of the delineation of the Drinking Water Source Protection (DWSP) zones for the springs and wells of the City of Moab completed for Phase 3 (Figure 2), as well as for the development of the water resources monitoring plan.

The HESA of the surface water and groundwater systems in the MCSW study area made extensive use of existing GIS databases and maps of geologic, hydrogeologic and hydrologic
characteristics, collected specifically for this study. Additional data layers and evaluations were prepared to illustrate the HESA – particularly with respect to the hydrogeological characteristics of the rock types present and the significance of hydrostructures (i.e., hydrogeologically significant faults and fracture zones). The results of the HESA provided the conceptual basis for the development of the hydrological water budget and storage for the City wells and springs in the 2nd and 4th project phases, and now for the updating of the delineation of the DWSP zones and the development of the monitoring plan, which in turn led to the preparation of a number of data layers and evaluations. The initial HESA included a few scoping site visits to the study area; numerous additional field surveys have been conducted as the project progressed.

![Figure 1. Topographic map showing the Phase 1 Moab City Springs and Wells (MCSW) study area, major watersheds within the study area, the location of the City’s springs and wells and the GWSSA wells, and the existing Drinking Water Source Protection (DWSP) zones for the City’s springs and wells.](image)

Various information sources have been consulted in preparation of the four phases of this project, including Federal, State and City reports and data bases. When applicable, data were organized in a Geographical Information System (GIS) using the ESRI® ArcMap™ software. The data sources included Utah AGRC (Automated Geographic Reference Center), Utah Division of Water Rights (UDWR), Utah Division of Environmental Quality (Utah DEQ), Utah Geological Survey (UGS), U.S. Geological Survey (USGS), Natural Resources Conservation...
Service (NRCS) of the U.S. Department of Agriculture, NOAA National Centers for Environmental Information, City of Moab, and others. In addition, HSA/HHI has prepared a number of data layers specifically for this report through interpretation of existing data sets and field reconnaissance.

Figure 2. View of the regional setting of the Moab City springs and wells and the approximate Phase 2 Preliminary Water Budget (PWB) area (GCMC area) and Phase 4 Preliminary Water Budget area (PCLA area) outlined in yellow (Source: Google Earth, Imagery October 2016).

It should be noted that this report will not obviate the need for additional hydrogeologic analysis on a site-specific/parcel-specific basis by developers and/or the City, or in any water right, geotechnical, or environmental study requiring due diligence. The information in this report is intended to be used as indicator only, as part of a multi-step land use or water management decision-making process, and to provide a starting point for further study of the City's surface water and groundwater resources.
2. GLEN CANYON GROUP MILL CREEK (GCMC) AND PACK CREEK LOWER ALLUVIUM (PCLA) HYDROLOGIC SYSTEMS

Based on field surveys and a preliminary HESA (Hydrologic and Environmental System Analysis), a number of hydrologic systems were identified within the MCSW study area (Figure 3). Each of these hydrologic systems is characterized by a unique combination of surface water hydrology, hydrogeologic setting, and groundwater flow and is described in detail in the Phase 1 report (Kolm and van der Heijde, 2018). Of specific interest to the protection and management of the City of Moab’s water supply resources are the Glen Canyon Group Mill Creek or lower Mill Creek (GCMC) hydrologic system (Number 3 in Figure 3) and the Pack Creek Lower Alluvium (PCLA) or Lower Pack Creek hydrologic subsystem (Number 5 in Figure 3). Section 2 of the Phase 2 report by Kolm and van der Heijde (2019) describes the HESA-based conceptual model of the Glen Canyon Group Mill Creek (GCMC) hydrologic system, and discusses the unique hydro-zones within that system. Section 2 of the Phase 4 report by Kolm and van der Heijde (2020) describes the HESA-based conceptual model of the Pack Creek Lower Alluvium (PCLA) hydrologic system, and discusses the unique hydro-zones within that system. These two systems presented in the Phase 4 report of Kolm and van der Heijde (2020), including their hydrogeologic characteristics, groundwater flow, external boundary conditions, and internal boundary fluxes are the focal points of the DWSP zonation analysis and Preliminary Monitoring Plan (PMP) presented in Chapters 3 and 4 of this report.

In summary, the Glen Canyon Group - Mill Creek (GCMC) hydrologic system is a complex mix of fractured and faulted Entrada Sandstone and Glen Canyon Group rock, Eolian (wind-deposited) Sand, Alluvium, and hydro-structures (fault and fracture zones that are either conductive or a barrier to groundwater flow). These hydrogeologic units form the robust integrated groundwater and surface water system that sustains the City of Moab springs and wells in the vicinity of the golf course and the Skakel Spring (Figures 4, 5, and 6). The HESA completed in Phase 1 and water budget in Phase 2 showed that the GCMC hydrologic system is a well-defined system for which the groundwater flow pathways; hydrogeologic characteristics, such as permeability, hydraulic conductivity, and storativity; boundary conditions; and internal surface water–groundwater interactions are well-understood and quantifiable to various degrees of accuracy (Figures 4 and 5; Appendix A).

The Pack Creek Lower Alluvium Subsystem (PCLA), located in the southwestern part of the study area (CSM 5 in Figure 3), is a complex mix of fractured and faulted, and unfractured Glen Canyon Group, Stream Alluvium, Alluvial Fan Deposits and hydrostructures (fault and fracture zones) which form the robust groundwater system and surface water system that is directly connected to the City of Moab and Grand County wells in the central part of the Spanish Valley (Figures 4 and 6). This subsystem is hydraulically connected to the Glen Canyon Group Mill Creek (GCMC) and La Sal Mountain Upper Alluvium Subsystem (LSMA-P) upgradient primarily by surface water (Mill Creek and Pack Creek, respectively, by outflow streams from the major springs like Skakel Spring, and by surface water diversions from Mill Creek (Sheley Tunnel diversion to Ken’s Lake) and does not have significant direct groundwater connection through shallow or deep hydrogeologic units with adjacent hydrologic subsystems.
Figure 3. Plan view of the hydrologic subsystems in the MCSW study area on top of hydrogeologic units: 1a. La Sal Mountain Upper Alluvial Subsystem (LSMA-M) Mill Creek Headwaters; 1b. La Sal Mountain Upper Alluvial Subsystem (LSMA-P) Pack Creek Headwaters; 2a. Wilson Mesa Alluvial Fan Subsystem (WMAF); 2b. South Mesa Alluvial Fan Subsystem (SMAF); 3. Glen Canyon Group Mill Creek Subsystem (GCMC); 4. Glen Canyon Group Grandstaff Creek Subsystem (GCGC); 5. Pack Creek Lower Alluvium Subsystem (PCLA); and 6. Morrison Formation and other Confining Units. Modified from Figure 21 in Kolm and van der Heijde (2018).

The Glen Canyon Group bedrock in the GCMC and PCLA subsystems has both matrix flow and fracture flow. The matrix flow has ranges estimated from 0.3 – 1.0 ft/day (Jobin, 1962; Blanchard, 1990; Lowe and others, 2007); and the fracture flow can be as high as 88 ft/day (Freethey and Cordy, 1991; see Appendix A for a list of hydrogeologic characteristics). Therefore, fracture flow will dominate travel times and direction of groundwater flow, and will be most important for contaminant studies and DWSP well/spring protections. The bedrock matrix flow is mostly located underneath the center of the central and southern Spanish Valley and in upland, and in poorly fractured outcrop areas to the east of Spanish Valley (Figures 5 and 6). The Glen Canyon Group fault and fracture zones groundwater flow is mostly associated with the two fault and fracture zones located on either side of the Spanish Valley (Figures 5 and 6), including the Kayenta Fault and Fracture Zone and the Moab Rim Fault and Fracture Zone, the fault and fracture zones associated with Mill Creek and its tributaries, and the Moab Springs and Golf Course fault and fracture zone.
Figure 4. Plan view of the flow directions in the groundwater system on top of the hydrogeologic units of the MCSW study area. The small arrows are local groundwater flow directions. The larger blue arrows show groundwater flow direction along major hydrostructures and the major groundwater flow directions in the Mill Creek and Pack Creek groundwater systems. Modified from Figure 22 in Kolm and van der Heijde (2018).

The general aspects of groundwater flow in the Quaternary unconsolidated materials have been discussed in Section 2.5 of Kolm and van der Heijde (2018). Estimates of hydraulic conductivity (K) of these unconsolidated materials range from 1 to 225 ft per day (Lowe and others, 2007). These hydrogeologic units in the PCLA system most likely contain the greatest amount of groundwater, albeit, in general, of lesser quality than in the GCMC system (Figure 3).

Kolm and van der Heijde, 2019, 2020 discuss hydro zones for calculation of recharge and storage in the GCMC and PCLA hydrologic systems. The delineation of these hydro zones and their hydrologic characteristics are basic elements used in updating the DSWP zones and the formulation of the monitoring plan discussed in chapters 3 and 4 of this report. The location of these hydro-zones are shown in Figures 5 and 6.
Figure 5. Map showing the location of the Preliminary Water Budget (PWB) area and Hydro Zones of the GCMC hydrologic system with boundary conditions and location of City of Moab springs. Modified from Figure 10a in Kolm and van der Heijde, 2019.
Figure 6. Map showing the location of the Preliminary Water Budget (PWB) area and Hydro Zones of the PCLA hydrologic system with boundary conditions. FFZ1 is the Moab Rim Fault and Fracture Zone; FFZ2 is the Kayenta Heights Fault and Fracture Zone Extension. Modified from Figures 11 and 15 in Kolm and van der Heijde, 2020.
3. UPDATED DRINKING WATER SOURCE PROTECTION (DWSP) ZONES

3.1 Approach to Update City Springs and Wells Protection Zones

The City of Moab has three original documents (JMM - James M. Montgomery Consulting Engineers, Inc. (1989); and Montgomery Watson (2001a and b), and several recently updated City of Moab documents (2006 and 2011) that delineate the Drinking Water Source Protection (DWSP) Zones for its wells and springs (Figures 1 and 7). These documents describe the delineation of the DWSP Zones at the well head or spring location, and within the watershed and ground-water basin. The DWSP Zones for springs are particularly sensitive to groundwater recharge amounts and catchment area, flow paths, and discharge areas, and surface water/groundwater interactions as these are potential areas of drinking water supply increase or reduction, and drinking water contamination. Drinking water vulnerability in wells is measured in travel times and corresponding travel distances, therefore, the delineations required four different space/time measures of vulnerability: Zone 1: 100 ft around the well head or spring location; Zone 2: Area affected within 250 days travel time; Zone 3: Area affected within 3 years travel time; and Zone 4: Area affected within 15 years travel time. These calculated travel-time-based zones take into consideration anisotropic flow conditions, subregional flow patterns, and the flow barrier at the contact between the Navajo Sandstone Aquifer and the Paradox Formation directly west of the wellfield. These zones are calculated by radius of influence of pumping wells, and enable the City of Moab to make an inventory of potential water gains and/or losses, and water contamination sources and hazards that affect the well field.

The City commissioned studies by JMM James M. Montgomery Consulting Engineers Inc. (1989) and Montgomery Watson (MW) (2001a and 2001b) of the groundwater systems affecting the City’s wells and springs based on available data at the time, and follow the guidelines of the US EPA in order to make the delineations for these DWSP zones. The hydrogeology of the system was analyzed for framework and hydraulics. This enabled JMM (1989) and MW (2001a and 2001b) to determine the optimal hydrogeologic characteristics for recharge and groundwater flow paths, and determine the hydraulic conductivity of the materials (fracture and matrix) for the travel time-based vulnerability analysis (Figures 1 and 7). The approach to Phase 3 of this study was to determine, using HESA, how the hydrogeologic and hydrologic system worked on a broader, subregional and regional scale, then scale down to the specific springs and well sites. This would enable the determination of broader vulnerabilities to the City of Moab drinking water supply and water quality, and to determine if the original DWSP zones and guidelines were adequate. The HESA-based results, including surface water inputs and outputs; surface water/groundwater interactions; and groundwater inputs and outputs, such as recharge areas or zones, flow paths and flow velocities, and discharge areas, are summarized in Chapters 1 and 2 of this report, and in more detail in the Phase 1, 2, and 4 reports (Kolman and van der Heijde; 2018, 2019, 2020). Therefore, the approach is to evaluate and modify the currently used DWSP zones by comparing the previously published documents and delineation of vulnerability regions with the results of the HESA-based analysis as discussed in Sections 3.2 and 3.3.
3.2 Updated Moab City Springs Protection Zones in the GCMC/PCLA Hydrologic System

The DWSP zones delineated by Montgomery Watson (2001a and 2001b) for the Skakel and City of Moab Golf Course springs are overlain on the plan view of the flow directions in the groundwater system on top of the hydrogeologic units of the MCSW study area (as shown in Figure 8). The results of earlier phases of this project Kolm and van der Heijde (2018, 2019, 2020) confirm that the DWSP delineations for Skakel Spring, and City Springs # 1, #2, and #3 that were produced by Montgomery Watson consultants (2001a and 2001b) are reasonably accurate with regards to groundwater flow paths and groundwater basin/surface water watershed interaction for the GCMC groundwater systems near to the springs.
However, using the same methods for calculating catchment area used by Montgomery Watson (2001a and 2001b) and approved by the Utah State EPA, but with updated recharge rates and spatial distribution of variation of recharge based on the location of high K zones show that the delineation of the DWSP zones for these springs need updating. The findings of Phase 1, 2 and 4 of this project show that proper accounting for the amount of groundwater flowing to these springs require expansion of the catchment areas for both Skakel and Golf Course Springs. Proposed protection zone expansions are solely based on hydrologic considerations and primarily located in the Kayenta Heights Fault and Fracture Zone, parts of the groundwater systems in the North Fork/Mill Creek groundwater basins, the Spring Fork Mill Creek groundwater region, and the Mill Creek Fracture Zone (Figure 8). There is some regulatory question if the delineations should include the entire Mill Creek watershed in the La Sal Mountains (Figures 3 and 9).

Figure 8. Map of the GCMC and PCLA Hydro Zones showing the location of the City of Moab springs and wells, related current Drinking Water Source Protection (DWSP) zones, and proposed updated DSWP zones.
Figure 9. Map of the MCSW study area with hydrogeologic units and groundwater flow system showing the location of the City of Moab springs and wells, related current Drinking Water Source Protection (DWSP) zones, and proposed updated DSWP zones (see Figure 3 for legend of hydrogeologic units, figure 4 for legend of flow symbols)

3.2.1 Skakel Spring DWSP Zone

Regarding Skakel Spring, it is hard to distinguish between the Catchment Area for Skakel Spring proper and for the other springs in the vicinity. Matrimony and the other springs along HW128 have water rights amounting to about 210 acre.ft/yr. Skakel Spring has a water right (Utah Water Rights Data Base or UWRDB) of about 455 acre.ft/yr (Note that MW (2001a Table 10.1) lists its capacity as 450 gpm or 725 acre.ft/yr); the water rights for the other springs near Skakel Spring or in its protection zone amount to about 230 acre.ft/yr. Thus, based on water rights, which for springs may be a reasonable estimate for sustained predevelopment outflow, this amounts to a total of 895 acre.ft/yr. If the higher number for Skakel Spring is used, as reported by MW (2001a), the total discharge of all springs amounts to 1165 acre.ft/yr. The current DWSP Zone for Skakel Spring is about 590 acres with an average annual precipitation of 9 inches. Using a recharge rate of 20% of precipitation, recharge in the protection zone is about 90 acre.ft/yr. Note that the current protection zone only covers the Kayenta Heights fracture zone (KHFZ) southeast of Skakel Spring extending to Mill Creek, and that this protection zone overlaps with the Catchment Areas of the other springs in the KHFZ including those springs along Utah State Highway 128. Part of the recharge of the Catchment Area comes from the
losing stretch of Mill Creek where it crosses the KHFZ. According to Blanchard (1990) this amounts to about 240 ac.ft/yr.

For Skakel Spring, the groundwater flow paths from the Mill Creek recharge source, (losing stretch of Mill Creek from just west of the North Fork Mill Creek and Mill Creek confluence to near the Mill Creek powerhouse), to the discharge area springs, including Skakel Spring, are aligned with the Kayenta fault and fracture zone interpreted as a highly transmissive groundwater conduit (Figures 8 and 9; Kolm and van der Heijde; 2018, 2019). The area on the surface, and the ephemeral streams crossing the width perpendicular to the Kayenta fault and fracture zone, should also be protected as shown by the MW (2001a) delineation as these are areas of local recharge to this part of the Glen Canyon group hydrogeologic unit (Figures 8 and 9).

In reassessing the protection of Skakel Spring, 3 scenarios or set of assumptions for calculating the required catchment area have been considered: 1) using all spring data from the UWRDB only for Skakel and vicinity springs as they have overlapping catchment areas; 2) using MW’s (2001a) estimate for Skakel Spring and UWRDB numbers for other springs; and 3) using Skakel Spring discharge only (2 scenarios). Using an average of 10 inches of precipitation per year and recharge is 20% of precipitation, we get the following results for catchment area:

1. UWRDB only: spring outflow = 895 acre.ft/yr; Mill Creek recharge = 240 acre.ft/yr; required groundwater recharge from precipitation = 655 acre.ft/yr or catchment area = 3930 acres (compare with current DWSP Zone of 590 acres);
2. MW (2001a) number for Skakel Spring and UWRDB numbers for other springs: outflow = 1165 acre.ft/yr; Mill Creek recharge = 240 acre.ft/yr; required groundwater recharge from precipitation = 925 acre.ft/yr or catchment area = 5550 acres (compare with current DWSP Zone of 590 acres);
3. Skakel only: 455 acre.ft/yr (UWRDB) or 725 Acre.ft/yr (MW 2001); Mill Creek recharge = 240 acre.ft/yr; required groundwater recharge from precipitation = 215 or 485 acre.ft/yr or catchment area = 1290 or 2910 acres (compare with current DWSP Zone of 590 acres).

In light of the difficulty in separating flow paths and catchment areas for Skakel Spring from those of nearby springs that are part of the same hydrogeologic and groundwater flow system, scenario #2 was selected as representative and necessary for the City of Moab to protect its resource, resulting in a required catchment area size of 5550 acres (currently 590 acres). Given scenario #2, the proposed delineation extends the current DWSP protection zone to include: 1) the synclinal area between the Kayenta Heights fault and fracture zone to the fault that bounds the Sand Flat recreation area on the western side, 2) areas south of the Powerhouse, 3) parts of the North Fork groundwater basin towards Wilson and South Mesas, and 4) parts of the main Mill Creek watershed towards Spring Canyon (Figures 8 and 9). The expanded Skakel Spring DWSP zone includes the Moab City Landfill, and the Lionsback development. Greater Mill Creek may also be polluted by activity upstream in the Sand Flats area south, or the upper groundwater systems of Wilson Mesa (2a) and South Mesa (2b), or the entire Mill Creek surface water system in the La Sal Mtns (Figures 3, 4, 8, and 9). Since the DWSP zones aren’t required to extend to hydrologic systems beyond the calculated required catchment area, a monitoring
plan is provided in Chapter 4 to help protect the City of Moab water supply and water quality at Skakel Spring.

3.2.2 The City of Moab Golf Course Springs DWSP Zone

The City of Moab Golf Course Springs #1, #2, and #3, have a distinct Catchment Area assumed to not overlap with other springs to the north (having their own distinct catchment area to the East) or west (discharging into another hydro-system). The current DWSP Catchment Area of Montgomery Watson (2001b) is 4815 acres. Assuming 10 inches of precipitation and 20% recharge, this amounts to about 800 acre-ft/yr of recharge. Montgomery Watson (2001b) listed the joint capacity of City Springs #1, 2, and 3 as 845 gpm or 1365 acre.ft/yr (MW 2001b, Golf Course springs DWSP table 10.1), which means a Catchment Area of about 8190 acres. If aquifer recharge is included from the relevant losing Mill Creek reaches at 465 acre.ft/yr (Blanchard, 1990), the required catchment recharge is 900 acre.ft/yr. At 10 inches precipitation/yr and a recharge rate of 20%, this requires a catchment area of 5400 acres. The required DWSP Zone expansion of 585 acres should cover the Golf Course Fracture Zone north of the current MW (2001b) protection zone as well as the Spring Canyon area east of Mill Creek and the Mill Creek fracture zone and high K zones above the confluence with Spring Canyon (Figures 8 and 9). The protection of the broader source of water for City Springs #1, #2, and #3 and for the City Springs fault and fracture zone involves monitoring the water quality of Mill Creek at the intake source for the City Springs fault and fracture zone, and the monitoring of Mill Creek and Spring Canyon Springs located east and south of the fault zone. The potential source of water quantity and water quality decline of the City of Moab Springs #1, #2, and #3 would then include the Moab City Golf Course (being monitored), nearby private wells on the City Springs fault and fracture zone, private well and activity of private inholdings along Mill Creek, Steel Bender road 4X4 activity, and US BLM grazing activity. Based on the results of Phase 1, 2 and 4 of this study (Kolm and van der Heijde 2018, 2019, 2020), the existing section of the DWSP zone located on South Mesa and outside the GCMC hydrologic system is not included in the proposed update of the DWSP zone for Golf Course Springs #1, #2, and #3. Greater Mill Creek may also be polluted by human activity upstream in the South Mesa Hydrologic System (#2b on Figure 3), or the entire Mill Creek watershed system in the La Sal Mtns (Figures 3, 4, and 9). Since the DWSPs aren’t required to delineate these systems, a monitoring plan is provided in Chapter 4 to help protect the City of Moab water supply Springs #1, #2, and #3.

