HCC UTILITY DEPARTMENT
MAKING CONNECTIONS

NOTICE

The Utility Board will meet on Thursday, June 23rd ,2020 at 6:00 p.m. M.D.T.
At 320 East Newel Ave, Hildale UT 84784

AGENDA:

1. Call to Order
2. Prayer & Pledge of Allegiance
3. Public Comment
4. Approval of Meeting Minutes
5. Director Report
6. Consideration and Possible Action of FY 2021 Budget and Action Items
7. Consideration and Possible Action on Employee Bonus
8. Consideration and Possible Action on North Jessop Avenue Water Line Extension Project Funding
9. Discussion of COVID 19 Deferments
10. Review of Water Distribution Mainline Extension Policy
11. Review of Utility Vehicle Demarcation Policy
12. Review of Bowen & Collins Water Study
13. Adjournment
14. DOJ Constitutional Training

Agenda items and any variables thereto are set for consideration, discussion, approval or other action. The Utility Board may, by motion, recess into executive session which is not open to the public, to receive legal advice from the their attorney(s) on any agenda item, or regarding sensitive personnel issues, or concerning negotiations for the purchase, sale or lease of real property. Board Members may attend by telephone. The Agenda may be subject to change up to 24 hours prior to the meeting. Individuals needing special accommodations should notify the City Recorder at 435-874-2323 at least three days prior to the meeting.

HCC UTILITY DEPARTMENT

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Director's Report

June 2020

Hildale-Colorado City Utility Department

320 East Newel Avenue, Hildale UT 84784

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Account Update

Number of accounts billed for May 2020:

Water base rate	890
Sewer	833
Gas base rate	688
Water Penalties	469
Gas Penalties	354

of COVID-19 Deferments 23

of shut off notices printed May 15, 2020 193

of final billed accounts with final bill date in May is 8

of new connect accounts in May is 6

COVID-19 Pandemic Operational Response

The Department has suspended operational measures for the current time, and our office has reopened to the public.

COVID-19 Pandemic Financial and Billing Response

Our total billing amount is now over $13,000 for deferments.

Operational Planning

The Department is preparing an operational plan that will highlight critical needs within the next fiscal year.

Compliance Assistance Program

The Department has completed its first compliance case involving theft of services to an agreeable solution. Taylor's efforts in his investigation were an invaluable tool in ensuring that correct and complete information was available. Additionally, his personal demeanor and professionalism deserves our gratitude.

Water Project-Rights Discussion

The Department has completed preliminary water project financial analysis and will be distributing it to all the relevant parties. Additionally, we've started discussions with the Division of Drinking

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Hildale, UT 84784

Water, the United States Department of Agriculture, and some private organizations on project funding mechanisms.

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Operations Manager's Report

May/June 2020

Hildale-Colorado City Utility Department

320 East Newel Avenue, Hildale UT 84784

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Operations Summary

Three tank Propane customers on East Mohave have been converted to metered propane.

We installed a fiber optic conduit along Mohave east of Central Street. We are currently installing a conduit on the west of Central. We spent considerable time getting residences connected to fiber in Hildale, as well as setting up our switch gear for the ISP network.

On the water system we have pulled the pumps on wells 17 & 19. We will plan on cleaning the well screens before putting the pumps back in.

The treatment ponds levels have been dropping with the heat, we may have to add additional water to keep the levels up. We will have to repair a pump in order to push storage water back to the upper ponds.

Safety Program Implementation

Ongoing use of traffic signs, cones, and barricades.

Training Objectives

Ongoing covered task training for gas system operators.

Repairs and Maintenance

1000ft of sewer main cleaned and videoed.

Pulled pumps on well 17 and well 19

Operational Gas System Projects

We will be completing the gas customer connections on Redwood St.
Completing monitor for distribution gas system pressures on Richard St.

Operational Water System Projects

Clean well screens and replace pumps in Well 17 and Well 19.

Add VF drive and well controls to Academy Ave well.

Operational Sewer System Projects

Repair pumps at Sewer plant.

Repair manhole on A-Line (supplies are on hand)

Operational Fiber/Communication Projects

Upgrading fiber to lab shop, repairing fiber link to well 22. Installing fiber conduit to sewer plant.

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Installing fiber communications to Academy Ave well.

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To: Hildale-Colorado City Utility Board

From: Harrison Johnson

Date: May 18th, 2020

Subject: End of Year Employee Bonuses

Due to the significant budgetary surplus of employee compensation I would like propose the following employee bonuses:

- Department Managers (Director, Operations Manager, Superintendents and Administrative Managers): $3,000 x 4 employees
- Technical and Administrative Staff: $2,000 x 6 employees

Total cost to the Department: $24,000

Coded to 65-41-110

Harrison Johnson
Director
Hildale-Colorado City Utility Department

HCC UTILITY DEPARTMENT

MAKING CONNECTIONS

Water Distribution Mainline Upgrade and Extension Funding Policy

V.01 061820

Hildale-Colorado City Utility Department

320 East Newel Avenue, Hildale UT 84784

Department Objective

The Department's objective is to effectively upgrade and extend mainline services to residents while maintaining lower costs for rate payers as a whole. Additionally, as distribution mainline upgrades and extensions tend to singularly benefit only a specific geography, this policy will ensure that neither Hildale nor Colorado City will receive unbalanced benefits from infrastructure spending.

Policy

Article I.- Distribution Mainline Defined

This policy shall cover retail connected water mainline extensions and upgrades that are NOT part of a separate development agreement. This policy will cover extensions or upgrades regardless of whether they are a result of regulatory requirements. This policy may cover mainline repairs or upgrades that occur as part of a repair.

Article II.- Cost Burden

In the application of every mainline extension or upgrade covered under this policy, the Department shall make every effort to place the cost burden upon those customers who are receiving the benefits.

Article III.- Extension and Upgrade Funding

For upgrades and extensions under this policy, the Department may expense the entire project cost onto the affected customer through an applied fee to their utility bill or through payment form from the property owner(s).

The project cost may include the following items:

- Engineering
- Administration
- Financing Fees
- Materials
- Equipment
- Labor

Article IV.- Upgrades, Repairs and Maintenance Not Applicable

Generalized expenditures that do not include mainline extensions or upgrades may include, but are not limited to fire hydrants, and water meters.

Implementation

Department Management will primarily responsible for preparing an authorizing water mainline extension.

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Impact Assessments

Legal

(Insert Legal Comments Here)

Financial

This policy will ensure that responsive and equitable funding for area and city specific distribution upgrades occur for our joint system. Essentially, we are ensuring that operational or capital funds borne by the whole of all rate payers will be burdened by area specific improvements.

Operational

This is mostly an administrative policy and will likely have little effect on operations lower than the Department Management level.

IGA

Perhaps the impetus of this policy, ensuring equitable funding across the system that does not unfairly benefit one political body or the other is its primary goals.

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Utility Department Vehicle Demarcation Safety Policy

V.01 052720

Hildale-Colorado City Utility Department

320 East Newel Avenue, Hildale UT 84784

HCC UTILITY DEPARTMENT
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Department Objective

The Department's Objective is to enhance the safety and presence of our staff in our community through vehicle information and high visibility demarcation.

Policy

Article I.- Utility Vehicle Assignment

The Department shall assign vehicles in three classes.

I. Class I-Administrative/Office Vehicles: These vehicles are acquired to assist in transportation of administrative staff and are not intended for assisting in field operations.
II. Class II-Field Operating Vehicles: These vehicles are primarily acquired to provide transportation and assistance to field technicians on roadways and project sites.
III. Class III-Emergency/Special Operating Vehicles: These vehicles have special primary purposes that include emergency gas operations, fiber repair, and the sewer maintenance.

Article II.- High-Visibility Demarcation Requirements

All Class II vehicles shall have high-visibility panels placed the rear of the vehicle so as to warn drivers coming from the rear to proceed with caution. Additionally, high-visibility marking shall adorn both the driver and passenger side of the vehicle where practical.

Class III Vehicles shall have high-visibility markings where practical.

Article III- Lights Usage

All Class II vehicles and street operating Class III vehicles shall be equipped with flashing yellow, white, green and/or red lights on the front and rear of the vehicle. Class I vehicles shall only be equipped with flashing lights with authorization from the Director for operations in public roadways only.

All vehicles shall activate their flashing lights when required by local, state and federal safety regulations, and when performing operations in a roadway in which the vehicle or personnel are acting in a manner NOT consistent with regular traffic patterns.

Article IV-Department Identification and Information

All vehicles shall have the following information on the drivers and passenger side of the vehicle so as to be visible to the public:

- Hildale-Colorado City Utility Department
- HCCUD Icon
- Office Phone Number
- On-Call Emergency Number

All vehicles shall have an 811 Digging reminder on one or both sides of all Department vehicles.

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Hildale, UT 84784

Article V- High-Visibility Demarcation and Department Identification and Information Design Approval

All designs for high-visibility, Department Identification and Information will need prior approval by the Director before purchase.

Impact Assessments

Legal

(Insert Legal Comments Here)

Financial

The cost of implementation will be less than $2,500 in total.

Operational

Ideally this would increase the Department's visibility in the community and increase the safety for our technicians as they conduct work on the public roadways.

IGA

N/A

320 East Newel Ave
Hildale, UT 84784

Draft Print
05/25/2020 9:50:02 AM

FEASIBILITY STUDY

For the Hildale Groundwater System

Prepared For:

Hildale City
320 East Newel Avenue
Hildale, Utah 84784

Prepared by:

Bowen, Collins & Associates, Inc.
154 East 14075 South
Draper, Utah 84020

May 2020

Consultant Job No. 632-19-01

FEASIBILITY STUDY

For the Hildale Groundwater System

Prepared by:

Bowen, Collins & Associates, Inc.
154 East 14075 South
Draper, Utah 84020

May 2020

Consultant Job No. 632-19-01

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EXECUTIVE SUMMARY

This report presents the results of a feasibility study for developing a new groundwater source to provide drinking water to Hildale City (City). The City contracted with Bowen Collins & Associates (BC&A) to conduct the feasibility assessment. Hildale City is located in Washington County, Utah just north of the Arizona border.

PURPOSE OF FEASIBILITY STUDY

The purpose of the study was to evaluate the feasibility, costs, and challenges of developing a new alternate groundwater supply source in existing or new aquifer sources for the City's drinking water. The City's drinking water need and goal for the study is to identify a new 1,200 gallons per minute (gpm) source. The study area includes land that is owned by the Bureau of Land Management (BLM), Hildale City, and other private landowners. Results from the study will be used by the City to determine whether updating the water treatment plant or developing a new groundwater source is a more viable alternative. The initial scope was to focus on the Navajo Aquifer in the study area, however, the study was expanded to include the Kayenta and Moenave Aquifers to provide additional options to the City.

GROUNDWATER RESOURCE EVALUATION

Evaluation of groundwater resources focused on three aquifers in the study area, the Navajo Aquifer, and the Kayenta and Moenave Aquifers. Regional hydrogeologic studies indicate the Navajo and Kayenta aquifers provide drinking water for southwestern Utah, however there is significant variability in the well yield from these aquifers depending on location. There is very little local data or existing wells completed in the Navajo, Kayenta and Moenave Aquifers in the study area. There was one deep well drilled by the City in Maxwell Canyon in 1994. The Well was drilled to a depth of 1,100 feet deep but did not produce significant water and was abandoned. The well was not located at any of the drill sites targeted by geophysical surveys conducted for this study.

Water samples were obtained from the City's spring sources at the base of the Navajo Formation in Maxwell and Water Canyons for age dating analysis and basic geochemistry parameters. Both samples indicate high quality groundwater with low total dissolved solids (TDS) concentrations. The Maxwell Canyon sample had a TDS concentration of 84 mg/L, and the Water Canyon sample had a TDS concentration of 68 mg/L. Both samples indicate the water is suitable for drinking water use without treatment.

The age of the water is an important factor in sustainability of the source. The older the water, the less likely it is replenished seasonally or even annually. Conversely, the younger the water the more readily available and "sustainable" the water source is likely to be. Age dating results indicated that the waters were not modern with an estimated age of between 70 and 1,000 years old. The tritium results indicate the average age of the water is older than 1950. The upper age limit of 1,000 years is uncertain due to the possibility of gas exchange (loss) during sample collection. The lower age limit estimate of 70 years is due to the low values of tritium present in the samples. The measured values are much lower than present day tritium concentrations that are elevated due to atmospheric testing of nuclear weapons. None of the noble gas, CFC's or SF_6 concentrations indicated that the groundwater had a very modern signature of less than 5 years old. There is no available water quality data for the Kayenta and Moenave Formations in the study area.

Geophysical surveys were conducted in Jans, Water, Maxwell, and Squirrel Canyons, and across the top of Navajo Formation between Maxwell and Water Canyons. The surveys consisted of a lineament

study showing surface fractures in the Navajo sandstone, a lightning resistivity model that shows deep geologic structural trends, a passive seismic survey that measures resonant properties of the rock to detect fractured and weak bedrock, and a radiometric gamma survey that indirectly measures for the presence of water in the rocks. Results of all the surveys were overlain and evaluated to identify the target locations for future wells. From the geophysical survey a total of 56 prospective locations in the Water Canyon, Maxwell Canyon, Squirrel Canyon and Canaan Mountain were identified. These were reduced to five highly prospective "zones" in order to identify preferred targets for future wells. Zones 1, 2, and 3 are preferred targets for vertical wells in the Kayenta and Moenave Aquifers. Zone 1 is located near the Squirrel Canyon Trailhead at the bottom of Water Canyon. Zone 2 is located near the City's Maxwell Canyon spring source. Zone 3 is located near the Water Canyon Reservoir and trailhead. Zones 4 and 5 are the preferred targets for horizontal wells completed in the Navajo Aquifer at the base of the Navajo Sandstone walls that rise above Hildale. These zones would require horizontal borings to intercept the fractured zones indicated by the geophysical survey. BC&A recommends of these horizontal well targets be drilled using the same starting location (drill pad) in Water Canyon in order to minimize access road and drill pad construction costs.

BC&A evaluated the potential yield from horizontal wells completed in the Navajo Aquifer. BC&A used a hydraulic conductivity value of 5 ft/day to represent the expected value for the Navajo Aquifer at the target zones. We believe this is a reasonable expected value based on the geophysical surveys identifying fractured rock at the target zones. BC&A evaluated the potential yield of a 10-inch diameter horizontal borehole completed with 2,000 feet of well screen in the Navajo Aquifer. The calculation indicates that 1 horizontal well would be capable of producing at least 1,200 gpm if there was 50 feet of water in the aquifer above the well screen elevation. Two horizontal wells would be required if there was only 25 feet of water above the screen. The results indicate that 1 or 2 horizontal wells completed in Navajo would be capable of producing 1,200 gpm.

BC&A evaluated the potential yield from vertical wells completed in the Kayenta Aquifer. BC&A used an aquifer transmissivity value of 2,000 ft^2/day for the evaluation that was based a saturated aquifer thickness of 400 feet and a conductivity of 5 ft/day. We believe these are reasonable values based on regional hydrogeologic studies and the geophysical surveys identifying fractured rock. BC&A evaluated the potential yield of a 12-inch diameter vertical well completed in the Kayenta and Moenave Aquifers. The results indicate a vertical well would be capable of producing 250 gpm with a pumping level about 160 feet below ground surface. From this finding, we estimate it would require 5 wells to achieve the project goal of a 1,200 gpm supply.

BC&A evaluated the recharge to the Navajo Aquifer. An average of 13-inches of precipitation falls on the Canaan Mountain Wilderness area annually. Regional studies of the Navajo have shown that infiltration rates vary from 1- to 20-percent of the annual precipitation. BC&A used a recharge rate of 12.5-percent of annual precipitation. We believe this is reasonable and representative estimate based on site conditions of an exposed bedrock surface on Canaan Mountain/Plateau and the presence of fractures. Using 12.5-percent of the annual precipitation results in a recharge rate of 1.63-inches per year. For the entire exposed top of the Navajo Formation in the Cannaan Mountain Wilderness Area we estimate a surface area of about 11,000 acres. Using the recharge rate of 12.5-percent of the annual precipitation results in an annual aquifer recharge volume of 1,450 ac-ft of water. The City requires a groundwater supply of 1,200 gpm which equates to about 1,900 ac-ft/year on a year-round basis. From this analysis it is apparent the recharge volume for the entire exposed top of the Navajo Formation in the Canaan Mountain Wilderness Area (1,450 ac-ft) is less than the City's annual water need (1,900 ac-ft). Not all of the infiltrated water will recharge the Hildale side or south side of the Canaan Mountain where horizontal wells would be located. BC&A estimates the

area of influence for potential future horizontal wells installed in Water Canyon to be 800 acres, with an annual aquifer recharge volume of only 110 ac-ft. The potential to extract more groundwater than is annually recharged raises concerns about the sustainability of the aquifer. Further analysis of the deficit between the recharge and withdrawal volumes indicates that aquifer water levels would decline about 9 ft/yr over the 800-acre area. Based on this finding we have concern about the long-term sustainability of horizontal wells tapping the Navajo Aquifer.

BC&A qualitatively evaluated the recharge to the Kayenta and Moenave Aquifers. The estimated recharge area for the Kayenta Aquifer includes the recharge area of the overlying Navajo Sandstone itself, and the surface areas of the Jans, Maxwell, Water, and Squirrel Canyons and surroundings low lying areas. Therefore, the recharge area and the recharge volume to the Kayenta Aquifer is larger than that of the Navajo Formation. In addition, portions of the Kayenta and Moenave Aquifers are buried beneath ground surface and therefore have a larger aquifer saturated thickness and aquifer storage volume from which to draw water. The saturated thickness of the Kayenta and Moenave Aquifers is greater than that estimated for the Navajo Aquifer. While we have not attempted to quantify recharge to the Kayenta Formation, it is our finding that the Kayenta and Moenave Aquifers have both a larger annual recharge volume and larger storage volume than the Navajo Aquifer. We conclude the Kayenta and Moenave Aquifers are a better option with a higher likelihood of success for developing a 1,200 gpm groundwater supply.

CONCEPTUAL ALTERNATIVE ANALYSIS

BC&A evaluated two alternatives for developing a new 1,200 gpm groundwater source for the City:

- Deep vertical wells completed in the Kayenta and Moenave Aquifers
- Horizontal wells completed in the Navajo Aquifer

Because the study did not find hard evidence of sustainable groundwater source in the Navajo, the feasibility of success was estimated based on our professional opinion.

CONCEPTUAL COST SUMMARY AND OPINIONS

Results of the study were used to identify and prioritize potential sites for groundwater wells. A total of five priority sites were identified, including three vertical well sites and two horizontal well sites.

Conceptual cost estimates were developed for the alternatives water sources described in Section 3 of this report. Detailed cost information is included in Appendix D for reference. Any single alternative does not necessarily provide a full replacement to the water system. It is recommended to take a phased approach with the alternatives listed to construct a low-cost vertical well in an accessible location first. This would allow for data collection and aquifer characterization. Once this was complete a decision can be made on whether to continue to build out the alternatives if sufficient water is discovered.

Costs estimates for all options that were evaluated are included in Table ES-1 on the following page.

2. Conduct a limited exploratory well drilling program to determine the water quality and yield. Use information from the exploratory drilling program to determine the feasibility of creating a new 1,200 gpm water supply.
3. Proceed to phased approach in installing production wells.

Reducing the gap in the age range of the water or potentially defining a more precise time may be possible by performing carbon-14 age dating at the two locations previously analyzed for water produced from the Navajo Sandstone. The City may want to pursue this analysis in the event Alternative 2, horizontal wells, is chosen. No special sampling method is required and may be performed by City personnel. A lab located at the University of Utah has the capabilities to perform the analysis in the event this alternative is selected.

SECTION 1
INTRODUCTION

This report presents the results of a feasibility study for developing a new groundwater source to provide culinary water to Hildale City (City). The City contracted with Bowen Collins & Associates (BC&A) to conduct the feasibility assessment. Hildale City is located in eastern Washington County, Utah just north of the Arizona border. Figure 1 shows the location of the study area to the north of the City.

PURPOSE

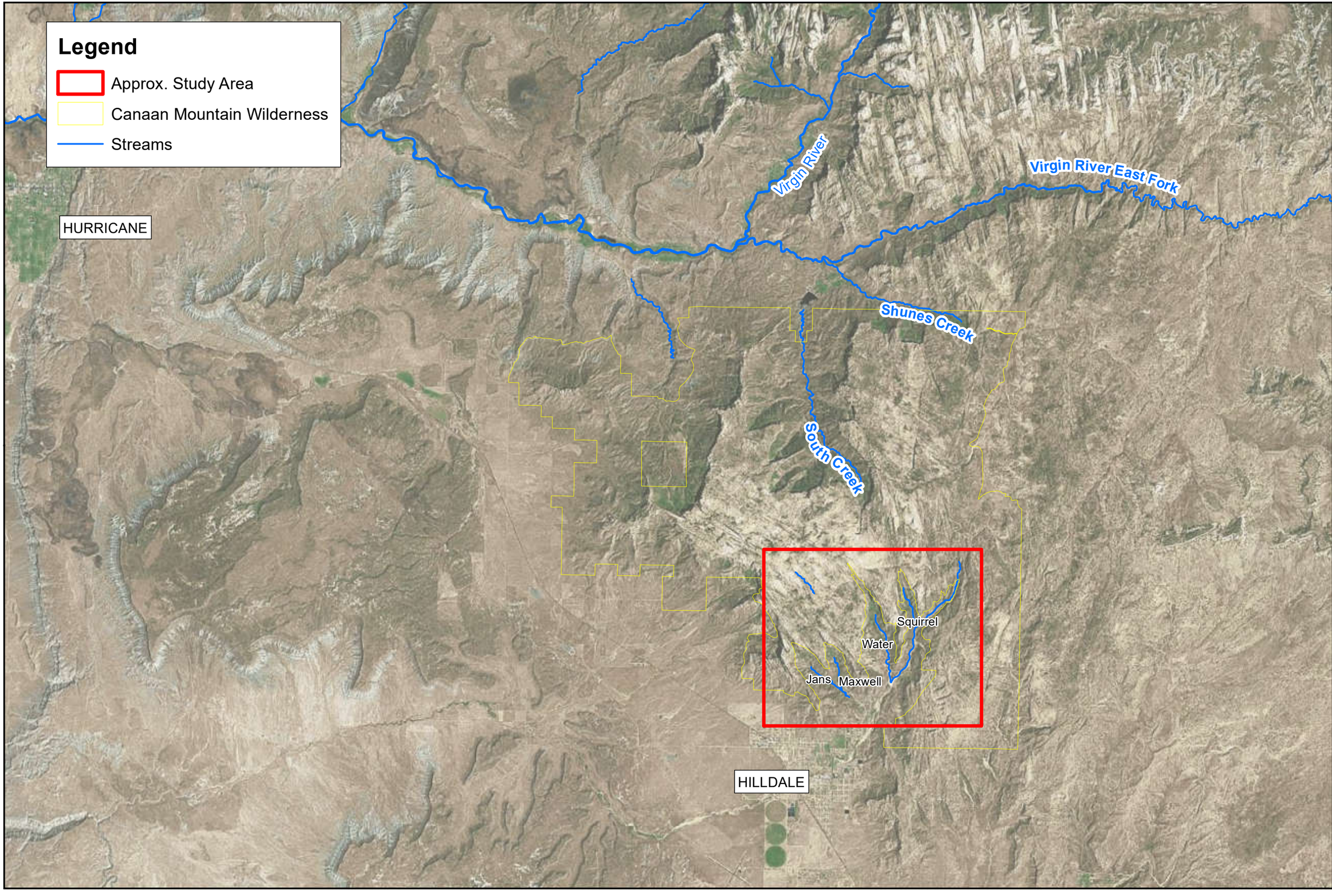
The purpose of the study was to evaluate the feasibility, costs, and challenges of developing a new alternate groundwater supply source in an existing aquifer for the City's drinking water. The City's drinking water need and goal for the study is to identify a new 1,200 gpm source. The study area includes land that is owned by the Bureau of Land Management (BLM), Hildale City, and other private landowners. Results from the study will be used by the City to determine whether updating the water treatment plant or developing a new groundwater source is a more viable alternative. The initial scope was to focus on the Navajo Aquifer in the study area, however, the study was expanded to include the Kayenta and Moenvave Aquifers to provide additional options to the City. The study area includes Canaan Mountain area where the Navajo Formation is exposed, along with Jans, Water, Maxwell, and Squirrel Canyons. A goal of the project was to conduct geophysical surveys to characterize the hydrogeologic conditions and identify preferred drill sites for future wells.

BACKGROUND

The City contracted with BC&A to evaluate the feasibility of developing a new groundwater source to provide drinking water to the City. An overall site map of the study area is provided in Figure 1. The study area includes land that is owned by Hildale City, the Bureau of Land Management (BLM), and other private landowners. BLM land is designated the Canaan Mountain Wilderness Area.

The City plans to either update its existing water treatment plant to treat water produced from the Shinarump Aquifer, or develop a new alternate groundwater supply source in a different aquifer. The City currently relies on deep wells in the Shinarump Aquifer for a portion of its drinking water. The Shinarump Aquifer wells contain levels of radium that require the City to update the water treatment plant to continue to use them for drinking water. BC&A has been tasked with evaluating the feasibility and conceptual costs of developing an alternate groundwater supply source in the study area. The City's drinking water supply need and goal for the study is to identify a new 1,200 gpm groundwater source.

In addition to its Shinarump Aquifer wells the City uses wells completed in a shallow alluvial aquifer in the City. The alluvial aquifer wells are reportedly high in iron, and have low yields in the 10-200 gpm range. The City also obtains a small portion of its drinking water from spring sources located high up in Maxwell and Jans Canyons. These spring sources consist of shallow horizontal collector pipes that collect water seeping out of the ground at the base of the Navajo Sandstone. The Jans and Maxwell Canyon spring sources produce very high quality water that would not require water treatment for use as drinking water. Because of the very high water quality of these sources, an initial concept for the project was to drill horizontal wells that penetrate into the Navajo Formation to increase the amount of water that can be obtained. The study was expanded to include aquifers that underlie (are deeper than) the Navajo Aquifer, namely the Kayenta and Moenave Formations.



SCALE: 1 in. = 10,000 ft.

NORTH: NORTH

REGIONAL OVERVIEW: APPRIXMATE STUDY AREA BOUNDARY

HILLDALE CITY
GW FEASIBILITY STUDY

BOWEN COLLINS & ASSOCIATES

FIGURE NO.
1

S:\Hildale City\632-19-01 Groundwater Feasibility Study\4.0 GIS\4.1 Projects\Figure 1 - Overview Map.mxd cdekover 5/12/2020



Photo looking north in Water Canyon at the numerous springs that discharge at the lower boundary of the Navajo Sandstone into Water Canyon.

GEOLOGIC SETTING

Hilldale City is located approximately 40 miles east-southeast of St. George, Utah in Washington County. The City is approximately one mile to the south of the Canaan Mountain Wilderness Area and the Vermillion Cliffs of southwestern Utah. The Hilldale region is known for the spectacular Vermillion Cliffs that consist of sandstone and siltstone outcrops of the Jurassic age Navajo Sandstone Formation, and the underlying Jurassic age Kayenta Formation and Triassic age Moenave Formation. The cliffs have nearly 2,000 feet of vertical relief and are deeply incised by surface runoff directed through the fractured sandstone carving deep river valleys like Water, Jans and Maxwell Canyons. Fractures in the sandstone are near vertical sets with two primary orientations; NE-SW and NW-SE. Structurally, the sedimentary formations are characterized by gently dipping strata that dips to the N-NE about 1-3 degrees. Regional faulting in southwestern Utah includes the Hurricane, Sevier and Paunsaugunt faults. These are nearly vertical normal faults with large offsets up to 2,000 feet. These faults are known to completely offset stratigraphic units and have been noted to suppress groundwater flow across the fault zone. Figure 2 shows the geology of the study area in relation to the City and the major Canyons investigated in the study.

Figure 2A shows a cross section line A-A' intersecting Jans, Maxwell, and Water Canyon with associated faulting, thicknesses and stratigraphy of the layers. Locally, in the study area, the geology includes outcrops of the Moenave Formation, the Kayenta Formation, and the Jurassic Navajo Sandstone Formation. Quaternary alluvial deposits are present in the canyons and stream beds in the study area. The Triassic Chinle Formation underlies the Moenave Formation beneath Hildale and consists of the upper Petrified Forest member and the lower Shinarump conglomerate member. The Shinarump has historically been targeted and used as aquifer in Hildale as it has high porosity and permeability. Descriptions of each of the formations, and corresponding label, from oldest to youngest is provided below.

LEGEND

- Crosss_Section_Line
- Fracture_Traces
- Canaan Mountain Wilderness

SCALE: 1 in. = 4,552 ft.

NORTH: NORTH

GEOLOGIC MAP FRACTURE TRACES

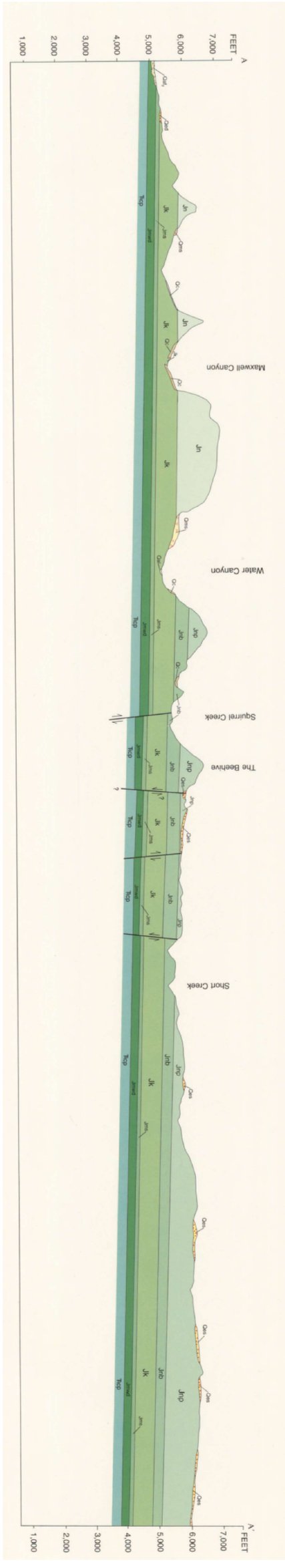
HILLDALE CITY

GW FEASIBILITY STUDY

BOWEN COLLINS & ASSOCIATES

FIGURE NO. 2

S:\Hildale City\632-19-01 Groundwater Feasibility Study\4.0 GIS\4.1 Projects\Figure 2 - Geologic Map.mxd cdekonver 5/20/2020



LEGEND

FIGURE NO. 2A

BOWEN COLLINS & ASSOCIATES

HILLDALE CITY
GW FEASIBILITY STUDY

CROSS SECTION
A-A'

NORTH:

SCALE:

P:\Murray City\2018 Park and 4500 South Wells\4.0 Construction Phase\Drilling\DWSP Update\GIS\Figure 2a - Geologic Map Cross-Section A-A'.mxd cdekorver 5/20/2020

Lithology

Triassic Chinle Formation (TRcp). The Chinle Formation is estimated to be 350 feet thick and consists of 2 members, the upper Shinarump Member and the lower Petrified Forest Member. The lower Shinarump Member is a grey to yellow-gray conglomeratic sandstone, sandstone and mudstone. It is ledge and cliff forming and is massive. It unconformably overlies the Moenkopi Formation and is up to 155 feet thick (Doelling, 2008). The Shinarump Member is an aquifer in the Hildale area that is recharged to the southeast of the study area. The upper Petrified Forest Member is a multi-colored claystone, siltstone and channel fill sandstone. It has a grey, red, purple and brown claystone and clay beds. Some of these clays have been described as volcanically derived and swelling (Sable, 1995). There are siltstone beds and some channel fill sandstones and slumped sandstone. No continuous exposures of the Petrified Forest Member are exposed in the study area, but it is an important dividing unit between the Shinarump Member of the Chinle and the Moenave Formation. The thickness is estimated to be 150 to 200 feet thick in the study area.

Moenave Formation (Jmwd, Jms). The Moenave Formation is estimated to be 300 feet thick and consists of three members. The lower Dinosaur Canyon Member is a reddish-brown siltstone and mudstone that is slope forming and contains lesser amounts of sandstone, claystone and conglomerate (Sable, 1995). The middle member is the Whitmore Point member that lies conformably above the Dinosaur Canyon Member. The Whitmore Point sandstone is about 50 feet thick and contains tabular beds of sandstone, claystone and siltstone. The upper Springdale Sandstone Member overlies the Whitmore point member conformably and is up to 125 feet thick. It is a light grey fine to very-fine sandstone with silty intervals. Uppermost beds of the Springdale Sandstone are tabular and are yellow in color. The Moenave Formation is generally considered an aquitard, except where fractures are present and it can transmit water.

Kayenta Formation (Jk). The Kayenta Formation makes up the base of the Vermillion Cliffs in the study area. It is exposed from Maxwell Canyon Park up to the base of the Navajo Sandstone where the canyon walls become narrow and vertical. The Kayenta Formation is a ledge and slope forming unit that is up to 600 feet thick. It primarily consists of red siltstone, sandstone and mudstone. About 25-percent its thickness consists of cliff-forming sandstone beds. The sandstone beds are described as fine-grained with tabular crossbedding and ripple marks. The Kayenta Formation coarsens upwards and about 80 percent of the upper 100 feet of the formation are sandstones. The depositional environment is interpreted to be fluvial (Sable, 1995) and contains few conglomerate beds. The Kayenta Formation is generally considered an aquifer across southern unit, especially where fractures are present to increase water transmission.

Navajo Sandstone Formation (Jn, Jnb, Jnp). The Navajo Sandstone Formation is the white to pink cliff-forming unit that overlies the Kayenta Formation. It is a fine- to medium-grained sandstone that is well cemented with a high percentage of carbonate cement. The Navajo is massive with about 90-percent quartz grains and large scale tabular cross beds. The Navajo forms the vertical Vermillion cliffs that rise to the north of Hildale. The depositional environment of the Navajo Sandstone is interpreted to be eolian and its thickness is up to 1,000 feet in the Hildale and Water Canyon regions. The Navajo Sandstone is heavily fractured and contains two main joint sets that strike NW to SE and N-NE to S-SW. The Navajo Formation is considered an important water supply aquifer across southern Utah.

Quaternary Alluvial Deposits (Qa, Qaf, Qafo, Qea, Qes, Qmsc, Qmt). Alluvial deposits are present in the study area and result from erosion and deposition of the Navajo and Kayenta Formations. They result from alluvial, mass wasting and eolian processes. The alluvial deposits consist of floodplain and streambed deposits resulting from transport of sediment through

runoff events and year-round streamflow. Alluvial fan and mass wasting deposits exist at the base of the cliffs where rockfall debris and talus exist primarily from weathering of the Navajo Sandstone.

Structure

The Hildale study area is located between the Hurricane Fault Zone to the west and the Sevier Fault Zone to the east. Some studies have identified this region as the Zion block that denotes the area between these two fault zones. A known fault along Squirrel Creek has a displacement of 200 feet or less and is a steep easterly dipping normal fault. The attitude of the bedding in the Hildale area is a northeast to east-northeast homocline dipping 2 degrees or less. The Navajo Sandstone is highly fractured and joint sets strike north-northwest and north-northeast. The joints are nearly vertical and may extend into older units below.

Strata in this region that influence the groundwater from oldest to youngest (lowest to highest in stratigraphic column include):

- Triassic Moenkopi Formation. Crops out 4-5 miles west of Hildale and consists of interbedded siltstone, shales, very-fine to fine-grained sandstone with some amounts of low-porosity gypsum and limestone.
- Triassic Chinle Formation. Contains the lower Shinarump member that crops out to the south and southwest of Hildale and is a conglomeratic sandstone containing petrified wood and moderate to high porosity. It is up to 350 feet thick and is the aquifer unit in many of the deep groundwater wells in Hildale. The upper member of the Chinle Formation is the Petrified Forest Member and is mainly shale, siltstone and thin sandstone beds. It has little porosity.
- The Jurassic Moenave Formation forms the base of the Canaan Mountains and the Vermillion Cliffs and outcrops in the study area. It is 300-400 feet thick in the region and consists of shale, siltstone and sandstone bed with the occasional pebble conglomerate.
- The Jurassic Kayenta formation underlies the Navajo Sandstone. It is up to 700 feet thick and forms the lower reddish slopes and cliffs of the Canaan Mountains. It is predominantly beds of siltstone and shale with sandstone units that are cliff forming and have higher porosities.
- The Jurassic Navajo Sandstone overlies the Kayenta formation and forms the massive cross-bedded cliffs of the Canaan Mountains. Generally, a quartzose sandstone with locally high permeability in the highly jointed areas of the sandstone. The base of the Navajo sandstone is the aquifer unit where the groundwater samples were obtained.

Quaternary alluvial and colluvial deposits are present lying unconformably above the Navajo Sandstone in the region.

HYDROGEOLOGIC SETTING

Water supplies in southwestern Utah and surrounding areas are predominately derived from groundwater sources, as wells and springs. The principal aquifer in southwestern Utah is the Navajo Aquifer or the saturated portion of the Navajo Sandstone Formation. There are several other aquifers present in the Hildale study area and vicinity. Alluvial fill aquifers are the shallowest and consist of unconsolidated sediments and alluvial deposits. These aquifers have been used for irrigation water and shallow well targets but can sometimes have poor water quality. Bedrock aquifers in the area include the Navajo Aquifer. Vertical wells penetrate the Navajo Aquifer in other parts of southwestern Utah where it is buried. In the Hildale area the Navajo is elevated above the City and is exposed (outcrops) on the top of Canaan Mountain/Plateau and along its exposed sides as vertical cliffs. The aquifer discharges as springs and seeps along the base of the formation. In other parts of

southern Utah some wells have been drilled into the Kayenta and Moenave Formations, but it is relatively few compared to the Navajo Formation. However, both the Kayenta and Moenave contain sandstone beds and may be a viable aquifer unit, especially where fractures are present. Underlying the Navajo, Kayenta and Moenave formation is the Chinle Formation which contains the Shinarump Conglomerate Aquifer.

Aquifers in the Study Area

Shinarump Aquifer. The Shinarump Aquifer is the deepest water source for the City and is currently used by the City for a portion of its drinking water. The formation rests between 600-800 feet below ground surface in the City. The City has six Shinarump Aquifer wells that are screened in the 500-800 foot depth range (Sunrise Engineering, 2020). The Shinarump Aquifer is the lower member of the Chinle Formation that underlies the Moenave, Kayenta and Navajo Formations. Locally the Shinarump is a semi-consolidated conglomerate unit that is able to provide deep vertical wells of moderate yield and efficiency. It is a confined aquifer that is recharged from outcrops located several miles southeast of Hildale. The Shinarump Aquifer is known to have elevated levels of radium that require water treatment to meet drinking water quality standards. The Shinarmp Aquifer was excluded from consideration for this study.

Alluvial Aquifer (Shallow). The alluvial aquifer consists of alluvial deposits eroded from the overlying rocks and fluvial transport proximal to the Vermillion Cliffs. These alluvial aquifers are generally less than 100 feet thick and reportedly can contain groundwater that is high in iron. The City has seven wells completed in the shallow alluvial aquifer that are used for drinking water (Sunrise Engineering, 2020). The aquifer is reportedly a low producer which is more than likely due to the limited saturated thickness and fine-grained sediments present. A single well north of the City indicates that it produces about 200 gpm and has a specific capacity of about 4 gpm/foot of drawdown, however, other alluvial wells produce 25 to 150 gpm. Due to its potential low-moderate yield and it has already been developed, the shallow alluvial aquifer was not considered viable to replace the City's water supply and was excluded from the study.

Navajo Sandstone Aquifer. The Navajo Sandstone Aquifer is a regional aquifer in southwestern Utah that provides high quality water in the Cedar City, St. George, and Kanab regions. The Navajo aquifer is in existence primarily where the Navajo Sandstone outcrops and is recharged by precipitation. It is considered a water table, or unconfined aquifer in the Hildale area due to its exposure at the surface. The Navajo Aquifer is also a major source of water for surrounding springs, creeks and rivers from seepage. Seepage to rivers and creeks is the largest known discharge from the aquifer, with spring discharge being the second largest. The Navajo Aquifer is not well understood in the Hildale study area and there are no known local wells completed in this formation.

The Navajo Sandstone Aquifer is currently used by the City via two "spring" sources located at the base of the formation in Jans and Maxwell Canyons. Maxwell and Jans Canyon Spring sources are horizontal or angled collector pipes drilled up to 160 feet laterally from the collection boxes. These angle or horizontal collector pipes (springs) currently produce a total of about 80 gpm of the City's drinking water with no treatment required. The total dissolved solids of these wells is less than 100 mg/L which is very fresh indicating high quality groundwater.

Recharge to the Navajo aquifer comes from infiltration of precipitation on Canaan Mountain and through infiltration of collected runoff in stream channels. Regional studies indicate infiltration rates vary greatly due to topography, precipitation rates, temperature and elevation. It has been estimated that infiltration and recharge rates to the Navajo Aquifer can be between 1% and 20% of the annual precipitation for the area (Heilweil and Freethey, 1992). Additionally Heilweil and Freethey (1992)

estimate the Zion Block of the Navajo aquifer between the Sevier and Hurricane Faults to have 0.6 to 3.7 inches of infiltration annually. The Navajo Aquifer contains intergranular porosity which drives the primary permeability of the formation. However, fracture networks can increase secondary porosity in the Navajo by an order of magnitude or more (Heilweil and Others, 1997).

Aquifer testing has been completed regionally in the Navajo Aquifer and has been summarized in several state and federal geologic reports (Heilweil and Freethey, 1992; Heilweil and Others, 1997; Heilweil and Solomon, 2001; Hurlow, 1998, 2002; Inkenbrandt and others, 2013). The permeability and hydraulic conductivity of the aquifer was found to be highest near heavily faulted or fractured zones in the sandstone. Aquifer testing in the Navajo aquifer indicates hydraulic conductivity values range from 0.3 feet/day (ft/day) to as much 30 ft/day, however, most of the results are 1 to 5 ft/day. The testing locations are located throughout southwestern Utah, however no local estimates in the Hildale area are available.

A concern with tapping this aquifer is the long-term sustainability of the water supply due to insufficient local recharge. It is also important to note that the Navajo Sandstone is located on Bureau of Land Management (BLM) land, specifically land designated as the Canaan Wilderness. Access to these areas may prove to be a considerable hurdle for the project. This considered, drilling horizontal wells to increase the City's existing Navajo Aquifer spring sources may be a possible alternative for sourcing high quality groundwater. The Navajo Aquifer was a specific target for the study.

Kayenta and Moenave Aquifers (Intermediate). The Moenave and Kayenta Formations are interbedded siltstone, sandstone and shale formations unit that underlie the Navajo Sandstone. They contain tabular beds of fluvial sandstones that have primary and secondary fracture permeability. Combined with the Navajo Formation, the Kayenta and Moenave formations have made for productive aquifers in southwestern Utah. No data is available locally to estimate a potentiometric surface or aquifer hydraulic parameters of the Kayenta or Moenave but it is anticipated that fractures in the Navajo are continuous into the sandstone and siltstone beds of the Kayenta and Moenave. The Kayenta crops out at the base of the Vermillion cliffs in the Hildale area where the Moenave does not have a surface exposure in the region. The total thickness of these units is nearly 1,000 feet which would provide enough depth for a vertical production well. The Kayenta and Moenave Aquifer were identified as a specific targets for the study.

Recharge to these Kayenta and Moenave Aquifers comes from seepage from the overlying Navajo Aquifer, and also infiltration of precipitation and stream flows where the formations are exposed. Given that the recharge area for these formations is larger than the Navajo Sandstone itself indicates the recharge potential for these aquifers exceeds the recharge potential for the Navajo Aquifer. In addition, portions of these formations are buried beneath ground surface and therefore result in a larger aquifer saturated thickness from which to draw water.

Aquifer testing has been completed on the Kayenta Formation near Leeds, Utah (Cordova, 1978). The aquifer transmissivity was estimated at 3,500 feet squared per day (ft^2/day), or a hydraulic conductivity of 6 ft/day. This value is similar to the higher hydraulic conductivities values found for the Navajo Aquifer. The results indicate the Kayenta and Moenave Aquifers may be possible alternatives for a replacement groundwater source for the City. There are no known wells completed in these formations in the Hildale study area.

A concern with tapping the Kayenta and Moenave Aquifers is water quality. It would be expected that water quality would deteriorate as the recharge water passes from the Navajo Aquifer into these

formations and then migrates through them. There are no known wells with water quality information in the Hildale study area.

SECTION 2
GROUNDWATER RESOURCE EVALUATION

This section presents the results of investigations conducted to characterize the water quality and age date of Navajo Aquifer water, and geophysical surveys to identify the most promising sites locations for future wells. It also discusses the estimated well yields and aquifer recharge potential for the aquifers considered and the feasibility of developing an adequate groundwater supply. The evaluations focus on the Navajo, Kayenta, and Moenave Aquifers.

GROUNDWATER CHEMISTRY AND AGE DATING

BC&A collected samples from two locations; the City's Maxwell Canyon spring source (shallow horizontal well), and from an unnamed spring at the base of the Navajo Formation in Water Canyon. Water samples were collected by BC&A on September 4-5, 2019. Both samples were collected of groundwater emanating from the bottom of the Navajo Aquifer and represent high quality spring fed groundwater. The samples were submitted to Chemtech-Ford Laboratories in Sandy, Utah for analysis of major common ions and general chemistry. Samples were also submitted to the Dissolved and Noble Gas Laboratory at the University of Utah for age dating analyses. The samples were analyzed for noble gases, tritium, helium, sulfur hexafluoride and chlorofluorocarbons. These constituents in the groundwater are tracers that can represent transit times of the water in the subsurface, or more commonly referred to as the age of the groundwater. The age of the water is an important factor in sustainability of the source. Meaning, the older the water, the less likely it is replenished regularly. Conversely, the younger the water the more readily available and "sustainable" the water source is likely to be.

Common Ions and General Chemistry

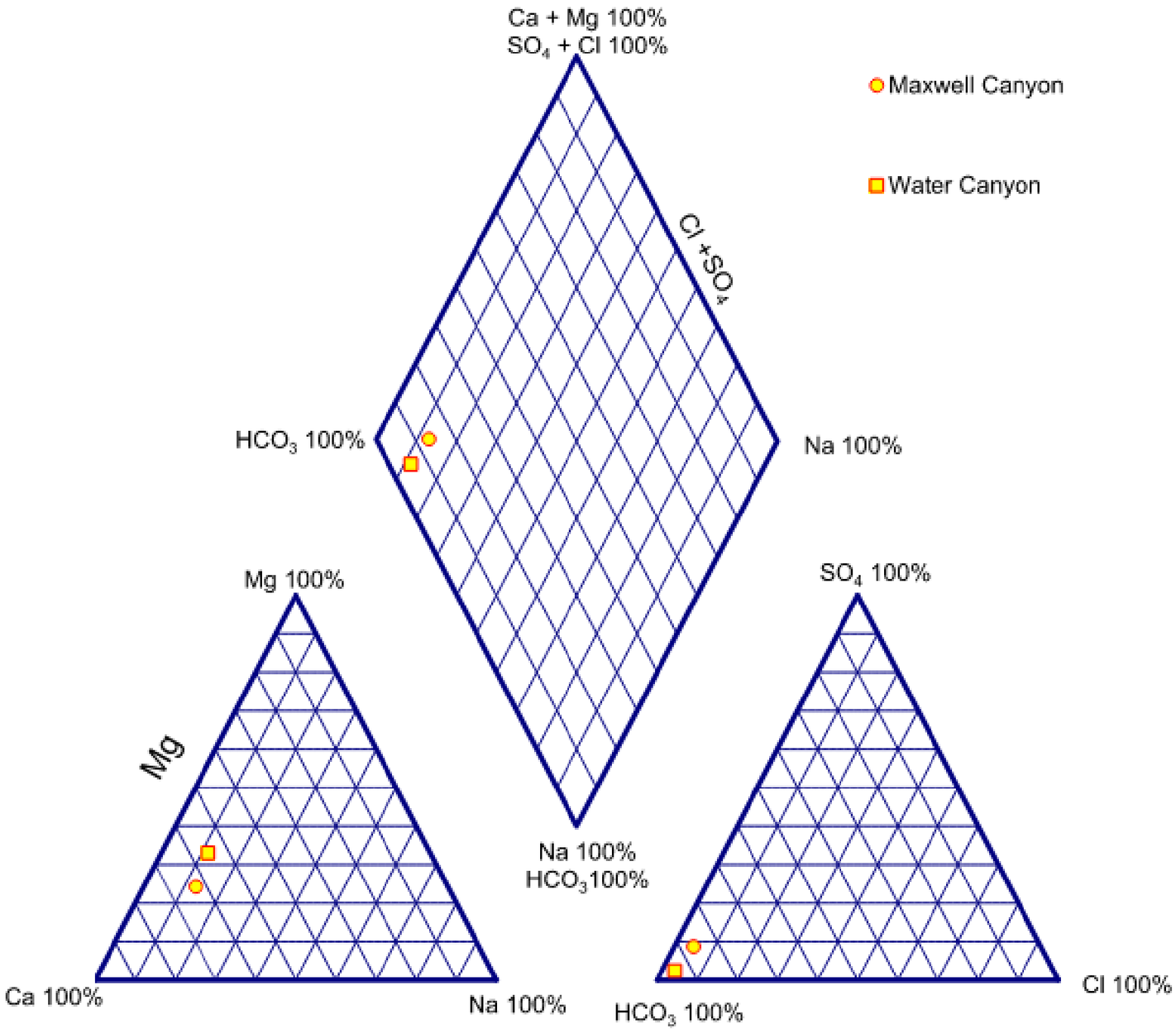
The Chemtech-Ford data report is located in Appendix A. The results indicate both samples are high quality groundwater with low total dissolved solids (TDS) concentrations. The Maxwell Canyon sample had a TDS concentration of 84 mg/L, and the Water Canyon sample had a TDS concentration of 68 mg/L. Figure 3 shows the general chemistry of the samples plotted on a trilinear diagram. The results show that both the Maxwell Canyon and Water Canyon samples are a calcium magnesium bicarbonate type water. The similarity of where they plot indicates the waters emanates from the same aquifer, namely the Navajo Aquifer. Both samples indicate the water is suitable for drinking water use without treatment.

There is no available water quality data for the Kayenta and Moenave Formations in the study area.

Groundwater Age Dating

The University of Utah Dissolved and Noble Gas Laboratory data report is located in Appendix B. The report contains the details on methodology and data analysis used. We will present the results and interpretation in this report and more details can be found in the report from the Dissolved and Noble Gas Lab. The results of the analysis indicate that there is a non-modern component of recharge to the Navajo Aquifer.

Noble gases that were analyzed in the sample include Argon, Neon, Krypton and Xenon. The detected values for the noble gases listed were within the expected range for waters that have been equilibrated with the atmosphere above the water table. Noble gases are also used to estimate a recharge temperature, the analysis indicated a temperature of 9.5 ˚C (49.1 ˚F) for Water Canyon and 12.5 ˚C (54.5 ˚F) for Water Canyon. This is below the mean annual temperature for Hildale of 17.8 ˚C



Trilinear Diagram Geochemistry of Hildale Springs

TRILINEAR DIAGRAM
MAXWELL AND WATER CANYONS

HILLDALE CITY
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FIGURE NO.
3

S:\Hildale City\632-19-01 Groundwater Feasibility Study\4.0 GIS\4.1 Projects\Figure X - BCA Border.mxd aitow 3/3/2020

(64.0 ˚F) but likely in the range for the mean annual temperature for Canaan Mountain where recharge occurs which is located at a much higher elevation than Hildale City.

Helium-4 is measured in the samples and compared to the atmospheric solubility value. If the levels recorded become elevated above the solubility level the atmosphere it can be interpreted that the Helium-4 has accumulated in the groundwater from the decay of naturally produced uranium for a period of approximately 1,000 years. It generally takes 1,000 years to accumulate a detectable amount of Helium-4 but this value has some uncertainty due to the aquifer conditions. In the samples collected, there was a small amount of Helium-4 detected that was lower than the uncertainty in the measurement. Due to this very low concentration detected it was interpreted that the water is less than 1,000 years old. There is a possibility though that during the sampling process gas exchange occurred causing a loss of any Helium-4 that was stored in the aquifer.

Tritium (^3H) values measured in the sample were 0.14 tritium units (TU) to 0.28 TU. These values are much lower than a modern measurement from precipitation. Salt Lake City measurements of tritium are on the order of 5 to 10 TU. Because of above ground Nuclear testing a modern sample would have elevated tritium values. Since our samples exhibit low tritium they are more than 70 years old.

