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

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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
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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.

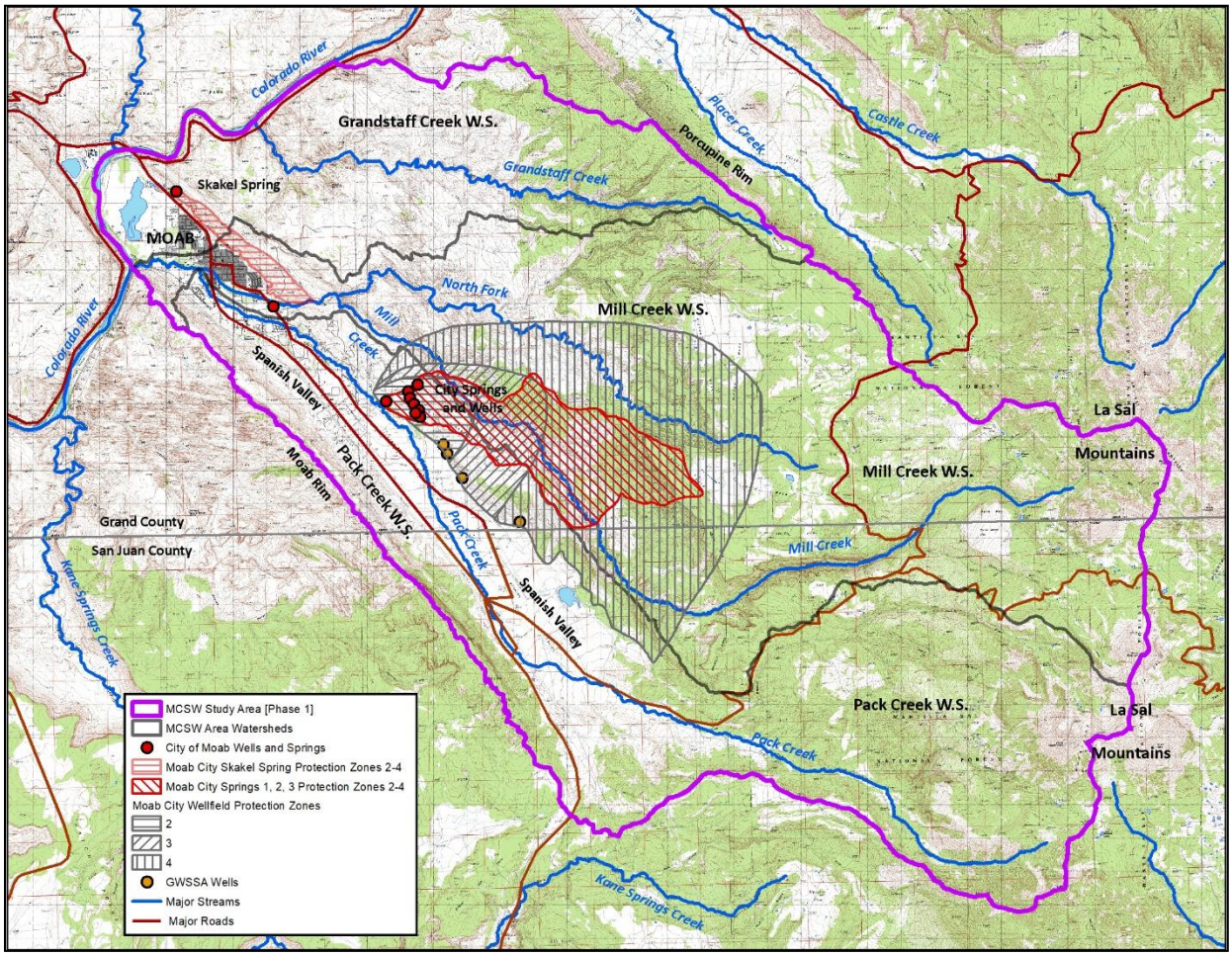

Figure 1. Topographic map showing the Phase 1 Moab City Springs and Wells (MCSW) study area, major watersheds within the study area, the location of the City's springs and wells and the GWSSA wells, and the existing Drinking Water Source Protection (DWSP) zones for the City's springs and wells.

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.

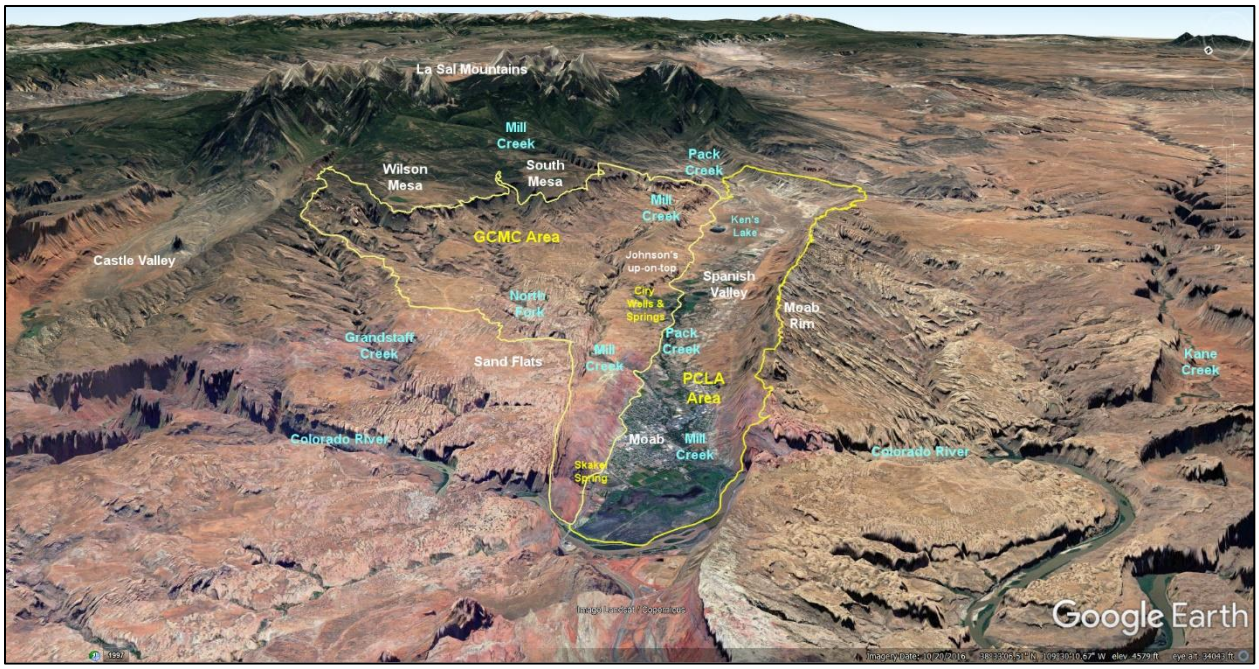

Figure 2. View of the regional setting of the Moab City springs and wells and the approximate Phase 2 Preliminary Water Budget (PWB) area (GCMC area) and Phase 4 Preliminary Water Budget area (PCLA area) outlined in yellow (Source: Google Earth, Imagery October 2016).

It should be noted that 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.

