REGIONAL D- AND N-AQUIFER BASEFLOW AND SPRING DISCHARGE FIELD EVALUATION
BLACK MESA, ARIZONA – APRIL 4 – 7, 2016

Purpose: To assemble representatives responsible for and knowledgeable of Black Mesa surface and groundwater resources, and to assess the need and potential for increased monitoring; with emphasis on the Navajo Aquifer System.

The field evaluation is the culmination of in person working meetings, quarterly presentations, and teleconference updates during development of the NGS-KMC Draft EIS from April 2013 to April 2016. Appendix B is intended to satisfy Settlement Condition No.3 associated with Docket No. DV-2012-3-R, that states, "OSM shall produce a written assessment of the need and potential for increased N aquifer spring monitoring. This written evaluation will be documented in the CHIA update and developed in consultation with the Hopi Tribe, Navajo Nation, PWCC, and USGS."

Objectives:

1. Discuss USGS Black Mesa Monitoring Program status and available monitoring results.
2. Identify the need and potential for increased monitoring of N aquifer discharge, and if additional information is necessary to evaluate industry and community water resource impacts.
3. Field verify N aquifer discharge Groups B, C, D, E, F1, and G are adequately characterized in the USGS spring inventory, and spring inventories used during impact analysis of surface coal mining operations.

The long-term effects of groundwater withdrawal from regional aquifers is a concern largely addressed through monitoring by the United States Geological Survey (USGS). USGS monitoring is supported through participation with the Arizona Water Commission, the Bureau of Indian Affairs (BIA), Navajo Tribal Utility Authority, Peabody Western Coal Company (PWCC), the Hopi Tribe, and the Western Navajo, Chinle, and Hopi Agencies of the BIA. Additionally, the Office of Surface Mining Reclamation and Enforcement (OSMRE) has a regulatory responsibility to complete a cumulative hydrologic impact assessment (CHIA) to assess hydrologic impacts associated with PWCC's Kayenta Mine Complex surface mining and reclamation operations. OSMRE's 2011 CHIA document was challenged and settled in May 2014 with the condition to assess the need and potential for increased N aquifer spring monitoring, and to develop the assessment in consultation with the Hopi Tribe, Navajo Nation, PWCC, and the USGS.

Further, the Navajo Generating Station – Kayenta Mine Complex (NGS-KMC) EIS necessitated an evaluation of the Black Mesa Regional D and N aquifers, impacts to baseflow and spring discharge, and impacts to uses of hydrologic resources associated with the proposed project. A review of available spring location and discharge information was completed and the figure below illustrates areas where N aquifer discharge is being monitored or likely to occur based on available information. Specifically, Groups B, C, D, E, F1, and G are of interest for this evaluation. Field verification will provide an understanding if the degree and magnitude of known discharge information is adequately captured through existing documentation and monitoring for assessing hydrologic impacts of the proposed NGS-KMC project.

These efforts are overlapping and often involve many of the same organizations and individuals. In an effort to be more efficient with time and resources, the Week of April 4th, 2016 provided an opportunity to consolidate these multiple efforts. The field stops provided and opportunity to further the discussion and review of D and N aquifer hydrologic resources, associated uses, and hydrologic impacts related to the objectives outlined above.

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BLACK MESA, ARIZONA – APRIL 4 – 7, 2016

Participants (listed with days of participation and listed as pictured from left to right):

James Boswell	Peabody Energy (M, W, Th)
Jamie Macy	USGS Arizona Water Science Center (M, T, W, Th)
Jon Mason	USGS Arizona Water Science Center (M, T, W, Th)
Jim Duffield	Hopi Water Resources Program (M, T, W)
Raymond Roessel	BIA Hopi Region (M, T, W, Th)
Bernadette Tsosie	BIA Navajo Region (M, T, W, Th)
Jim Burrell	AECOM Environment (representing Bureau of Reclamation) (M, T, W, Th)
Lisa Yellow Eagle	Navajo Nation Water Rights Protection (W, Th)
Randy Poleahla	Hopi Department of Natural Resources (M, T, W, Th)
Paul Clark	Office of Surface Mining Reclamation and Enforcement (M, T, W, Th)
Max Taylor	Hopi Water Resources Program (M)
Albert (not provided)	Hopi Water Resources Program (T, W, Th)
Yolanda Taho	Hopi Water Resources Program (T, W, Th)

Picture by: Bill Greenslade, Southwest Ground-water Consultants (working with AECOM) (M, T, W, Th)

Not Pictured

Ray Benally	Navajo Nation Department of Water Resources (M)
Jason John	Navajo Nation Department of Water Resources (M)
Robert Kirk	Navajo Nation Water Rights Protection (W, Th)
Lionel Puhuyesva	Hopi Water Resources Program (M)
Marie Shephard	Peabody Energy (M)
John Cochran	Peabody Energy (M)

Precipitation Prior to Field Assessment:

Precipitation recorded February 5th in Flagstaff and February 1st in Kayenta, AZ; on ground snowmelt completed on February 12th. No additional measurable precipitation prior to field assessment.

U.S. climate data
Temperature - Precipitation - Sunshine - Snowfall

Home United States Arizona

Monthly Daily History Geo & Map Weather Forecast

Select year: February

Weather history Flagstaff february 2016

Day	High (°F)	Low (°F)	Precip. (inch)	Snow (inch)	Snow depth (inch)
1 feb 2016	41.0	12.0	-	-	-
2 feb 2016	25.0	-7.1	-	9.80	12.01
3 feb 2016	30.9	-17.0	0.00	0.00	9.02
4 feb 2016	39.9	-9.9	0.00	0.00	9.02
5 feb 2016	39.9	-2.0	0.35	0.00	7.99
6 feb 2016	45.0	-0.9	0.00	0.00	7.01
7 feb 2016	46.0	7.0	0.00	0.00	5.98
8 feb 2016	51.1	33.1	0.00	0.00	5.98
9 feb 2016	55.9	15.1	0.00	0.00	5.98
10 feb 2016	63.0	12.9	0.00	0.00	5.98
11 feb 2016	60.1	12.9	0.00	0.00	5.00
12 feb 2016	63.0	16.0	0.00	0.00	4.02
13 feb 2016	62.1	18.0	0.00	0.00	0.00
14 feb 2016	60.1	16.0	0.00	0.00	0.00

