MOAB AND SPANISH VALLEY’S GROUNDWATER CONDITIONS

Insights from a Scientific Peer Review of Published Research

Should the Moab-Spanish Valley Basin remain open to future groundwater withdrawals?

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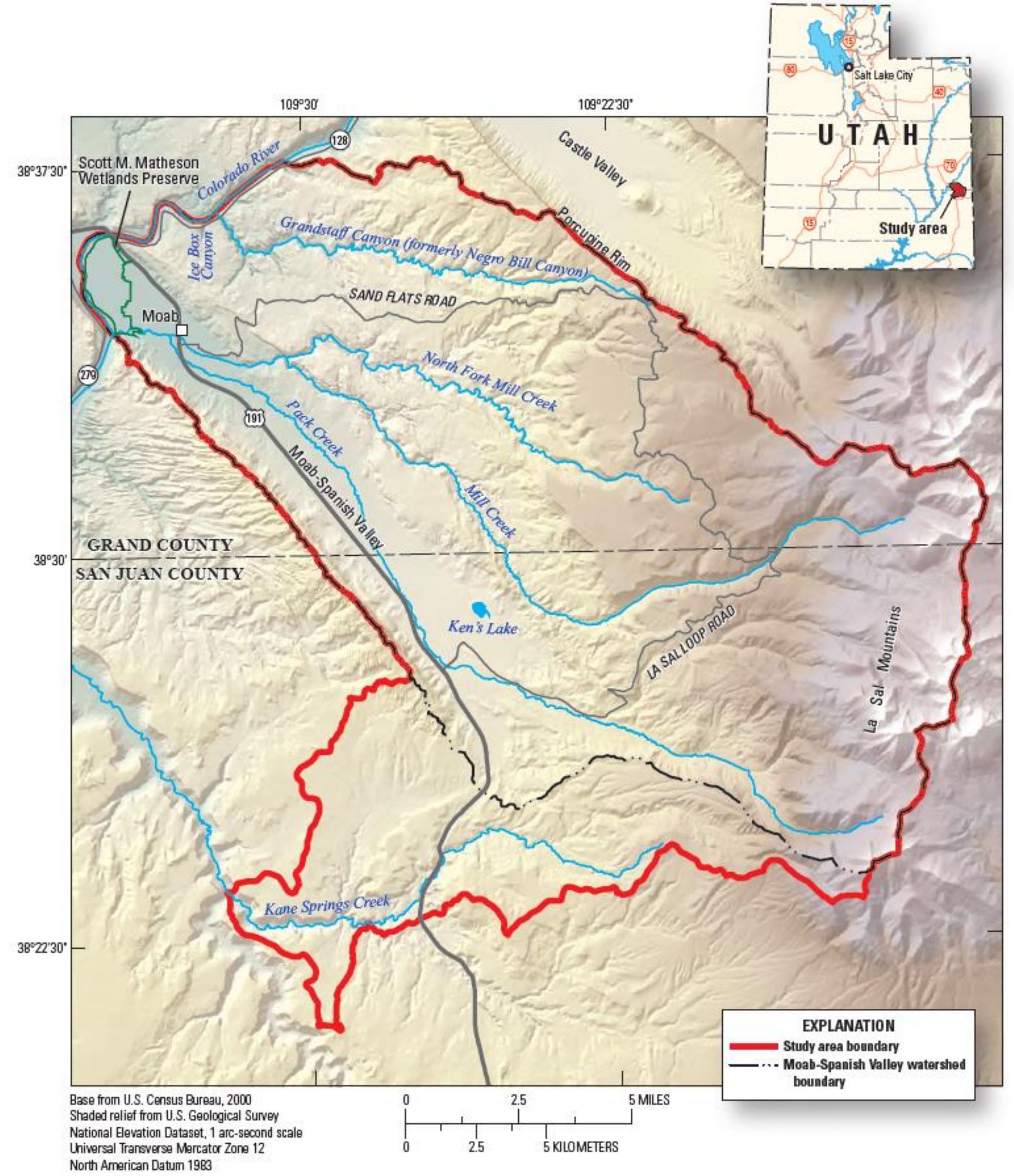
INTRODUCTION

- Present situation
  - Increased groundwater withdrawals from development combined with decreased recharge from climate change
  - Recent investigations to determine whether UDWRi should be approached to request restrictions on future withdrawals
- History
  - First investigation published by Sumison in 1971
  - Four reports prepared for City of Moab by Kolm and van der Heijde (2018; 2019; 2020a; 2020b)
  - USGS (Scientific Investigations Report 2019-5062; Journal of Hydrology, Volume 590, November 2020, 125512)
  - At least ten others between and three after, including USGS/University of Utah suggestions for groundwater monitoring
- Need for peer review
  - It was decided that a peer review of the many technical documents would be appropriate prior to collecting additional data
  - USU selected because: (1) State Land Grant University and respected by UDWRi and UGS; (2) not involved in any of previous investigations, as has U of U; (3) Moab campus is new water user and will impose a significant load
- Organization of results
  - Non-technical summaries of individual documents in chronological order
  - Summary, conclusions and recommendations
  - List of references
  - General questions, and compilation of list of most important questions/data left still to answer/collect

Figure 1. Location map of the Spanish Valley study area, and the Moab-Spanish Valley watershed, Grand and San Juan Counties, Utah (Masbruch, Gardner, Nelson, Heilweil, Solder, Hess, McKinney, Briggs and Solomon, 2019).



Base from U.S. Census Bureau, 2000
Shaded relief from U.S. Geological Survey
National Elevation Dataset, 1 arc-second scale
Universal Transverse Mercator Zone 12
North American Datum 1983

DOCUMENT SUMMARIES

- Sumison (USGS), 1971
  - Identified two principal aquifer systems: (1) Glen Canyon Group (Navajo and Wingate Sandstones); (2) Quaternary deposits in Spanish Valley
  - Created first “Hydrologic Balance” (Table 2)

Table 1. Major geologic units (Eisinger and Lowe, 1999).