3.3 Updated City of Moab Wells Protection Zones in the GCMC/PCLA Hydrologic System

The DWSP zones delineated by JMM (1989) for the City of Moab Wells #4, #5, #6, #7, and #10 are overlain on the plan view of the flow directions in the groundwater system on top of the hydrogeologic units of the MCSW study area (as shown in Figure 10), and on the plan view of the hydro-zones in the groundwater of the GCMC and PCLA hydrologic systems in the MCSW study area (as shown in Figure 11). The results of this Phase 3 study, and Kolm and van der Heijde (2018, 2019, 2020) verify that the DWSP delineations for City of Moab Wells #4, #5, #6, #7, and #10 that were produced by JMM (1989) are reasonably accurate with regards to groundwater flow path and groundwater basin/surface water watershed interaction for the
GCMC groundwater systems near to the Wells. The assumptions made to complete the calculations by JMM (1989) include: 1) Glen Canyon aquifer is homogeneous and isotropic; 2) Glen Canyon hydraulic conductivity is 20 ft per day; 3) Groundwater boundaries most affecting the wells are the no-flow boundary defined by the extended Kayenta fault and fracture zone to the south of the well sites, and the City springs fault and fracture zone to the north of the well sites. The results of Kolm and van der Heijde (2018; 2019; and 2020) agree with the boundary conditions, and have no data (particularly water quality data) thus far to dispute the fact that no water comes from the Spanish Valley into the City wells, even while pumping. The City Well DWSP delineations cover the main groundwater systems to the east and south of the well sites, and the protection from these delineations covers the main flow paths (Figure 10) and the main high K zones (Figure 11) that need to be protected, both for the Moab City Springs and Wells. Therefore, it is not recommended for these Well delineations to be updated and extended. There is some regulatory question if the delineations should include the entire Mill Creek watershed in the La Sal Mountains (Figure 10).

Figure 10. Plan view of the Moab City Wells DWSP Zones overlain on the flow directions in the groundwater system on top of the hydrogeologic units of the MCSW study area. (see Figure 3 for legend of hydrogeologic units)
3.4 Updated City of Moab Springs and Wells DWSP Delineations: Discussion of Uncertainty

The main uncertainties in the expansion of the DWSP delineations are: 1) recharge rate assumptions for the spring catchment areas; 2) precision of groundwater flow paths within the spring catchment areas considering presence of high-K fracture zones and anisotropy; 3) extent, effective depth and K-values in fracture zones and fracture enhanced matrix areas; 4) assumption underlying selection of scenario #2 for calculation of Skakel Spring catchment area; 5) accuracy of spring discharge amounts in initial water rights declarations; and 6) effects of long term decline of recharge rates regarding spring discharges. Uncertainties of recharge rate, flow path determination, long term decline in recharge rates and spring discharges, and location of high K regions are discussed in Kolm and van der Heijde (2018; 2019; and 2020). The selection of Scenario #2 for calculation was chosen to give a conservative approach for protection of Skakel Spring, and to aid in the protection of surrounding springs.
4. PRELIMINARY MONITORING PLAN (PMP)

4.1 Approach to Preliminary Monitoring Plan Development

The focus of DWSP is the protection of the groundwater systems that function as a source for drinking water supplies. As the main source of drinking water for the City of Moab are springs and wells, their protection through delineation and enforcing DWSP zones is paramount. However, because of 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, it is important to have an adequate monitoring system in place that collects essential climatic, hydrologic, and water quality data within and beyond the DWSP zones. Groundwater and surface water outside the 15 year guidance limit or the spring catchment area, such sections of Mill Creek, North Fork, and Rill Creek, and Burkholder Draw in the GCMC hydrologic system, may eventually become part of the drinking water source and should be monitored, especially for water quality issues. Specifically, greater Mill Creek is susceptible to water supply declines and water quality issues by activity upstream in the Sand Flats area south, or the upper groundwater systems of Wilson Mesa (2a) and South Mesa (2b), or the entire Mill Creek surface water system in the La Sal Mountains (Figures 3, 4, 12, and 13). Note that the greater Brumley and Pack Creeks are also susceptible to water supply declines and water quality issues by activity upstream from the Spanish Valley in the upper groundwater system of the La Sal Mountain system, which may affect the City’s ability to effectively use its water rights in the valley.

To have the necessary climatic, hydrologic and water quality data within and beyond he DWSP zones, a preliminary monitoring plan (PMP) is provided to help protect the City of Moab water supply and water quality at Skakel Spring, and Moab City golf course springs and wells. This preliminary monitoring plan may also be used in managing water rights for the City and for other water users in the greater Mill Creek/Pack Creek watershed.

Developing a preliminary monitoring plan for both the GCMC and PCLA hydrologic systems requires an understanding of how the hydrologic systems work and determination of boundary conditions, flow paths, and inputs and outputs for each hydrologic system, as provided by the HESA performed in Phase 1, 2 and 4 of this project (Kolm and van der Heijde, 2018, 2019, 2020), together with quantification of the involved water budgets as provided the results of Phase 2 and 4 of this project (Kolm and van der Heijde, 2019, 2020). This information is then used to determine the critical surface water, groundwater, and atmospheric data collection points for water quantity and quality. Considerations include determining methods and frequency of data collection, type of hydrological data to be collected, hydrochemical constituents to be analyzed, the costs involved, seasonal and terrain accessibility of the sampling sites, and the processing and management of the data being collected.

4.2 City of Moab Springs and Wells Preliminary Monitoring Plan

The preliminary monitoring sites for the combined Moab City springs and wells are located on a topographic map (Figure 12) to show the relationship with terrain and proximity to...
streams and watersheds, and are overlaid on the plan view of the flow directions in the groundwater system on top of the hydrogeologic units of the MCSW study area (Figure 13) to show the relationship with the groundwater systems. The description of each monitoring site is given in Appendix B and includes site name and number, site type, hydro system, priority, type of measurement, water quality sampling, site description, and comparison to previous sites (for example Blanchard, 1990).

There are six types of monitoring stations in the PMP (Figures 12 and 13, Appendix B): 1) surface water monitoring (discharge and water quality); 2) lake monitoring (evaporation, inflow and outflow, and water quality); 3) monitoring wells (groundwater level and water quality); 4) municipal and other public supply wells (discharge/pumping rates; water quality); 5) City and other springs (discharge rate, water quality); and 6) weather stations (precipitation). Some of the monitoring stations in the PMP are already monitored on a regular basis (i.e., City wells and springs, creek gages MC02A/02B at Sheley diversion), and some other station may have been monitored in the past.

Figure 12. Map with locations of the monitoring sites of the Preliminary Monitoring Plan overlain on the GCMC and PCLA hydro zones.
(see Figure 11 for legend of hydro zones)
Figure 13. Map with locations of the monitoring sites of the Preliminary Monitoring Plan overlain on the hydrogeology and groundwater flow systems of both the GCMC and PCLA hydrologic systems. (see Figure 3 for legend of hydrogeologic units, figure 4 for legend of flow symbols)

Note that the implementation of the PMP requires a significant investment upfront regarding the construction of some of the monitoring facilities and the data collection infrastructure, as well as commitment to long-term maintenance and data collection activities. The City of Moab should use the priority rating in Appendix B as a guidance in making monitoring plan elements operational.
5. CONCLUSIONS AND RECOMMENDATIONS

Under an agreement with City of Moab, Utah, Hydrologic Systems Analysis LLC (HSA) of Golden, Colorado, in conjunction with Heath Hydrology, Inc. (HHI) of Boulder, Colorado, was tasked to complete Phase 3: Review three existing drinking water source protection plans (DWSPP) and update the delineations of the drinking water source protection (DWSP) zones, one for the City’s Skakel Spring, one for the City's Springs 1, 2, and 3 near the golf course (referred to as "City of Moab Springs"), and one for the City's wells (Wells 4, 5, 6, 7, and 10), also near the golf course. This Phase 3 report contains the proposed expanded delineations of the DWSPs for the Skakel Spring and the Moab City’s Springs 1, 2, and 3, and adds a comprehensive preliminary water monitoring plan for the combined GCMC/PCLA hydrologic systems as a new deliverable.

The updated DWSP zones for springs were derived using the same methods for calculating catchment areas as employed in delineating the existing spring DWSP zones, but with updated and refined recharge rates and adhering to new insights in spatial variability of recharge based on the presence of high hydraulic conductivity fracture zones derived from findings on Phases 1, 2, and 4 of this project. These new calculations resulted in updated and extended protection zones for Skakel Spring, and City Springs #1, #2, and #3 to include additional areas of the Kayenta Heights Fault and Fracture Zone, parts of the North Fork Mill Creek and Mill Creek groundwater basins, the Spring Fork/Mill Creek groundwater region, the City Springs and Wells Fracture Zone, and the Mill Creek Fracture Zone. The Phase 3 evaluations also verify that the existing DWSP delineations for City of Moab Wells #4, #5, #6, #7, and #10 are reasonably accurate and do not need adjustments at this time.

As the focus of the DWSPP is the protection of the groundwater systems that function as a source for drinking water supplies, this approach does not provide 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. Therefore, it is important to have an adequate monitoring system in place that collects essential climatic, hydrologic, and water quality data within and beyond the DWSP zones. To provide guidance in developing such a data collection network, a preliminary monitoring plan (PMP) is provided to help protect the City of Moab water supply and water quality at Skakel Spring, and Moab City golf course springs and wells.

The proposed monitoring plan requires a significant initial time and economic investment regarding the construction of some of the monitoring facilities, adapting existing monitoring facilities, and the data collection infrastructure, as well as commitment to long-term maintenance and data collection activities. The City of Moab may use the priority rating provided as a guidance in making monitoring plan elements operational. The monitoring plan also includes important monitoring elements in the Spanish Valley to develop future water supply sources for the City and to protect the City of Moab water rights in the watershed.
6. REFERENCES


Montgomery Watson. 2001a. *Skakel Spring Drinking Water Source Protection Plan: City of Moab (System No 10003), Grand County, Utah*.

Montgomery Watson. 2001b. *Moab City Springs Nos. 1, 2, and 3 Drinking Water Source Protection Plan: City of Moab (System No 10003), Grand County, Utah*


### APPENDICES

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* Based on valley fill thickness published in Lowe and others 2007.

**Appendix A. Aquifer Hydraulic Conductivity, Hydro Zones, and Storage.**
Moab City Springs and Wells Study – Phase III

Appendix B. Preliminary Monitoring Plan (PMP) for Protection of City of Moab Springs and Wells.
HYDROLOGIC AND HYDROGEOLOGIC ASSESSMENT OF THE SURFACE WATER AND GROUNDWATER RESOURCES AFFECTING THE MOAB CITY SPRINGS AND WELLS, MOAB, UTAH: PHASE 4: PRELIMINARY HESA-BASED WATER BUDGET AND AQUIFER STORAGE EVALUATION FOR SPANISH VALLEY AND COMBINED MILL CREEK / PACK CREEK HYDROLOGIC SYSTEMS

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Prepared For:
City of Moab, Utah

March 2020
Front Page: View of Moab, Utah in the northern area of the Pack Creek Lower Alluvium (PCLA) Subsystem from the Moab Rim Trail. Mill Creek and Pack Creek are perennial streams that flow in the Quaternary Alluvium Aquifer (Hydrogeologic Unit).
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EXECUTIVE SUMMARY

This report presents the findings of Phase 4 of a 4-phase project focused on improving the understanding of the hydrogeological setting of the water supply sources for the City of Moab, the quantification of the water resources available to the City, and updating the City springs and wells protection against contamination. In Phase 1, a Hydrologic and Environmental System Analysis (HESA) of the Mill Creek and Pack Creek watersheds was performed to identify the hydrological systems of specific importance to the sustainability of the Moab City springs and wells as water supply for the City. It was concluded that the City’s water supply was mainly dependent on the hydrologic system formed by the Mill Creek Watershed and the Glen Canyon aquifer underlying the Sand Flats region, including Johnsons-on-the-Top. This hydrologic system, referred to as the Glen Canyon Group - Mill Creek (GCMC) hydrologic system, was chosen in Phase 2 of the project as the setting for the quantification of the water resources available to the City, resulting in a preliminary global water budget of the entire GCMC hydrologic system. In July, 2019, the project was expanded as Phase 4 to include performing a Hydrogeologic and Environmental Systems (HESA) Analysis (including an expanded water budget and storage analysis) of the Spanish Valley, which is the Pack Creek Lower Alluvium (PCLA) hydrologic system as part of protecting the remaining City wells and for water management and water rights purposes. Preliminary water budgets (PWB) for pre-development (natural) and post-development (natural and current) combined GCMC/PCLA hydrologic systems was completed. In summary, the results of the HESA of the MCSW area performed in Phase 1 were documented in Kolm and van der Heijde (2018), the results of the HESA and water budgets for the GCMC area performed in Phase 2 are documented in Kolm and van der Heijde (2019), and the results of the HESA and water budgets for the PCLA area and the combined GCMC/PCLA area performed in Phase 4 are in this document.

The Pack Creek Lower Alluvium (PCLA) hydrologic system is a complex mix of Alluvium and Alluvial Fan sediments overlying or adjacent to fractured and faulted Glen Canyon Group rock, and hydro-structures (fault and fracture zones that are either conductive or a barrier to groundwater flow). These hydrogeologic units form the robust integrated groundwater and surface water system that sustains the Spanish Valley springs and wells particularly in the
southern two-thirds of the Valley. The HESA completed in phase 4 showed that the PCLA hydrologic system is a well-defined system for which the boundary conditions and internal surface water–groundwater interactions are well-understood and quantifiable to various degrees of accuracy.

In order to estimate the upper bounds of the water resources present in the PCLA hydrologic system, a preliminary (global) water budget (PWB) has been developed for the PCLA hydrologic system, focused on the external inputs (inflows) and outputs (outflows). In addition, an analysis was made of the storage capacity of the PCLA aquifer in the PWB area. The area in PCLA for which the water budget is determined is based, in part, on the locations of various stream gages on Pack Creek and Mill Creek (Blanchard, 1990; USGS Surface-Water Dailey Statistics, Mill Creek at Shelley Tunnel Sites, 2019); the location of most anthropogenic activities (diversions, domestic and agricultural water use); the natural boundaries of the PCLA hydrologic system including Pack Creek and tributaries; and the hydrogeologic and hydrostructural boundaries of the Pack Creek Alluvium Aquifer as determined by HESA. The water budget area is bounded by the Glen Canyon Group Mill Creek Subsystem (GCMC) to the northeast and east; the Morrison Formation to the east and southeast; the La Sal Mountain Upper Alluvial Subsystem (LSMA-P) Pack Creek Headwaters to the southeast; the Moab Rim and Kane Creek hydrological divides to the south, southwest, and west; and the Colorado River to the northwest. The PWB area used in this report covers almost all of the PCLA hydrologic system.

There are two distinct time periods of anthropogenic stresses in the PCLA hydrologic system: pre-development or natural conditions; and post-development or current conditions, which includes both natural and anthropogenic conditions. The most significant anthropogenic change in conditions happened in the early 1980s, the start of the Sheley diversion, together with the initiation of a steady increase in municipal and domestic water use that represents a significant increase in the anthropogenic withdrawals from the PCLA hydrologic system that continues to the present day. This latter period is referred to in this report as the post-development phase. A preliminary water budget (PWB) has been developed for each of these two time periods.

The pre-development PCLA water budget has as inputs: 1) direct runoff of precipitation to streams; 2) recharge by infiltration of precipitation (rain and snow) across the entire PWB area using the concept of hydro zones explained later in this report; 3) Pack Creek groundwater flux, called groundwater underflow, in the Quaternary hydrogeologic units (Qal) at the SE corner of the water budget area; 4) Brumley Creek groundwater flux, called groundwater underflow, in the Quaternary hydrogeologic units (Qal) at the SE corner of the water budget area; 5) Mill Creek groundwater flux, called groundwater underflow, in the Quaternary hydrogeologic units (Qal) at the Mill Creek delta (Powerhouse); 6) Pack Creek surface water inflow above the later ditch diversion in the SE corner of the water balance area; 7) Brumley Creek surface water inflow to Pack Creek in the SE corner of the water balance area; 8) Mill Creek surface water inflow at the Mill Creek delta (powerhouse) in the northeast water balance area; 9) Sheley diversion in post-development/current conditions; and 10) springs at eastern PWB boundary from the GCMC system (including City Springs and Skakel spring). The outputs of the PWB are: 1) evapotranspiration or consumptive use by native phreatophytes (cottonwoods, willows, tamarisk, and other riparian species); 2) evaporative loss open water; 3) Mill Creek surface water outflow.
at the northern end of Spanish Valley to the Colorado River; and 4) groundwater discharge to the Colorado River. The closing term or balancing term in the pre-development PWB is formed by direct runoff to streams from precipitation. That term, adjusted for changes in average precipitation, is then used as an input for the preliminary post-development water budget.

The post-development PCLA water budget has the same type of inputs as the pre-development water budget, but has an additional inflow term, the Sheley diversion). The post-development PCLA water budget has the same type of outputs as the pre-development water budget, but has additional anthropogenic terms: 1) consumptive use of crops; 2) net municipal use (GWSSA and losses/return flow of City Water); and 3) domestic consumptive use by private wells.

Recharge to groundwater is estimated using 5-25% of precipitation dependent on hydro zone type. The average annual precipitation was calculated for each hydro zone for both the periods 1971-2000 (considered representative for pre-development conditions) and 1981-2010 (representative for “current” conditions) resulting for the period 1971-2000 in 3170 ac-ft/yr or 1.9 inches across the entire PWB area; and for the period 1981-2010 in 2765 ac-ft/yr or 1.6 inches across the entire PWB area. Note that the estimate for recharge in both periods amounts to about 16-17 % of overall precipitation in the PWB area.

Direct runoff of precipitation to streams amounts to 815 ac-ft/yr. This term, corrected for the decline in precipitation between the two climate periods and the increase of direct runoff in buildup/urbanized areas amounting to a total of 1300 ac-ft/yr, is used in the post-development scenario. Direct evapotranspiration (ET) in the PWB area (excluding riparian vegetation), calculated as precipitation minus groundwater recharge and direct runoff to streams, amounts to about 14,525 ac-ft/yr for the pre-development period and to 13,565 ac-ft/yr for the post-development period, or about 75-78% of total precipitation, based on 30-year averages for the two climate periods.

The primary conclusion regarding the PWB is that there is a significant amount of surface water and groundwater contributed to the PCLA hydrological system from the La Sal Mountain and GCMC hydrological systems, or in percentages of pre-development input into the PCLA hydrologic system: surface water and groundwater derived from the GCMC hydrologic system (Mill Creek + groundwater underflow at the Mill Creek delta + springs at eastern PWB boundary from GCMC system) is 13,270 ac-ft/yr and counts for approximately 65%; local recharge from precipitation and direct runoff from precipitation to streams counts for 20%; and directly linked groundwater inflow and surface water inflow (Pack Creek and Brumley Creek) from the La Sal Mountains hydrological subsystems counts for 15%. This means that the La Sal Mountain and GCMC subsystems contribute more than 80% of the total inflow in the PWB area. Note that a combined consumptive use riparian vegetation and evaporative loss open water accounts for 35% of the total water budget out, and remainder is subsurface and surface discharge to the Colorado River. By comparison, in the post development time period, the contribution of the Sheley diversion to the overall input becomes more of a factor, or in percentages of post development input into the PCLA hydrologic system: surface water (Mill Creek + Pack Creek + Brumley Creek) counts for approximately 55%; local recharge from precipitation and direct runoff to streams for 19%; groundwater inflow from the GCMC hydrological subsystems counts for about
9%; and the Sheley diversion provides 17% of the total inflow to the PCLA hydrologic system and has resulted in a 17% reduction of Mill Creek inflows towards Spanish Valley under base flow conditions and 31% reduction of springs and seeps discharge in the most likely scenario. Therefore, any decline in upstream total average flows in Mill Creek, Pack Creek, or Brumley Creek from natural or man-made causes will have an immediate and significant impact on the various outflows of the PCLA hydrologic system and poses a potential threat to the sustainability of the City of Moab’s and the County’s water supply.