U.S. climate data
Temperature - Precipitation - Sunshine - Snowfall

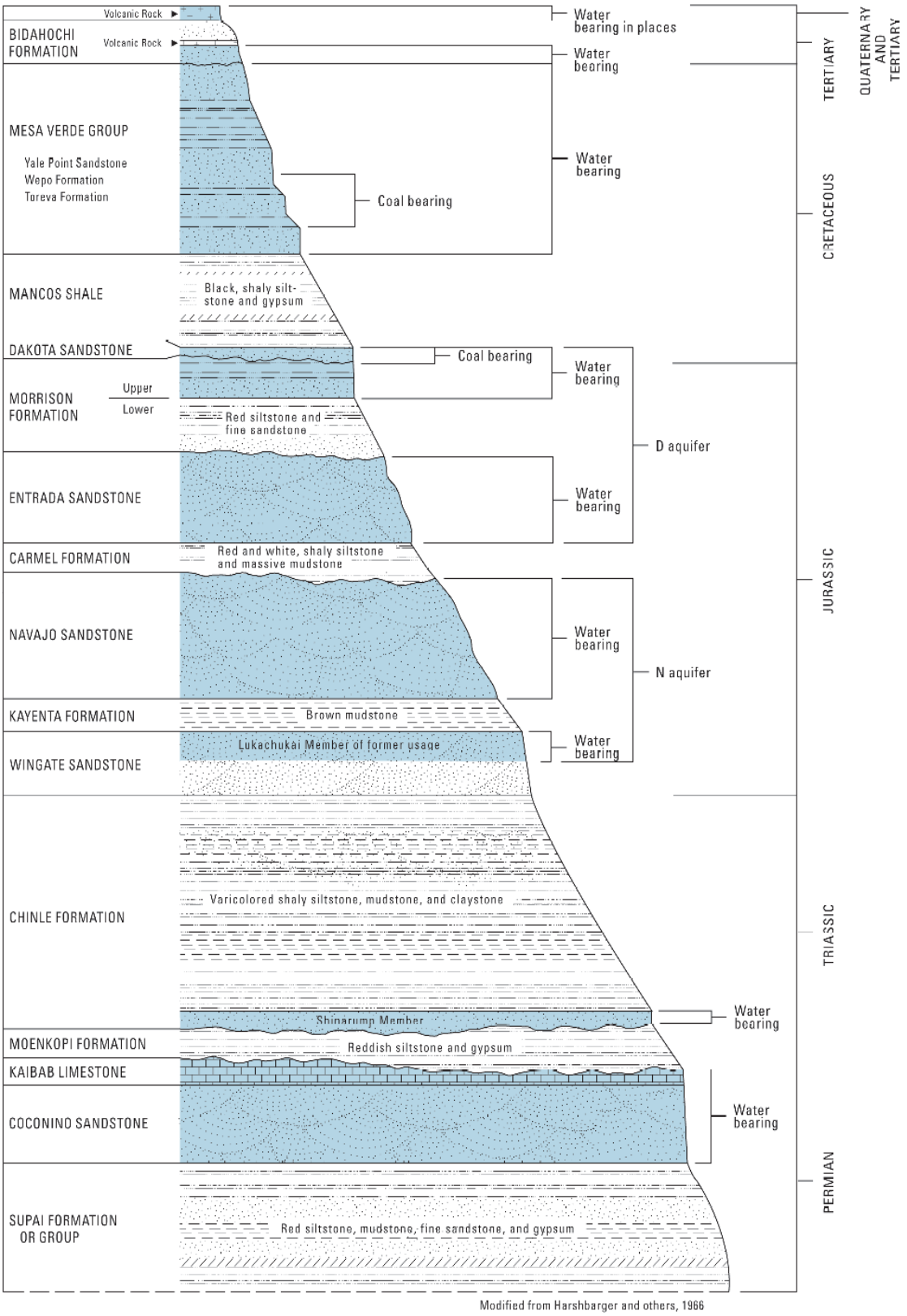
Home United States Arizona

Monthly Daily History Geo & Map Weather Forecast

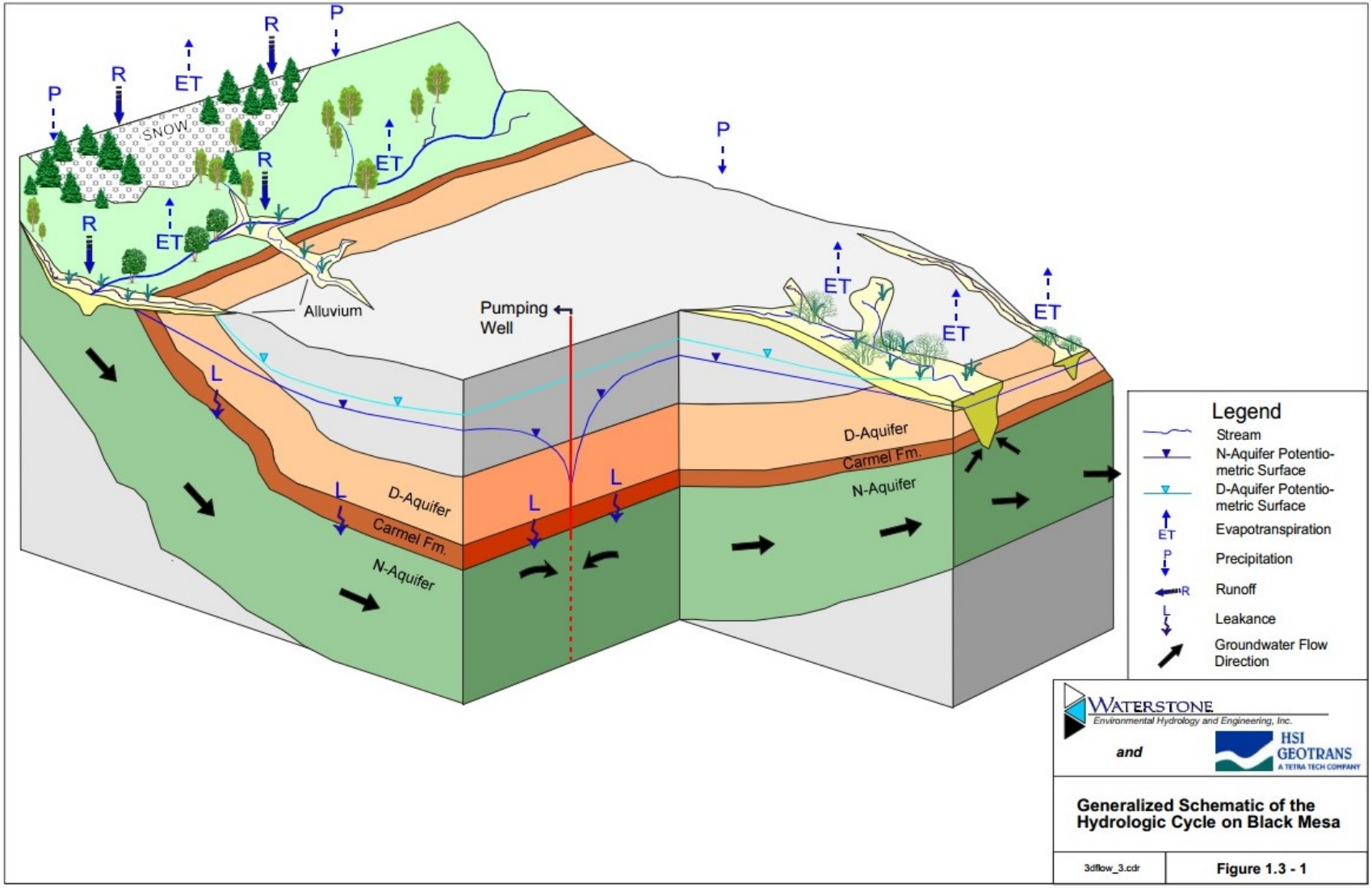
2016 February

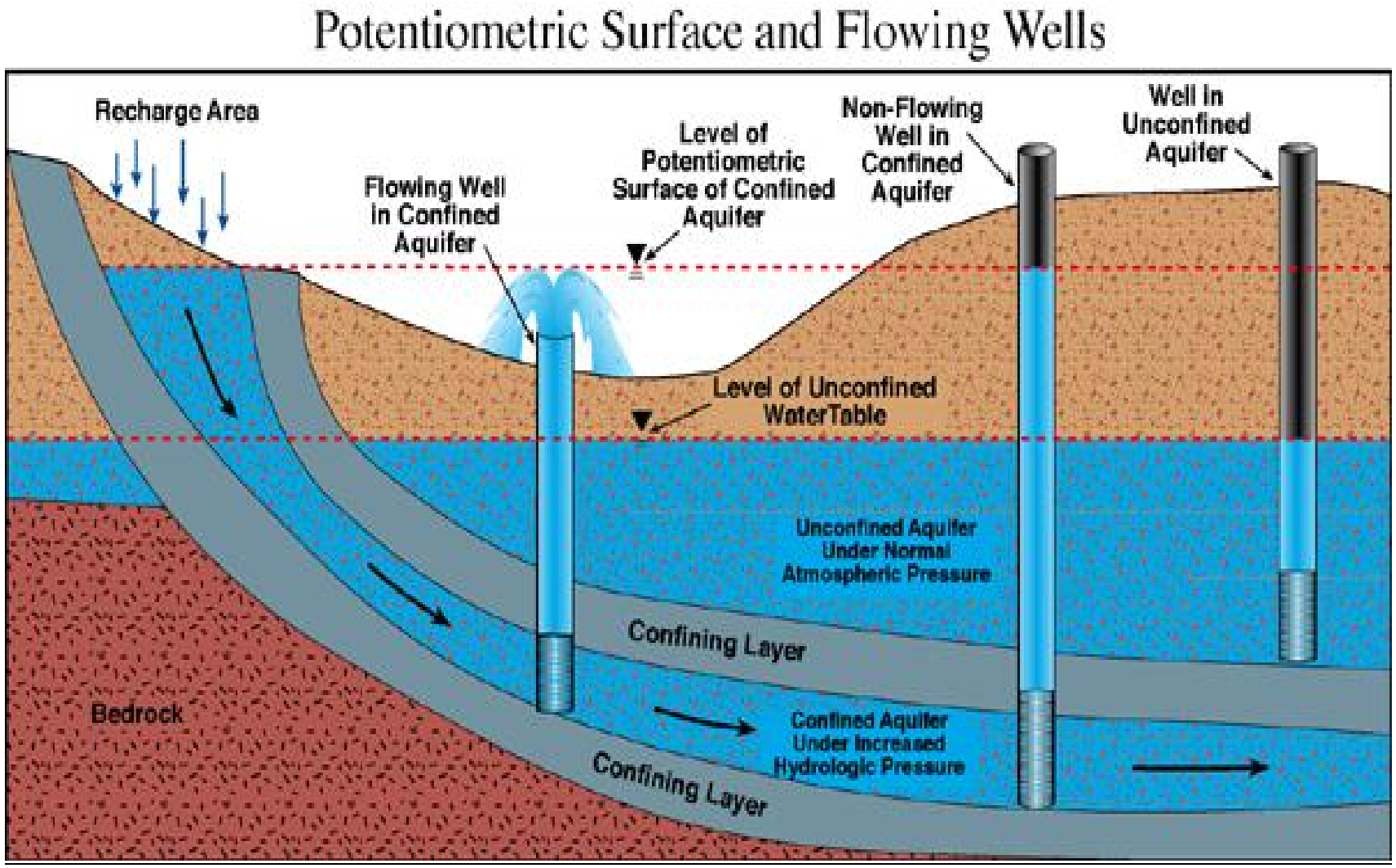
Weather history Kayenta february 2016

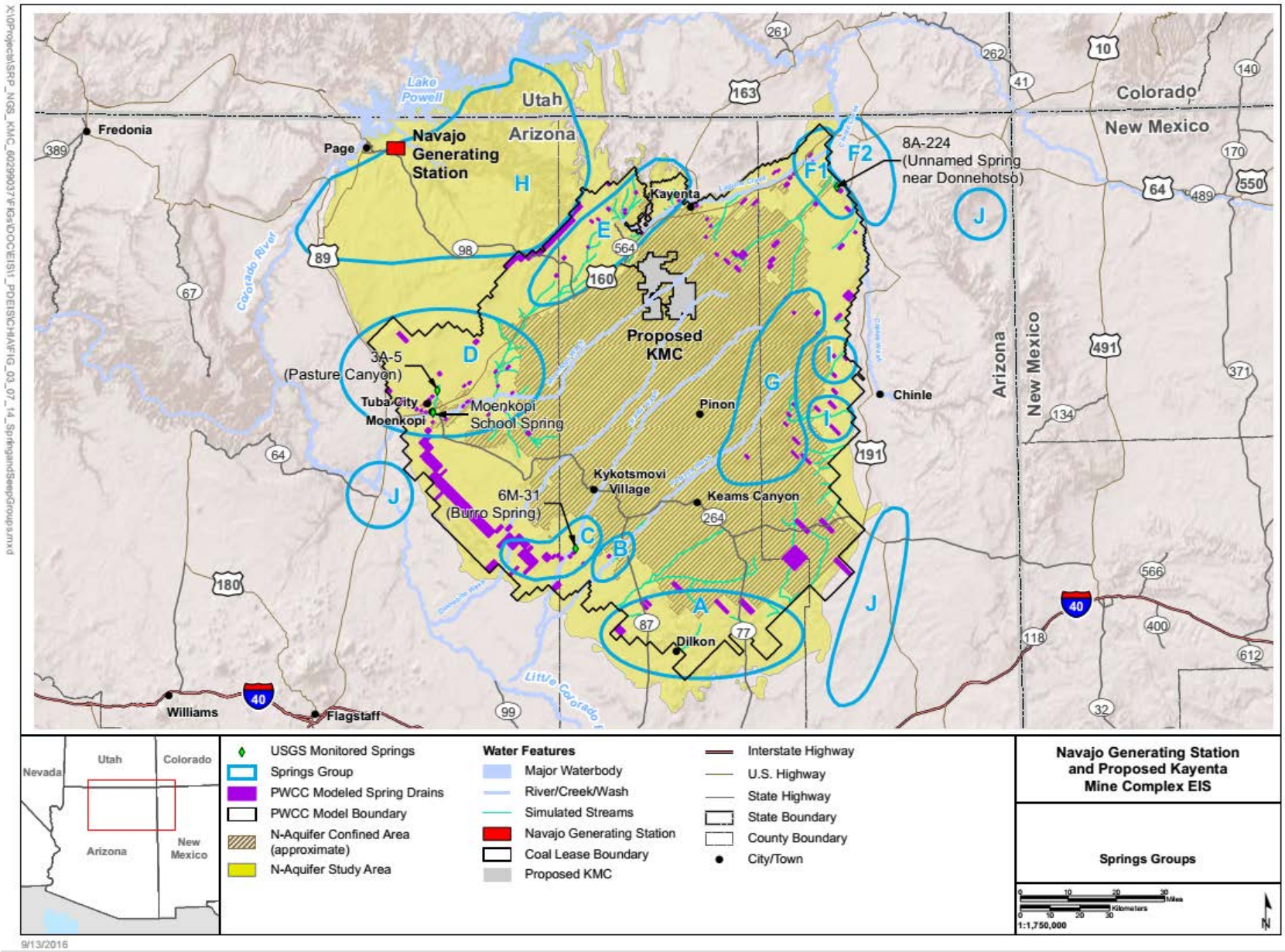
Day	High (°F)	Low (°F)	Precip. (inch)	Snow (inch)	Snow depth (inch)
1 feb 2016	42.1	1.0	0.50	9.02	14.02
2 feb 2016	32.0	3.0	0.00	0.00	12.99
3 feb 2016	42.1	3.9	0.00	0.00	12.01
4 feb 2016	42.1	3.0	0.00	0.00	12.01
5 feb 2016	28.0	12.0	0.00	0.00	12.01
6 feb 2016	43.0	12.0	0.00	0.00	10.98
7 feb 2016	44.1	12.9	0.00	0.00	9.02
8 feb 2016	46.0	30.0	0.00	0.00	5.98
9 feb 2016	50.0	30.0	0.00	0.00	4.02
10 feb 2016	55.9	30.0	0.00	0.00	4.02
11 feb 2016	59.0	35.1	0.00	0.00	2.99
12 feb 2016	60.1	37.9	0.00	0.00	0.98
13 feb 2016	61.0	35.1	0.00	0.00	0.00
14 feb 2016	55.9	32.0	0.00	0.00	0.00