Sulfur hexafluoride (SF_6) concentrations are very consistent between the Maxwell and Water Canyon samples. The concentrations are 1.4 fmole/kg and 1.2 fmole/kg for Maxwell and Water Canyon. This indicates a recharge time of less than 30 years ago. This is likely due to partial mixing of the sample and the current atmosphere during spring collection and sampling. A small amount of air was noted in the sample and was corrected for. These results are not consistent with the tritium results and therefore have been interpreted to have a component of mixing with the modern atmosphere. However, even with mixing the results indicate that the springs are not discharging modern (<5-year-old) water.

Chlrofluorocarbons (CFC-11 (freon-11), CFC-12 (R-12) and CFC-113 (freon-113)) were analyzed and measured in each location. There is excellent agreement between the two locations and the analysis results. Apparent recharge years ranged from 1984 to 1995.5 (last in contact with the atmosphere). These results are slightly older than those derived from the SF_6 analysis, though are younger than the tritium results. It is likely that a similar mixing occurred at the sample collection from contact with the atmosphere, however, like SF_6, the results of either location are considered modern water.

Based on the limited tritium in the samples and very low levels of Helium-4 the samples are likely older than 70 years and less than 1,000 years. The age range does have uncertainty and is orders of magnitude apart, however, the bottom line is that the water is not considered modern. There is a possiblity that all or a portion of terregenic Helium-4 was released by gas exchange during sample collection and that the water is older than 1,000 years. This could be verified by using Carbon-14 age dating. Carbon-14 dating has a high level of uncertainty in itself (~500 years) and may not provide the accuracy needed if samples are less than 1,000 years old. However, if the samples are over 1,000 years old, carbon-14 may provide a higher level of certainty in the age. The Carbon-14 analysis was not in the project scope and can still be conducted if desired.

In summary, the results indicate an estimated age range of 70 to 1,000 years for the spring discharges at the base of the Navajo Formation. The upper age limit of 1,000 years is uncertain due to the possibility of gas exchange (loss) during sample collection. The lower age limit estimate of 70 years is due to the low values of tritium present in the samples. The measured values are much lower than present day tritium concentrations that are elevated due to atmospheric testing of nuclear weapons.

None of the noble gas, CFC's or SF_6 concentrations indicated that the groundwater had a very modern signature of less than 5 years old.

GEOPHYSICAL SURVEY INVESTIGATIONS

Introduction

Geophysical surveys were completed by Willowstick, LLC beginning in October 2019 and completed at the end of February 2020. The survey included two desktop analysis from readily available data and two field surveys that required on-site data acquisition in the study area. Copies of the geophysical survey reports are located in Appendix C. The purpose of the geophysical surveys was to identify aquifer zones with enhanced permeability, primarily due to fractures in the rock that would narrow down or pinpoint the best locations for future wells.

Geophysical surveys were originally scoped to target the Navajo Aquifer by surveying on top of Canaan Mountain, the high plateau to the north of Hildale. The scope of the surveys was expanded to include Water Canyon, Jans Canyon, Maxwell Canyon, Squirrel Canyon, and the low-lying areas near the City in an effort to gather information on the Kayenta and Moenave Aquifers. Figure 4 shows the area covered by the geophysical surveys. While the depth of surveys was focused on the depth of the Navajo Aquifer the geophysical methods were able to investigate the Kayenta, Moenave and Shinarump formations as well.

Geophysical Methods

Four geophysical survey methods were used in the study and are described as follows.

Lightning Data Analysis. Lightning strike data was retrieved from public and private databases (some for purchase) and analyzed through a patented technique to create a deep and broad geologic framework for exploration. The method generates large-scale resistivity volumes that can define deep basement faults and structure, which are known to be related to shallower joints and lineaments where groundwater can be channeled (Gay, 2012). The depth of visibility of the lightening analysis is controlled by the height of lightning strikes.

Lineament Study and Fracture Trace Analysis. A lineament study was conducted by analyzing enhanced satellite imagery, airborne mosaics, digital elevation models, and stereo infrared imagery. This work was done by hydrogeologists with experience drilling for water including many fractured rock aquifers. The lineament study identifies surficial or shallow fractures and compliments the deep structures provide by the lightning strike data.

Rapid Acoustic Profiling (RAP) Passive Seismic Survey. RAP detects rock density and structural weakness in rocks and can locate fracture zones with high accuracy down to depths of 3,000 feet or more. The results are analyzed in conjunction with radiometric gamma data to identify highly permeable zones with water for prospective drill targets.

Radiometric Gamma Survey. Radiometric gamma is a passive measurement the aggregate gamma emissions from subsurface rocks and soil. Most importantly, the signal is attenuated where water is present in permeable (fracture) zones beneath the sensor, making it an excellent tool to use in conjunction with the RAP system to locate permeable (fracture) zones that contain water. Where the gamma signal is low or attenuated indicates the possibility of water within the rock/fracture.

Legend

Geophysical Survey Line

- Survey Point
- Approx. Study Area
- Canaan Mountain Wilderness
- Streams

Water Canyon

Squirrel Canyon

Jans Canyon

Maxwell Canyon

HILLDALE

SCALE: 1 in. = 3,000 ft.

NORTH: NORTH

GEOPHYSICAL SURVEY LINES

HILLDALE CITY

GW FEASIBILITY STUDY

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FIGURE NO. 4

S:\Hildale City\632-19-01 Groundwater Feasibilty Study\4.0 GIS\4.1 Projects\Figure 4 - Geophysical Survey Map.mxd atrow 3/17/2020

IDENTIFIED TARGET "ZONES" FOR FUTURE WELLS

Results of the different geophysical surveys were combined and analyzed in a 3D Site Model. The results were overlain on one another and analyzed to determine areas of enhanced permeability (fractures) and the presence of water. Overall, the complete analysis generated over 50 enhanced permeability targets that showed favorable RAP signals, presence of linaments, and gamma lows. Due to the clustering of targets in certain areas, the results were further prioritized into the top five highly prospective "zones". An overview map of the study area and the targets is shown in Figure 5. Figures 5 shows the different prospects as colored circles where circle size indicates the degree of fracturing/permeability detected, and the color of circle indicates the degree of gamma attenuation signifying the presence of water. Purple circles indicate a general low gamma signal in the area. Yellow circles are used when gamma data was not collected but the RAP seismic study indicates high favorability. Blue lines in the figures are the fracture-traces from the lineament study. Targets were ranked based on their quality. The identified top 5 zones are outlined in Figure 6.

Zones 1, 2, and-3 all target the Kayenta and Moenave Aquifers beneath the Navajo Sandstone. These would be vertical well options targeting fractured formations with depths from 500 feet to 1,000 feet. Zones 1 and 2 would have the easiest access as they are located near existing roads which would minimize road improvement and mobilization costs. Additionally, vertical well drilling allows for an exploratory pilot hole to be drilled that could phase the drilling approach generating data and information at each step.

Zones 4 and 5 both target the Navajo Aquifer with horizontal boreholes beneath Canaan Mountain. Zones 4 and 5 both show low gamma signals with fractured structure from the RAP data. These zones would require significant improvements (access road) to mobilize a drill rig to the base of the Navajo Formation in order to drill horizontally into it.

Zone 1 Description

Zone 1 is located near the Squirrel Canyon Trailhead at the bottom of Water Canyon as shown on Figures 6 and 7. Evidence from both the fracture-trace and lightning data analysis supports this site as a good candidate to find water. Blue lines on the map (Figures 5 and 6) are the lineaments from the HydroSource fracture-trace study, and some of the longest, most significant fractures point to this area indicating high fracture density. In Figure 7, Section a-a′ shows the location of the lightning resistivity data, plotted in Figure 8. The lightning study indicates deep basement fracturing and/or faulting in this area as well. The geophysical survey identified eight total prospects in Zone 1.

In Prospective Zone 1, the most important targets are T4 and T5. Targets T4 and T5 were detected on two separate lines very near their point of intersection, and both exhibit a significant gamma drop. Each RAP section shows strong fracturing and high permeability from about 100 ft down to the section's extent, around 1,600 feet. At this location, the Shinarump member is roughly 850 ft deep. The target would be in the upper 600-700 feet avoiding the contact with the Shinarump Aquifer.

Zone 1 is an option for vertical wells near the Squirrel Canyon Trailhead at the bottom of Water Canyon. Wells in Zone 1 would target the Kayenta and Moenave Aquifers and penetrate the top of the Chinle Formation. The wells would be 700 feet in depth to capture the partial thickness of the sandstone units of the Kayenta and the complete Moenave Formation. Drilling will be completed when the top of the Chinle Formation has been reached at approximately 700 feet. The well would be completed above the top of the Shinarump Aquifer to avoid the radium impacted water. A site specific geophysical survey is recommended before drilling to confirm these results and refine the well(s) location.

56 Prospects Located

RAP Prospect Category

- SIZE of circle indicates relative degree of Fracturing/Permeability:

1 2 3

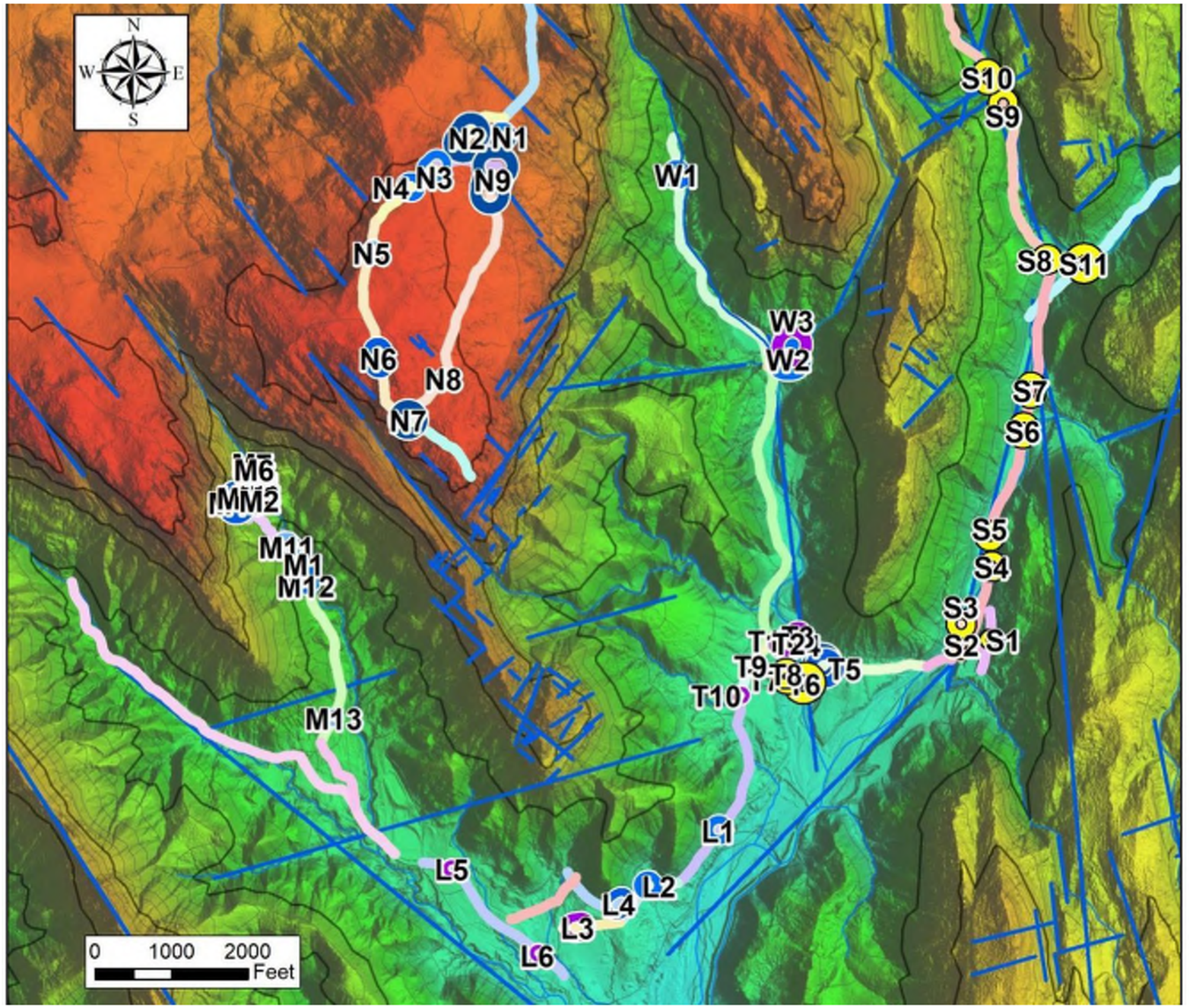
Gamma Indicator

- COLOR of circle indicates relative strength or character of signal drop related to presence of water below:

Darker blue equals stronger indicator of water presence

General Gamma "Low"
(unable to measure the degree of drop, but water presence still likely)

Gamma Not available



SCALE: See Inset Scale

NORTH:

FIGURE 5
GEOPHYSICAL PROSPECTS
FROM WILLOWSTICK (2020)

HILLDALE CITY
GW FEASIBILITY STUDY

BOWEN COLLINS & ASSOCIATES

FIGURE NO.
5

S:\Hildale City\832-1901 Groundwater Feasibility Study\4.0 GIS\4.1 Projects\Figure 5 - BCA Border.mxd atrow 3/3/2020

56 Prospects Located

RAP Prospect Category

- SIZE of circle indicates relative degree of Fracturing/Permeability:

1 2 3

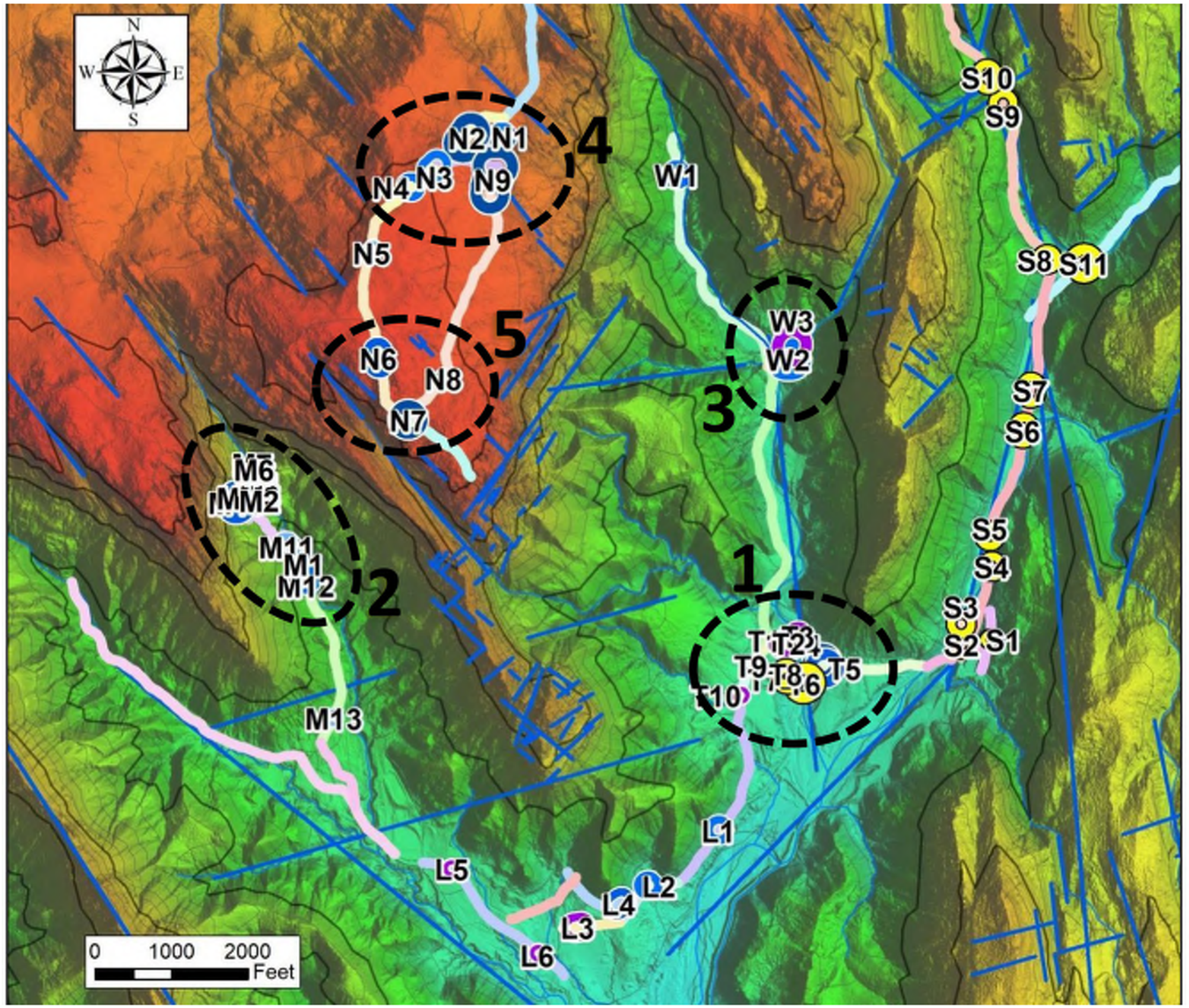
Gamma Indicator

- COLOR of circle indicates relative strength or character of signal drop related to presence of water below:

Darker blue equals stronger indicator of water presence

General Gamma "Low"
(unable to measure the degree of drop, but water presence still likely)

Gamma Not available



SCALE: See Inset Scale

NORTH:

FIGURE 6
TARGET ZONES
FROM WILLOWSTICK (2020)

HILLDALE CITY
GW FEASIBILITY STUDY

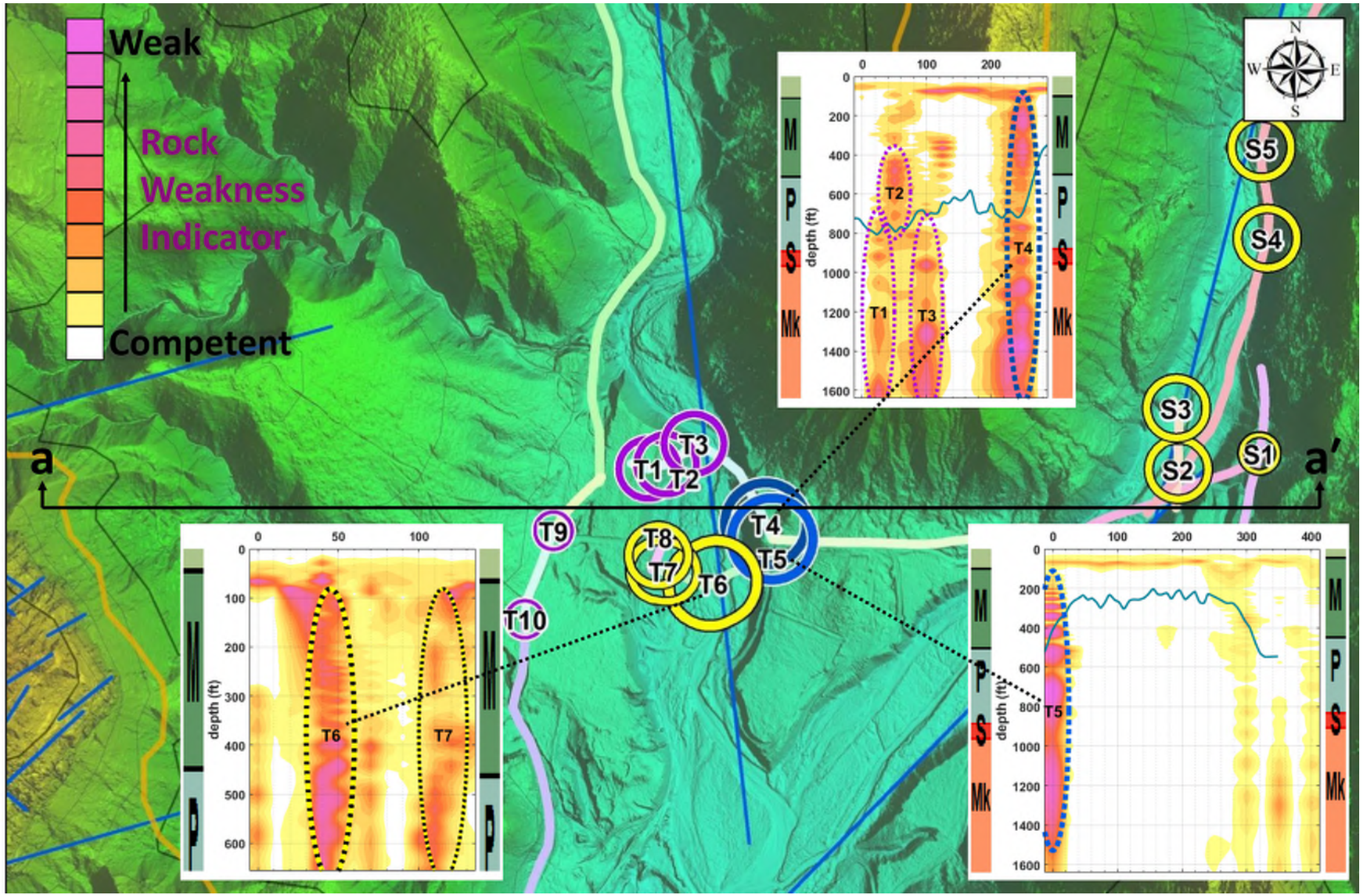
BOWEN COLLINS & ASSOCIATES

FIGURE NO.
6

S:\Hildale City\632-1940\1 Groundwater Feasibility Study\4.0 GIS\4.1 Projects\Figure 6 - BCA Border.mxd atrow 3/3/2020

Figure 7
Prospective Zone 1

Trailhead Area (T)



Lithology Key

N	Navajo Fm
K	Kayenta Fm
M	Moenave Fm
P	PF Member
S	Shinarump
Mk	Moenkapi Fm

SCALE: See Inset Scale

NORTH:

FIGURE 7
ZONE 1 ZOOM
FROM WILLOWSTICK (2020)

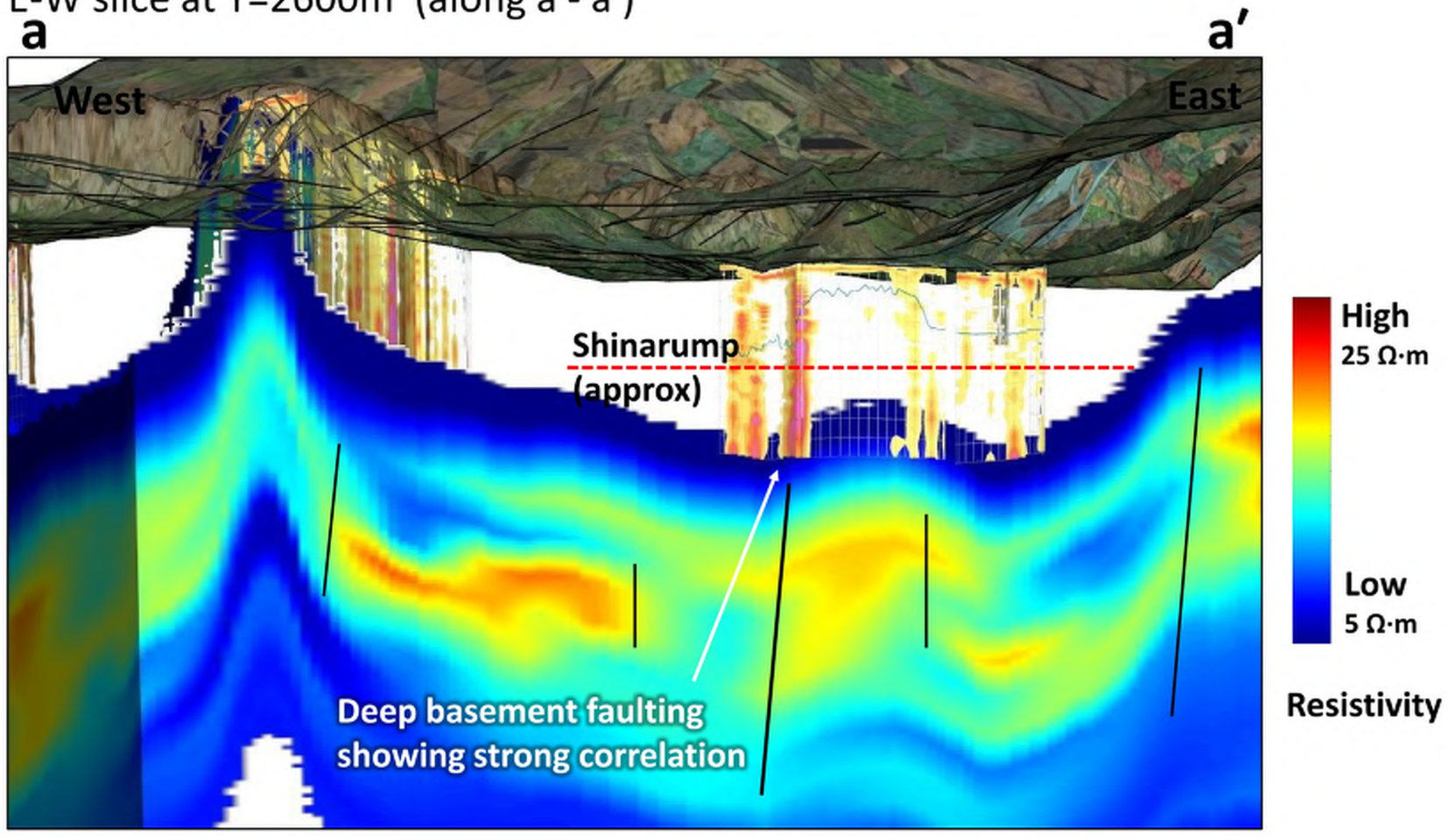
HILLDALE CITY
GW FEASIBILITY STUDY

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FIGURE NO.
7

S:\Hildale City\822-19-01 Groundwater Feasibility Study\4.0 GIS\4.1 Projects\Figure 7 - BCA Border.mxd altrow 3/3/2020

Deep Resistivity Slice from Lightning Data
E-W slice at Y=2600m (along a - a')



SCALE: See Inset Scale

NORTH:

FIGURE 8
ZONE 1 LIGHTNING SLICE
FROM WILLOWSTICK (2020)

HILLDALE CITY
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FIGURE NO.
8

S:\Hildale City\832-19-01 Groundwater Feasibility Study\4.0 GIS\4.1 Projects\Figure 7 - BCA Border.mxd atrow 3/3/2020

Zone 2 Description

Zone 2 is located near the City's Maxwell Canyon spring collection site at the base of the west-side cliffs in Maxwell Canyon as shown on Figures 6 and 9. Numerous fractured-rock features with gamma indicators were detected in this part of the canyon (see Figure 9). It has low signal from the gamma survey that indicates water is present and the RAP seismic survey shows broken and fractured rock in this zone. Strong fracturing at the M10 location extends from about 150 feet all the way down to at least 1,600 feet. At this location the Shinarump Aquifer is estimated at over 1,300 feet deep. The target would be the base of the Moenave Formation at approximately 1,000 feet in depth. Nine total prospects were identified in the geophysical study in this zone.

Zone 2 is an option for vertical wells near the Maxwell Canyon spring collection site. Wells would target the Kayenta and Moenave Aquifers and penetrate the top of the Chinle Formation. The well(s) would be 1,000 feet in depth to capture the full thickness of the sandstone units of the Kayenta and Moenave. The well would be completed above the top of the Shinarump Aquifer to avoid the radium impacted water. A site specific geophysical survey is recommended before drilling to confirm these results and refine the well(s) location.

Zone 3 Description

Zone 3 is located in the heart of Water Canyon near the Water Canyon Reservoir and Trailhead as shown on Figures 6 and 10. This Zone was expected to have higher-than-average probability of finding concentrated fracturing due to the confluence of several strong lineament features. The RAP system detected significant fracturing, particularly at features W2 and W3, and the gamma signal dropped and remained low in the area (Figure 10). The gamma survey also shows a low-gamma zone indicating water in this area. The RAP settings were not for looking particularly deep on these RAP lines, only to about 650 feet. Zone 3 targets an area of dense fractures as indicated by the RAP geophysical survey and the lineament study. Due to the low gamma signal and weakness of the rocks the geophysical study has identified three prospects in this area.

Zone 3 is an option for vertical wells near the Water Canyon Reservoir and Trailhead. Wells would target the Kayenta and Moenave Aquifers and penetrate the top of the Chinle Formation. The well(s) would be 750 feet in depth to capture the maximum thickness of the Kayenta and Moenave. Drilling will be completed when the top of the Chinle Formation has been reached. The well would be completed above the top of the Shinarump Aquifer to avoid the radium impacted water. A site specific geophysical survey is recommended before drilling to confirm these results and refine the well(s) location.

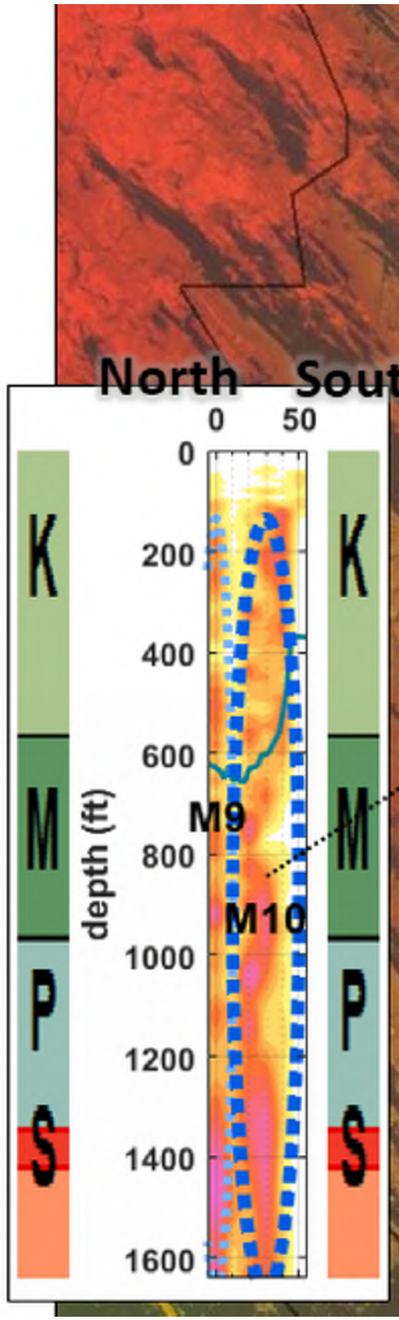
Zones 4 and 5 Description – Navajo Aquifer

Zones 4 and 5 are separate targets but are both in the Navajo Aquifer and are discussed together. Zones 4 and 5 are located within the boundaries of the Canaan Mountain Wilderness as shown on Figures 6 and 11.

Zone 4 includes six targets with N2 and N9 being the largest targets that align along the strike of fractures identified in the lineament study. These targets are aligned in a way that allows a single horizontal boring to intersect both target zones with a starting location in Water Canyon. Figure 11 shows a close-up of Zone 4, where the strongest targets are N2 and N9. These targets intersect fractures in the Navajo aquifer with generally low gamma signals. Figure 12 shows a plan and profile view for Zone 4. Zone 4 includes six targets with N2 and N9 being the largest targets that align along the strike of fractures identified in the lineament study. Both targets could be intersected by the proposed drilling trajectory in Figure 12.

Prospective
Zone 2
(close-up)

Vertical Drilling prospect in Maxwell Canyon



Lithology Key

- N — Navajo Fm
- K — Kayenta Fm
- M — Moenave Fm
- P — PF Member
- S — Shinarump
- Mk — Moenkapi Fm

SCALE: See Inset Scale

NORTH:

FIGURE 9
ZONE 2 ZOOM
FROM WILLOWSTICK (2020)

HILLDALE CITY
GW FEASIBILITY STUDY

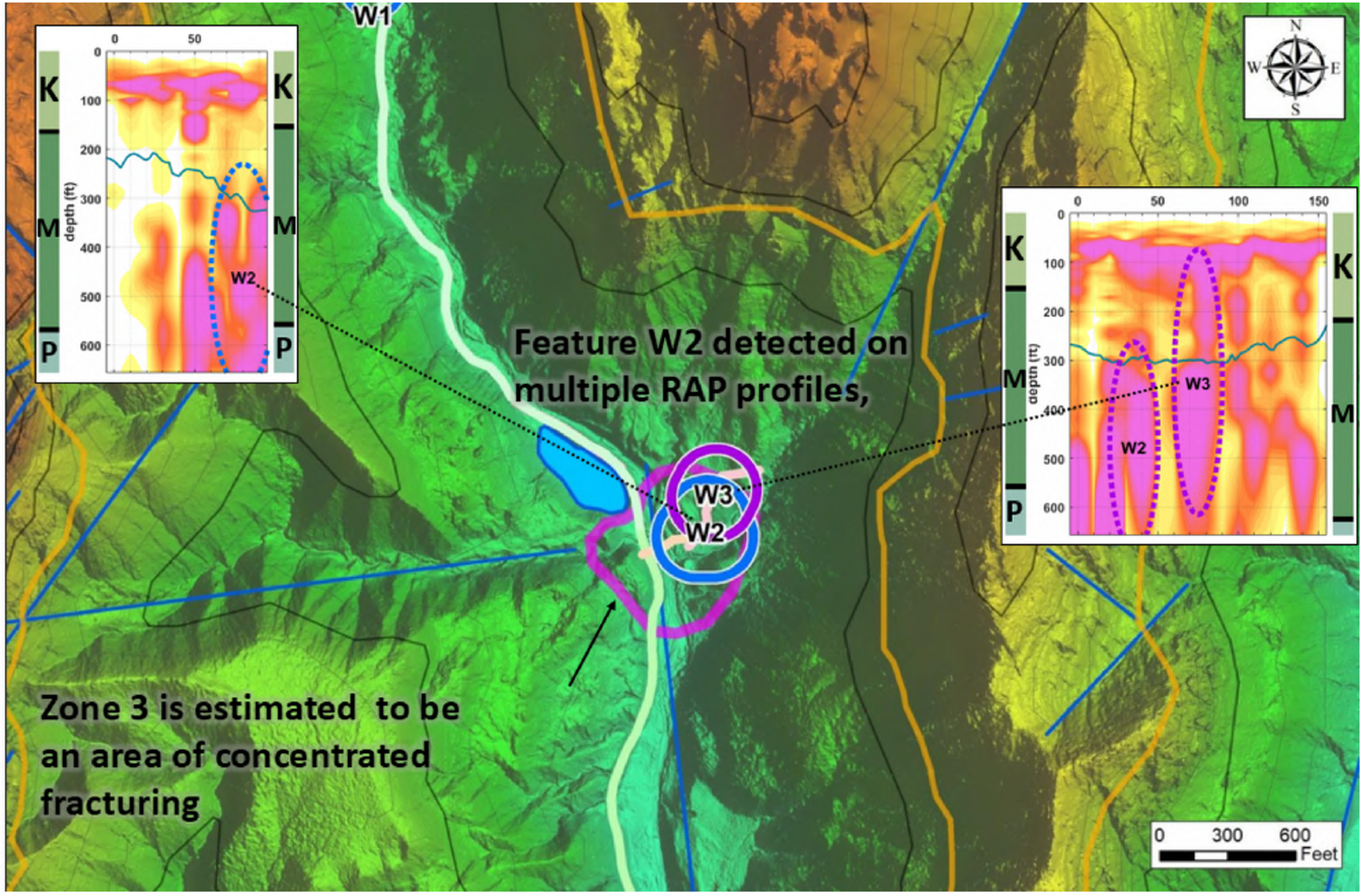
BOWEN COLLINS & ASSOCIATES

FIGURE NO.
9

S:\Hildale City\832-1901 Groundwater Feasibility Study\4.0 GIS\4.1 Projects\Figure 9 - BCA Border.mxd cdekorver 5/18/2020

Figure 10
Zone 3

Vertical Drilling Prospect in Water Canyon Area



Lithology Key

N	Navajo Fm
K	Kayenta Fm
M	Moenave Fm
P	PF Member
S	Shinarump
Mk	Moenkapi Fm

SCALE: See Inset Scale

NORTH:

FIGURE 10
ZONE 3 ZOOM
FROM WILLOWSTICK (2020)

HILLDALE CITY
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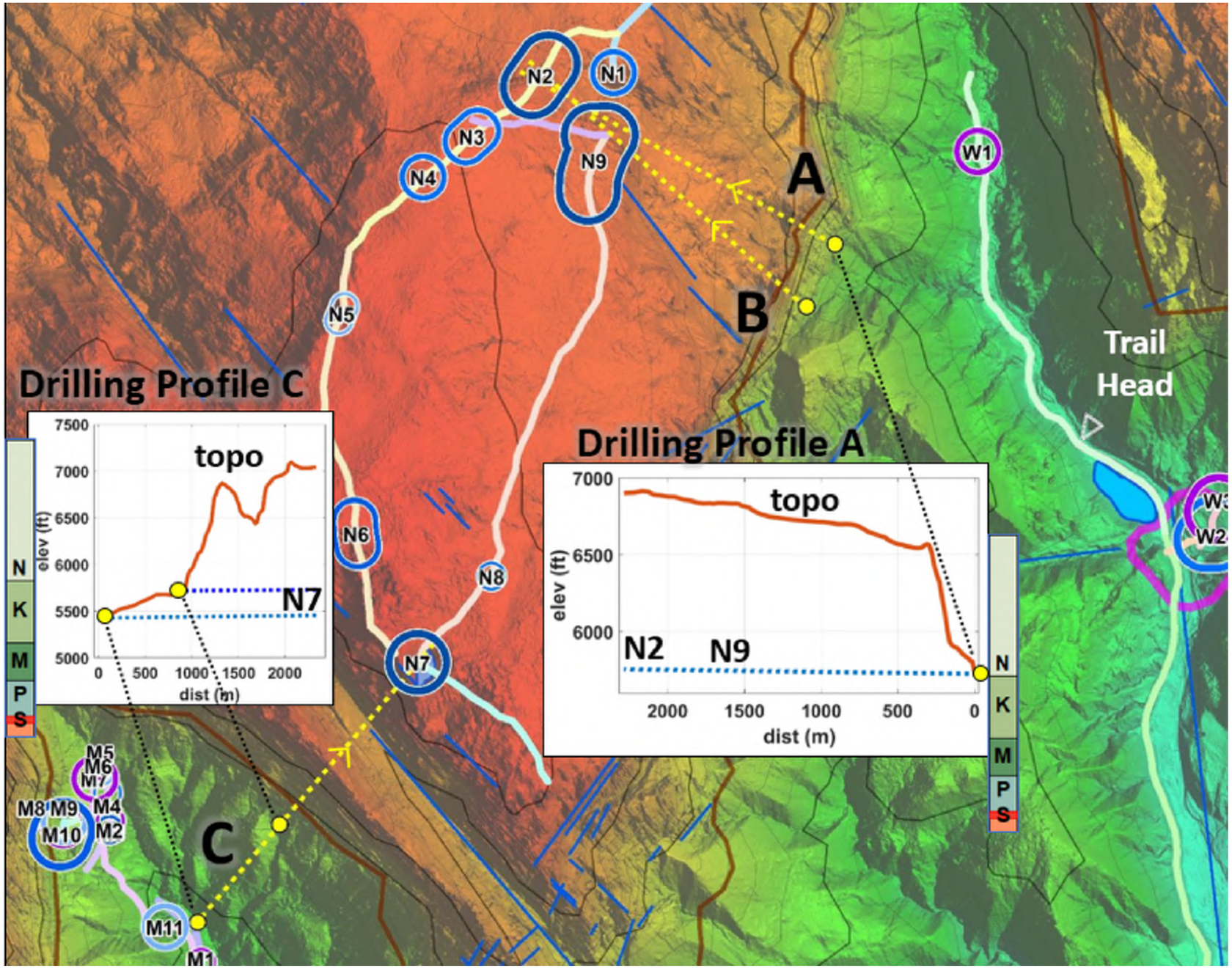
FIGURE NO.
10

S:\Hildale City\632-19-01 Groundwater Feasibility Study\4.0 GIS\4.1 Projects\Figure 10 - BCA Border.mxd cdekorver 9/18/2020

Prospective

Zones 4 and 5

Horizontal **Drilling into the Navajo and/or Kayenta**



SCALE: See Inset Scale

NORTH:

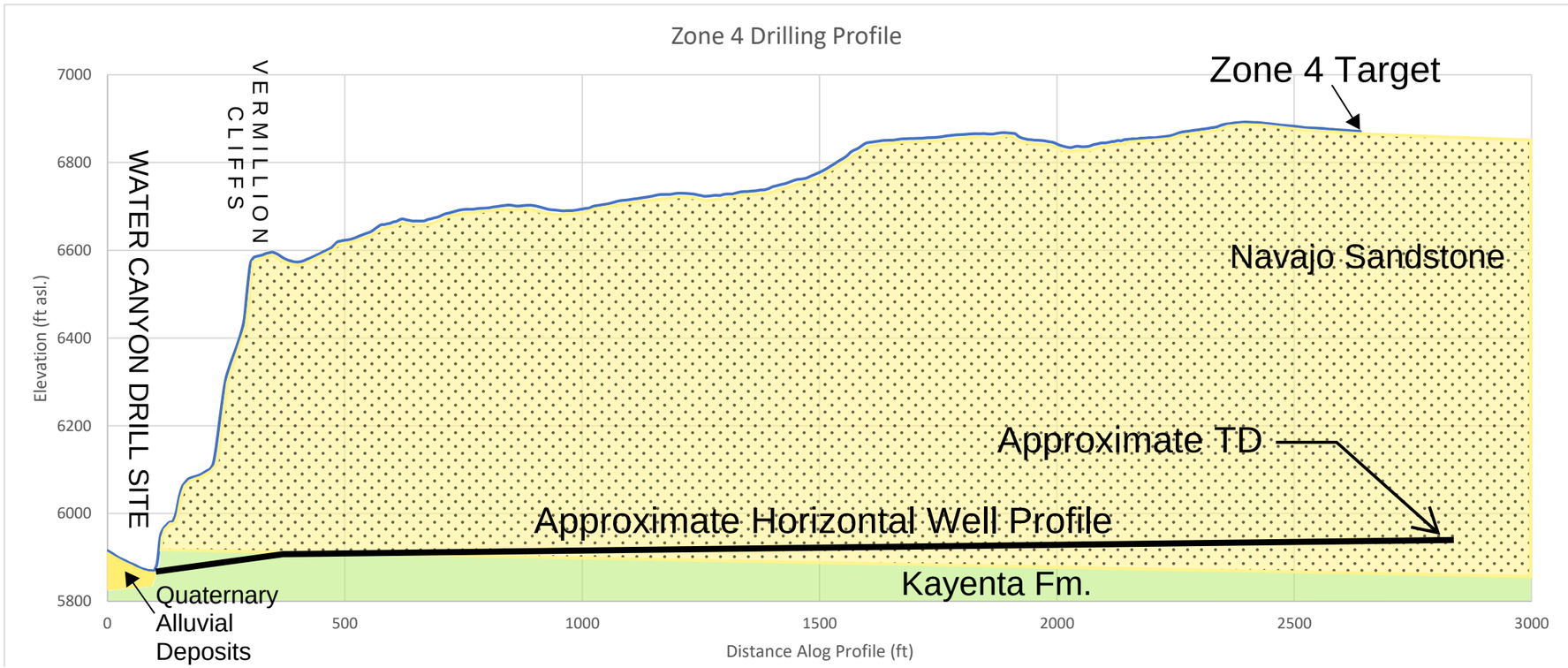
ZONE 3 ZOOM
FROM WILLOWSTICK (2020)

HILLDALE CITY
GW FEASIBILITY STUDY

BOWEN COLLINS & ASSOCIATES

FIGURE NO.
11

S:\Hildale City\632-19-01 Groundwater Feasibility Study\4.0 GIS\4.1 Projects\Figure 11 - BCA Border.mxd cdekorver 9/20/2020



Legend

- Possible Drill Pad
- Unimproved Roads
- Maintained Dirt Roads
- Proposed Roads

Geophysical Survey Line

- Survey Point
- Canaan Mountain Wilderness

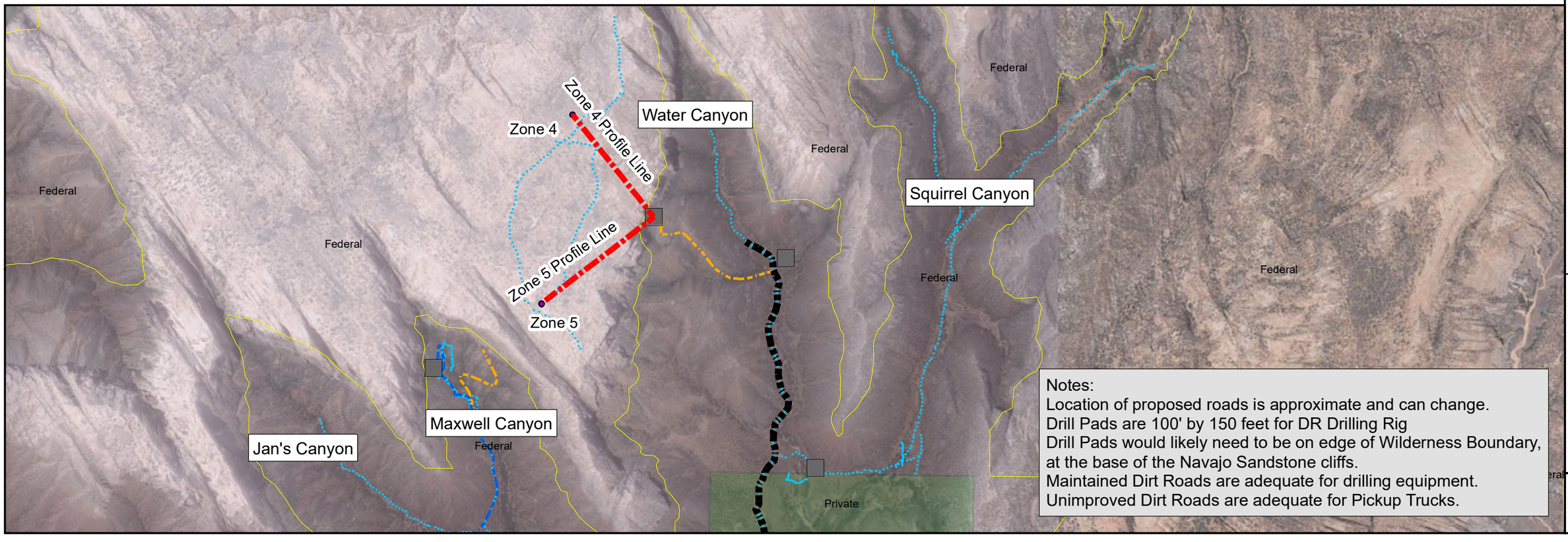
Owner

- Federal
- Private
- State
- Tribal

SCALE: 1 in. = 2,000 ft.

NORTH: NORTH

ZONE 4
PLAN AND PROFILE



Notes:
Location of proposed roads is approximate and can change.
Drill Pads are 100' by 150 feet for DR Drilling Rig
Drill Pads would likely need to be on edge of Wilderness Boundary, at the base of the Navajo Sandstone cliffs.
Maintained Dirt Roads are adequate for drilling equipment.
Unimproved Dirt Roads are adequate for Pickup Trucks.

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FIGURE NO.
12

S:\Hildale City\832-19\01 Groundwater Feasibility Study\4.0 GIS\4.1 Projects\Figure 12 - Plan View Map.mxd atrow 3/2/2020

Zone 5 contains two targets, N7 and N8. These targets are shown in the close up map in Figure 11. The RAP survey indicates heavily fractured rock in the Navajo formation and the gamma signal was very low near N7. N7 is also located at a pond denoted as Sawmill Springs on the USGS topographic map. This pond may also be an indication of water at this location. Figure 13 shows a plan and profile view of a horizontal boring that would intersect the Zone 5 target and N7. This boring would have the same starting location as the N4 boring but it would be directed southwest as opposed to northwest.

Zones 4 and 5 are an option for horizontal wells in the Navajo Aquifer at the base of the Navajo Sandstone walls that rise above Hildale. These zones would require horizontal borings to intercept the fractured zones indicated by the geophysical survey. Horizontal borings would extend about 3,000 feet into the formation for each target Zone. BC&A would recommend both of these targets could be drilled using the same starting location (drill pad) in Water Canyon. This approach would minimize access road construction and drill site improvements.

AQUIFER WELL YIELD EVALUATIONS

Navajo Aquifer

Aquifer testing has been completed regionally in the Navajo Aquifer and has been summarized in available reports (Heilweil and Freethey, 1992; Heilweil and Others, 1997; Heilweil and Solomon, 2001; Hurlow, 1998, 2002; Inkenbrandt and others, 2013). Aquifer testing in the Navajo aquifer indicates hydraulic conductivity values range from 0.3 feet/day (ft/day) to as much 30 ft/day, however, most of the results are 1 to 5 ft/day. The higher hydraulic conductivity values are believed to correlate to heavily faulted or fractured zones in the sandstone. The testing locations are located throughout southwestern Utah, however no local estimates in the Hildale area are available.

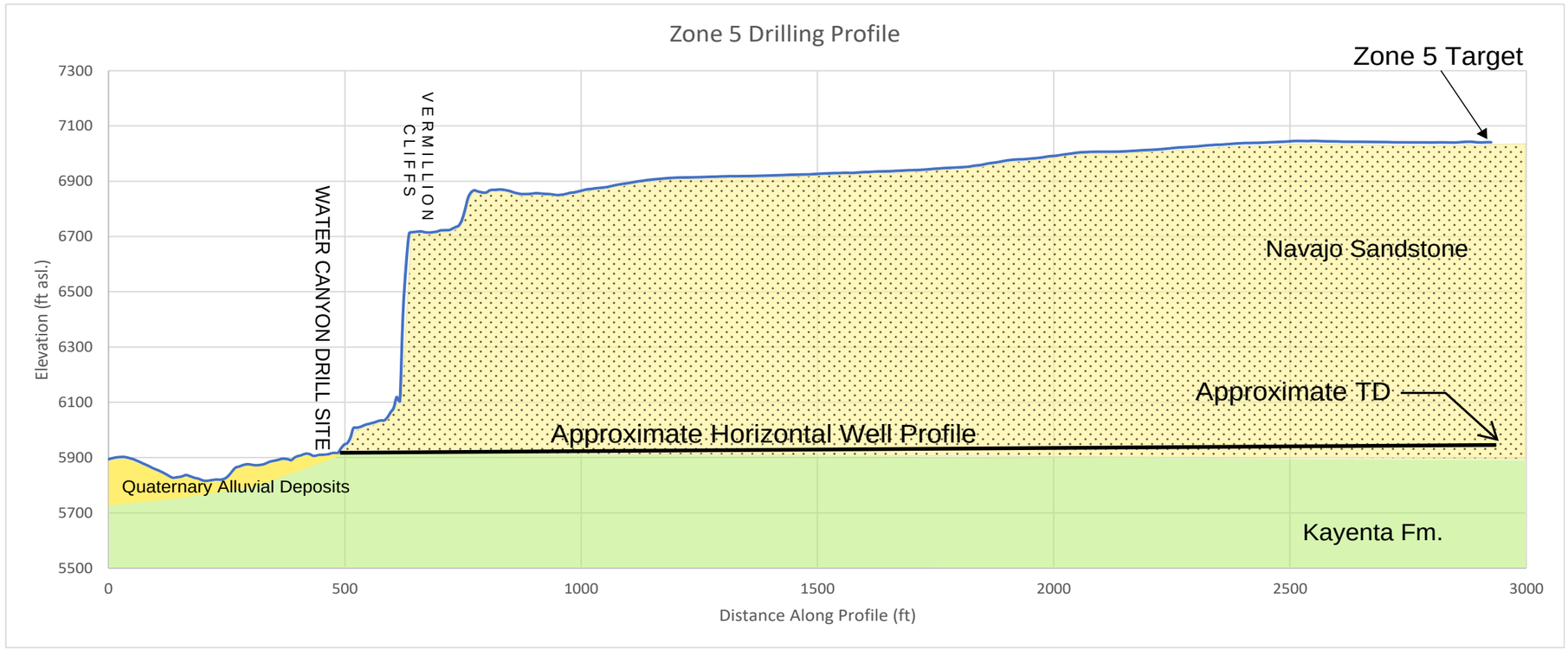
BC&A used a hydraulic conductivity value of 5 ft/day to represent the expected value for the Navajo Aquifer at the target zones. We believe this is a reasonable expected value based on the geophysical surveys identifying fractured rock at the target zones.

BC&A evaluated the potential yield of a 10-inch diameter horizontal well completed with 2,000 feet of well screen in the Navajo Aquifer. The calculation indicates that 1 horizontal well would be capable of producing at least 1,200 gpm if there was 50 feet of water in the aquifer above the well screen elevation. Two horizontal wells would be required if there was only 25 feet of water above the screen. The results indicate that horizontal wells completed in Navajo would be capable of producing 1,200 gpm.