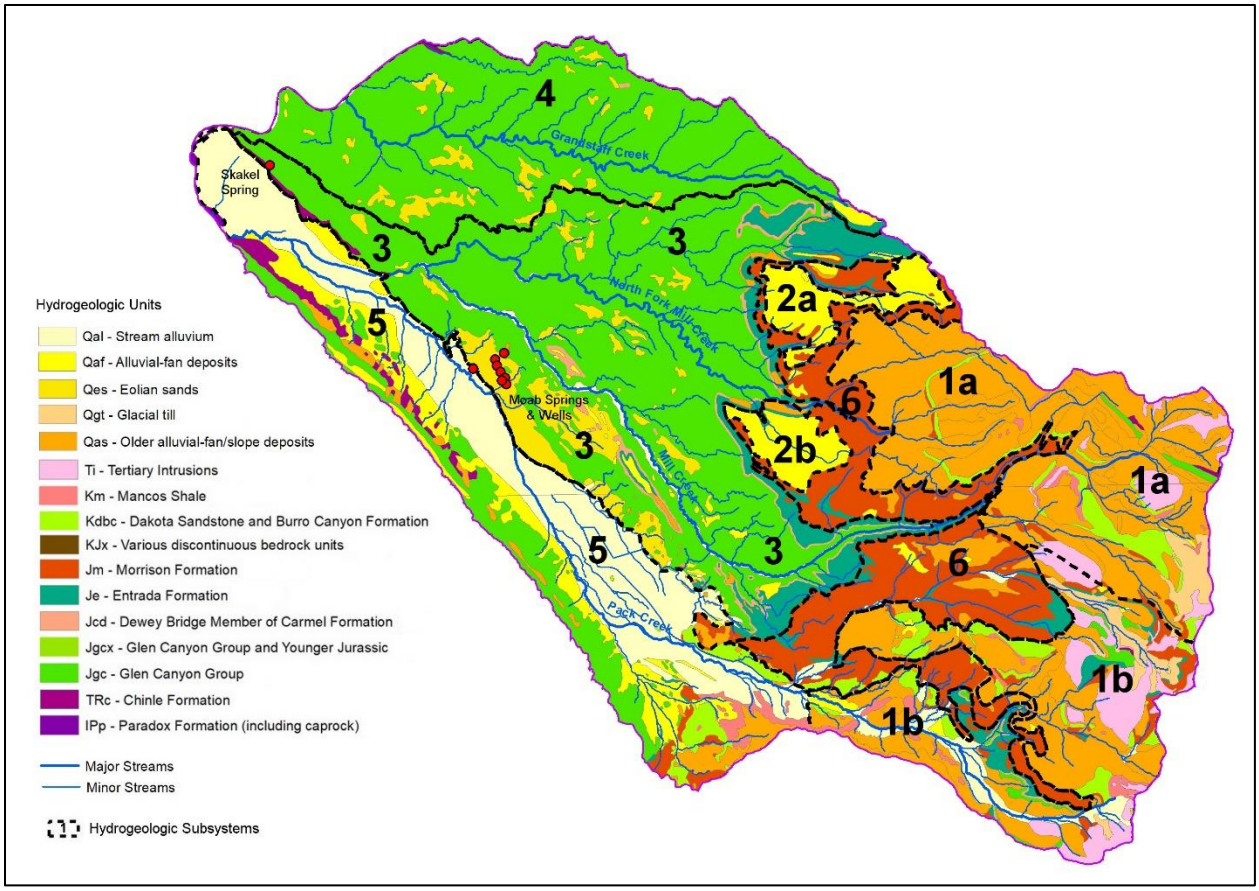

Figure 3. Plan view of the hydrologic subsystems in the MCSW study area on top of hydrogeologic units: 1a. La Sal Mountain Upper Alluvial Subsystem (LSMA-M) Mill Creek Headwaters; 1b. La Sal Mountain Upper Alluvial Subsystem (LSMA-P) Pack Creek Headwaters; 2a. Wilson Mesa Alluvial Fan Subsystem (WMAF); 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.

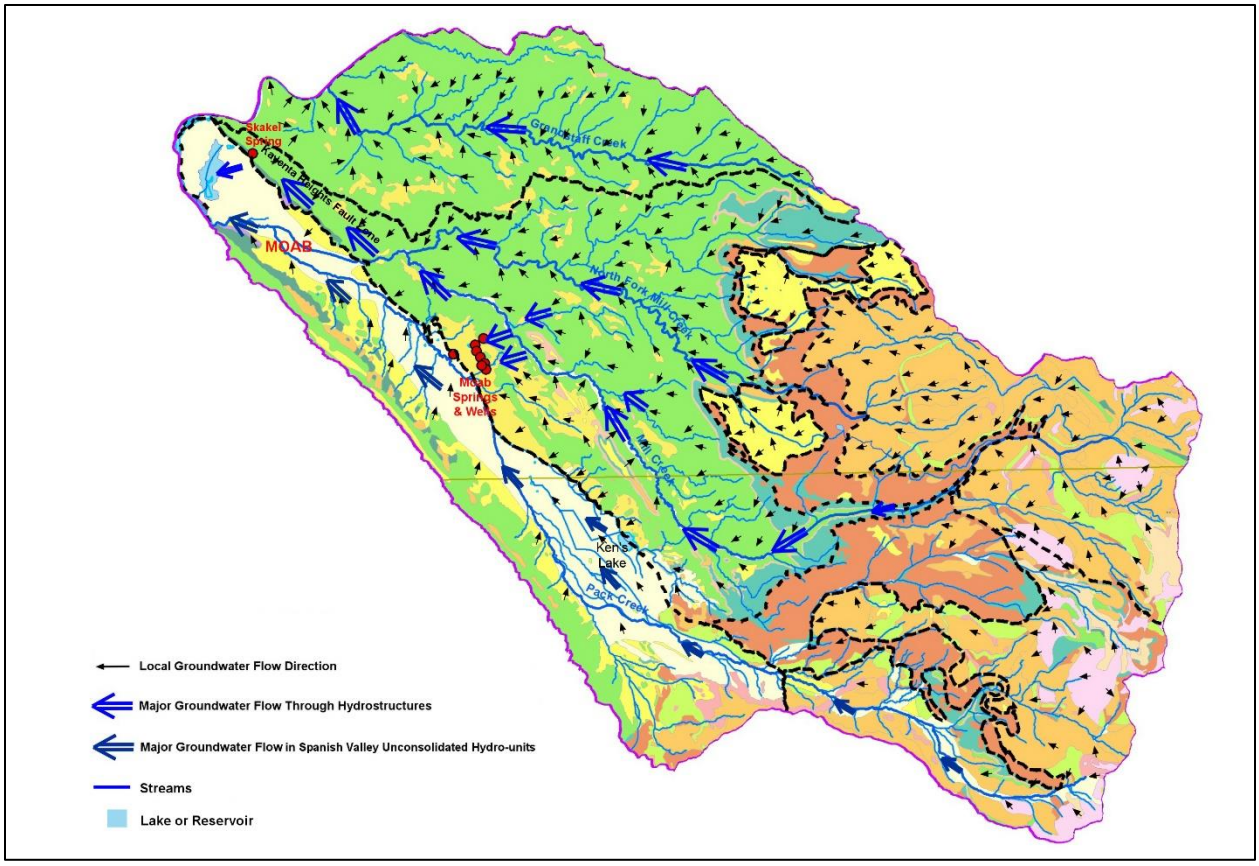

Figure 4. Plan view of the flow directions in the groundwater system on top of the hydrogeologic units of the MCSW study area. The small arrows are local groundwater flow directions. The larger blue arrows show groundwater flow direction along major hydrostructures and the major groundwater flow directions 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.