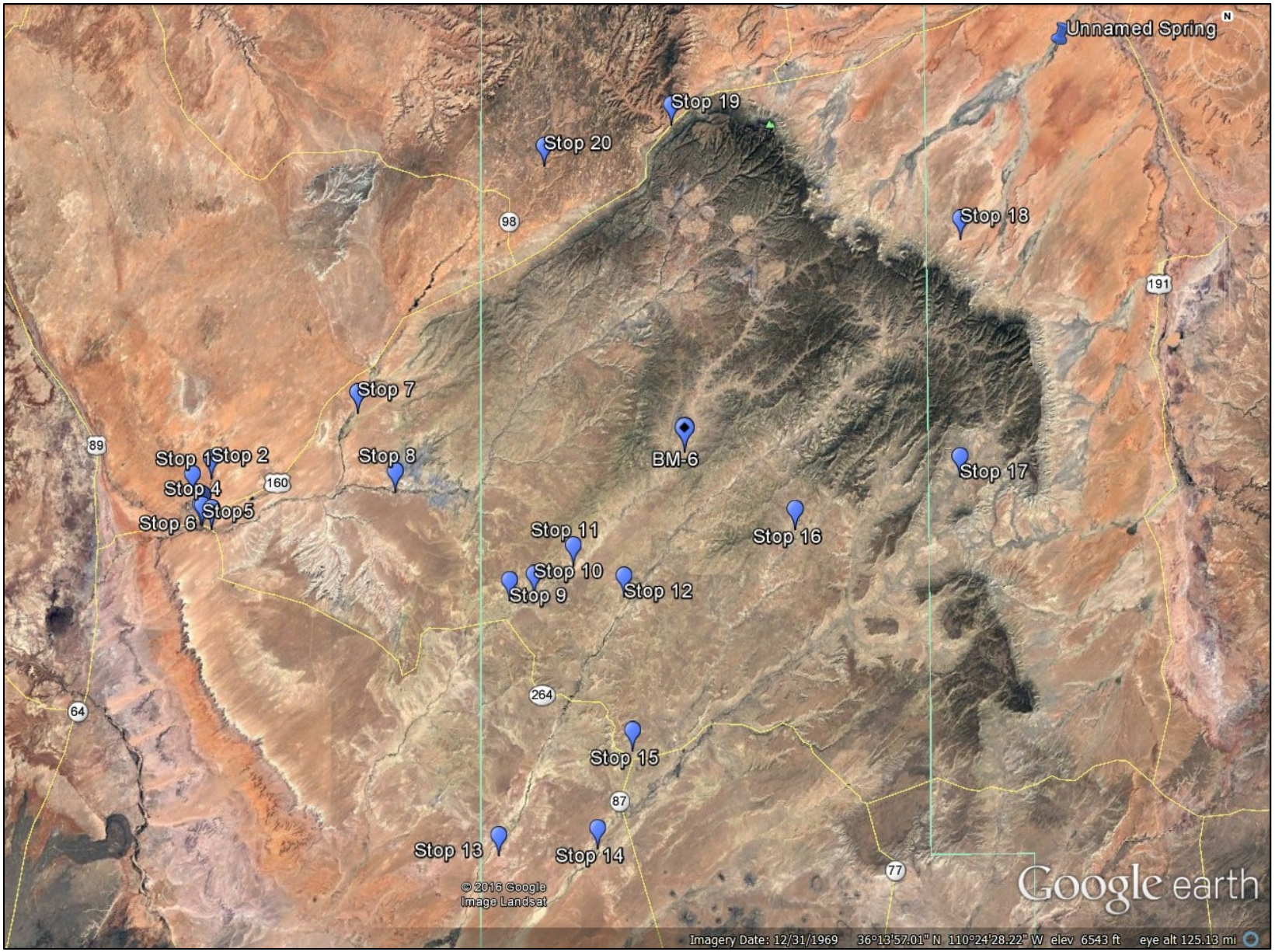


Rock Formations and Major Aquifer Zones of the Black Mesa Area (Macy and Unema, 2014).


P
R
ET
SNOW
Alluvium
Pumping Well
L
D-Aquifer
Carmel Fm.
N-Aquifer
Legend
Stream
N-Aquifer Potentio-metric Surface
D-Aquifer Potentio-metric Surface
Evapotranspiration
Precipitation
Runoff
Leakance
Groundwater Flow Direction
WATERSTONE
Environmental Hydrology and Engineering, Inc.
and
HSI GEOTRANS
A TETRA TECH COMPANY
Generalized Schematic of the Hydrologic Cycle on Black Mesa
3dflow_3.cdr
Figure 1.3 - 1

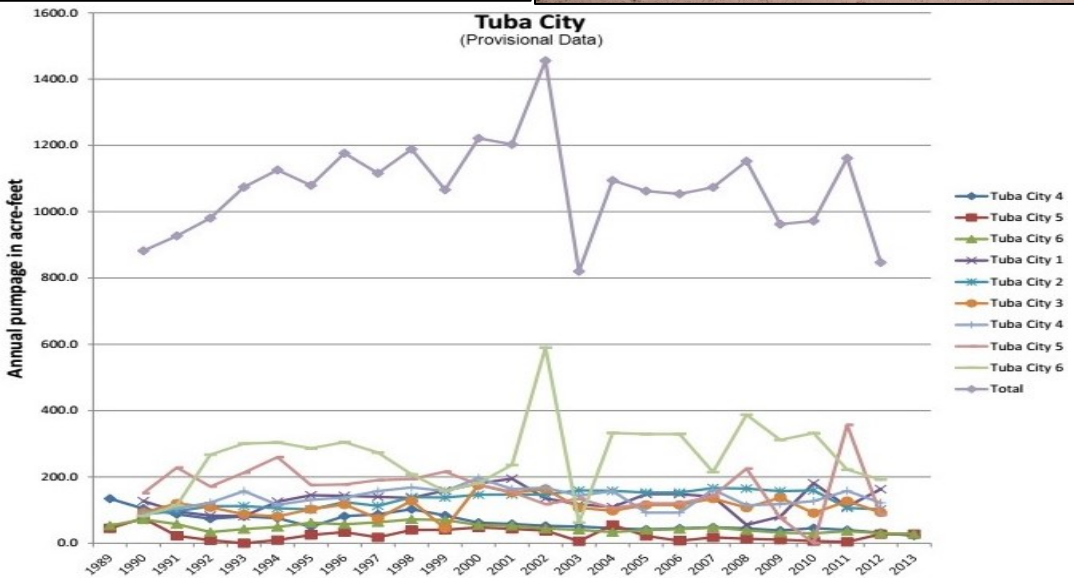

Potentiometric Surface and Flowing Wells
Recharge Area
Flowing Well in Confined Aquifer
Level of Potentiometric Surface of Confined Aquifer
Non-Flowing Well in Confined Aquifer
Well in Unconfined Aquifer
Level of Unconfined WaterTable
Unconfined Aquifer Under Normal Atmospheric Pressure
Confining Layer
Bedrock
Confined Aquifer Under Increased Hydrologic Pressure
Confining Layer


Lake Powell
Utah
Arizona
Colorado
New Mexico
Fredonia
Page
Navajo Generating Station
H
Kayenta
E
F1
F2
8A-224 (Unnamed Spring near Donnehotso)
J
Colorado River
Proposed KMC
D
3A-5 (Pasture Canyon)
Tuba City
Moenkopi
Moenkopi School Spring
G
I
Pinon
Chinle
Kykotsmovi Village
Keams Canyon
6M-31 (Burro Spring)
C
B
A
Dilkon
Williams
Flagstaff
Little Colorado
Nevada
USGS Monitored Springs
Springs Group
PWCC Modeled Spring Drains
PWCC Model Boundary
N-Aquifer Confined Area (approximate)
N-Aquifer Study Area
Water Features
Major Waterbody
River/Creek/Wash
Simulated Streams
Navajo Generating Station
Coal Lease Boundary
Proposed KMC
Interstate Highway
U.S. Highway
State Highway
State Boundary
County Boundary
City/Town
Navajo Generating Station and Proposed Kayenta Mine Complex EIS
Springs Groups
1:1,750,000
9/13/2016


Unnamed Spring
Stop 19
Stop 20
Stop 18
Stop 7
BM-6
Stop 17
Stop 1
Stop 2
Stop 8
Stop 4
Stop5
Stop 6
Stop 11
Stop 16
Stop 10
Stop 9
Stop 12
Stop 15
Stop 13
Stop 14
98
191
89
160
264
64
87
77
© 2016 Google
Image Landsat
Google earth
Imagery Date: 12/31/1969 36°13'57.01" N 110°24'28.22" W elev 6543 ft eye alt 125.13 mi

Stop 2
Stop 1
Rare Metals
Moenave
Tuba City
Cooperators Meeting
Stop 3
U.S. Hwy 160
Stop 4
Stop5
Stop 6
160
264
89
© 2016 Google
Google earth
Imagery Date: 6/11/2014 36°07'05.33" N 111°14'22.01" W elev 4779 ft eye alt 19.14 mi

Stop 1 (Spring Group D): Tuba City Wellfield



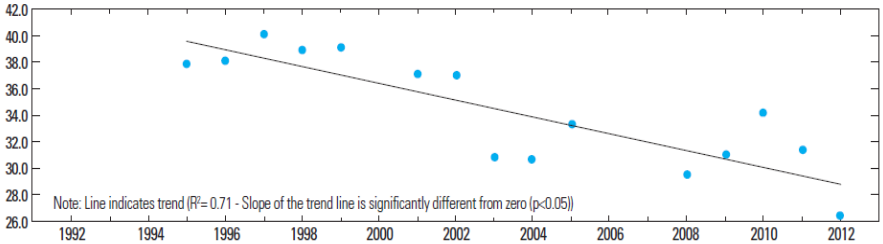
Group Discussion:

Nine (9) Production wells comprise the Tuba City Wellfield. We discussed the wellfield history of operation and the graph of annual production. The wells are positioned in a linear north-south pattern. The group discussed that the installation pattern was likely associated with large water bearing fractures in the Navajo Sandstone. Above, Jamie Macy (USGS) points to an area of high relief that receives above average precipitation compared to the surrounding area. Mr. Macy also indicates the Tuba City syncline trending northwest-southeast, which may provide recharge from the high relief area to the unconfined fractured Navajo Sandstone aquifer.

Key Reference:

Macy, J.P., 2012. Characterization of subsurface geologic structure for potential water resources near the Village of Moenkopi, Arizona, 2009-2010: U.S. Geological Survey Scientific Investigations Report 2012-5180, 24 p. (Available at http://pubs.usgs.gov/sir/2012/5180/.)

Stop 2 (Spring Group D): USGS Pasture Canyon Surface Water Monitoring Location 09401265

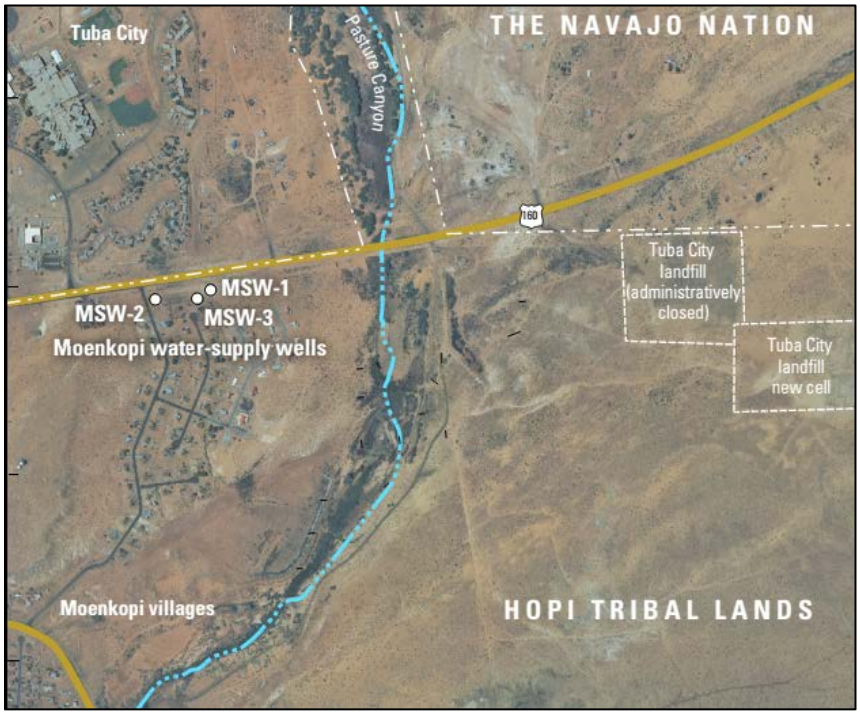


Pasture Canyon flow measured in gallons per minute (gpm) at USGS 09401265 (Macy and Unema, 2014).

<u>Group Discussion:</u>

Pasture Canyon is approximately 6 miles in length from the upper headwater near sand dunes to the mouth downstream at Moenkopi Wash, and thought to intercept the Tuba City syncline. Pasture Canyon has agricultural, recreational, aquatic, and biological uses, and is approximately 1.5 – 2.0 miles from the Tuba City wellfield. Measured water levels reflect influences of annual variations in precipitation recharge and pumping influences. Small caves approximately 10-20 feet deep and about 10-20 feet in height indicate where water seepage has weakened the formation. At the time of visit, the downstream Tuba City reservoir was under major renovation and drained at time of observation.

Stop 3 (Spring Group D): Moenkopi Wellfield



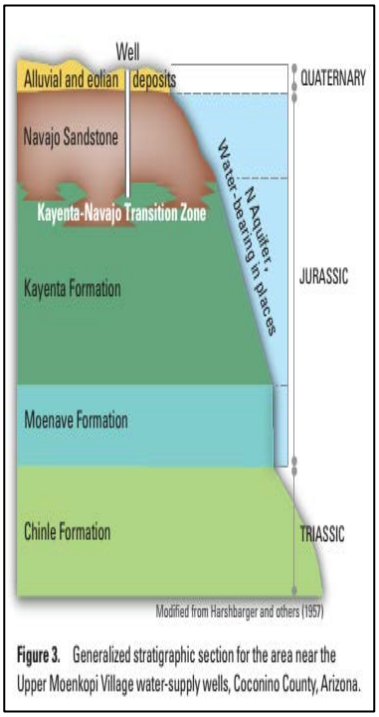


Figure 3. Generalized stratigraphic section for the area near the Upper Moenkopi Village water-supply wells, Coconino County, Arizona.