Age	Geologic Unit	Thickness (ft)	Aquifer System
Quaternary	Valley-fill deposits	0 – 300	Unconsolidated
Tertiary	La Sal igneous rocks		
Tertiary	Green River Formation	0 – 5,000+	Parachute Creek
Tertiary	Wasatch Formation	1,000 – 1,600	Wasatch
Cretaceous	Mesaverde Group	1,150 – 1,950	Confining unit
Cretaceous	Mancos Shale	300 – 1,100	Confining unit
Cretaceous	Dakota, Cedar Mountain & Burro Canyon	80 – 450	Dakota
Jurassic	Morrison Formation	400 – 900	Morrison confining unit
Jurassic	Summerville-Curtis Formation	100 – 400	Confining unit
Jurassic	Entrada Sandstone	290 – 920	Entrada
Jurassic	Carmel Formation	220 – 300	Confining unit
Jurassic	Navajo Sandstone	0 – 500	Navajo
Jurassic	Kayenta Formation	140 – 300	

Table 1. (continued).

Age	Geologic Unit	Thickness (ft)	Aquifer System
Jurassic	Wingate Sandstone	150 – 450	Wingate
Triassic	Chinle Formation	150 – 650	Confining unit
Triassic	Moenkopi Formation	590 – 750	Confining beds
Permian	Cutler Group	400 – 6,000+	Cutler
Pennsylvanian	Hermosa Group	3,500 – 7,000+	Confining beds
Pennsylvanian	Molas Formation	0 – 100	Confining beds
Mississippian	Leadville Limestone	300 – 600	Confining beds
Devonian	Ouray Limestone	0 – 150	Lower Paleozoic
Devonian	Elbert Formation	125 – 300	Lower Paleozoic
Cambrian	Lynch Dolomite	800 – 1,000	Confining beds
Cambrian	Bright Angel Shale	0 – 100	Confining beds
Cambrian	Ignacio Quartzite	100 – 300	Confining beds
Precambrian	Undifferentiated crystalline rocks		

Figure 2. Aerial view of Moab and Spanish Valley

Figure 3. Extent of Quaternary deposits in Spanish Valley (Gardner, Nelson, Heilweil, Solder and Solomon, 2020).