Many of the components of the PWB calculations include large uncertainties. The most reliable data are the USGS stream flow data in Mill Creek at and below the Sheley diversion; the springs and wells production data from the City of Moab and GWSSA, and the precipitation data from NOAA used to develop various recharge scenarios. However, these data sets are not all complete or cover comparable time periods. All other data sets provide a “snap shot” of a particular variable in time as they were gathered at various, non-comparable moments in time and, thus, should be considered a first estimate, subject to refining by further field studies. Another area where significant cost-effective improvements to the PWB can be made is more detailed and frequent monitoring of the Pack Creek surface water system. Gaging stations at Mill Creek (Powerhouse, Junction with Pack Creek, Colorado River), Pack Creek (City Springs and Perennial Flow locations, Pack Creek Bridge, Settlement of Pack Creek, and Brumley Creek that record daily, seasonal, and annual information would improve the measurements of the City of Moab and Spanish Valley protected areas. Water quality measurements would be recommended at these sites as well. In addition, continued monitoring of City Springs and Wells, including Skakel Spring, for daily, seasonal, and annual information regarding flow and water usage is recommended. An analysis of this and the data currently available, in addition to continued analysis of the climate data compared to the City Springs and Wells, and Skakel Spring, is recommended as a future part of this study.

The Quaternary alluvium and fan gravels, and the fractured Glen Canyon Group groundwater system is mostly unconfined, i.e., having a readily fluctuating water table, and the aquifer storativity is characterized by so-called specific yield. The alluvium and alluvial fan gravels has matrix specific yield with estimates of 10 – 30%, and the Glen Canyon Group bedrock has both matrix specific yield (small) and fracture specific yield (large); the matrix specific yield estimates range from 1.0 – 10.0%; the fracture specific yield estimates range from 10.0 – 40.0%. As there is a significant presence of fracture zones in the bedrock of the PCLA system, fractures are the dominant feature in determining available groundwater storage at these locations. The results of GIS-based calculations show that the PCLA groundwater system has a variable storage low of 38,375 ac-ft, and a variable storage high of 101,400 ac-ft. The Quaternary alluvial deposits, designated storage zone 1, had the largest amount of variable storage with a range of 24,850-74,550 ac-ft. Areas along the groundwater flow paths that directly affect the yields and water quality of the GWSSA wells have the largest amount of storage. The current City of Moab source protection plans identify some of these hydro zones as critical, and an update to these plans will be completed in Phase 3 of this project.

In order to develop a preliminary water budget of the combined Pack Creek Lower Alluvium (PCLA) and Glen Canyon Group Mill Creek (GCMC) Subsystems of the MCSW study area, it was first necessary to 1) create a true PWB of the Pre-development natural
conditions of the GCMC subsystem and to 2) slightly revise the PWB of the post development (current) conditions based on new information obtained since the original release of Kolm and van der Heijde (2019) report on the GCMC subsystem. The Kolm and van der Heijde (2019) report discusses the HESA-derived conceptual model for the GCMC subsystem in great detail, and provides PWBs for pre-Sheley diversion conditions (not a true predevelopment scenario since the report focused on the effects of the Sheley diversion on the City of Moab water supply), and the current conditions. A PWB for the GCMC Hydrologic System under natural (pre-development) conditions was developed using a modified PWB described in the Phase 2 report (Kolm and van der Heijde, 2019). This GCMC PWB is then combined with the PCLA PWB to provide estimates for water rights and water management purposes. The water balance inflow terms are the same as those in the Kolm and van der Heijde (2019) Phase 2 report, and all terms are rounded off. By comparison, the pre-development outflow terms have been increased by about 8.3% compared with Kolm and van der Heijde (2019) due to absence of municipal and domestic use. A discussion of these two budgets is provided.

A preliminary water budget (PWB) for the combined GCMC/PCLA hydrologic systems is calculated based upon the information previously collected and analyzed by Kolm and van der Heijde (2018), Kolm and van der Heijde (2019), the HESA-based conceptual model of the GCMC hydrologic system determined in Phase 1, and the HESA-based conceptual model of the PCLA hydrologic system determined in Phase I and refined in Task 1 of this Phase (4) project. The combined GCMC and PCLA water budget area is bounded by the Glen Canyon Group Grandstaff Creek Subsystem (GCGC) to the northeast and east; the Morrison Formation to the east and southeast; the La Sal Mountain Upper Alluvial Subsystem (LSMA-P) Pack Creek Headwaters to the southeast; the Moab Rim and Kane Creek hydrological divides to the south, southwest, and west; and the Colorado River to the northwest. The PWB area used in this report covers almost all of the PCLA and GCMC hydrologic systems.

The significant inputs of the PWB for the combined GCMC/PCLA hydrologic systems are: 1) direct runoff of precipitation to streams; 2) recharge by infiltration of precipitation (rain and snow) across the entire PWB; 3) Mill Creek groundwater flux, called groundwater underflow, at the upper Mill Creek boundary (inflow through Mill Creek fracture zone); 4) Pack Creek groundwater flux, called groundwater underflow, in the Quaternary hydrogeologic units (Qal) at the SE corner of the water budget area; 5) Brumley Creek groundwater flux, called groundwater underflow, in the Quaternary hydrogeologic units (Qal) at the SE corner of the water budget area; 6) Mill Creek inflow above later location of Sheley diversion; 7) Upper North Fork Cr. and Burkholder Draw inflow from Mesas; 8) Pack Creek surface water inflow above the later ditch diversion in the SE corner of the water balance area; and 9) Brumley Creek surface water inflow to Pack Creek in the SE corner of the water balance area. The outputs of the combined PWB are: 1) Consumptive use crops; 2) evapotranspiration or consumptive use by phreatophytes (cottonwoods, willows, tamarisk, and other riparian species); 3) Evaporative loss open water; 4) Net Municipal use GWSSA and losses/return flow City of Moab Water; 5) domestic consumptive use by private wells; 6) groundwater discharge to the Colorado River; 7) Mill Creek surface water outflow at the northern end of Spanish Valley to the Colorado River, and 8) Release from groundwater storage in the post-development (current) PWB.

In the combined GCMC/PCLA pre-development scenario, the water budget closing term represents the term for direct runoff to streams and amounts to 5950 ac-ft/yr. The combined
GCMA/PCLA post-development scenario incorporates human activities, such as the Sheley Diversion intake of 3665 ac-ft/yr, but the water budget treats that as an internal process, which doesn’t appear in the global PWB for the combined GCMC/PCLA area. However, due to the diversion, and the increase water use by human activity, the closing term is release from groundwater storage in the GCMC part of the combined system of 3995 ac-ft/yr, which is approximately 14% of the total yearly budget. The deficit may be reduced over time by increased recharge in above average precipitation years, or as increased flow to Mill Creek into the GCMC hydrologic systems upgradient due to increased groundwater release in upgradient groundwater systems, or increased runoff from higher than average snowpack. This depletion of upgradient storage or mining of groundwater is also a concern for the sustainability of both the City’s and the PCLA water supply.

The primary significance of the combined PWB is that there is a significant amount of surface water and groundwater contributed to the GCMC and PCLA hydrological systems from the La Sal Mountain systems, or in percentages of pre-development input into the GCMC/PCLA hydrologic system: surface water and groundwater derived from the La Sal Mtns is 11,515 ac-ft/yr and counts for approximately 45%, and local recharge from precipitation counts for 33%. This means that the La Sal Mountain climate regimes can affect directly 78% of the water supply. Note that a combined consumptive use riparian vegetation and evaporative loss open water accounts for 49% of the total water budget out (almost one-half!), and the remainder of 51% is subsurface and surface discharge to the Colorado River. By comparison, in the post development time period, the development of the Sheley diversion to the overall redistribution of the water supply plus the increase in municipal use and consumptive use becomes more of a factor, or in percentages of post development change into the GCMC/PCLA hydrologic system: consumptive use crops accounts for 13%, municipal use and domestic consumptive use accounts for 11%, and groundwater released from storage accounts for approximately 14%. The Sheley diversion yearly amounts is almost entirely accounted for in the consumptive use of crops and domestic consumptive use. The most notable decline is the amount of Mill Creek outflow to the Colorado River of 1,620 acre-ft/year or 13%.

Many of the components of the PWB calculations include large uncertainties. The most reliable data are the USGS stream flow data in Mill Creek at and below the Sheley diversion; Pack Creek in the southeastern part of the Spanish Valley; Mill Creek in the GCMC system, the springs and wells production data from the City of Moab, and the precipitation data from NOAA used to develop various recharge scenarios. However, these data sets are not all complete or cover comparable time periods. All other data sets provide a “snap shot” of a particular variable in time as they were gathered at various, non-comparable moments in time and, thus, should be considered a first estimate, subject to refining by further field studies.

There are a number of potential threats to the sustainability of the GCMC/PCLA hydrologic system and thus to the water supply of the City of Moab and Grand County, both natural and man-made. Climate change may reduce water contributions originating from the La Sal Mountain subsystem, both in amounts and timing. In addition, water diversion projects to other watersheds, especially up-stream of the GCMC/PCLA hydrologic system, will result in decreased surface water flows and groundwater recharge from losing streams. Impacts on the GCMC/PCLA hydrologic system may also result from deforestation due to lumbering or fire
(increased unchanneled surface runoff and stream flow peaks, and decreased stream base flow); increased forestation (increased ET; decrease of runoff and stream flows); and mining (increased or decreased stream flows and groundwater fluxes). Land use conversions/changes resulting in more or less consumptive uses need to be evaluated regarding the surface water output to Mill Creek, Pack Creek and Brumley Creek at the east and southeast end of the GCMC/PCLA hydrologic system. Increased consumptive use would result from increased urbanization (more wells, non-native vegetation), or increased irrigation. Any long term decline in inflows to the GCMC/PCLA hydrologic system will result in further decline of outflows such as at Mill Creek, Pack Creek and Brumley Creek in the eastern and southern part of the study area and various springs, and will likely lead to decline in storage and subsequent lowering of groundwater levels and groundwater availability for phreatic consumption.

Based upon associated uncertainties with estimates, the greatest cost-effective improvements to the PWB, primarily post-development, is better monitoring of the Mill Creek and Pack Creek surface water system. Gaging stations at Mill Creek (Powerhouse, Junction with Pack Creek, Colorado River), Pack Creek (City Springs and Perennial Flow locations, Pack Creek Bridge, Settlement of Pack Creek, and Brumley Creek that record daily, seasonal, and annual information would improve the measurements of the City of Moab and Spanish Valley protected areas. Water quality measurements would be recommended at these sites as well. In addition, continued monitoring of City Springs and Wells, including Skakel Spring, for daily, seasonal, and annual information regarding flow and water usage is recommended. An analysis of this and the data currently available, in addition to continued analysis of the climate data compared to the City Springs and Wells, and Skakel Spring, is recommended as a future part of this study. This Phase IV HESA revealed that the GCMC/PCLA groundwater system was complex being both matrix and fracture-type flow, and that the design, implementation, and calibration of a mathematical model can be done, and may be cost-effective at this time. Given the uncertainties with the data available, the results would still tend to be questionable. The PWB of the GCMC groundwater system in Phase II would provide inputs into a Spanish Valley model, and the HESA of the PCLA and GCMC groundwater systems would provide boundary conditions for that model.
1. INTRODUCTION

Under an agreement with City of Moab, Utah, Hydrologic Systems Analysis LLC (HSA) of Golden, Colorado, in conjunction with Heath Hydrology, Inc. (HHI) of Boulder, Colorado, was tasked to: 1) Perform a Hydrologic and Environmental System Analysis (HESA) of the Moab City Springs and Wells (MCSW) area, supported by GIS databases and maps, to develop a comprehensive and updated understanding of hydrogeologic and hydrologic characteristics of the groundwater system, using currently available data and published analyses; 2) Collect hydrological, hydrogeological and other data, and develop an as-accurate-as-possible water budget for the segment of the MCSW area affecting the City’s springs and wells; and 3) Update three drinking water source protection plans and the delineations of the drinking water source protection zones, one for the City's Skakel Spring, one for the City's Springs 1, 2, and 3 near the golf course (referred to as "City of Moab Springs", and one for the City's wells (Wells 4, 5, 6, 7, and 10), also near the golf course (see Figure 1 for the current delineation of the Moab Drinking Water Source Protection (DWSP) Zones for the wells and springs). In July, 2019, the agreement was expanded to include Task 4: Perform a Hydrogeologic and Environmental Systems (HESA) Analysis (including an expanded water budget and storage analysis) of the Spanish Valley as part of protecting its remaining wells and for water management and water rights purposes, and a combined water budget analysis for the combined Pack Creek Lower Alluvium (PCLA) and Glen Canyon Mill Creek (GCMC) hydrologic subsystems of the MCSW. Each of these tasks constitutes a phase of the project. This report contains the results of Phase 4: Collect hydrological, hydrogeological and other data, and develop an as-accurate-as-possible water budget for PCLA hydrologic system, covering the Spanish Valley part of the MCSW area, and the water budget for the combined Lower Pack Creek and Mill Creek hydrological subsystems. The results of the HESA of the entire MCSW area performed in Phase 1 are documented in Kolm and van der Heijde (2018), and the results of the study of the GCMC area performed in Phase 2 are documented in Kolm and van der Heijde (2019).

The Phase 1 study area 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 (Figure 1). Based on the results of Phase 1, the Glen Canyon aquifer and Mill Creek Watershed (GCMC) underlying the Sand Flats region was chosen as the setting for the water budget developed in Phase 2 of this project, and the Pack Creek Watershed and the Quaternary unconsolidated alluvium (PCLA) in the Spanish Valley was chosen as the setting for the water budget developed in Phase 4 of this project. The analysis of these areas will be used for updating the Drinking Water Protection Plans for the springs and wells of the City of Moab planned for Phase 3 (Figure 2). The combined GCMC and PCLA water budgets included both of these areas (Figure 2).

The HESA of the surface water and groundwater systems in the MCSW study area made extensive use of existing GIS databases and maps of geologic, hydrogeologic and hydrologic characteristics, collected specifically for this study. Additional data layers and evaluations were prepared to illustrate the HESA – particularly with respect to the hydrogeological characteristics of the rock types present and the significance of hydrostructures (i.e., hydrogeologically significant faults and fracture zones). The results of the HESA provide the conceptual basis for the development of the hydrological water budget for the City wells and springs in the second,
and now this 4th project phase. The HESA included a few scoping site visits to the study area; additional field surveys have been conducted as the project progressed.

![Figure 1. Topographic map showing the Phase 1 Moab City Springs and Wells (MCSW) Study Area, and the location of the City of Moab springs and wells and GWSSA wells](image)

Various information sources have been consulted in preparation of the Phase 2 and Phase 4 analysis of the preliminary water budget (PWB) for the area affecting the City wells and springs, including Federal, State and City reports and data bases. When applicable, data were organized in a Geographical Information System (GIS) using the ESRI® ArcMap™ software. The data sources included Utah AGRC (Automated Geographic Reference Center), Utah Division of Water Rights (UDWR), Utah Division of Environmental Quality (Utah DEQ), Utah Geological Survey (UGS), U.S. Geological Survey (USGS), Natural Resources Conservation Service (NRCS) of the U.S. Department of Agriculture, NOAA National Centers for Environmental Information, City of Moab, and others. In addition, HSA/HHI has prepared a number of data layers specifically for this report through interpretation of existing data sets and field reconnaissance.
It should be noted that this report will not obviate the need for additional hydrogeologic analysis on a site-specific/parcel-specific basis by developers and/or the City, or in any water right, geotechnical, or environmental study requiring due diligence. The information in this report is intended to be used as indicator only, as part of a multi-step land use or water management decision-making process, and to provide a starting point for further study of the City's surface water and groundwater resources.
2. HESA-BASED CONCEPTUAL MODEL OF PACK CREEK LOWER ALLUVIUM (PCLA) HYDROLOGIC SUBSYSTEM OF THE MCSW STUDY AREA

Hydrologic and Environmental System Analysis (HESA) is an approach used to conceptualize and characterize relevant features of hydrologic and environmental systems, integrating aspects of climate, topography, geomorphology, groundwater and surface water hydrology, geology, ecosystem structure and function, and the human activities associated with these systems into a holistic, three-dimensional dynamic conceptual site model (CSM). This watershed-based, hierarchical approach is described by Kolm and others (1996) and codified in ASTM D5979 Standard Guide for Conceptualization and Characterization of Ground Water Systems (ASTM 1996, 2008). The CSM of the MCSW study area covers elements of climate, topography, soils and geomorphology, surface water characteristics, hydrogeologic framework, hydrology, and anthropogenic activity as related to the surface water and groundwater systems in the study area.

Based on field surveys and a preliminary HESA, a number of hydrologic subsystems were identified within the MCSW study area in Phase 1 of this project (Kolm and van der Heijde, 2018) (Figure 3). Each of these subsystems is characterized by a unique combination of surface water system, hydrogeologic setting, and groundwater flow system and is described in detail in the Phase 1 report. Section 2 of the Phase 4 report summarizes the HESA-based conceptual model of the Pack Creek Lower Alluvium (PCLA) Hydrologic Subsystem of the MCSW study area presented in the Phase 1 report. This subsystem is the focal point of the preliminary water budget analysis presented in later sections of this report.

The Pack Creek Lower Alluvium Subsystem (PCLA), located in the southwestern part of the study area (CSM 5 in Figure 3), is a complex mix of fractured and faulted, and unfractured Glen Canyon Group (Jgc), Stream alluvium (Qal), Alluvial fan deposits (Qaf/Qas) and hydrostructures (fault and fracture zones) which form the robust groundwater system and surface water system that is directly connected to the City of Moab and Grand County wells in the central part of the Spanish Valley (Figures 4, 5 and 6). Compared with the other 5 subsystems, PCLA is the second most important subsystem for the City of Moab wells sustainability and protection, and directly affects most of the Valley users for culinary water supply, although knowledge of the GCMC and LSMA-P subsystems is crucial in protecting these assets. This subsystem is hydraulically connected to the Glen Canyon Group Mill Creek (GCMC) and La Sal Mountain Upper Alluvium Subsystem (LSMA-P) upgradient primarily by surface water (Mill Creek and Pack Creek, respectively, by outflow streams from the major springs like Skakel Spring, and by surface water diversions from Mill Creek (Sheley Tunnel diversion to Ken’s Lake) and does not have significant direct groundwater connection through shallow or deep hydrogeologic units with adjacent hydrologic subsystems.
Figure 3. Plan view of the Conceptual Site Model (CSM) subsystems of the MCSW study area on top of hydrogeologic units: 1a. La Sal Mountain Upper Alluvial Subsystem (LSMA-M) Mill Creek Headwaters; 1b. La Sal Mountain Upper Alluvial Subsystem (LSMA-P) Pack Creek Headwaters; 2a. Wilson Mesa Alluvial Fan Subsystem (WM AF); 2b. South Mesa Alluvial Fan Subsystem (SM AF); 3. Glen Canyon Group Mill Creek Subsystem (GCMC); 4. Glen Canyon Group Grandstaff Creek Subsystem (GC GC); 5. Pack Creek Lower Alluvium Subsystem (PCA); and 6. Morrison Formation and other Confining Formations. Modified from Figure 21 in Kolm and van der Heijde (2018).

As stated in Section 2.5.2 in Kolm and van der Heijde (2018), there are two significant hydrogeologic groups in the PCA Subsystem, which includes Pack Creek and its tributaries: 1) Quaternary unconsolidated clastic materials (Figure 15; Table 2a in Kolm and van der Heijde, 2018), which are predominantly Stream Alluvium (Qal) and Alluvial Fan deposits (Qaf/Qas); partially overlying 2) Mesozoic bedrock units (Figure 16; Table 2b in Kolm and van der Heijde, 2018), including the following potentially water-bearing units: the Glen Canyon Group (Jge), including the Navajo Sandstone (Jn), the Kayenta Sandstone when fractured (Jk), and the Wingate Sandstone (Jw).

In addition, there are two types of geological structures in the PCA Subsystem of significance to the hydrogeology in general and to groundwater flow directions in particular (Figures 4 and 5): 1) northeast-southwest and north-south trending fault/fracture zone hydrostructures; and 2) northwest-southeast trending faults, and fault/fracture zones.
The two major northwest-southeast fault zones of importance to the PCLA hydrologic subsystem are located on both sides of the Spanish Valley (Figures 4 and 5). The northeastern fault zone bounds the eastern Spanish Valley rimlands for their entire length and has the name Kayenta Heights Fault Zone along the City of Moab and Extended Kayenta Heights Fault Zone between Mill Creek and the City of Moab Springs Fracture Zone. The Kayenta Heights fault zone is open and a groundwater conduit moving water from Mill Creek to various springs and discharge zones, including City of Moab’s Skakel Spring. The middle and southern part of this fault zone serves as a conduit and connects water leaking from Ken’s Lake with various Grand County wells to the northwest (Figure 6), but can also serve as a block bringing the Glen Canyon Group next to the Permian shales and salts, as evidenced by the City of Moab springs near the
Moab golf course. The southwestern fault zone along the Moab Rim also serves as a groundwater conduit, and allows water to flow from the southwestern part of Spanish Valley northwestward to a set of springs just southwest of the Moab City center (Figure 6).