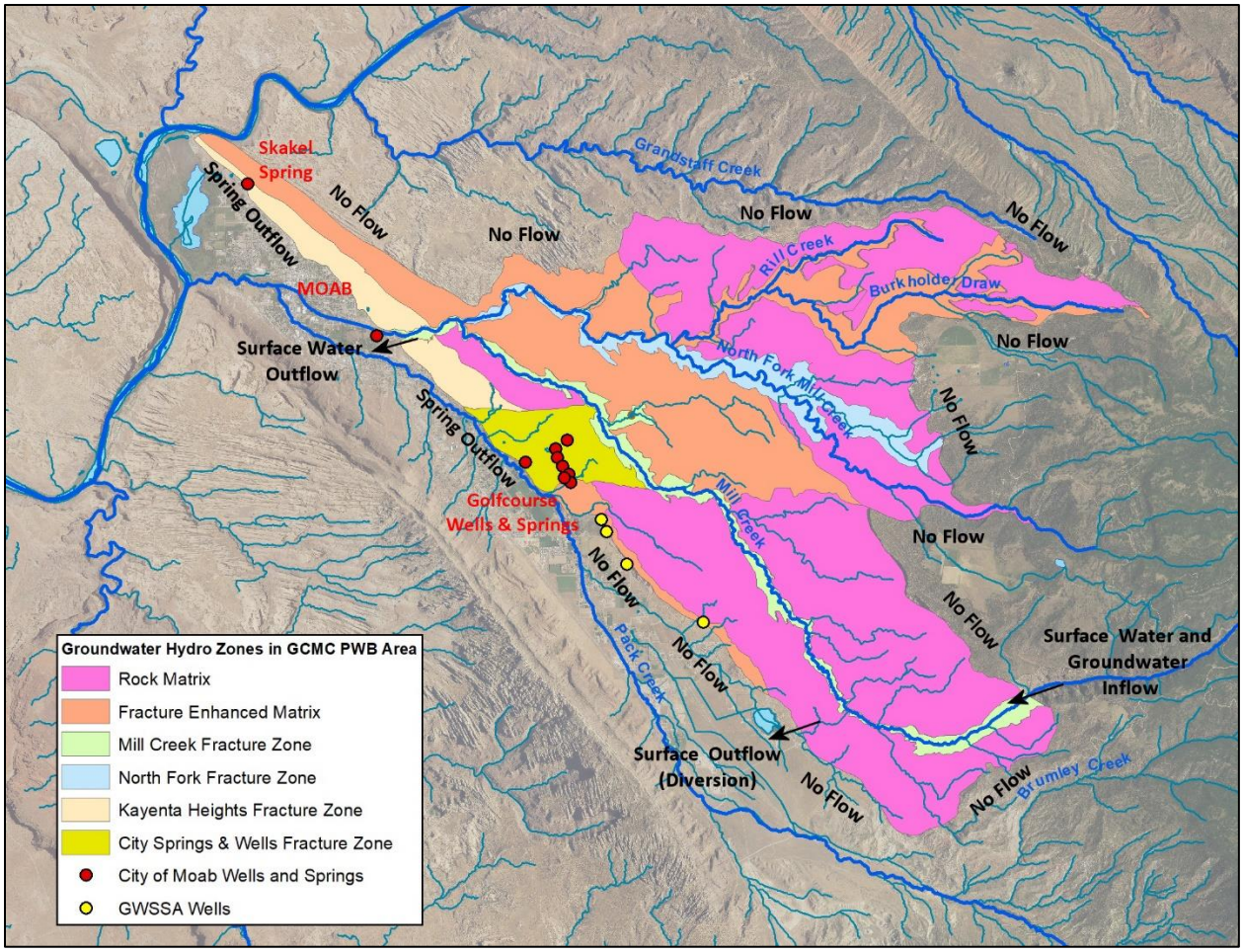

Figure 5. Map showing the location of the Preliminary Water Budget (PWB) area and Hydro Zones of the GCMC hydrologic system with boundary conditions and location of City of Moab springs. Modified from Figure 10a in Kolm and van der Heijde, 2019.

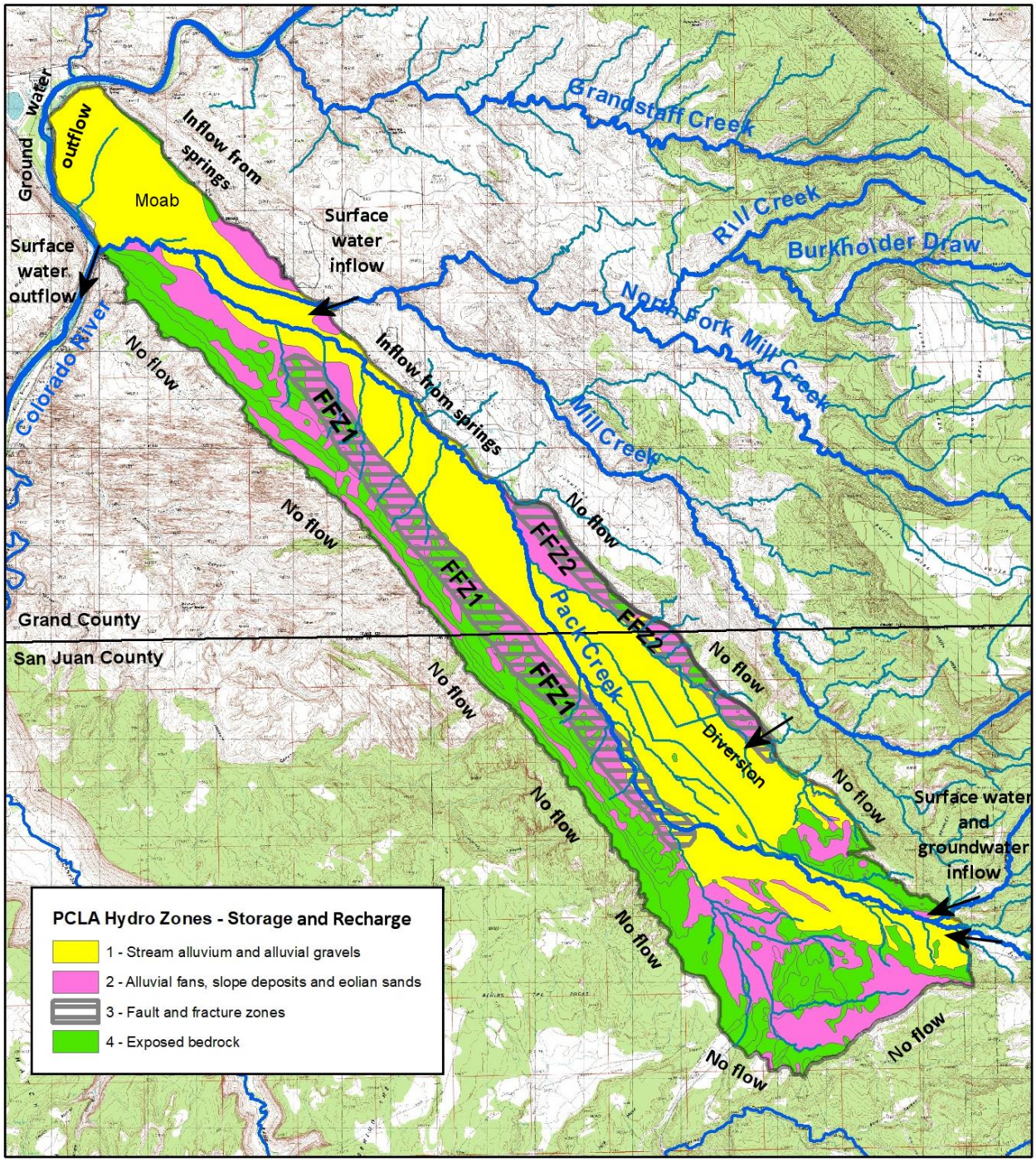

Figure 6. Map showing the location of the Preliminary Water Budget (PWB) area and Hydro Zones of the PCLA hydrologic system with boundary conditions. FFZ1 is the Moab Rim Fault and Fracture Zone; FFZ2 is the Kayenta Heights Fault and Fracture Zone Extension.
Modified from Figures 11 and 15 in Kolm and 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 (Kolm 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.