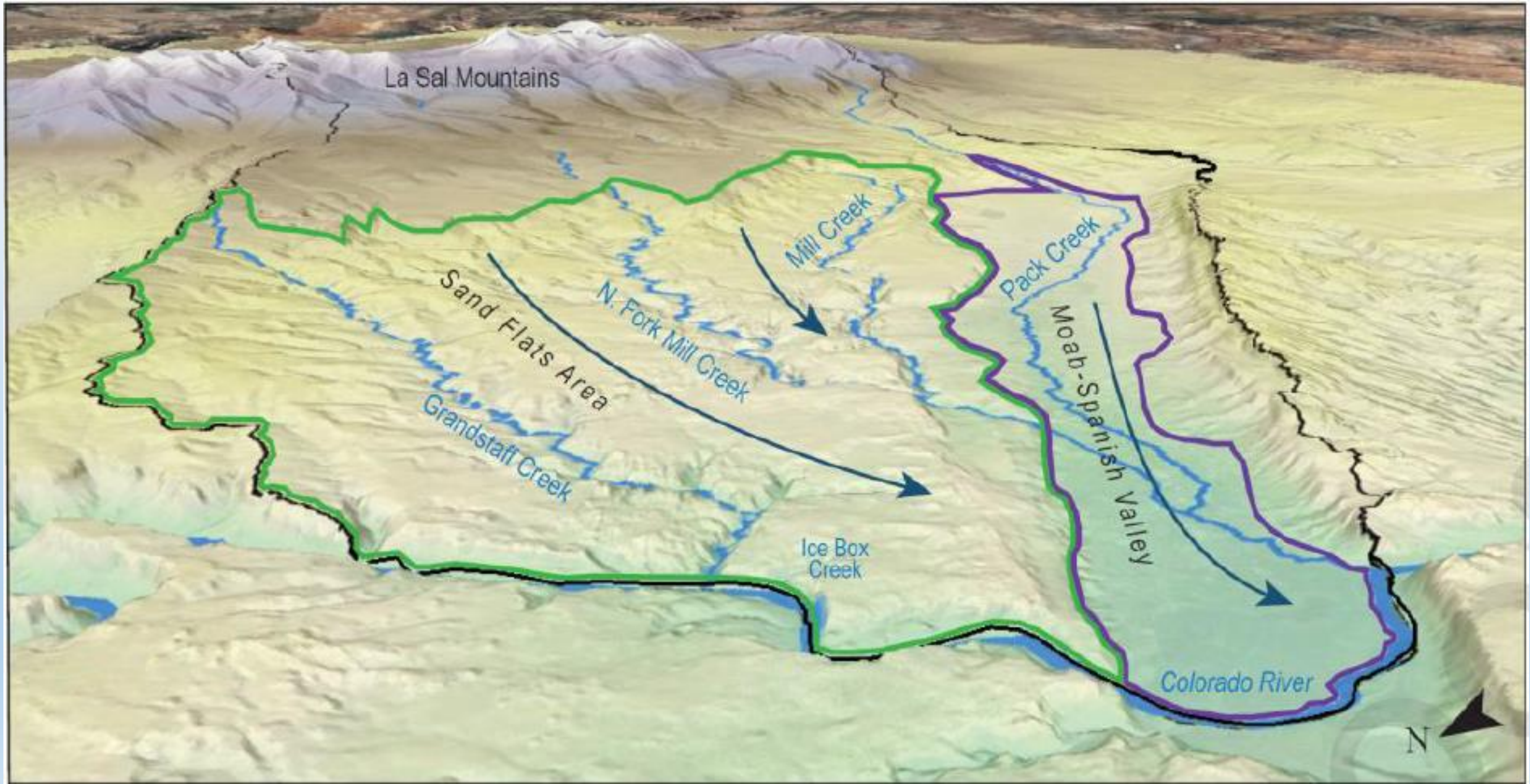
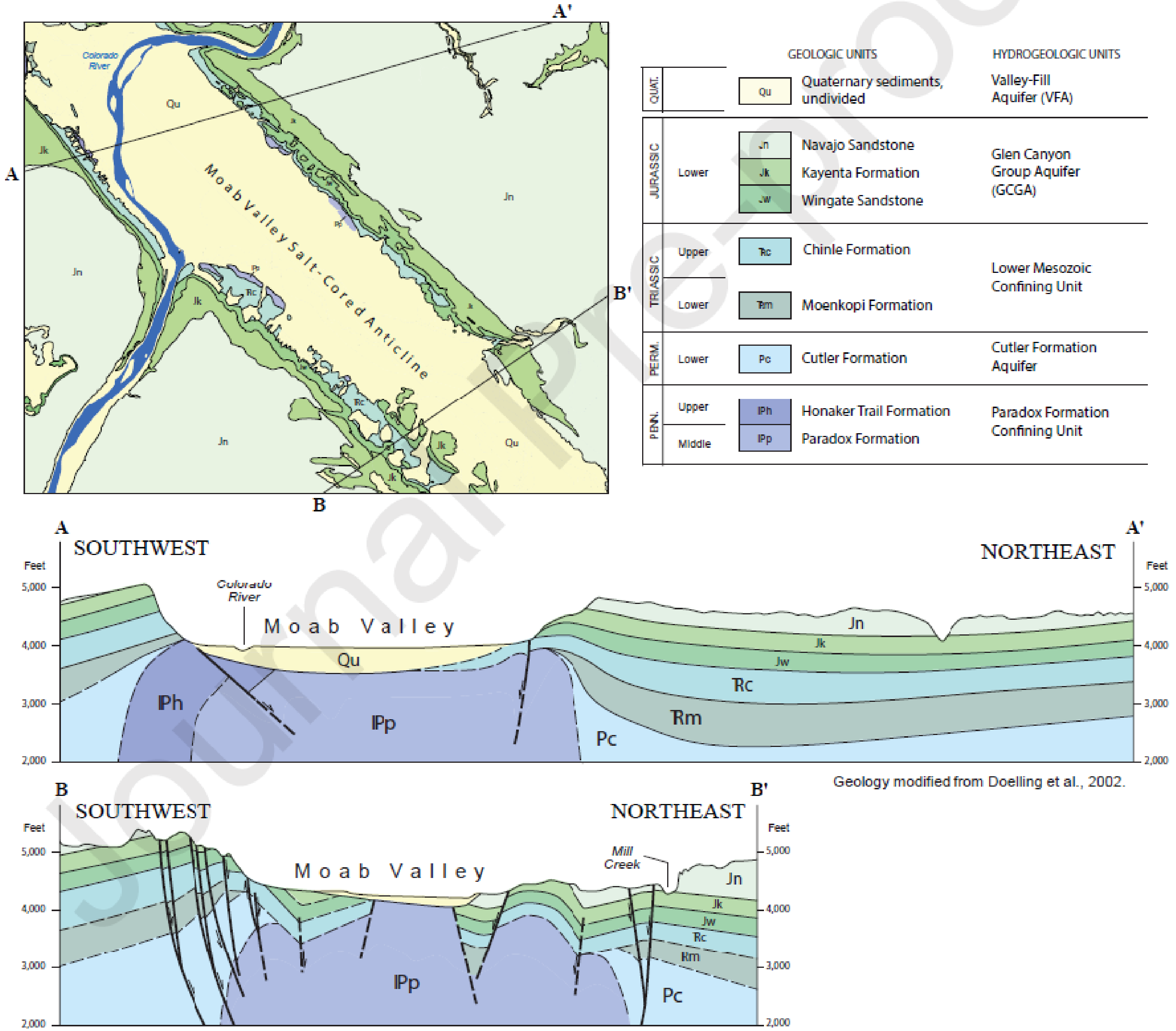


Figure 4. Geologic cross section (Gardner, Nelson, Heilweil, Solder and Solomon, 2020).



			GEOLOGIC UNITS	HYDROGEOLOGIC UNITS
QUAT.		Qu	Quaternary sediments, undivided	Valley-Fill Aquifer (VFA)
JURASSIC	Lower	Jn	Navajo Sandstone	Glen Canyon Group Aquifer (GCGA)
		Jk	Kayenta Formation	
		Jw	Wingate Sandstone	
TRIASSIC	Upper	Rc	Chinle Formation	Lower Mesozoic Confining Unit
	Lower	Rm	Moenkopi Formation	
PERM.	Lower	Pc	Cutler Formation	Cutler Formation Aquifer
PENN.	Upper	IPh	Honaker Trail Formation	Paradox Formation Confining Unit
	Middle	IPp	Paradox Formation	

Geology modified from Doelling et al., 2002.

Table 2. Sumison (1971) hydrologic balance.

Groundwater basin in Spanish Valley:	Acre-feet per year
Recharge (assumed equal to total discharge)	14,000
Discharge	
Groundwater outflow	8,000
Net groundwater withdrawal use	6,300
Total discharge (rounded)	14,000
Spanish Valley area:	
Inflow	
Weighted mean precipitation (15 in.)	115,000
Outflow	
Water yield	
Surface runoff (average discharge of Mill Creek and Pack Creek plus gain of Mill Creek from the gaging sites to the confluence of Mill Creek with the Colorado River)	14,000
Groundwater discharge from Spanish Valley (includes base flow)	14,000
Subtotal (3.6 in.)	28,000
Water loss	
Consumptive use (11.4 in.) (assumed equal to difference between inflow and outflow)	87,000
Total (15 in.)	115,000