The shallow Quaternary unconsolidated materials in this subsystem are located in two strategic locations: 1) directly along the main channels and subsurface paleochannels of the stream (Qal); and 2) aligned along the Moab Rim walls connected to the main channels (Qaf) (Figure 7 and Table 2a in Kolm and van der Heijde, 2018). These alluvial (Qal) highly-permeable deposits are heterogeneous, mostly sand and gravels, and regionally derived from fluvial and glacial activity associated with the La Sal Mountains. The alluvial fan (Qaf) deposits are locally derived from the weathering, mass wasting, and fluvial activity associated with the
mixed sedimentary rocks of the Moab Rim bedrock. The mixed history of the sedimentary rocks is partially responsible for the high TDS water quality of the shallow aquifer discussed in a later chapter.

Figure 6. Plan view of the flow directions in the groundwater system on top of the bedrock hydrogeologic units of the PCLA Subsystem area. The blue arrows are groundwater flow directions. The larger white arrows show groundwater flow direction along major hydrostructures and the major groundwater flow direction in the Spanish Valley area. Modified from Figure 22 in Kolm and van der Heijde (2018).

The Glen Canyon Group bedrock has both matrix flow and fracture flow. The matrix flow has ranges estimated from 0.3 – 1.0 ft/day (Jobin, 1962; Blanchard, 1990; Lowe and others, 2007); and the fracture flow can be as high as 88 ft/day (Freethey and Cordy, 1991). Therefore, fracture flow will dominate travel times and will be most important for contaminant studies and
well/spring protections, as well as estimating groundwater storage and recharge rates. The matrix flow is mostly located in the center of the central and southern Spanish Valley where the Glen Canyon Group located underneath is present, whereas the fracture flow is mostly associated with the two fault and fracture zones located on either side of the Valley (Figure 6).

Figure 7. Plan view of the flow directions in the shallow groundwater system on top of the Unconsolidated Hydrogeologic units of the PCLA Subsystem area. The arrows show groundwater flow direction along major subsurface paloevalleys and the major groundwater flow direction in the Spanish Valley area. Modified from Figure 22 in Kolm and van der Heijde (2018).

The general aspects of groundwater flow in the Quaternary unconsolidated materials have been discussed in Section 2.5 of Kolm and van der Heijde (2018)(Figure 8). Figure 8 (Figure 31 in Kolm and van der Heijde; 2018) specifically illustrates the groundwater flow paths along the
longitudinal axis of the Spanish Valley. The PCLA shallow groundwater flow systems (Qal and Qaf/Qas) recharge the Glen Canyon Group hydrogeologic units beneath the upper Spanish Valley as is illustrated by the losing reaches of Pack Creek and the Pack Creek diversion ditch. The PCLA subsystem then discharges groundwater as gaining stream reaches and springs in the lower Spanish Valley (Figures 6, 7, and 8).

In the lower Spanish Valley from the Moab City limits to the Colorado River, the shallow groundwater in the Pack Creek Lower Alluvial subsystem has little connection to the local bedrock or subregional groundwater systems, given the very low permeability Pennsylvanian Paradox Formation (IPpc) (Figure 8). As the shallow groundwater flows over this bedrock, a tremendous amount of salt is leached greatly reducing the water quality.

Figure 8. Schematic Northwest-Southeast Cross-sectional View of Part of the Conceptual Site Model of the PCLA Subsystem Along the Axis of the Spanish Valley, Utah (J-J’ in Figure 25 of Kolm and van der Heijde, 2019; modified from Figure 31 of Kolm and van der Heijde, 2018).

Recharge to the PCLA subsystem is by: infiltration of precipitation (snow and rain) directly into the unconsolidated deposits (Qal and Qaf/Qas); losing reaches of ephemeral streams from the Valley sides; losing reaches of Pack Creek, Mill Creek, and the Pack Creek diversion ditch; leakage from Ken’s lake and Faux Falls stream; return flow from irrigation (crops and lawns) and septic tanks; groundwater underflow from the LSMA-P, Brumley Creek, and Mill Creek near the Powerhouse; and springs overflow along the Kayenta Fault and Fracture Zone (Figures 6, 7, and 8). Groundwater flow in the PCLA unconsolidated materials is with topography from hilltop and ridgetop down the hillslope to the valley bottom, and then parallel with the valley bottom streams (Figures 7 and 8). Groundwater in the valley bottom stream unit moves in the same direction as the stream with various stream reaches being gaining or losing depending on subsurface topography, saturated thickness of the alluvium, or the seasonal variations caused by snowpack runoff or storm events.
In the lower part of the PCLA subsystem, the alluvial deposits are underlain by a paleo-topographic surface carved out by paleo mass wasting and fluvial systems that eventually deposited the Quaternary unconsolidated materials that are the aquifers being evaluated. It is noted that the paleo-alluvial and modern alluvial systems followed structural fault zone controlled valleys and account for increased aquifer thicknesses in these paleo-valleys (Figure 7). Throughout the subsystem, there is groundwater discharge from the alluvium by phreatophytes, locally by groundwater wells and springs, gaining reaches of streams notably Pack and Mill Creeks from the City Springs area to the Colorado River, and as groundwater underflow to the Colorado River (Figures 7 and 8).
In section 2 of this report, the components of the Pack Creek Lower Alluvium (PCLA) hydrogeologic system and the surface water and groundwater flow systems have been discussed. The PCLA has been analyzed with respect to surface water dynamics (stream input or stream flux in, stream flow through the given area, stream output or stream flux out) and available stream flow data have been collected (for example, Blanchard, 1990; USGS Surface-Water Dailey Statistics, Mill Creek at Sheley Tunnel Sites, 2019). In addition, precipitation data relevant for the watershed have been collected in table and map format (Kolm and van der Heijde, 2018). Likewise, the major elements of the dynamics of the hydrogeologic system -- groundwater input or recharge areas, groundwater output or discharge areas, and the (internal) groundwater flow system -- have been determined (See Section 2.0 and Kolm and van der Heijde, 2018). Well and spring data to quantify groundwater output have been collected from various sources (Lowe and others, 2007; Kolm and van der Heijde, 2018; Utah Water Rights Data Base, 2017, 2018, 2019). Published groundwater level data have enabled the determination of groundwater flow direction and amount of water storage and well yield at a given point in the groundwater system (Lowe and others, 2007; Masbruch and others, 2019), which can be used to calculate groundwater flux and storage over time.

In order to further understand how the PCLA hydrologic system works, and to determine quantitatively if the hydrologic system is properly analyzed, a water budget may be developed for the PCLA hydrologic system. The hydrologic system water budget, or water balance, is the quantitative listing of the surface water and groundwater inputs and outputs, and changes in internal storage over a particular period of time. In its most simple form, the period of time is chosen such that the internal storage changes are so small that they do not have to be taken into account. Considering climatic variability, often a multi-year period with averaged inputs and outputs is selected to determine the water budget for a particular hydrologic system. The water budget inputs should be equal to or "balance" the water budget outputs. The selection of the time period for which to calculate the water budget depends, among others, on the nature of the climatic variability, and the availability of climatic and hydrologic records. Frequently this is done for a one- or multi-year period to capture a full cycle of seasons, or multi-year trends. For shorter periods of time, such as the growing season, water budget calculations may involve estimating the release from or addition to internal storage. This may also be the case if there is a systematic dewatering of an aquifer involved for, for example, over-pumping (i.e., “mining” of groundwater). The change in storage could be seasonal changes in measured water tables, long term decline in groundwater levels, or changes in (surface water) reservoir water levels.

The first step in determining a water budget for the PCLA hydrologic system is to determine the correct hydrologic system conceptual model using HESA. With HESA, individual components of the hydrologic system are analyzed, followed by evaluating the aggregate of components and their interactions, to locate and quantify relevant hydrologic subsystems. The results of the HESA for the PCLA analysis area are given in Section 2 of this report. Step 2 in determining the water budget is setting up a logic diagram based on the conceptual models to show all the significant hydrologic components and processes, including the external hydrologic
system inputs, outputs, and internal components or storage areas, and exchanges between internal components. Step 3 is to subset the overall conceptual model area to a manageable area where quantification of the hydrologic system will be most practical and accurate given the available data and the landscape terrain measurability (i.e., estimates of inputs and outputs where engineering data is not available or not practical/cost-effective at this time).

3.1 Water Budget Logic Diagram

Figure 9 shows the relevant generalized hydrologic system components and processes identified during the HESA of the MCSW study of Phase 1. In this diagram, hydrologic and hydrogeologic units or storage components are represented by boxes and the hydrologic exchange processes or fluxes by arrows. Note that the processes internal to the hydrologic units, such as atmospheric flow, stream flow, and groundwater flow, are not included. The main hydrologic units are: 1) atmosphere; 2) surface water system (streams, lakes and reservoirs); 3) unsaturated zone (between ground surface and water table); 4) shallow groundwater zone (saturated valley-fill unconsolidated sediments); and 5) deep groundwater zone (bedrock hydrogeologic units and hydrostructures). Figure 9 also shows the process-type interactions between these hydrologic units. These processes can be quantified as fluxes or flow rates such as precipitation rates (L/T), groundwater recharge (L/T), spring discharge (L^3/T), groundwater discharge to/recharge from streams (L^3/T/L'), and well discharge (L^3/T). It should be noted that many of the processes are difficult to measure or estimate and introduce significant uncertainty in water budget calculations when used.

Often, to get a better understanding of the water budget components and reduce uncertainty, the complex set of hydrologic units and processes shown in Figure 9 is simplified by reducing the number of units and processes based on HESA evaluated significance of and data availability for each of these components. For example, a water budget may focus on surface water and its interaction with the atmosphere. In that case, the subsurface units and processes, depicted in Figure 9 as the unsaturated zone, the shallow groundwater (saturated zone), and deep groundwater zone (bedrock) and related processes, would be represented by a single gain or loss flux. In comparison, a focus on the groundwater system may replace the atmosphere, streams, and unsaturated zone by inputs and outputs only, and any change in storage would be limited to the shallow and deep aquifers.

The Conceptual Site Model resulting from the HESA of the PCLA hydrologic system, together with the location of the Pack Creek stream flow gages and other available stream flow measurements, provided guidance on how to delineate the water budget area and how to simplify the complex hydrologic system components and process illustrated in Figure 9 in preparation of a preliminary water budget for PCLA hydrologic system.

3.2 Preliminary Water Budget for the PCLA Hydrologic System

A preliminary water budget (PWB) for the PCLA hydrologic system is calculated based upon the information previously collected and analyzed by Kolm and van der Heijde (2018), and
the HESA-based conceptual model of the PCLA hydrologic system determined in Phase I and refined in Task 1 of this Phase (IV) project. The area in PCLA for which the water budget is determined is based, in part, on 1) the locations of various stream gages on Pack Creek and Mill Creek (Blanchard, 1990; USGS Surface-Water Dailey Statistics, Mill Creek at Shelley Tunnel Sites, 2019); 2) the location of most anthropogenic activities (diversions, domestic and agricultural water use); 3) the natural boundaries of the PCLA hydrologic system including Pack Creek and tributaries; and 4) the hydrogeologic and hydrostructural boundaries of the Pack Creek Alluvium Aquifer as determined by HESA (Figure 10). The water budget area is outlined in both Figures 4 and 10 and is bounded by the Glen Canyon Group Mill Creek Subsystem (GCMC) to the northeast and east; the Morrison Formation to the east and southeast; the La Sal Mountain Upper Alluvial Subsystem (LSMA-P) Pack Creek Headwaters to the southeast; the Moab Rim and Kane Creek hydrological divides to the south, southwest, and west; and the Colorado River to the northwest (Figures 4 and 10). The PWB area used in this report covers almost all of the PCLA hydrologic system.

![Diagram of hydrologic system components and processes](image)

**Figure 9.** Generalized hydrologic system components and processes.

The surface and subsurface hydrologic systems or storage components and the hydrologic exchange processes or fluxes considered relevant for the PWB of the PCLA hydrologic system were derived from the conceptual models developed in the Phase 1 HESA as illustrated in Figure
10 (boundary conditions), Figures 11 and 12 (hydro zones with springs and wells), and Figure 13 (irrigated areas and riparian vegetation) and are shown in the diagrams in Figures 14a and 14b.

Figure 10. Map showing the location of the Preliminary Water Budget (PWB) area of the PCLA hydrologic system with boundary conditions, springs and relevant USGS gage locations.

The significant inputs of the PWB are: 1) direct runoff of precipitation to streams; 2) recharge by infiltration of precipitation (rain and snow) across the entire PWB area using the concept of hydro zones explained later in this report; 3) Pack Creek groundwater flux, called groundwater underflow, in the Quaternary hydrogeologic units (Qal) at the SE corner of the water budget area; 4) Brumley Creek groundwater flux, called groundwater underflow, in the Quaternary hydrogeologic units (Qal) at the SE corner of the water budget area; 5) Mill Creek groundwater flux, called groundwater underflow, in the Quaternary hydrogeologic units (Qal) at
the Mill Creek delta (Powerhouse); 6) Pack Creek surface water inflow above the later ditch diversion in the SE corner of the water balance area; 7) Brumley Creek surface water inflow to Pack Creek in the SE corner of the water balance area; 8) Mill Creek surface water inflow at the Mill Creek delta (powerhouse) in the northeast water balance area; 9) Sheley diversion in post-development/current conditions; and 10) springs at eastern PWB boundary from the GCMC system (including City Springs and Skakel spring). Note that precipitation itself and evapotranspiration (ET) for the area not covered by riparian vegetation is not included in the PWB, but is discussed in following sections. The outputs of the PWB are: 1) consumptive use crops; 2) evapotranspiration or consumptive use by phreatophytes (cottonwoods, willows, tamarisk, and other riparian species) (Figure 13); 3) evaporative loss open water; 4) net municipal use (GWSSA and losses/return flow of City Water); 5) domestic consumptive use by private wells (Figure 12b); 6) Mill Creek surface water outflow at the northern end of Spanish Valley to the Colorado River; and 7) groundwater discharge to the Colorado River.

To obtain an understanding on how development in the Spanish Valleys has changed the area’s water budget, two PWBs have been developed for: 1) natural conditions as they existed pre-development (no surface water and groundwater diversions, irrigation, etc.); and 2) natural and anthropogenic conditions as they exist today. Figures 14a and 14b show a diagrammatic representation of these water budget components.

A starting point for determining the PWB is the climate data collected for the weather station MOAB, UT (USC00425733) in the town of Moab at 4054ft (formerly known as National Weather Service (NWS) Cooperative Network (COOP) station 425733) and LASAL MOUNTAIN, UT (US009L03S) at 9560ft (see Figure 3 and Tables 1a, 1b and 1c in Kolm and van der Heijde; 2018). These two stations, for which the data are available at NOAA’s National Centers for Environmental Information, provide an overlapping period of observations (1982-2017) useful for comparative analysis, and the Moab station has a continuous record from 1971 to the present for analysis regarding predevelopment and current water budgets. The climate data for the Moab and La Sal Mountain stations, together with other neighboring stations, have been used to develop maps showing the spatial distribution of average annual precipitation for the period 1971-2000 and 1981-2010 (available from the Natural Resources Conservation Service; see Figure 4 in Kolm and van der Heijde; 2018). As these data sources show, there is a gradual precipitation gradient in Moab/Spanish Valley from about 9 inches annually at Moab, UT in the far northwestern boundary of the PCLA study area to greater than 13 inches near the southeastern edges of the PCLA hydrologic system. The availability of the spatial data sets for these two periods form the base for selecting these periods in determining precipitation related PWB terms.
Figure 11. Map showing the location of the Preliminary Water Budget (PWB) area and pre-development recharge Hydro Zones of the PCLA hydrologic system and spring locations.
Figure 12. Map showing the location of the Preliminary Water Budget (PWB) area and post-development recharge Hydro Zones of the PCLA hydrologic system and municipal and private well locations.
Figure 13. Map showing the location of riparian vegetation, open water and irrigated land Hydro Zones of the PCLA hydrologic system.
Fig 14a. Simplified diagram of inflows and outflows for the pre-development (natural) PCLA hydrologic system.

Fig 14b. Simplified diagram of inflows and outflows for the current (natural and anthropogenic) PCLA hydrologic system.
In addition, several other sources of published data provided input into the PWB: 1) Mill Creek discharge measurements on October 21, 1985 and October 14, 1986 as published in Blanchard (1990) provided surface water inputs to the PCLA hydrologic system at the Mill Creek delta (Powerhouse) (see Figure 8a-c in Kolm and van der Heijde; 2018); 2) USGS stream gage data collected above and below the Sheley diversion provided a long-term data set regarding stream flows in the upper reach of Mill Creek and the Sheley diversion (USGS Surface-Water Dailey Statistics, 2019); 3) historic USGS stream gage data for Mill Creek collected near the Mill Creek delta (Powerhouse) and for Pack Creek in the upper Spanish Valley area of the PWB (USGS Surface-Water Dailey Statistics, 2019); 4) adjudicated maximum sustainable spring and well use information culled from the State of Utah Division of Water Rights data base, together with spring and well data from the City of Moab and the Grand Water and Sewer Service Agency (GWSSA), provided a first approximation of related inputs and outputs in the PWB; and 5) phreatophyte consumptive use measurements published by Muckel and Blaney (1945) provided data regarding outputs due to natural vegetation effects in the PCLA hydrologic system.

3.3 Approach to Preliminary PCLA Water Budget Calculations

Many of the identified data sets provide a “snap shot” of a particular variable in time and were gathered at various, non-compatible moments in time. The challenge in this project is to extrapolate from measured values where necessary. The starting point is the determination of the pre-development (i.e., pre-human habitation or natural) annual averaged water budget components. The estimated pre-development direct runoff to streams, together with adjustments to some of the other water budget components, is then used for the post-development (current) water budget.

In order to quantify some of the components of the preliminary PCLA water budget given the sparseness of published data, the PCLA hydrologic system was spatially categorized into 7 types of hydro zones reflecting characteristic hydrologic processes such as recharge, evapotranspiration and evaporation from open water. The delineation of these zones is based upon the hydrogeology and geomorphology, groundwater and surface water hydrology, land use and distribution of phreatophytes (Figures 11 and 12; Figure 13). Hydro Zone 1 is the urban zone and is characterized by relatively impermeable materials (roads, parking lots, houses) with minimal groundwater recharge and storage and maximum surface water runoff (Figures 11 and 12); this hydro zone only features in the post-development PWB calculation.

Hydro Zone 2 is the area covered by stream alluvium and alluvial gravels (Qal) and represents very rapid recharge and large storage. This zone is underlain by matrix (relatively non-fractured) Glen Canyon Group rocks that have minimal groundwater flow and storage compared to the overlying alluvium.

Hydro Zone 3 are the areas covered by alluvial fan and slope deposits (Qaf and Qas) and represents very rapid recharge and potentially large storage when saturated. This zone is primarily underlain by highly-fractured and faulted Glen Canyon Group rocks that may have significant groundwater storage comparable to the overlying alluvium. Hydro Zone 3 on the
northeast and east side of the valley consists of fan deposits on top of a highly transmissive (high-K) fracture zone (French Drain) that moves water from Ken’s Lake to Pack Creek at the GWSSA wells and near the outlet of the City Springs (Figure 11). This part of zone 3 has very large recharge and storage functions, but no significant phreatophyte discharge on the surface. Hydro Zone 3, located on the southwest and west side of the valley (along the Moab Rim), is present from near where Pack Creek (usually dry) makes a bend trending from west to northwest to Jackson and Pioneer springs near the southwest part of the City of Moab. The hydrostructure underneath these fan deposits is also a highly transmissive fracture zone (French Drain) that moves water from the usually dry stream of Pack Creek to the Jackson and Pioneer springs near the southwest part of Moab (Figure 11). Again, this part of zone 3 has very large recharge and storage functions, but no significant phreatophyte discharge on the surface until the springs (Figure 13).

Hydro Zone 4 is exposed bedrock mostly characterized by the presence of hydrostructures. On the southwest and west side of the valley (along the Moab Rim) is a fracture-enhanced high-K bedrock zone observed along most of the Spanish Valley. This hydrostructure is also highly transmissive, moving water from the Rim into the Valley where cross fractures are observed to the high K zone in Hydro Zone 3, which discharges to Jackson and Pioneer springs near the southwest part of Moab (Figure 11). This zone has small recharge and storage functions, and no significant phreatophyte discharge on the surface (Figure 13).

Hydro Zone 5 is the phreatophyte zone with consumptive use by riparian vegetation, including wetlands. Hydro zone 6 represents irrigated lands characterized by consumptive use by crops and return flow of excess irrigation water (recharge). Hydro Zone 7 is open water (lakes, ponds, reservoirs) with evaporative losses to the atmosphere. The extent of hydro zones 5, 6 and 7 is depicted in Figure 13. The City of Moab provided assistance in digitizing the hydro zones and sub-zones.