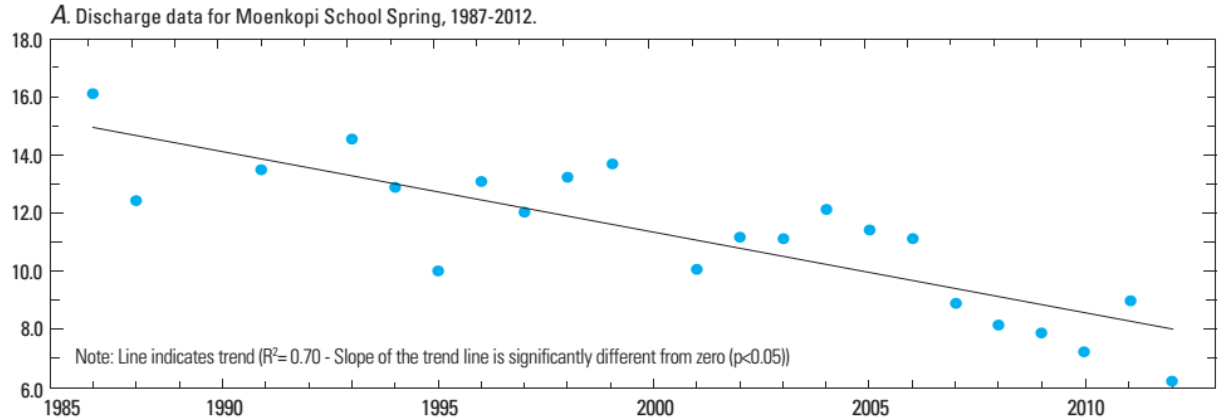
Group Discussion:

The productivity of three (3) Moenkopi water supply wells is limited. Efforts to identify and develop additional water supply capacity are underway. The group discussed the follow two (2) USGS scientific reports.

- Carruth, R.L., Beisner, Kimberly, and Smith, Greg, 2013, Quality, isotopes, and radiochemistry of water sampled from the Upper Moenkopi Village water-supply wells, Coconino County, Arizona: U.S. Geological Survey Open-File Report 2013-1162, 18 p. (above images from report).

- Macy, J.P., 2012, Characterization of subsurface geologic structure for potential water resources near the Villages of Moenkopi, Arizona, 2009–2010: U.S. Geological Survey Scientific Investigations Report 2012–5180, 24 p. (Available at http://pubs.usgs.gov/sir/2012/5180/.)

Stop 4 (Spring Group D): Hopi Susunova Spring



Susunova Spring (aka: Moenkopi School Spring) flow in gallons per minute (Macy and Unema, 2014).

<u>Group Discussion:</u>

On arrival, a local was filling several jugs of water from the spring discharge for household consumption. He noted the group water resource discussion, and politely commented that a lot more water used to flow from the pipe. The comment is supported by the above discharge hydrograph, illustrating a declining trend. The most recent measurement is a low for the 30-year period of record. The origin of the spring is thought to be associated with the fracture pattern consistent the other water bearing fractures in the Navajo Sandstone.

The group discussed that Susunova Spring is a place of cultural importance, and religious ceremonies are conducted at this location. Water from the discharge pipe is routed through irrigation ditches, and fields are irrigated based on agreed allocation within the tribe.

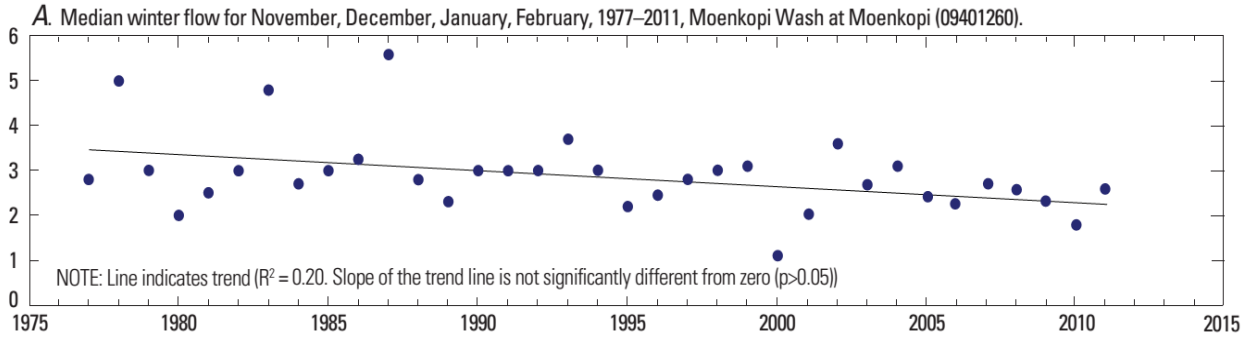
Stop 5 (Spring Group D): Moenkopi Overlook

Group Discussion:

The practice of pumping water from Moenkopi Wash for supplemental irrigation water was discussed. During low flow periods, pits can be dug in Moenkopi Wash to expose the saturated alluvial and the water pumped to adjacent fields. Storm flow water is not used for supplemental irrigation since elevated suspended sediment load during runoff would either ruin pumps or damage crop productivity if applied.

The group also discussed Dripping Spring, which is a hanging garden emanating from a bedding plane adjacent to the highway. Navajo sedge and other sedges populate the seepage face, and is illustrated on the bottom right photo.

Stop 6 (Spring Group D): USGS Moenkopi Monitoring Station 09401260



Moenkopi Wash Location 09401260 discharge in cubic feet per second (Macy and Unema, 2014).

<u>Group Discussion:</u> Moenkopi HUC 15020018 Watershed drains an area of 2,635 square miles. USGS Monitoring Location 09401260 measures flow from 1,629 square miles of the Moenkopi Watershed. Discussed recent upgrades to monitoring equipment including a sonic monitor secured on the bridge for more reliable measurements. However, shifting sand bars continue to challenge accurate measurements, especially during low flow periods. Prayer feathers are often left at places of water resource significance.

Stop 7 (Spring Group D): Begeshbito Wash

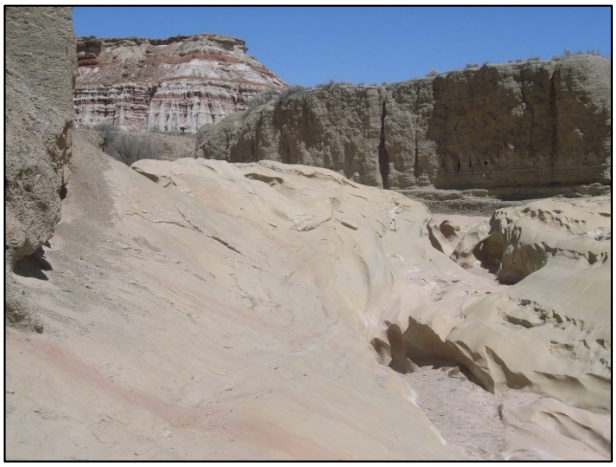
Group Discussion:

Begeshbito Wash is filled with Russian Olive limiting productive agricultural develop, although satellite imagery indicates remnants of agricultural plots. Far in the distance a few large cottonwoods still thrive, and are likely associated with water seeping from a local fracture in the surficial Navajo Sandstone Formation.

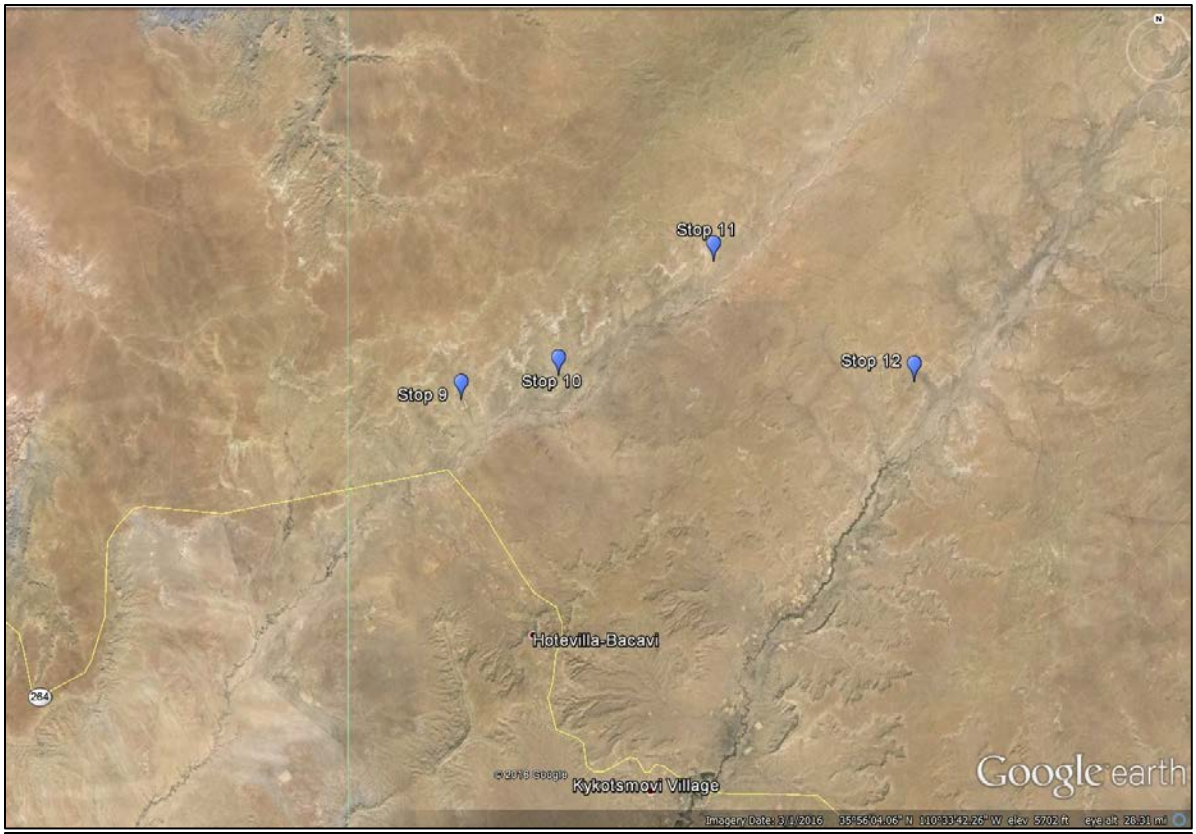
Stop 8 (Spring Group D): Blue Canyon Water Caves