DOCUMENT SUMMARIES

- Eychaner (USGS), 1977
  - “Modern” digital computer model
  - Model used to predict effects of proposed annual diversion of 3,200 ac-ft from Mill Creek through new tunnel near Sheley Tunnel into Pack Creek channel near head of Spanish Valley
  - Diverted water would recharge Quaternary deposits, permitting increased well withdrawals for irrigation
  - Predicted maximum 28-foot water-level rise in recharge area, and maximum 5-foot decline in irrigated area
- Blanchard (USGS), 1990
  - Focused exclusively on Glen Canyon Group; added Entrada Sandstone
  - Collected much new data consisting of: (1) inventory of wells and springs, including discharge measurements, field water quality parameters and samples for chemical analysis; (2) water levels in wells; (3) streamflow gain-loss for Mill Creek and North Fork Mill Creek; (4) multiple-well pumping test in Moab City well field
  - Noted that water levels declined until 1979, then rose from 1979 to 1987
  - Noted that well and spring discharges ranged from 10-2,000 gpm and from 15-390 gpm, respectively
  - Noted higher TDS and SO_4 south and west of Moab City well field due to Quaternary deposits; TDS also higher in Navajo along Moab fault

DOCUMENT SUMMARIES

- Steiger and Susong (USGS), 1997
  - Focused on groundwater quality in Glen Canyon and valley-fill aquifers
  - Included results of 141 chemical analyses from 57 wells and springs
  - Report identifies and provides maps of primary recharge areas for, and water-quality characteristics in, the two aquifers
  - With three exceptions (two in valley-fill (Pb & NO_3), one Glen Canyon (NO_3)), all samples met State of Utah standards
- Eisinger and Lowe (UGS),1999
  - Examined in detail all geologic units in Grand County, emphasizing their hydrologic characteristics and significance
  - Information summarized in five-page table
  - Subdivided units into nine fractured rock aquifers (Wingate, Navajo & Entrada = 3) plus unconsolidated deposits
  - Emphasized importance of unconsolidated deposits, and especially the Navajo Sandstone because they are the target for most wells and the principal source of drinking water
- (Downs and) Kovacs (BYU), 2000
  - Digital computer model using MODFLOW and GMS, including particle tracking using MODPATH and GMS
  - Based on BYU MS thesis
  - Estimated how much of 4,234 ac-ft/yr water rights acquired by Grand Water and Sewer Service Agency (GWSSA) could be withdrawn without affecting water quality
  - Results showed that entire 4,234 ac-ft/yr could be withdrawn

DOCUMENT SUMMARIES

- Solomon (U of U), 2001
  - Performed at request of Moab Land Company
  - Evaluated age, and temperature and elevation of recharge to three springs and two wells analyzed for ^{18}O, ^{2}H, ^{3}H and noble gases
  - Recharge from high elevation (~2,000-2,500 m) before 1960 and possibly before 1,000 AD
  - Cautioned that results not definitive due to small number of samples
- Gardner and Solomon (U of U), 2003; Gardner (U of U), 2004
  - Second document is U of U student's MS thesis; first is report with advisor as second author
  - Concerned with subsurface hydrologic connection between Moab Mill Tailings and Matheson Wetland Preserve
  - Drilled three new wells on Wetland Preserve, and collected samples analyzed for U as well as ^{18}O, ^{2}H, ^{3}H and noble gases
  - Old river gravels exist below 18 ft, extending 2,300 ft from Colorado River into northwestern portion of Wetland Preserve
  - Denser, contaminated brine lies in old gravels underneath fresh, uncontaminated water
- Crowley (U of U), 2004
  - Focused on quantifying evapotranspiration for Matheson Wetland Preserve
  - Estimated wetland evapotranspiration at 3,200 ac-ft/yr, remarkably close to Sumison's (1971) estimate of 3,000 ac-ft/yr

DOCUMENT SUMMARIES

- Lowe, Wallace, Kirby and Bishop (UGS), 2007
  - Drew heavily on data from Sumison (1971), Blanchard (1990), Steiger and Susong (1997), Eisinger and Lowe (1999), including Table 1 presented as Table 4, and (Downs and) Kovacs (2000)
  - Purpose was to recommend appropriate septic-tank density requirements using (Downs and) Kovacs (2000) digital computer model
  - Recommended minimum lot size in central portion of Spanish Valley was 10 acres; 20 acres in southeastern portion and along valley margins

DOCUMENT SUMMARIES

- Kolm and van der Heijde, 2018; 2019
  - First two of four reports prepared for Moab City
  - First (Phase 1) report developed conceptual model for Moab City Springs and Wells (MCSW) area using Hydrologic Environmental System Analysis or HESA
  - MCSW divided into five Hydrogeologic Subsystems: (1) La Sal Mountain Alluvium, Mill Creek (LSMA-M) and Pack Creek (LSMA-P); (2) Wilson Mesa and South Mesa Alluvial Fans (WMAF and SMAF); (3) Glen Canyon Group Mill Creek (GCMC); (4) Glen Canyon Group Grandstaff Creek (GCGC); (5) Pack Creek Lower Alluvium (PCLA)
  - Second (Phase 2) report presented water budget (actually four) for GCMC (Table 3); (1=Pre-development, low estimate consumptive use by phreatophytes; 2=Post-development, low estimate; 3=Pre-development, high estimate; 4=Post-development, high estimate)
- Kolm and van der Heijde, 2020a
  - Focus of Phase 3 report is three Drinking Water Source Protection (DWSP) plans and zones for Moab City's: (1) Skakel Spring; (2) Springs 1, 2 & 3 (City of Moab Springs); (3) Wells 4, 5, 6, 7 & 10
  - Proposed expanding DWSP zones for Skakel Spring and City of Moab Springs; zones for wells not recommended for expansion
  - Also provides Preliminary Monitoring Plan (PMP) to protect Moab City's water supply

Table 3. Kolm and van der Heijde (2019) water budgets (all units ac-ft/yr).