The preliminary pre-development (natural conditions) PCLA water budget has as inputs (Table 1): 1) direct runoff of precipitation to streams; 2) recharge by infiltration of precipitation (rain and snow) across the entire PWB area; 3) Pack Creek groundwater flux, called groundwater underflow, in the Quaternary hydrogeologic units (Qal) at the SE corner of the water budget area; 4) Brumley Creek groundwater flux, called groundwater underflow, in the Quaternary hydrogeologic units (Qal) at the SE corner of the water budget area; 5) Mill Creek groundwater flux, called groundwater underflow, in the Quaternary hydrogeologic units (Qal) at the Mill Creek delta (Powerhouse); 6) Pack Creek surface water inflow above the later ditch diversion in the SE corner of the water balance area; 7) Brumley Creek surface water inflow to Pack Creek in the SE corner of the water balance area; 8) Mill Creek surface water inflow at the Mill Creek delta (powerhouse) in the northeast water budget area; and 9) spring runoff from the GCMC system at eastern PWB boundary, including the current City springs at the golf course and Skakel spring. Note that precipitation itself and evapotranspiration (ET) for the area not covered by riparian vegetation is not included in the PWB, but is discussed in following sections. The predevelopment (natural) outputs of the PWB are: 1) consumptive use by native phreatophytes (cottonwoods, willows, tamarisk, and other riparian species) (Figure 13); 2) evaporative loss open water; 3) groundwater and spring discharge to the Colorado River; and 4) Mill Creek...
surface water outflow at the northern end of Spanish Valley to the Colorado River. Each of these terms are discussed in detail in following sections.

Preliminary post-development PCLA water budget calculations (from the early 1980s to present) are completed with the recharge, direct runoff and consumptive use inputs determined in the pre-development water budgets adjusted for climate change, land use changes, and diversions (Table 2). Specifically, the effects of the Sheley diversion, the development of municipal and domestic water supply, and irrigation on input and output are evaluated. Although some wells in Spanish Valley show a decline in water levels, uncertainties in the PWB do not support including a continuing, multi-year release of water from subsurface storage at this time.

3.4 Calculation of Groundwater Recharge and Direct Runoff to Streams

Average annual precipitation ranges from about 9 inches in Moab in the far northwestern corner of the PCLA hydrologic system to greater than 13 inches near the southeastern edges of the PCLA hydrologic system, most of which is in the form of rain. To evaluate recharge, three recharge scenarios have been evaluated as a function of the spatial distribution and amount of precipitation in each recharge hydro zone (hydro zones 1-4): 1) low estimate using 5-20% of precipitation dependent on hydro zone type; 2) a high estimate using 5-30% of precipitation and 3) a “best” estimate using 5-25% of precipitation (Appendix A and B). The average annual precipitation was calculated for each hydro sub-zone in both inches and acre-ft for both the periods 1971-2000 (considered representative for pre-development conditions) and 1981-2010) representative for “current” conditions) by overlaying the sub-zone GIS layer with the two precipitation GIS layers. The calculations are listed in Appendix A and Appendix B and can be summarized as follows: 1) for the period 1971-2000 the low estimate is 2500 ac-ft/yr, the high estimate is 3865 ac-ft/yr; and the “best” estimate is 3170 ac-ft/yr or 1.9 inches across the entire PWB area; 2) for the period 1981-2010 the low estimate is 2215 ac-ft/yr, the high estimate is 3315 ac-ft/yr, and the “best” estimate is 2765 ac-ft/yr or 1.6 inches across the entire PWB area (Tables 1 and 2). Note that the “best” estimate for recharge in both periods amounts to about 16-17% of overall precipitation in the PWB area. Note also that groundwater recharge of 1-3 inches per year are common estimates in groundwater modeling and water budget studies for these types of environments.

The Preliminary Water Budget closing term (i.e., balancing term) for the pre-development scenario (Table 1) consists of direct runoff of precipitation to streams and amounts to 815 ac-ft/yr. This term, corrected for the decline in precipitation between the two climate periods and the increase of direct runoff in buildup/urbanized areas amounting to a total of 1300 ac-ft/yr, is used in the post-development scenario (Table 2). Note also that direct evapotranspiration (ET) in the PWB area (excluding riparian vegetation), calculated as precipitation minus groundwater recharge and direct runoff to streams, amounts to about 14,525 ac-ft/yr for the pre-development period and to 13,565 ac-ft/yr for the post-development period, or about 75-78% of total precipitation. All these numbers are based on 30-year averages for the two climate periods.
3.5 Calculation of Groundwater Underflow at Upper Pack Creek Boundary

The basis for the calculation of groundwater underflow at the Upper Pack Creek in the southeastern boundary of the PWB area (Figure 10) is Darcy’s Law:

\[ Q = KIA; \]

where \( Q \) is discharge per unit time; \( K \) is hydraulic conductivity of the fractured Hydrogeologic Unit; \( I \) is \( \frac{dH}{dL} \) or hydraulic gradient (change in head \( H \) over a distance \( L \)); and \( A \) is cross-sectional area. \( Q \) will be the groundwater input/inflow into the water budget that is derived from the upper La Sal Mountain subsystems. \( K \) is determined by aquifer tests, which reveal a range of values that average approximately 1-10 ft/day for stream alluvium and alluvial gravels in the PWB area ((Lowe and others, 2007; Masbruch and others, 2019)). Hydraulic gradient calculated based on potentiometric surfaces published in Lowe and others (2007) and Masbruch and others (2019) of 0.025. The cross-sectional area to calculate groundwater underflow flux is estimated as the geometry of the stream alluvium and alluvial gravels: 20-50 ft depth, average 35 ft (from well measurements) and 2700 ft width (from topographic data). An average \( K \) value for the underflow component of the PWB of 5 ft/day is used. This results in a groundwater underflow flux (inflow) of 100 ac-ft/yr (Tables 1 and 2).

3.6 Calculation of Groundwater Underflow at Brumley Creek Boundary

The basis for the calculation of groundwater underflow at the Upper Pack Creek in the southeastern boundary of the PWB area (Figure 10) is Darcy’s Law:

\[ Q = KIA; \]

where \( Q \) is discharge per unit time; \( K \) is hydraulic conductivity of the fractured Hydrogeologic Unit; \( I \) is \( \frac{dH}{dL} \) or hydraulic gradient (change in head \( H \) over a distance \( L \)); and \( A \) is cross-sectional area. \( Q \) will be the groundwater input/inflow into the water budget that is derived from the upper La Sal Mountain subsystems. \( K \) is determined by aquifer tests, which reveal a range of values that average approximately 1-10 ft/day for stream alluvium and alluvial gravels in the PWB area ((Lowe and others, 2007; Masbruch and others, 2019)). Hydraulic gradient calculated based on potentiometric surfaces published in Lowe and others (2007) and Masbruch and others (2019) of 0.025. The cross-sectional area to calculate groundwater underflow flux is estimated as the geometry of the stream alluvium and alluvial gravels: 20-50 ft depth, average 35 ft (from well measurements) and 600-700 ft width, average 650 ft (from topographic data). An average \( K \) value for the underflow component of the PWB of 5 ft/day is used. This results in a groundwater underflow flux (inflow) of 25 ac-ft/yr (Tables 1 and 2).

3.7 Calculation of Groundwater Underflow at Mill Creek delta (Powerhouse)

The basis for the calculation of groundwater underflow at Mill Creek delta (Powerhouse) in the northeastern boundary of the PWB area (Figure 10) is Darcy’s Law:
\[ Q = K \times I \times A; \]

where \( Q \) is discharge per unit time; \( K \) is hydraulic conductivity of the fractured Hydrogeologic Unit; \( I \) is \( dH/dL \) or hydraulic gradient (change in head \( H \) over a distance \( L \)); and \( A \) is cross-sectional area. \( Q \) will be the groundwater input/flow into the water budget that is derived from the GCMC subsystem described in the project’s phase 2 report (Kolm and van der Heijde, 2019). \( K \) is determined by aquifer tests, which reveal a range of values that average approximately 1-10 ft/day for stream alluvium and alluvial gravels in the PWB area ((Lowe and others, 2007; Masbruch and others, 2019)). Hydraulic gradient calculated based on potentiometric surfaces published in Lowe and others (2007) and Masbruch and others (2019) of 0.010 – 0.0125, average 0.01125. The cross-sectional area to calculate groundwater underflow flux is estimated as the geometry of the stream alluvium and alluvial gravels: 20-50 ft depth, average 35 ft. (from well measurements) and 500 ft width (from topographic data). An average \( K \) value for the underflow component of the PWB of 5 ft/day is used. This results in a groundwater underflow flux (inflow) of 10 ac-ft/yr (Tables 1 and 2).

3.8 Calculation of Pack Creek Surface Water Inflow above Ditch Diversion

For a short period in the 1950s (1955-1959) the USGS operated a stream gage on Pack Creek just upstream from the southeast PWB boundary (USGS gage 09184500 Pack Creek at M4 Ranch near Moab Utah, Figure 10). The annual discharge values for this period range from 0.647 to 5.05 cfs with an average of 2.541 cfs or about 1845 ac-ft/yr. As no other published information on Pack Creek flows in this area is available, the above multi-year average has been used for the pre-development PWB. Recognizing significant variability in the above data and the short collection period, this PWB term should be considered a first approximation. For the post-development Pack Creek inflow term, the pre-development term has been adjusted for the 5% decline in 30-year average precipitation between the 1971-2000 and 1981-2010 climate periods, resulting in a post-development term of 1755 ac-ft/yr. This latter term may need to be further adjusted to compensate for diversions in the upper Pack Creek reaches within the La Sal Mountain hydrologic subsystem that were introduced after the period of record at gage 09184500.

3.9 Calculation of Brumley Creek Inflow to Pack Creek

There is no formal stream gage on Brumley Creek to date. Field estimates of 1.5 -2.0 cfs or 1085 – 1450 ac-ft/yr were taken November 2019 during baseflow (no phreatophyte activity, no rainfall or snow events for 5 previous weeks) several miles above the confluence of Brumley and Pack Creeks where the stream was flowing. 1100 ac-ft/yr was used in the water budget calculations.
3.10 Calculation of Mill Creek Surface Water Inflow at Mill Creek Delta (Powerhouse)

The Mill Creek inflow into the PCLA PWB is based on the daily gage readings by the USGS at USGS 09184000 in the vicinity of the Powerhouse during the period 1949-1993 with a hiatus from 1958 to 1987 (Figure 10). The average annual flow at gage 09184000 for the period of record is 9928 ac-ft/yr. This number is adjusted for pre-development (natural) conditions taking in consideration the absence of municipal and domestic consumptive use in the GCMC area in the pre-development era (pre-1950s) by redistributing the consumptive use number among the other PWB terms and is estimated at 10755 ac-ft/yr. This number minus the water that the stream loses to groundwater between the gage site and the PWB boundary as is accounted for in the underflow term of 10 ac-ft/yr, is used in the pre-development PWB as a first approximation (10745 ac-ft/yr, Table 1). Note that this number differs from the phase 2 reported “pre-development” or pre-1980 number of 9928 ac-ft/yr as the latter number includes pre-Sheley diversion development of the GCMC and PCLA areas. The post-development Mill Creek outflow reported in Phase 2 (9020 ac-ft/yr) has been further reduced to reflect current conditions including increased municipal and domestic consumptive use and is estimated at 8960 ac-ft/yr. Taking into consideration the loss to groundwater between the gage site and the PWB boundary of 10 ac-ft/yr, the post-development PWB term for the inflow from Mill Creek at the eastern PWB boundary is set at 8950 ac-ft/yr. (Table 2).

3.11 Calculation of Sheley Diversion

The inflow in the post-development PCLA PWB from the Sheley diversion (post-2003) is based on the difference between daily gage readings by the USGS at USGS 09183500 just above the location of the Sheley diversion and at USGS 09183600 below the Sheley diversion for the period 2004-2017 (Figure 10). The average annual discharge at gage 09183500 for this period is 6814 ac-ft/yr, while the average annual discharge at gage 09183600 for the same period is 3149 ac-ft/yr, a difference of 3665 ac-ft/yr or 54% of the discharge at gage 09183500 (Table 2). This is the average annual amount of water diverted from the GCMC hydrologic system to the PCLA system. Note that the average annual flow at gage 09183500 for the period 2004-2017 is 732 ac-ft/yr less than for the entire period of record 1954-2017 (minus data gap), a decline of about 10%.

3.12 Calculation of Input from GCMC Springs at eastern PWB boundary

The values for GCMC hydrologic springs were collected from the Utah State Division of Water Rights database as being the maximum sustained amounts produced by each spring (Utah State Water Rights Data Base, 2017, 2018) and presented in this project’s phase 2 report. The pre-development runoff from these springs was GCMC groundwater output that flowed directly into the Pack Creek hydrologic system (PCLA) as input to the PCLA water budget. There may be springs and seeps that are not accounted for as they are not registered in the water rights data base. Because the phase 2 report excluded the City’s springs at the golf course and the diversion at Skakel spring, as they were included in municipal consumptive use term, the phase 2 “pre-development” term has been adjusted for the new pre-development (natural) conditions taking in
consideration the absence of municipal and domestic consumptive use in the GCMC area in the pre-development era (pre-1950s) by redistributing the consumptive use number among the other PWB terms and is estimated at 2515 ac-ft/yr (Table 1). Additional decline in spring runoff due to the coming on line of the Sheley diversion in Mill Creek and increased municipal and domestic consumptive use has been taken into account in estimating the “current” (post-development) spring runoff term set at 1725 ac-ft/yr (Table 2).

3.13 Evaporative Loss Open Water

The two main bodies of open water in the PCLA PWB area are Ken’s Lake and the wetlands in the northwest corner of the PWB area for a total of 1950 acres (Utah SGID Lakes in Grand and San Juan Counties GIS layers, 2019). Assuming an effective open water evaporation rate of 90 in/yr, the PWB term for this process in both pre- and post-development PWB is set at 1460 ac-ft/yr.

3.14 Calculation of Consumptive Use by Riparian Vegetation

Muckel and Blaney (1945), Mayboom (1964), and Gatewood and others (1950) determined that riparian vegetation (notably Cottonwoods, Willows, and Tamarisk) had consumptive use ranging from 40 – 93 in/year depending upon percentages of each species present, the healthiness or stress level of the vegetation, and the location in the ecosystem (seeps, springs, stream bottoms and floodplains). A recent study by Crowley (2004) on the Matheson Wetland Preserve located by the City of Moab inventoried the published data regarding consumptive use of riparian vegetation in the Moab, Utah area, and calculated consumptive use of vegetation at that location. For the purposes of calculating the preliminary water budget of the GCMC hydrologic system, Muckel and Blaney’s (1945) mixed riparian category of 60 – 92.7 in/year was used as guidance for the calculation of the consumptive use of riparian vegetation. The mapped area of current riparian vegetation is about 520 acres. Assuming a consumptive use rate of 90 in/yr this post-development PWB term amounts to 3900 ac-ft/yr. In the pre-development PWB it is assumed that significant more water was available for riparian vegetation. For the purpose of calculating the PWB term it is assumed that the pre-development area of riparian vegetation was about 755 acres; using 90 in/yr of consumptive use, the related pre-development PWB term is 5665 ac-ft/yr.

3.15 Calculation of Consumptive Use by Crops

The consumptive use of crops term only applies to the post-development PWB. The Utah SGID Irrigated Lands GIS layer (2019) shows an irrigated area within the PCLA of 2030 acres. As there is an overlap with open water area of about 100 acres, the effective irrigated area is set at 1930 acres of which about 70% is estimated to be actually used. Net consumptive use is estimated at 32 in/yr (Castle Valley, Ford, 2006) for a total of 3600 ac-ft/yr.
3.16 Calculation of Municipal Use

The municipal consumptive use term consists of water diverted from either surface water or groundwater within the PCLA PWB area minus water returned to the hydrologic system from leaking pipelines in the distribution and collection systems, lawn watering, etc. There are 2 major municipal water systems in the PCLA area: City of Moab and GWSSA. The City of Moab has it water sources outside the PWB area, while the GWSSA has it water sources within the PCLA area (wells). In 2017 the GWSSA had an annual production of about 815 ac-ft/yr (GWSSA, 2017). Assuming the return flow from the distribution and collection systems at about 100 ac-ft/yr, the post-development (current) PWB term for municipal consumptive use is set at 715 ac-ft/yr.

3.17 Calculation of Domestic Consumptive Use

There are many domestic wells in the PCLA area of which about 475 are estimated to be household wells (UDWR, 2019). The Ford (2006) report, referring to the data collected in the mid-1990s by Ford and Grandy in the Castle Valley area, determined a domestic use of 0.42 ac-ft/yr per household, resulting in approximately 200 ac-ft/yr post-development. Note that this consumptive use numbers is a first estimate of actual consumptive use, taking into consideration the presence of both permanently and occasionally occupied dwellings.

3.18 Groundwater and Spring Discharge to Colorado River

The PCLA PWB term for groundwater and spring discharge to the Colorado River is based on the findings published in a recent USGS study (Masbruch and others, 2019). The report provides a range of 300-1000 ac-ft/yr). As a first approximation 750 ac-ft/yr is used in both the pre- and post-development PWBs.

3.19 Mill Creek Outflow to Colorado River

The PCLA PWB term for Mill Creek discharge to the Colorado River is based on the findings published in a recent USGS study (Masbruch and others, 2019). The report sets this number at 10830 ac-ft/yr. This number is used in the post-development PWB. For the pre-development this number has been multiplied by 1.15, the ratio between pre- and post-development streamflow in Mill Creek entering the PCLA PWB area, for a total of 12450 ac-ft/yr.

3.20 PWB and the PCLA Hydrologic System: Discussion of Uncertainty

There are many uncertainties in these preliminary calculations, so further analysis is needed and should be planned. The primary significance of the PWB is that there is a significant
amount of surface water and groundwater contributed to the PCLA hydrological system from the La Sal Mountain and GCMC hydrological systems, or in percentages of pre-development input into the PCLA hydrologic system: surface water and groundwater derived from the GCMC hydrologic system (Mill Creek + groundwater underflow at the Mill Creek delta + springs at eastern PWB boundary from GCMC system) is 13,270 ac-ft/yr and counts for approximately 65%; local recharge from precipitation and direct runoff from precipitation to streams counts for 20%; and directly linked groundwater inflow and surface water inflow (Pack Creek and Brumley Creek) from the La Sal Mountains hydrological subsystems counts for 15%. This means that the La Sal Mountain and GCMC subsystems contribute more than 80% of the total inflow in the PWB area. Note that a combined consumptive use riparian vegetation and evaporative loss open water accounts for 35% of the total water budget out, and remainder is subsurface and surface discharge to the Colorado River. By comparison, in the post development time period, the contribution of the Sheley diversion to the overall input becomes more of a factor, or in percentages of post development input into the PCLA hydrologic system: surface water (Mill Creek + Pack Creek + Brumley Creek) counts for approximately 55%; local recharge from precipitation and direct runoff to streams for 19%; groundwater inflow from the GCMC hydrological subsystems counts for about 9%; and the Sheley diversion provides 17% of the total inflow to the PCLA hydrologic system and has resulted in a 17% reduction of Mill Creek inflows towards Spanish Valley under base flow conditions and 31% reduction of springs and seeps discharge in the most likely scenario.

The reduction of water contributions originating from the La Sal Mountain subsystem in amounts and timing of precipitation (rain and snowfall) and snowmelt resulting from climate change may have a significant impact on stream flows, groundwater recharge and subsurface inflow into the valley. In addition, water diversion projects to other watersheds, especially up-valley, will result in decreased surface water flows and groundwater recharge from losing streams. Impacts on the PCLA water budget may also result from deforestation due to lumbering or fire (increased surface runoff and stream flows); increased forestation (increased ET; decrease of runoff and stream flows); and mining (increased or decreased stream flows and groundwater fluxes). Land use conversions/changes resulting in more or less consumptive uses need to be evaluated regarding the surface water output to Pack Creek and Brumley Creek at the southeast end of the PCLA hydrologic system. Increased consumptive use would result from increased urbanization (more wells, non-native vegetation) or increased irrigation.

Many of the components of the PWB calculations include large uncertainties. The most reliable data are the USGS stream flow data in Mill Creek at and below the Sheley diversion and in Pack Creek in the southeastern part of the Spanish Valley; the springs and wells production data from the City of Moab and GWSSA, and the precipitation data from NOAA used to develop various recharge scenarios. However, these data sets are not all complete or cover comparable time periods. All other data sets provide a “snap shot” of a particular variable in time as they were gathered at various, non-comparable moments in time and, thus, should be considered a first estimate, subject to refining by further field studies.