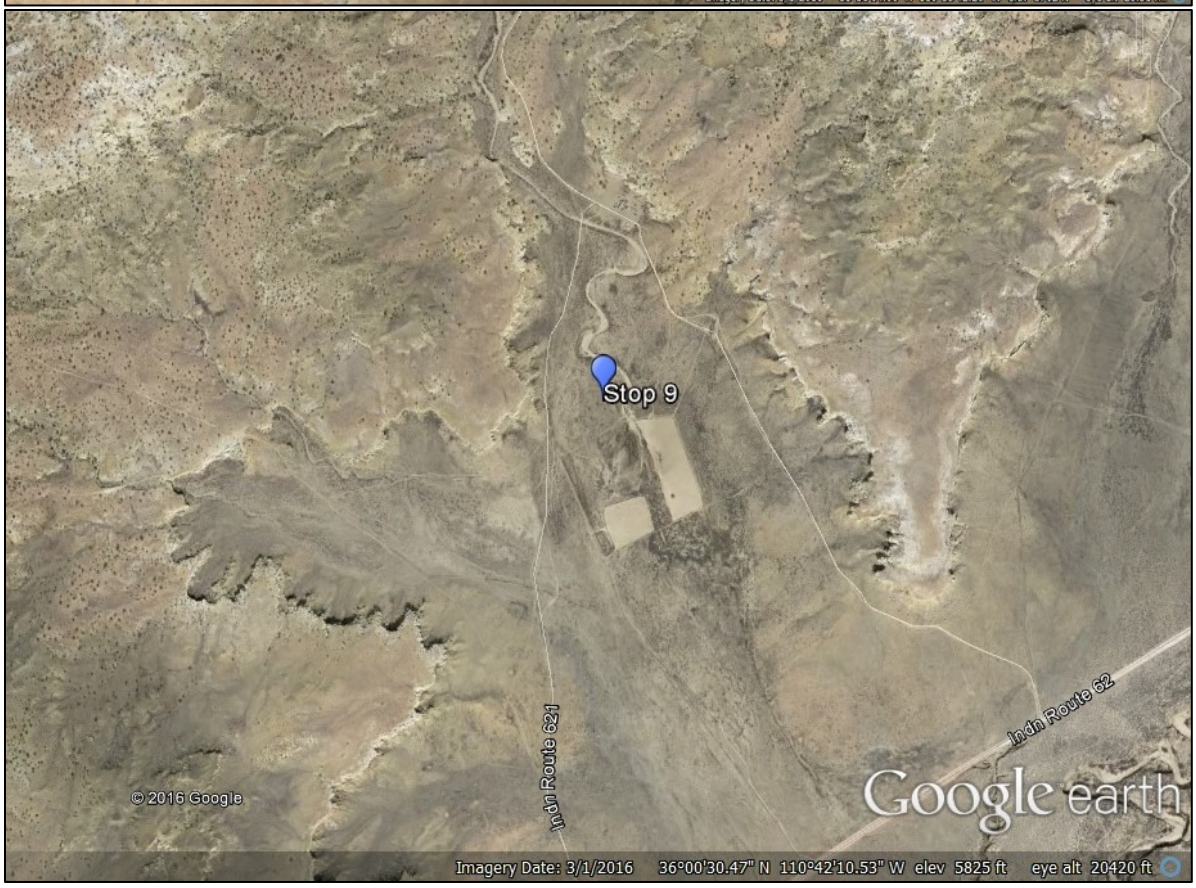
The Hopi Tribe's Department of Natural Resources established the 2014 Blue Canyon Wilderness Visitation Policy. This area is part of the Hopi Indian Reservation and land use is managed by the Hopi Dept. of Natural Resources. Visitation by Non-Hopi Tribal Members is Restricted and by Permit Only. Visitors must be accompanied by a Hopi Licensed Tour Guide who is permitted to visit this area.

The Blue Canyon Trading Post, opened in 1882 by Jonathan Williams, an unsuccessful prospector who decided to become a trader instead. He gave it up in 1889, and it was taken over by the federal government's Indian Service, which started an agency and a school there in 1900. C.H. Algert, another trader, built an extension on the government buildings, but also gave up shortly thereafter. While there, he managed to get the Post Office Department to open a facility there in 1900, and name it after him. It closed in 1903 when the federal government's BIA moved all its operations, including the school, to Tuba City. A Hubert Richardson then took over the post and its buildings; he ceased operations in 1921. There are the walls of some of the school buildings still standing, as well as some of the walls of the trading post itself.



Group Discussion: Location is on Moenkopi Wash approximately 20 miles upstream from Moenkopi Village. The group discussed the need and potential to enhance the existing monitoring program at Blue Canyon where no water monitoring occurs. Although there is not a need for additional monitoring to satisfy SMCRA permitting, or the NGS-KMC EIS decision, there is an information need for Hopi resource management. The information need is aligned with the Hopi BIA mission. Potential funding to support Hopi resource management in the Blue Canyon area was discussed with Hopi BIA, but rejected.


Stop 11
Stop 10
Stop 9
Stop 12
Hotevilla-Bacavi
264
Kykotsmovi Village
Google earth


Stop 9
Indn Route 621
Indn Route 62
© 2016 Google
Google earth
Imagery Date: 3/1/2016 36°00'30.47" N 110°42'10.53" W elev 5825 ft eye alt 20420 ft

Stop 9: Water Impoundment – Dry Farming

Group Discussion: Stop 9 presented an illustration of agricultural development in the arid region. Arroyos are partially dammed with earthen embankments to retain sufficient surface water and soil moisture to support a small farm plot. This practice occurs throughout the area.

Stop 10: Water Impoundment – Livestock Watering

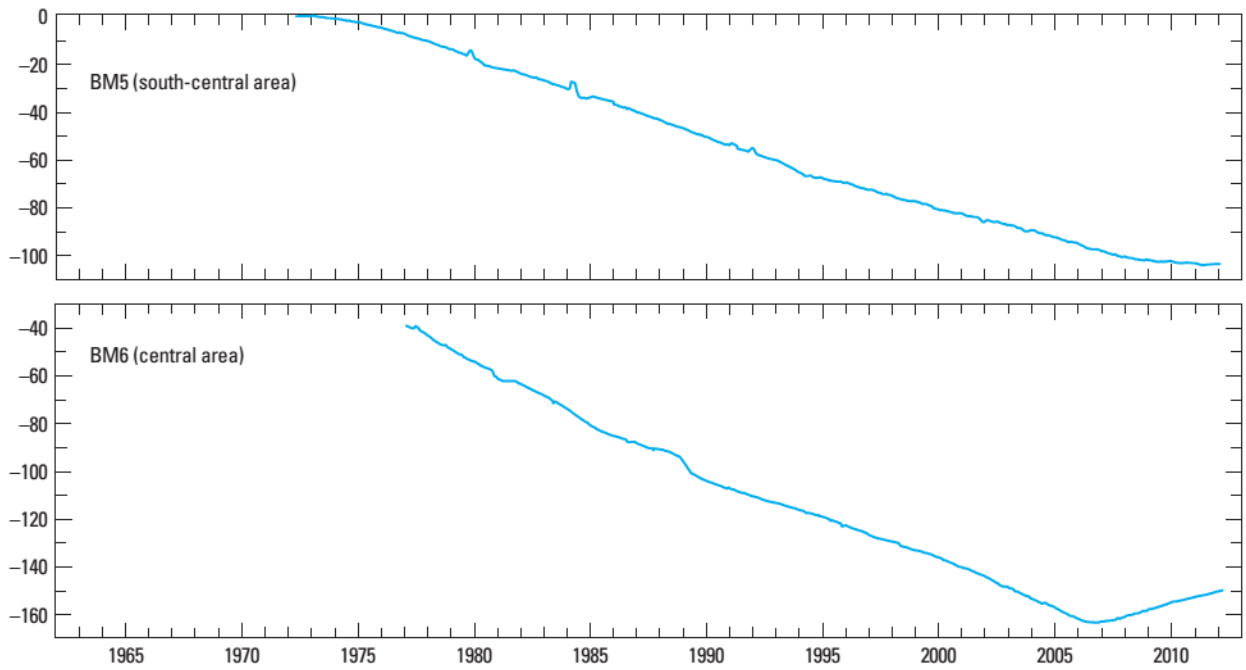
Group Discussion: Some arroyos are a sufficient size to support measurable surface water when impoundments are created. Stop 10 is located at an arroyo adjacent to Stop 9, yet standing water is available. Note: Google imagery collected on same date.

Stop 11: Dinnebito Dam

Group Discussion:

Pictured above is Dinnebito Wash, trending northeast-southwest. A tributary branch joins Dinnebito Wash. Agricultural development is apparent on the tributary but not on Dinnebito Wash. Similar to the dry farming technique discussed at Stop 9, farm plots in the tributary take advantage of the alluvial soil moisture, and implement earthen dams which route flow from the arroyo channel during storm flow events. The storm flow events on the main channel of Dinnebito Wash are too great a magnitude for sustainable agricultural development. Earthen road crossing structures such as Indian Route 5571 are often not sustainable. Indian Route 5571 is thought to be the location identified as Dinnebito Dam. A more modern paved highway with an engineered bridge crossing Dinnebito Wash is illustrated above and north of Indian Route 5571. See also the Dinnebito Wash discharge hydrograph illustrated below at Stop 14.

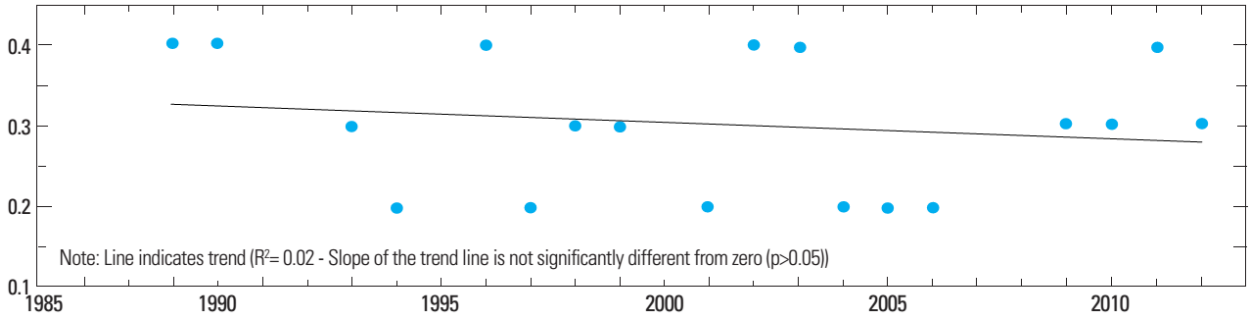
Stop 12: USGS Monitoring Well BM5



Group Discussion: All USGS BM-series monitoring wells are installed with satellite telemetry, and water level data is measured at 15-minute intervals and uploaded every 4-hours to the USGS webpage at: http://waterdata.usgs.gov/az/nwis/current/?type=gw&group_key=county_cd

BMOBS5 (BM5) is pictured below. The BM5 hydrograph indicates the Navajo aquifer is beginning to respond to PWCC reduced pumping, which occurred on January 1, 2006. BM6 is closer to the PWCC, and aquifer response to PWCC reduced pumping began in 2006.

Stop 13 (Spring Group C): Burro Spring

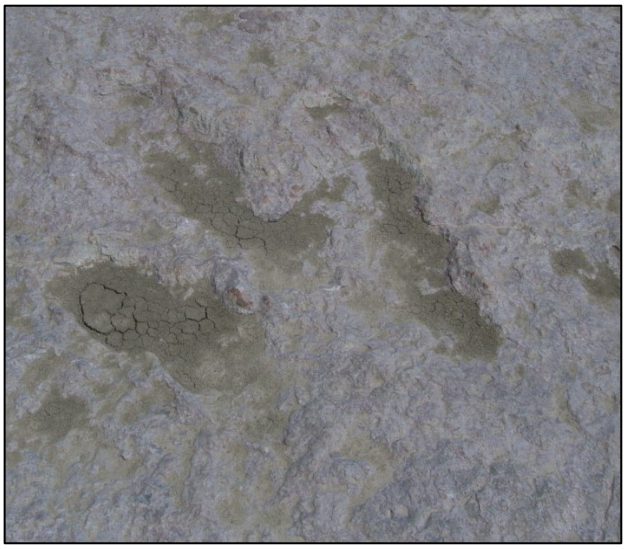


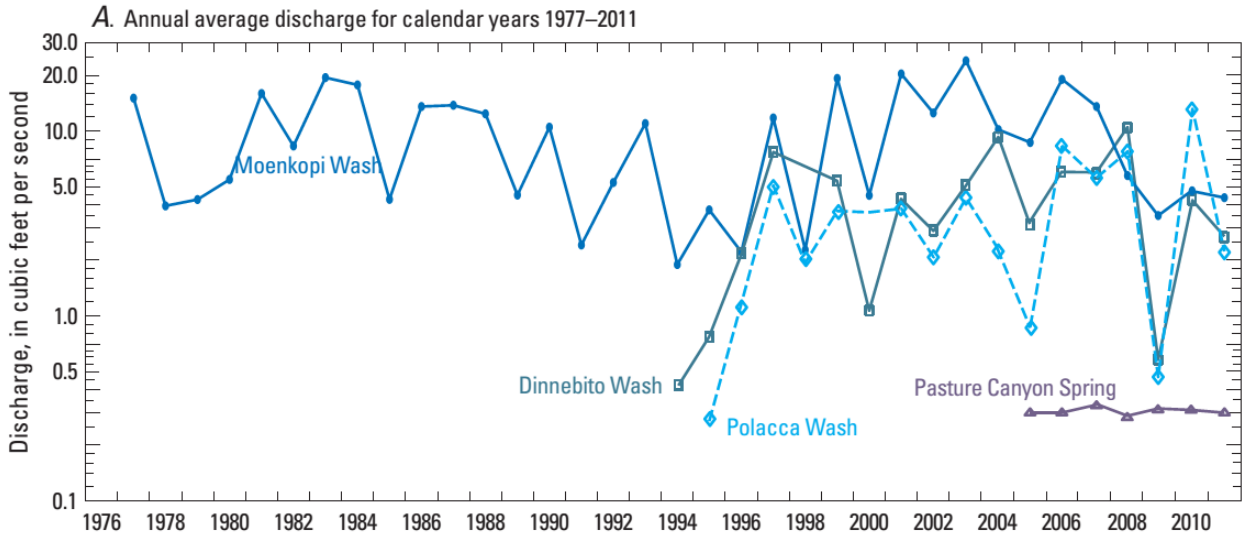
Burro Spring Location 09400568 discharge in gallons per minute (Macy and Unema, 2014)

Group Discussion:

Burro spring emanates from a sandstone outcrop approximately ¼ mile east of Oraibi Wash. The area is thought to be hydrologic isolated from confined N aquifer based on the topographic relief observed by the group. Two springs in the area are named Burro Spring. One Burro Spring is developed with a water tank, pictured above, and flows less than USGS monitored Burro Spring. The USGS monitored Burro Spring is identified by the well house pictured above. A seepage area was observed adjacent to the USGS monitored Burro Spring location, but the seepage flow was not monitored.