Key to this evaluation of potential yield from the Navajo Aquifer is the assumption of water above the screen, or the saturated thickness of the aquifer. If there is no water above the screen, obviously there is no flow from the well. Horizontal wells would flow under gravity conditions and as such they have the potential to entirely drain or dewater the aquifer. When initially turned on the horizontal wells would easily produce the required 1,200 gpm flow. However, as they continue to operate and drain water from the aquifer over time their yield would diminish as the height of water above the well screens is lowered. Therefore it is also important that the aquifer be recharged at the same rate it is drained for the yield to be sustainable in the long term. The well heads will also require flow control devices to regulate the flow to keep up with demand and close when not needed.

Kayenta and Moenave Aquifers

Aquifer testing has been completed on the Kayenta Formation near Leeds, Utah (Cordova, 1978). The aquifer hydraulic conductivity was estimated at 6 ft/day. This value is similar to the higher hydraulic



Legend

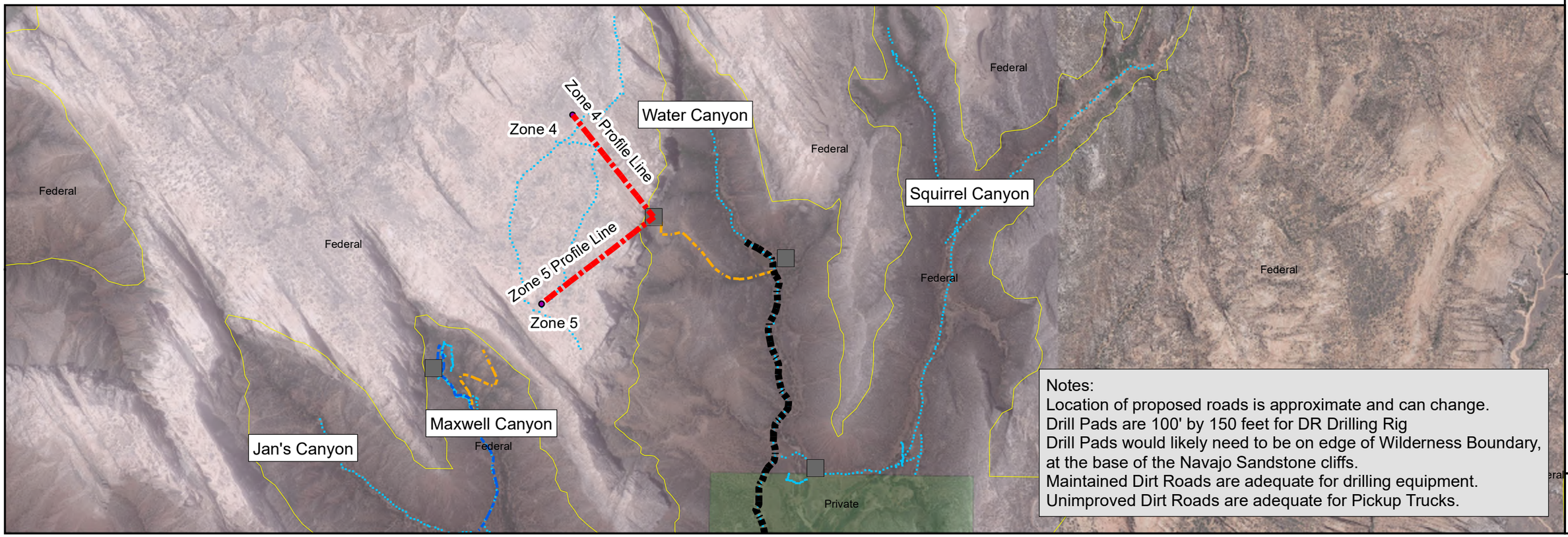
- Possible Drill Pad
- Unimproved Roads
- Maintained Dirt Roads
- Proposed Roads

Geophysical Survey Line

- Survey Point
- Canaan Mountain Wilderness

Owner

- Federal
- Private
- State
- Tribal



Notes:
Location of proposed roads is approximate and can change.
Drill Pads are 100' by 150 feet for DR Drilling Rig
Drill Pads would likely need to be on edge of Wilderness Boundary, at the base of the Navajo Sandstone cliffs.
Maintained Dirt Roads are adequate for drilling equipment.
Unimproved Dirt Roads are adequate for Pickup Trucks.

SCALE: 1 in. = 2,000 ft.

NORTH: NORTH

ZONE 5
PLAN AND PROFILE

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FIGURE NO.
13

S:\Hildale City\832-19\01 Groundwater Feasibility Study\4.0 GIS\4.1 Projects\Figure 12 - Plan View Map.mxd atrow 3/2/2020

conductivities values found for the Navajo Aquifer and may indicate a highly fractured area within the Kayenta Aquifer. There are no known wells completed in these formations in the Hildale study area.

BC&A used a hydraulic conductivity value of 5 ft/day to represent the expected value for the Kayenta and Moenave Aquifers in the study area. We believe this is a reasonable value based on the above described pump test and the geophysical surveys identifying fractured rock. The saturated thickness of the aquifer was estimated at 400 feet. This estimate is reasonable given the well(s) will be about 700 feet deep with a static water level estimated at 50 feet below ground surface. An aquifer transmissivity value of 2,000 feet^2/day was estimated using a saturated thickness of 400 feet and a conductivity of 5 feet/day.

BC&A evaluated the potential yield of a 12-inch diameter vertical well completed in the Kayenta and Moenave Aquifers. The results indicate a vertical well would be capable of producing 250 gpm with a pumping level about 160 feet below ground surface. From this finding, we estimate it would require 5 wells to achieve the project goal of a 1,200 gpm supply.

AQUIFER RECHARGE EVALUATION

Navajo Aquifer

An average of 13-inches of precipitation falls on the Canaan Mountain Wilderness area annually. Recharge to the Navajo Aquifer occurs through infiltration of precipitation that falls on Canaan Mountain/Plataeu and through infiltration of collected runoff in stream channels. Aquifer recharge rates can vary greatly due to topography, precipitation rates, temperature and elevation. Higher infiltration occurs from snowmelt and winter recharge rather than summer precipitation. Regional studies of the Navajo have shown that infiltration rates vary from 1- to 20-percent of the annual precipitation for the area (Heilweil and Freethey, 1992).

BC&A evaluated the recharge to the Navajo Aquifer. BC&A used a recharge rate of 12.5-percent of annual precipitation. We believe this is reasonable and representative estimate based on site conditions of an exposed bedrock surface on Canaan Mountain/Plateau and the presence of fractures. Using 12.5-percent of the annual precipitation results in a recharge rate of 1.63-inches per year.

For the entire exposed top of the Navajo Formation in the Cannaan Mountain Wilderness Area we estimate a surface area of about 11,000 acres. Using the recharge rate of 12.5-percent of the annual precipitation results in an annual aquifer recharge volume of 1,450 ac-ft of water. The City requires a groundwater supply of 1,200 gpm which equates to about 1,900 ac-ft/year on a year round basis. From this analysis it is apparent the recharge volume for the entire exposed top of the Navajo Formation in the Canaan Mountain Wilderness Area (1,450 ac-ft) is less than the City's annual water need (1,900 ac-ft).

Not all of that infiltrated water will recharge the Hildale side or south side of the Canaan Mountain where horizontal wells would be located. BC&A estimates the area of influence for potential future horizontal wells installed in Water Canyon to be approximately 800 acres, with an annual aquifer recharge volume of only 110 ac-ft. The potential to withdraw more groundwater than is annually recharged raises concerns about the sustainability of the withdrawals. Further analysis of the deficit between the recharge and withdrawal volumes indicates that aquifer water levels would decline about 9 feet per year over the 800 acres area. Based on this finding we have concern about the long term sustainability of horizontal wells tapping the Navajo Aquifer.

Kayenta and Moenave Aquifers

Recharge to these Kayenta and Moenave Aquifers comes from seepage from the overlying Navajo Aquifer, and also infiltration of precipitation and stream flows where the formations are exposed. The estimated recharge area for the Kayenta Formation includes the recharge area of the overlying Navajo Sandstone itself, and also the surface areas of the Jans, Maxwell, Water, and Squirrel Canyons and surroundings low lying areas. Therefore the recharge volume to the Kayenta Formation is larger than that of the Navajo Formation. In addition, portions of the Kayenta and Moenave Formations are buried beneath ground surface and therefore have a larger aquifer saturated thickness and aquifer storage volume from which to draw water. The saturated thickness of the Kayenta and Moenave Aquifers is greater than that estimated for the Navajo Aquifer. While we have not attempted to quantity recharge to the Kayenta Formation, it is our finding that the Kayenta and Moenave Aquifer have a larger annual recharge volume and a significantly larger storage volume than the Navajo Aquifer. We conclude the Kayenta and Moenave Aquifers are a better option with a higher likelihood of success for developing a 1,200 gpm groundwater supply.

SECTION 3
ALTERNATIVE ANALYSIS

Information from regional hydrogeologic studies, geophysical survey results, and our professional opinions have been used to develop and describe the alternatives considered for developing a 1,200 gpm groundwater supply for the City. Aside from the City's existing spring sources at the base of the Navajo Formation in Maxwell and Jans Canyons (shallow horizontal collector pipes), there are no existing wells in the study area to confirm the potential yield of future wells drilled into the Navajo, or Kayenta and Moenave Aquifers. BC&A has developed 2 alternatives for the analyses:

- Deep vertical wells completed in the Kayenta and Moenave Aquifers
- Horizontal wells completed in the Navajo Aquifer

The alternatives have been estimated assuming complete buildout of the alternative and do not take advantage of a phased approach to implementation to verify potential well yields. BC&A recommends an exploratory Test Well be drilled at the Zone 1 location to determine well yield and water quality. The Test Well results would be used to revise the potential well yield, number of wells required, and costs for the project.

ALTERNATIVE 1 – VERTICAL WELL FIELD IN KAYENTA AND MOENAVE AQUIFERS

Description

Alternative 1 is to construct a well field targeting the Kayenta and Moenave Aquifers. A total of five deep vertical wells are included based on the City's 1,200 gpm water supply need and estimated well yield from regional studies. It is assumed each well would produce approximately 250 gpm, or 1,250 gpm in total. The wells would be located at Zones 1, 2, and 3 the recommended target areas determined from geophysical surveys. Zone 1 is located near the Squirrel Canyon Trailhead at the bottom of Water Canyon. It is assumed 2 wells would be constructed in the Zone 1 area to a depth of 700 feet. Zone 2 is located near the City's Maxwell Canyon spring source. It is assumed 1 well would be constructed to a depth of 1,000 feet. Zone 3 is located near the Water Canyon Reservoir and trailhead. It is assumed two wells would be constructed in the Zone 3 area to a depth of 750 feet. Prior to drilling the wells a site specific geophysical survey would be conducted to refine or optimize the drilling locations.

Each well would be equipped with a pump station and conveyance piping connecting back into the Hildale City water system. It is assumed the conveyance piping would be constructed in the existing dirt roadways leading to the drill sites.

Design Criteria

Design criteria for the project are the State of Utah Rules for public drinking water systems and the City's water supply requirement of 1,200 gpm.

The new wells are anticipated to be drilled with the mud rotary method. A small diameter pilot hole, or exploratory borehole, would be drilled first to the targeted well depth. Lithologic and geophysical logging would be completed in the pilot hole. The pilot hole would then be reamed to a larger diameter and the well constructed. The constructed well would then be developed and pump tested to estimate aquifer properties and equipping parameters.

Water Rights

The City would need to obtain new water rights or transfer existing water rights via a change application to the targeted drill locations. Approval of the water rights by the Utah Division of Water Rights is required.

Land Requirements

The targeted wells sites are located on land owned by the BLM. The City would need BLM approval on an access agreement or a land purchase/swap for the project. The City owns property to the southeast of Zone 1 and it may be possible to drill on city property just outside of the Zone 1 area identified in the geophysical survey. The cost of land purchase is not included in the estimated project costs at this time.

The Zone 2 well site is located at higher elevations near the base of the Navajo Sandstone cliffs above the Maxwell Canyon Spring Collection. This site would require extensive road improvements and a significant embankment construction for a drill pad on the steep slopes.

Environmental Impacts and Approvals

Environmental impacts would include construction disturbance for access roads, well drill pads, pump houses, and conveyance piping back to the City. The targeted wells sites and pump houses would be on BLM owned land that has not been previously disturbed. It is anticipated that NEPA permitting will be required by BLM. The conveyance piping would be constructed under the existing dirt roadways that have been previously disturbed. The cost for environmental permits is not included in the estimated project costs at this time.

Other Challenges

Well pump rates and drawdown estimates are based on regional aquifer properties and not site specific data. There is uncertainty in these assumptions and the wells may not be capable of producing the estimated pump rates at specific locations due to spatial variability in the aquifer properties.

The time required to implement this alternative is a challenge. It is undefined how long it would take to implement a land purchase/swap with BLM and obtain environmental permits. Those challenges aside it is estimated it would take 2-3 years to drill, develop, and equip the wells and construct the conveyance piping.

Cost Estimates

An opinion of probable construction cost (OPCC) for the construction of the new wells at the three zones as well as capital costs for equipping the wells and installing conveyance piping is provided in Table 1.

Table 1
Alternative 1 - Opinion of Probable Construction Costs

Item	OPCC
Zone 1 Well Construction	$1,453,000
Zone 1 Two Pump Station	$600,000
Zone 1 Conveyance Pipeline	$160,000
Zone 2 Well Construction	$1,017,000
Zone 2 Pump Station	$300,000
Zone 2 Conveyance Pipeline	$339,000
Zone 3 Well Construction	$1,481,000
Zone 3 Two Pump Station	$600,000
Zone 3 Conveyance Pipeline	$390,000
Zone 1 & 3 Conveyance Pipeline	$308,000
TOTAL CAPITAL COSTS	**$6,648,000**

The estimated costs for the wells include the drilling and construction of the five wells to the depths listed above. Costs to construct an access road to the site and preparing a pad for drilling equipment were also included in the cost for the well. The pipeline costs were based on the sizes and lengths shown on Figure 14. The pump station costs were based on a slab on grade building with block walls and a steel roof system. For power cost estimates it was assumed that underground power would be provided and the lengths for the services would be similar to the new waterline lengths. Detail breakdowns of the OPCC is provided in Appendix D for review.

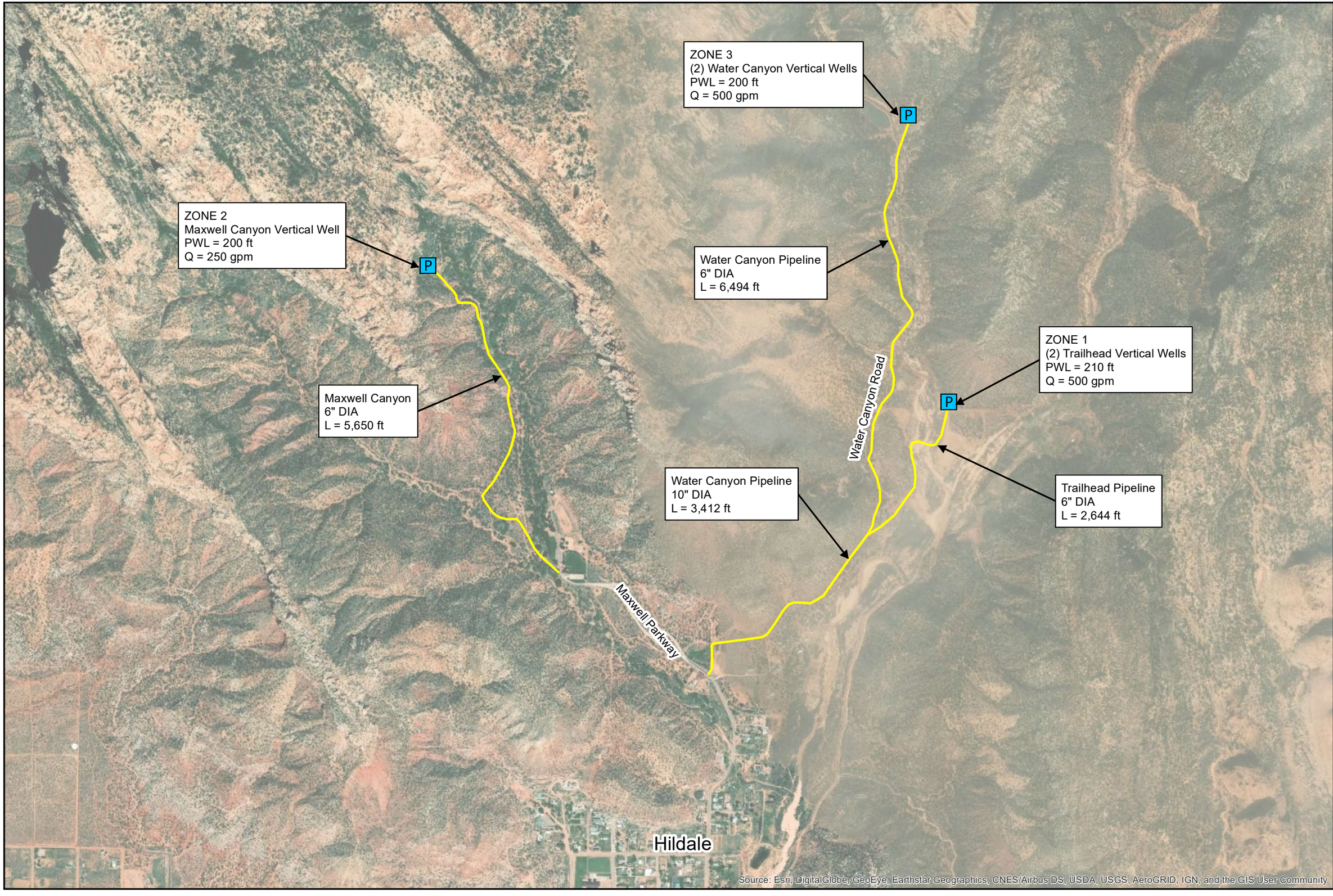
Along with the capital costs provided in Table 1, the annual pumping costs and operations and maintenance costs for the three pump stations is included in Table 2.

Table 2
Alternative 1 - Pumping and O&M Costs

Item	Annual Costs
Zone 1 Pump Station	$24,500
Zone 2 Pump Station	$11,400
Zone 3 Pump Station	$22,600
TOTAL PUMPING AND O&M COSTS	**$58,500**

The pump station annual pumping costs were estimated using the following assumptions:

- Pump Station assumed to operate pumping design flows twelve months out of the year (horsepower used to calculate the average kilowatt usage per year)
- Power usage charge of $0.0581 per kilowatt-hour (Garkane Energy Account)
- Power demand charge of $8.55 per month of operation, per peak kilowatt (Garkane Energy Account)
- Assumed average annual O&M cost of Pump Station is $5,000



SCALE: 1 in. = 1,250 ft.

NORTH:

VERTICAL WELL AND PIPELINE LOCATION MAP

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FIGURE NO.
14

S:\Hildale City\832-1901 Groundwater Feasibility Study\4.0 GIS\4.1 Projects\Figure X - Pipeline Length Figure2.mxd cdeloner 5/14/2020

ALTERNATIVE 2 – HORIZONTAL WELLS IN THE NAVAJO AQUIFER

Description

Alternative 2 is to construct horizontal wells targeting the Navajo Aquifer. A total of two horizontal wells are included. Both wells would be drilled from the same drill pad located in Water Canyon. This would minimize costs for road construction and drill site improvements. Each horizontal well would penetrate approximately 3,000 feet horizontally along the bottom of the Navajo Formation. The wells would target Zones 4 and 5 the preferred areas for the Navajo Aquifer identified by the geophysical investigations. It is assumed each well will produce 600 gpm, or 1,200 gpm total. Each well would be equipped with a gravity feed discharge, valve control, and conveyance piping connecting back into the Hildale City water system. It is assumed the conveyance piping would be constructed in the existing dirt roadways leading to the drill site.

Zones 4 and 5 are located in the Canaan Wilderness Area. Both would target prospective fractured areas in the Navajo Formation identified in the geophysical survey. For both sites the RAP seismic survey shows broken and fractured rock, and the gamma survey indicates that water is present. Zone 4 includes six targets with N2 and N9 being the largest targets. Zone 5 contains two targets, N7 and N8. Prior to drilling the wells a site specific geophysical survey would be conducted to refine or optimize the drilling locations.

Design Criteria

Design criteria for the project are the State of Utah Rules for public drinking water systems and the City's water supply requirement of 1,200 gpm.

The horizontal borings would be constructed from one drill pad located in Water Canyon. One trending NW to Zone 4 and one trending SW to Zone 5. Each of these borings would be approximately 3,000 feet and penetrate along the base of the Navajo Sandstone. A surface casing would need to be set to 100 feet in each well to control pressures and provide safety for the drilling contractor.

Water Rights

The City would need to obtain new water rights or transfer existing water rights via a change application to the targeted drill locations. Approval of the water rights by the Utah Division of Water Rights is required.

Land Requirements

The targeted wells sites are located on land owned by the BLM. The City would need BLM approval or an access agreement or a land purchase/swap for the project. The cost of land purchase is not included in the estimated project costs at this time.

The horizontal drill site would require extensive road construction from the Water Canyon Trailhead to the drill site. Additionally, a 150 foot by 100 foot drill pad would need to be constructed to provide working area for the horizontal drill rig. The drill site is located on BLM land above the popular Water Canyon hiking trail.

Environmental Impacts and Approvals

Environmental impacts would include construction disturbance for well drill pads, and conveyance piping back to the City. The targeted wells sites and pump houses would be on BLM owned land that has not been previously disturbed. It is anticipated that environmental permits will be required by BLM.

The conveyance piping would be constructed under the existing dirt roadways that have been previously disturbed. The cost for environmental permits is not included in the estimated project costs at this time.

Other Challenges

The horizontal well yield (pump rate) estimates are based on regional aquifer properties and not site specific data. There is uncertainty is these assumptions and the horizontal wells may not be capable of producing their estimated yields due to spatial variability in the aquifer properties.

Horizontal drilling can be more difficult than traditional vertical drilling projects. Advancing casing and well screen into a horizontal borehole is more challenging than lowering it vertically into a borehole.

The time required to implement this alternative is a challenge. It is undefined how long it would take to implement a land purchase/swap with BLM and obtain environmental permits. Those challenges aside it is estimated it would take 2-3 years to drill, develop, and construct the conveyance piping.

There is uncertainty in the saturated thickness, recharge rate, and sustainability of groundwater extraction for the Navajo Aquifer. Groundwater age dating indicates the Navajo Aquifer spring water in not modern (<5 year old) and there is not a deeper aquifer source that the springs are discharging from.

Cost Estimates

An OPCC was developed for the Alternative 2 construction of two new horizontal wells as described above. The estimated costs include construction of the two horizontal wells, access to the site, preparing a pad for the drilling equipment, and installing conveyance piping back to the existing distribution system. The OPCC for Alternative 2 is provided in Table 3.

Table 3
Alternative 2 - Opinion of Probable Construction Costs

Item	OPCC
Horizontal Well Construction	$2,354,000
Site Preparation (Drill pad, road & embankment)	$1,763,000
Conveyance Pipeline	$900,000
TOTAL CAPITAL COSTS	**$5,017,000**

The costs for the conveyance pipelines were estimated that approximately 12,840 linear feet of 10-inch waterline would be installed from the two new horizontal well to connect to the distribution system near the intersection of Water Canyon Road and Maxwell Parkway. Detail breakdowns of the OPCC is provided in Appendix D for review.

It is noted that the annual costs and operation and maintenance cost for Alternative 2 will be negligible due to the system operating by gravity.

SECTION 4
CONCLUSIONS AND RECOMMENDATIONS

The following conclusions and recommendations summarize the feasibility of a new water source for the City of Hildale.

CONCLUSIONS

Evaluation of a new water source for the City of Hildale focused on three aquifers, the Navajo, Kayenta and the Moenave. These three aquifers overlie and are up-gradient of the sources currently utilized by the City for the water system. Regional hydrogeologic studies indicate the Navajo and Kayenta aquifers provide drinking water for southwestern Utah, however there is significant variability in the well yield from these aquifers depending on location. There is very little local data or existing wells completed in the Navajo, Kayenta and Moenave Aquifers in the study area. Age dating analysis for water emenating from Navajo in springs or seeps located in Maxwell and Water Canyons indicated waters were not modern with an estimated age of between 70 and 1,000 years old. Further defining the age of the water may be possible by use of carbon-14 age dating. Additionally, the water quality indicated high quality water with TDS levels below 100 mg/L. There is no available water quality data for the Kayenta and Moenave Formations in the study area.

Geophysical surveys were conducted in Jans, Water, Maxwell, and Squirrel Canyons, and across the top of Navajo Formation between Maxwell and Water Canyons. From the geophysical survey multiple prospective locations in the Water Canyon, Maxwell Canyon, Squirrel Canyon and Canaan Mountain were identified and reduced to five zones. Zones 1, 2, and 3 are preferred targets for vertical wells in the Kayenta and Moenave Aquifers. Zones 4 and 5 are the preferred targets for horizontal wells completed in the Navajo Aquifer at the base of the Navajo Sandstone walls that rise above Hildale.

The potential yield from the vertical wells in Zones 1, 2 and 3 in the Kayenta and Moenave formations and the horizontal wells from Zones 4 and 5 in the Navajo Formation were evaluated using regional data for conductivity and assumed saturated thickness of the target formations. These locations were also chosen due to the likelihood of intersecting vertical fractures located in the geophysical surveys. Our estimation is that up to five vertical wells (250 gpm each) are required in Zones 1, 2 and 3 or up to two horizontal wells (600+ gpm each) are required at Zones 4 and 5 to obtain the required flow of 1,200 gpm (1,900 ac-ft).

The recharge to the Navajo Aquifer in the Canaan Mountain Wilderness area annually is approximately 12.5-percent of annual precipitation. This results in approximately 1.63 inches per year, or 1,450 ac-ft of water. The area of influence from the horizontal wells is approximately 800 acres or 110 ac-ft of water. This is approximately 18-percent of the required amount needed for the City water system demand. The potential to extract more groundwater than is annually recharged raises concerns about the sustainability of the aquifer. Further analysis of the deficit between the recharge and withdrawal volumes indicates that aquifer water levels would decline about 9 ft/yr over the 800 acre area. Based on this finding we have concern about the long term sustainability of horizontal wells tapping the Navajo Aquifer.

The recharge to the Kayenta and Moenave Aquifers was qualitatively evaluated and estimated over the project area. The two formations underlie the Navajo and have a larger recharge area and saturated thickness. While we have not attempted to quantify recharge to the Kayenta Formation, it is our finding that the Kayenta and Moenave Aquifers have both a larger annual recharge volume and

larger storage volume than the Navajo Aquifer. We conclude the Kayenta and Moenave Aquifers are a better option with a higher likelihood of success for developing a 1,200 gpm groundwater supply.

The likelihood of success in completing a new source in the three aquifers is unknown at this time. Little to no physical information is available on the long-term production rate of the three aquifers in the vicinity of Hildale. Because the study did not find hard evidence of sustainable groundwater source in the Navajo, the feasibility of success was estimated based on our professional opinion. An exploratory/phased program is necessary to obtain additional information and determine the feasibility.

RECOMMENDATIONS

There are two identified alternatives for developing new groundwater sources for the City of Hildale. Phasing of either alternative is recommended due to the variability and uncertainty of each alternative and cost associated with each alternative. The findings of the study are that Alternative 1, vertical wells in Kayenta and Moenave Aquifers are preferred and recommended because of the larger recharge volume and storage volume (i.e. sustainability) of the aquifers and the phased approach being the most cost effective.

In the event the City elects to proceed with Alternative 1 BC&A recommends:

1. Contacting the BLM and determine the likelihood of obtaining permission to drill on BLM land, buy/trade BLM land, permitting requirements, and timeframe for decisions.
2. Conduct a limited exploratory well drilling program to determine the water quality and yield. Use information from the exploratory drilling program to determine the feasibility of creating a new 1,200 gpm water supply.
3. Proceed to phased approach in installing production wells.

Reducing the gap in the age range of the water or potentially defining a more precise time may be possible by performing carbon-14 age dating at the two locations previously analyzed for water produced from the Navajo Sandstone. The City may want to pursue this analysis in the event Alternative 2, horizontal wells, is chosen. No special sampling method is required and may be performed by City personnel. A lab located at the University of Utah has the capabilities to perform the analysis in the event this alternative is selected.

SECTION 5
REFERENCES

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APPENDICIES

APPENDIX A

WATER QUALITY RESULTS FOR MAXWELL AND WATER CANYON SPRINGS

CHEMTECH-FORD
LABORATORIES

9/17/2019

Work Order: 19I0343
Project: [none]

Bowen-Collins
Attn: Andy Trow
154 East 14000 South
Draper, UT 84020

Client Service Contact: 801.262.7299

The analyses presented on this report were performed in accordance with the National Environmental Laboratory Accreditation Program (NELAP) unless noted in the comments, flags, or case narrative. If the report is to be used for regulatory compliance, it should be presented in its entirety, and not be altered.

NELAP ACCREDITED TNI LABORATORY

Approved By:

Dave Gayer, Laboratory Director

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Certificate of Analysis

Bowen-Collins
Andy Trow
154 East 14000 South
Draper, UT 84020

PO#:
Receipt: **9/6/19 10:30 @ 5.5** °C
Date Reported: 9/17/2019
Project Name: **[none]**

Sample ID: **Maxwell Canyon**

Matrix: **Drinking Water**
Lab ID: **19I0343-01**
Date Sampled: **9/4/19 14:00**
Sampled By: **Andy Trow**

	Result	Units	Minimum Reporting Limit	Method	Preparation Date/Time	Analysis Date/Time	Flag(s)
Calculations							
Anions, Total	1.4	meq/L		SM 1030 E	9/16/19	9/16/19	
Cation/Anion Balance	7.0	%		SM 1030 E	9/16/19	9/16/19	
Cations, Total	1.6	meq/L		SM 1030 E	9/16/19	9/16/19	
Inorganic							
Alkalinity - Bicarbonate (as CaCO3)	61.8	mg/L	1.0	SM 2320 B	9/13/19	9/13/19	
Alkalinity - Carbonate (as CaCO3)	ND	mg/L	1.0	SM 2320 B	9/13/19	9/13/19	
Alkalinity - Hydroxide (as CaCO3)	ND	mg/L	1.0	SM 2320 B	9/13/19	9/13/19	
Alkalinity - Total (as CaCO3)	61.8	mg/L	1.0	SM 2320 B	9/13/19	9/13/19	
Chloride	2	mg/L	1	EPA 300.0	9/6/19	9/6/19	
Nitrate as N	0.1	mg/L	0.1	EPA 300.0	9/6/19 13:35	9/6/19 13:35	
pH	7.2	pH Units	0.1	SM 4500 H-B	9/6/19 14:20	9/6/19 17:16	SPH
Sulfate	5	mg/L	1	EPA 300.0	9/6/19	9/6/19	
Total Dissolved Solids (TDS)	84	mg/L	20	SM 2540 C	9/9/19	9/9/19	
Metals							
Calcium, Dissolved	19.6	mg/L	0.2	EPA 200.7	9/9/19	9/10/19	
Magnesium, Dissolved	4.6	mg/L	0.2	EPA 200.7	9/9/19	9/10/19	
Potassium, Dissolved	4.3	mg/L	0.5	EPA 200.7	9/9/19	9/10/19	
Sodium, Dissolved	2.1	mg/L	0.5	EPA 200.7	9/9/19	9/10/19	

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Certificate of Analysis

Bowen-Collins
Andy Trow
154 East 14000 South
Draper, UT 84020

PO#:
Receipt: **9/6/19 10:30 @ 5.5** °C
Date Reported: 9/17/2019
Project Name: **[none]**

Sample ID: **Water Canyon**

Matrix: **Drinking Water**
Lab ID: **19I0343-02**
Date Sampled: **9/5/19 12:00**
Sampled By: **Andy Trow**

	Result	Units	Minimum Reporting Limit	Method	Preparation Date/Time	Analysis Date/Time	Flag(s)
Calculations							
Anions, Total	1.0	meq/L		SM 1030 E	9/16/19	9/16/19	
Cation/Anion Balance	3.3	%		SM 1030 E	9/16/19	9/16/19	
Cations, Total	1.1	meq/L		SM 1030 E	9/16/19	9/16/19	
Inorganic							
Alkalinity - Bicarbonate (as CaCO3)	48.5	mg/L	1.0	SM 2320 B	9/13/19	9/13/19	
Alkalinity - Carbonate (as CaCO3)	ND	mg/L	1.0	SM 2320 B	9/13/19	9/13/19	
Alkalinity - Hydroxide (as CaCO3)	ND	mg/L	1.0	SM 2320 B	9/13/19	9/13/19	
Alkalinity - Total (as CaCO3)	48.5	mg/L	1.0	SM 2320 B	9/13/19	9/13/19	
Chloride	1	mg/L	1	EPA 300.0	9/6/19	9/6/19	
Nitrate as N	0.2	mg/L	0.1	EPA 300.0	9/6/19 14:16	9/6/19 14:16	
pH	7.3	pH Units	0.1	SM 4500 H-B	9/6/19 14:20	9/6/19 17:16	SPH
Sulfate	1	mg/L	1	EPA 300.0	9/6/19	9/6/19	
Total Dissolved Solids (TDS)	68	mg/L	20	SM 2540 C	9/10/19	9/10/19	
Metals							
Calcium, Dissolved	12.4	mg/L	0.2	EPA 200.7	9/9/19	9/10/19	
Magnesium, Dissolved	4.5	mg/L	0.2	EPA 200.7	9/9/19	9/10/19	
Potassium, Dissolved	3.2	mg/L	0.5	EPA 200.7	9/9/19	9/10/19	
Sodium, Dissolved	1.1	mg/L	0.5	EPA 200.7	9/9/19	9/10/19	

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Certificate of Analysis

Bowen-Collins
Andy Trow
154 East 14000 South
Draper, UT 84020

PO#:
Receipt: **9/6/19 10:30 @ 5.5** °C
Date Reported: 9/17/2019
Project Name: **[none]**

Report Footnotes

Abbreviations

ND = Not detected at the corresponding Minimum Reporting Limit (MRL).
1 mg/L = one milligram per liter or 1 mg/kg = one milligram per kilogram = 1 part per million.
1 ug/L = one microgram per liter or 1 ug/kg = one microgram per kilogram = 1 part per billion.
1 ng/L = one nanogram per liter or 1 ng/kg = one nanogram per kilogram = 1 part per trillion.

Flag Descriptions

SPH = Sample submitted past method specified holding time.

DRINKING WATER SAMPLES ONLY

CHEMTECH - FORD ANALYTICAL LABORATORY

CHAIN OF CUSTODY

COMPANY: Bowen Collins
ADDRESS: 154 East 14000 South
CITY/STATE/ZIP: Draper, UT 84020
PHONE #: 801-495-2224 FAX:
CONTACT: Andy Trow PROJECT:
EMAIL: atrow@bowencollins.com

BILLING ADDRESS: Bowen Collins & Assoc.
BILLING CITY/STATE/ZIP:
PURCHASE ORDER: atrow@bowencollins.com

CHEMTECH-FORD LABORATORIES

TURNAROUND TIME REQUIRED*:
* Expedited turnaround subject to additional charge

State System Number	Send to State
None	☐ Yes ☐ No

Please fill in all blue highlighted areas. Thank you!

Lab Use Only	CLIENT SAMPLE INFORMATION						TESTS REQUESTED														Bacteria					
							Cation-Anion Balance (Diss)	Nitrate	Nitrite	pH	Turbidity	TDS	Dissolved: As, Fe, Pb, Mn								Total Coliform + E. coli (Present/Absent)	Total Coliform + E. coli (Enumerated)	HPC (Plate Count)			LAB FAIL Ref #
I0343		LOCATION	DATE	TIME	FACILITY ID (source code)	POINT CODE (DBP)	Field: Residual Chlorine																			
01	1.	Maxwell Canyon	9/4	2 PM	N/A	N/A		X	X	X	X	X	X	X												
02	2.	Water Canyon	9/5	12 PM	N/A	N/A		X	X	X	X	X	X	X												
	3.				N/A	N/A		X	X	X	X	X	X	X												
	4.				N/A	N/A		X	X	X	X	X	X	X												
	5.																									
	6.																									
	7.																									
	8.																									
	9.																									
	10.																									

R = Routine
I = investigative
TR = Trigger Source
RP = Repeat

REPEAT
OR = Original Location
UP = Upstream
DN = Downstream

Sampled by: [print] Andy Trow
Sampled by: [signature] Andy Trow

ON ICE NOT ON ICE Temp (C°): 5.5

Special Instructions:

Samples received outside the EPA recommended temperature range of 0-6 C° may be rejected.

Relinquished by: [signature] Andy Trow	Date/Time 9/6/2019 10:30 am	Received by: [signature]	Date/Time 9/6/19 1030 am
Relinquished by: [signature]	Date/Time	Received by: [signature]	Date/Time
Relinquished by: [signature]	Date/Time	Received by: [signature]	Date/Time

CHEMTECH-FORD
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866.792.0093 FAX
www.ChemtechFord.com

Payment Terms are net 30 days OAC. 1.5% interest charge per month (18% per annum).
Client agrees to pay collection costs and attorney's fees.

Work Order # I0343

CHEMTECH FORD LABORATORIES
Sample Receipt

CHEMTECH-FORD LABORATORIES

Delivery Method:

- ☐ UPS
- ☐ USPS
- ☐ FedEx
- ☐ Chemtech Courier
- ☑ Walk-in
- ☐ Customer Courier

Receiving Temperature 5.5 °C

Sample #	Container	Chemtech Lot # or Preservative	Number of Subsamples	Preserved by Client/Third Party	Preserved in Receiving/Laboratory	Filtered in Field by Client	Misc Volume (oz/mL)	Comments
01-02	AG		1					

Sample Condition
(check if *yes*)

- ☐ Custody Seals
- ☑ Containers Intact
- ☑ COC/Labels Agree
- ☑ Preservation Confirmed
- ☑ Received on Ice
- ☑ Correct Containers(s)
- ☑ Sufficent Sample Volume
- ☐ Headspace Present (VOC)
- ☐ Temperature Blank
- ☑ Received within Holding Time

Plastic Containers

A- Plastic Unpreserved
B- Miscellaneous Plastic
C- Cyanide Qt (NaOH)
E- Coliform/Ecoli/HPC
F- Sulfide Qt (Zn Acetate)
L- Mercury 1631
M- Metals Pint (HNO3)
N- Nutrient Pint (H2SO4)
R- Radiological (HNO3)
S- Sludge Cups/Tubs
Q- Plastic Bag

Glass Containers

D- 625 (Na2S2O3)
G- Glass Unpreserved
H- HAAs (NH4Cl)
J- 508/515/525 (Na2SO3)
K- 515.3 Herbicides
O- Oil & Grease (HCl)
P- Phenols (H2SO4)
T- TOC/TOX (H3PO4)
U- 531 (MCAA, Na2S2O3)
V- 524/THMs (Ascorbic Acid)
W- 8260 VOC (1:1 HCl)
X- Vial Unpreserved
Y- 624/504 (Na2S2O3)
Z- Miscellaneous Glass

APPENDIX B

GROUNDWATER AGE DATING REPORT FOR MAXWELL AND WATER CANYON SPRINGS

Analysis of Environmental Tracers in Maxwell Canyon and Water Canyon near Hildale Utah

D. Kip Solomon
Ph.D., P.G.

January 28, 2020



Introduction

The Dissolved Gas Lab at the University of Utah analyzed water samples collected from two springs located near Hildale Utah. The samples were collected by Bowen Collins & Associates staff at the following locations:

1. Maxwell Canyon Sample Location (Lower Maxwell Canyon Manhole)
   Lat: 37.030453°
   Lon: -112.975972°
2. Water Canyon Sample Location
   Lat: 37.049701°
   Lon: -112.960890°

Samples were analyzed for tritium (^3H), noble gases (including ^3He and ^4He), sulfur hexafluoride (SF_6), and chlorofluorocarbons (CFC-11, CFC-12, and CFC-113). Collectively these analytes are referred to as environmental tracers and their concentrations in water are related to the water transit times (commonly referred to as "groundwater age") in the subsurface. Because springs typically collect groundwater samples from a range of subsurface flow paths that converge near the spring orifice, a sample collected from a spring is often a mixture of waters having different transit times. By analyzing a suite of environmental tracers it is sometimes possible to evaluate the existence of water mixtures having a range of transit times.

Concepts of Groundwater Dating and Noble Gas Thermometry

The concept of groundwater dating differs between the various environmental tracers measured. Sulfur hexafluoride and CFCs are known as transient tracers as their concentration in the atmosphere has been changing with time as shown in Figure 1. When precipitation infiltrates the land surface, it equilibrates with gases in the atmosphere and the shallow soil-atmosphere according to Henry's Law. When the atmospheric concentration increases monotonically with time, the dissolved concentration in soil water is uniquely related to time. Once the water goes below the water table and becomes isolated from the atmosphere, the recharge concentration remains constant as the water continues to flow through the saturated zone. Thus, the dissolved concentration in a groundwater sample can be compared to the equilibrium concentration in the atmosphere to provide an estimate of the time when the groundwater was last in contact with the atmosphere, known as the recharge year. Since the late 1990's, dating with CFC is more complicated due to declining atmospheric concentrations (i.e. certain concentrations are associated with two points in time instead of one point in time). Other complications include biogeochemical reactions in the subsurface that can alter concentrations. For additional information see Cook and Solomon (1997), and Busenberg and Plummer (1992, 2000).

Tritium (^3H) is also a transient tracer as shown in Figure 1, but is radioactive with a half-life of 12.32 years. Unlike the other environmental tracers measured in this project that are gases in the atmosphere, tritium is a part of the water molecule (^3HHO) and does not

exchange significantly with the vapor phase. The combination of a complex atmospheric concentration (Figure 1) and radioactive decay, makes it difficult to uniquely date water with tritium alone when the age is between about 10 and 60 years. However, the daughter of ^{3}H decay is the noble gas helium-3 (^{3}He). By measuring both ^{3}H (the parent) and ^{3}He (the daughter) it is possible to determine the transit time using the ratio of ^{3}He that comes from ^{3}H decay (known as tritiogenic helium -3 or $^{3}He^{*}$) to ^{3}H. Because $^{3}He^{*}$ is a gas and can exchange with the atmosphere above the water table, the tritium/helium-3 "clock" starts at the water table and records the transit time in the saturated zone. There are other sources of ^{3}He in groundwater besides ^{3}H decay including the atmosphere and subsurface production. The computation of $^{3}H^{*}$ from the total measured amount of ^{3}He requires the measurement of other noble gases such as neon to subtract the atmospheric component. The practical dating range for the $^{3}H/^{3}He$ method is 0 to 60 years. See Solomon and Cook (2000) for additional details.

Radioactive uranium and thorium are present in virtually all rocks and sediments and produce helium-4 (^{4}He) in the subsurface. Because very few minerals retain ^{4}He, it is readily transferred to groundwater. As a result, the longer water is in contact with U- and Th-bearing minerals, the higher the ^{4}He concentration becomes. Although groundwater dating with ^{4}He is conceptually simple, it can be difficult to evaluate the production rate as U and Th concentrations and He retention vary from one rock type to another. As a result, ^{4}He is often used as a relative, rather than a precise, dating tool. See Solomon and Cook (2000) for more details.

Noble gases such as neon (Ne), argon (Ar), krypton (Kr) and xenon (Xe) are present in groundwater due mostly to their presence in the atmosphere. The solubility of these gases in recharging water is a function of temperature and atmospheric pressure, which in turn is a function of elevation. When the elevation of the water table at the recharge location is known, it is possible to use measured noble gas concentrations to evaluate the temperature when the water was last in contact with the atmosphere at the water table. In most aquifers, the dissolved concentration of these noble gases does not change in the subsurface even when the water itself changes temperature. Thus, measured concentrations can be used to estimate the recharge temperature. This procedure is relatively straightforward in non-mountainous areas, but become more complicated when the recharge elevation is not know because air temperature and pressure are correlated. See Aeschbach-Hertig and Solomon (2013) for more details.

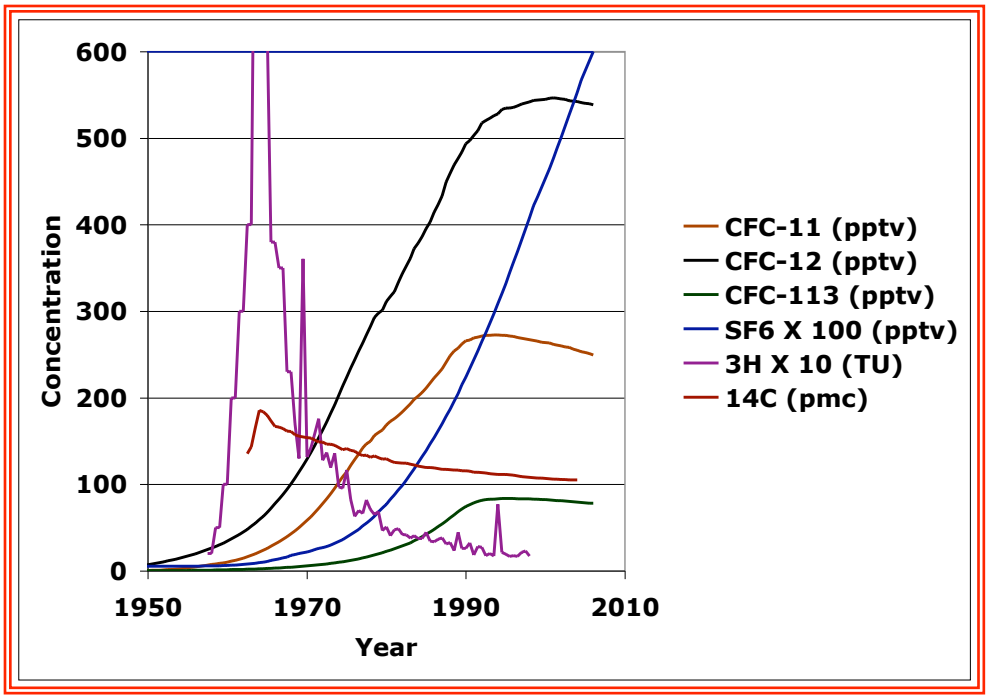


Figure 1. Atmospheric concentrations of transient environmental tracers. Groundwater dating with transient tracers relies on recharging water equilibrating with a unique concentration in the atmosphere each year such as is the case for SF_6. Dating with CFCs since the late 1990s is complicated by the decline in atmospheric concentrations. Dating with ^{3}H is also complicated by radioactive decay in addition to the declining atmospheric concentration. Note that ^{14}C was not measured in the present study.

Results

Noble Gases and Tritium

Measured concentrations of dissolved noble gases and tritium are shown in Table 1. The value R/Ra is the $^{3}He/^{4}He$ ratio measured in the sample (R) normalized by the $^{3}He/^{4}He$ ratio in air (1.384×10^{-6}). Argon, Ne, Kr, and Xe values are all within the range expected for natural waters that equilibrated with the atmosphere above the water table. Helium-4 values range from 3.9×10^{-8} to 4.1×10^{-8} ccSTP/g and are near the atmospheric equilibrium value. When groundwater is in contact with sediments and rocks that are producing ^{4}He (from the radioactive decay of U and Th), the ^{4}He concentration becomes elevated above the atmospheric solubility value. The difference between the measured concentration of ^{4}He and the theoretical solubility of ^{4}He is known as terrigenic ^{4}He. It generally takes up to 1000 years to generate enough ^{4}He to be measurably greater than the solubility value (i.e. to have measureable amounts of terrigenic ^{4}He). Thus, the observed (low) concentrations of ^{4}He suggest that the water is younger than about 1000 years.

Tritium values shown in Table 1 range from 0.14 to 0.28 TU. These values are significantly lower than modern precipitation that is likely to be in the range of 5 to 10 TU (based on measurements in Salt Lake City). Since the half-life of tritium is 12.32 years, these samples appear to have been isolated from the atmosphere for at least 70 years (see below).

Tritium/helium-3 Dating

Calculated $^3H/^3He$ ages range from 16 ± 33 years for Maxwell Canyon to –50 ± 28 years from Water Canyon. Negative ages are obviously impossible and result from very small analytical errors. This is further illustrated by the large uncertainty in these calculated ages. Essentially these waters are too old to be dated using the $^3H/^3He$ method.

Mixture of old and young

Since spring discharge typically consists of groundwater having a range of transit times, I have evaluated the possibility that the measured ^3H values result from mixing very old (low ^3H) water with some amount of modern (high ^3H) precipitation. The ^3H value in a binary mixture is given by:

$$3H_{mix} = 3H_{young}F + 3H_{old}(F - 1)$$

where F is the fraction of young water in the mixture. The ^3H value of the old fraction of water can be estimated using the law of radioactive decay and assuming that the atmospheric ^3H value prior to 1950 (i.e. prior to above-ground testing of nuclear weapons) was the same as the current value. Using maximum and minimum values for atmospheric ^3H of 10 and 5 TU, and a maximum and minimum age for the old water of 1000 and 70 years (the minimum age cannot be less than 70 years because above-ground testing of nuclear weapons would make the sampled values be much larger than the measured values) I calculate maximum and minimum values of F for Water Canyon and Maxwell Canyon of 7.4% to 2.8% and 4.7% to 1.4% respectively. In other words, the ^3H values lead to an interpretation that nearly all of the groundwater in both springs is more than 70 years, and that neither spring contains significant amounts of modern water.

Table 1. Measured concentrations of dissolved noble gases and tritium.

Sample I.D.	Ar total (ccSTP/g)	Ne total (ccSTP/g)	Kr total (ccSTP/g)	Xe total (ccSTP/g)	He4 (ccSTP/g)	R/Ra	3H (TU)	1-sigma error +/-
Maxwell Canyon	2.95E-04	1.62E-07	6.36E-08	9.43E-09	3.9E-08	0.975	0.14	.01
Water Canyon	3.17E-04	1.76E-07	7.14E-08	1.05E-08	4.1E-08	0.978	0.28	.01

Recharge Temperature

The noble gas measurements can be used to estimate the temperature of the water when it was last in contact with the atmosphere (i.e. at the water table where the recharge

occurred). This is possible because the solubility of atmospherically derived gases is temperature dependent. The recharge temperature calculated using the Closed System Equilibrium (CE) model (Aeschbach-Hertig and Solomon, 2013) for Maxwell Canyon and Water Canyon are 12.5 ˚C and 9.5 ˚C respectively. The noble gas concentrations fit the CE model well with the sum of chi-squared being 2.5 and 0.6 for the Maxwell Canyon and Water Canyon respectively. The mean annual air temperature in Hilldale is 17.8 ˚C and the lower values for the samples likely reflect a mean annual temperature at a higher elevation where recharge occurs.

SF_6

Measured concentrations of SF_6 along with calculated apparent recharge year and age are shown in Table 2. Concentrations range from 1.4 to 1.2 fmole/kg with apparent ages ranging from 21.7 to 26.2 years. The recharge years and apparent ages include corrections for a small amount of excess air (0.0006 and 0.0011 ccSTP/g for Maxwell Canyon and Water Canyon) as given by the noble gas results. These apparent ages are younger than those derived from ^3H and likely reflect some contact between the atmosphere and the water between the point of discharge and collection. Although these apparent ages are not completely consistent with ^3H-derived ages, it is clear that neither of these springs is discharging modern water.

Table 2. Measured concentrations of SF_6 and calculated apparent recharge year and age.

Sample ID	SF6 Conc. (fmole/kg)	Apparent recharge year	Apparent age (yr)
Maxwell Canyon	1.4	**1998.0**	**21.7**
Water Canyon	1.2	**1993.5**	**26.2**

CFCs

Measured concentrations of CFC-11, CFC-12, and CFC-113 are shown in Table 3. CFC samples were measured in triplicate and all analyses are shown in Table 3. There is excellent agreement between the replicate analyses. Values of CFC-11 range from 3.06 to 2.78 pmole/kg and CFC-12 ranges from 1.80 to 1.65 pmole/kg with CFC-113 ranging from 0.20 to 0.17 pmole/kg. Apparent recharge years (year in which water was last in contact with the atmosphere at the water table) range from 1995.5 to 1984 and are remarkably similar especially given that the uncertainty in CFC ages is on the order of ± 5 years. The apparent ages derived from CFCs (sampling date minus recharge year) are somewhat older than the SF_6-derived ages, but are still younger than the ages derived from ^3H. Like SF_6, it is likely that some (or most) of the CFCs in the samples resulted from contact with the atmosphere between the point of discharge and sample collection. Similar to SF_6, it is clear that neither of these springs is discharging modern water.

Table 3 Measured Concentrations of CFC-11, CFC-12, and CFC-113 and Apparent Recharge Years.