Consumptive use by phreatophytes (riparian vegetation) is variable seasonally and annually by changes in species composition, species health, spatial distribution of vegetation, and length of growing season among other factors. An estimate of annual evapotranspiration for
a water budget misses the seasonal effects of water usage and water availability, as well as multi-
year natural or anthropogenic variations in water availability. However, for the cost and effort, it
is difficult to improve on the studies that have been published. A possible follow-up study may
focus on the changes over time in riparian vegetation coverage using historical aerial
photography between the pre-1980s and later.

Spring discharge measurements are based on State of Utah Water Rights data which
allude to the available groundwater that is measured at the source when the water right was
secured, often without consideration of seasonal and multi-year variability. The actual daily and
seasonal flow of the springs is for the most part unmeasured and may fluctuate significantly.
Improvements of the springs related PWB terms may be obtained by more regular measuring of
the discharge of some of the larger springs.

Non-GWSSA well discharge data are taken from the State of Utah Water Rights data
base and considered maximum allowed discharge. Well water usage depends on the type of
usage (residence, secondary home, garden watering, and livestock water) and may fluctuate on a
daily, seasonal, and annual basis. The domestic consumptive use is highly variable, and the data
are not available to improve upon this in great detail. However, the domestic consumptive use is
small by comparison to other PWB terms.

The Mill Creek gage data at the Sheley diversion, below the Sheley diversion, and at the
Powerhouse near the outflow into Spanish Valley are some of the best and most accurate data
available to this study, although the data gap in the pre-1988 record limits the accuracy of
comparative evaluations. These hydrologic data sets offer insight in annual, seasonal, and daily
variability of stream flows and were used to interpret and modify other useful data, for example
Blanchard (1990). It should be noted that for optimal management of the City’s water resources
resuming of monitoring Mill Creek flows at the abandoned USGS gage site USGS 09184000
near the Powerhouse is crucial.

Although the Pack Creek inflow into the PCLA system is significant smaller than the
Mill Creek contribution (17%), Pack Creek still provides a significant contribution to the PCLA
system, especially in the upper section of Spanish Valley. As USGS gage 09184500 has only be in
operation for a short time in the 1950s, resuming of monitoring Pack Creek at this site should
be considered.

Concurrently, the climate data used to estimate groundwater recharge as infiltration from
precipitation (rain and snow, matrix and fracture zone) is some of the best and most accurate data
available to this study, although somewhat limited by the overlapping of the 30-year climate
periods available in spatially distributed format.

3.21 PWB and the PCLA Hydrologic System: Concerns Regarding Sustainability

There are a number of potential threats to the sustainability of the PCLA hydrologic
system and thus to the water supply of the City of Moab and Grand County, both natural and
man-made. Climate change may reduce water contributions originating from the La Sal
Mountain subsystem, both in amounts and timing. In addition, water diversion projects to other watersheds, especially up-stream of the PCLA hydrologic system, will result in decreased surface water flows and groundwater recharge from losing streams. Impacts on the PCLA hydrologic system may also result from deforestation due to lumbering or fire (increased unchanneled surface runoff and stream flow peaks, and decreased stream base flow); increased forestation (increased ET; decrease of runoff and stream flows); and mining (increased or decreased stream flows and groundwater fluxes). Land use conversions/changes resulting in more or less consumptive uses need to be evaluated regarding the surface water output to Pack Creek and Brumley Creek at the southeast end of the PCLA hydrologic system. Increased consumptive use would result from increased urbanization (more wells, non-native vegetation), or increased irrigation. Any long term decline in inflows to the PCLA hydrologic system will result in further decline of outflows such as at Pack Creek and Brumley Creek in the southern part of the study area and various springs, and will likely lead to decline in storage and subsequent lowering of groundwater levels and groundwater availability for phreatic consumption.

3.22 PWB and the PCLA Hydrologic System: Recommendations for Monitoring and Modelling

Based upon associated uncertainties with estimates, the greatest cost-effective improvements to the PWB, primarily post-development, is better monitoring of the Pack Creek surface water system. Gaging stations at Mill Creek (Powerhouse, Junction with Pack Creek, Colorado River), Pack Creek (City Springs and Perennial Flow locations, Pack Creek Bridge, Settlement of Pack Creek, and Brumley Creek that record daily, seasonal, and annual information would improve the measurements of the City of Moab and Spanish Valley protected areas. Water quality measurements would be recommended at these sites as well. In addition, continued monitoring of City Springs and Wells, including Skakel Spring, for daily, seasonal, and annual information regarding flow and water usage is recommended. An analysis of this and the data currently available, in addition to continued analysis of the climate data compared to the City Springs and Wells, and Skakel Spring, is recommended as a future part of this study.

Mathematical groundwater modelling using the USGS Finite Difference MODFLOW Model or other integrated finite difference or finite element groundwater or groundwater/surface water models has been proposed in the past to quantify the PCLA hydrologic system. This study estimates both pre-development (steady state) and post-development (transient) water budgets that would be useful for the calibration of these types of models. Phase 1 of the current study, HESA of the GCMC hydrologic system, and Phase 4, Chapter 2 of the current study, provides a surface water and groundwater conceptual model that would be useful for the design, implementation, and calibration for these types of models. This Phase 4 HESA revealed that the PCLA groundwater system was complex being both matrix and fracture-type flow, and that the design, implementation, and calibration of this type of model can be done, and may be cost-effective at this time. Given the uncertainties with the data available, the results would still tend to be questionable. The PWB of the GCMC groundwater system in Phase 2 would provide inputs into the Spanish Valley model, and the HESA of the PCLA and GCMC groundwater systems would provide boundary conditions for that model.
## WATER BUDGET COMPONENT

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<th>WATER BUDGET COMPONENT</th>
<th>IN (ac-ft/yr)</th>
<th>OUT (ac-ft/yr)</th>
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<tr>
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</tr>
<tr>
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<td>Calculated (section 3.6)</td>
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<td></td>
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<tr>
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Table 1. Preliminary pre-development water budget estimates for PCLA hydrologic system under natural conditions.
<table>
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<th>WATER BUDGET COMPONENT</th>
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<td>Direct runoff to streams</td>
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<td>Groundwater underflow at Mill Creek delta (Powerhouse)</td>
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<td>Estimate (section 3.9)</td>
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<td>Springs at eastern PWB boundary from GCMC system (excluding City Springs, including Skakel overflow)</td>
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Table 2. Preliminary post-development water budget estimates for PCLA hydrologic system under current (natural and anthropogenic) conditions.
4. PRELIMINARY GROUNDWATER STORAGE CALCULATIONS FOR THE PCLA HYDROLOGIC SYSTEM

4.1 Groundwater Storage Quantification

Groundwater is potentially stored, either as part of the saturated zone of the aquifer or the unsaturated zone above the aquifer in the pore spaces between the sand grains of unconsolidated eolian, pedogenic, colluvial, or alluvial materials (Qaf, Qal, Qas and Qes), in the pore spaces of the sedimentary bedrock, or in the multiple-scale hydrofractures including fractures, fracture zones, bedding planes, faults, or fault zones. Groundwater that is stored in the pore spaces is considered matrix water and may be in considerable amounts in unconsolidated materials (such as the Pack Creek alluvium and alluvial fans) or may be in very small amounts in well consolidated bedrock (such as the non-fractured Glen Canyon Group aquifer). Groundwater that is stored in the hydrostructures may be in very small amounts in microfractures or may be in considerable amounts in large scale fracture and faults zones (for example, the Kayenta Fault Zone extending up to Ken’s Lake, and the Moab Rim Fracture Zone). Most of the unconsolidated materials that form the colluvium or fan deposits (Qaf, Qas) and soils (mostly Qes) in the Spanish Valley area, for example, are unsaturated and the amount of groundwater storage is small. By comparison, the unconsolidated alluvium (Qal) in the Spanish Valley Pack Creek gorge is partially saturated, and the storage is significant as indicated by the extensive phreatophyte vegetation that is observed in area with shallow groundwater.

There are multiple descriptors of storage in aquifers. Storativity or the storage coefficient is the volume of water released from storage per unit decline in hydraulic head in the aquifer, per unit area of the aquifer. Storativity is a dimensionless quantity, and ranges between 0 and the effective porosity of the aquifer, or the percentage of open space in a unit of rock from which water can be drained under gravity. For a confined aquifer or aquitard, storage is described by specific storage, i.e., the volume of water released from one unit volume of the aquifer under one unit decline in head. Specific storage is related to both the compressibility of the aquifer and the compressibility of the water itself. Volumetric specific storage (or volume specific storage) is the volume of water that an aquifer releases from storage, per volume of aquifer, per unit decline in hydraulic head (Freeze and Cherry, 1979).

In hydrogeology, volumetric specific storage is much more commonly encountered than mass specific storage. Consequently, the term specific storage generally refers to volumetric specific storage. The compressibility terms relate a given change in stress to a change in volume. Specific yield, also known as the drainable porosity, is a ratio, less than or equal to the effective porosity, indicating the volumetric fraction of the bulk aquifer volume that a given aquifer will yield when all the water is allowed to drain out of it under the forces of gravity. Specific yield is primarily used for unconfined aquifers since the elastic storage component is relatively small and usually has an insignificant contribution. Specific yield can be close to effective porosity, but there are several subtle things which make this value more complicated than it seems. Some water always remains in the formation, even after drainage; it clings to the grains of sand and clay in the formation. Also, the value of specific yield may not be fully realized for a very long time, due to complications caused by unsaturated flow.
4.2 Approach and Calculation of Groundwater Storage for the PCLA System

The Pack Creek Alluvium (Qal) groundwater systems in Storage Zone 1 (Figure 15) is mostly under unconfined or water table conditions and is characterized by specific yield estimates for unconsolidated sand and gravel deposits in the range 10 – 30%. Due to the extent and depth of these unconsolidated sediments, the Pack Creek alluvium will be most important for estimating total groundwater storage in the Spanish Valley and identify the areas that need the most protection for water quality and water quantity in the main Spanish Valley.

The (Older) Alluvial Fans and Slope Deposits (Qaf/Qas) (Storage Zone 2) are for a large part underlain by the hydrostructures in the Glen Canyon Group (Jgc) and are mostly unsaturated or only seasonal filled with water and are not considered a major storage unit. Precipitation rapidly infiltrates and quickly flows either downwards into the Glen Canyon rocks, or down gradient to the stream alluvium (Qal).

The Glen Canyon Group groundwater systems in Storage Zone 3 is mostly unconfined (water table conditions) and its storage capability is characterized by specific yield estimates. While estimates for the matrix specific yield estimates range from 1.0 to10%; estimates for the specific yield in fractures dominates zones are in the 20 – 40% range. Therefore, fracture dominated areas will be most important for estimating groundwater storage in these zones and will be the bedrock areas that need the most protection for water quality and water quantity.

The Glen Canyon Group aquifer is a complex mix of nonfractured, fractured and faulted Entrada Sandstone (Je) and Glen Canyon Group Formations (Navajo, Kayenta, Wingate; Jgc), and hydrostructures (fault and fracture zones) outcropping on the sides of and underlying the central and southern Spanish Valley (Figures 4, 5, and 6). The Moab Rim and the Kayenta Heights Fault and Fracture Zones of the Glen Canyon Group located on the southwest and northeast sides of the Spanish Valley, respectively, are the peripheral groundwater systems supporting the PCLA hydrologic system (Figure 6) and are designated Storage Zone 3 (Figure 15 and Appendix C). The Glen Canyon Group bedrock that underlies the rest of the Spanish Valley (Storage Zone 4) predominantly has matrix flow, and has insignificant storage capabilities. The matrix flow has ranges estimated from 0.3 – 1.0 ft/day (Jobin, 1962; Blanchard, 1990; Lowe and others, 2007); and the fracture flow can be as high as 88 ft/day (Freehey and Cordy, 1991). Therefore, fracture flow will dominate travel times in the Glen Canyon Group aquifer and the well-connected fractures in these zones will be most important for estimating groundwater storage.

The Kayenta Heights Fault and Fracture Zone Extension and the Moab Rim Fault and Fracture Zone are Glen Canyon Group fracture zones with fracture storage and an effective depth of up to 500 feet (well log based) and, specific yield (Sy) range 20% – 40% at the surface diminishing to close to 0% at 500 ft. The Pack Creek Alluvium has matrix storage and depths up to 300+ feet. The specific yield (Sy) for this unit is in the range of 10%-30%. Low total water content was estimated using low Sy percentages as a minimum, and high total water content was estimated using the high Sy percentages as a maximum. Each hydrogeologic zone had an estimated volume (GIS area multiplied by a representative average depth), and the storage zone volume was multiplied by the storage zone Sy to yield a hydrogeologic zone water content value (Appendix C) Only part of this total water storage is considered variable or recoverable storage;
accessing additional storage is unsustainable and considered groundwater mining. A first approximation for variable storage (used in the phase 2 report) is 10% of total water content (Appendix C).

The calculations show that the PCLA groundwater system has a variable storage low of 38,375 ac-ft, and a variable storage high of 101,400 ac-ft (Appendix C). Storage zone 1 (Figure 15) had the largest amount of variable storage with a range of 24,850-74,550 ac-ft.

It should be cautioned that the storage or underground reservoir is primarily a measure of how robust and sustainable the PCLA hydrologic system is under the current climatic and human use conditions. If the reservoir is significantly reduced by aquifer development, the hydraulics of the system will be affected initially by stream flows (riparian habitat both aquatic and vegetation), and by a rapid reduction of spring flows and well yields. In addition, the effects of reduced stream flows in Pack Creek, Brumley Creek, and Mill Creek through diversion or climate change will rapidly affect the recharge and storage functions of hydrogeologic zones 1, 2, 3, which are critical to Geyser Springs, and the City of Moab and Grand County Springs and Wells.

4.3 Storage and the PCLA Hydrologic System: Discussion of Uncertainty

There are many uncertainties in these preliminary calculations, so further analysis is needed, benefitting from more rigorous and continuous data collection. The primary significance of the storage calculations is that there is a significant amount of groundwater stored in the PCLA hydrologic system, particularly in hydro zones 1 and 3, that is directly connected to the City of Moab Well, Grand County Wells, and discharge to the Colorado River. This storage is accumulated by groundwater recharge from infiltration of precipitation, by losing reaches of Pack Creek, Brumley Creek, and Mill Creek, particularly in hydro zones 1 and 3, and by artificial recharge from Ken’s Lake, particularly in hydrogeologic zone 3 (Figure 15).

The largest uncertainties in the storage calculations is the correct delineation of each hydrogeologic zone area (volume), and the correct attribution of specific yield to each hydrogeologic zone. In order to reduce uncertainty, Specific yield ranges were assigned to each hydrogeologic zone based on published results of other studies, and hydrogeologic judgement by the investigators.
Figure 15. Storage (Hydro) Zones in the PCLA area.
5. PRELIMINARY WATER BUDGET OF COMBINED PACK CREEK LOWER ALLUVIUM AND GLEN CANYON GROUP MILL CREEK HYDROLOGIC SUBSYSTEMS OF THE MCSW STUDY AREA

5.1 Preliminary Pre-Development and Revised Post Development Water Budgets for the GCMC Hydrologic System

In order to develop a preliminary water budget of the combined Pack Creek Lower Alluvium (PCLA) and Glen Canyon Group Mill Creek (GCMC) Subsystems of the MCSW study area, it was first necessary to 1) create a true PWB of the pre-development natural conditions of the GCMC subsystem and to 2) slightly revise the PWB of the post-development (current) conditions based on new information obtained since the original release of Kolm and van der Heijde (2019) report on the GCMC subsystem. The Kolm and van der Heijde (2019) report discusses the HESA-derived conceptual model for the GCMC subsystem in great detail, and provides PWBs for pre-Sheley diversion conditions (not a true pre-development scenario since the report focused on the effects of the Sheley diversion on the City of Moab water supply), and the current conditions. Table 3 provides a PWB for the GCMC Hydrologic System under natural (pre-development) conditions modified from the City of Moab Phase 2 report (Kolm and van der Heijde, 2019). This PWB can then be combined with the pre-development PWB for the PCLA hydrologic system to provide estimates for the entire hydrologic system for water rights and water management purposes.

The water balance inflow terms in Table 3 are the same as those in the Kolm and van der Heijde (2019) Phase 2 report, and all terms are rounded off. By comparison, the pre-development outflow terms in Table 3 have been increased by about 8.3% compared with Table 1a in the Kolm and van der Heijde (2019) due to absence of municipal and domestic use. Calculations are derived from the phase 2 report pre-development table minus municipal and domestic use (1364+80=1445) which has been redistributed as follows: 1) Consumptive use riparian vegetation: 5101 (phase 2) + 424 (redistribution) = 5525 ac-ft/yr; and 2) Springs at the PWB boundary: (2325 (phase 2) + 190 (redistribution) = 2515 ac-ft/yr. The Mill Creek outflow at the Powerhouse (some of which will be groundwater underflow out to the PCLA after the location of the old USGS gage): 9928 (phase 2) + 827 (redistribution) = 10755 ac-ft/yr). Note that groundwater inflow into Kayenta Height Fault Zone is considered internal to the GCMC PWB. Note also that the best estimate for Skakel pre-development (including later overflow) is about 350 ac-ft/yr average based on the Utah State Water Rights data base, and the Moab City springs flow rate before the use of City wells is unknown.

Table 4 shows the PWB estimates for the GCMC hydrologic systems under current (natural and anthropogenic) conditions as modified from the Kolm and van der Heijde (2019) report. It should be noted that municipal and domestic use have been increased; whereas consumptive use by vegetation, spring flow and Mill Creek outflow have been reduced by up to 8% in comparison with Table 1b in Kolm and van der Heijde Phase 2 report (2019) due to increased pumping. The spring outflow is impacted the most (Table 4). Note the inflow terms are the same as Table 1b in Kolm and van der Heijde (2019), and that all terms are rounded off.
### Water Budget Component

<table>
<thead>
<tr>
<th>Component</th>
<th>IN  (ac-ft/yr)</th>
<th>OUT (ac-ft/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direct runoff to streams</td>
<td>4840</td>
<td>-</td>
</tr>
<tr>
<td>Recharge</td>
<td>5510</td>
<td>-</td>
</tr>
<tr>
<td>Groundwater underflow at upper Mill Creek boundary (inflow through Mill Creek fracture zone)</td>
<td>900</td>
<td>-</td>
</tr>
<tr>
<td>Mill Creek inflow above later location of Sheley diversion</td>
<td>7545</td>
<td>-</td>
</tr>
<tr>
<td>Upper North Fork Creek and Burkholder Draw inflow from mesas</td>
<td>minor</td>
<td>-</td>
</tr>
<tr>
<td>Consumptive use crops</td>
<td>-</td>
<td>0</td>
</tr>
<tr>
<td>Consumptive use riparian vegetation</td>
<td>-</td>
<td>5525</td>
</tr>
<tr>
<td>Springs at PWB boundaries (including City Springs and Skakel spring)</td>
<td>-</td>
<td>2515</td>
</tr>
<tr>
<td>Municipal use (City of Moab)</td>
<td>-</td>
<td>0</td>
</tr>
<tr>
<td>Domestic consumptive use</td>
<td>-</td>
<td>0</td>
</tr>
<tr>
<td>Sheley diversion</td>
<td>-</td>
<td>0</td>
</tr>
<tr>
<td>Mill Creek outflow at delta (including underflow)</td>
<td>-</td>
<td>10755</td>
</tr>
<tr>
<td>Release from storage</td>
<td>0</td>
<td>-</td>
</tr>
<tr>
<td><strong>TOTALS</strong></td>
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<td>18795</td>
</tr>
</tbody>
</table>

Table 3. Preliminary water budget estimates for GCMC hydrologic system under natural (pre-development) conditions (modified from Phase 2 report).
## WATER BUDGET COMPONENT

<table>
<thead>
<tr>
<th>Component</th>
<th>IN (ac-ft/yr)</th>
<th>OUT (ac-ft/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direct runoff to streams</td>
<td>4650</td>
<td>-</td>
</tr>
<tr>
<td>Recharge</td>
<td>5285</td>
<td>-</td>
</tr>
<tr>
<td>Groundwater underflow at upper Mill Creek boundary (inflow through Mill Creek fracture zone)</td>
<td>900</td>
<td>-</td>
</tr>
<tr>
<td>Mill Creek inflow above Sheley diversion</td>
<td>6815</td>
<td>-</td>
</tr>
<tr>
<td>Upper North Fork Creek and Burkholder Draw inflow from mesa’s</td>
<td>minor</td>
<td>-</td>
</tr>
<tr>
<td>Consumptive use crops</td>
<td>-</td>
<td>minor</td>
</tr>
<tr>
<td>Consumptive use riparian vegetation</td>
<td>-</td>
<td>4945</td>
</tr>
<tr>
<td>Springs at PWB boundaries (excluding City Springs, including Skakel overflow)</td>
<td>-</td>
<td>1725</td>
</tr>
<tr>
<td>Municipal use (City of Moab)</td>
<td>-</td>
<td>2200</td>
</tr>
<tr>
<td>Domestic consumptive use</td>
<td>-</td>
<td>150</td>
</tr>
<tr>
<td>Sheley diversion</td>
<td>-</td>
<td>3665</td>
</tr>
<tr>
<td>Mill Creek outflow at delta (including underflow)</td>
<td>-</td>
<td>8960</td>
</tr>
<tr>
<td>Release from storage</td>
<td>3995</td>
<td>-</td>
</tr>
<tr>
<td><strong>TOTALS</strong></td>
<td><strong>21645</strong></td>
<td><strong>21645</strong></td>
</tr>
</tbody>
</table>

Table 4. Preliminary water budget estimates for GCMC hydrologic system under current (natural and anthropogenic) conditions (modified from Phase 2 report).
5.2 Preliminary Pre-Development and Post Development Water Budgets for the Entire GCMC/PCLA Hydrologic System

A preliminary water budget (PWB) is calculated based upon the information previously collected and analyzed by Kolm and van der Heijde (2018), Kolm and van der Heijde (2019), the HESA-based conceptual model of the GCMC hydrologic system determined in Phase 1, and the HESA-based conceptual model of the PCLA hydrologic system determined in Phase I and refined in Task 1 of this Phase (4) project. The area for the combined GCMC and PCLA hydrologic systems for which the water budget is determined is based, in part, on 1) the locations of various stream gages on Pack Creek and Mill Creek (Blanchard, 1990; USGS Surface-Water Data Summary, Mill Creek at Shelley Tunnel Sites, 2019); 2) the location of most anthropogenic activities (diversions, domestic and agricultural water use); 3) the natural boundaries of the GCMC and PCLA hydrologic systems including Pack Creek and tributaries and Mill Creek and tributaries; and 4) the hydrogeologic and hydrostructural boundaries of the Pack Creek Alluvium Aquifer and Glen Canyon Group Aquifer as determined by HESA (Figure 16). The water budget area is outlined in Figure 16 and is bounded by the Glen Canyon Group Grandstaff Creek Subsystem (GCGC) to the northeast and east; the Morrison Formation to the east and southeast; the La Sal Mountain Upper Alluvial Subsystem (LSMA-P) Pack Creek Headwaters to the southeast; the Moab Rim and Kane Creek hydrological divides to the south, southwest, and west; and the Colorado River to the northwest (Figure 16). The PWB area used in this report covers almost all of the PCLA and GCMC hydrologic systems.