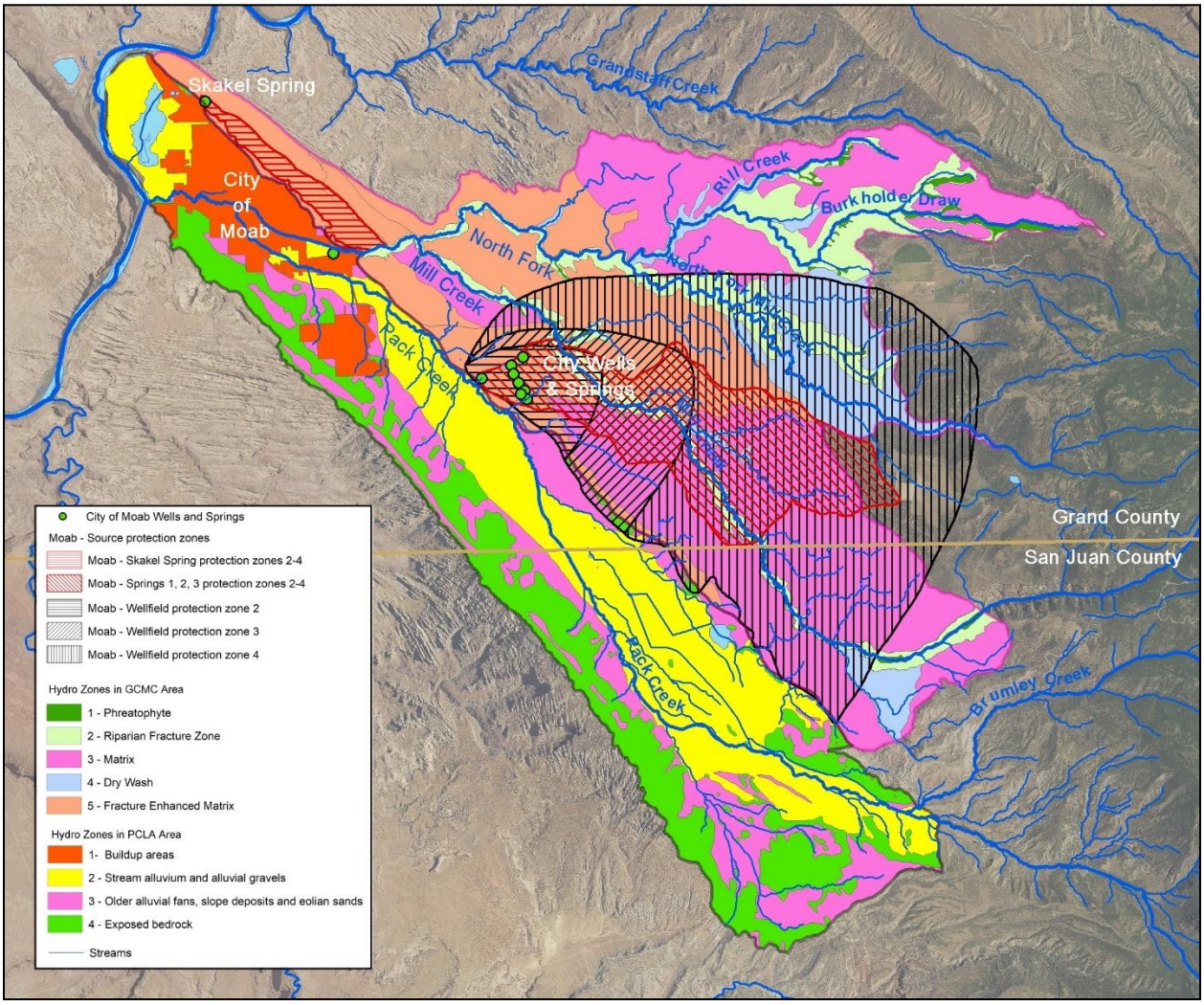

Figure 7. Map of the GCMC and PCLA Hydro Zones showing the location of the City of Moab springs and wells and related existing Drinking Water Source Protection (DWSP) zones.

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 (2001 a and 2001 b) 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).

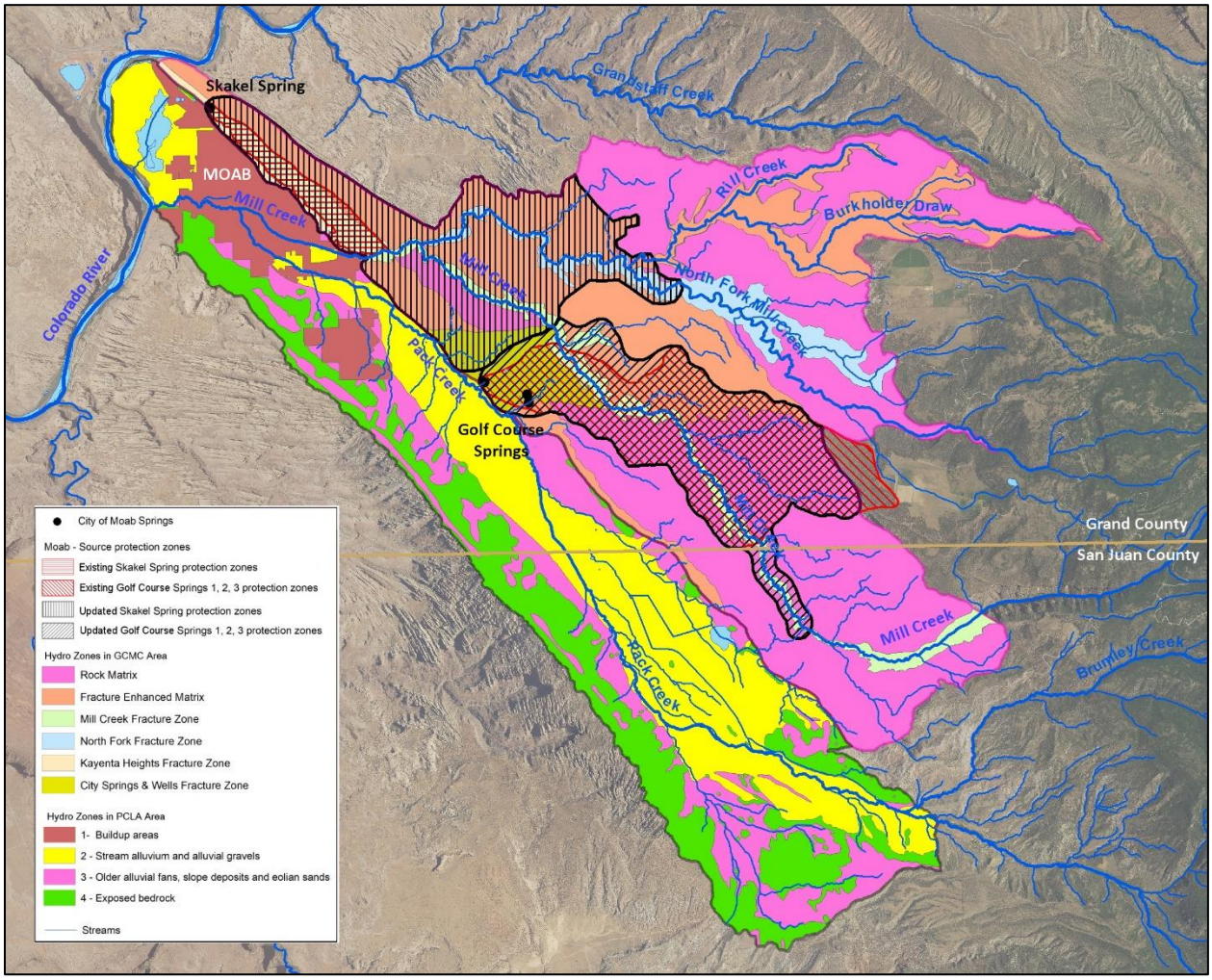

Figure 8. Map of the GCMC and PCLA Hydro Zones showing the location of the City of Moab springs and wells, related current Drinking Water Source Protection (DWSP) zones, and proposed updated DSWP zones.