WATER BUDGET COMPONENT	IN[1]	OUT[1]	IN[2]	OUT[2]	IN[3]	OUT[3]	IN[4]	OUT[4]
Recharge from precipitation	9155	-	9155	-	11339	-	11339	-
Groundwater underflow at upper Mill Creek boundary	4	0	4	0	4	0	4	0
Direct runoff from precipitation to streams from storms + local snowmelt within budget area	0	-	0	-	0	-	0	-
Mill Creek inflow above later location of Sheley diversion	7546	-	6814	-	7546	-	6814	-
Irrigation return flow + septic tank infiltration	0	-	0	-	0	-	0	-
Consumptive use crops	-	0	-	0	-	0	-	0
Consumptive use riparian vegetation	-	4009	-	4009	-	6193	-	6193
Springs (including Skakel)	-	2325	-	1860	-	2325	-	1860
Municipal use	-	1364	-	1875	-	1364	-	1875
Domestic consumptive use	-	80	-	120	-	80	-	120
Sheley diversion	-	0	-	3665	-	0	-	3665
Mill Creek outflow at delta	-	8927	-	5317	-	8927	-	5317
Change of storage			873	-			873	-
TOTALS	16705	16705	16846	16846	18889	18889	19030	19030

DOCUMENT SUMMARIES

- Kolm and van der Heijde, 2020b
  - Final (Phase 4) report added to project in July 2019 to create expanded water budget of Spanish Valley, including PCLA and GCMC subsystems of MCSW
  - Budgets developed for both pre- (1) and post- (2) development, but not for low and high estimates of consumptive use by phreatophytes (Table 4)

Table 4. Kolm and van der Heijde (2020b) water budgets (all units ac-ft/yr).

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

DOCUMENT SUMMARIES

- Masbruch, Gardner, Nelson, Heilweil, Solder, Hess, McKinney, Briggs and Solomon (USGS and U of U), 2019; Gardner, Nelson, Heilweil, Solder and Solomon (USGS and U of U), 2020
  - First document is USGS report, second is journal publication by five of nine co-authors based on USGS report
  - Updated (ground)water budget for Glen Canyon Group aquifer (GCGA) and valley-fill aquifer (VFA); prepared contemporaneously with Kolm and van der Heijde (2019; 2020a) water budgets; first since Sumison (1971)
  - Unlike Kolm and van der Heijde, collected much valuable new data, including: (1) water samples from wells, springs and surface water sites; (2) vadose-zone pore-water samples from cores along Sand Flats Road; (3) stream and spring discharge measurements; (4) electrical conductivity geophysical survey, and drilling and testing of 12 new wells in Matheson Preserve
  - Water samples analyzed for: (1) field parameters; (2) major ions; (3) ^{18}O, ^{2}H, ^{3}H, ^{3}He & ^{4}He; (4) noble gases; (5) CFCs & SF_6; (6) ^{13}C & ^{14}C
  - 16 cores analyzed for vadose-zone ^{18}O, ^{2}H, ^{3}H & Cl; 10 cores also analyzed for vadose-zone Br
  - Conclusions: (1) recharge to deep GCGA only from La Sal Mountains; (2) recharge to shallow GCGA probably along mountain front, with only a little from Sand Flats; (3) recharge to VFA from upper Pack Creek drainage and loss from Pack Creek; (4) outflow to Colorado River much smaller than previous estimates; (5) overall groundwater budget much less, too
  - Greatly revised (reduced) annual 2014, 2015 & 2016, and average annual groundwater budgets (Table 5); (1=Average annual values of in-place recharge and recharge from runoff from 1940-2012 from Basin Characterization Model; 2=Based on sensitivity analysis of Basin Characterization Model from Flint and others, 2011; Masbruch and others, 2011; 3=Averae of assumed measurement error; 4=Based on average error of transmissivity estimates for hydraulic-gradient method, and errors in age difference and distance for age-gradient method)

Table 5. USGS groundwater budget (all units ac-ft/yr).

Recharge	2014	2015	2016	Average annual	Uncertainty (percent)
Direct infiltration of precipitation (in-place recharge)[1]	N/A	N/A	N/A	9,000 to 27,000	[2]50
Infiltration of runoff (includes recharge from losing reaches of streams and unconsumed surface-water irrigation)[1]	N/A	N/A	N/A	510 to 2,550	[2]50
Unconsumed irrigation from well withdrawals	25 to 125	8 to 40	9 to 45	N/A	unknown
Total:				9,550 to 30,000	
Discharge					
Streams and springs (base flow)	10,600	11,700	10,200	N/A	[3]5
Springs and well withdrawals for culinary use	2,400	3,000	3,300	N/A	unknown
Well withdrawals for irrigation (net depletion)	250	80	89	N/A	unknown
Subsurface outflow	N/A	N/A	N/A	300 to 1,000	[4]40-50
Total:				14,000 to 16,000	

DOCUMENT SUMMARIES

- Heilweil, Masbruch, Gardner, Nelson, O’Leary, Solomon and Wilkowske (USGS and U of U), 2020
  - Short (4-1/2 pages) report written in response to UDWRi request for suggestions for additional groundwater monitoring to aid UDWRi in making future decisions on well withdrawals in Spanish Valley
  - Contains prioritized list of seven monitoring suggestions for consideration by UDWRi: (1) continuous spring discharge measurements; (2) continuous groundwater-level monitoring using dedicated submersible pressure transducers; (3) stream gage on upper Pack Creek; (4) water-quality sampling; (5) continuous water-quality monitoring (T^o and EC); (6) data to support future numerical groundwater flow modeling; (7) utilize USGS “Furnished Data” program to publish water-level data collected by other agencies