SAMPLE ID	CFC-11 (pmoles/kg)	CFC-12 (pmoles/kg)	CFC-113 (pmoles/kg)	CFC-11 Rech. year	CFC-12 Rech. year	CFC-113 Rech. year
Maxwell Canyon	2.86	1.71	0.18	1986	1991	1985.5
Maxwell Canyon	3.06	1.80	0.20	1987	1995.5	1986
Maxwell Canyon	2.86	1.72	0.18	1986	1991.5	1985
Water Canyon	2.76	1.67	0.17	1983.5	1988	1984.5
Water Canyon	2.79	1.71	0.18	1984	1989	1985
Water Canyon	2.78	1.65	0.19	1984	1988	1985

Interpretations and Recommendations

The low ^{3}H and low terrigenic ^{4}He suggest that the mean age of the water is older than 70 years, but still younger than 1000 years. The apparent age of both springs using CFCs is 26 to 35 years with relatively good agreement between the three CFC tracers. Because the samples could not be collected before contacting the atmosphere, it is likely that most of the CFCs in the samples resulted from contact with the modern atmosphere between discharge and sample collections. The apparent SF_6 ages ranges from 22 to 26 years. Like CFCs, it is likely that most of the SF_6 in the samples resulted from contact with the atmosphere prior to sample collections. Nevertheless, both the CFCs and SF_6 values make it clear that the waters are not modern.

Both water samples are too old to be dated with the $^{3}H/^{3}He$ method, but reliable recharge temperatures of 9.5 to 12.5 ˚C were derived from the noble gas analyses. These temperatures are colder than the mean annual air temperature in Hildale, Utah (17.8 ˚C) and likely result from recharge that occurs at a higher elevation where the mean annual temperature is colder. This is also consistent with the other environmental tracers in that the water was not recharged locally and thus does not have a young age.

While the low ^{3}H values effectively constrain the age of the samples to be older than 70 years, the upper age deduced from low terrigenic ^{4}He is much less certain. The discordance between the ^{3}H-derived age and the CFC/SF_6-derived age suggests that some

gas exchange occurred between the discharge and collection points. This gas exchange could also result in a loss of terrigenic ^{4}He from the samples. Furthermore, the production rate of ^{4}He in the aquifer is not known precisely. Thus, the upper age estimate of 1000 years is relatively uncertain. If greater certainty in the upper age limited is desired, analysis of ^{14}C (half-life of 5730 years) may be helpful, although the uncertainty in ^{14}C groundwater dating is often 500 to 1000 years. Thus, ^{14}C could potentially add more certainty to the interpretation that the waters are younger than 1000 years (and could reliably date the waters should their ages be in the range of 1000 to 30,000 years), but the uncertainty in the age estimate would still be rather large.

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APPENDIX C
GEOPHYSICAL SURVEY REPORTS

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www.teamhydrosource.com

October 23, 2019

Mike Jessop
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132 East 13065 South, Suite 100
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Dear Mike:

This is a report on a fracture-trace study done by HydroSource Associates to support a groundwater development project being undertaken by Willowstick Technologies in Hildale, Utah, and Colorado City, Arizona. The work is being done on behalf of the utilities department of Hildale, Utah, and Colorado City, Arizona. The study area for this project is a circle with a radius of two miles centered on a point northeast of Hildale. Willowstick will be doing geophysical surveying in this area to identify precise locations for test wells.

The purpose of the fracture-trace work is to identify zones inside the study area where the likelihood of concentrated bedrock fracturing appears high, and where prospects for development of high-yielding supply wells are enhanced. Willowstick is to use the results of the fracture-trace work to help it determine how to lay out its survey grids in a manner most likely to identify the most promising available test drilling targets.

Scope of Work

The main purpose of HydroSource's work was to produce a fracture-trace map of the study area and the immediately surrounding region. The map was to be based on appropriate and readily available imagery platforms, several of which were included in a GIS file collection provided by Willowstick. Aside from mapping lineaments, HydroSource was to interpret the lineament patterns in context with available background data. Willowstick provided the following data sources:

- a bedrock geologic map and accompanying report (Sable, 1995);
- a USGS report on the mineral resources of an area including the study area (Van Loenen et al., 1988);
- a digital elevation model with a resolution of 10 meters;
- topographic maps at several scales;
- several maps from a Bowen Collins & Associates (BC) report;
- a document collection from BC that included SOQs from several engineering companies.

The 1988 USGS mineral resources report contained several maps with relevant information. These included: a structural contour on the top of the Moenave Formation; an aeromagnetic anomaly map; and a gravity anomaly map. Information on several wells was included on one of the maps from BC, and more well information was found in one of the engineering company SOQs.

Geology

The lithologic descriptions provided here are mostly summarized from the description of map units that accompanies the Geologic Map of the Hildale Quadrangle.

The study area is underlain by a nearly flatlying sequence of sedimentary rocks. The youngest unit exposed at the surface is the Lower Jurassic Navajo Sandstone, which forms the top surfaces and upper parts of the cliffs of the dissected plateaus on both sides of Short Creek. The Navajo is a mostly aeolian sandstone, and is subdivided into an upper pink or vermillion unit, and a lower gray and reddish-brown unit. The lower unit tends to be a ledge-former.

The Navajo is underlain by the Lower Jurassic Kayenta Formation. The Kayenta is the reddish, shaley unit that is exposed along many creek bottoms and partway up the adjacent slopes. Lithologies included in the Kayenta are siltstone, sandstone, mudstone, and shale. The full section of Kayenta is 600 to 630 feet thick.

Units below the Kayenta are not exposed at the surface within the study area. These include the three members of the Lower Jurassic Moenave Formation (Springdale, Whitmore Point, and Dinosaur Canyon), and the two members of the Upper Triassic Chinle Formation (Petrified Forest and Shinarump Conglomerate). Below that are the Middle to Lower Triassic Moenkopi Formation and the Lower Permian Kaibab Limestone.

The sedimentary sequence above the Kaibab includes sandstone, siltstone, mudstone, and shale, with scattered conglomerate layers and a few thin limestone layers. It is assumed that the units with the best potential to host high-yielding wells will be those that deform via brittle fracturing. These would tend to be the conglomerates, sandstones with a low proportion of silt and clay, and carbonates.

The Shinarump Conglomerate member of the Chinle would normally be a natural drilling target, given the likelihood that deformation of the rock would probably be expressed by brittle fracturing rather than plastic deformation. In zones of concentrated fracturing along regional-scale structures, the Shinarump might be highly productive. However, as noted in the BC SOQ, Hildale/Colorado City wells tapping the Shinarump have high radium levels, and it is likely that Shinarump wells in other locations would have similar problems. The Shinarump hosts the uranium deposits of the Monument Valley area and other parts of the Colorado Plateau, and it is not surprising that elevated radium would be widespread in this unit.

The Jones & DeMille Engineering SOQ included a description of a high-yielding well in the Kaibab Limestone. Deformation of the Kaibab would tend to produce brittle fractures, and the

formation could be very productive in zones of concentrated fracturing along major structures, where solution enlargement produced interconnected zones of open space in the limestone.

Approach

Lineaments are linear or curvilinear features that can be recognized on map-like products of various kinds. They can be manifested topographically, or as tonal, color, or textural anomalies. For this study, we assembled a GIS file set based primarily on the shape files, bitmaps, and DEM supplied by Willowstick. We assessed the available layers of imagery for their usefulness in mapping lineaments.

We concluded that the most useful imagery source for our purposes at this site was the satellite imagery directly available through Google Earth, and most of the lineament mapping was done directly in the Google Earth application. Lineament mapping was done both with and without the application's three-dimensional terrain feature activated. Lineament mapping was also done using a variety of Google Earth zoom settings, so that the imagery was viewed at a wide range of scales. Mapping was also done as separate sessions, spread out over the course of several days. This basically allowed time for us to view the site with "fresh eyes" during each new mapping session. After the Google Earth lineament map was complete, the lineaments were exported from the application as a KMZ file, and then were imported to QGIS, the open-source GIS software that we use.

Lineaments were also mapped on hillshaded DEM backdrops. Several different hillshaded DEMS were produced, using a range of lighting directions and angles to accentuate linear features at different orientations.

In general, lineaments were deliberately mapped without too much concern for whether any particular lineament represented a structural feature in the bedrock. That is, some linear features may be explained by a cause other than bedrock structure, but we do not attempt to filter such features out during mapping. Instead, we assume that significant structural fracture fabrics will be represented by many example lineaments, and that the frequency of occurrence of lineaments unrelated to bedrock structure will be low. Although our policy was to be "agnostic" in mapping lineaments, not requiring that every lineament obviously have a bedrock structural explanation, our sense on this project is that the great majority of lineaments identified do in fact have a structural basis.

The lineaments shown on the following maps should be considered a representative sampling. Many more lineaments could have been drawn, but the mapping provided here is considered adequate to illustrate the important trends of the main lineament families.

The designated study area for the fracture trace mapping project was the area within a circle with a radius of two miles. The center of the circle was north of Hildale, at approximately the junction of Water Canyon Road with Canyon Street. Although it was understood that potential locations for test wells would be restricted to the region within the two-mile radius, it was necessary to map lineaments in a rather larger area to understand how lineaments inside the study area fit into the larger regional structural pattern. Consequently, the lineament map

extends for several miles beyond the edge of the study area to the northwest, north, and east. Attention was focused on the expansive plateau areas underlain by the Navajo rather than on the broad valley floor southwest of the Vermillion Cliffs, since the relatively young apron of sediments covering bedrock in the valley effectively hides bedrock structures.

Results

Figure 1 shows the lineaments mapped by HydroSource. The map uses Google Earth satellite imagery as a backdrop, and it also shows the study area. As already mentioned, lineaments were mapped in an area that extended well beyond the edge of the study area, in order to provide the regional structural context needed to understand the lineament patterns within the study area.

Lineament mapping was largely confined to areas underlain by the Navajo Sandstone, because the Navajo is a brittle unit that responds to stress by fracturing. In contrast, the Kayenta is a shaley unit. It appears to respond to stress via plastic deformation distributed more nearly uniformly throughout the mass of the rock.

Figure 2 shows the same lineaments as Figure 1, but in this map the region of mapped lineaments has been divided into three domains (A, B, and C) to facilitate the discussion. The map shows one dominant lineament fabric, consisting of close-spaced lineaments with a northwesterly trend. These lineaments are most often very clearly defined steeply dipping joints. Individual joints can often be traced continuously for several thousand feet.

Because there is so little vegetation on the Navajo, and so little cover of unconsolidated sediments, these fractures can be observed directly. Sometimes they are marked by lines of low shrubs (presumably something like sagebrush), and sometimes by minor cliffs. The joints cut across easily recognizable bedding planes in the Navajo, and in general no offset of the bedding planes is seen on opposite sides of a joint. In regions where the jointing is well developed, individual joints are typically separated from each other by 20 to 60 feet.

In much of the region underlain by the Navajo sandstone, these joints are distributed fairly evenly. The joints appear to be the formation's response to regional-scale stresses. This even distribution of joints with a northwesterly orientation is most clearly expressed in Domain A of Figure 2. In this domain, the lineament fabric shows a very gently curving arcuate form, concave to the southwest. The domain contains only a few lineaments that are not part of the main joint family.

The same lineament set also dominates Domain B. However, this domain includes a higher frequency of lineaments representing other trends. One set of several lineaments has a NNE trend, and generally appears related to a fault shown on the geologic map. Another lineament set has an ENE trend, and is also seen in Domain C.

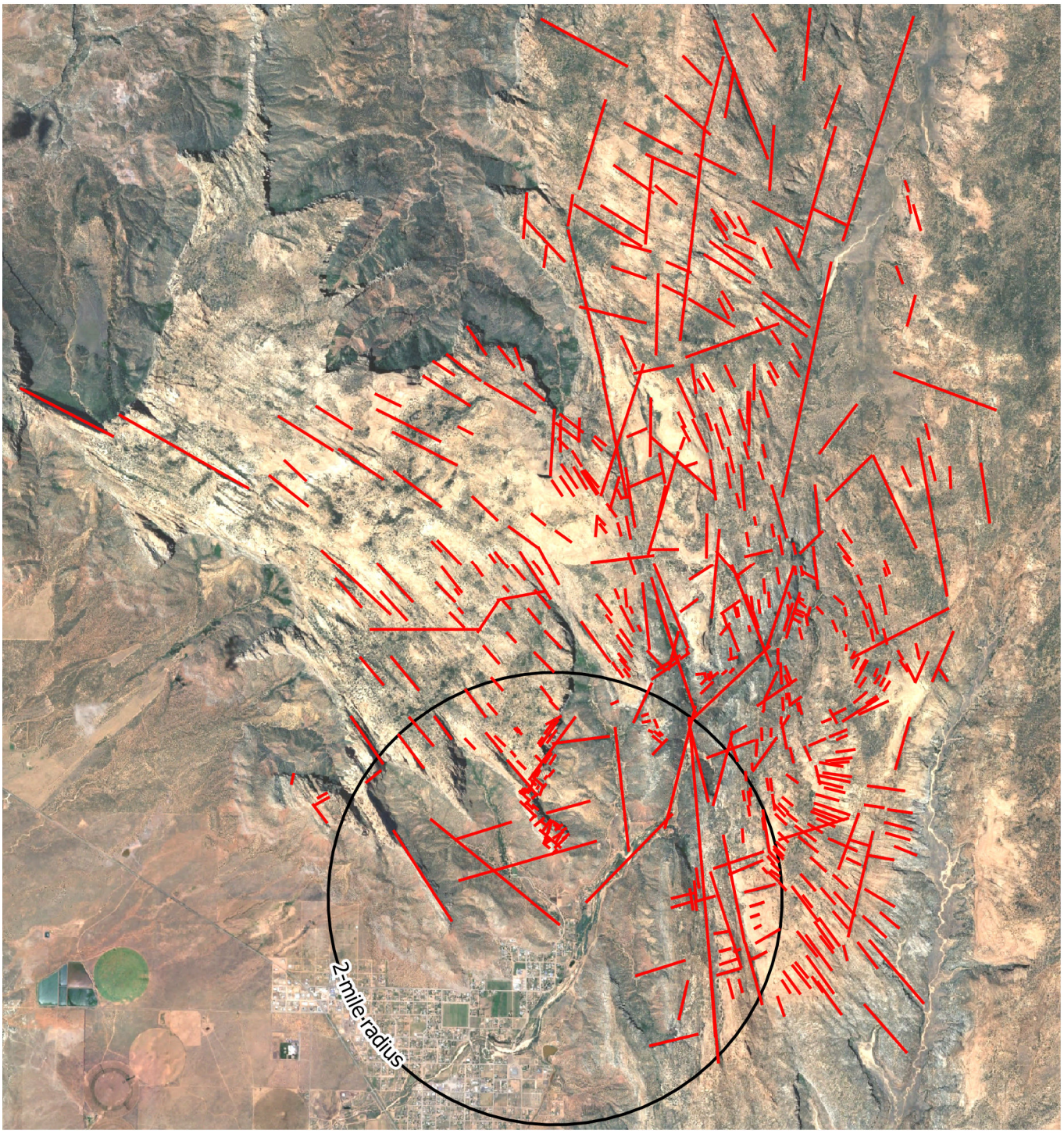


Figure 1 - Lineaments

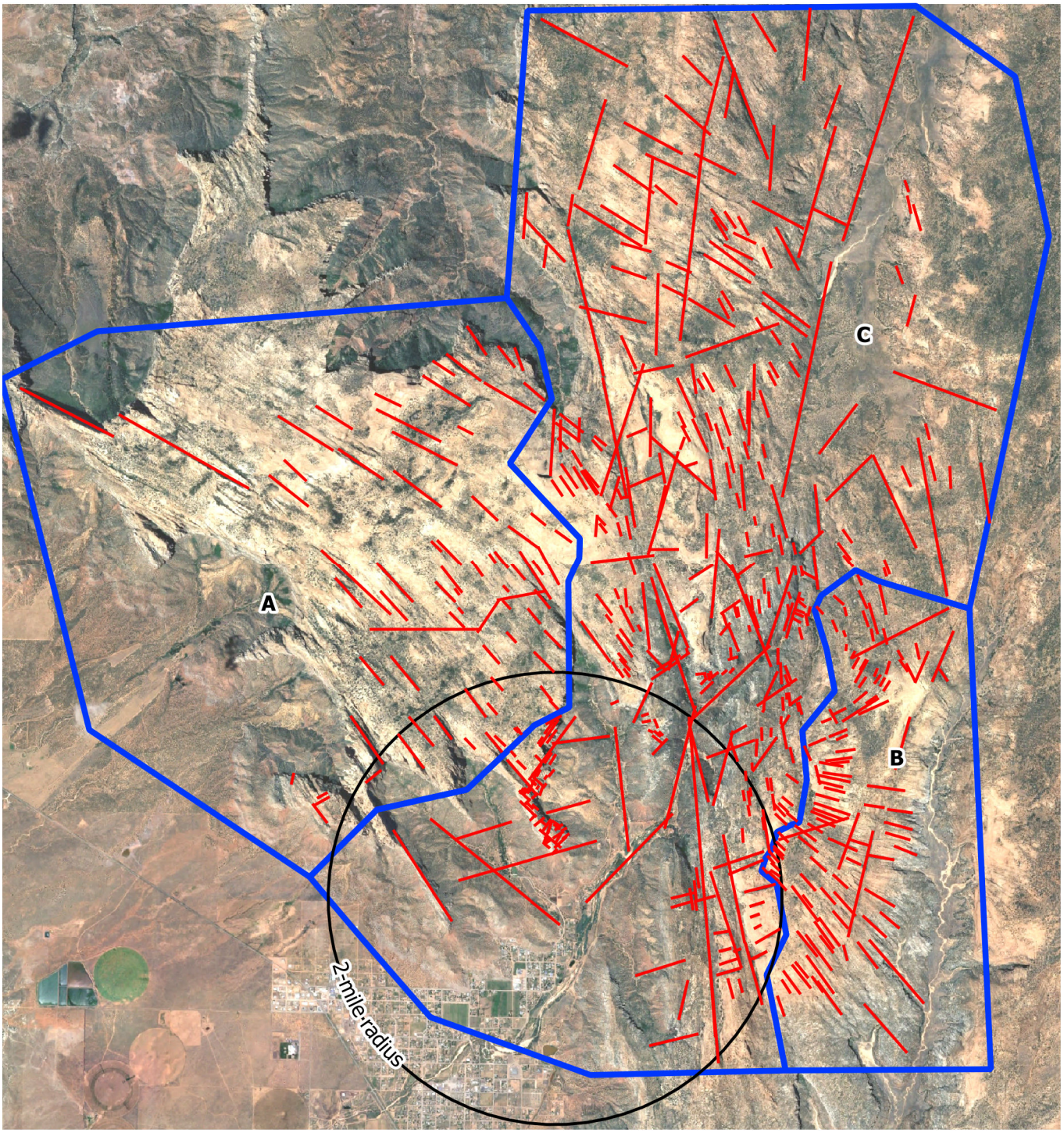


Figure 2 - Lineaments and Domains

Domain C also has many representatives of the primary lineament/joint family manifested in Domains A and B. However, the trend of the joints in the main family becomes distorted and disrupted in Domain C, as two regional-scale structures in that domain are approached. Before considering those structures we will discuss diagrams showing variations in lineament trend frequency in the domains.

Figure 3 shows four rose diagrams. These diagrams are essentially circular histograms that show the frequency of occurrence of lineaments at different orientations. In interpreting these diagrams, it is important to keep in mind that they measure lineament orientation frequency without regard to lineament length. Short lineaments count the same as long ones, which might be considered to have more structural significance. We could have weighted the lineaments to account for length, but this was not done because it was not considered likely to support the main purpose of this work, which is to identify areas where concentrated bedrock fracturing seems especially likely.

The diagram at the upper left shows lineament trend frequency for all 577 lineaments together. Separate diagrams have been prepared for the lineaments in the three domains. The "All Domains" diagram requires no discussion. In Domain A, the dominance of the main northwesterly trend is obvious. The narrowness of the rose petal with an azimuth peak at 139 degrees shows that the curvature of the main trend over the extent of the domain is modest.

The diagram for Domain B is similar, with a single dominant petal at an azimuth orientation of 141 degrees. However, the diagram shows several shorter petals representing trends cutting across the trend of the main joint set.

In the diagram for Domain C, it can be seen that the trend representing the primary lineament family of Domains A and B has been overwhelmed and disrupted by lineaments at other orientations. The strongest peak in this diagram is centered on an azimuth of 168 degrees. This corresponds with one of the discrete structures already mentioned.

Figure 4 includes the same data shown in Figure 2, but with the addition of two linear corridors that appear to coincide with discrete regional-scale structures. Structure 1 is very straight, and has a NNW trend. A portion of this feature coincides with a fault shown on the geologic map. It can be seen that joints in the main joint trend west of Structure 1 appear to become more nearly parallel with this feature as they approach it, so that the main joint trend seems to gradually merge with the Structure 1 trend. Something similar can be seen east of the structure, especially in Domain B. The trend of the main joint set seems to wrap around as Structure 1 is approached, becoming more nearly parallel with the structure's more northerly trend.

Structure 2 cuts across Structure 1. It follows a zigzag path up the canyon of Short Creek, continuing north beyond the upper end of the canyon. We do not see evidence of offset along these two structures, but conclude that they probably indicate some amount of relative movement along discrete features separating blocks in the deeper basement. This movement at depth appears to have been transmitted through the sedimentary section to the surface.

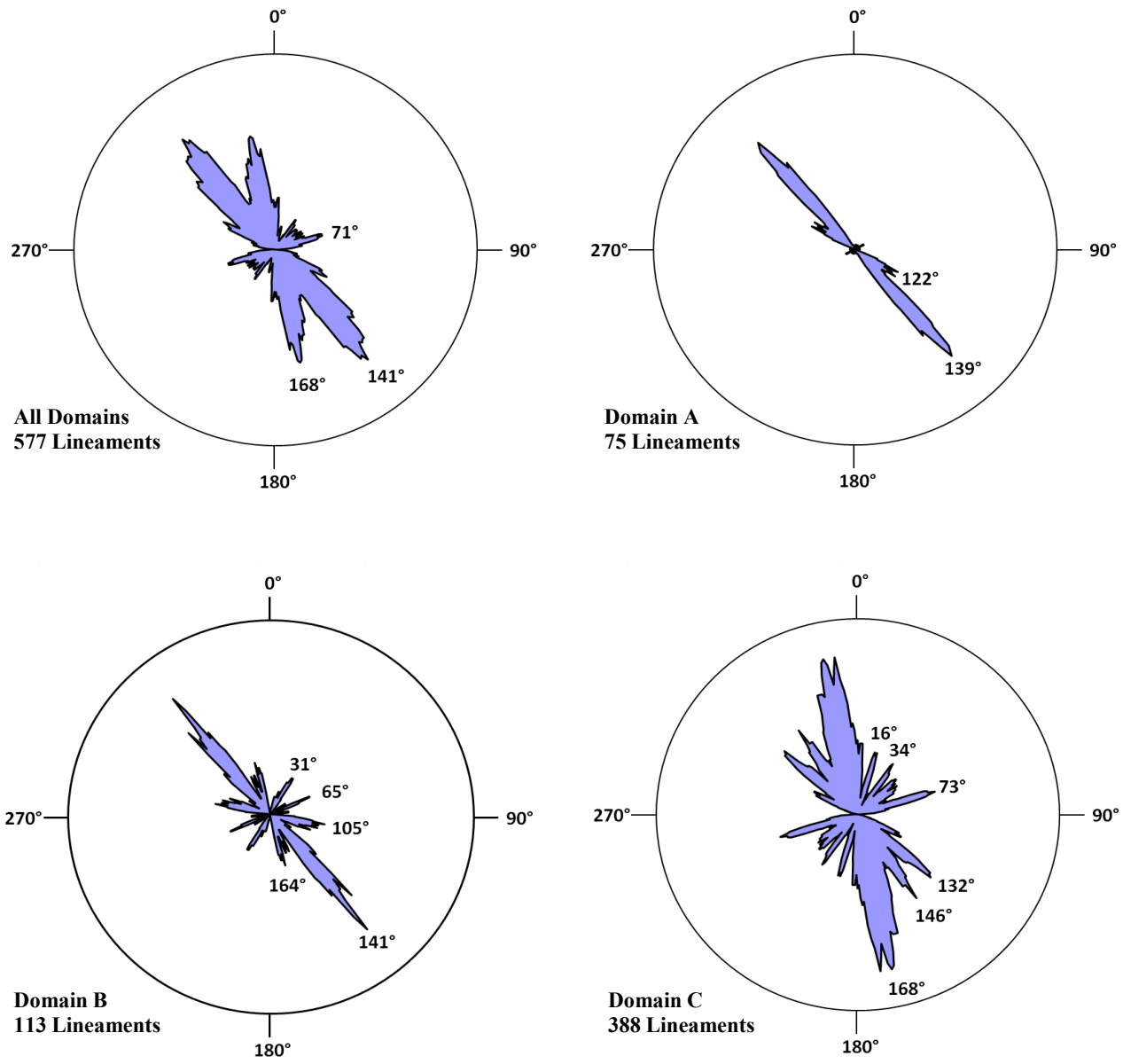


Figure 3 - Lineament Rose Diagrams

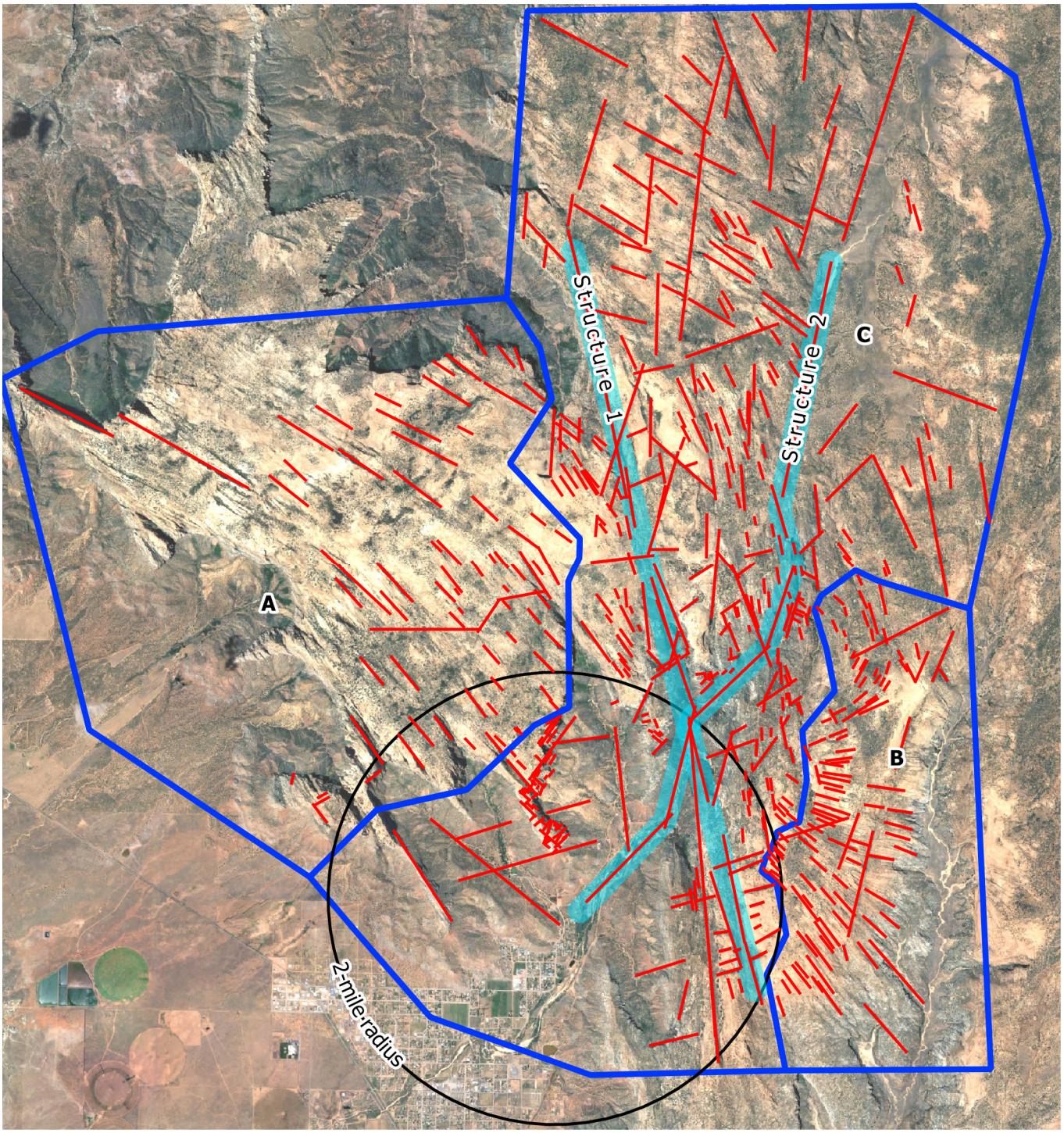


Figure 4 - Lineaments, Domains, and Structures

Interpretation of Other Data

Willowstick provided a shape file containing the lineaments that had been shown on the 1995 geologic map of the Hildale quadrangle. These lineaments closely match our lineaments that trace the main northwest-trending joint family. However, the 1995 map shows fewer of the lineaments that cross-cut the dominant family, and includes few of the lineaments that we saw in Domain C, where the main family was most disrupted by the regional-scale structures.

The Willowstick GIS file set included three maps that we thought might show some relationship with lineament patterns or the two large-scale structures that we inferred. One of these was the contour map of the top of the Moenave Formation. We saw nothing in the Moenave map that we were able to relate to the lineament observations, but that may not be surprising because the east edge of the contour map stops short of our two regional-scale structures. We see nothing in the aeromag map that clearly correlates with our lineament and structural observations.

The gravity anomaly map shows an embayment in the contour lines that includes the point where Structure 1 and Structure 2 cross. However, this may be simply a function of the presence of Short Canyon itself, where the mass of the Navajo is missing along the axis of the canyon. Consequently, these other data sources did not have much influence on our conclusions.

Favorable Zones

Figure 5 is a map showing limited-size zones where we would expect a higher-than-average probability of finding concentrated fracturing at depth, based on the lineament patterns. We have delineated six Favorable Zones. The zones are numbered in their order of perceived favorability. The rankings are based on our experience, and it should be kept in mind that they are subjective. Four of the zones are within the two-mile radius the defines the study area; two of them are slightly outside the radius. Our understanding is that Willowstick's geophysical surveys will focus on these zones.

> **Zone Z1** - This zone is at the intersection of Structure 1 and Structure 2, and of the individual lineaments that were the basis for recognizing these two structures. Note that the lineament that follows the canyon segment from Z1 to Z4 is paralleled by many smaller lineaments on both sides of the canyon. This increases the likelihood that the lineament along the canyon has structural significance. The lineament between Z1 and Z2 is also paralleled by several other nearby lineaments. Based on both the intersection of the interpreted major structures and observations related to individual lineaments, Zone 1 is our top-ranked target.
>
> **Zone Z2** - This zone is at the intersection of two of the linear segments making up the zigzag pathway of Structure 2. The lineament segment southwest of Z2 parallels the lineament between Z1 and Z4. This lineament is also parallel to repetitive joint sets that are seen as short northeast-trending lineaments at the west edge of Figure 5. The presence of these parallel joint sets in the canyon walls adjacent to this straight canyon segment lends support to the supposition that the segment is structurally controlled.

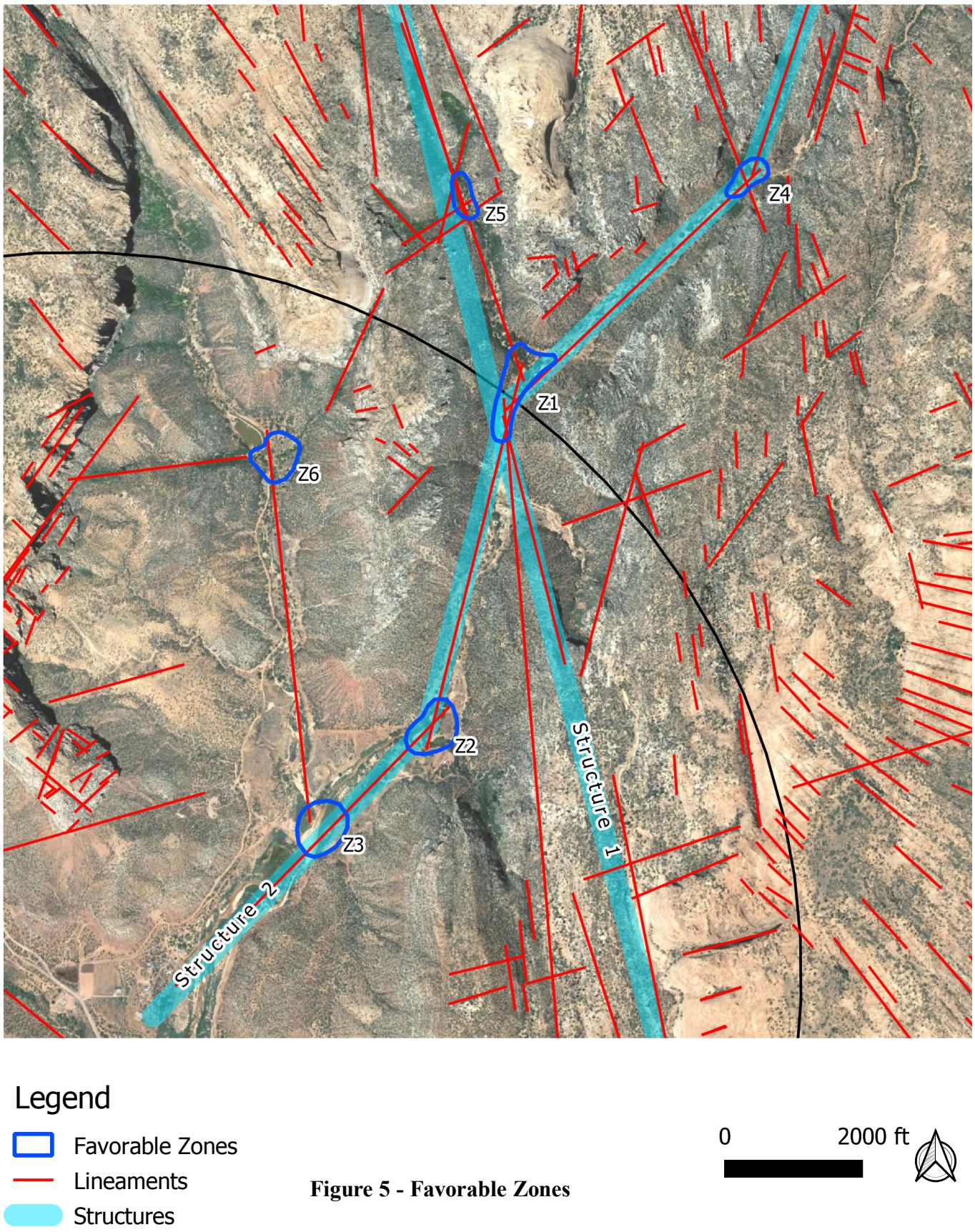


Figure 5 - Favorable Zones

Zone Z3 - This zone is 2000 feet southwest of Z2, at a point where the straight-line canyon segment is intersected by a north-trending lineament. The northeast-trending lineament of the canyon has already been described. The north-trending lineament might be a structural "echo" of Structure 1.

Zone Z4 - This zone is nearly one mile up Short Canyon from Z1, just east of the topographic feature known as "The Beehive." It is at another junction in the zigzag pattern of Structure 2, and it is at a point where the canyon is crossed by a prominent lineament from a lineament family that is parallel to Structure 1. Although the zone is beyond the two-mile radius, we have included it because the lineament evidence seemed too strong to ignore.

Zone Z5 - This zone is also beyond the limits of the circular study area. It represents a second opportunity to test Structure 1, at a point a half-mile north of Z1. At this location, Structure 1 is intersected by lineaments roughly parallel to two of the lineament segments that make up Structure 2.

Zone Z6 - This zone is at a junction of several lineaments that look like they might represent subordinate structural features west of the intersection of Structure 1 and Structure 2. Although we have assigned this zone the lowest ranking, it is still considered of interest.

Conclusions and Recommendations

The results of the lineament analysis suggest to us that bedrock structures exist in the study area that could be associated with concentrated zones of fracturing, which in turn may translate into good opportunities for developing high-yielding wells. We recommend that Willowstick's geophysical surveying be centered as much as possible on the Favorable Zones described above. We recommend that the highest-ranked zones be given preference, assuming that it will not be feasible to conduct surveying in all the zones.

We expect that the geophysical surveys will allow confirmation of the existence of at least some of the bedrock structures that have been tentatively identified with lineament mapping. Our expectation is that these structures are near vertical, but that the geophysics will allow Willowstick to project how these structures extend into the subsurface. Presumably the structures will have a more distinctive geophysical signature in some stratigraphic units than others.

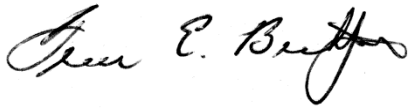
It could be useful to supplement the geophysics with at least a limited amount of structural mapping. It is clear that the joint sets that account for most of the lineaments we have mapped are well exposed, and there is little vegetation or cover of unconsolidated sediment to interfere with obtaining a representative sampling of joint orientations in the areas around all of the Favorable Zones. A basic structural mapping program would include measurement of joint orientations, checking outcrops for evidence of fault displacement, and preparation of stereonets to identify systematic three-dimensional patterns in the vicinity of each Favorable Zone. This

could be used to refine or confirm the favorability rankings of the Favorable Zones, and also to help in predicting the dip of individual structural features.

A structural mapping task would probably require three to five days of field work to produce useful results. Whether such a program would be considered would depend partly on the expense of the geophysical surveying, and partly on your schedule. If the cost per unit area of carrying out geophysical surveys is sufficiently high, committing to several days of structural mapping could be a reasonable investment.

I am sending you this letter as a PDF file. I am also attaching KMZ versions of the Favorable Zones and the lineaments. Please let me know if you have any questions.

Sincerely yours,



Fred E. Bickford

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21 November 2018

ABSTRACT

Willowstick Technologies LLC won a contract with the municipality of Hildale, Utah to help them use geophysical technologies to explore for new aquifers. On 02 October 2019 Willowstick entered into an agreement with Dynamic Measurement LLC to do a SPOT^{sm} Lightning Analysis across the area of interest (Figure 1).

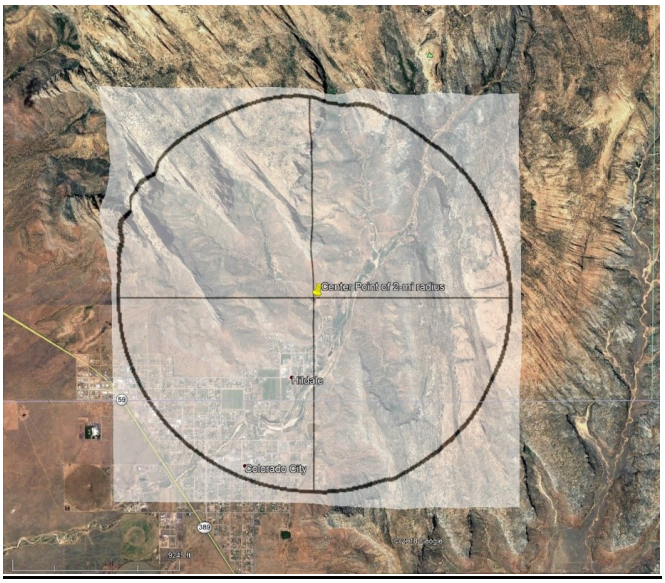


Figure 1. Area of Hildale SPOT^{sm} Analysis, northwest of Hildale, Utah.

Lightning data were ordered, cleaned (Data Cleaning Report delivered 17 October 2019), processed, and maps of lightning attributes were completed and delivered on 18 October 2019 (*.pdf and *.kmz) and on 23 October 2019 (*.asc). The first display of in-line, cross-line, and horizontal-slice sections was delivered on 22 October 2019. The 24 SEG-Y volumes of lightning attributes were generated and delivered on 23 October 2019, and an ASCII Apparent Resistivity volume was delivered on 28 October 2019. Location of the passive seismic collection data points was received on 26 October 2019. The HydroSource Associates Hildale Lineament Report was received on 01 November 2019. A status report was received from Mike Jessop on 11 November 2019, thanking Dynamic for the ASCII Apparent Resistivity volume and stating “it is going to be a while before” he can get the data integrated in the Willowstick system. Dynamic had problems with our Oracle database, and a couple of weeks work were lost. The Oracle problems were solved on 08 November 2019 and 7 pages of screen captures with sections across possible locations Z1, Z2, Z3, and Z6 from HydroSource were provided later that day. After catching up on other projects, a fault interpretation tied to the HydroSource lineaments was completed last week. This report summarizes interpretation work done to date, and provides a series of display types, which can be the basis for additional display requests to meet additional specific Willowstick objectives. Although this is the final Hildale report, Dynamic wants to understand what helps Willowstick the most, and look forward to generating additional images upon request.

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INTRODUCTION

Willowstick signed an agreement with the municipality of Hildale, Utah and received initial payment 18 October 2019. As per a verbal agreement, Dynamic had previously ordered the lightning data, had received the data, finished cleaning the data, and was able to deliver a Data Cleaning Report on 18 November 2019. The first display of in-line, cross-line, and horizontal-slice sections was delivered 4 days later on 22 October 2019 (Figure 2).

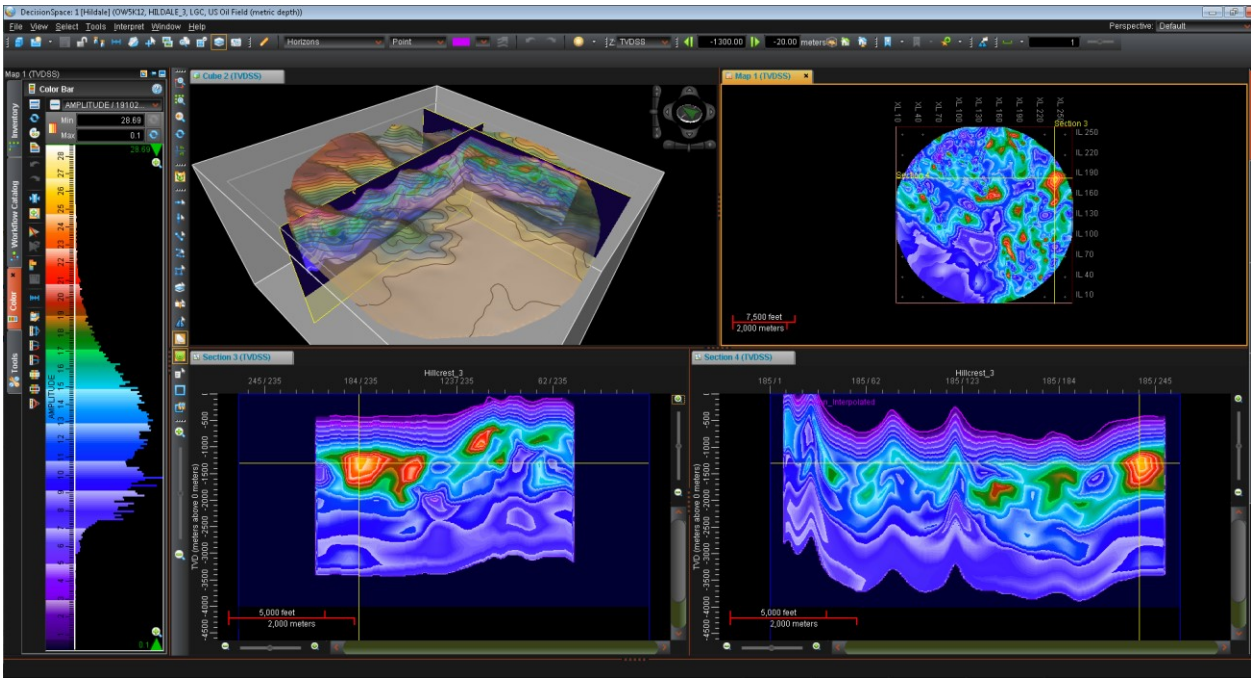


Figure 2. In-Line, Cross-Line, and Horizontal-Slice through Apparent Resistivity Anomaly.

Lightning analysis is a new branch in the geophysical services industry. It works like any other geophysical evaluation. There is an energy source, in this case passive lightning strikes, which strokes are an extremely high energy pulsed power source. There are receivers, in this case - after data cleaning - between 3 and 28 lightning detection sensors collected data on every lightning strike to occur in the Hildale, Utah area over the last 21.75 years. These data are collected for insurance, meteorology, and safety purposes by Vaisala, Inc. The data are pulled from their privately-owned database, as part of an exclusive license Dynamic Measurement has to use this data for geologic interpretation and natural resource exploration. Patented and proprietary algorithms and procedures are used to clean, process, map, create volumes from, and interpret the lightning data. This process is more completely described below. This report summarizes work to date on the Hildale Lightning Analysis Project.

HISTORICAL DATA

Willowstick provided a summary map of data surrounding the Hildale SPOT^{sm} analysis area (see Figure 3). This map and GoogleEarth^{tm} provided maps and cross-sections and the initial data to correlate with new lightning derived geophysical data. There is a lot of elevation changes in the study area, as shown on GoogleEarth^{tm} and captured as Figure 4, south-to-north elevation profile, on Figure 5, west-to-east elevation profile, and Figure 6, west-to-north-to east-to-south elevation profile around the edge of the SPOT^{sm} analysis area. As with any scientific study, this work can go on for years, and the goal of this report is to provide an integrated starting place for future work Willowstick might do for the municipality of Hildale, Utah (see Figure 1 for location area). Of course, Dynamic hopes this work will also provide a basis for many joint projects in the future.

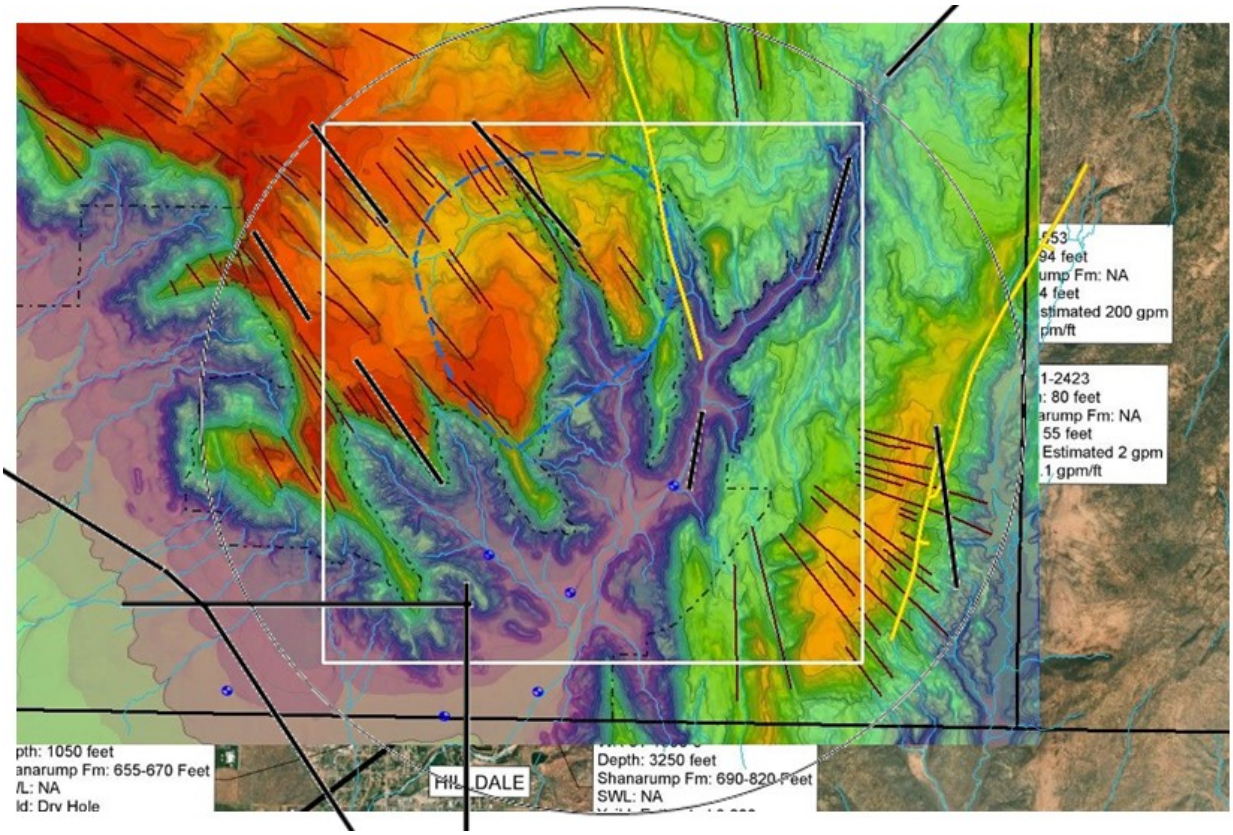


Figure 3. Willowstick Summary Map of Data Surrounding the Hildale SPOT^{sm} Analysis Area.

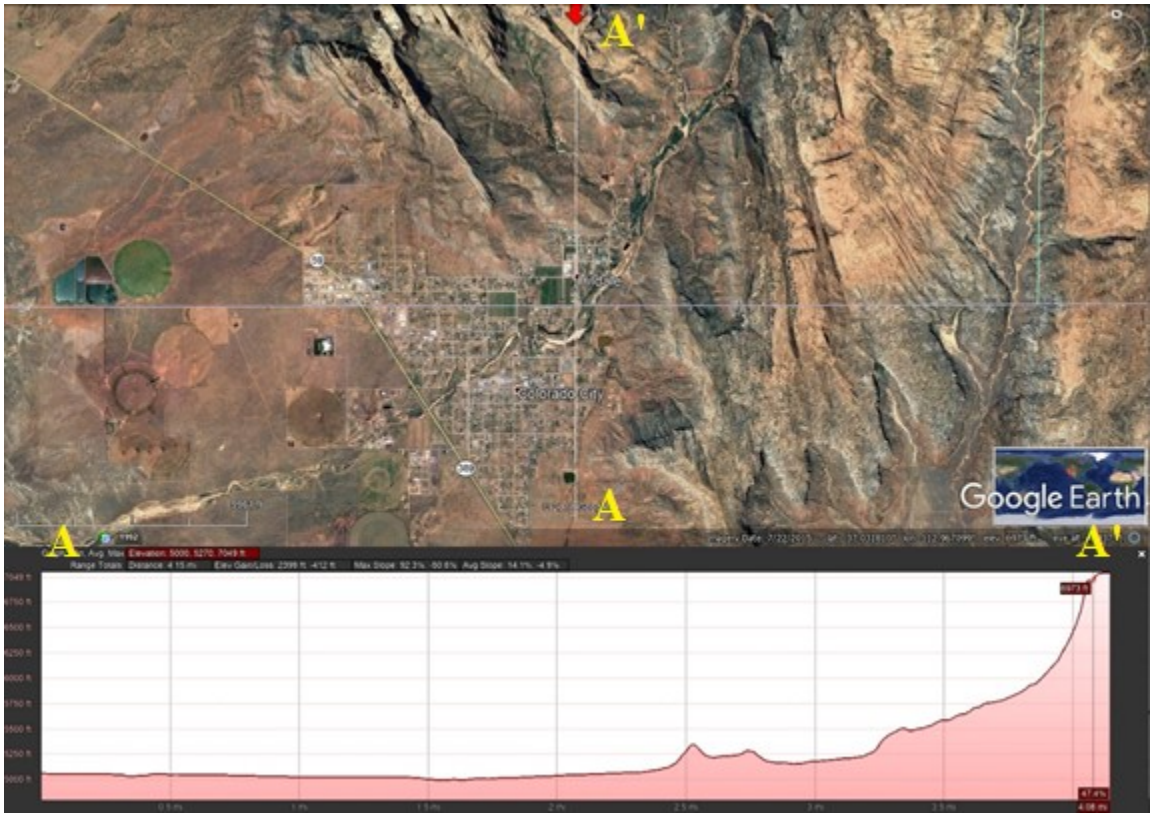


Figure 4. South-to-North Elevation Profile through the SPOT^{sm} analysis area.



Figure 5. West-to-East Elevation Profile through the SPOT[sm] analysis area.