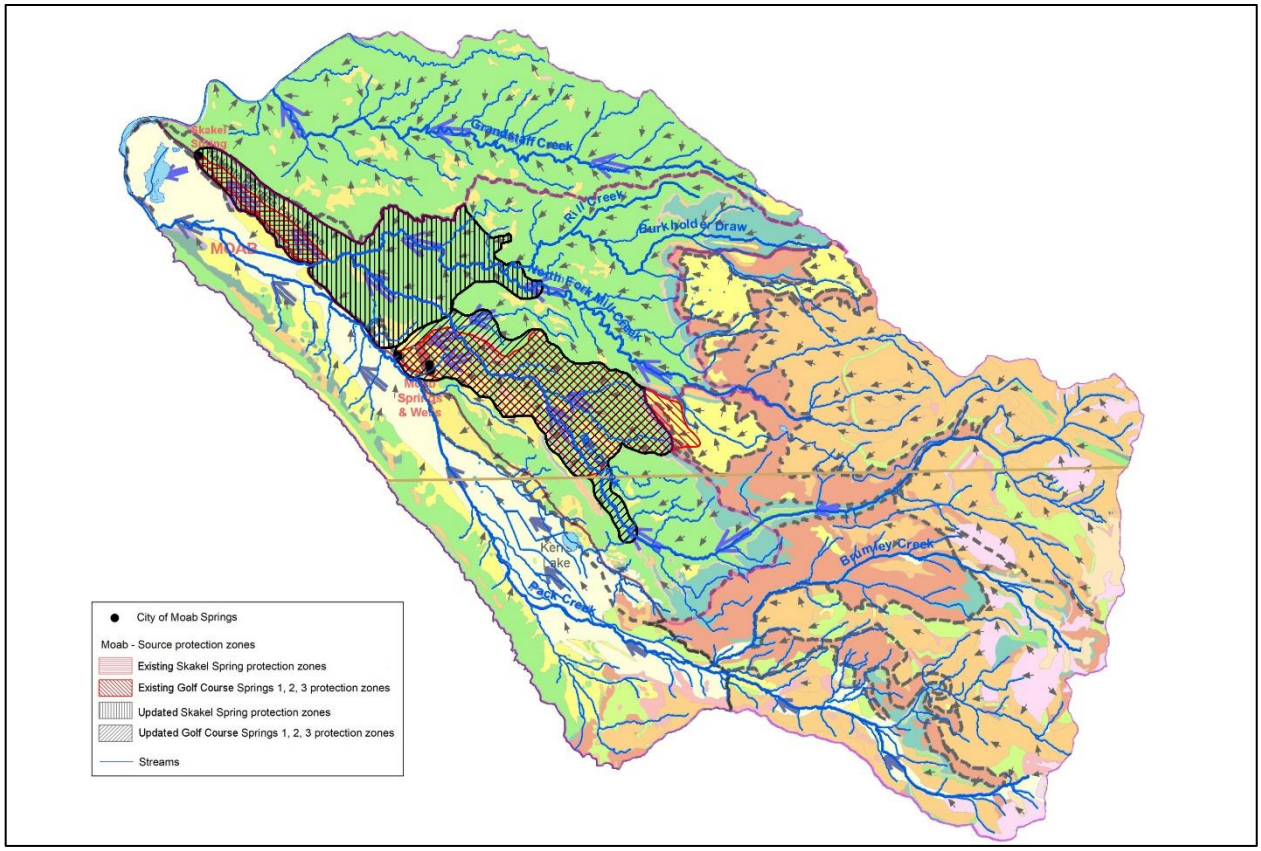

Figure 9. Map of the MCSW study area with hydrogeologic units and groundwater flow system showing the location of the City of Moab springs and wells, related current Drinking Water Source Protection (DWSP) zones, and proposed updated DSWP zones
(see Figure 3 for legend of hydrogeologic units, figure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

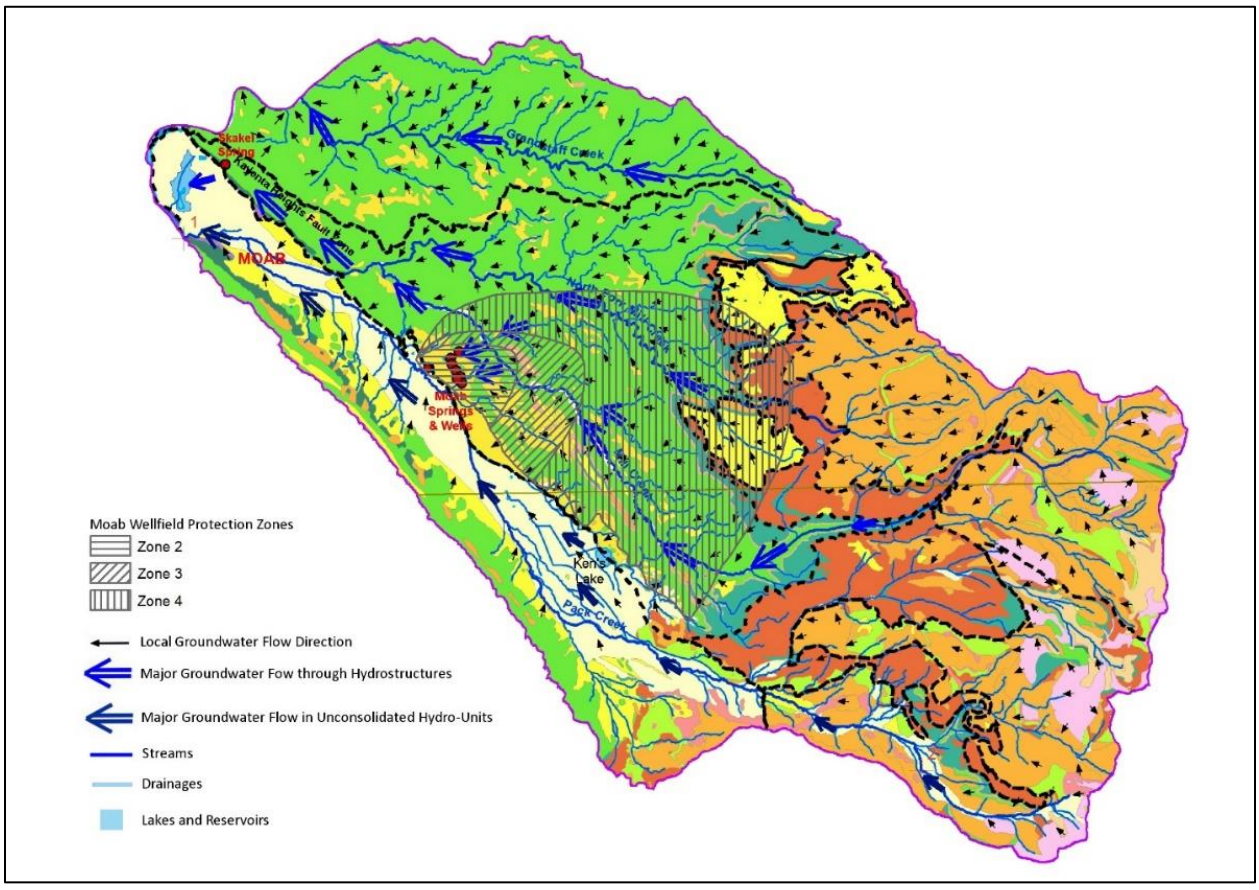

Figure 10. Plan view of the Moab City Wells DWSP Zones overlain on the flow directions in the groundwater system on top of the hydrogeologic units of the MCSW study area.
(see Figure 3 for legend of hydrogeologic units)