Stop 14 (Spring Group B): Polacca Wash





Polacca Wash flow relative to flow in other monitored washes in area (Macy and Unema, 2014)

Group Discussion:

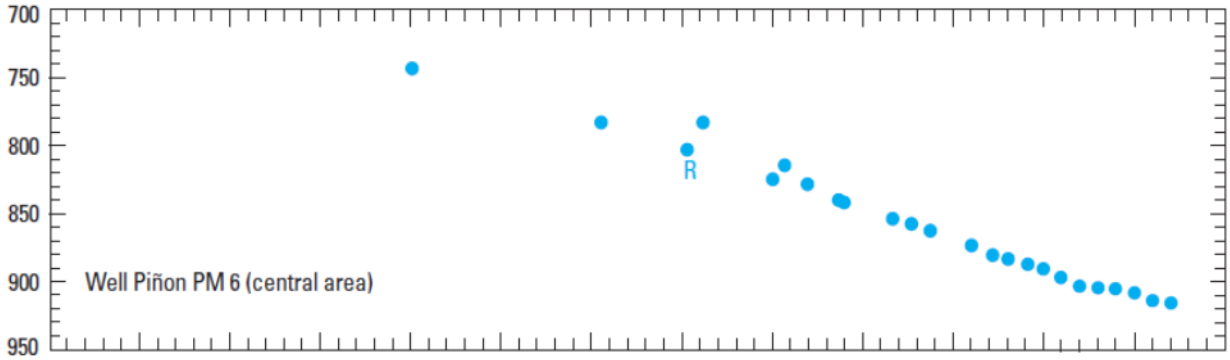
The discharge location is identified by the 1997 Hopi Tribe Water Resources Program marker. Dinosaur tracks on the cap rock adjacent to the marker indicate the Formation is associated with the lower Morrison Formation, and discharge emanates from the underlying Entrada Sandstone. The presence of a conglomerate layer also supports that the lithology is associated with the D aquifer system. Noticeable salts covered the channel, further indicating the discharge emanates from the poorer quality D aquifer system. The USGS monitoring station is equipped with satellite telemetry as illustrated above.

Stop 15: Flute Spring

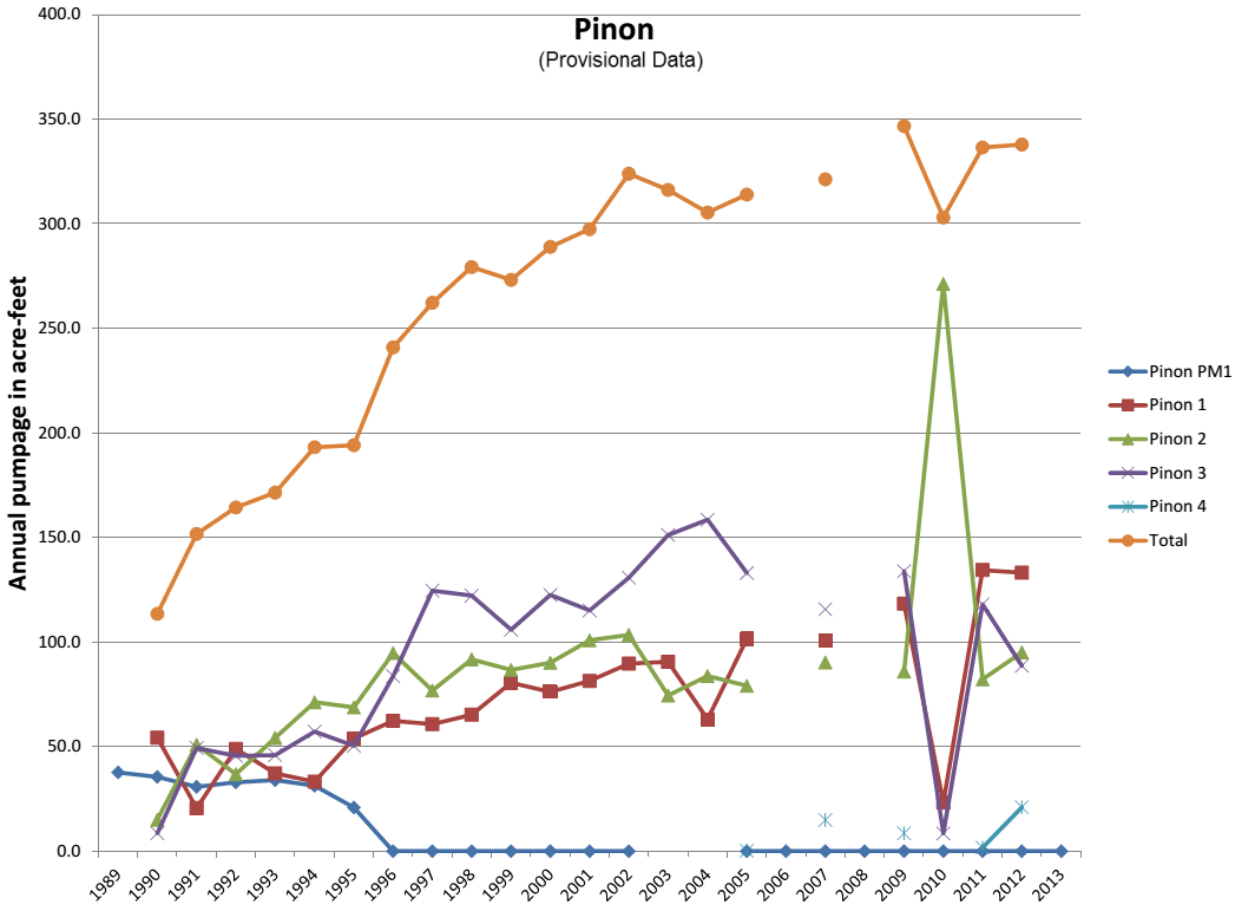
Group Discussion:

Flute Spring is near Second Mesa. Water has not been present at the spring from many years, but has been photographed with flute players sitting around the spring several decades ago. Locals report being able to dig down to expose the water, but the water table has dropped below the current depth. The depletion of water is thought to be attributable to PWCC N aquifer pumping; however, the spring location is positioned on the Toreva Formation. Spring depletion is likely attributable to a combination of climatic conditions and the influence of nearby Polacca pumping.

Stop 16: Pinon



Observed Water Level Measurements in feet below land surface (Macy and Unema, 2014).



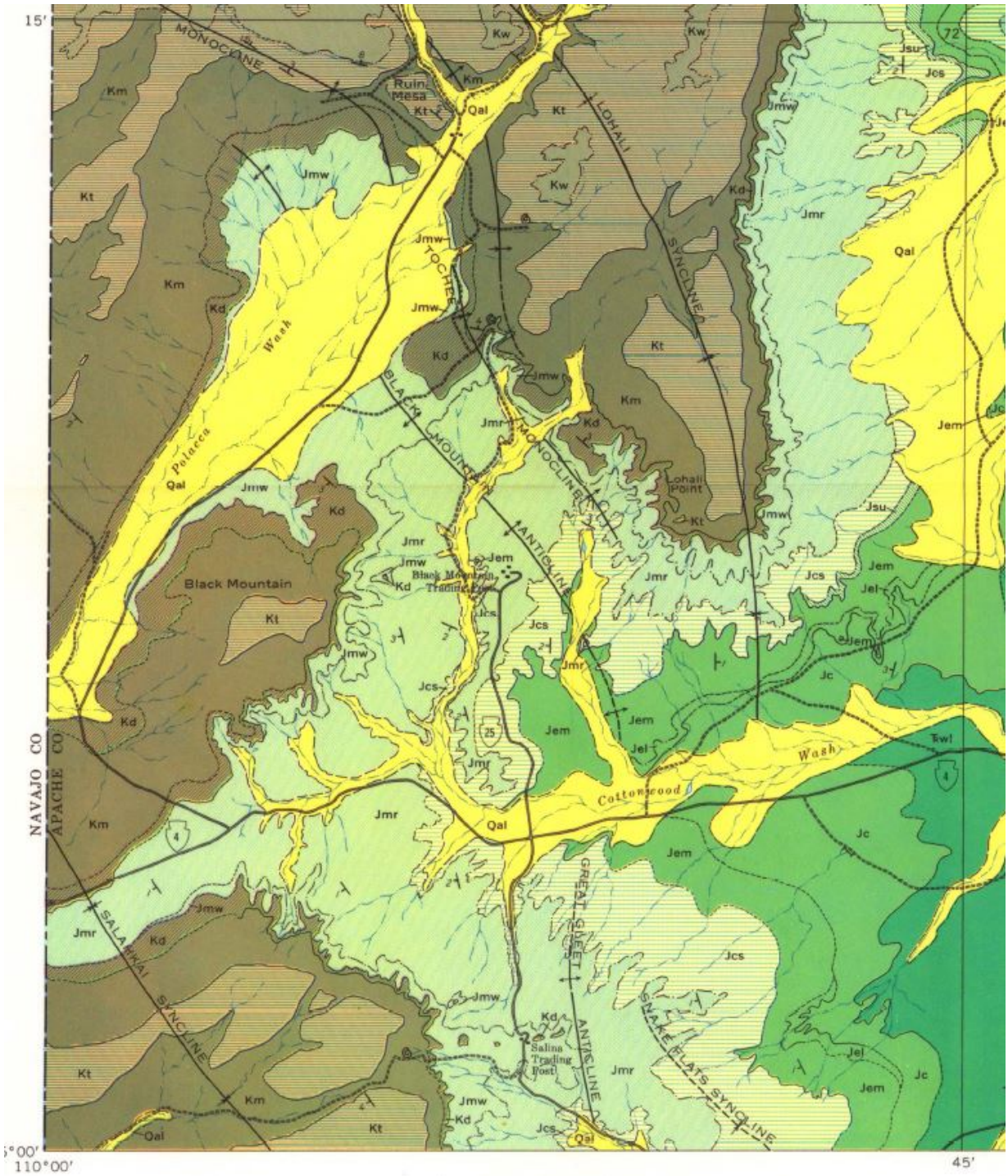
Group Discussion:

A highway closure prohibited the group from driving to Pinon.

Pinon is on a tributary headwater branch of Polacca Wash, and relies on a system of five (5) N aquifer wells for water supply. Water use tripled during growth and development from 1990 to 2000, and total use is beginning to stabilize at approximately 340 acre-feet per year. Pinon pumps the most water of all communities in the confined N aquifer, but was four (4) times less than PWCC industrial pumping of 1390 acre-feet in 2011.