The surface and subsurface hydrologic systems or storage components and the hydrologic exchange processes or fluxes considered relevant for the PWB of the combined GCMC and PCLA hydrologic systems were derived from the conceptual models developed in the Phase 1 HESA as illustrated in Figure 16 (with boundary conditions). The significant inputs of the PWB are: 1) direct runoff of precipitation to streams; 2) recharge by infiltration of precipitation (rain and snow) across the entire PWB area using the concept of hydro zones explained earlier in this report and in Kolm and van der Heijde (2019); 3) Mill Creek groundwater flux, called groundwater underflow, at the upper Mill Creek boundary (inflow through Mill Creek fracture zone); 4) Pack Creek groundwater flux, called groundwater underflow, in the Quaternary hydrogeologic units (Qal) at the SE corner of the water budget area; 5) Brumley Creek groundwater flux, called groundwater underflow, in the Quaternary hydrogeologic units (Qal) at the SE corner of the water budget area; 6) Mill Creek inflow above later location of Sheley diversion; 7) Upper North Fork Creek and Burkholder Draw inflow from Mesas; 8) Pack Creek surface water inflow above the later ditch diversion in the SE corner of the water balance area; and 9) Brumley Creek surface water inflow to Pack Creek in the SE corner of the water balance area. Note that precipitation itself and evapotranspiration (ET) for the area not covered by riparian vegetation is not included in the PWB, but is discussed in earlier sections of this report.

The outputs of the combined PWB are: 1) consumptive use crops; 2) evapotranspiration or consumptive use by native phreatophytes (cottonwoods, willows, tamarisk, and other riparian species) (Figure 13 and Figure 12 in Kolm and van der Heijde (2019); 3) evaporative loss open water; 4) net municipal use GWSSA minus losses/return flow City of Moab Water; 5) domestic consumptive use by private wells (Figure 12 and Figure 10b in Kolm and van der Heijde (2019)); 6) groundwater discharge to the Colorado River; 7) Mill Creek surface water outflow at the
northern end of Spanish Valley to the Colorado River, and 8) release from groundwater storage in the post-development (current) PWB, primarily in the GCMC PWB area.

Figure 16. Map showing the location of the Preliminary Water Budget (PWB) area of the combined GCMC and PCLA hydrologic systems with boundary conditions, and spring locations.
<table>
<thead>
<tr>
<th>WATER BUDGET COMPONENT</th>
<th>IN (ac-ft/yr)</th>
<th>OUT (ac-ft/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Direct runoff to streams</strong>&lt;br&gt;Estimated (section ...)&lt;br&gt;</td>
<td>5925</td>
<td>-</td>
</tr>
<tr>
<td><strong>Recharge</strong>&lt;br&gt;Calculated (section ...)&lt;br&gt;</td>
<td>8410</td>
<td>-</td>
</tr>
<tr>
<td><strong>Groundwater underflow at upper Mill Creek boundary</strong>&lt;br&gt;(inflow through Mill Creek fracture zone)&lt;br&gt;Calculated (section...)&lt;br&gt;</td>
<td>900</td>
<td>-</td>
</tr>
<tr>
<td><strong>Groundwater underflow at upper Pack Creek boundary</strong>&lt;br&gt;Calculated (section ...)&lt;br&gt;</td>
<td>100</td>
<td>-</td>
</tr>
<tr>
<td><strong>Groundwater underflow at Brumley Creek</strong>&lt;br&gt;Calculated (section ...)&lt;br&gt;</td>
<td>25</td>
<td>-</td>
</tr>
<tr>
<td><strong>Mill Creek inflow above later location of Sheley diversion</strong>&lt;br&gt;Measured (section...)&lt;br&gt;</td>
<td>7545</td>
<td>-</td>
</tr>
<tr>
<td><strong>Upper North Fork Cr. and Burkholder Draw inflow from mesa’s</strong>&lt;br&gt;Estimated (section ....)&lt;br&gt;</td>
<td>minor</td>
<td>-</td>
</tr>
<tr>
<td><strong>Pack Creek inflow above later ditch diversion</strong>&lt;br&gt;Measured (section ...)&lt;br&gt;</td>
<td>1845</td>
<td>-</td>
</tr>
<tr>
<td><strong>Brumley Creek flow into Pack Creek</strong>&lt;br&gt;Estimated (section ...)&lt;br&gt;</td>
<td>1100</td>
<td>-</td>
</tr>
<tr>
<td><strong>Consumptive use crops</strong>&lt;br&gt;Not present (section ...)&lt;br&gt;</td>
<td>-</td>
<td>0</td>
</tr>
<tr>
<td><strong>Consumptive use riparian vegetation</strong>&lt;br&gt;Calculated (section ...)&lt;br&gt;</td>
<td>-</td>
<td>11190</td>
</tr>
<tr>
<td><strong>Evaporative loss open water</strong>&lt;br&gt;Calculated (section ...)&lt;br&gt;</td>
<td>-</td>
<td>1460</td>
</tr>
<tr>
<td><strong>Municipal use (City of Moab and GWSSA)</strong>&lt;br&gt;Not present (section ...)&lt;br&gt;</td>
<td>-</td>
<td>0</td>
</tr>
<tr>
<td><strong>Domestic consumptive use</strong>&lt;br&gt;Not present (section ...)&lt;br&gt;</td>
<td>-</td>
<td>0</td>
</tr>
<tr>
<td><strong>Groundwater discharge to Colorado River</strong>&lt;br&gt;Estimated (section ...)&lt;br&gt;</td>
<td>-</td>
<td>750</td>
</tr>
<tr>
<td><strong>Mill Creek outflow to Colorado River</strong>&lt;br&gt;Measured (section ...)&lt;br&gt;</td>
<td>-</td>
<td>12450</td>
</tr>
<tr>
<td><strong>Release from storage</strong>&lt;br&gt;Naturally balanced system (section...)&lt;br&gt;</td>
<td>-</td>
<td>0</td>
</tr>
<tr>
<td><strong>TOTALS</strong></td>
<td>25850</td>
<td>25850</td>
</tr>
</tbody>
</table>

Table 5. Preliminary water budget estimates for the combined PCLA and GCMC hydrologic systems under natural (pre-development) conditions.
<table>
<thead>
<tr>
<th>WATER BUDGET COMPONENT</th>
<th>IN (ac-ft/yr)</th>
<th>OUT (ac-ft/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direct runoff to streams</td>
<td>5950</td>
<td>-</td>
</tr>
<tr>
<td>Estimated (section ...)</td>
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<td></td>
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<tr>
<td>Recharge</td>
<td>8050</td>
<td>-</td>
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<tr>
<td>Calculated (section ...)</td>
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<tr>
<td>Groundwater underflow at upper Mill Creek boundary (inflow through Mill Creek fracture zone)</td>
<td>900</td>
<td>-</td>
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<tr>
<td>Calculated (section ...)</td>
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<td></td>
</tr>
<tr>
<td>Groundwater underflow at upper Pack Creek boundary</td>
<td>100</td>
<td>-</td>
</tr>
<tr>
<td>Calculated (section ...)</td>
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<td></td>
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<tr>
<td>Groundwater underflow at Brumley Creek</td>
<td>25</td>
<td>-</td>
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<tr>
<td>Calculated (section ...)</td>
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<td></td>
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<tr>
<td>Mill Creek inflow above Sheley diversion</td>
<td>6815</td>
<td>-</td>
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<tr>
<td>Measured (section ...)</td>
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<td></td>
</tr>
<tr>
<td>Upper North Fork Cr. and Burkholder Draw inflow from mesa’s</td>
<td>Minor</td>
<td>-</td>
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<tr>
<td>Estimated (section ...)</td>
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<td></td>
</tr>
<tr>
<td>Pack Creek inflow above ditch diversion</td>
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<tr>
<td>Measured (section ...)</td>
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<td></td>
</tr>
<tr>
<td>Brumley Creek flow into Pack Creek</td>
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<td>-</td>
</tr>
<tr>
<td>Estimated (section ...)</td>
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<td></td>
</tr>
<tr>
<td>Consumptive use crops</td>
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<td>3600</td>
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<td>Estimated (section ...)</td>
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<td></td>
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<tr>
<td>Consumptive use riparian vegetation</td>
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<tr>
<td>Calculated (section ...)</td>
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<td>Evaporative loss open water</td>
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</tr>
<tr>
<td>Calculated (section ...)</td>
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<td></td>
</tr>
<tr>
<td>Municipal use (City of Moab and GWSSA)</td>
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<tr>
<td>Measured (section ...)</td>
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<td></td>
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<td>Domestic consumptive use</td>
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<td>Estimated (section ...)</td>
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<td>Groundwater discharge to Colorado River</td>
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<td>Estimated (section ...)</td>
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<td>Mill Creek outflow to Colorado River</td>
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<td>TOTALS</td>
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</table>

Table 6. Preliminary water budget estimates for the combined PCLA and GCMC hydrologic systems under current (natural and anthropogenic) conditions.
Table 5 and Table 6 present a preliminary pre-development water budget and a preliminary post-development water budget for the combined GCMC and PCLA hydrologic systems. In each PWB, the difference between the calculated and estimated inputs and the calculated and estimated outputs is the PWB closing or balancing term. In the pre-development scenario, this closing term represents the term for direct runoff to streams and amounts to 5950 ac-ft/yr (Table 5). The post-development scenario presented in Table 6 incorporates among other human activities, the Sheley Diversion intake of 3665 ac-ft/yr, but the water budget treats that as an internal process, which doesn’t appear on either table. However, due to the diversion, and the increase water use by human activity, the closing term is release from groundwater storage in the GCMC part of the combined system of 3995 ac-ft/yr, which is approximately 14% of the total yearly budget. The deficit may be reduced over time by increased recharge in above average precipitation years, or as increased flow to Mill Creek into the GCMC hydrologic systems upgradient due to increased groundwater release in upgradient groundwater systems, or increased runoff from higher than average snowpack. This depletion of upgradient storage or mining of groundwater is also a concern for the sustainability of both the City’s and the PCLA water supply.

5.3 PWB and the GCMC/PCLA Hydrologic System: Significance

There are many uncertainties in these preliminary calculations, so further analysis is needed and should be planned. The primary significance of the PWB is that there is a significant amount of surface water and groundwater contributed to the GCMC and PCLA hydrological systems from the La Sal Mountain systems, or in percentages of pre-development input into the GCMC/PCLA hydrological system: surface water and groundwater derived from the La Sal Mtns is 11,515 ac-ft/yr and counts for approximately 45%, and local recharge from precipitation counts for 33%. This means that the La Sal Mountain climate regimes can affect directly 78% of the water supply. Note that a combined consumptive use riparian vegetation and evaporative loss open water accounts for 49% of the total water budget out (almost one-half!), and the remainder of 51% is subsurface and surface discharge to the Colorado River. By comparison, in the post development time period, the development of the Sheley diversion to the overall redistribution of the water supply plus the increase in municipal use and consumptive use becomes more of a factor, or in percentages of post development change into the GCMC/PCLA hydrologic system: consumptive use crops accounts for 13%, municipal use and domestic consumptive use accounts for 11%, and groundwater released from storage accounts for approximately 14%. The Sheley diversion yearly amounts is almost entirely accounted for in the consumptive use of crops and domestic consumptive use. The most notable decline is the amount of Mill Creek outflow to the Colorado River of 1,620 acre-ft/year or 13%.

The reduction of water contributions originating from the La Sal Mountain subsystem in amounts and timing of precipitation (rain and snowfall) and snowmelt resulting from climate change may have a significant impact on stream flows, groundwater recharge and subsurface inflow into the valley. In addition, water diversion projects to other watersheds, especially up-valley, will result in decreased surface water flows and groundwater recharge from losing streams. Impacts on the GCMC/PCLA water budget may also result from deforestation due to lumbering or fire (increased surface runoff and stream flows); increased forestation (increased
ET; decrease of runoff and stream flows); and mining (increased or decreased stream flows and groundwater fluxes). Land use conversions/changes resulting in more or less consumptive uses need to be evaluated regarding the surface water output to Mill Creek, Pack Creek and Brumley Creek at the east and southeast end of the GCMC/PCLA hydrologic system. Increased consumptive use would result from increased urbanization (more wells, non-native vegetation) or increased irrigation.

5.4 PWB and the GCMC/PCLA Hydrologic System: Sustainability Concerns

There are a number of potential threats to the sustainability of the GCMC/PCLA hydrologic system and thus to the water supply of the City of Moab and Grand County, both natural and man-made. Climate change may reduce water contributions originating from the La Sal Mountain subsystem, both in amounts and timing. In addition, water diversion projects to other watersheds, especially up-stream of the GCMC/PCLA hydrologic system, will result in decreased surface water flows and groundwater recharge from losing streams. Impacts on the GCMC/PCLA hydrologic system may also result from deforestation due to lumbering or fire (increased unchanneled surface runoff and stream flow peaks, and decreased stream base flow); increased forestation (increased ET; decrease of runoff and stream flows); and mining (increased or decreased stream flows and groundwater fluxes). Land use conversions/changes resulting in more or less consumptive uses need to be evaluated regarding the surface water output to Mill Creek, Pack Creek and Brumley Creek at the east and southeast end of the GCMC/PCLA hydrologic system. Increased consumptive use would result from increased urbanization (more wells, non-native vegetation), or increased irrigation. Any long term decline in inflows to the GCMC/PCLA hydrologic system will result in further decline of outflows such as at Mill Creek, Pack Creek and Brumley Creek in the eastern and southern part of the study area and various springs, and will likely lead to decline in storage and subsequent lowering of groundwater levels and groundwater availability for phreatic consumption.
6. CONCLUSIONS AND RECOMMENDATIONS

The Pack Creek Lower Alluvium (PCLA) hydrologic system is a complex mix of Alluvium and Alluvial Fan sediments overlying or adjacent to fractured and faulted Glen Canyon Group rock, and hydro-structures (fault and fracture zones that are either conductive or a barrier to groundwater flow). A preliminary (global) water budget (PWB) has been developed for the PCLA hydrologic system, focused on the external inputs (inflows) and outputs (outflows), and an analysis was made of the storage capacity of the PCLA aquifer in the PWB area. The most significant anthropogenic change in conditions happened in the early 1980s, the start of the Sheley diversion, together with the initiation of a steady increase in municipal and domestic water use that represents a significant increase in the anthropogenic withdrawals from the PCLA hydrologic system that continues to the present day. The “best” estimate for recharge in both periods amounts to about 16-17% of overall precipitation in the PWB area. Direct runoff of precipitation to streams and amounts to 815 ac-ft/yr. This term, corrected for the decline in precipitation between the two climate periods and the increase of direct runoff in buildup/urbanized areas amounting to a total of 1300 ac-ft/yr, is used in the post-development scenario. Direct evapotranspiration (ET) in the PWB area (excluding riparian vegetation), calculated as precipitation minus groundwater recharge and direct runoff to streams, amounts to about 14,525 ac-ft/yr for the pre-development period and to 13,565 ac-ft/yr for the post-development period, or about 75-78% of total precipitation, based on 30-year averages for the two climate periods. The total water budget of the PCLA amounts to 20,325 ac-ft/yr predevelopment, and 21,395 ac-ft/yr post-development/current conditions.

The primary significance of the PWB is that there is a significant amount of surface water and groundwater contributed to the PCLA hydrological system from the La Sal Mountain and GCMC hydrological systems: surface water and groundwater derived from the GCMC hydrologic system (Mill Creek + groundwater underflow at the Mill Creek delta + springs at eastern PWB boundary from GCMC system) is 13,270 ac-ft/yr and counts for approximately 65%; local recharge from precipitation and direct runoff to streams counts for 20%; and directly linked groundwater inflow and surface water inflow (Pack Creek and Brumley Creek) from the La Sal Mountains hydrological subsystems counts for 15%. The La Sal Mountain and GCMC subsystems contribute more than 80% of the total inflow in the PWB area. A combined consumptive use riparian vegetation and evaporative loss open water accounts for 35% of the total water budget out, and remainder is subsurface and surface discharge to the Colorado River. By comparison, in the post development time period, the contribution of the Sheley diversion to the overall input becomes more of a factor, or in percentages of post development input into the PCLA hydrologic system: surface water (Mill Creek + Pack Creek + Brumley Creek) counts for approximately 55%; local recharge from precipitation and direct runoff to streams for 19%; groundwater inflow from the GCMC hydrological subsystems counts for about 9%; and the Sheley diversion provides 17% of the total inflow to the PCLA hydrologic system and has resulted in a 17% reduction of Mill Creek inflows towards Spanish Valley under base flow conditions and 31% reduction of springs and seeps discharge in the most likely scenario. Therefore, any decline in upstream total average flows in Mill Creek, Pack Creek, or Brumley Creek from natural or man-made causes will have an immediate and significant impact on the various outflows of the PCLA hydrologic system and poses a potential threat to the sustainability of the City of Moab’s and the County’s water supply.
The Quaternary alluvium and fan gravels, and the fractured Glen Canyon Group groundwater system is mostly unconfined, has a readily fluctuating water table, and the aquifer specific yield of the alluvium and alluvial fan gravels matrix is estimated at 10 – 30%, and the fractured/faulted Glen Canyon Group bedrock has a fracture specific yield estimated range from 10.0 – 40.0%. The results of GIS-based calculations show that the PCLA groundwater system has a variable storage low of 38,375 ac-ft, and a variable storage high of 101,400 ac-ft. The Quaternary alluvial deposits, designated storage zone 1, had the largest amount of variable storage with a range of 24,850-74,550 ac-ft. The current City of Moab source protection plans identify some of these hydro zones as critical, and an update to these plans will be completed in Phase 3 of this project.

In order to develop a preliminary water budget of the combined Pack Creek Lower Alluvium (PCLA) and Glen Canyon Group Mill Creek (GCMC) Subsystems of the MCSW study area, the true PWB of the Pre-development natural conditions of the GCMC subsystem and the updated PWB of the post development (current) conditions of the GCMC subsystem were evaluated. Then, this PWB was combined with the PWB for the PCLA hydrologic system to provide estimates for the entire City of Moab hydrologic system for water rights and water management purposes. In the combined GCMC/PCLA pre-development scenario, the water budget amounts to 25,850 ac-ft/yr, and the water budget closing term represents the term for direct runoff to streams and amounts to 5950 ac-ft/yr. The combined GCMC/PCLA post-development scenario, which amounts to 28,690 ac-ft/yr, incorporates human activities, such as the Sheley Diversion intake of 3665 ac-ft/yr, but the water budget treats the diversion as an internal process, which doesn’t appear in the PWB. However, due to the diversion, and the increase water use by human activity, the closing term is release from groundwater storage in the GCMC part of the combined system of 3995 ac-ft/yr, which is approximately 14% of the total yearly budget. The deficit may be reduced over time by increased recharge in above average precipitation years, or as increased flow to Mill Creek into the GCMC hydrologic systems upgradient due to increased groundwater release in upgradient groundwater systems, or increased runoff from higher than average snowpack. This depletion of upgradient storage or groundwater mining is also a concern for the sustainability of both the City’s and the PCLA water supply.