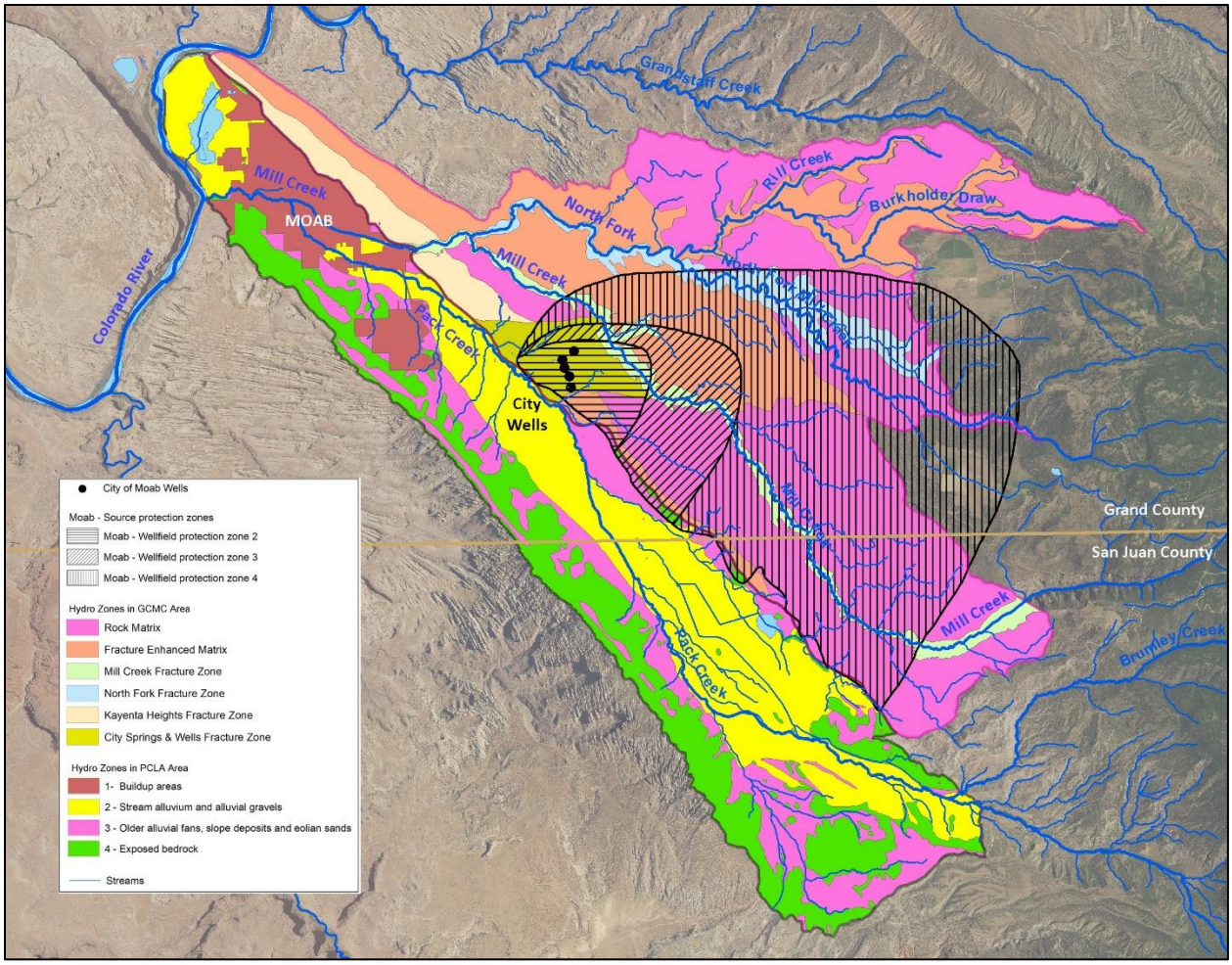

Figure 11. Plan view of the Moab City Wells DWSP Zones overlain on themap of hydro zones in the GCMC and PCLA hydrologic systems.

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.

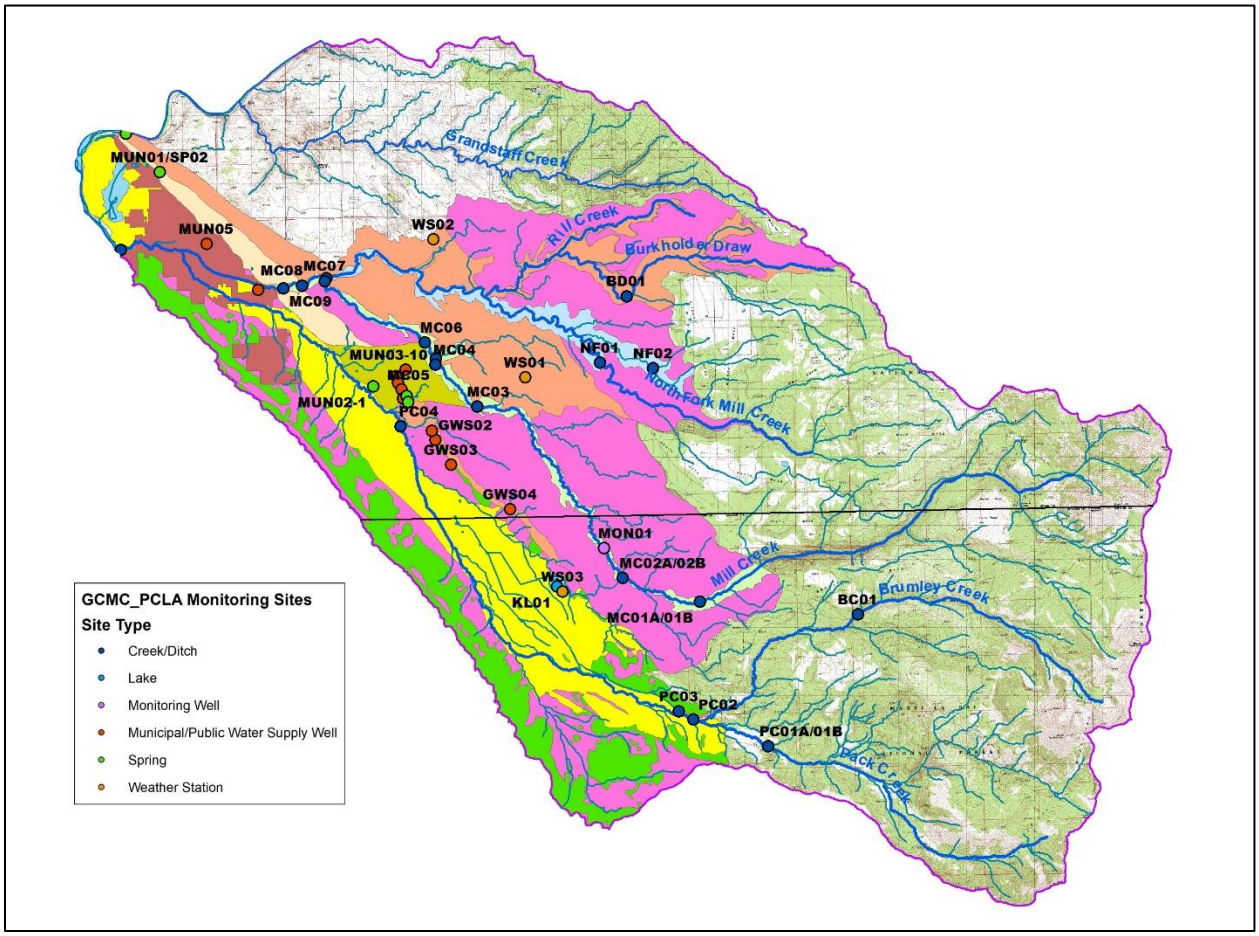

Figure 12. Map with locations of the monitoring sites of the Preliminary Monitoring Plan overlain on the GCMC and PCLA hydro zones.
(see Figure 11 for legend of hydro zones)