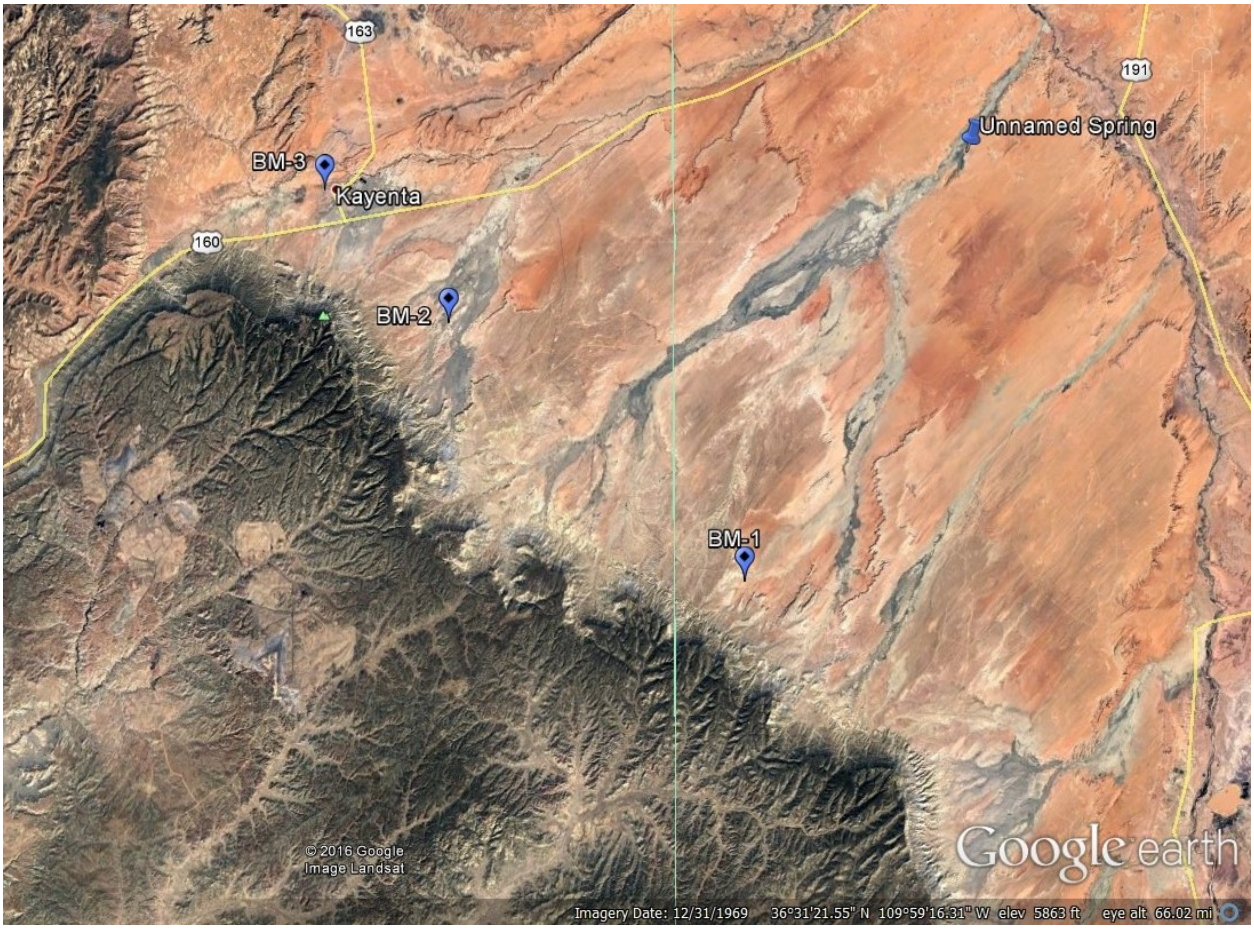
Stop 17 (Spring Group G): Blue Gap

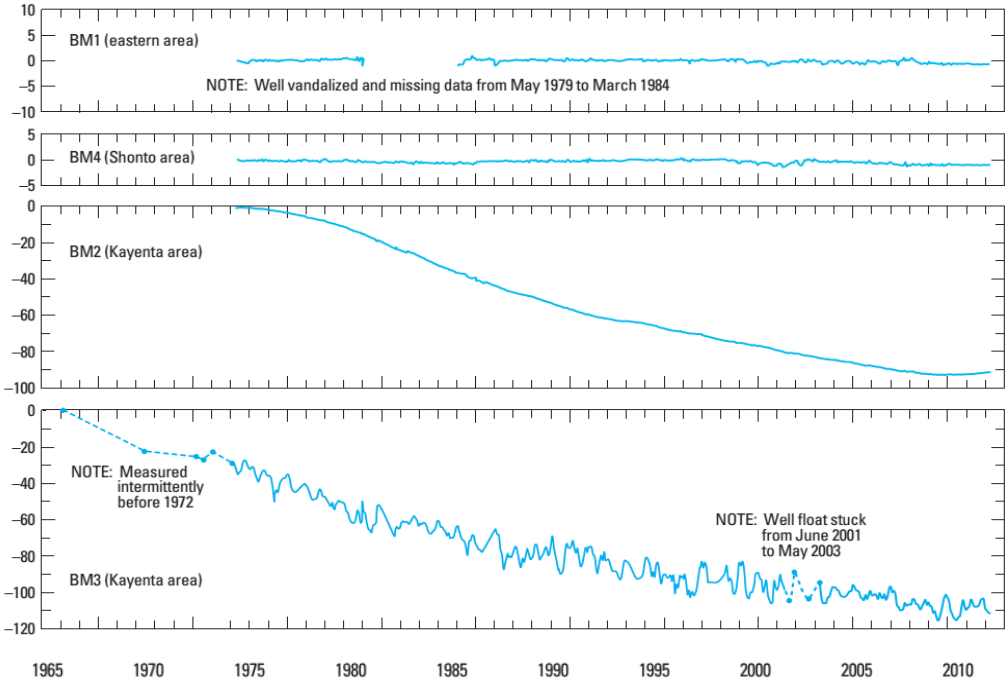
A highway closure prohibited the group from driving to Blue Gap.



Group Discussion: Blue Gap area was visited during public scoping meetings in June 2014. At that time, several narrow and quite deep fissures in the meadow area near the Blue Gap Chapter House were identified. The geology coverage indicates the area of fissures is underlain by Quaternary alluvium, which likely formed from valley fill associated with the Mancos Shale, the Westwater Canyon Member of the Morrison Formation, and some of the Dakota Formation. Fissures are likely associated with water piping through and eroding the alluvium during precipitation events.

Stop 18: USGS Monitoring Wells BM1, BM2, BM3

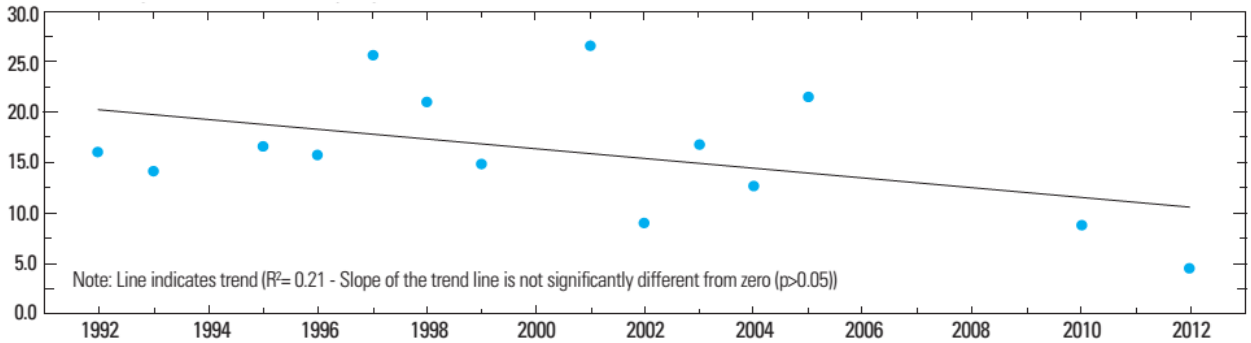




Group Discussion:

Plots of observed water-level changes in continuous-record observation wells BM1 – BM4 over 1963-2012 in the N-aquifer, Black Mesa area, northeastern Arizona (Macy and Unema, 2014) are provided above. Wells BM1 and BM2 are located in the confined area of the N aquifer and have experienced little water level change over the period of record. Well BM2 is in the confined N aquifer, and monitoring indicates the water level is beginning to respond to reduced PWCC pumping. Well BM3 is located in the town of Kayenta and monitoring illustrates the variable influence of Kayenta wellfield pumping.

Unnamed Spring near Dennhotso (Spring Group F1)