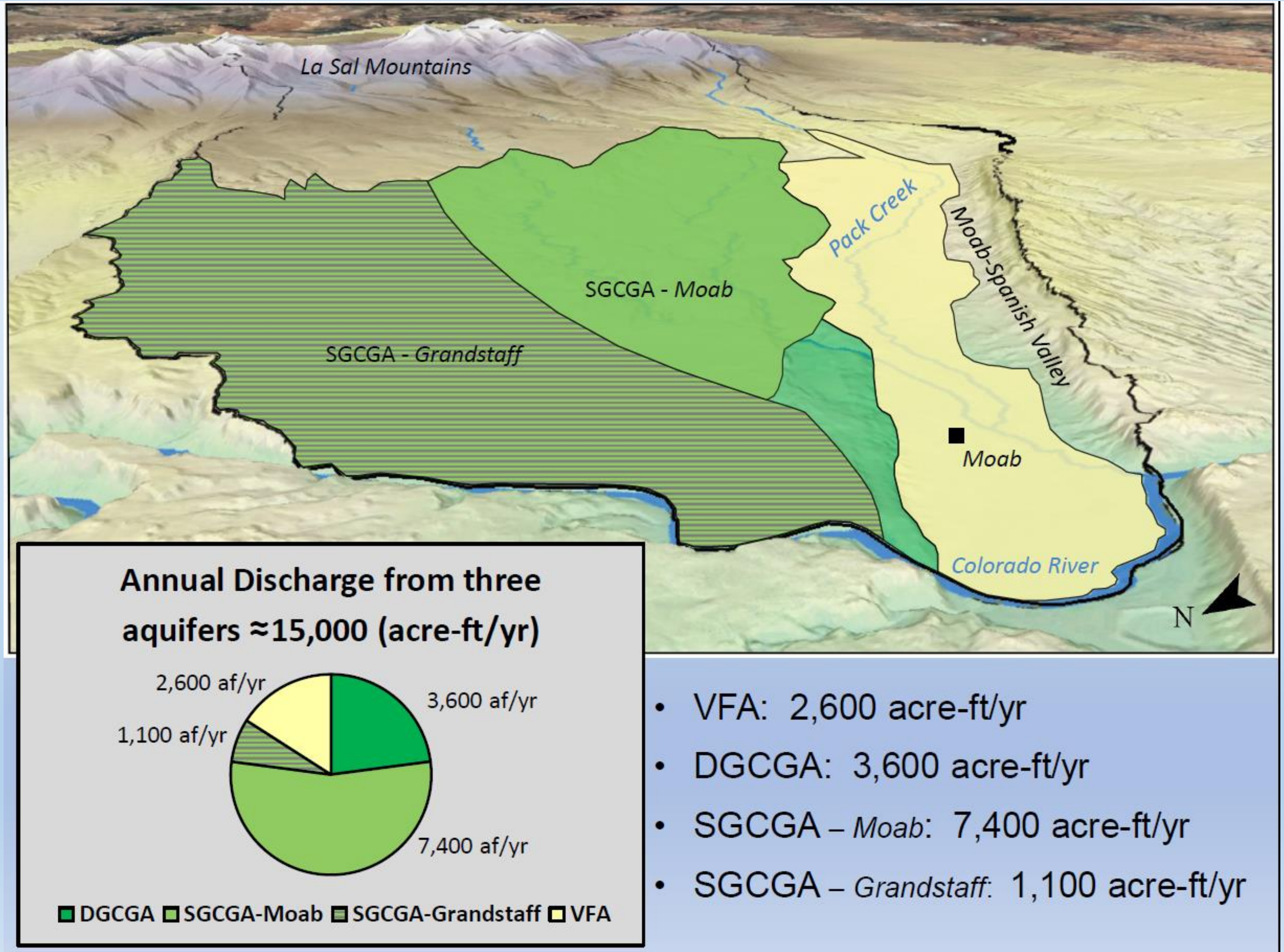
DOCUMENT SUMMARIES

- Western Water Assessment, 2019; Arens, 2021
  - Both documents concerned with possible impacts of climate change on groundwater in Spanish Valley
  - First document presents results of workshop consisting of two half-day meetings attended by Moab City, Grand Water and Sewer Service Agency (GWSSA), San Juan Spanish Valley Special Service District, and others
  - Reviewed data on: (1) water budget and drought; (2) observed precipitation (high variability, no long-term trend); (3) observed temperatures (strong recent warming trend); (4) observed snowpack and streamflow (a little less, a little earlier)
  - Also presented possible future trends in: (1) temperatures (even warmer); (2) precipitation (large variability continues)
  - Then discussed a drought and reduced water supply scenario, including: (1) groundwater depletion; (2) extreme precipitation; (3) wildfire risk; (4) flora and wildlife risk; (5) water quality and extreme heat
  - Second document from PowerPoint presentation consisting of introductory slide and seven substantive slides: (1) decreasing recharge and increasing demand; (2) increasing temperature and slight decrease in precipitation but with increased variability; (3) decreasing snow-water equivalent and soil moisture, decreasing aquifer recharge; (4) increase in extreme precipitation, with increasing runoff and decreasing recharge; (5) increasing potential evapotranspiration, reducing recharge and increasing water use; (6) summary slide; (7) long-term water table decline, and historical temperature anomalies and precipitation