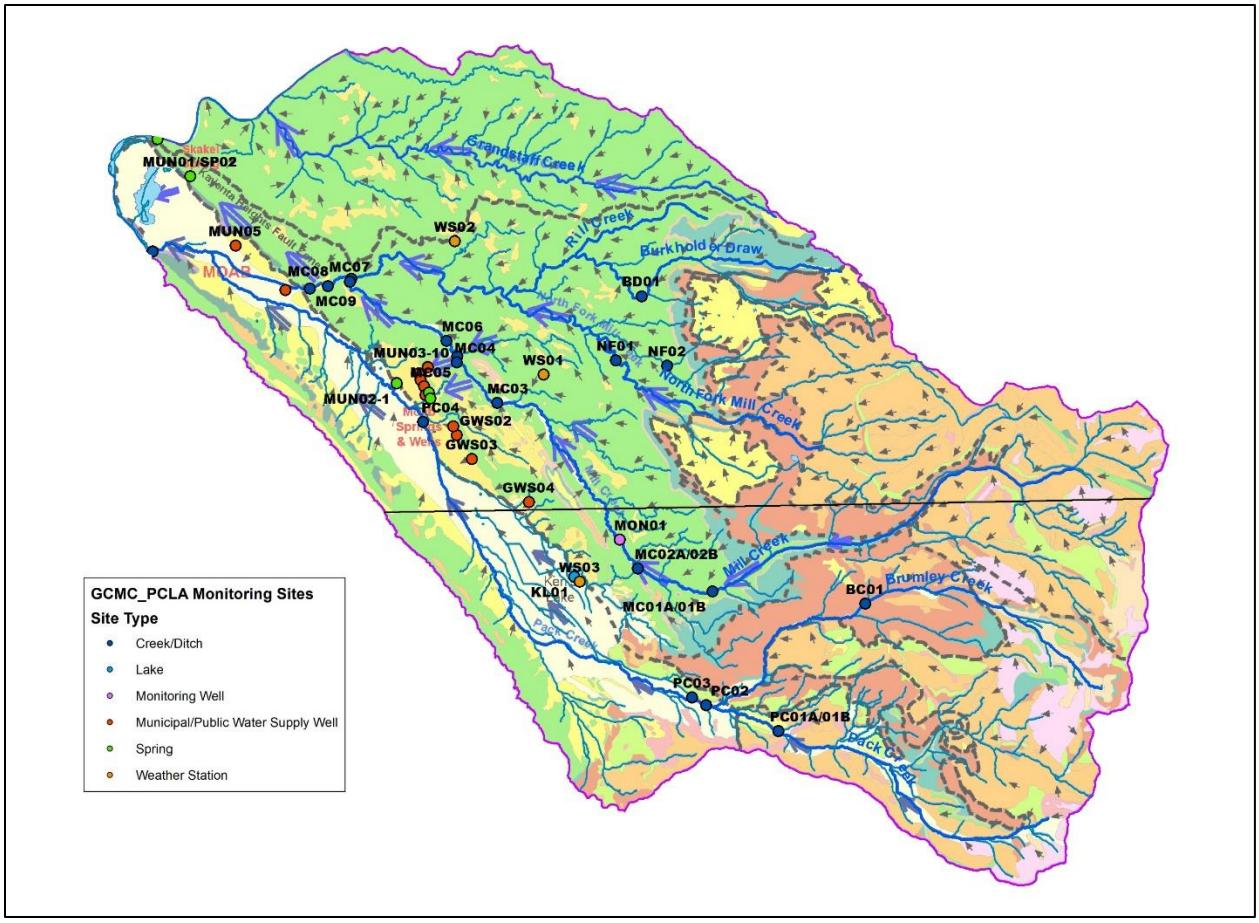

Figure 13. Map with locations of the monitoring sites of the Preliminary Monitoring Plan overlain on the hydrogeology and groundwater flow systems of both the GCMC and PCLA hydrologic systems. (see Figure 3 for legend of hydrogeologic units, figure 4 for legend of flow symbols)

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.

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APPENDICES

Storage Hydro Zone Number	Storage Hydro Zone Type	Hydro Zone Average Depth (ft)	Hydro Zone Area (acres)	Hydraulic Conductivity (ft/day)	Total Storage (acre-ft)	Available Storage 10% (acre-ft)
1	Stream Alluvium & Alluvial Gravels	175*	14220	1-230	248500-745500	24850-74550
2	Alluvial Fans & Slope Deposits	-	5090	1-230	minor	minor
3a	Moab Rim Fault and Fracture Zone	500/2	1935	Up to 88 ft/day; average 50 ft/day	96250-192500	9625-19250
3b	Kayenta Heights Fault and Fracture Zone Extension	500/2	760	Up to 88 ft/day; average 50 ft/day	38000-76000	3800-7600
4	Glen Canyon Group Mill Creek Drainage and Tributaries Fault and Fracture Zones	500	5485	Up to 88 ft/day; average 50 ft/day	minor	minor
5	Glen Canyon Group Matrix Zones	500	27490	0.1-10	382750-1014000	38375-101400

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

Appendix A. Aquifer Hydraulic Conductivity, Hydro Zones, and Storage.