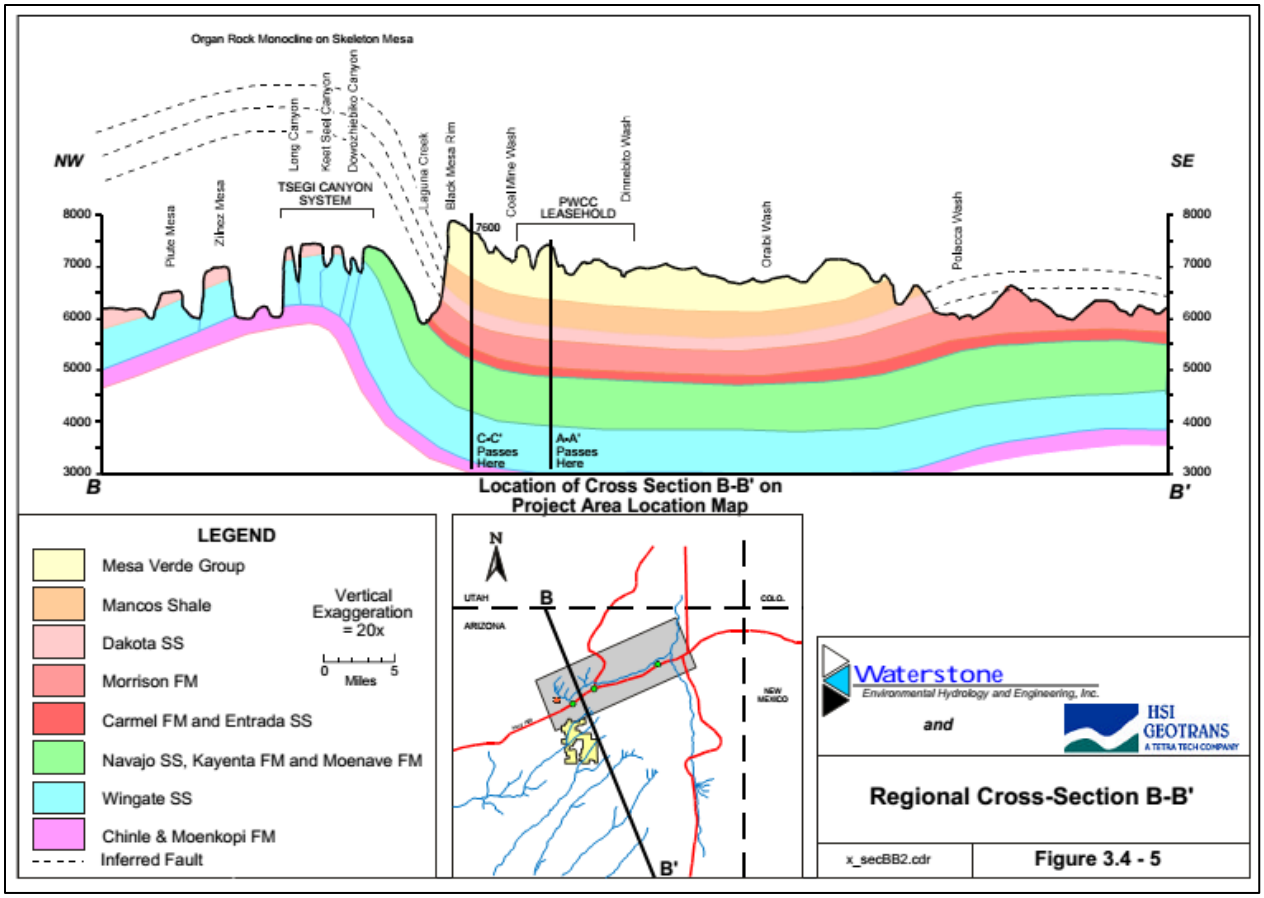


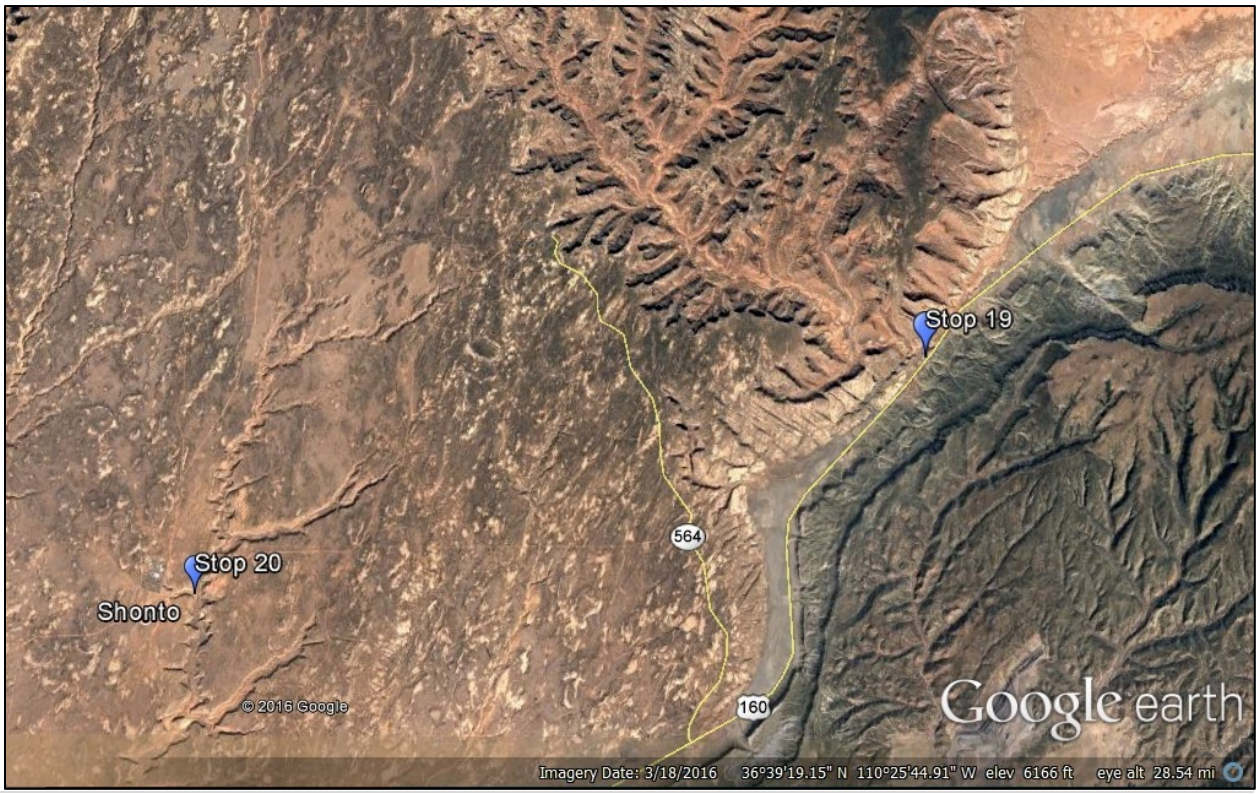
Unnamed Spring near Dennehotso discharge in gallons per minute (Macy and Unema, 2014).

Group Discussion:

Unnamed Spring near Dennehotso was not visited by the group; however, discussed in relation to the measured water levels at the BM-series monitoring wells. The spring location can only be accessed via ATV as migrating sand dunes have made the approach impassable in recent years. Although the trend line is not significantly different than zero at Dennehotso Spring, recent measurements are the lowest on record at the location.

Stop 19 (Spring Group E): Tsegi Canyon Recharge Area

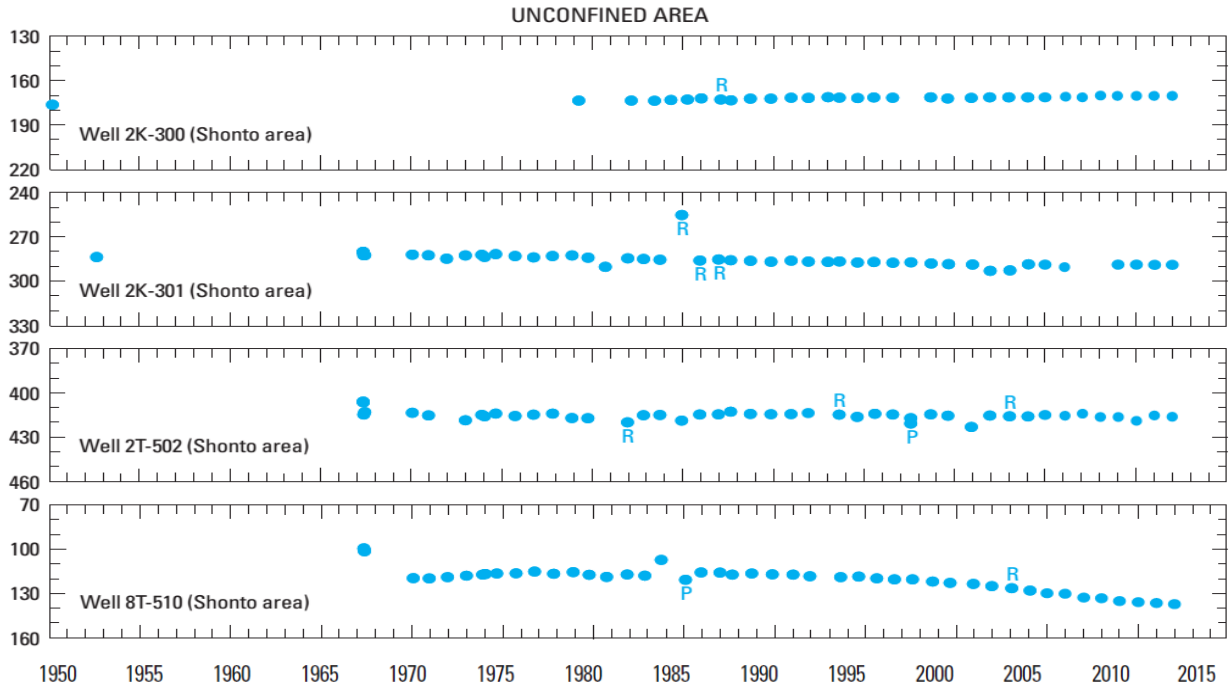

Organ Rock Monocline on Skeleton Mesa
NW
SE
Long Canyon
Keet Seel Canyon
Dowozhiebito Canyon
Laguna Creek
Black Mesa Rim
Coal Mine Wash
Dinnebito Wash
Oraibi Wash
Polacca Wash
Piute Mesa
Zibez Mesa
TSEGI CANYON SYSTEM
PWCC LEASEHOLD
7600
8000
7000
6000
5000
4000
3000
C-C' Passes Here
A-A' Passes Here
B
B'
Location of Cross Section B-B' on Project Area Location Map
LEGEND
Mesa Verde Group
Mancos Shale
Dakota SS
Morrison FM
Carmel FM and Entrada SS
Navajo SS, Kayenta FM and Moenave FM
Wingate SS
Chinle & Moenkopi FM
Inferred Fault
Vertical Exaggeration = 20x
0
5
Miles
N
UTAH
ARIZONA
COLO.
NEW MEXICO
Waterstone
Environmental Hydrology and Engineering, Inc.
and
HSI GEOTRANS
A TETRA TECH COMPANY
Regional Cross-Section B-B'
x_secBB2.cdr
Figure 3.4 - 5

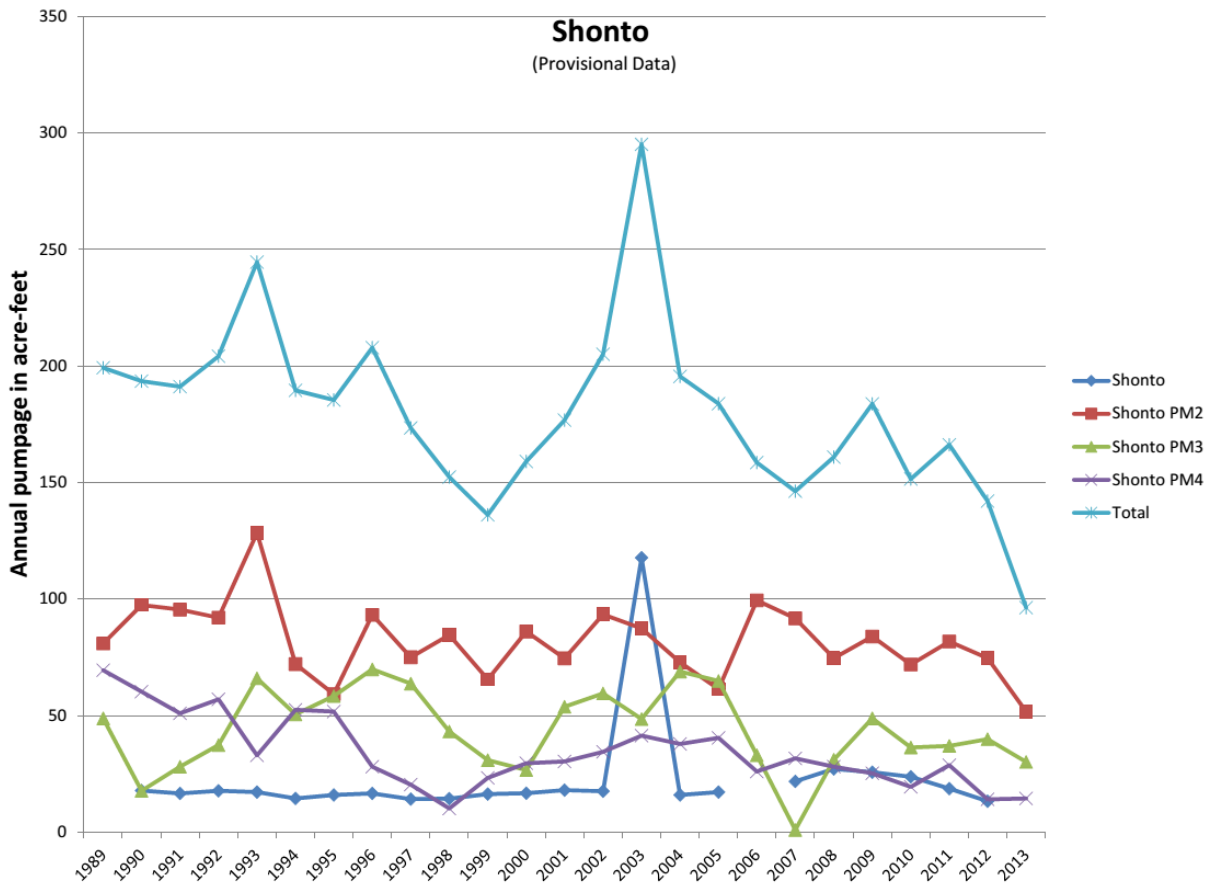

Stop 19
Stop 20
Shonto
564
160
© 2016 Google
Google earth
Imagery Date: 3/18/2016 36°39'19.15" N 110°25'44.91" W elev 6166 ft eye alt 28.54 mi

Group Discussion:

The structure of the Organ Rock Monocline facilitates recharge to the N aquifer north of Black Mesa. The first figure illustrates the dip of the Navajo Sandstone. The second figure a Tsegi Canyon illustrates the fracture pattern that allows hydrologic communication from the recharge area at Navajo National Monument to the N aquifer system. The cross section illustrates the lithology confining the N aquifer below the PWCC permit area. The aerial view illustrates the dendritic pattern of canyons incised in the Navajo Sandstone at Navajo National Monument, which with a major N aquifer recharge area. The surface water runoff is retained in the valley alluvium and recharged through fractures in the Navajo Sandstone. Pictured above is a view from the top of Black Mesa looking northeast. The view from Black Mesa illustrates the dip of the Navajo Sandstone, the valley alluvium where recharge predominantly occurs, and the PWCC coal conveyor belt in the foreground that conveys coal from the mine area to highway 160 where it is loaded on electric rail to Page, Arizona.

Stop 20 (Spring Group E): Shonto





Group Discussion:

A public water stand is available at Shonto for local water hauling. A fracture in the Navajo Sandstone creates as tributary from Navajo National Monument to Shonto, trending northeast to southwest. The tributary continues past Shonto, and becomes Begeshbito Wash, discussed at Stop 7. Begeshbito Wash ultimately joins Moenkopi Wash. Above, USGS monitoring from wells in the area (Macy and Unema, 2012) indicate little water level change over the period of record. However, well 8T-510 has recorded 36 feet of drawdown (Macy and Unema, 2012). Total groundwater pumping at Shonto is highly variable over the period of record since 1989, increasing from approximately 135 ac-ft in 1999 to approximately 300 ac-ft in 2002. Yet, the overall trend indicates a reduction in groundwater pumping over time, with the most recent measurement of approximately 100 ac-ft in 2013, the lowest during the period of record.

The headwater of the canyon picture above indicates good soil moisture in the valley alluvium based on productive vegetation. The interwoven pattern of trails in the picture is the product of a local corralling several horses in the canyon for livestock grazing.