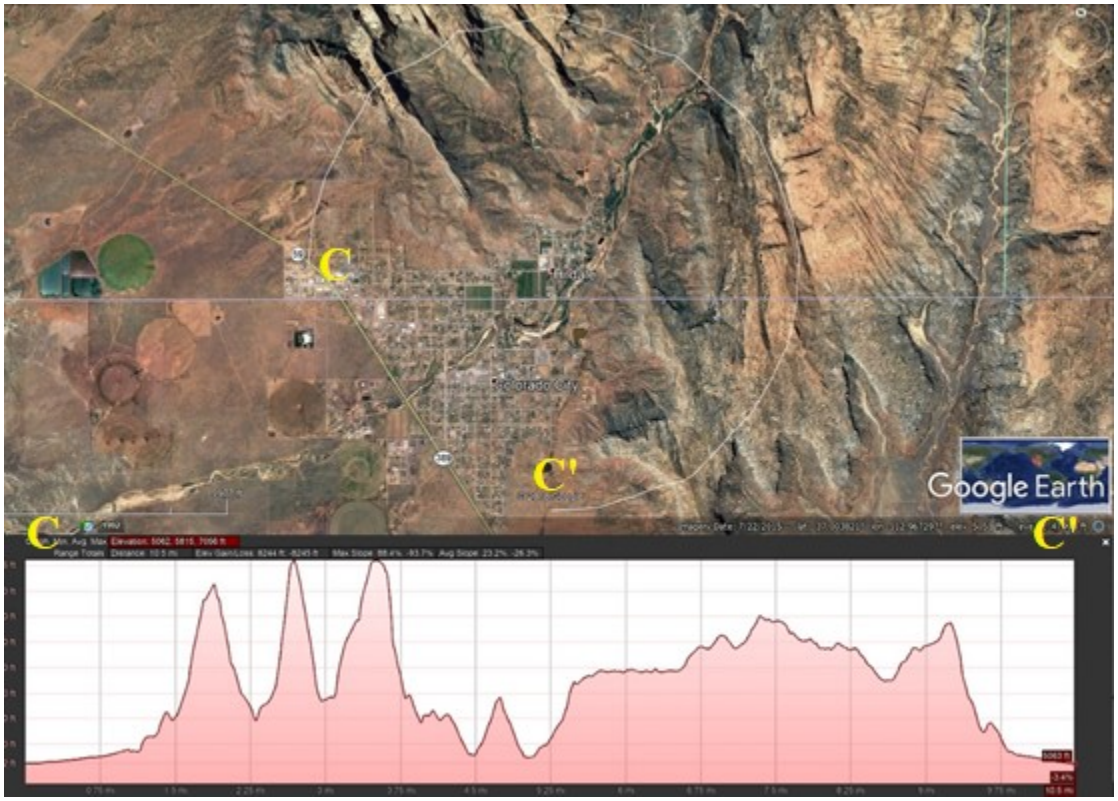


Figure 6. West-to-North-to-East-to-South Elevation Profile Around the Edge of the SPOT[sm] Analysis Area.

Hildale has a need for new municipal water sources, and this report provides a lightning derived geological framework for use and adjustment with new calibrations as new water wells are drilled and as new data becomes available to correlate with and calibrate the results herein. In terms of historical data, one of the things we were hoping is there would be deep wells with geophysical logs which we could correlate with the lightning analysis. Turns out the closest well in Utah was about 15 miles away from the SPOT^{sm} Analysis Area (see Figure 7), and the closes well in the Arizona Oil and Gas Conservation Commission website was about 4 miles away from the SPOT^{sm} Analysis Area (see Figure 8). The lightning analysis based geologic framework is now in place, and as additional historical data are identified, it can easily be integrated within this framework.

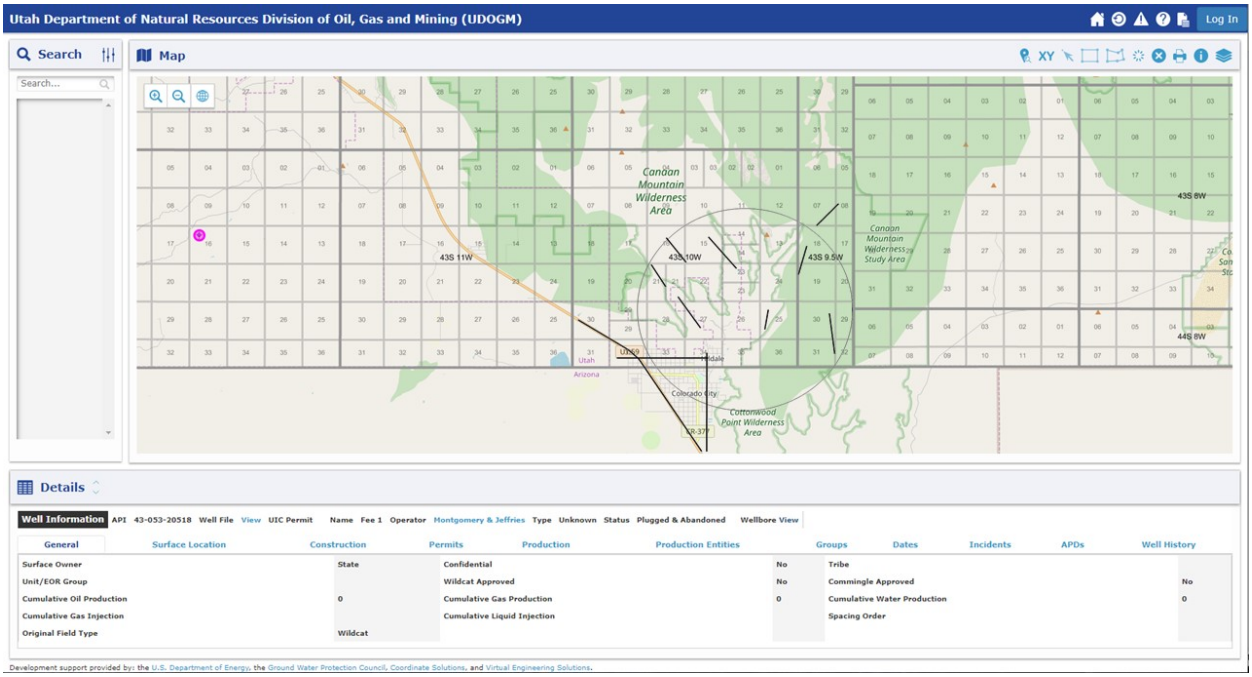


Figure 7. Closest Well in the Utah Department of Natural Resources Division of Oil, Gas, and Mining is about 15 miles away from the SPOT^{sm} Analysis Area.

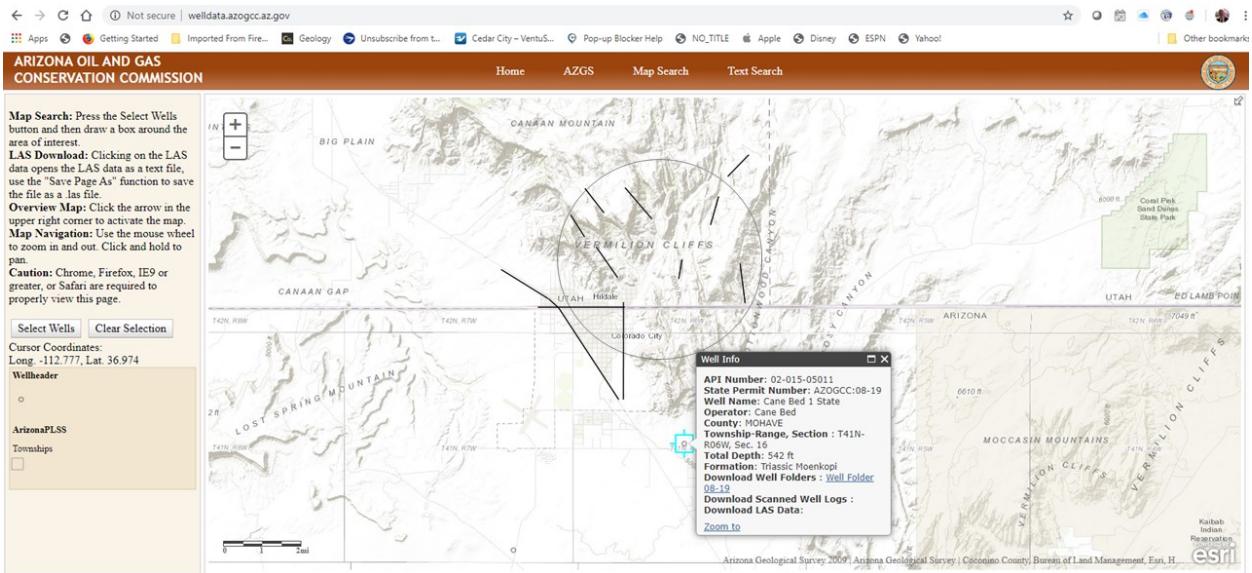


Figure 8. Closest Weill in the Arizona Oil and Gas Conservation Commission Database is about 4-miles from the SPOT^{sm} Analysis Area.

GEOPHYSICS

While this report is about the lightning analysis project in the Hildale Area, it seems appropriate to briefly review the different types of geophysical analysis which can be performed to assist in identifying data about the subsurface of the earth. This will be summarized with two tables summarizing key geophysical technologies. Table 1 below lists 28 remote imaging geophysical techniques, including domestic U.S. and International lightning analysis, and Table 2 gives more details about 8 of these techniques.

Discipline	Technique	Source	Receiver	Power	Remote
Potential Fields	Gravity	Passive	Required	High	Some
Potential Fields	Magnetics	Passive	Required	High	Yes
Electrical Methods	D.C. Resistivity	Required	Required	Low	No
Electrical Methods	Electrical Resistivity Tomography (ERT)	Required	Required	Low	No
Electrical Methods	Induced Polarization (IP)	Required	Required	Low	No
Electrical Methods	Time-Domain IP	Required	Required	Low	No
Electrical Methods	Magnetotellurics (MT)	Passive	Required	Low	No
Electrical Methods	Audio-Frequency MT (AMT)	Passive	Required	Low	No
Electrical Methods	Controlled Source Electromagnetics (CSEM)	Required	Required	Medium	No
Electrical Methods	Transient Electromagnetic Time-Domain EM (TEM)	Required	Required	Low	No
Electrical Methods	Controlled Source Audio Magnetotelluric (CSAMT) techniques	Required	Required	Low	No
Electrical Methods	Frequency-Domain EM Induction	Required	Required	Low	No
Electrical Methods	AquaTrack (leak detection at dams, mines, etc.)	Required	Required	Low	No
Electrical Methods	Borehole Techniques like Self-Potential (SP)	Passive	Required	Low	No
Electrical Methods	Ground Penetrating Radar (GPR)	Required	Required	Low	No
Electrical Methods	Very Low Frequency Methods (VLF)	Required	Required	Medium	No
Electrical Methods	High-Frequency Techniques (radar, etc.)	Required	Required	Low	No
Electrical Methods	Airborne Electromagnetic Systems	Required	Required	Low	No
Electrical Methods	Tipper	Passive	Required	Low	Some
ElectroSeis	ElectroSeis	Passive	Required	Low	No
Seismic	Micro-Seismic	Required	Required	Low	No
Seismic	Earthquake Seismology	Passive	Required	High	Yes
Seismic	Refraction Seismic	Required	Required	Medium	No
Seismic	Reflection Seismic	Required	Required	Medium	No
Satellite	Spatial, Spectral, Temporal, & Geometric Resolution	Passive	Database	Low	Yes
Satellite	Radiometric Resolution: Thermal, Reflectance, Elevation	Passive	Database	Low	Yes
Lightning	National Lightning Detection Network (NLDN)	Passive	Database	High	Yes
Lightning	Global Lightning Database (GLD-360)	Passive	Database	High	Yes

Table 1. 28 Remote Imaging Geophysical Techniques.

Discipline	Technique	Source	Receiver	Power	Remote
Potential Fields	Gravity	260 feet (80 m)	Ground, Helicopter, or Satellite	High	Some
Potential Fields	Magnetics	4,000 ft (1200 m)	Airplane or Satellite	High	Yes
Electrical Methods	Tipper (powered by lightning)	Chile-SLC	Ground or Helicopter	Low	Some
Seismic	Earthquake Seismology	Chile-SLC	Remote Seismographs	High	Yes
Satellite	Spatial, Spectral, Temporal, & Geometric Resolution	100-22,000 miles	Low, Medium, Geocentric Orbits	Low	Yes
Satellite	Radiometric Resolution: Thermal, Reflectance, Elevation	160-35,000 kilometers	Low, Medium, Geocentric Orbits	Low	Yes
Lightning	National Lightning Detection Network (NLDN)	Vertically 800-33,000 ft	Horizontally <600 miles (<965 km)	High	Yes
Lightning	Global Lightning Database (GLD-360)	Vertically 0.25-10 km	Horizontally <6,000 miles (<9,650 km)	High	Yes

Table 2. 8 Remote Imaging Geophysical Techniques.

LIGHTNING ANALYSIS

Lightning analysis is a relatively new (Nelson, Jr., Siebert, & Denham, Lightning Data: the new EM 'seismic' data, November 8, 2012) remote imaging branch in the geophysical services industry (Nelson, Jr., Berent, Haggar, Denham, & Siebert, 19 October 2018). The basic concept is lighting strikes are not random. Strike locations are primarily controlled by subsurface earth currents, known as telluric currents. There is an impact on strike location by topography (tall mountains and particularly cliffs), vegetation (oak, fir, and pine trees and the soils they prefer to grow in), and infrastructure (tall radio and television towers and tall pointed buildings like the San Jacinto Monument). However, these factors are minor compared to telluric currents in the rock matrix. Since this technology is new, this section will introduce the basic concepts behind lightning analysis. Additional articles and publications on lightning analysis are available at http://www.dynamicmeasurement.com/TAMU, including the October 2018 article published in the London Geo ExPro (Nelson, Jr., Denham, Siebert, & Haggar, 2018).

Data about lightning strikes have been collected since the early 1980's. Early on the value of lightning data for insurance, meteorology, and safety industries was recognized. Starting in 1998, the NLDN (National Lightning Detection Network) started archiving all lightning strike data in the continental United States in a private archive, and have built a nice business around distributing this data to the above-named industries. The CLDN (Canadian Lightning Detection Network) is a public domain Canadian database administrated by the same company, Vaisala, Inc. of Helsinki, Finland. These two databases form the NALDN (North American Lightning Detection Network). Figure 9 shows lightning density for the continental United States.

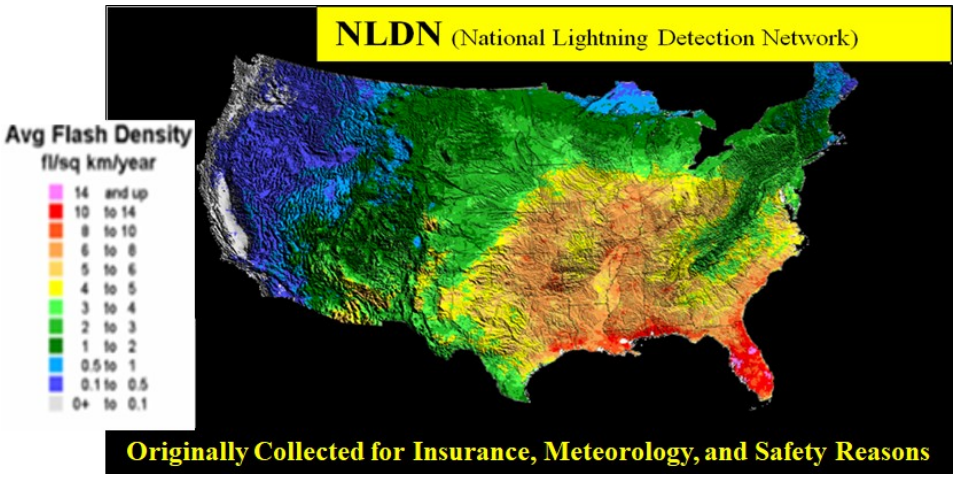


Figure 9. NLDN Lightning Density overlaid on topography.

Lightning, of course, occurs all over the world. In 2012 Vaisala introduced the GLD-360 worldwide lightning detection network. Figure 10 shows worldwide lightning density from 2013-2017. This network uses VLF (very low frequency) measurements and satellite data. One result is horizontal location accuracy is on the order of 3,000 feet instead of the 300 feet horizontal location accuracy of data from the NLDN database. Dynamic Measurement has an exclusive license to use Vaisala's databases for geologic mapping and natural resource exploration. The best lightning database is the NALDN. Like standard EM (electromagnetic) surveys, there is a source, very powerful lightning strikes), and receivers. There are about 145 lightning detection sensors (see Figure 11) providing coverage for the U.S. and Canada, as shown on Figure 12. The sensors use magnetic declination to identify direction to a strike location from electromagnetic wave fronts from the lightning strike. In Utah, 3-28 sensors record most lightning strikes. Instead of having one source and thousands of receivers, like with 3-D seismic, lightning provides hundreds to millions of source points from a very strong electrical source recorded by these sensors. Because geology does not change in human timeframes, telluric currents don't change. Though each storm is different, the constant geologic background means that lightning strike data from over 21 years of data collection can be added (like stacking seismic data) to increase signal and decrease noise. The horizontal location accuracy is between 150 and 600 feet, and lightning analysis projects have demonstrated mapping fault locations with a 30-100-foot horizontal accuracy. Using reciprocity this data provides sufficient coverage to make maps and volumes which can match the line & trace spacing of any planned or existing 3-D seismic, aeromagnetic, or other geophysical survey.

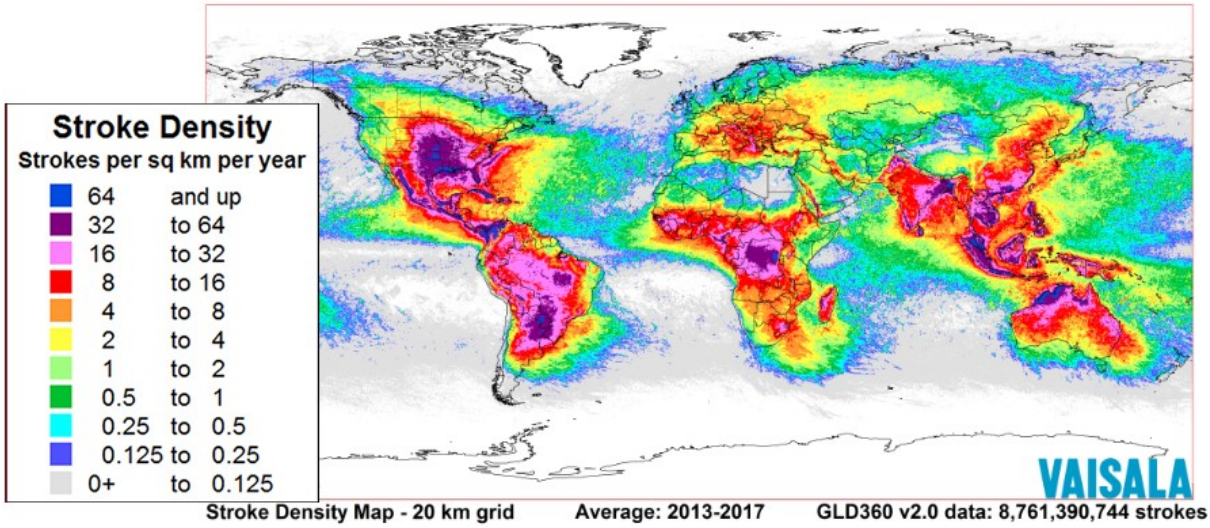
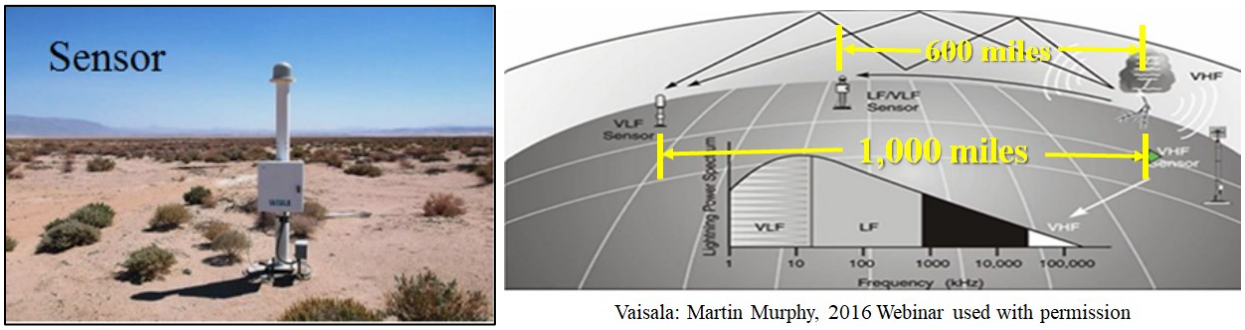


Figure 10. GLD-360 worldwide lightning density from 2013-2017.



Vaisala: Martin Murphy, 2016 Webinar used with permission

Figure 11. Lightning detection sensors are about 6 feet tall, and measure lightning strikes up to 600 miles away.

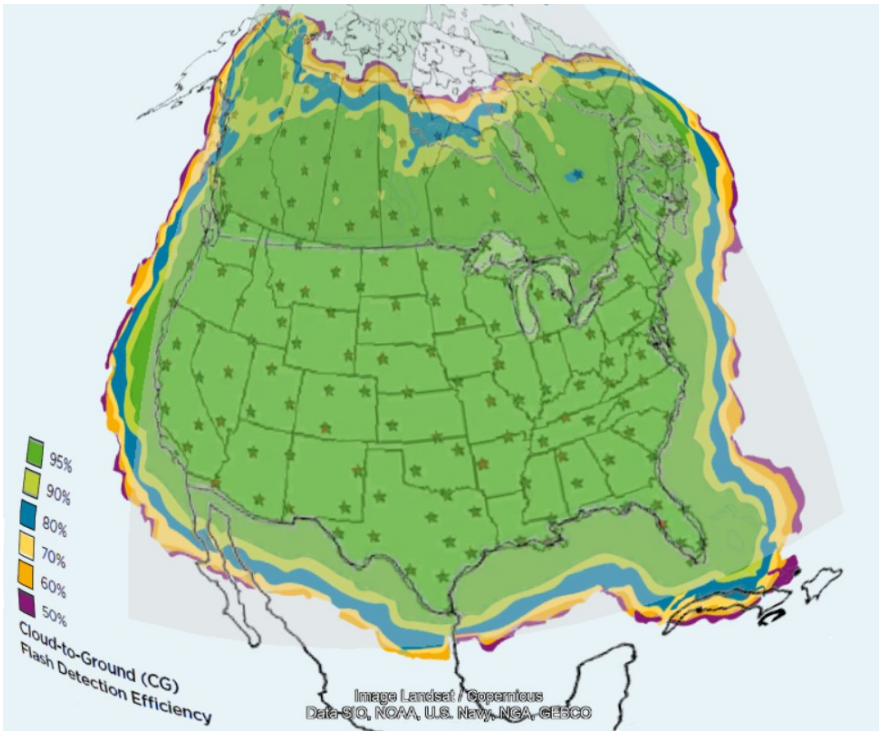


Figure 12. Vaisala's NALDN Lightning Sensor Locations and Flash Detection Efficiency.

There are two primary types of lightning recorded in lightning databases: cloud-to-cloud (C2C); and cloud-to-ground (C2G). Figure 13 illustrates the difference between C2C and C2G lightning. The NLDN sensors can fairly accurately distinguish between C2C and C2G strokes. There are 16 attributes recorded in the NLDN lightning database for each lightning stroke. The time is recorded to the nearest microsecond, and location with less than 300-foot horizontal accuracy. Rise-time and peak-to-zero time (see the right side of Figure 13) are measured to the nearest microsecond, and peak current in positive or negative amperes. From these basic attributes Dynamic derives total wavelet time (rise-time plus peak current time), (absolute, positive, and negative) energy (area under the curve), symmetry (total wavelet time divided by rise-time), rate of rise-time (the first derivative of the rise-time), frequency (1 divided by total wavelet time), (positive, negative, and average) peak-current (there can be many strikes within a cell, and measurements are "stacked" or averaged to get values both at the surface and at depth [the calculation of depth will be described below]).

In addition, there are other natural processes which can be related to when a lightning strike occurs, including position of the sun, position of the moon, the phase of the moon at the location, state of earth tides at the location, the gradient of the tide, the tidal gravity, and others. Dynamic has come up with a way to calculate two rock properties from the lightning measurements: (1) apparent resistivity (related to resistivity log measurements); and (2) apparent permittivity (related to IP [induced polarization] measurements) [both calculations are summarized below]. Lightning derived maps and volumes of apparent resistivity and apparent permittivity provide a new way to map subsurface geology, faults, and geologic frameworks.

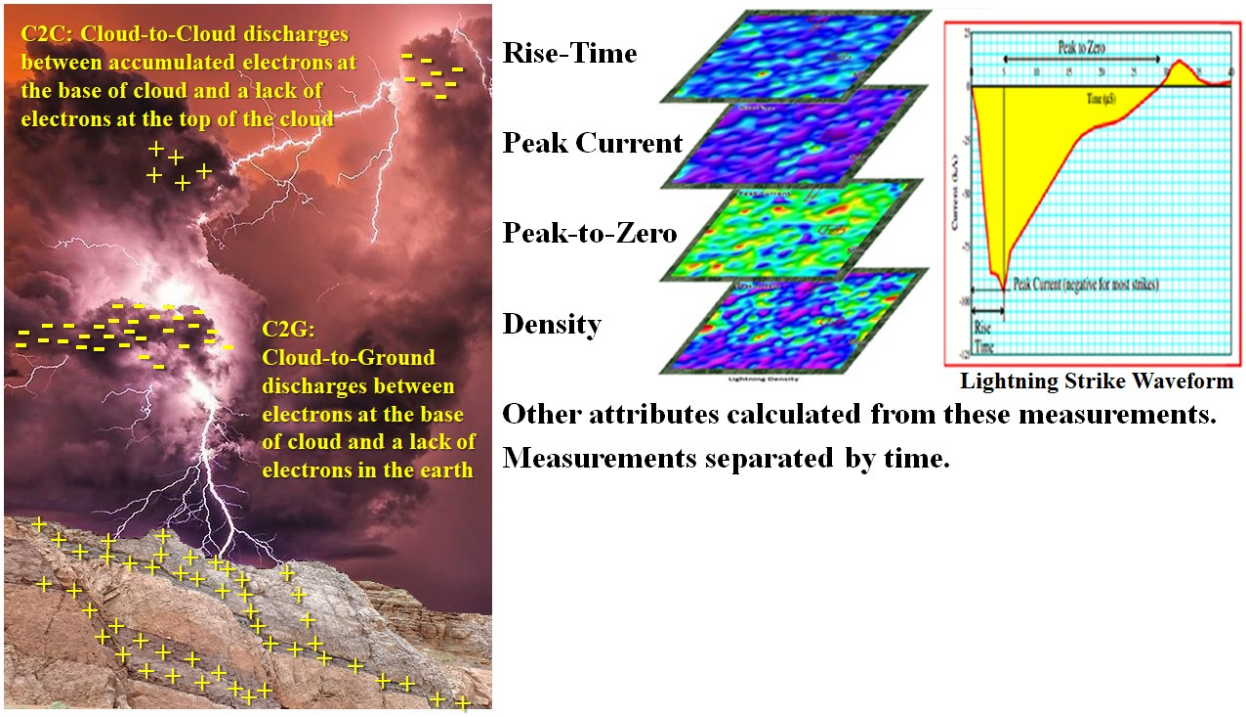


Figure 13. C2C and C2G lightning (right), key attributes, and the Lightning Strike Waveform.

On a clear day the earth's surface is electrically an equipotential surface. Telluric currents in the subsurface do not change quickly, because geology does not change quickly. However, atmospheric currents change with every new electrical storm. These changes happen over hours, minutes, and microseconds. As the atmospheric currents change, it induces changes in subsurface telluric currents. The earth's electromagnetic half-space mirrors the atmospheric electromagnetic half-space. Electrical signals with a period of 24 hertz can have a skin depth of 375-500 miles. While, at best, a lightning stroke only has a skin depth of a few hundred meters, the electrical build-up to the lightning stroke happens over tens of milliseconds, which provides skin depths reaching the Mohorovičić Discontinuity. Lighting is a key source charging telluric currents, which is what magnetotelluric measurements measure at depths to 40,000 feet.

Lightning can be compared to a capacitor. The energy required to jump a short distance is less than the energy required to jump a long distance. Lightning stroke distances range from 800 feet to 35,000 feet vertically (see Figure 14). Most stokes come from the base of clouds, and are negative. Because these lightning strokes do not travel as far, they do not have as strong of a peak current as the strong positive strokes coming from top of thunderheads, which can be 20,000 to 35,000 feet above the surface of the earth. Because these strokes have to travel farther in the atmospheric dielectric to reach the surface of the earth, they have much stronger peak current measurements.

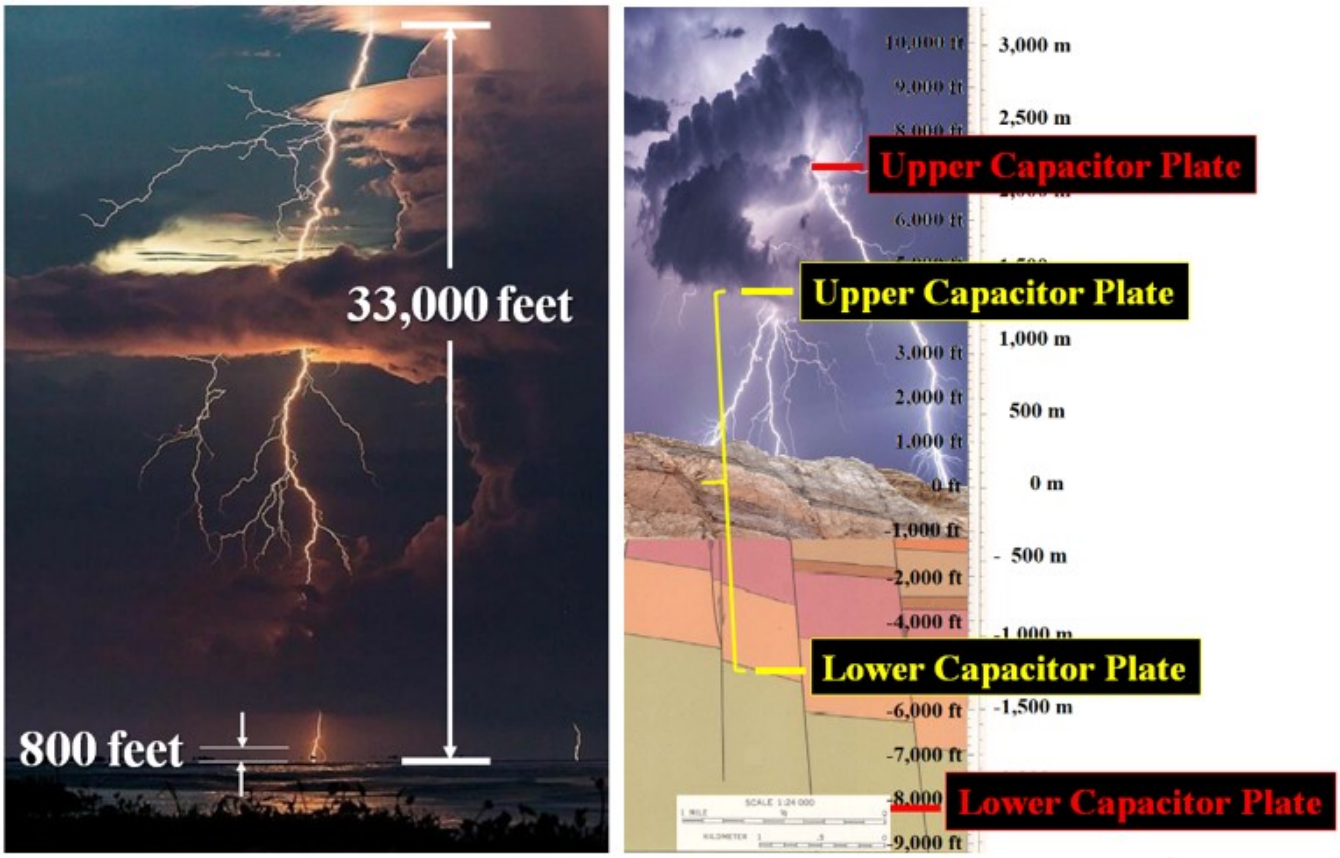


Figure 14. The vertical range of lightning strikes (left) and how lightning is like a capacitor (right).

Dynamic Measurement's first issued patent is titled: "Method for Locating Sub-Surface Natural Resources," and provides a basis for this new branch in the geophysical service industry, based on data mining lightning databases. Lightning density is calculated by summing the number of lightning strikes which occur within specific sized cells. Averaging lightning strike attribute values within each cell and then interpolating each attribute value between each cell with a lightning strike location, enables the creation of lightning attribute maps. These maps provide a first pass picture of the subsurface geologic framework.

Two key assumptions Dynamic Measurement makes are: (1) lightning occurs when there is sufficient charge to bridge the atmospheric capacitor; and (2) lightning is impacted by geologic telluric currents to a depth proportional to the height of the clouds, as derived from peak current measurements. Since peak current is proportional to the height of a cloud, given a peak current measured for a lightning stroke, Dynamic estimates the depth of telluric current interaction by assigning estimated cloud height derived from Peak Current to depth. With hundreds or even millions of strikes over 21^{+} years for a specific lightning analysis project, this provides a three-dimensional set of points which can be interpolated to create lightning attribute and rock property volumes. Lightning attribute volumes, for example rise-time, are created by placing the measured rise-time for all strikes at their respective surface strike location (x and y) and peak current estimated depth (z), and interpolating between values in order to create a 3-D volume. These volumes are then converted into SEG-Y volumes or ASCII volumes for easy entry into a standard geophysical interpretation workstation.

Dynamic has created and patented a methodology for the creation of rock property maps and volumes from lightning strike databases. Dynamic Measurement's second issued patent is titled: "Method for Determining Geological Surface and Subsurface Resistivity." There are now two rock properties that are standard products for an NLDN or NALDN based lightning analysis project: (1) Apparent Resistivity; and (2) Apparent Permittivity. This is an important development. Prior to this development, in order to derive a measurement of resistivity or permittivity, you had to either: (1) do an electrical geophysical survey (which limits you to the location of the source and the receiver and their offsets and which is expensive); or to drill a well and drop a logging tool down the hole to make the measurements (which limits you to measurements being valid only a few inches away from the well and which is much more expensive). Lightning analysis allows us to create Apparent Resistivity and Apparent Permittivity maps and volumes anyplace in the U.S. or Canada, and, given the right lightning detection network, anyplace in the world.

Figure 15 shows the basic concepts behind Dynamic's issued patent for calculating Apparent Resistivity. Dynamic is still working on optimizing the international database to calculate Apparent Resistivity. However, Dynamic's agreement with Vaisala allows us to contract to set up a private lightning network anyplace, which will provide the data to do lightning analysis within 3 years. The more experience Dynamic gets with these lightning database derived maps and volumes, the more important the Apparent Resistivity maps and volumes become. We have reasonable calibration in South Texas of the depth of Apparent Resistivity anomalies, and a very good correlation of the calculated Apparent Resistivity in ohm-meters with well log resistivity measurements, also in ohm-meters. As mentioned above, we did not have this type of well log depth control in the Hildale project area, and thus do not have a good calibration for the depth of the calculated apparent resistivity volume in the Hildale project area.

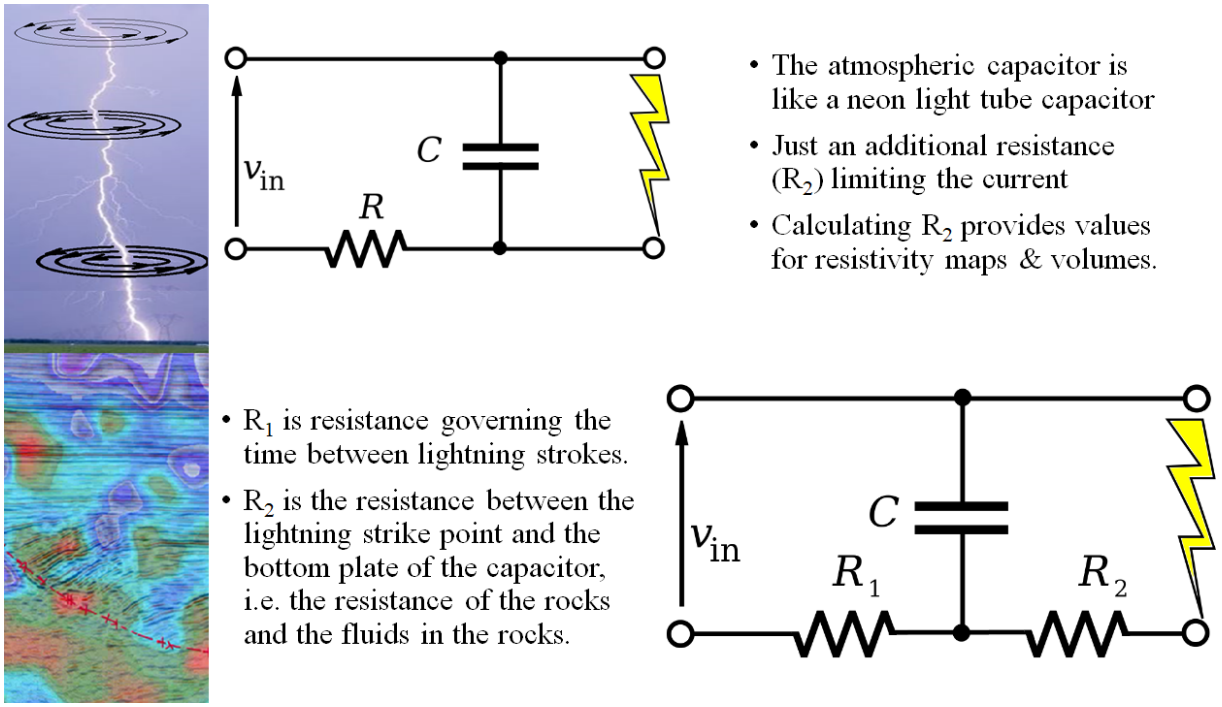
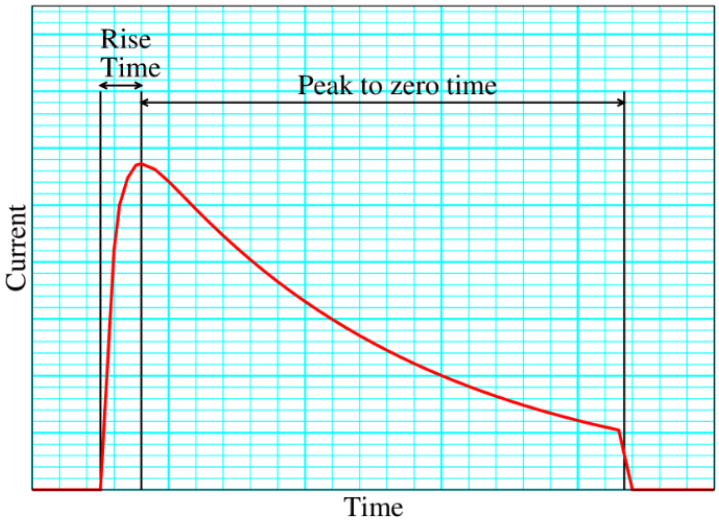


Figure 15. Lightning strike calculation of apparent resistivity comparable to neon light tube mathematics.

Figure 16 shows the basic concepts behind Dynamic's methodology for calculating apparent permittivity. Permittivity is a measurement of the capacitance that is encountered when forming an electric field in a particular medium, or more specifically the amount of charge needed to generate electric flux in a given medium. Induced Polarization (IP) surveys put a current in the ground, then when the current over disseminated metal ores is sharply turned off (the edge of a square wave), the current will continue to flow for a period of microseconds. This allows identification of where these disseminated ores are concentrated.

- Lightning does not have a square waveform
- But it does have a very steep onset
- Variations in the onset as measured (rise-time) show the IP Effect



- By treating this as charging a capacitor (C_2) through a resistor (R_3), an apparent capacitance can be calculated
- From apparent capacitance a value for average permittivity can be calculated

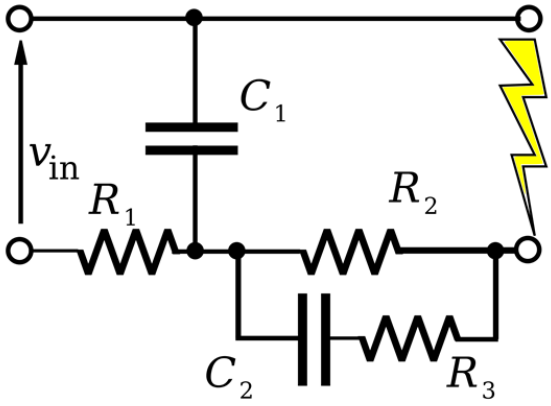


Figure 16. Calculating apparent permittivity adds a second circuit to apparent resistivity calculations.

To date, the work at the Hildale SPOT^{sm} has focused on using the apparent resistivity volumes. Examples of 23 other lightning attribute volumes, yet to be completely evaluated and correlated with other geophysical data Willowstick is creating for this project, are included later in this report.

GEOLOGY

HydroSource Associates report includes a nice summary of the geology of the Hildale Area. The lineaments they identified were not necessarily tied to structural features in the bedrock. Dynamic's fault interpretation, described below, shows that many of the lineaments HydroSource mapped do have a bedrock structural explanation, which confirms one of their conclusions. Their lineaments were largely confined to areas underlain by the Navajo Sandstone, because the Navajo is a brittle unit that responds to stress by fracturing. This response is different from the underlying Kayenta, which is a shaley unit and appears to respond to stress with plastic deformation distributed more or less uniformly throughout the rock mass (page 4 of the HydroSource Report). A key map used from this report is their Figure 5, which is replicated below as Figure 17, which shows 6 favorable areas for water exploration., 4 of which are in the northeast quadrant of the SPOT^{sm} Analysis Area.

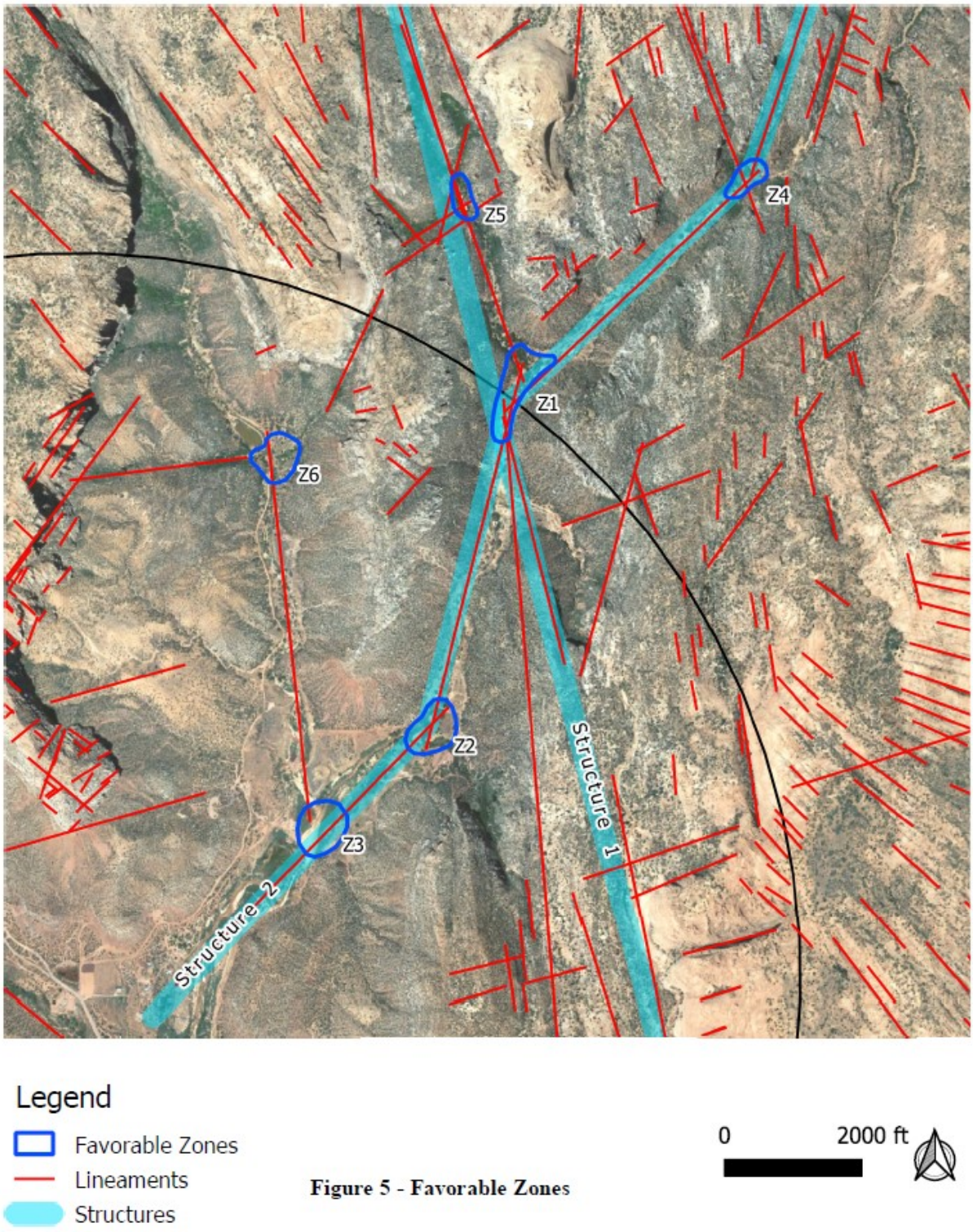


Figure 17. Favorable Zones for Water Exploration from the HydroSource Associates Report.

Future work could include comparing these lineaments with lineaments identified on all of the lightning attribute and rock property maps. We hope this report provides enough information Willowstick can guide us as to what makes the best set of standard deliverables. These various attribute maps, along with maps showing the location of Primary Water's Passive Seismic Surveys are discussed and shown in the next two sections of this report.

LIGHTNING DATA CLEANING REPORT

Once a lightning analysis project is defined, the data ordered, and the data received by Dynamic, the first part of an evaluation is to clean the data. The database includes some strikes which are not valid, as well as parameters for some strikes which may not be valid. In addition, there are some strikes which may have inaccurate locations. These errors need to be removed from the database. The recorded parameters for the data used in this study include:

1. Date: the calendar date of the stroke
2. Time: Coordinated Universal Time (UTC) to the nearest millisecond
3. Latitude: signed degrees to the nearest 0.0001 degree
4. Longitude: signed degrees to the nearest 0.0001 degree
5. Peak Current: kiloamperes to the nearest 0.1 kA
6. Chi^2: a measure of the reliability of correlation of signal between the different sensors used for the stroke
7. Semi-major: the length in kilometers of the semimajor axis of the ellipse of uncertainty for the location, to the nearest 0.1km
8. Semi-minor: the length in kilometers of the semi-minor axis of the ellipse of uncertainty for the location, to the nearest 0.1km
9. Rise Time: the time from when the stroke was first detected to the instant of peak current, measured in microseconds to the nearest 0.1 microsecond
10. Peak-to-zero: the time from when the instant of peak current to effective zero current, measured in microseconds to the nearest 0.1 microsecond
11. Number of sensors: the number of sensors used in computing parameters for the stroke

The Data Cleaning Methodology consists of:

1. Plot histograms of each parameter (excluding date, time, latitude & longitude) for all strokes in the data set.
2. For peak current and number of sensors pick a value below which the data point seems suspect, choosing a value separating true outliers. Strokes with these parameters less than the selected limit will be removed before any use is made of the data set: they may not be valid strokes.
3. For chi, semi-major and semi-minor, pick maximum values in the same manner. Strokes identified in this way probably have inaccurate locations, even if they are real lightning strokes, so they have little value for exploration. They too will be discarded.
4. For rise time and peak-to-zero times, we select both minimum and maximum values for reliable data. The strokes flagged in this way are not discarded completely, but they are not used for any calculations using these two parameters.

The cleaned data set has had the following filters applied:

- Strokes with chi equal to 0.0 or greater than 10.0 omitted.
- Strokes with semimajor axis greater than 2.0 omitted.
- Strokes recorded with fewer than three sensors will be omitted.
- Rise times greater than 22.0 microseconds will not be used in analysis.
- Peak to zero times of less than 4.0 as well as those equal to 30.2 microseconds or greater than 44 microseconds will not be used in the analysis.

The limits of the cleaned data set are shown in Table 3.

Parameter	Minimum	Maximum
Date	1998-03-06	2019-08-09
Time	0:00:00.000	23:59:59.000
Latitude	36.9868	37.0433
Longitude	-112.9266	-112.9985
Peak Current	-259.6	375.8
Chi	0.1	10.0
Semimajor Axis	0.2	2.0
Semiminor Axis	0.1	0.5
Rise Time	0.4	22
Peak to Zero Time	0.2	21.9
Number of Sensors	3	376
Number of strokes	2201	
No. strokes, RT limited	2168	
No. strokes, PZ limited	1739	
Elapsed time	21.75 years	

Table 3: Data limits for cleaned data. Note that the dataset runs from the beginning of 1998 to the end of September 2019, but no strokes were recorded before March in 1998.

LIGHTNING ATTRIBUTE MAPS

Once the center of a SPOT[sm] is defined, Dynamic goes out to public domain files and downloads topography data. The first map made shows a grid, within the SPOT[sm] area, which is the grid used to average the number of lightning strikes in each cell, and to average the various lightning attribute values for strikes falling within specific cells. The grid is based on The Infinite Grid[sm] (an area-based geographical information system). These cells are an IG-7, or a seventh level Infinite Grid[sm], with an area of about 50 meters x 30 meters at the latitude of Hildale. This grid is overlaid on the topography of the area on the upper left portion of Figure 18. The number of lightning strikes is plotted in the upper right portion of Figure 18. Although there are very few lightning storms in the deserts of Southern Utah and Northern Arizona compared to the Gulf Coast and Florida, because we can "stack" the data, there are sufficient lightning strikes over 21.75 years to get good results, as this report demonstrates.

One of the things Dynamic has learned how to do is to calculate where lightning is likely to strike, based on where it has struck in the past. The bottom two maps on Figure 18 show respectively the grid cells likely to have 1 lightning strike per year and the grid cells likely to have 1.1 lightning strikes per year. Again, this is a desert area, and there are not near as many lightning storms as in other parts of the country and the world.

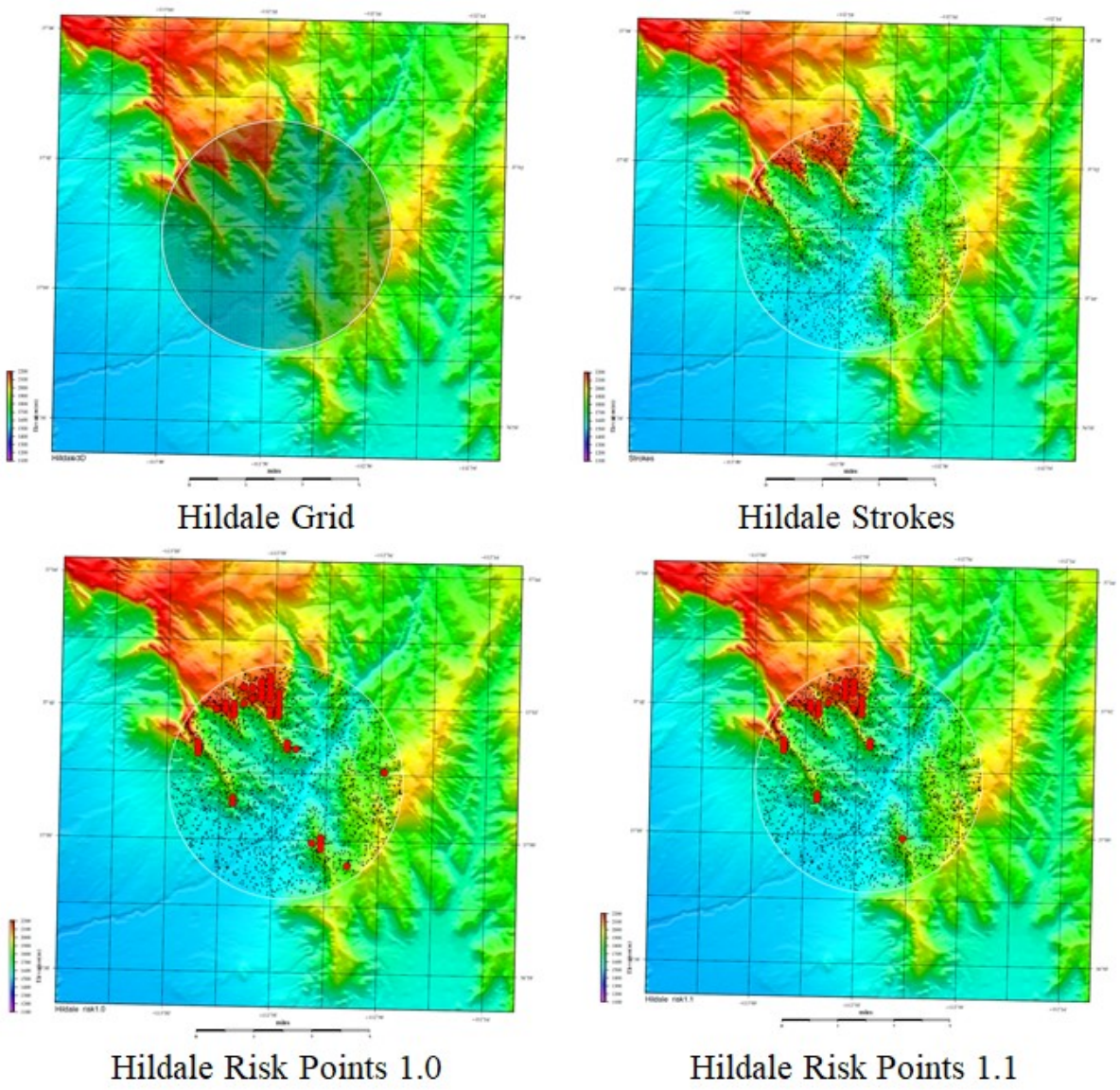


Figure 18. Hildale Grid, Stokes, Risk Points 1.0 and 1.1 Maps.