The primary significance of the combined PWB is that there is a large amount of surface water and groundwater contributed to the GCMC and PCLA hydrological systems from the La Sal Mountain systems totaling 11,515 ac-ft/yr and counts for approximately 45%, and local recharge from precipitation counts for 33% or the La Sal Mountain climate regimes can affect directly 78% of the water supply. A combined consumptive use riparian vegetation and evaporative loss open water accounts for 49% or one-half of the total water budget out, and the remainder of 51% is subsurface and surface discharge to the Colorado River. By comparison, in the post development time period, the development of the Sheley diversion to the overall redistribution of the water supply plus the increase in municipal use and consumptive use becomes more of a factor, or in percentages of post development change into the GCMC/PCLA hydrologic system: consumptive use crops accounts for 13%, municipal use and domestic consumptive use accounts for 11%, and groundwater released from storage accounts for approximately 14%. The Sheley diversion yearly amounts is almost entirely accounted for in the consumptive use of crops and domestic consumptive use. The most notable decline is the amount of Mill Creek outflow to the Colorado River of 1,620 acre-ft/year or 13%.
There are a number of potential threats to the sustainability of the GCMC/PCLA hydrologic system and thus to the water supply of the City of Moab and Grand County, both natural and man-made. Climate change may reduce water contributions originating from the La Sal Mountain subsystem, both in amounts and timing. In addition, water diversion projects to other watersheds, especially up-stream of the GCMC/PCLA hydrologic system, will result in decreased surface water flows and groundwater recharge from losing streams. Impacts on the GCMC/PCLA hydrologic system may also result from deforestation due to lumbering or fire (increased unchanneled surface runoff and stream flow peaks, and decreased stream base flow); increased forestation (increased ET; decrease of runoff and stream flows); and mining (increased or decreased stream flows and groundwater fluxes). Land use conversions/changes resulting in more or less consumptive uses need to be evaluated regarding the surface water output to Mill Creek, Pack Creek and Brumley Creek at the east and southeast end of the GCMC/PCLA hydrologic system. Increased consumptive use would result from increased urbanization (more wells, non-native vegetation), or increased irrigation. Any long term decline in inflows to the GCMC/PCLA hydrologic system will result in further decline of outflows such as at Mill Creek, Pack Creek and Brumley Creek in the eastern and southern part of the study area and various springs, and will likely lead to decline in storage and subsequent lowering of groundwater levels and groundwater availability for phreatic consumption.

Based upon associated uncertainties with estimates, better monitoring via gaging stations at Mill Creek (Powerhouse, Junction with Pack Creek, Colorado River), Pack Creek (City Springs and Perennial Flow locations, Pack Creek Bridge, Settlement of Pack Creek), and Brumley Creek that record daily, seasonal, and annual information would improve the measurements of the City of Moab and Spanish Valley protected areas. Water quality measurements would be recommended at these sites as well. In addition, continued monitoring of City Springs and Wells, including Skakel Spring, for daily, seasonal, and annual information regarding flow and water usage is recommended. An analysis of this and the data currently available, in addition to continued analysis of the climate data compared to the City Springs and Wells, and Skakel Spring, is recommended as a future part of this study. This Phase IV HESA revealed that the GCMC/PCLV groundwater system was complex being both matrix and fracture-type flow, and that the design, implementation, and calibration of a mathematical model can be done, but given the uncertainties with the data available, the results would still tend to be questionable. The PWB of the GCMC groundwater system in Phase II would provide inputs into a Spanish Valley model, and the HESA of the PCLV and GCMC groundwater systems would provide boundary conditions for that model.
7. REFERENCES


### APPENDICES

#### Appendix A. Recharge calculation: Pre-development (natural)

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Total: 19986.87 acre-ft, 18509.92 acre-ft, 2504.04 acre-ft, 3863.17 acre-ft, 3170.43 acre-ft

#### Appendix B. Recharge calculation: Post-development (current)

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Total: 19981.88 acre-ft, 17632.63 acre-ft, 2216.20 acre-ft, 3315.73 acre-ft, 2765.97 acre-ft
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* Based on valley fill thickness published in Lowe and others 2007.

**Appendix C. Aquifer storage calculations.**
OUTLINE OF WATER CONSERVATION PLAN UPDATE

1) CITY OF MOAB and ITS WATER SYSTEM
   i) History Gov't and Population
      (a) Include the resident population and the visiting population & how that complicates water
      (b) Institutional and political factors
      (c) Upcoming groundwater management planning process (regional)
   ii) Water Source: Includes Geology and Origin of our water
      (a) Aquifer and surface water descriptions
      (b) Aquifer recharge estimates/models/equilibrium

Mike Duncan’s thoughts:

Model recharge directly. This requires defining a geographic surface area, a watershed or water table into which precipitation falls either as rain or snow; observing or modeling annual precipitation over that watershed as a function of elevation and geography; and modeling infiltration into the aquifer underlying the watershed as a function of surface properties including slope and matrix composition. There are substantial uncertainties associated with many facets of the modelling process. Nonetheless, the USGS attempted such a model and arrived at a recharge value with certain error bounds.

Estimate recharge from discharge: assume aquifer storage is in equilibrium, then use aquifer discharge as a surrogate for recharge. This requires modelling or observing spring discharges; well withdrawals; Mill Creek surface flow that originates from groundwater as a "gaining stream,"; groundwater lost to phreatophytes (riparian vegetation); and groundwater that escapes as groundwater flow to the Colorado River. There are substantial uncertainties associated with many facets of the modelling process. Nonetheless, the USGS attempted such a model and arrived at a recharge value with certain error bounds. This method is fundamentally flawed if the assumption that the aquifer is in equilibrium cannot be verified. To my knowledge, no such verification exists, particularly in Moab's post-1970's era.

See if water tables can maintain an acceptable equilibrium: Keep aquifer well withdrawals constant for a suitably long period of time, then see if water table levels come to an equilibrium. If they do, total aquifer discharge (including all the discharges listed above) is less than safe yield; if not, the water table will continue to drop towards zero since we are discharging more water than is being recharged. This is the strategy Marc Stilson has outlined in at least two presentations to MAWP, and it enjoys freedom from many modelling errors of the techniques above. But it has limitations. One is that, practically speaking, and in the absence of refusal to issue new "will serve" commitments, it's not possible to keep well withdrawals constant. A "suitably long period of time" required to permit groundwater to move throughout the aquifer and average over seasonal variations is too long to be of practical use to city/county planners who must promise and provide water far in the future. Further, the only way to provide greater well withdrawals at a given recharge rate is to reduce spring flow (part of the city's water supply), creek flow (whose surface rights are owned by Moab Irrigation Co.) and phreatophyte growth, i.e. to dry the place up. Clearly, a commitment to err on the conservative side is the responsible strategy. No public water supplier wishes to make promises they can't keep.
(c) Water Quality
(d) Environmental Concerns (Arne wants to be a part of it). OCTOBER to get started on some of this... We’ll use 2019 #s as a basis for these things not waiting for 2020 numbers... we can likely update these figures in future fairly easily. WE DID NOT SEE THE TOURIST POPULATION NUMBERS
(i) Geology
(ii) Regional nature of aquifer
   1. Quantity/overdrafting or not etc??
(iii) Changing climate
(iv)
(e) Political Boundaries & other entities involved
   1. GWSSA
   2. San Juan County
   3. MIC
   4. Existing Intersystem agreements and opportunities for expansion

iii) Water Rights
   (a) Moab’s Water Rights
   (b) Other Rights that are using the same source
   (c)

iv) Water System
   (1) Distribution system (Late fall seems reasonable to start to get into some of this information) ... We’ll use 2019 #s as a basis for these things
      (a) # of connections by type
      (b) Emergency Action Plan
      (c) Condition of the distribution system/maintenance backlog/needs
         (i) May include some priorities
      (d) Possibility of secondary water system/pressurized....

   (2) Treatment System
      (a) New sewer plant, potential needs
      (b) Reuse potential

   (3) Fiscal Structure and Financial Resources
      (a) Rates
      (b) Needed repairs/expansion
      (c)

v) Water Use
   (1) Current Use
      Count at wells/source end and springs and also count at water use end
      Have daily numbers for source end of this. In theory you could split it out by day of the week vrs weekend..... have that resolution of data
      (a) # of connections (by type)
      (b) Current Use: Per Capita
         Specifications on the water conservation plan by DWR to get funding. In that documentation they define commercial versus not commercial – breaking
those into parts. This also means that there will be some splitting of some of the lumped categories so that we can better understand OUR use patterns.

(c) Current Use: by residential, industrial and commercial
(d) Impacts of visitor population on use

(2) Trends/Anticipated changes

2) Water Conservation

i) Why conserve water?

(1) Impact of various users on conservation
(a) How much water will we have for future – especially in light of the water quantity being unknown – are we overdrawning already

(2) Current efforts
(a) Ground water management planning and protection needed and in process
(b) Tiered water rates implemented in July 2020 – show improvement from old rates
(c) Current outreach going on now

(d) JEREMY WILL REVIEW EXISITING PLAN AND BEGIN TO MAKE SUGGESTIONS FOR IMPROVEMENTS AND OTHER MEASURES TO ADD TO THIS SECTION

(3) Goals of conservation (Jeremy’s expanded comments about how to make conservation appealing to everyone. (Jeremy is happy to take a first draft at this to parse out and use in a meeting to discuss.....)

How to break down of conservation into a more nuanced approach that does not simply focus on up-and-coming technologies and strategies alone (which are often the rediscovered practices of yesteryear’s farmers anyway). Develop an approach that balances the conservation value in existing (old; often municipal) and recommended (new; often residential/commercial) infrastructure. Emphasize support for our City staff - particularly public work - and particularly at a time when broadscale budget cuts and property tax increases are inevitable. Focus on the baseline.

(A) Conservation as securing the integrity of existing municipal infrastructure to prevent substantial or cumulative losses to water quantity in transmission. IE - update aged-out pipes and other buried infrastructure; improve wells and storage capacity.

(B) Conservation as recommending, incentivizing, or promoting ordinances for new practices and infrastructure. IE - greywater, secondary water use, passive and active water harvesting, native plant palette design. Both on the residential-scale (incentives) and the commercial scale (ordinances).

The ultimate goal is to better define and deliver conservation as a term and set of practices to a public of which some may embrace blindly the concept while others outright reject the presumed precepts.

(a) State imposed (numerical goals) –

(i) 25% 2025...and now it is reduced even more – 17% from a recent year...Arne and Jeff worked on that and found that in 2018 ish to meet the state imposed goals.......ARNE WILL START WITH SOME NUMERICAL FACTS

Comparison of State Conservation Goals and City of Moab’s Water Use (by Arne)

In 2000, Governor Levitt proclaimed a conservation goal of 25% in gallons per capita day (gpcd) by 2050 using 2000 water use as the indexing year. The conservation proclamation was aimed at municipal and industrial (M&I) users, agriculture was intentionally omitted from the goal. A few years later Governor Herbert decreased the time line and proclaimed a conservation goal of 25% by 2025 using the same year, 2000, as the indexing year. The
goals were not intended to reduce the total demand for M&I water, they were established to make room for new growth because a fair number of regions were reaching the limit of their water resources.

Since then the Utah Legislature began getting involved which led to a 2015 Legislative Audit, followed by a 2017 Follow-up Audit, then a Third-Party Review, and finally a 2017 Recommended State Water Strategy. Those efforts recommended the State develop regional water conservation goals. The Utah Division of Water Resources (UDWRe) was tasked with the project and developed the latest goals in their document *Utah’s Regional M&I Water Conservation Goals*. Grand County was put in the “Upper Colorado Region” which also includes Carbon, Emery and San Juan County. The draft recommendations were for the Upper Colorado Region to reduce their per-capita water consumption by another 17% and the final recommendations were for 20% from 2015 usage by 2030. The 20% reduction for the region resulted in a recommended goal for the Southeast region of 267 gpcd.

Using the data submitted by the City of Moab to the UDWRi site (https://waterrights.utah.gov/cgi-bin/wuseview.exe?Modinfo=Pwsview&SYSTEM_ID=1164) and the dates of 2000 and 2015, if the City of Moab were to embrace these goals the total per capita consumption decrease since 2000 would be 36.7%. This data is shown in Table 1: It would appear from Table 1 that the City of Moab has met the original goals set in 2000 by the year 2019, six years earlier than suggested and has already met the 2030 per-capita goal of the State’s Regional Goals of 267 gpcd.

<table>
<thead>
<tr>
<th>year</th>
<th>people</th>
<th># of connections</th>
<th>total acrft</th>
<th>gallons per capita day</th>
<th>% change from 2000</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000</td>
<td>5000</td>
<td>1775</td>
<td>1926.63</td>
<td>344.00</td>
<td>0.0%</td>
</tr>
<tr>
<td>2015</td>
<td>5430</td>
<td>2018</td>
<td>1657.96</td>
<td>272.58</td>
<td>20.8%</td>
</tr>
<tr>
<td>2019</td>
<td>5775</td>
<td>2159</td>
<td>1629.77</td>
<td>251.94</td>
<td>26.8%</td>
</tr>
<tr>
<td>2030 w/20%</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>218.07</td>
<td>36.6%</td>
</tr>
<tr>
<td>2030 w/267gpcd</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>267</td>
<td>22.4%</td>
</tr>
</tbody>
</table>

However, the City of Moab’s M&I annual water use and per-capita use have large annual fluctuations. Taking a hard look at those numbers it appears that water usage regularly fluctuates by over 10% annually and using metrics based upon single years doesn't provide meaningful trend data. A five year average of annual gpcd around the years stipulated in the State’s Regional Goals, 2000 and 2015, would provide more meaningful trend data. Table 2 shows the changes in water use using this methodology. Please note the year 1999 was not include in the tabulations.

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</table>

Table 1: Statistics on percent change of M&I Water Use using the years 2000 and 2015 and State of Utah’s 2017 M&I conservation goals

Table 2: Statistics on percent change of M&I water use using the five year averages around the 2000 and 2015 with the exception of 1999
Using the five year average methodology, it can be seen from Table 2 that the City of Moab was well on its way to making the goal of 25% by 2025. It can also be seen that cutting another 20% from the 2015 average would put the City of Moab well below the regional goal of 267 gpcd. It would also mean cutting the water use by a total of 33.7%. If the regional goals of 267 gpcd are used for the 2030 calculation instead of the 20% decrease in use the total percent reduction in gpcd water use would be 29.1%

State Water Conservation Goals, Metrics and the City of Moab’s Demographics

The State has determined the metric for conservation goals at gpcd, or gallons per capita day. The metric is a reasonable measure if you were only measuring municipal use. The concept being we are measuring household use and the number of people in households affects that number. However, adding commercial, industrial and institutional into the metric is problematic because the people who are supported by that water use may not be living in the area where the water is being used. Furthermore, differing industrial and commercial uses may not have any relationship to the number of people actually being served by the water provider. Furthermore, trying to determine whether metrics actually represent conservation or a change in economy are not represented in the metric.

The City of Moab’s has a tourism economy as was discussed in Section. There are between 1.6 and 2.6 visitors in our community for most of the “tourist season” Although they are a transient they are also here all the time. As such the metric per capita doesn’t include the numbers of visitors our municipality supports. The City of Moab is interested in considering other metrics to determine their conservation goals. One which has potential is Equivalent Residential Unit (ERU). It is already used for a variety of requirements associated with water supply and could be a metric which normalizes the metric to provide comparison between economies and water conservation strategies. It is unfortunate that statistics for that metric, gallons per ERU per day are not available and it unfortunate that the State has not seriously considered or evaluated the possibility of using that metric.

(b) Soft goals – and why these are important.
(i) Types of irrigation systems – to help with this
   1. automated irrigation at night to help to help with the surges in the system – between 11 pm and 4 am....4 or 5 am starts up fast
   2. Drip irrigation preferred.

(c) Local goals (of different)

Water Conservation Goals for the City of Moab (by Arne)
The City of Moab is growing. As was stated earlier in Section, the amount of available water in the sole source of Moab’s water supply is limited. This document also points out
that the sole source resource for the Moab is shared with other water providers. At this time there hasn’t been a determination by the UDWRi on the extent of those resources. Without knowledge of the extent of those resources it would be difficult if not impossible to set meaningful goals for conservation.

However, The City of Moab has about 10,000 acft of senior water rights to their sole source groundwater aquifer. The City of Moab is currently using about 2,000 acft per year. Using simple mathematics, with the current population in the City being about 5,000, the City could support about 25,000 people with that water right. It will be a long time before the City of Moab will “need” to conserve to meet increasing population requirements.

There are numerous reasons to conserve water beyond the simplistic matter of whether it is necessary. Those will be discussed in Section 3.0. Conservation measures that have been implemented and will be discussed Section 3.1. The City of Moab has determined that the measures discussed in Section 3.1 for water use conservation will be applied using voluntary participation for existing developments. Future developments will be required to implement practices described in 3.2. The City of Moab is not setting water conservation goals at this time. It is believed that the practices discussed in Section 3.1 and 3.2 will lead to gpcd of 267 by 2030.

Of greater concern to the City of Moab is the ramifications of a long term drought on water supply. The City is well aware that historically long term drought has occurred in our region. The City is very concerned that conservation measures taken to far won’t leave any means to limit water uses during a drought. Drought contingency plans, including water use buffers and amounts of water to be buffered and measures that will be saved for use during a drought are discussed in Section 7.

(i) Green infrastructure concepts may fit here: Adding more parking spots to downtown modeled after Lancaster CA with folks parked in the middle of the road with lots of trees planted in the middle of the road too.... Looks gorgeous but is it reasonable? Can this be accommodated with green infracture and tree species

(ii) In stream flow in Mill Creek
1. Water banking MIGHT fit into this based on current physical distribution system
2. Secondary water use in the city – historically wanted to own the water rights and not just shares....

(4) Policies/Ordinances

3) CONSERVATION MEASURES TO IMPLEMENT

The City of Moab has been implementing water conservation measures for a number of years. Putting some of the practices into use throughout the community is an ongoing process. The practices that have been and are currently being implemented on existing development are discussed in Section 6.1.1. The practices that will be implemented in the future include new practices for existing development and new required practices for future developments are discussed in Section 6.1.2

i) Stormwater Management to improve retention/recharge
(1) Green Infrastructure needs to be more implemented
(2) Improvements to stormwater management

ii) Infrastructure Needs to sustain and improve delivery

(1) Secondary water use in the city – historically wanted to own the water rights and not just shares...pressurized water of MIC

Water Conservation Practices Being Implemented or Considered for Water Use (By Arne)

NOT necessarily in this order and please add some items,

- First is a list of practices implemented on existing and new infrastructure:
- Green infrastructure to replenish groundwater and result in less irrigation...
- Secondary water use in the City, A discussion of both the pressurizing of the MIC for current infrastructure.
- Irrigation systems upgrades, and discussion on the types, including smart.
- Indoor water fixtures, just mention the ongoing replacement
- Education and outreach for all of the “use” practices. Including watering schedules and type of irrigation infrastructure.
- Not ordinances for irrigation and/or landscaping for existing developments.

iii) Conservation Outreach

(1) EDUCATION and OUTREACH

(a) Types of irrigation systems – to help with this
   1. automated irrigation at night to help to help with the surges in the system – between 11 pm and 4 am....4 or 5 am starts up fast
   2. Drip irrigation preferred.

(b) Irrigation timing: duration and frequency does not need to be EVERY DAY

(c) Xeric Landscape Education....

(d) Better and more outreach – we need a real plan that is actually followed
   (i) Social media – this is WAY under used....
      1. Videos
      2. Regular postings
      3.
   (ii) Newspapers and traditional media
   (iii) Others methods for this

(e) PERSONAL INFRASTRUCTURE MAINTENANCE resources and methods for fixing. NEED INFO FROM PUBLIC WORKS & TREASURER to outline existing programs.
   (i) Swamp coolers that don’t work right/not maintained
   (ii) Toilets and other leaks
   (iii) When people get repairs done city can compensate for someone doing repairs by giving them some rebating
   (iv) Program that city has to help fix leaks...during meter reading process can let folks know about leaks or other problems.

(2) Guidelines and suggestions

(a)

(b)
Ordinances and Rules to work on
(a) Drought Management Plan –
   (i) historical precedents
   (ii) what do we currently have and
   (iii) if there is not one let’s draft it....we need to tell people what they
(b) CONSIDER IF AN ORDINANCE IS NEEDED TO CODIFY effective irrigation
(c)
(4) Interagency/Regional Coordination
(a) Groundwater management plan
(b)
(c)
John concern: we need to talk about the water availability of water in the future of water availability