Name	Site Number	Site Type	Hydro System	Priority	Cost	Flow/Head Meaurements	Quality Sampling	Description	Notes
Brumley Creek 1	BC01	Creek	PCLA	2		Daily flow	All (esp. e. coli, nitrates, phosphates, pesticide) SSFW	New stream monitoring site for flow and quality; main gateway of upper system for all Spanish Valley wells and springs	
Burkholder Draw 1	BD01	Creek	GCMC	2		Spring and Autumn flow	Pesticide, defoliants, nitrates, sulfates	New stream monitoring site for flow and quality; captures gaining stream flow and runoff, and water quality from	
Ken's Lake	KL01	Lake	PCLA	1		Lake levels, leakage (estimated)	All (esp. e. coli, nitrates, phosphates, pesticide) SSFW	New site; ET, irrigation use, infiltration. See upcoming study on Ken's lake.	
Mill Creek 1A	MC01A	Creek	GCMC	1		Daily flow	All (esp. e. coli, nitrates, phosphates, pesticide) SSFW	New stream monitoring site for flow and quality; is main gateway for monitoring upstream system for all Moab City wells & springs	Sample initially for high altitude signature
Mill Creek 1B	MC01B	Monitoring well	GCMC	1		Daily head	All (esp. e. coli, nitrates, phosphates, pesticide) SSFW	New monitoring well; see also MC01A	Sample initially for high altitude signature
Mill Creek 2A [above Sheley diversion]	MC02A	Creek	GCMC	1		Daily Flow	All (esp. e. coli, nitrates, phosphates, pesticide) SSFW	Existing USGS gauge above Sheley diversion; continue current continous flow measuring and add quality	Blanchard MC-07
Mill Creek 2B [below Sheley diversion]	MC02B	Creek	GCMC	1		Daily flow	All (esp. e. coli, nitrates, phosphates, pesticide) SSFW	Existing USGS gauge above Sheley diversion; continue current continuous flow measuring	Blanchard MC-08
Mill Creek 3	MC03	Creek	GCMC	1		Spring and Autumn flow	All (esp. e. coli, nitrates, phosphates, pesticide, defoliants) SSFW	New stream monitoring site for flow and quality; main surface water outflow of Mill Creek hydro system to Colorado River	Blanchard MC-13
Mill Creek 4	MC04	Creek	GCMC	1		Spring and Autumn flow	All (esp. e. coli, nitrates, phosphates, pesticide, defoliants) SSFW	New stream monitoring site for flow and quality; main gateway for middle hydro system and Moab City wells and springs at Golfcourse	Blanchard MC-15
Mill Creek 5 [Spring Canyon]	MC05	Spring	GCMC	1		Spring and Autumn flow	All (esp. e. coli, nitrates, phosphates, pesticide, defoliants) SSFW	New spring monitoring site for flow and quality; main gateway for middle hydro system and Moab City wells and springs at Golfcourse	
Mill Creek 6	MC06	Creek	GCMC	1		Spring and Autumn flow	All (esp. e. coli, nitrates, phosphates, pesticide, defoliants) SSFW	New stream monitoring site for flow and quality; main gateway for middle hydro system and Moab City wells and springs at Golfcourse	Blanchard MC-16
Mill Creek 7	MC07	Creek	GCMC	1		Daily flow	All (esp. e. coli, nitrates, phosphates, pesticide, defoliants) SSFW	New stream monitoring site for flow and quality; main gateway for lower hydro system and Moab City Skakel Spring	Blanchard MC-19
Mill Creek 8 [at Powerhouse]	MC08	Creek	GCMC	1		Daily flow	All (esp. e. coli, nitrates, phosphates, pesticide, nickel, cadmium, mercury, lead, radionuclides) SSFW	New stream monitoring site for flow and quality; main gateway for lower hydro system and Moab City Skakel Spring	Blanchard MC-21
Mill Creek 9 [below Powerhouse]	MC09	Creek	GCMC	1		Daily flow	All (esp. e. coli, nitrates, phosphates, pesticide, nickel, cadmium, mercury, lead, radionuclides) SSFW	New stream monitoring site for flow and quality; main gateway for lower hydro system and Moab City Skakel Spring	Blanchard MC-22
Mill Creek 10 [outflow to Colo River]	MC10	Creek	PCLA	1		Daily flow	All (esp. e. coli, nitrates, phosphates, pesticide, nickel, cadmium, mercury, lead, radionuclides) SSFW	New stream monitoring site for flow and quality; main surface water outflow of Mill Creek hydro system to Colorado River, main exit entire system all GSMS and PCLA wells & springs; monitoring well in place	
Monitoring Well [private or monitoring well]	MON01	Monitoring Well	GCMC	1		Spring and Autumn head	All (esp. e. coli, nitrates, phosphates, pesticide, defoliants) SSFW	Select existing private well or monitoring well for groundwater table elevation and quality monitoring	
Skakel Spring	MUN01	Municipal Spring	GCMC	1		Daily flow	All (esp. e. coli, nitrates, phosphates, pesticide, nickel, cadmium, mercury, lead, radionuclides)	Continue monitoring SkakelSpring for flow and quality	
City Springs at Golf Course	MUN02	Municipal Spring	GCMC	1		Daily flow	All (esp. e. coli, nitrates, phosphates, pesticide, nickel, cadmium, mercury, lead, radionuclides)	Continue monitoring existing City springs	
City Wells at Golf Course	MUN03	Municipal Well	GCMC	1		Daily flow	All (esp. e. coli, nitrates, phosphates, pesticide)	Continue monitoring existing City wells	
Cemetery Well	MUN04	Municipal Well	PCLA	1		Daily flow, head	All (esp. e. coli, nitrates, phosphates, pesticide, nickel, cadmium, mercury, lead, radionuclides) SSFW	New monitoring site for flow, head and quality	
Moab City Well inTown	MUN05	Municipal Well	PCLA	2		Head	None	Use existing Moab City well somewhere in town (Swanny, City Hall, etc)	
GWSSA George White Well 5	GWS01	Municipal Well	PCLA	1		Daily flow	All (esp. e. coli, nitrates, phosphates, pesticide) SSFW	Flow and quality of existing GWSSA well	
GWSSA George White Well 4	GWS02	Municipal Well	PCLA	1		Daily flow	All (esp. e. coli, nitrates, phosphates, pesticide) SSFW	Flow and quality of existing GWSSA well	
GWSSA Chapman Well	GWS03	Municipal Well	PCLA	1		Daily flow	All (esp. e. coli, nitrates, phosphates, pesticide) SSFW	Flow and quality of existing GWSSA well	
GWSSA Spanish Valley Well	GWS04	Municipal Well	PCLA	1		Daily flow	All (esp. e. coli, nitrates, phosphates, pesticide) SSFW	Flow and quality of existing GWSSA well	
North Fork 1	NF01	Creek	GCMC	2		Spring and Autumn flow	Pesticide, defoliants, nitrates, sulfates	New stream monitoring site for flow and quality; captures gaining stream flow and runoff, and water quality from upstream sources	Blanchard NFT-1
North Fork 2	NF02	Creek	GCMC	2		Spring and Autumn flow	Pesticide, defoliants, nitrates, sulfates	New stream monitoring site for flow and quality; captures gaining stream flow and runoff, and water quality from upstream sources	Blanchard NF-01
North Fork 3	NF03	Creek	GCMC	1		Daily flow	All (esp. e. coli, nitrates, phosphates, pesticide, defoliants) SSFW	New stream monitoring site for flow and quality; main gateway for lower hydro system and Moab City Skakel Spring	Blanchard NF-12
Pack Creek 1A	PC01A	Creek	PCLA	2		Daily flow	All (esp. e. coli, nitrates, phosphates, pesticide) SSFW	New stream monitoring site for flow and quality; main gateway of upper system for all Spanish Valley wells and springs	
Pack Creek 1B	PC01B	Monitoring Well	PCLA	2		Daily head	All (esp. e. coli, nitrates, phosphates, pesticide) SSFW	New monitoring well; see also PC01A	
Pack Creek 2	PC02	Creek	PCLA	2		Daily flow	All (esp. e. coli, nitrates, phosphates, pesticide) SSFW	New stream monitoring site for flow and quality	
Pack Creek 3 [Diversion ditch]	PC03	Ditch	PCLA	2		Daily flow	All (esp. e. coli, nitrates, phosphates, pesticide) SSFW	New stream monitoring site for flow and quality	
Pack Creek 4	PC04	Creek	PCLA	1		Daily Flow	All (esp. e. coli, nitrates, phosphates, pesticide) SSFW	New stream monitoring site for flow and quality	
Matrimony, Goatman/Lions Springs	SP01	Spring	GCMC	2		Daily flow	All (esp. e. coli, nitrates, phosphates, pesticide, nickel, cadmium, mercury, lead, radionuclides)	New site; flow and quality, two locations: Matrimony, Goatman/Lions	
Paladium and Ranch Springs	SP02	Spring							
Weather station recharge zone #1	WS01	Weather Station	GCMC	1		Daily precip.	Sulfates, nitrates, PH, particulates	New rain gauge	
Weather station recharge zone #2	WS02	Weather Station	GCMC	1		Daily precip.	Sulfates, nitrates, PH, particulates	New rain gauge	
Weather station recharge zone #3	WS03	Weather Station	PCLA	1		Daily precip.	Sulfates, nitrates, PH, particulate	New rain gauge, pan evaporation measurements	

Appendix B. Preliminary Monitoring Plan (PMP) for Protection of City of Moab Springs and Wells.