Figures 19A, 19B, and 19C show elevation and 17 of the 24 lightning attribute maps generated for the Hildale Lightning Analysis Project. One of the interesting aspects of this work with lightning data is how different each of the attribute maps look and yet how they each have similar trend lines. Lightning Density shows that the cliffs associated with the mesas have more strikes, which is what is expected, because the edge of the cliff acts as an antenna. These maps are displayed with the same basic spectrum colormap, which is anticipated will be improved with additional interpretation projects, and experience. We are very interested to learn the patterns Willowstick sees.

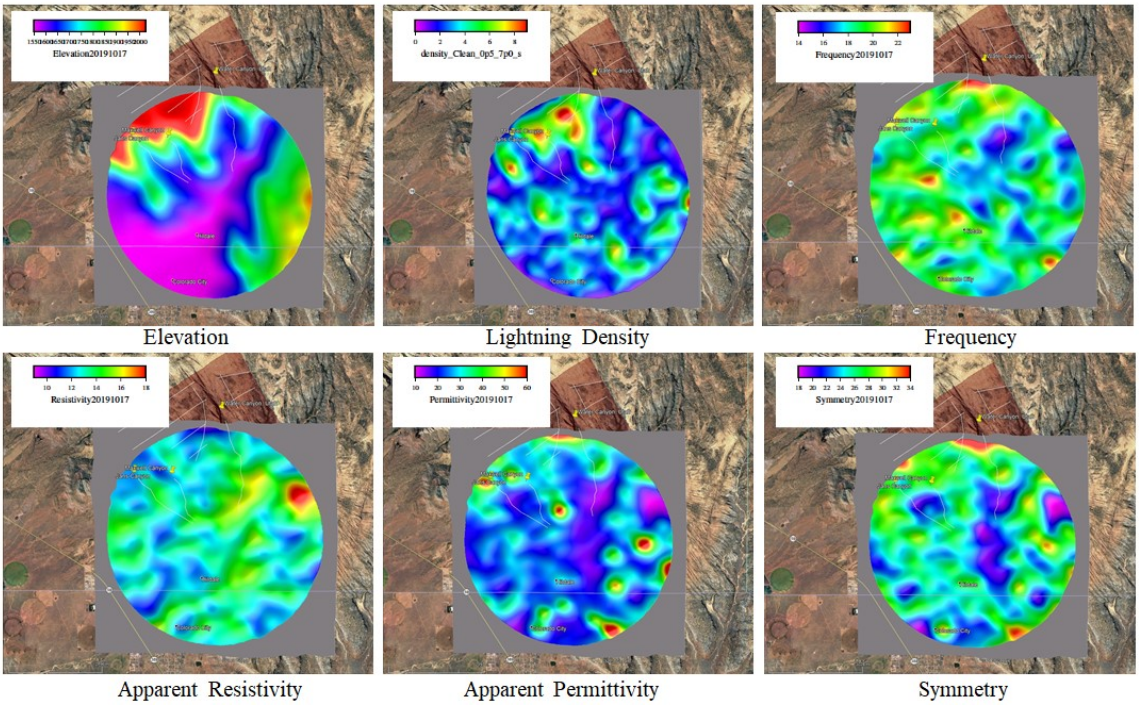


Figure 19A. Topography, Density, Frequency, Apparent Resistivity, Apparent Permittivity, and Symmetry Maps.

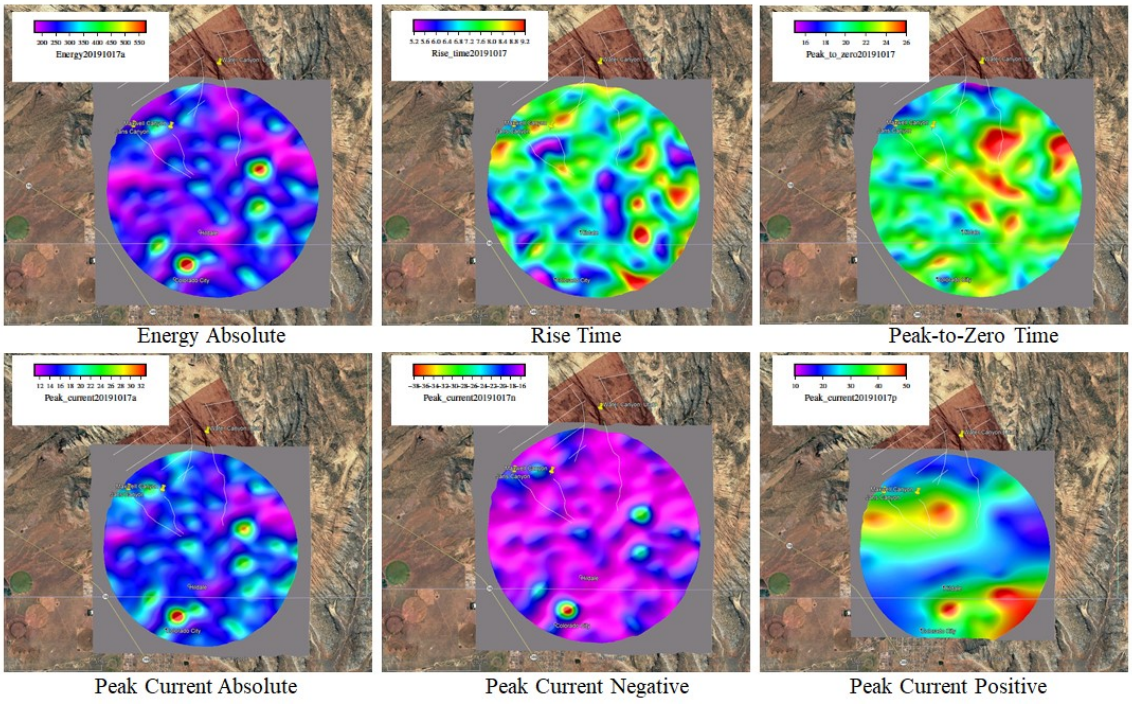


Figure 19B. Energy Absolute, Rise Time, Peak-to-Zero Time, & Peak Current Absolute, Neg., and Pos. Maps.

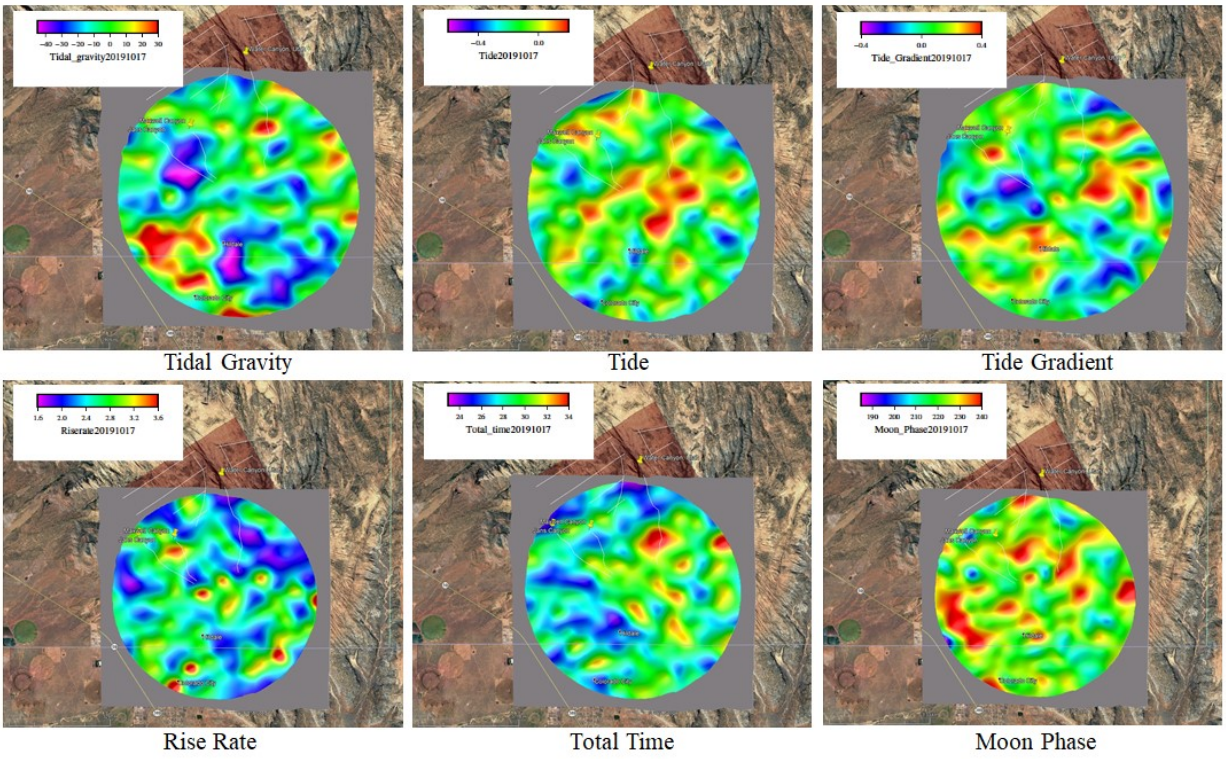


Figure 19C. Tidal Gravity, Tide, Tide Gradient, Rise Rate, Total Time, and Moon Phase Maps.

PASSIVE SEISMIC PROFILES

Mark Burr of Primary Water provided 5 sets of maps showing the location of Passive Seismic Profiles made. These maps are shown in Figure 20A. Apparent Resistivity Volumes along profiles A-A'-A", B-B', C-C'-C", D-D'-D", and E-E' are shown in Figure 20B. These were the first Apparent Resistivity cross-section captures after Figure 2.

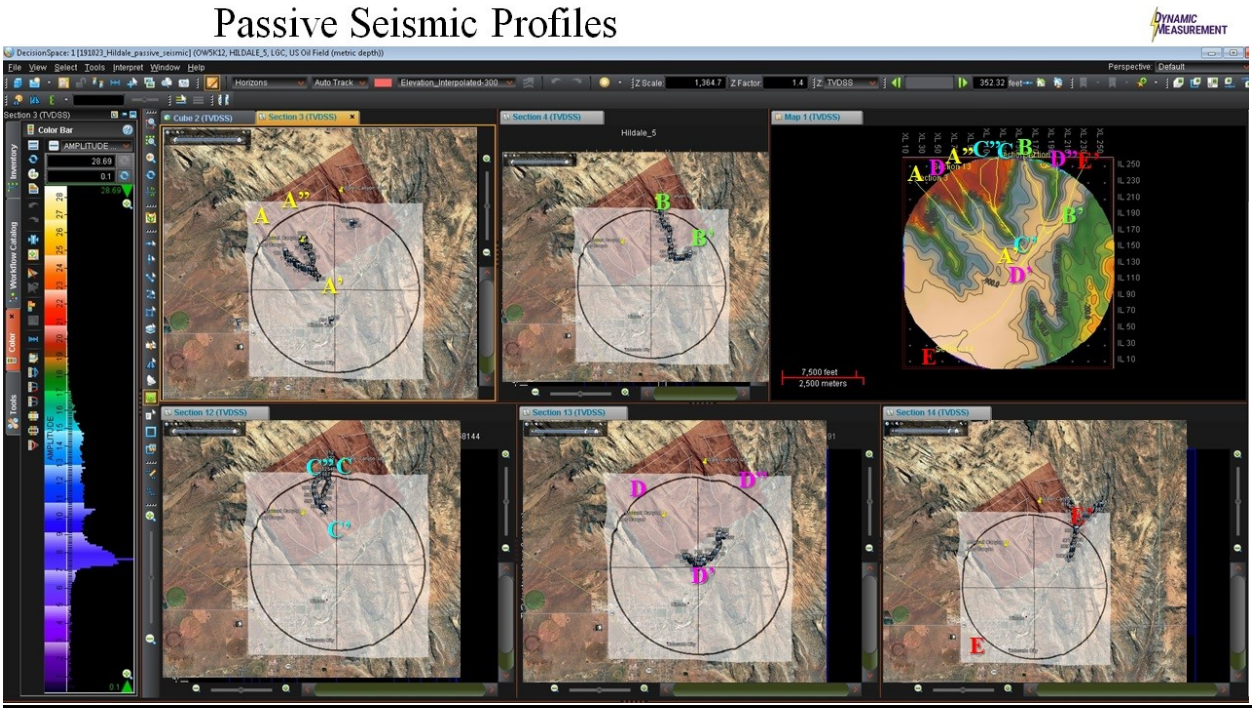


Figure 20A. Location of Passive Seismic Profiles from Primary Water Transferred to Interpretation System.

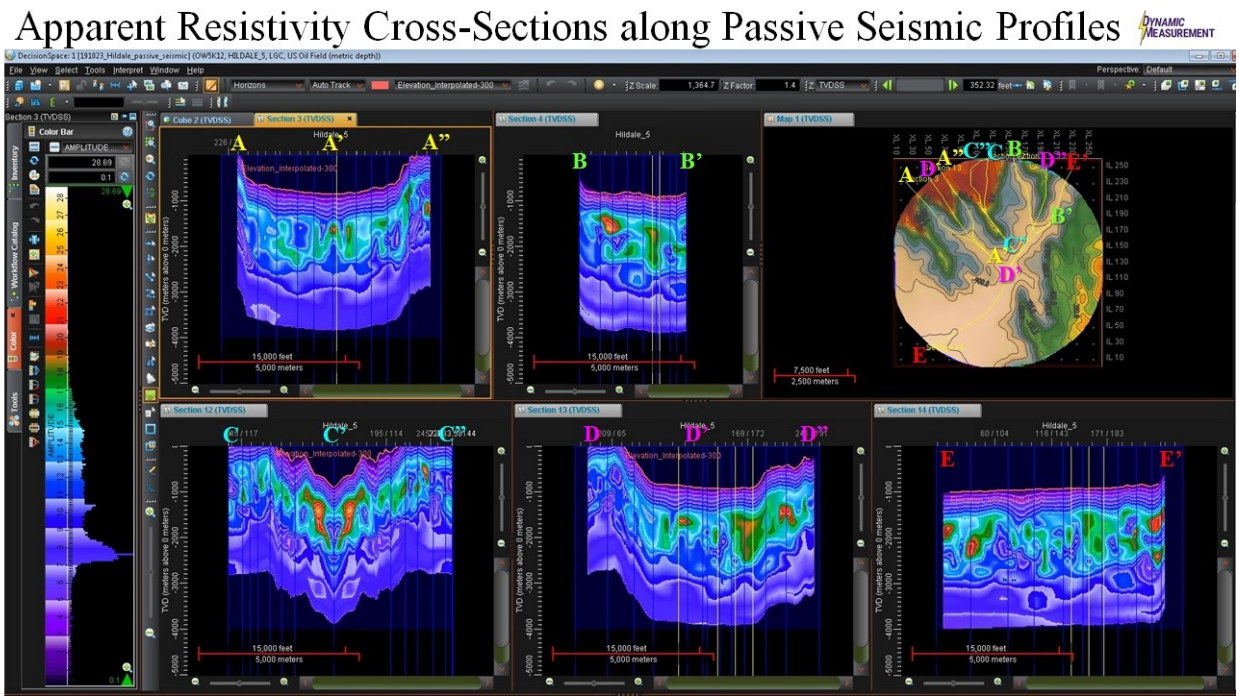


Figure 20B. Location of Passive Seismic Profiles from Primary Water Transferred to Interpretation System.

FAULT INTERPRETATION

The main lineaments HydroSource interpreted were moved to Landmark Graphics' DecisionSpace[tm] Geoshapes, as shown in Figure 21A. The Red north-south lineament predominates, and so it was used as the first lineament to check against the Apparent Resistivity volume. Apparent Resistivity cross-sections were displayed in Section 3, a point-to-point cross-section orthogonal to the red lineament, as shown in Figure 21B. Stepping through the volume from north to south there was obviously a break in calculated apparent resistivity anomalies underneath this lineament. Another arbitrary section was brought up orthogonal to the southwest to northeast lineaments. This is Section 12 in Figure 21B. Again, there were obvious fault breaks in the Apparent Resistivity calculations underneath the HydroSource lineaments. These breaks were interpreted as faults as shown in Figure 21C.

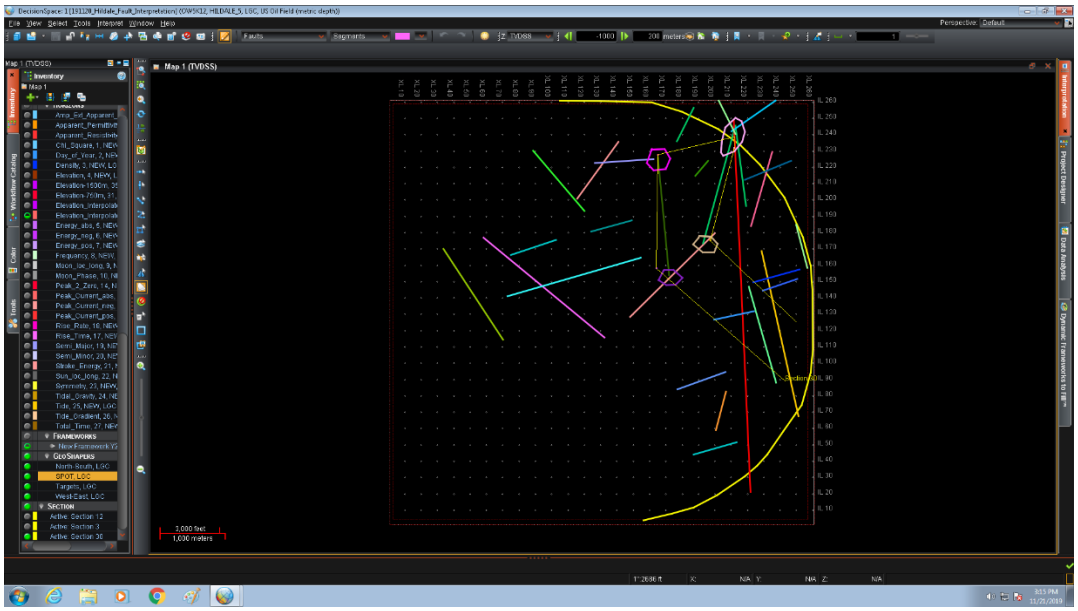


Figure 21A. HydroSource Lineaments transferred to DecisionSpace[tm].

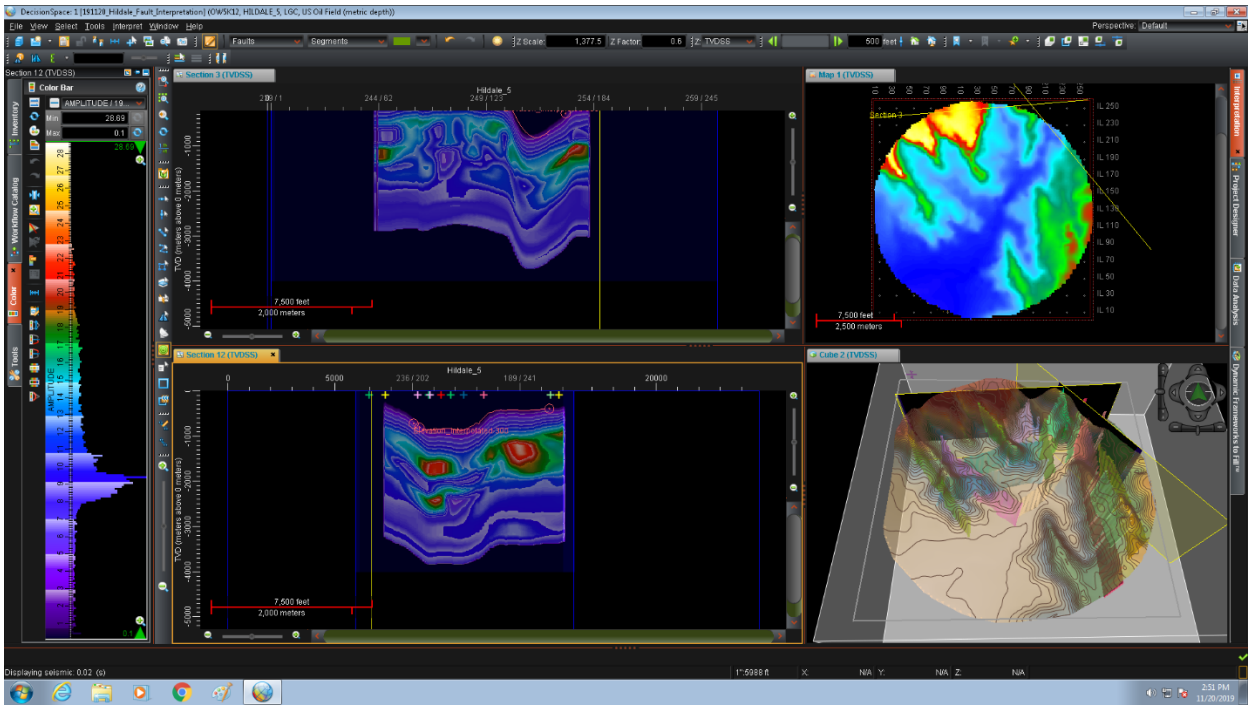


Figure 21B. Section 3 and Section 12 at the northeast corner of the SPOT^{sm} volume.

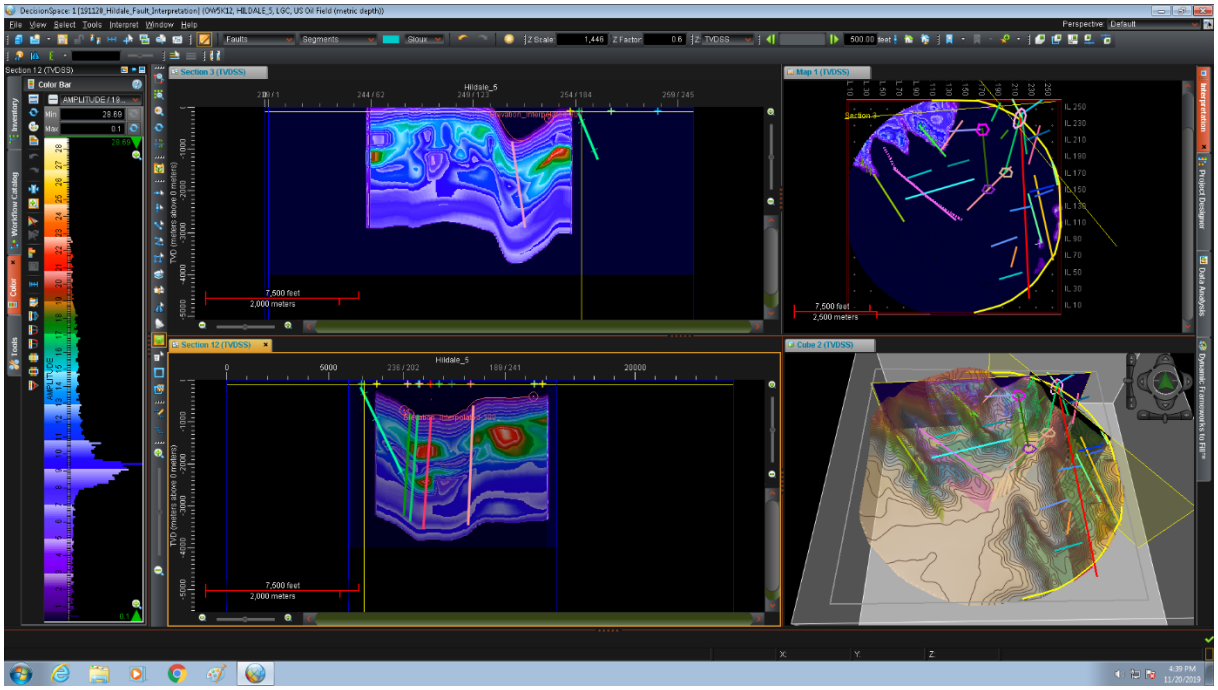


Figure 21C. Fault interpretations on Section 3 and Section 12 at the northeast corner of the SPOT^{sm} volume.

A fault was created for each lineament, and was assigned a name, based on different American Indian Tribes. The faults interpreted were named Apache, Arapaho, Cheyenne, Chickasaw, Chumash, Comanche, Crow, Hopi, Navajo (the red lineament), Pawnee, Piute, Pueblo, Shawnee, Shoshone, Sioux, and Ute. The faults fell within the SPOT^{sm} survey somewhat proportional to distribution of these American Indian Tribes across the United States. The arbitrary lines were moved 500 meters, and faults were interpreted on each section stepping through the Apparent Resistivity Volume. There were 67 screen captures made of these cross-sections, which have been uploaded with other data transferred to Willowstick (http://www.dynamicmeasurement/160202_Willowstick/Hildale/191120_Resistivity_Review).

Figures 21D-E shown uninterpreted and interpreted sections through the middle of the volume. Note how well the interpreted faults match the HydroSource lineaments. Figures 21F-G show the same type of displays for sections at the southwest side of the SPOT^{sm}. There are not as many lineaments interpreted in in the southwest sector, because the bedrocks are covered by unconsolidated sediments. Animations stepping through these sections, uninterpreted, and then interpreted, have also been uploaded to this site. The animations allow viewers to see spatial relationships cross-section to cross-section at three different speeds (slow, medium, and fast).

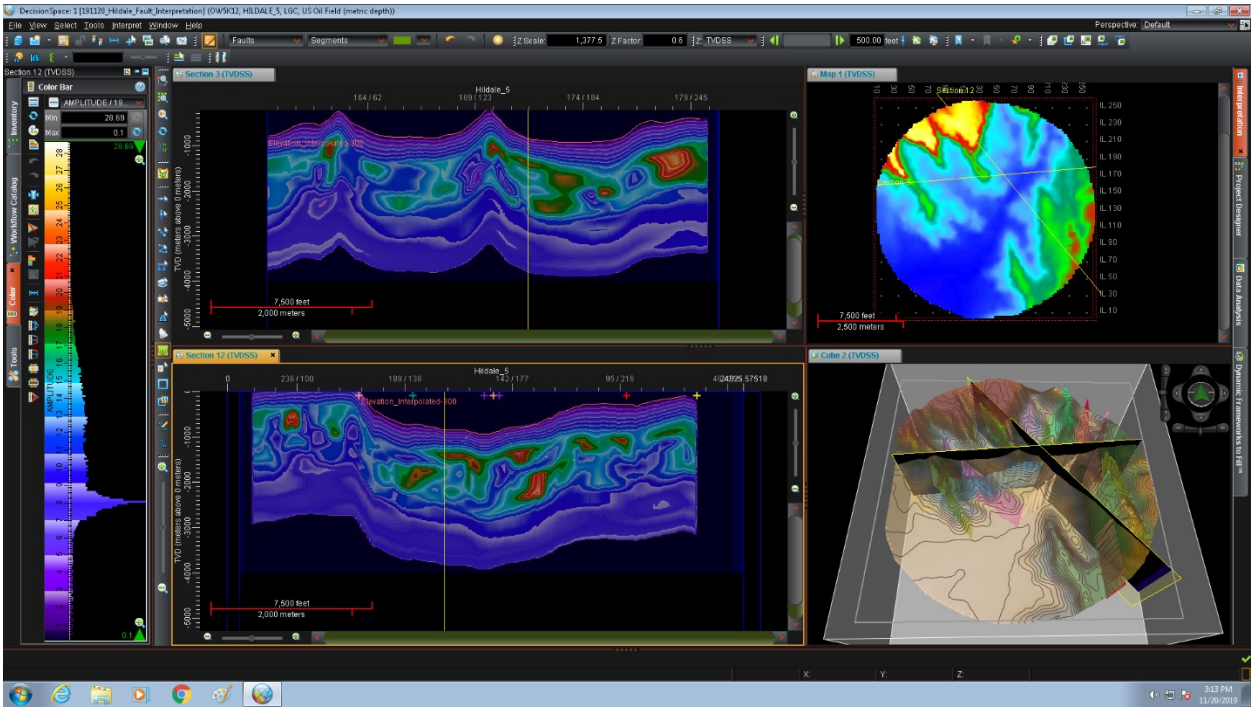


Figure 21D. Uninterpreted Section 3 and Section 12 in the center of the SPOT^{sm} volume.

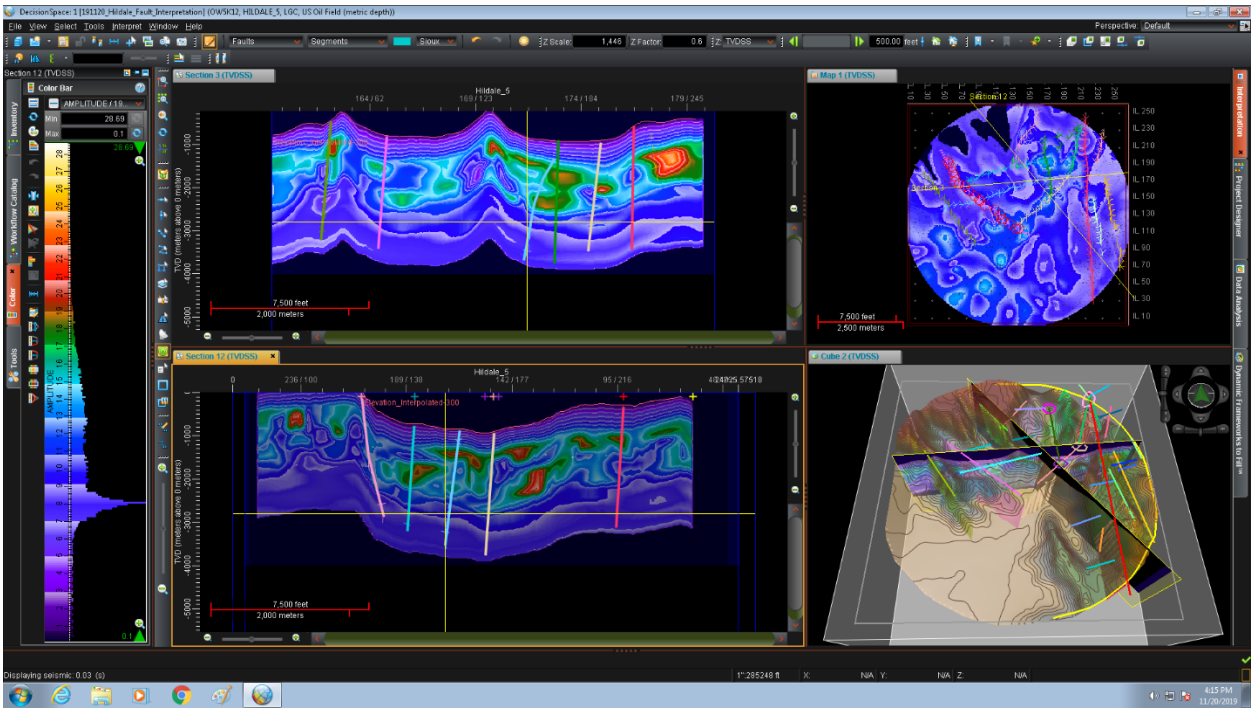


Figure 21E. Fault interpretations on Section 3 and Section 12 in the center of the SPOT^{sm} volume.

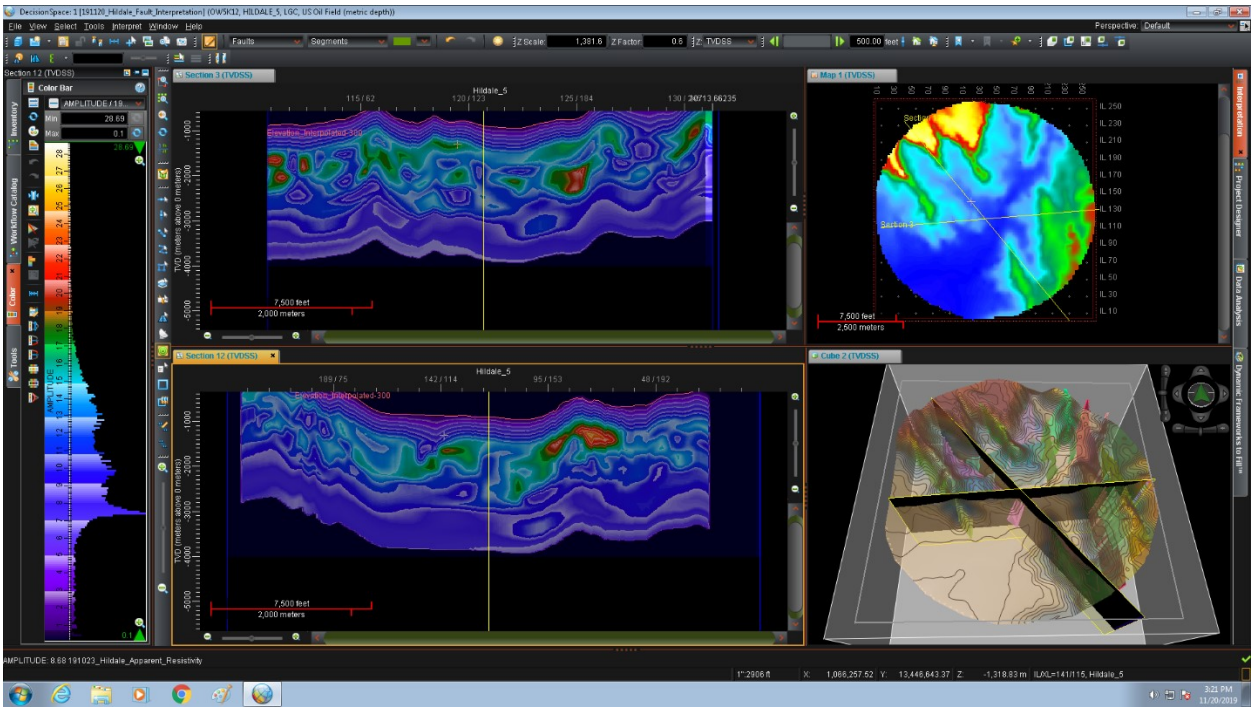


Figure 21F. Uninterpreted Section 3 and Section 12 in the center of the SPOT^{sm} volume.

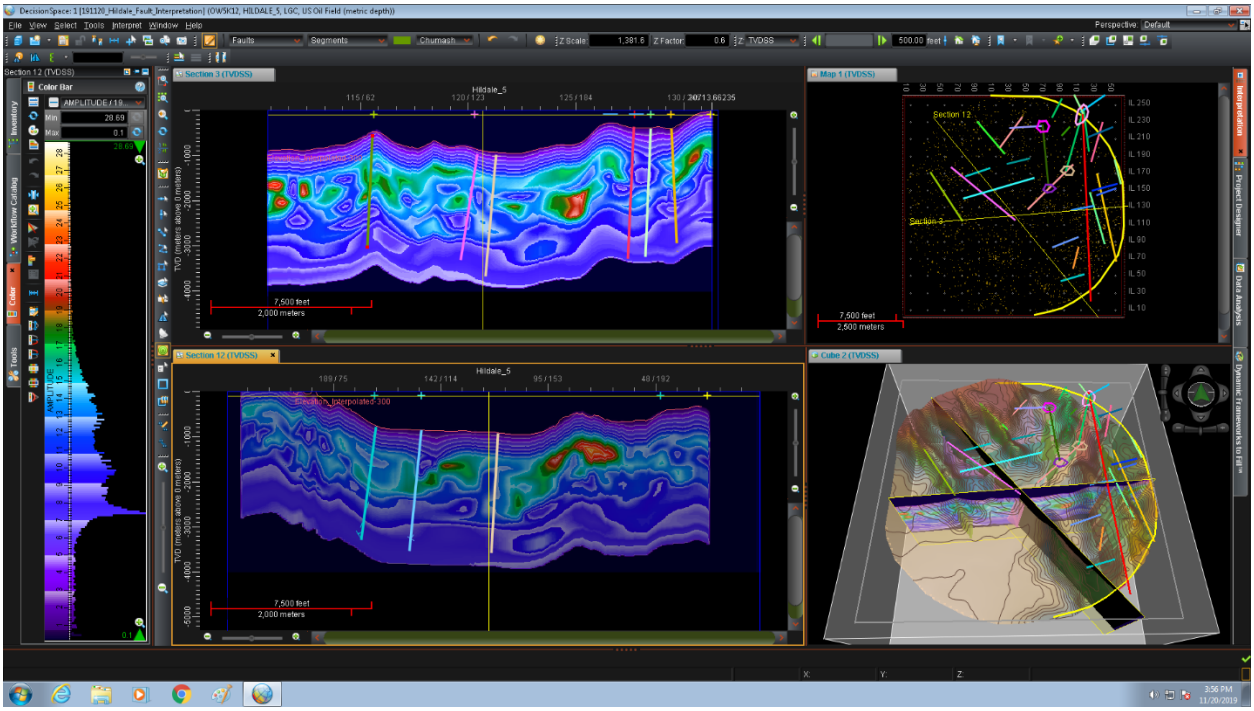


Figure 21G. Fault interpretations on Section 3 and Section 12 in the center of the SPOT^{sm} volume.

An alternative way to see these 3-D relationships is with cube display views. Figures 21H and 21I show two views of the faults and the HydroSource lineaments. A total of 56 rotational views were captures, and uploaded (see http://www.dynamicmeasurement/160202_Willowstick/Hildale/191120_191120_Cube_Display_Fault_Interpretation). As with the uninterpreted and fault interpreted cross-sections above, animations stepping through these rotating cube displays of the fault interpretation at three different speeds (slow, medium, and fast).

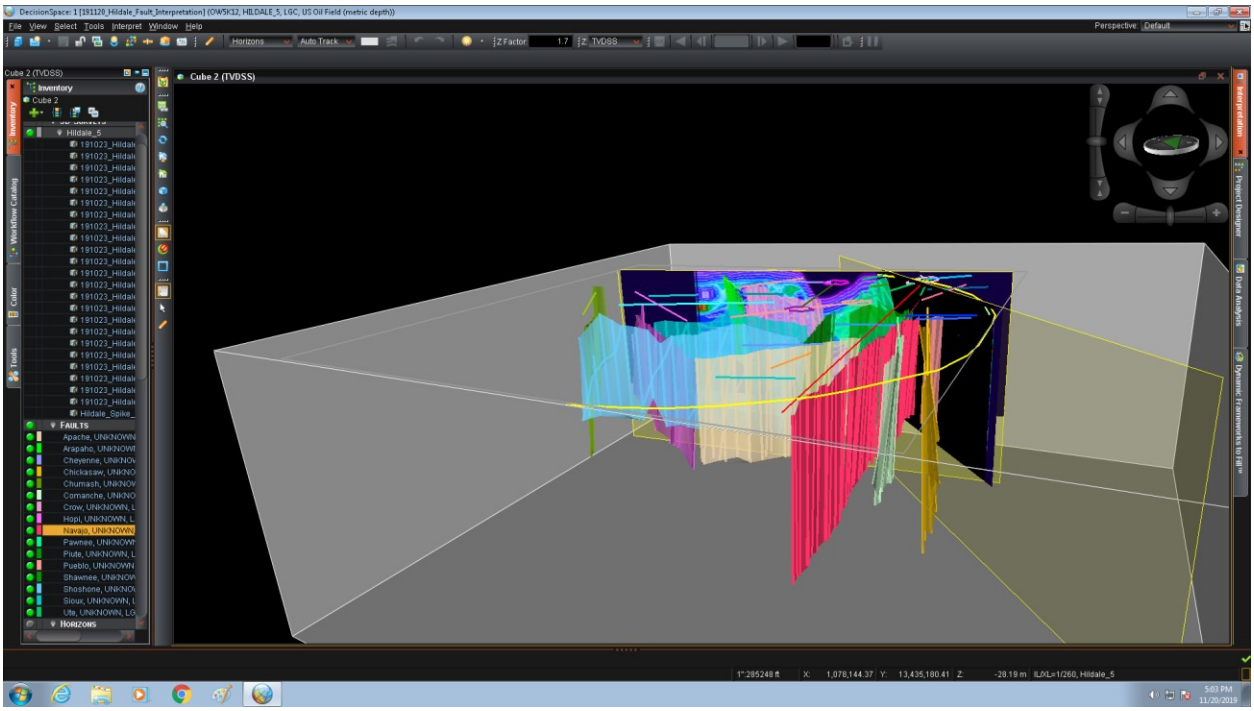


Figure 21H. Fault interpretations on Section 3 and Section 12 in the center of the SPOT^{sm} volume.

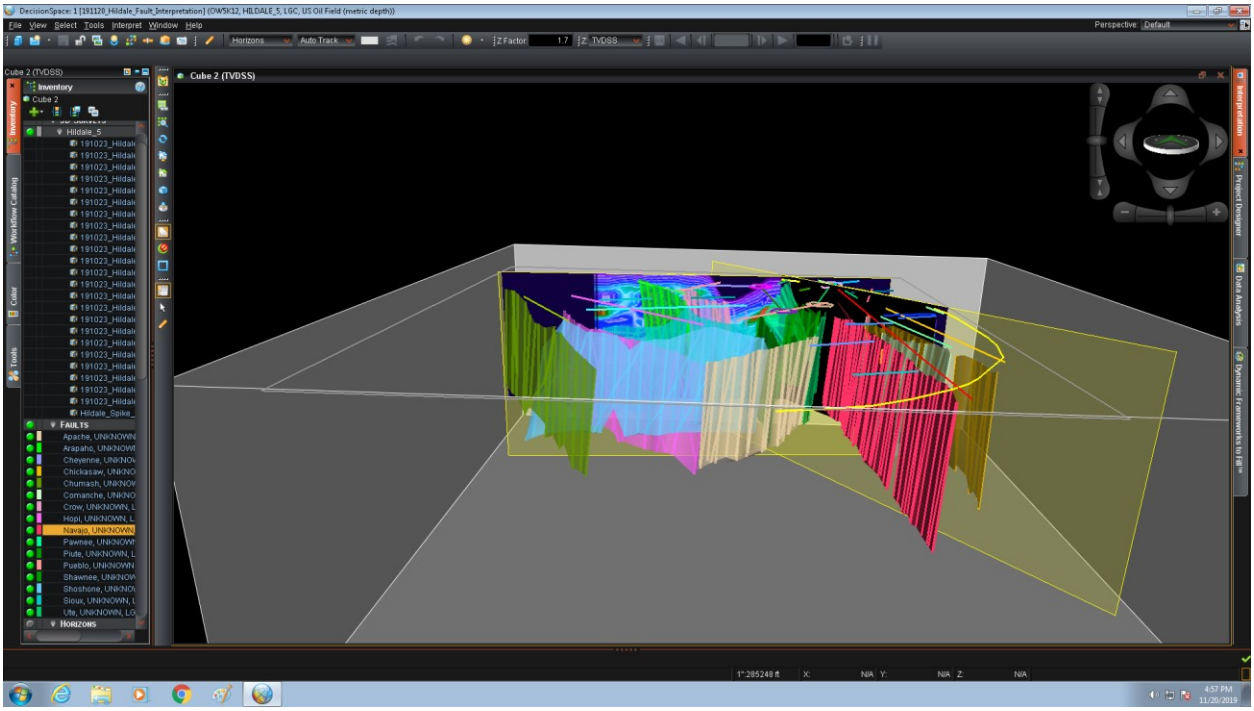


Figure 21I. Fault interpretations on Section 3 and Section 12 in the center of the SPOT^{sm} volume.

Two other ways of evaluating the internal validity of the fault interpretation were undertaken. First, an elevation horizon was made, a horizon parallel to the elevation and about 600 meters created, and then Apparent Resistivity amplitudes were extracted from the volume to create the map shown in Figure 22 below. The fault planes were displayed over this amplitude extraction map. Fault interpretation internal consistency is shown by how well the fault planes divide the various high resistivity areas extracted from the Apparent Resistivity volume. Fresh water has higher resistivity, and so the red areas (given the color map used) are more likely to be aquifers in these sandstones.

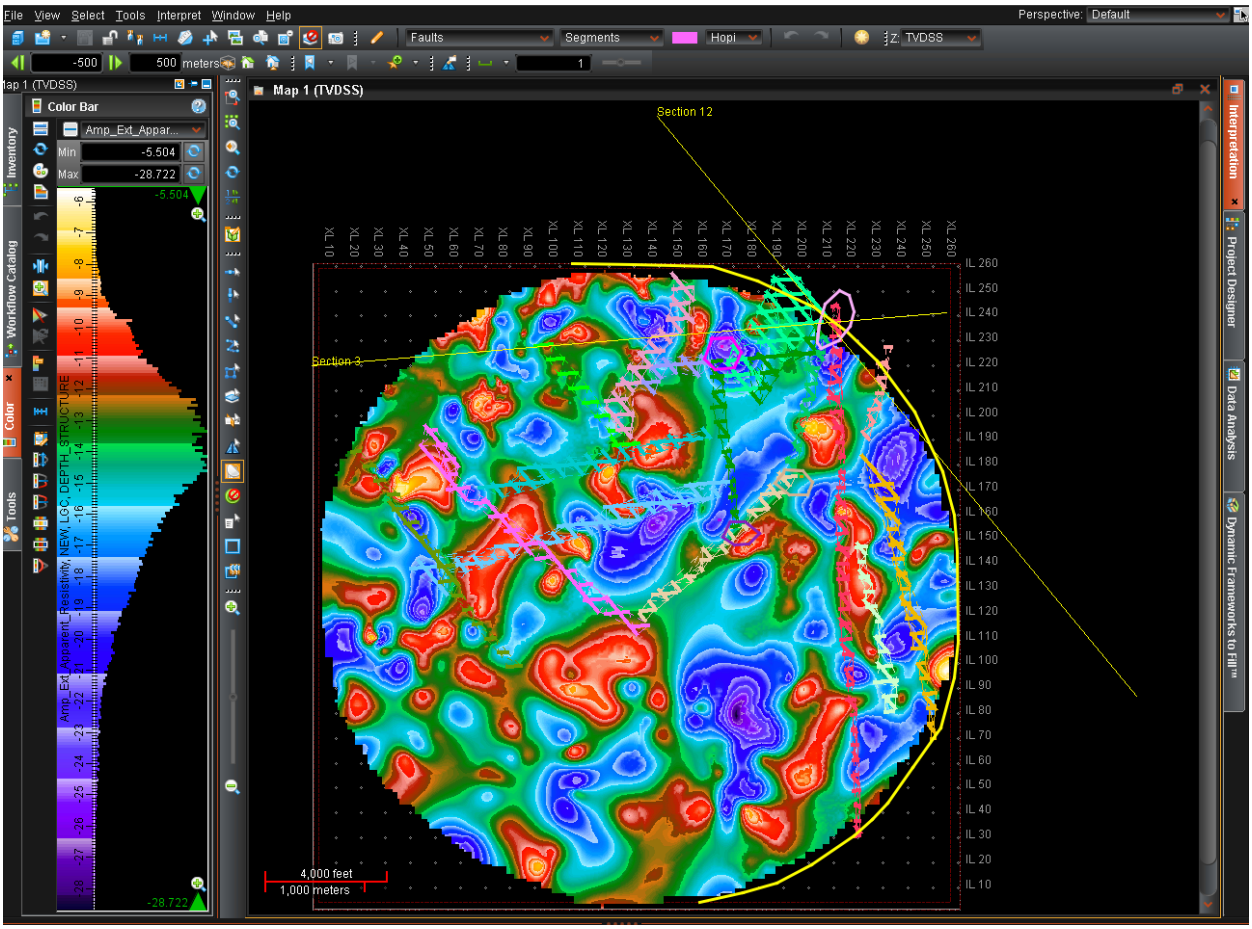


Figure 22. Amplitude Extraction through the vertical center of Apparent Resistivity with Faults.

Horizontal Slices through Apparent Resistivity volume provide the second way to confirm internal consistency of the fault interpretation. Horizontal slices were made ever 500 meters, and displayed with the cross-cutting fault planes at each depth. Figure 23A shows the 500-meter (1,640-foot) horizontal slice below 3000-meter (9,843-foot) datum. Figure 23B shows the 1,000-meters (3281-foot) slice below 3,000-meter (9,843-foot) datum. Figure 23C shows the 1,500-meters (4,921-foot) slice below 3,000-meter (9,843-foot) datum. Figure 23D shows the 2,000-meters (6,562-foot) slice below 3,000-meter datum (9,843-foot). And Figure 23E shows the 2,500-meters (8202-foot) slice below 3,000-meter (9,843-foot) datum. Dynamic did not have well data to calibrate the vertical axis.

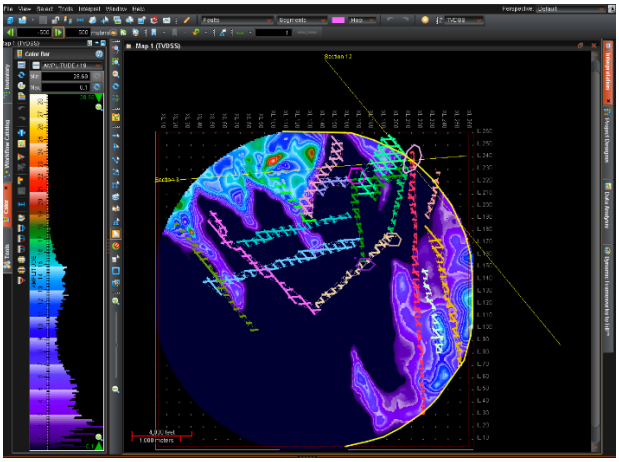


Figure 23A. Horizontal-Slice Resistivity 500 meters.

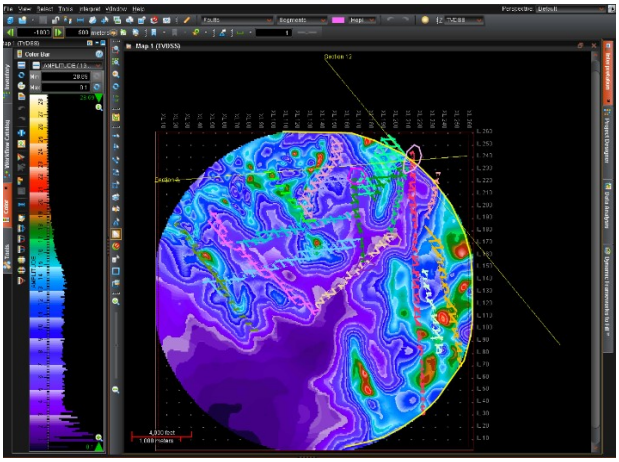


Figure 23B. Horizontal-Slice Resistivity 1000 meters.