DOCUMENT SUMMARIES

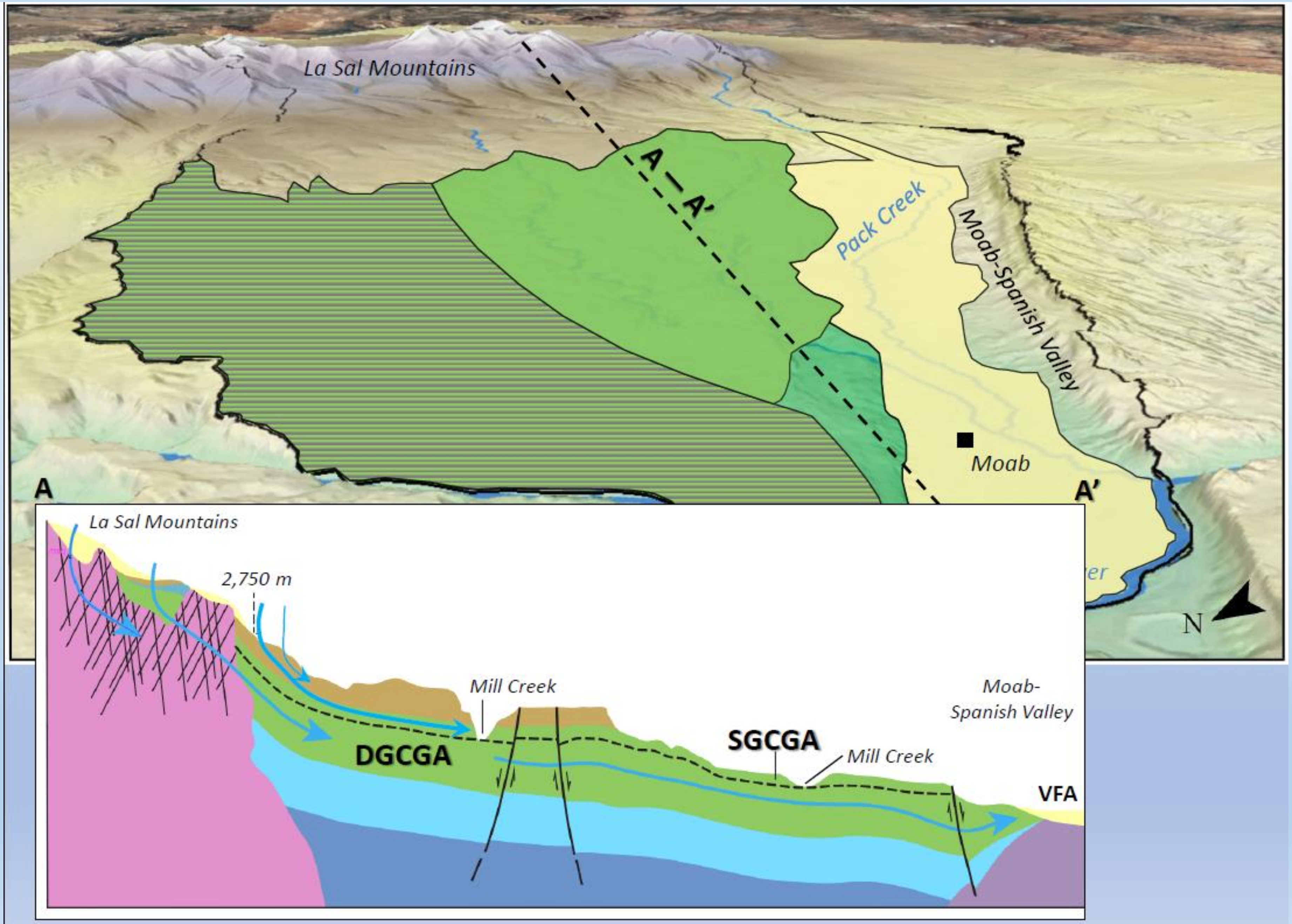
- Gardner, Solomon and Heilweil (USGS and U of U); Wilkowske (USGS)
  - Both PowerPoint presentations addressing two different aspects of groundwater system in Moab-Spanish Valley area
  - First consists of twelve substantive slides, plus introductory slide (#1) and concluding slide (#14). Slides 2-6 present estimated annual discharge from VFA (2,600 ac-ft/yr); deep GCGA (3,600 ac-ft/yr); shallow GCGA, Moab (7,400 ac-ft/yr); shallow GCGA, Grandstaff (1,100 ac-ft/yr). Slide 7 presents hydrogeologic cross section. Slides 8 and 11 present plots of stable isotope data for the three aquifers, and for the three aquifers and the Sand Flats pore water, respectively. Slide 9 presents major ion chemistry. Slides 10, 12 and 13 present results for SGCGA, VFA and DGCGA, respectively. Last slide (14) presents conclusions, specifically: (1) all methods employed are in relatively good agreement; (2) groundwater can be separated into three distinct aquifers; (3) stream loss from Pack Creek is primary recharge source to VFA; (4) Sand Flats not recharge source to DGCGA wells and springs; (5) flow through VFA less than previously estimated, and nearly all flow is consumed by evapotranspiration in Matheson Wetlands; (6) various methods produce consistent DGCGA discharge of 3,600 ac-ft/yr, indicating additional undiscovered water is unlikely
  - Second PowerPoint presentation consists of nine slides, including: (1) graphs of three water levels in VFA and four in GCGA with time (#3 & #4); (2) graph of discharge versus time for Mill Creek below Pack Creek near Moab (#5); (3) histogram of annual baseflow discharge from Pack Creek (#6); (4) graphs of salinity for Colorado River (#7 & #8). Slides 1 and 2 are introductory slides, and slide 9 is a concluding slide containing no technical information

Figure 5. Annual discharge from three aquifers (Gardner, Solomon and Heilweil).



- VFA: 2,600 acre-ft/yr
- DGCGA: 3,600 acre-ft/yr
- SGCGA – *Moab*: 7,400 acre-ft/yr
- SGCGA – *Grandstaff*: 1,100 acre-ft/yr

Figure 6. Hydrogeologic cross section (Gardner, Solomon and Heilweil).