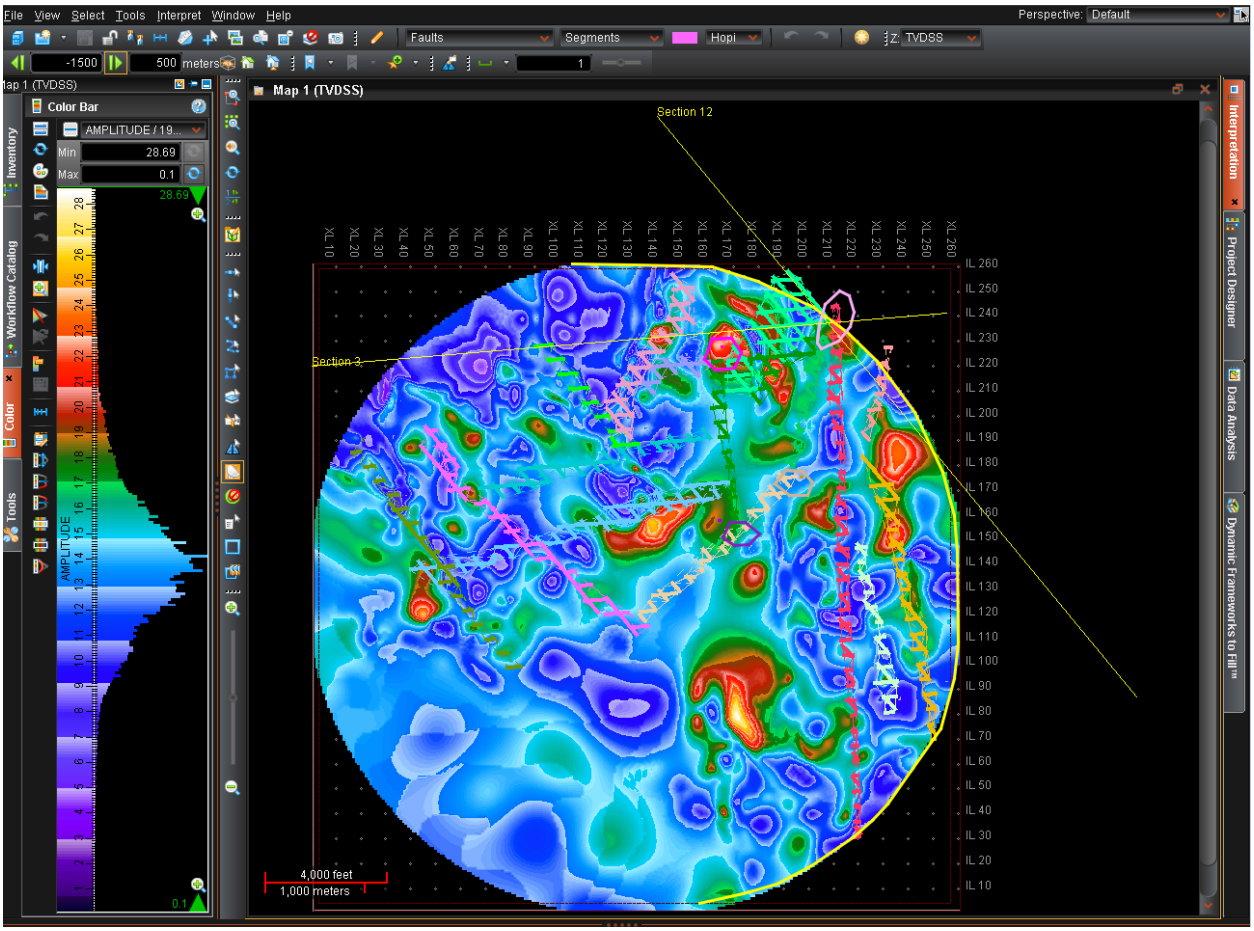


Figure 23C. Horizontal-Slice Apparent Resistivity at 1500 meters beneath 3,000 meter datum.

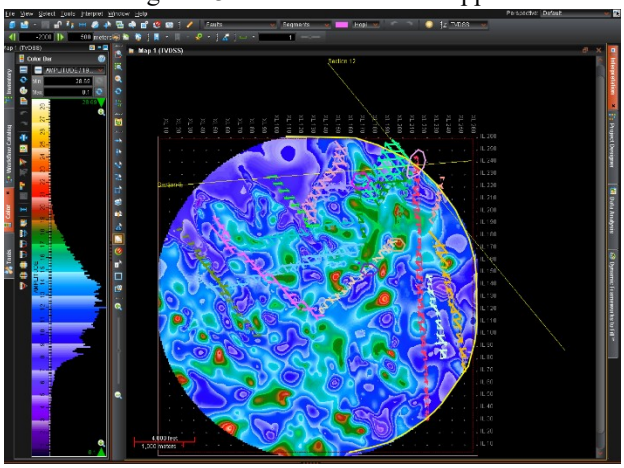


Figure 23D. Horizontal-Slice Resistivity 2000 meters.

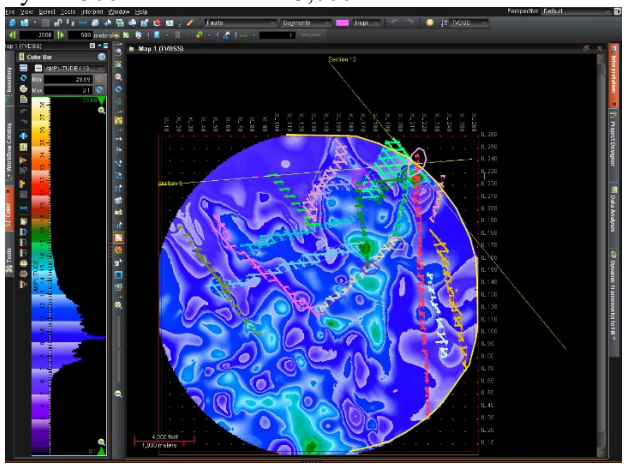


Figure 23E. Horizontal-Slice Resistivity 2500 meters.

The important thing about this section of the report is how the fault interpretation matches and flowed naturally from the HydroSource lineament study. Lightning analysis allows geoscientists to look underneath the ground, and to integrate available geologic and geophysical control within a common geologic framework. It seems logical this approach can be used on projects Willowstick, HydroSource, Primary Water, or other geophysical contractors undertake, in order to build a common geologic framework for their study area, and for integrating their unique data with other geological and geophysical data. Based on experience to date, this is particularly true whenever a project tied to any kind of fault compartments is undertaken.

Z1, Z2, Z3, and Z6 Possible HydroSource Locations

HydroSource provided 6 possible new aquifer drilling locations. Four of these locations are within the SPOT^{sm} analysis area. To demonstrate other types of displays Dynamic can create, Dynamic used a probe cube display, and covered the four anomalies within the SPOT^{sm}, as shown in Figure 24A. Note Z3 is above the Z2 vertical line, the perspective view makes the HydroSource ellipse appear to be to the right or east.

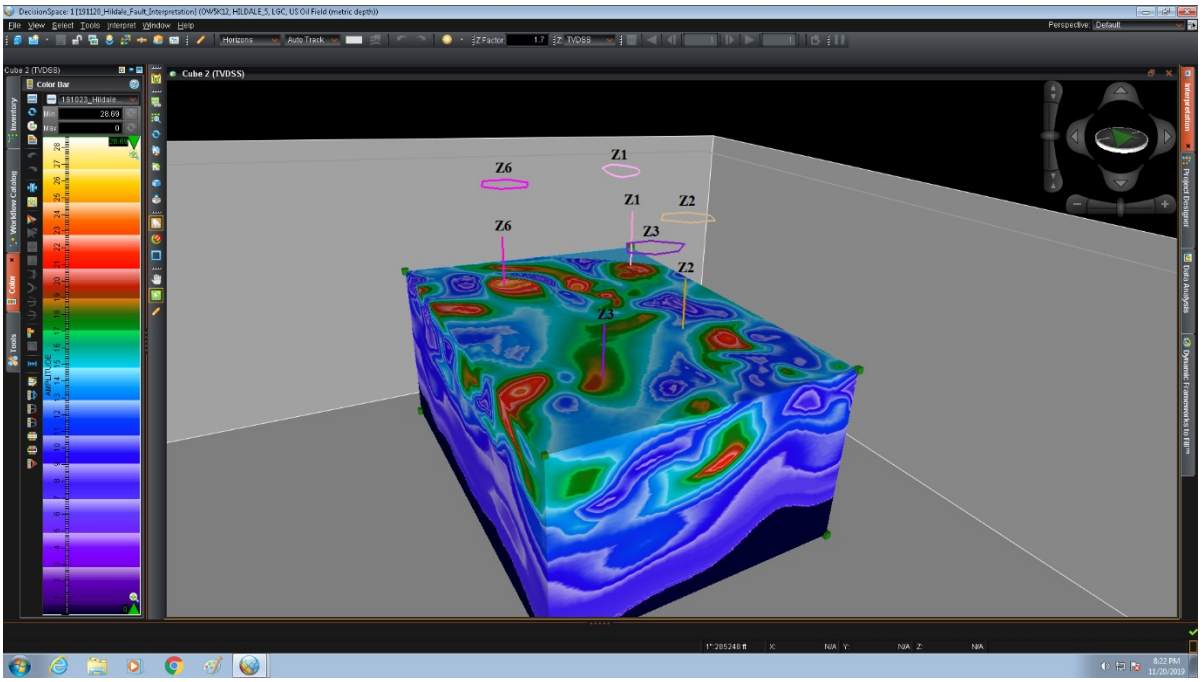


Figure 24A. Apparent Resistivity Probe showing Z1, Z2, Z3, and Z6 Anomalies Subsurface.

Figure 24B shows the Z1 anomaly. The illustrated well runs from 704 meters (2,310 feet) to 1,673 meters (5,489 feet), based on 20-meters per sample used to load the data. Because location is near cliffs, a horizontal well will not have to drill the 3,179 feet estimated in this display.

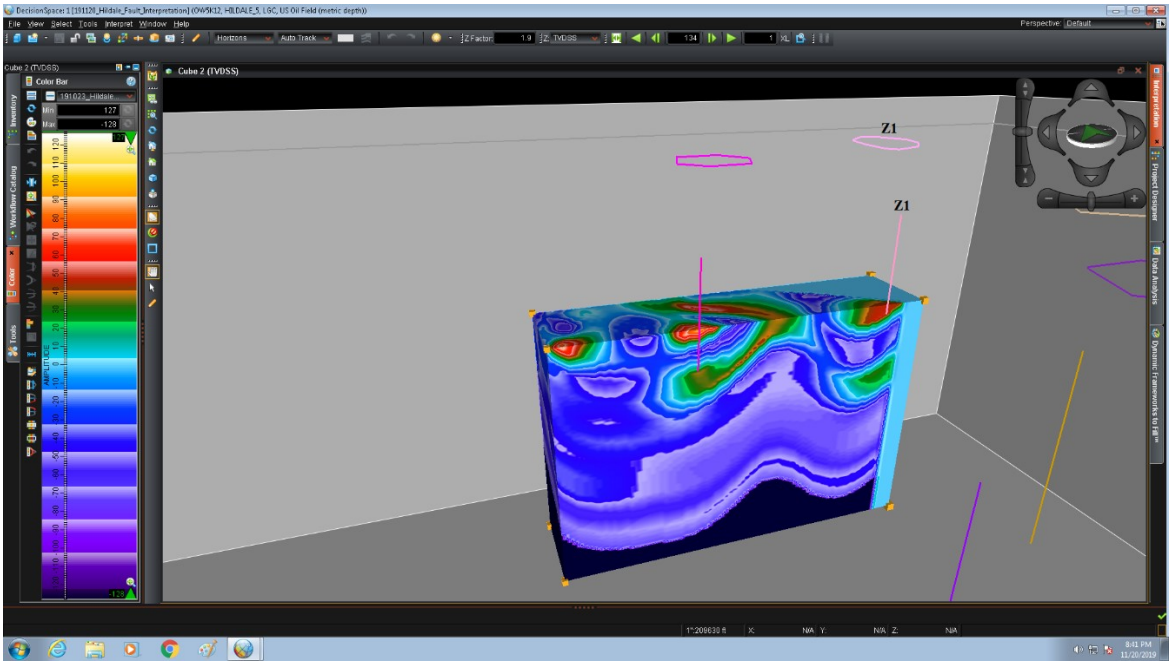


Figure 24B. They HydroSource Z1 Anomaly.

Figure 24C show the HydroSource Z2 anomaly. The illustrated well runs from 904 meters (2,966 feet) to 2,168 meters (7,113 feet), based on 20-meters per sample used to load the data. Because locations are near cliffs, a horizontal well will not have to drill the 4,147 feet estimated in this display.

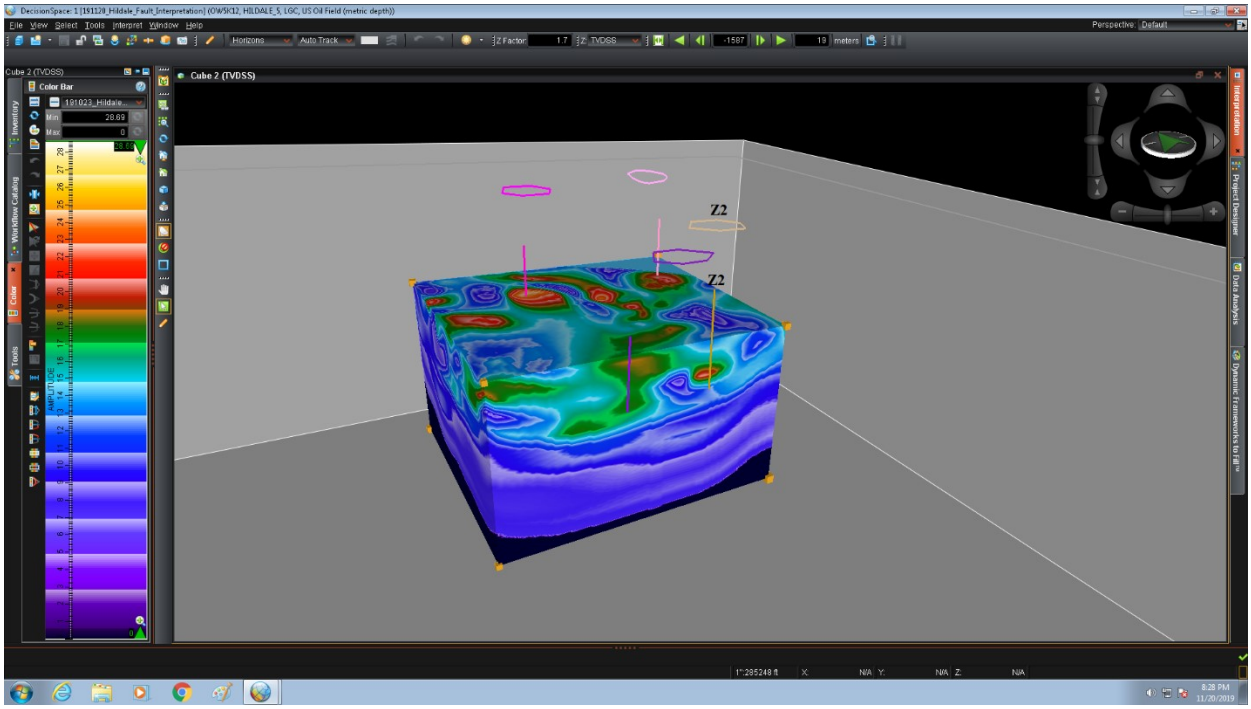


Figure 24C. The smaller HydroSource Z2 Anomaly.

Figure 24D shows the HydroSource Z3 anomaly. The illustrated well runs from 951 meters (3,120 feet) to 1,808 meters (5,932 feet), based on 20-meters per sample used to load the data. Because locations are near cliffs, a horizontal well will not have to drill the 2,812 feet estimated in this display.

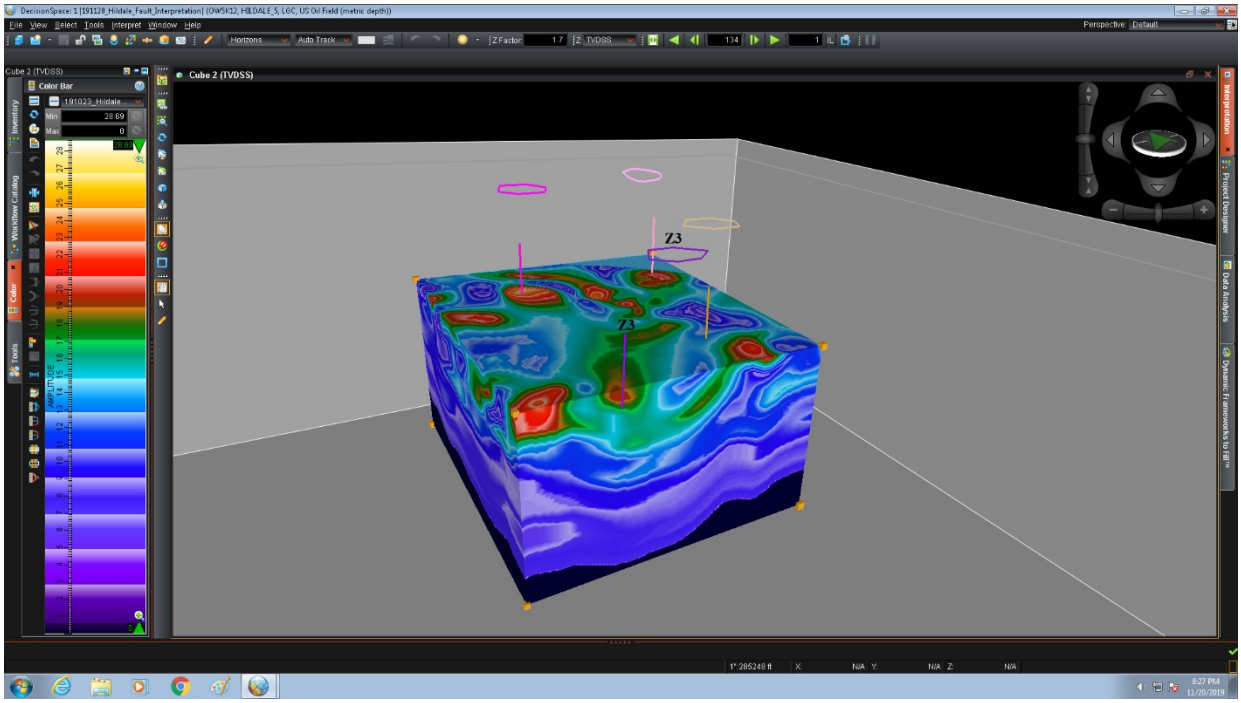


Figure 24D. The HydroSource Z3 Anomaly

Figure 24E shows the HydroSource Z6 anomaly. The illustrated well runs from 867 meters (2,845 feet) to 1,884 meters (6,181 feet), based on 20-meters per sample used to load the data. Because locations are near cliffs, a horizontal well will not have to drill the 3,336 feet estimated in this display.

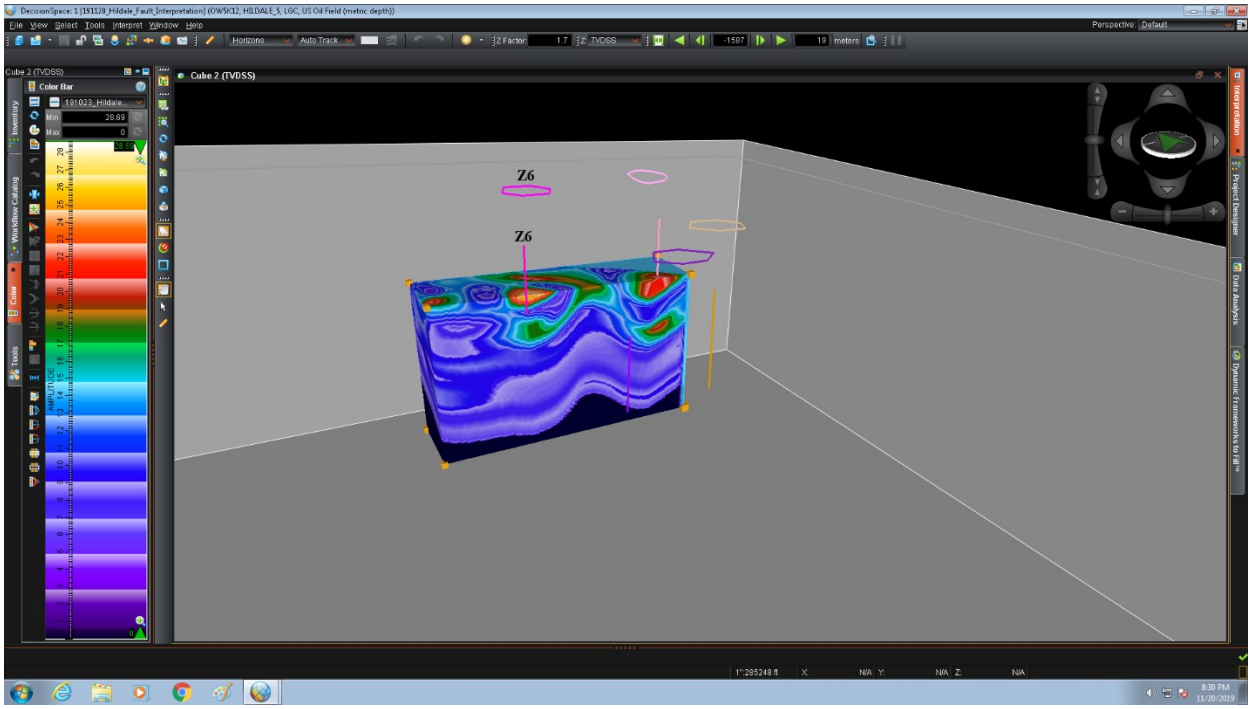


Figure 24E. The HydroSource Z6 Anomaly.

Point to point cross-sections can also be drawn through each of the HydroSource opportunities within the SPOT^{sm} analysis area. Figure 25A1 shows an arbitrary line running from south to the Purple Z3 Anomaly, then to the Violet Z6 anomaly, then east to the Pink Z1 anomaly, south to the Orange Z2 anomaly and then southeast parallel to the initial cross-section segment. Figure 25A2 is this same cross-section location map with Geoshapes. Figure 25A3 is again this same cross-section location map with Fault Planes.

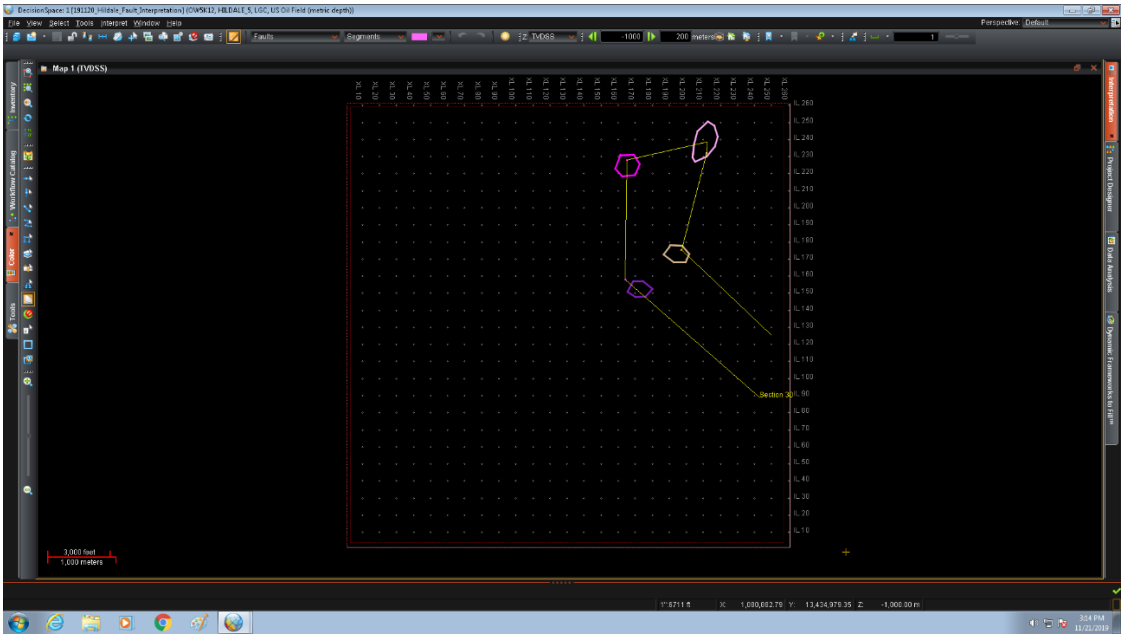


Figure 25A1. Location of Point-to-Point Cross-Section Through Z3, Z6, Z1, and Z2 respectively.

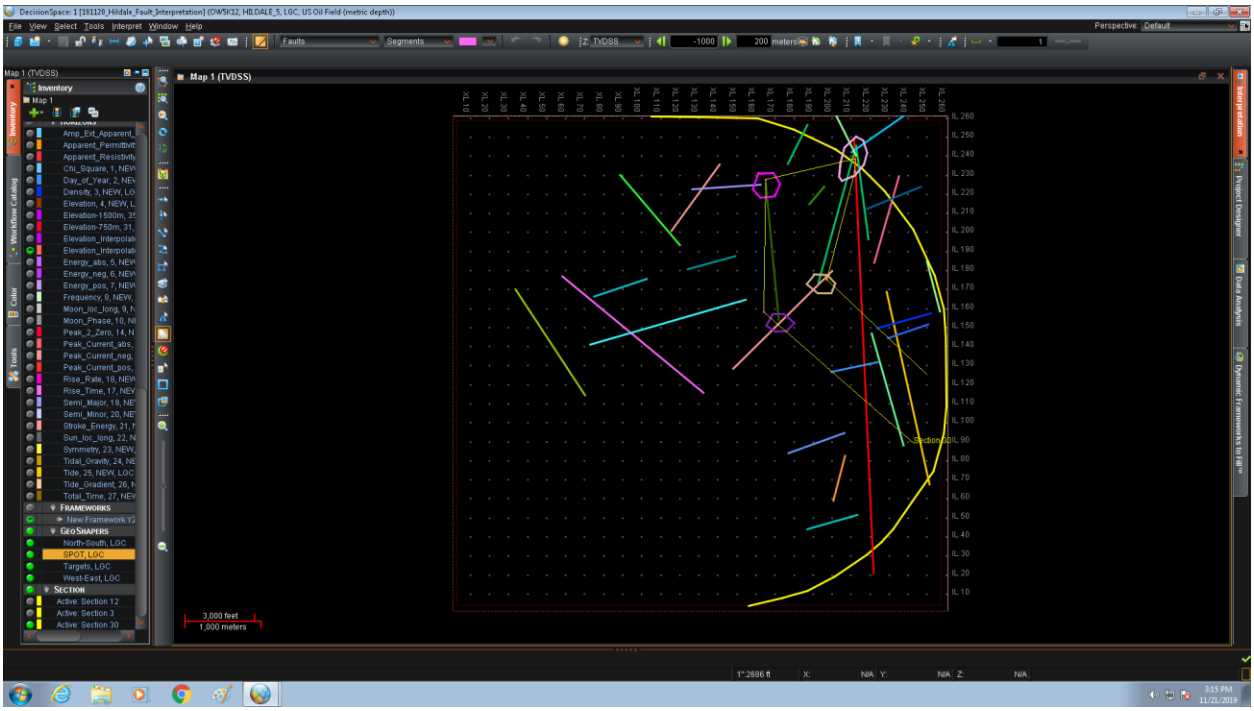


Figure 25A2. Location of Point-to-Point Cross-Section with HydroSource Lineaments.

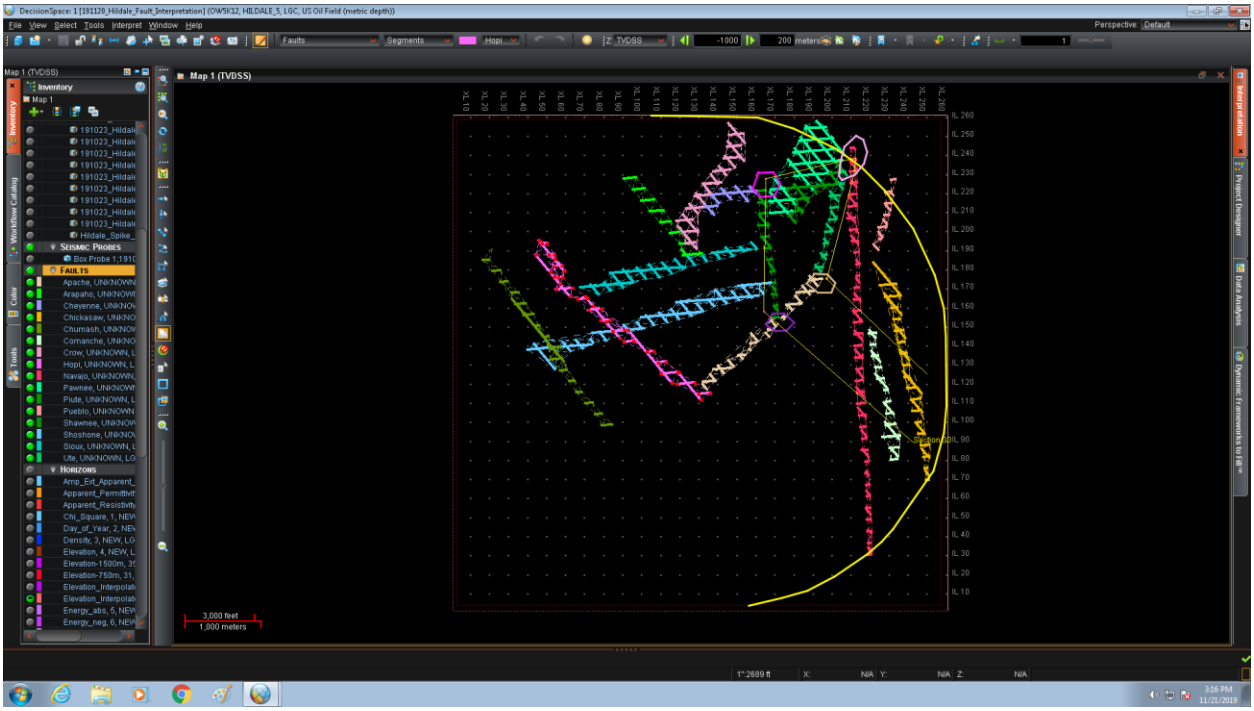


Figure 25A3. Location of Point-to-Point Cross-Section with Interpreted Fault Planes.

There were 23 different lighting results displayed on this point-to-point cross-section going through the Purple Z3 Anomaly, the Violet Z6 anomaly, the Pink Z1 anomaly, and the Orange Z2 anomaly. Figure 25B shows depth location data, the Spike volume. This volume has a spike at the depth calculated for each individual lightning stroke from the Peak Current. The calculated depth only shows about 11 depth locations on this arbitrary section. Remember, there are locations just inside, and just outside of this section. All of these points are interpolated with a three-dimensional interpolation algorithm to create the volumes these cross-sections are pulled from.

Figure 25C shows Apparent Resistivity along this cross-section; Figure 25D Apparent Permittivity; Figure 25E the Day-of-Year the lightning strike occurred; Figure 25F the absolute Energy, or area under the curve; Figure 25G the negative stroke Energy; Figure 25H the positive stroke Energy; Figure 25I the Frequency; Figure 25J the local Moon Longitude when the strike occurred; Figure 25K the phase of the Moon when the strike occurred; Figure 25L the Number of Sensors recording the stroke; Figure 25M the absolute Peak Current of the strikes; Figure 25N the negative Peak Current of the strikes; Figure 25O the positive Peak Current of the strikes; Figure 25P the Peak-to-Zero time of the strikes; Figure 25Q the Rise-Rate, or first derivative of the Rise Time of the strikes; Figure 25R the Rise Time of the strikes; Figure 25S the local longitude of the Sun at the time of the strike; Figure 25T the Symmetry of the strikes; Figure 25U the Tidal Gravity when the strikes occurred; Figure 25V the Tide when the strikes occurred; Figure 25W the Tidal Gradient or derivative of the Tide when the strike occurred; and Figure 25X Total Time or sum of Rise Time and Peak-to-Zero Time for each strike. These attribute cross-sections are displayed to show other data which can be used in future evaluation of the area.

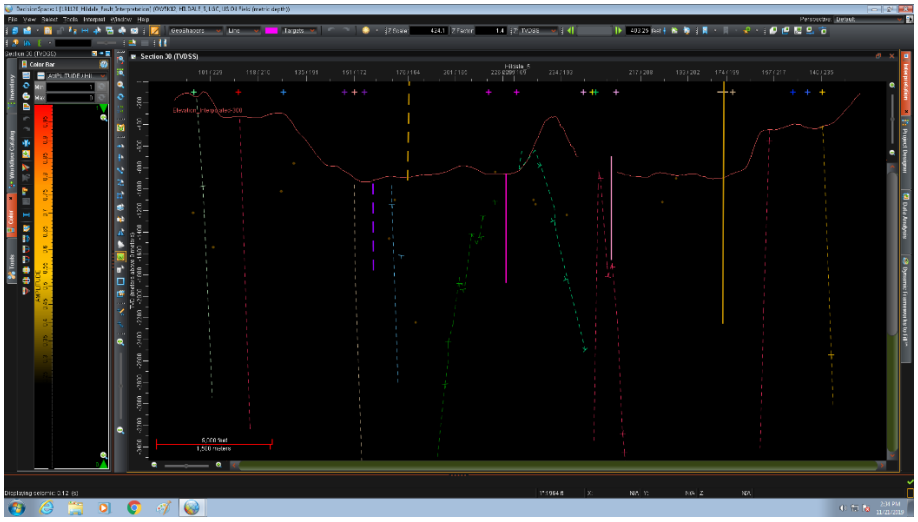


Figure 25B. Spike Subsurface Locations on Z3, Z6, Z1, & Z2 Opportunity Cross-Section with Faults.

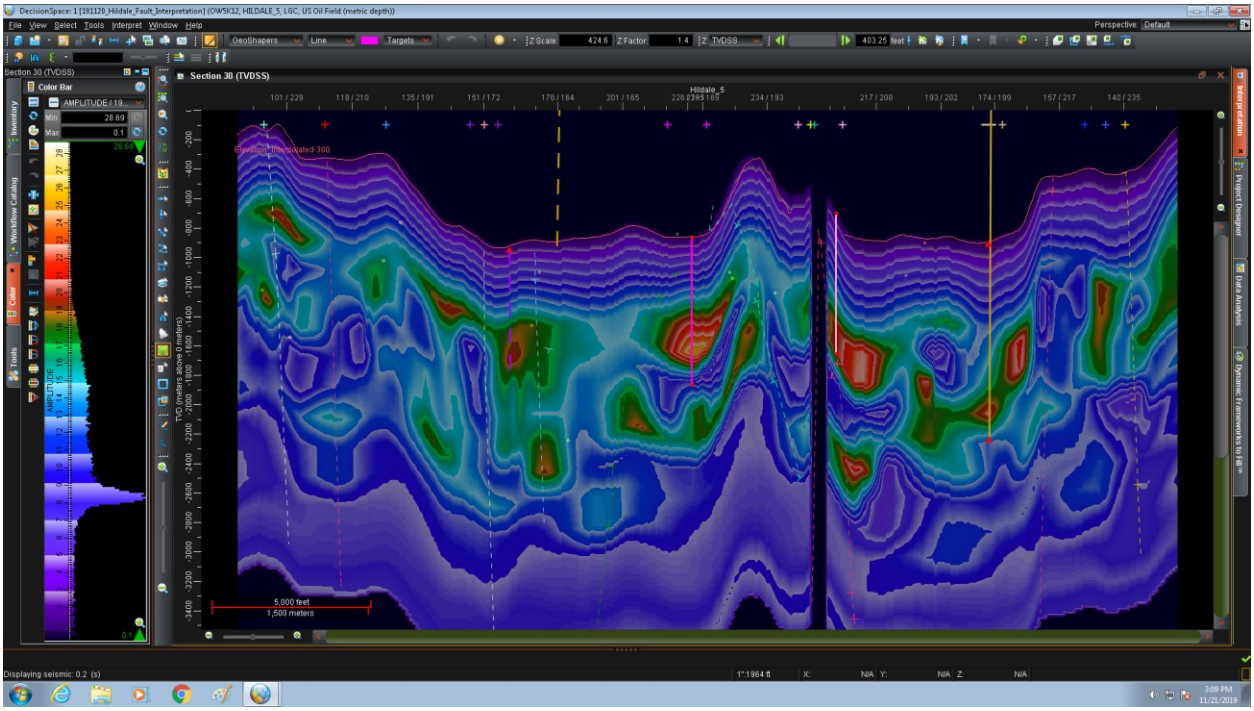


Figure 25C. Apparent Resistivity Opportunity Cross-Section.

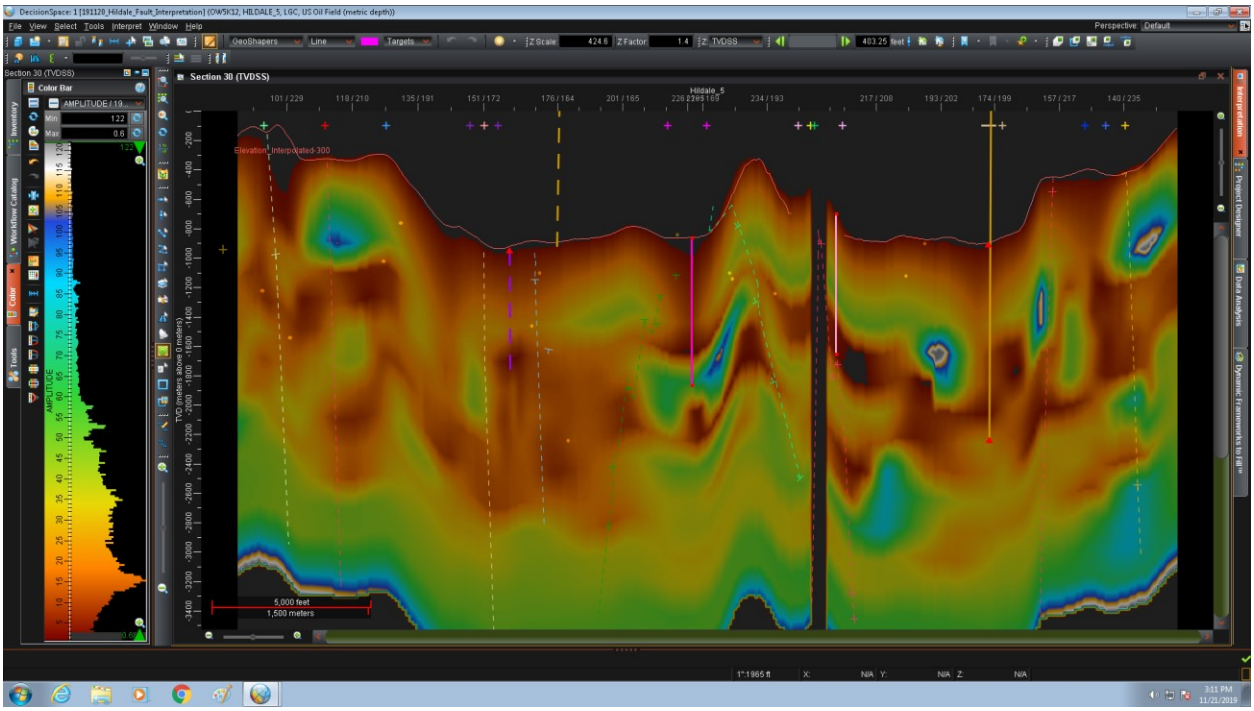


Figure 25D. Apparent Permittivity Opportunity Cross-Section.

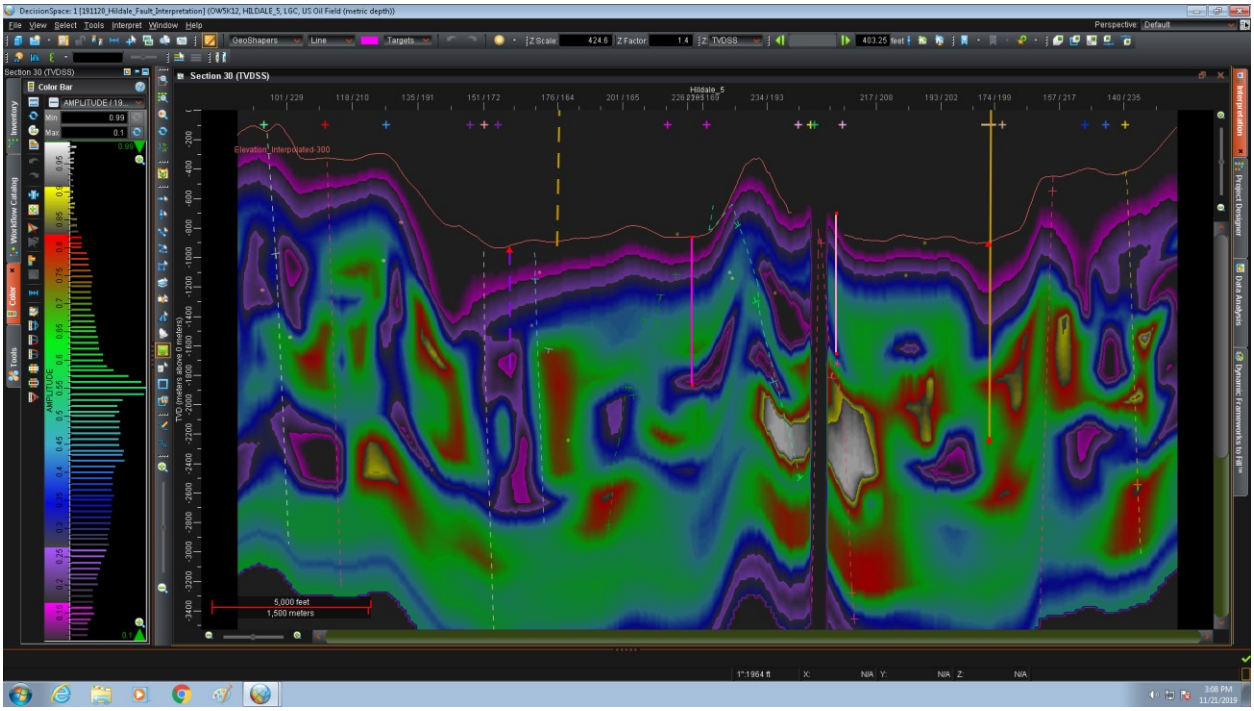


Figure 25E. Day-of-Year Opportunity Cross-Section.

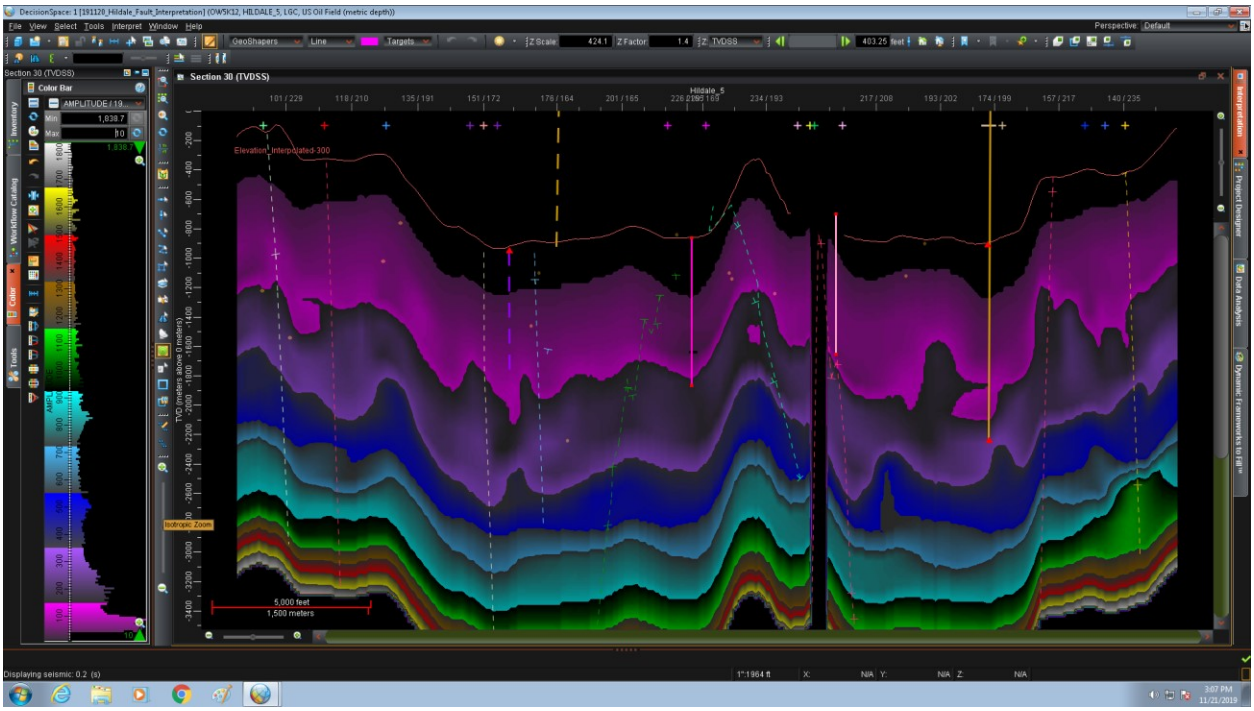


Figure 25F. Absolute Energy Opportunity Cross-Section.

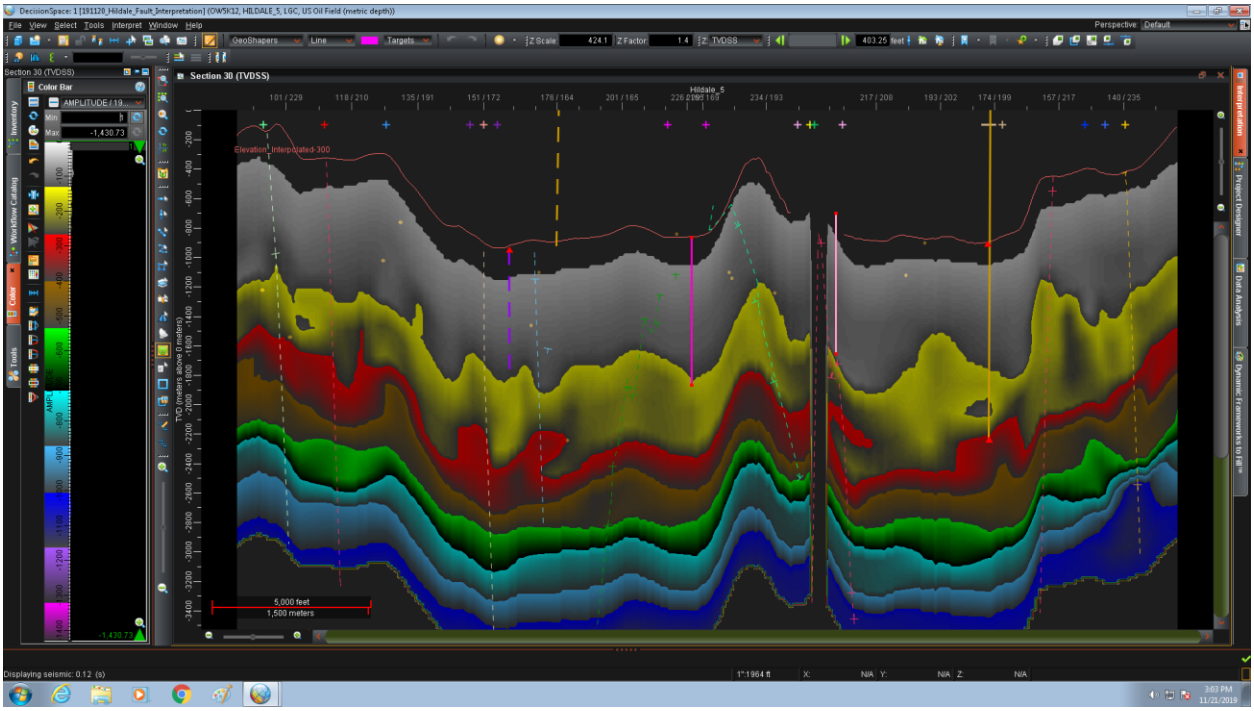


Figure 25G. Negative Energy Opportunity Cross-Section.

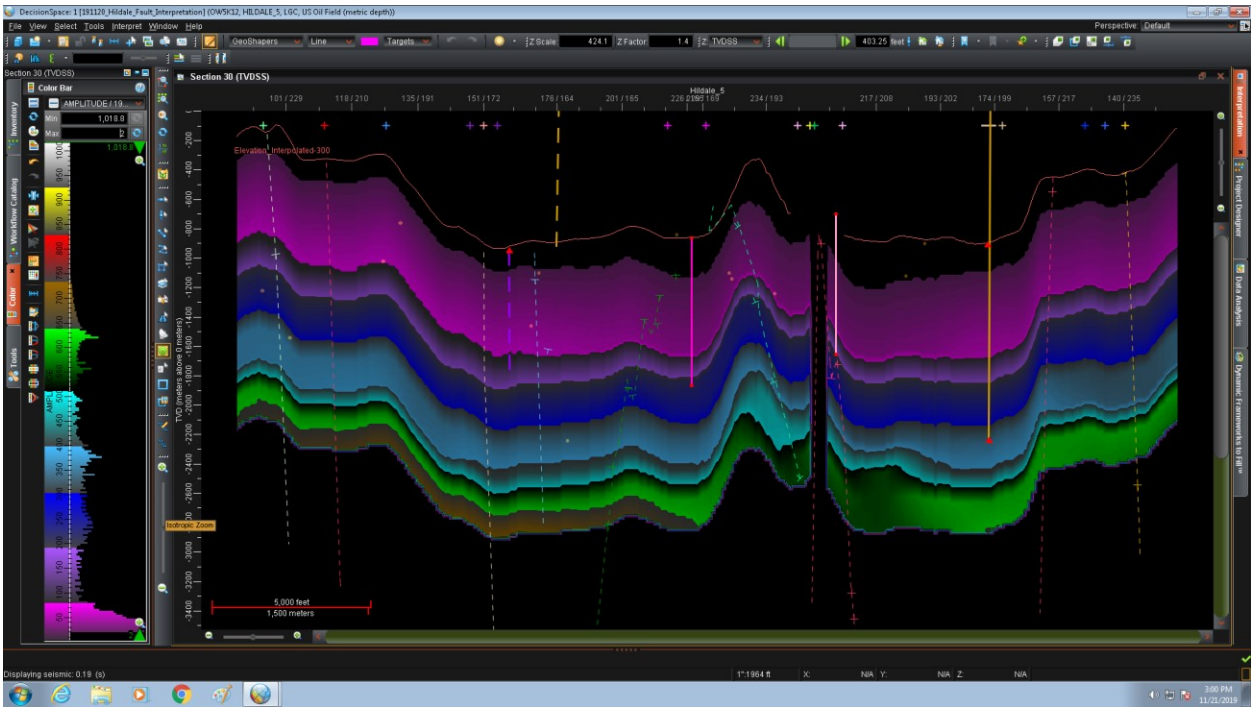


Figure 25H. Positive Energy Opportunity Cross-Section.

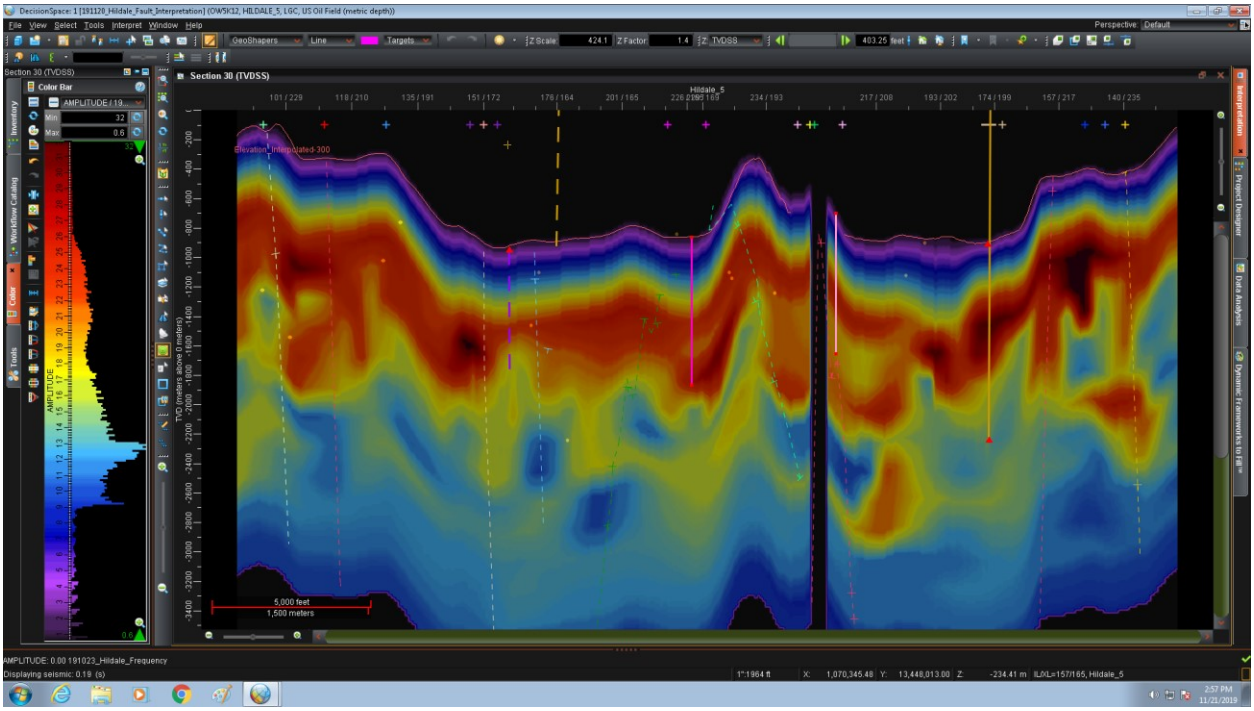


Figure 25I. Frequency Opportunity Cross-Section.