SUMMARY AND CONCLUSIONS

- Summary
  - USU selected for peer review and relatively non-technical summaries of numerous individual documents on groundwater resources of Moab-Spanish Valley area
  - Sumison (1971) identified two principal aquifer systems: (1) Glen Canyon Group; (2) Spanish Valley Quaternary deposits. Blanchard (1990) added Entrada Sandstone to Glen Canyon Group aquifer along with Navajo and Wingate Sandstones. Steiger and Susong (1997) referred to Quaternary deposits as valley-fill aquifer
  - Sumison (1971) also noted that Glen Canyon Group had lower TDS than Quaternary deposits. Confirmed by Blanchard (1990). Many subsequent investigators confirmed distinct chemical differences between water in higher-quality GCGA and in lower-quality VFA based on analyses for ^{18}O, ^{2}H, ^{3}H, ^{3}He, ^{4}He, ^{13}C, ^{14}C, noble gases, and CFCs & SF_6
- Conclusions
  - Sumison (1971) study was a remarkable initial attempt to characterize groundwater resources in Moab-Spanish Valley area, but it was constrained by the limited field data collected up to that time
  - Subsequent investigations prior to the Kolm and van der Heijde and USGS reports also are of limited value, even those for which additional field data were collected
  - USGS study stands out as superior to Kolm and van der Heijde reports because extensive new field data were collected expressly for that investigation
  - Kolm and van der Heijde reports relied exclusively on previously collected data, primarily from the older studies
  - Nonetheless, methods employed by Kolm and van der Heijde were sound, and their results and conclusions are credible and consistent with the data they used

RECOMMENDATIONS

- Recommendations
  - The most important document may well be the short report prepared by USGS and U of U personnel containing a prioritized list of seven monitoring suggestions for consideration by the UDWRi
  - Collecting the groundwater monitoring data suggested by the authors of this report will: (1) document any decreases in spring discharges or water-level declines in wells, and (2) act as an early warning system for protection of groundwater quantity and quality, allowing for the maximum amount of time to take any steps needed to address the problem(s)
  - I agree that: (1) continuous spring discharge measurements and (2) continuous groundwater-level monitoring using dedicated submersible pressure transducers should be given the highest, and equal, priority
  - However, I consider the sixth priority, collecting data to support future numerical groundwater flow modeling, to be the second most important. As noted by the authors of this report, such modeling can be used to: (1) test recently updated hypotheses regarding aquifer connections, recharge zones and flow directions; (2) assess the recently revised (reduced) groundwater budget estimates; (3) optimize the locations of additional groundwater monitoring sites; (4) simulate changes to the groundwater system based on potential future changes in groundwater development and/or climate

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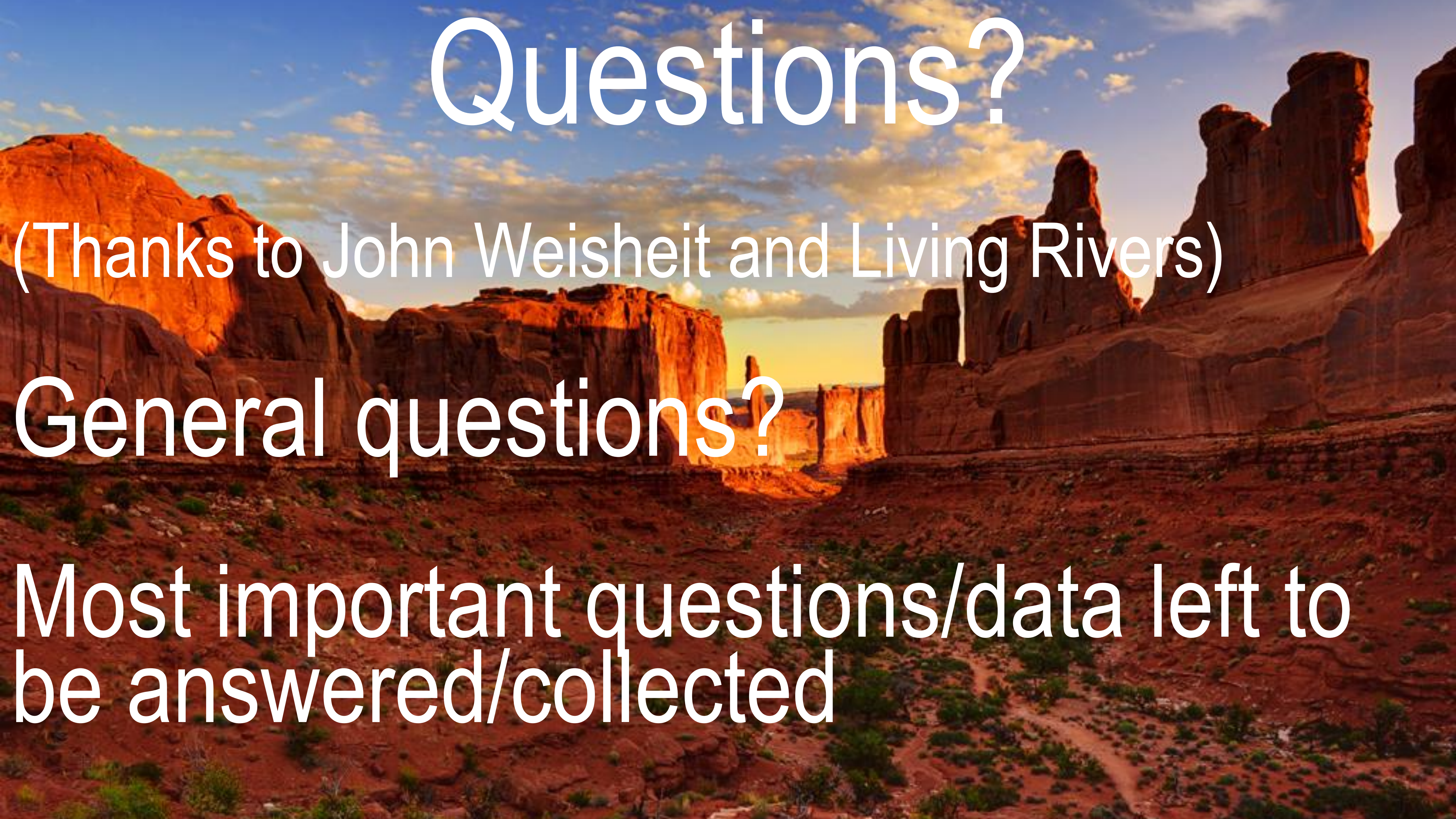

Questions?

(Thanks to John Weisheit and Living Rivers)

General questions?

Most important questions/data left to be answered/collected