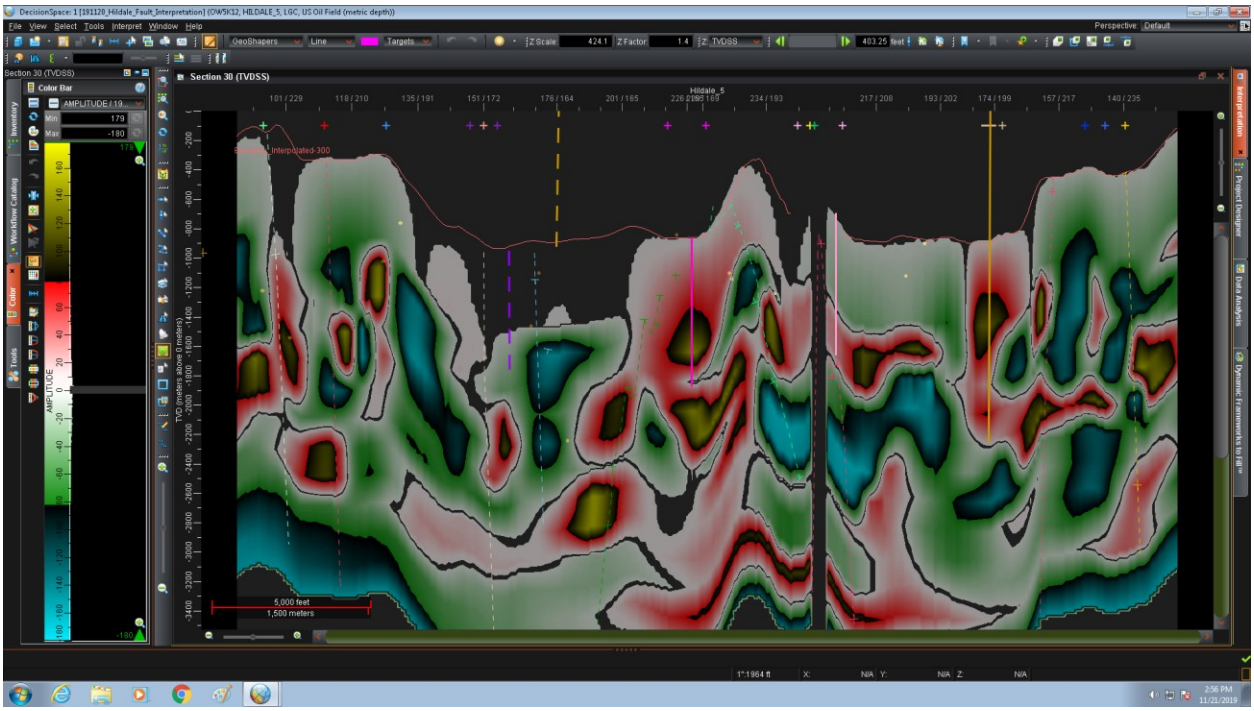


Figure 25J. Moon-Local-Longitude Opportunity Cross-Section.

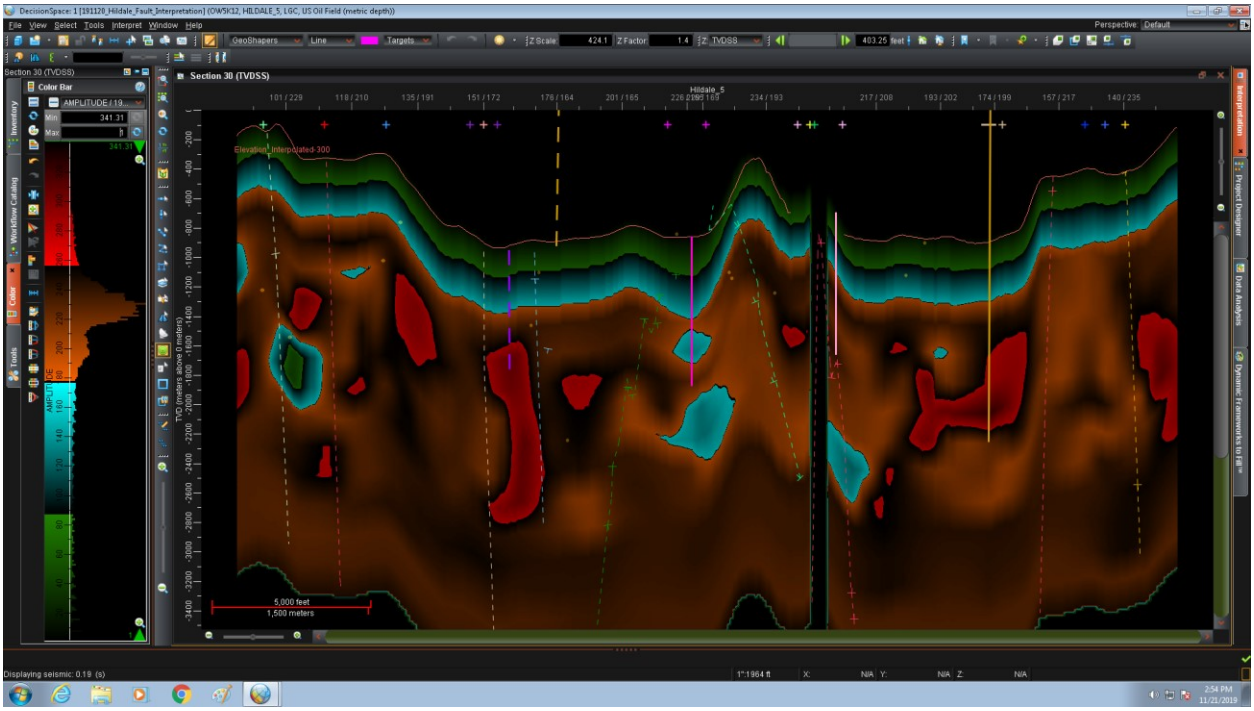


Figure 25K. Moon Phase Opportunity Cross-Section.

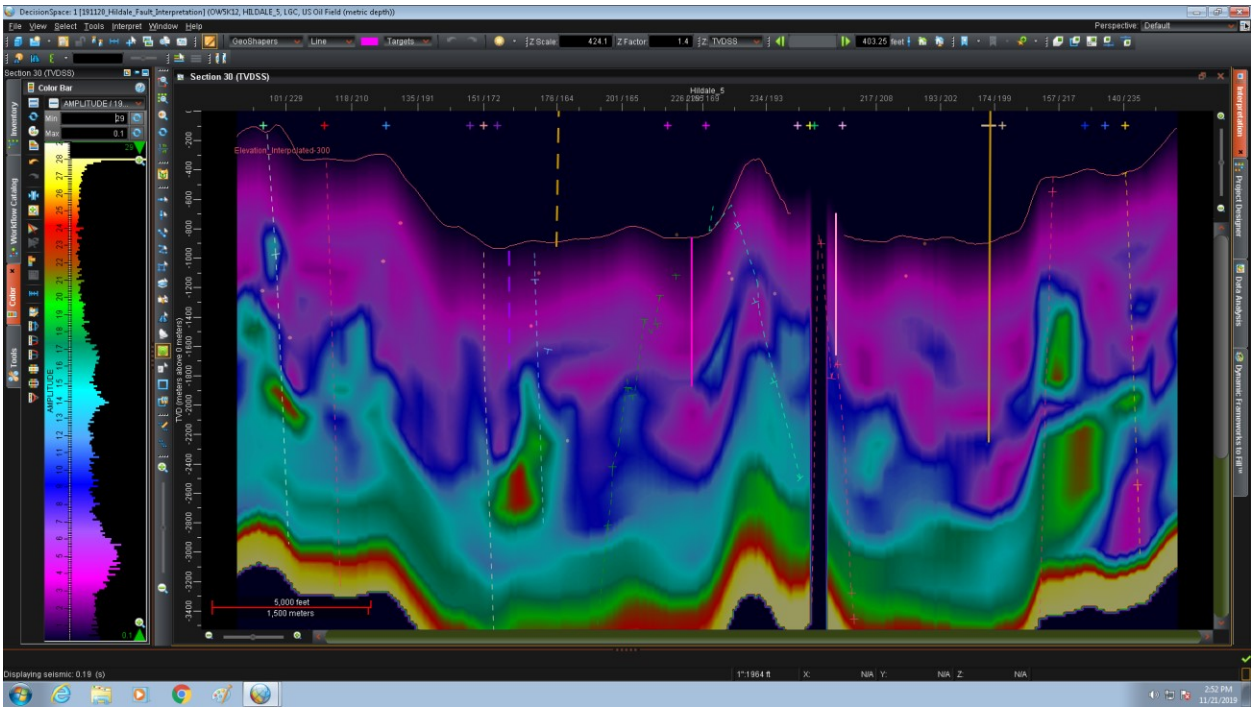


Figure 25L. Number-of-Sensors Opportunity Cross-Section.

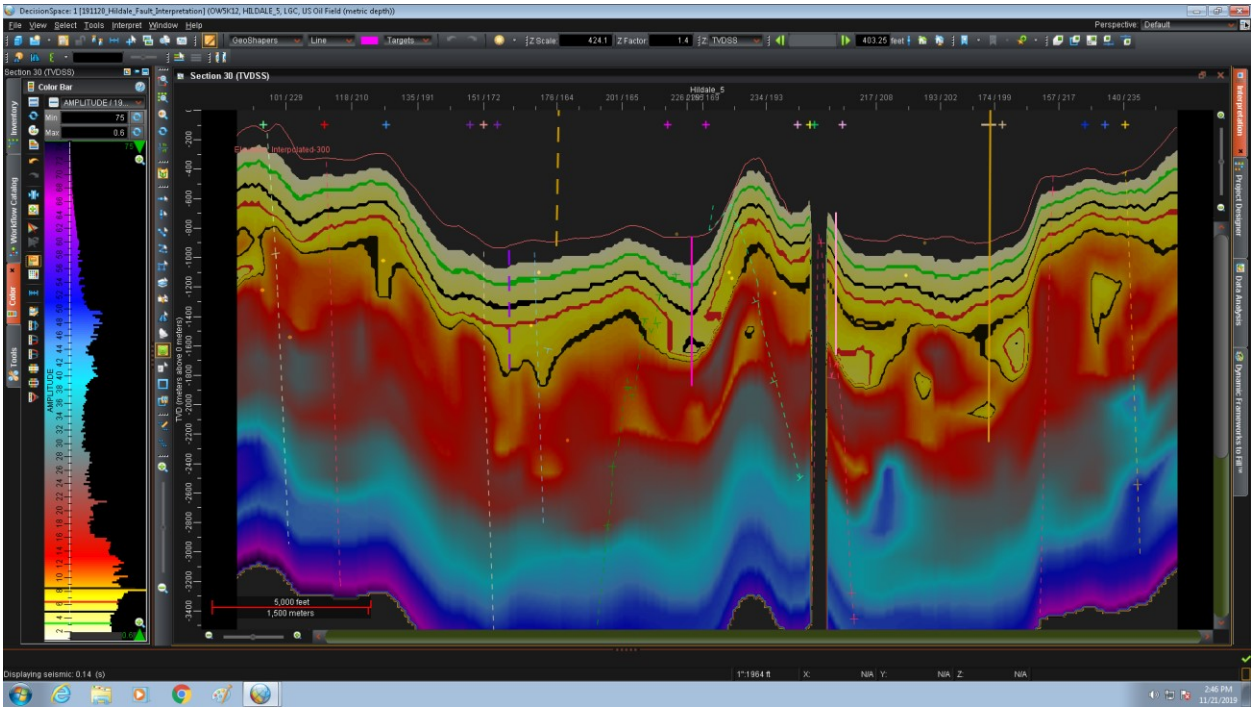


Figure 25M. Peak Current Absolute Opportunity Cross-Section.

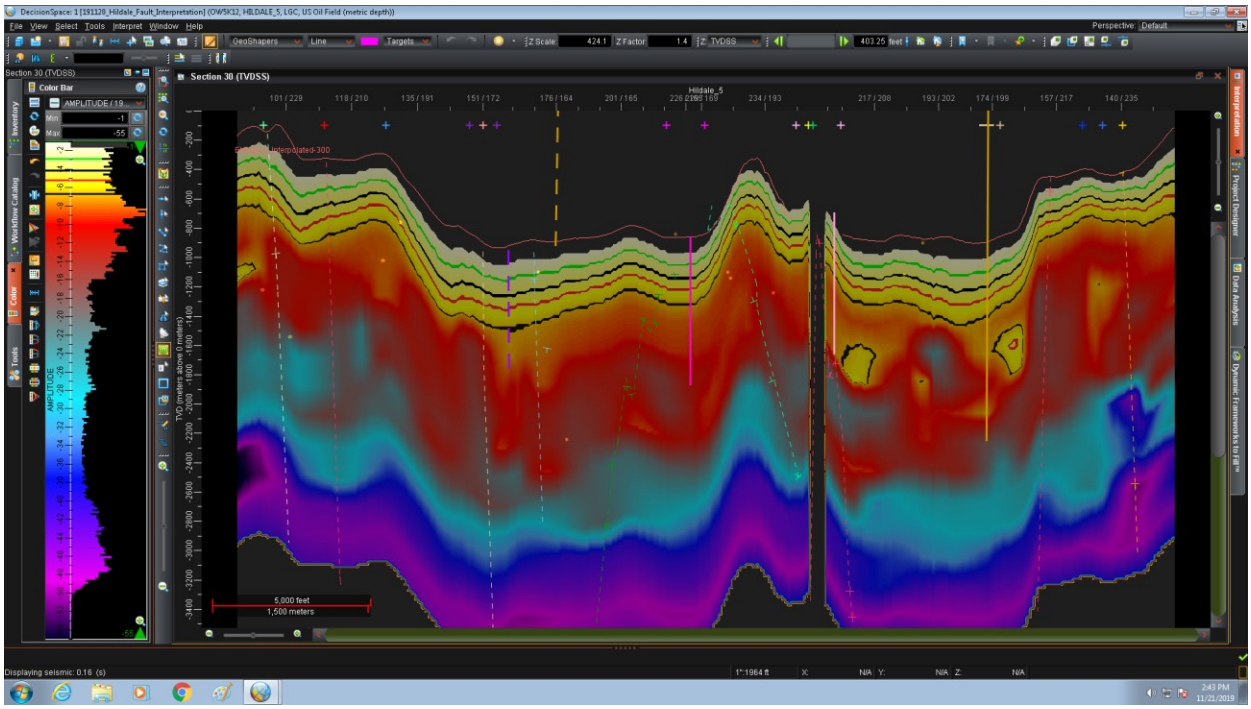


Figure 25N. Peak Current Negative Opportunity Cross-Section.

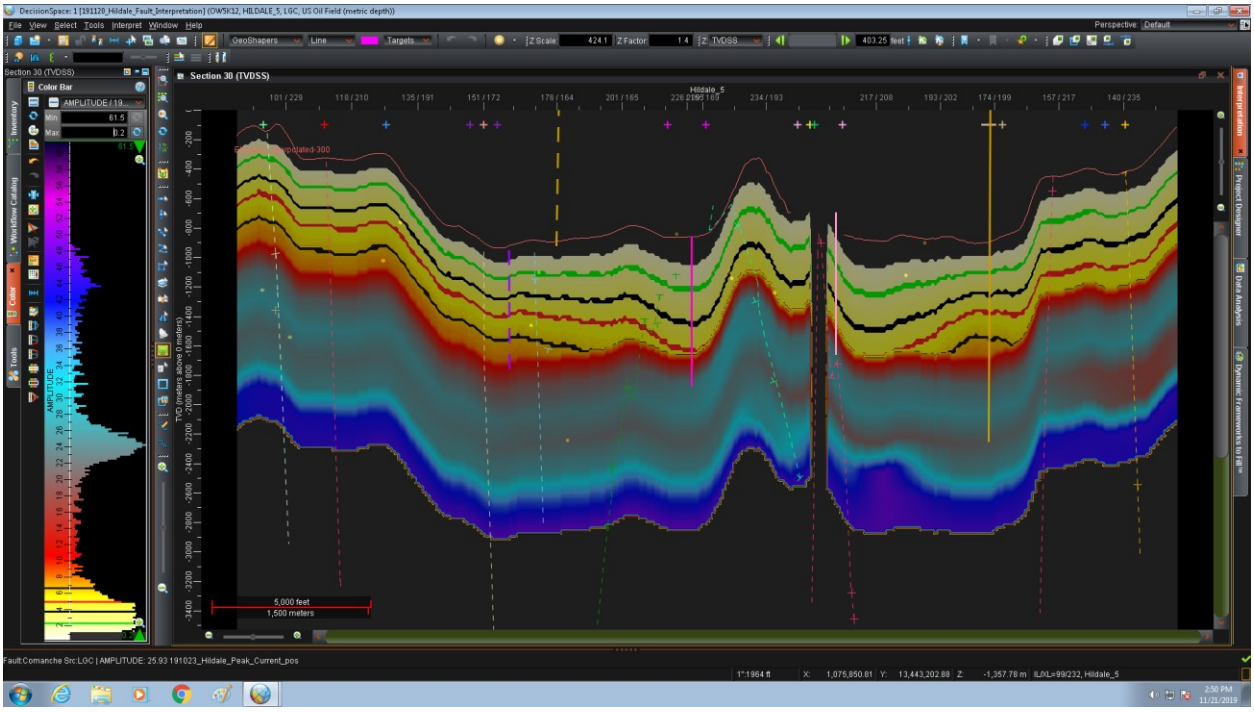


Figure 25O. Peak Current Positive Opportunity Cross-Section.

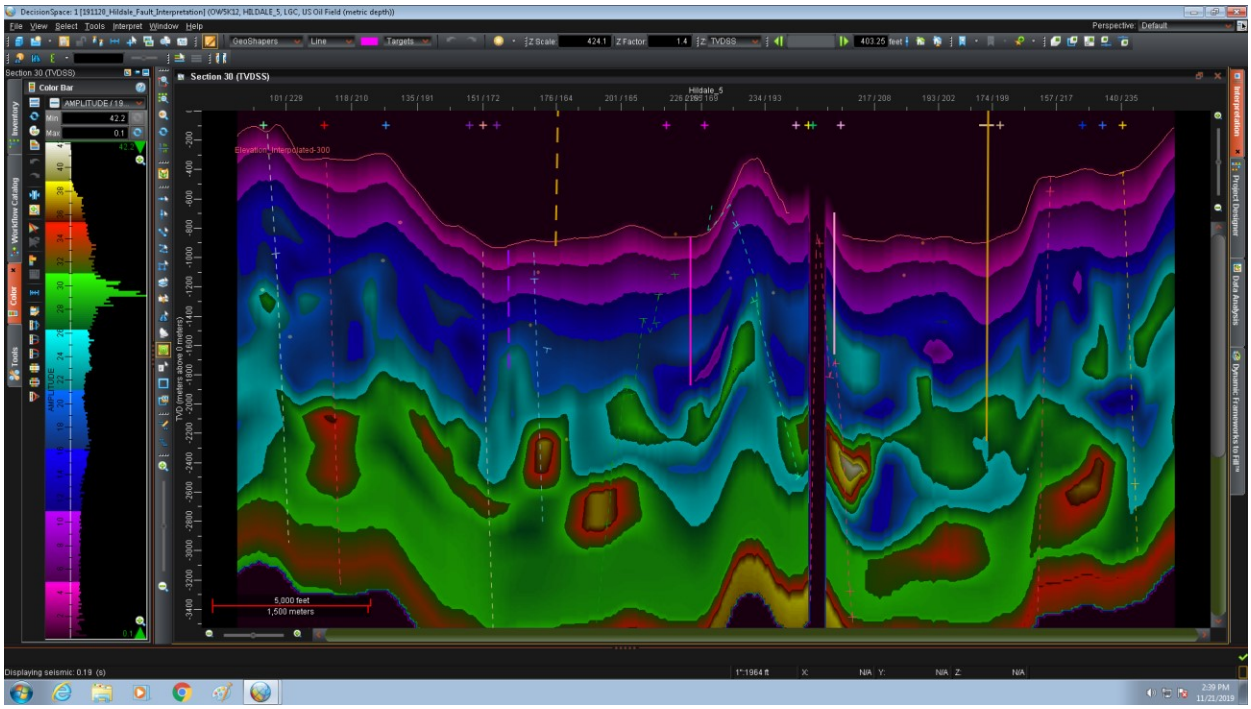


Figure 25P. Peak-to-Zero Opportunity Cross-Section.

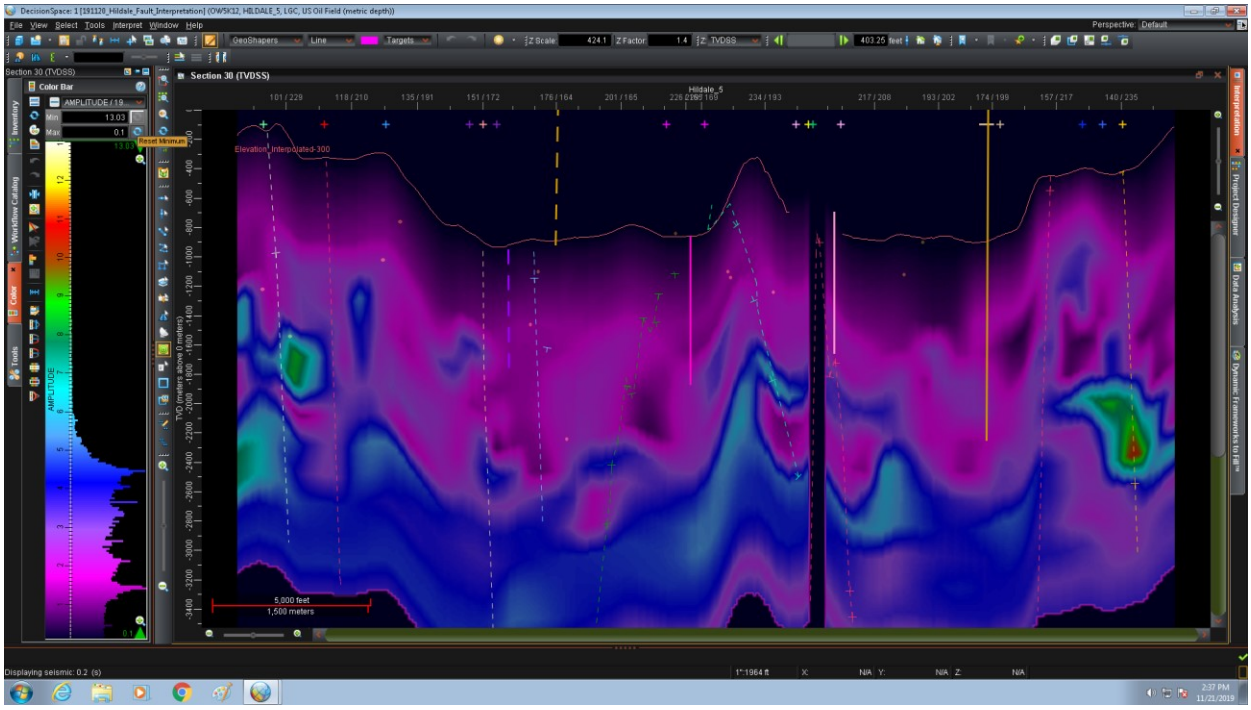


Figure 25Q. Rise-Rate Opportunity Cross-Section.

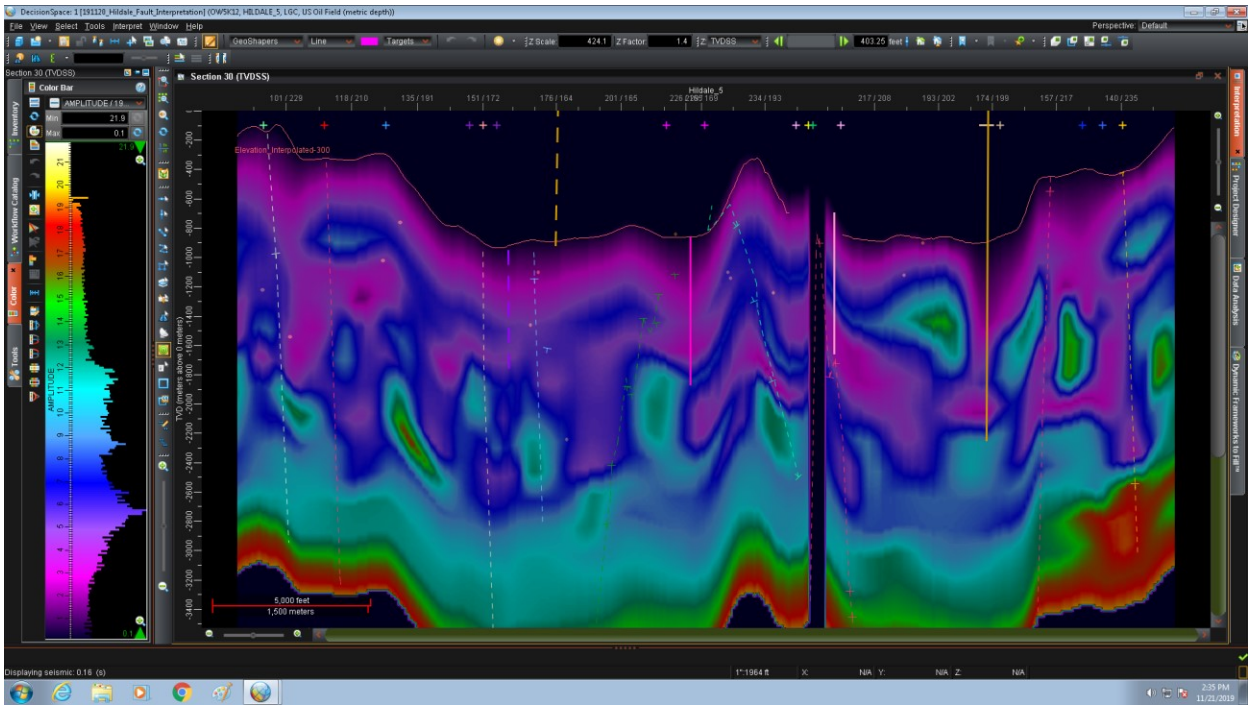


Figure 25R. Rise Time Opportunity Cross-Section.

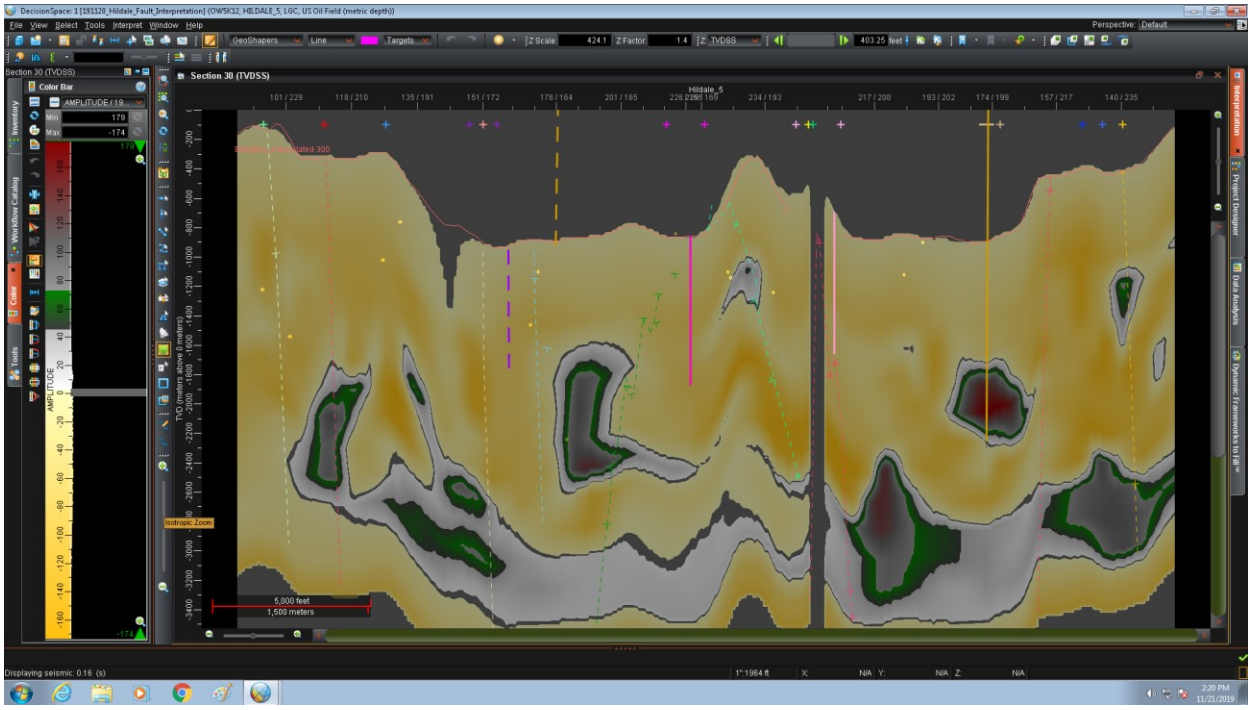


Figure 25S. Sun-Local-Longitude Opportunity Cross-Section.

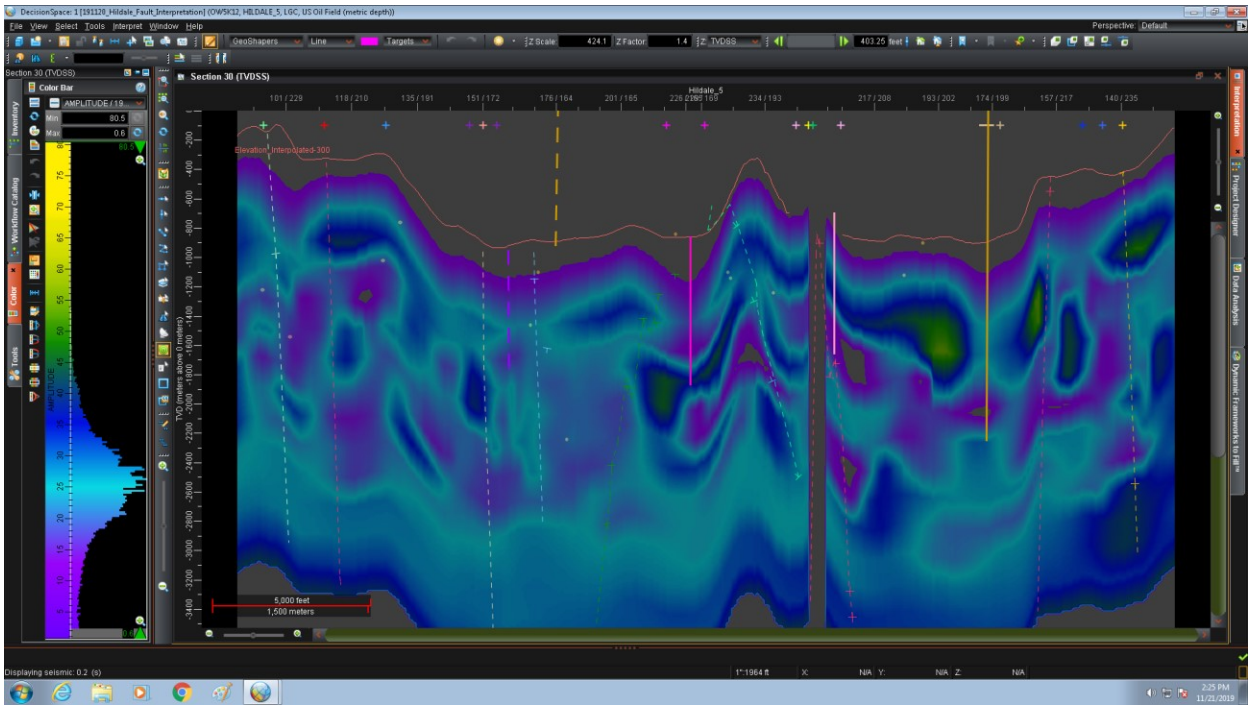


Figure 25T. Symmetry Opportunity Cross-Section.

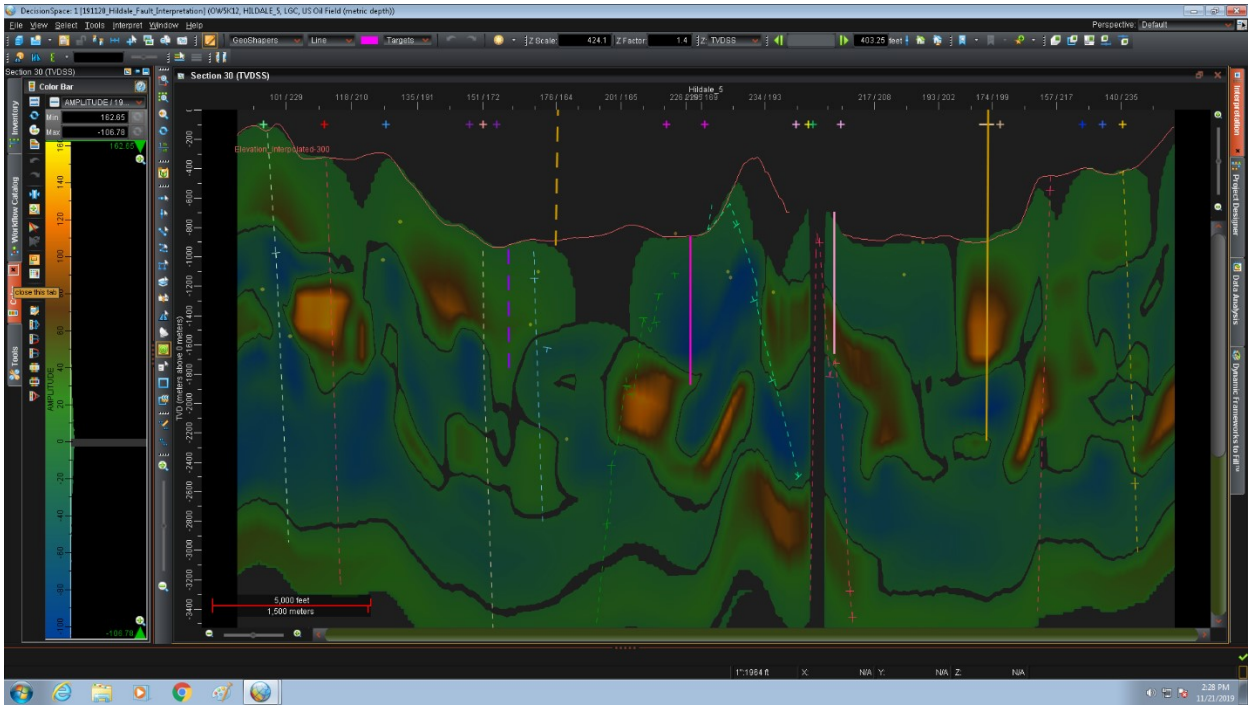


Figure 25U. Tidal Gravity Opportunity Cross-Section.

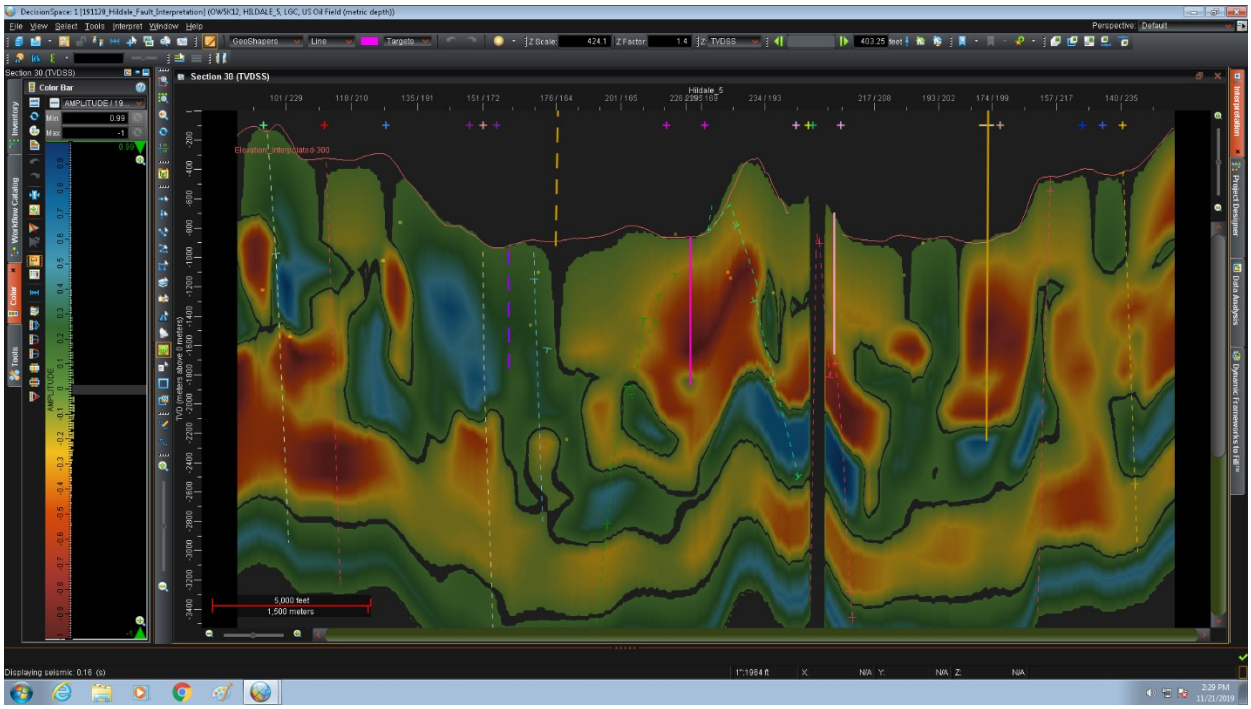


Figure 25V. Tide Opportunity Cross-Section.

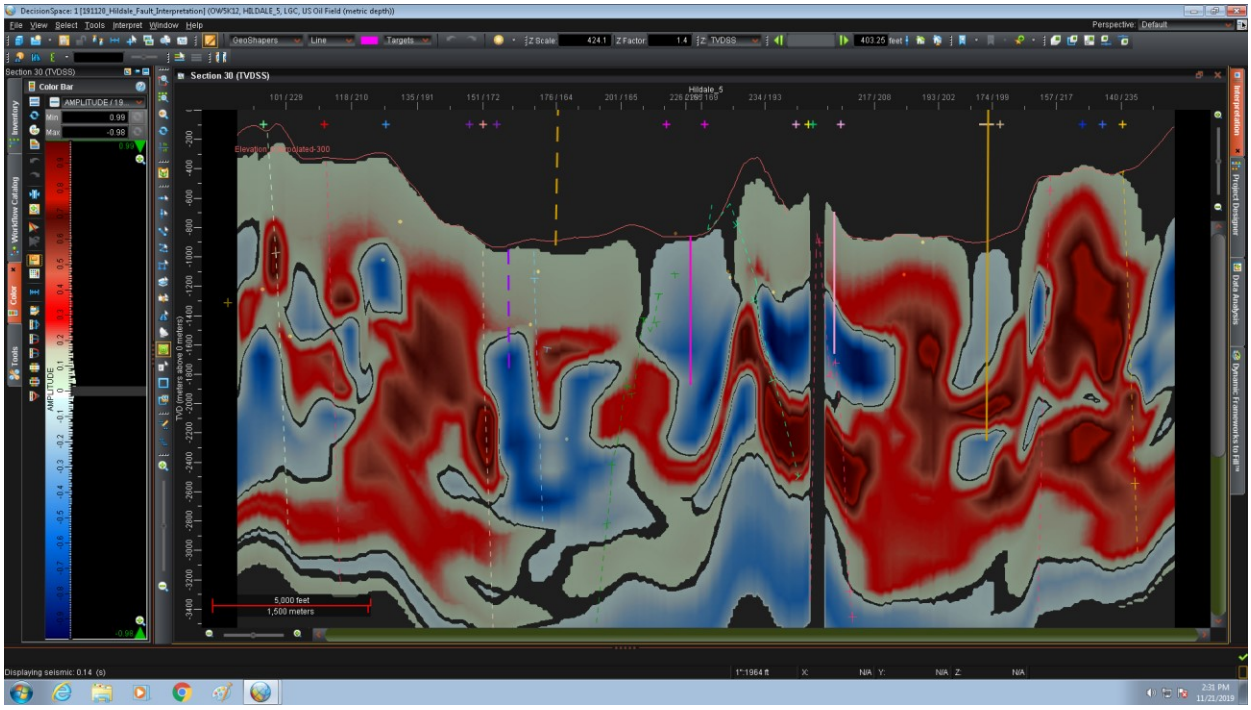


Figure 25W. Tide Gradient Opportunity Cross-Section.

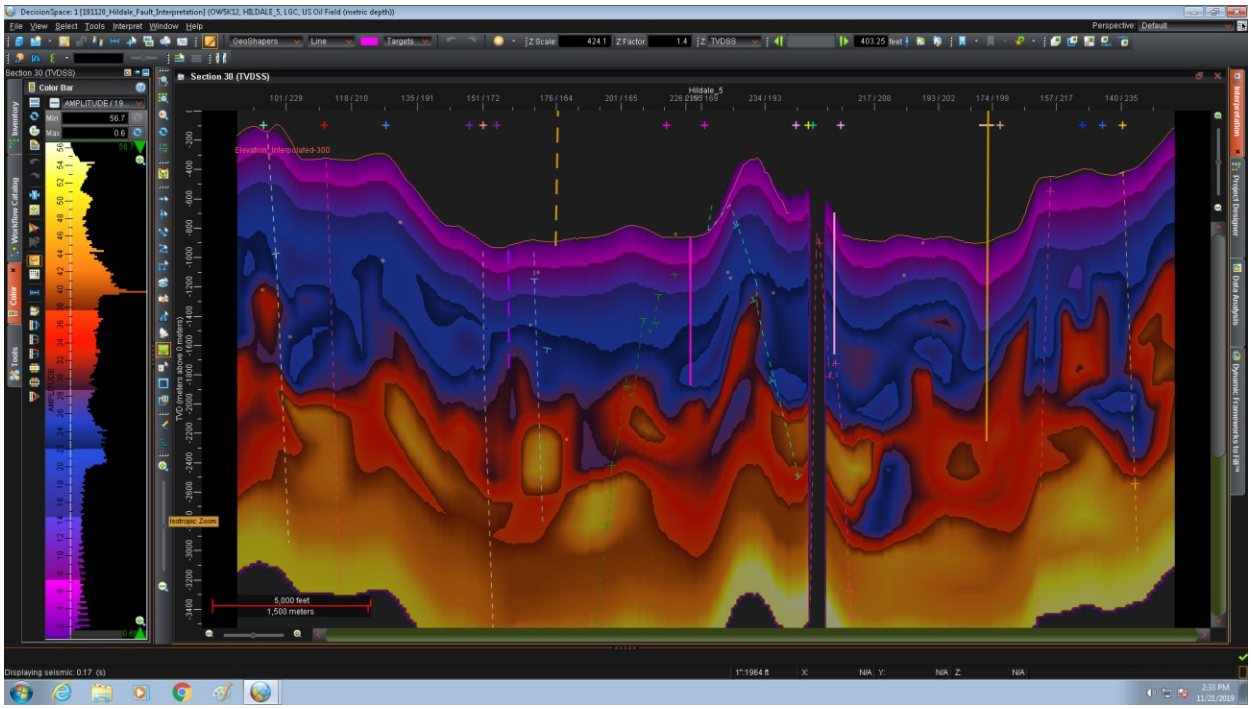


Figure 25X. Total Time Opportunity Cross-Section.

RECOMMENDATIONS

There are extensive additional interpretations, investigations, and analyses which can be performed on the lightning analysis data in the Hildale area. This will especially be appropriate once the first new water wells are drilled and results become available. Even then, the primary objective to be pursued is any analysis which will help specify the location for additional wells. This further analysis will be a function of funding to drill water well tests.

In the meantime, this report provides a number of examples of the types of displays and types of analysis Dynamic can perform. Because the Hildale project is being treated as a proof-of-concept project, Dynamic will create additional displays and do additional integration of data at no charge for this project. However, on future projects there will be a time and materials charge for this type of additional follow-up work.

We specifically recommend Willowstick establish a process, and specific subsets of the results presented which are of most use for Willowstick's internal data integration and interpretation, so future projects can be done quickly, inexpensively, providing the best results for the client, and maximizing profits for Willowstick and Dynamic.

CONCLUSIONS

Integration of available historical geological, geophysical, and other data with lightning analysis results and interpretations demonstrates the value of lightning analysis, even in the deserts of South Utah, where there are limited numbers of lighting strikes in the lightning strike database. HydroSource lineaments show good correlation with the related lightning derived apparent resistivity cross-sections. It is much easier to interpret faulting on the apparent resistivity volumes than to project faulting down from lineament analysis. The municipality of Hildale needs to collect all available relevant data and integrate within the framework provided by this lightning analysis. Lightning analysis is an efficient, quick, and economic way to build this type of regional geological framework.

ACKNOWLEDGEMENT

Mark Burr of Primary Water, who appears to have been the driving force behind this lightning analysis project.

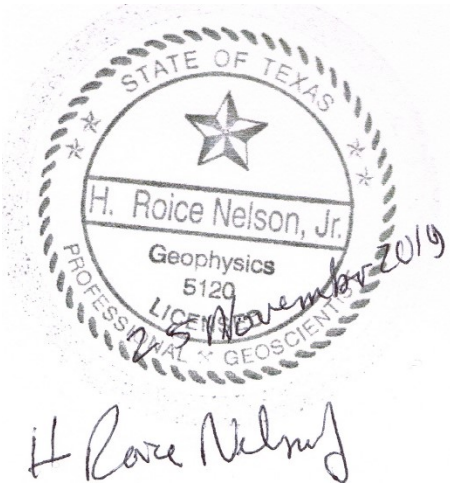
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25 November 2019

APPENDIX D

CONCEPTUAL COST ESTIMATES

Engineers Opinion of Probable Cost

BOWEN COLLINS & ASSOCIATES

Zone 1 - 12-inch Wells 250 gpm 700 ft *Date: 4/29/20*

Project: Alternative 1 Vertical Wellfield Zone 1 - 2 Vertical Production Wells

Prepared by: CM

Owner: Hildale City

No.	Item	Quantity	Units	Unit Cost	Cost
1	Geophysical Survey	1	lump	$ 15,000.00	$ 15,000.00
2	Access and Drill Pad Construction	1	lump	$ 119,000.00	$ 119,000.00
2	Mobilization/Demobilization/Cleanup	1	lump	$ 65,000.00	$ 65,000.00
3	Conductor Casing and Seal (32" hole/24" casing)	100	ft	$ 500.00	$ 50,000.00
4	Drill 12" Pilot Borehole	600	ft	$ 130.00	$ 78,000.00
5	Drill 20" Reamed Borehole	600	ft	$ 100.00	$ 60,000.00
6	Geophysical Logging	1	lump	$ 7,500.00	$ 7,500.00
7	Caliper	1	lump	$ 5,000.00	$ 5,000.00
8	Well Installation - 12" Steel Casing	500	ft	$ 80.00	$ 40,000.00
9	Well Installation - 12" SS Screen 70 slot	200	ft	$ 300.00	$ 60,000.00
10	Installation of Gravel Pack - 8-12	550	ft	$ 90.00	$ 49,500.00
11	Installation of Annular Grout Seal	150	ft	$ 90.00	$ 13,500.00
12	Initial Well Development	40	hr	$ 650.00	$ 26,000.00
13	Install Pump for Development and Testing	1	lump	$ 30,000.00	$ 30,000.00
14	Well Development by Pumping	80	hr	$ 350.00	$ 28,000.00
15	Step-Rate Drawdown Test	10	hr	$ 350.00	$ 3,500.00
16	Constant-Rate Discharge Test	24	hr	$ 350.00	$ 8,400.00
17	Video Camera Survey	1	lump	$ 2,500.00	$ 2,500.00
18	Plumbness and Alignment Testing	1	lump	$ 5,000.00	$ 5,000.00
19	Well Disinfecting	1	lump	$ 4,000.00	$ 4,000.00
20	Well Head	1	lump	$ 2,000.00	$ 2,000.00
21	Well Capping	1	lump	$ 500.00	$ 500.00
	Subtotal for Zone 3 Geophysical Survey/Drill Pad				***$ 134,000.00***
	Subtotal for 1st Well				***$ 538,400.00***
	Subtotal for 2nd Well				***$ 538,400.00***
	Contingency	***20%***			***$ 242,160.00***
	Total Cost (rounded to the nearest $1,000)				**$ 1,453,000.00**

This opinion of probable construction is based on experience with past projects of similar construction. It is understood that Bowen Collins & Associates has no control over economical factors or unknown conditions that may have a significant impact on actual project costs. Bowen Collins & Associates does not guarantee its cost estimates and accepts no liability for problems created by the difference in actual costs and this opinion of probable construction cost.

Engineers Opinion of Probable Cost

BOWEN COLLINS & ASSOCIATES

Zone 2 - 12-inch Well 250 gpm 1000 ft *Date: 4/29/20*

Project: Alternative 1 Vertical Wellfield Zone 2 - 1 Vertical Production Well

Prepared by: CM

Owner: Hildale City

No.	Item	Quantity	Units	Unit Cost	Cost
1	Geophysical Survey	1	lump	$ 15,000.00	$ 15,000.00
2	Access and Drill Pad Construction	1	lump	$ 194,000.00	$ 194,000.00
2	Mobilization/Demobilization/Cleanup	1	lump	$ 65,000.00	$ 65,000.00
3	Conductor Casing and Seal (32" hole/24" casing)	100	ft	$ 500.00	$ 50,000.00
4	Drill 12" Pilot Borehole	850	ft	$ 130.00	$ 110,500.00
5	Drill 20" Reamed Borehole	850	ft	$ 100.00	$ 85,000.00
6	Geophysical Logging	1	lump	$ 7,500.00	$ 7,500.00
7	Caliper	1	lump	$ 5,000.00	$ 5,000.00
8	Well Installation - 12" Steel Casing	750	ft	$ 80.00	$ 60,000.00
9	Well Installation - 12" SS Screen 70 slot	200	ft	$ 300.00	$ 60,000.00
10	Installation of Gravel Pack - 8-12	800	ft	$ 90.00	$ 72,000.00
11	Installation of Annular Grout Seal	150	ft	$ 90.00	$ 13,500.00
12	Initial Well Development	40	hr	$ 650.00	$ 26,000.00
13	Install Pump for Development and Testing	1	lump	$ 30,000.00	$ 30,000.00
14	Well Development by Pumping	80	hr	$ 350.00	$ 28,000.00
15	Step-Rate Drawdown Test	10	hr	$ 350.00	$ 3,500.00
16	Constant-Rate Discharge Test	24	hr	$ 350.00	$ 8,400.00
17	Video Camera Survey	1	lump	$ 2,500.00	$ 2,500.00
18	Plumbness and Alignment Testing	1	lump	$ 5,000.00	$ 5,000.00
19	Well Disinfecting	1	lump	$ 4,000.00	$ 4,000.00
20	Well Head	1	lump	$ 2,000.00	$ 2,000.00
21	Well Capping	1	lump	$ 500.00	$ 500.00
	Subtotal for Zone 2 Geophysical Survey/Drill Pad				***$ 209,000.00***
	Subtotal for 1st Well				***$ 638,400.00***
	Contingency	***20%***			***$ 169,480.00***
	Total Cost (rounded to the nearest $1,000)				**$ 1,017,000.00**

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Engineers Opinion of Probable Cost

BOWEN COLLINS & ASSOCIATES

Zone 3 - 12-inch Wells 250 gpm 750 ft *Date: 4/29/20*

Project: Alternative 1 Vertical Wellfield Zone 3 - 2 Vertical Production Wells

Prepared by: CM

Owner: Hildale City

No.	Item	Quantity	Units	Unit Cost	Cost
1	Geophysical Survey	1	lump	$ 15,000.00	$ 15,000.00
2	Access and Drill Pad Construction	1	lump	$ 102,000.00	$ 102,000.00
3	Mobilization/Demobilization/Cleanup	1	lump	$ 65,000.00	$ 65,000.00
4	Conductor Casing and Seal (32" hole/24" casing)	100	ft	$ 500.00	$ 50,000.00
5	Drill 12" Pilot Borehole	650	ft	$ 130.00	$ 84,500.00
6	Drill 20" Reamed Borehole	650	ft	$ 100.00	$ 65,000.00
7	Geophysical Logging	1	lump	$ 7,500.00	$ 7,500.00
8	Caliper	1	lump	$ 5,000.00	$ 5,000.00
9	Well Installation - 12" Steel Casing	550	ft	$ 80.00	$ 44,000.00
10	Well Installation - 12" SS Screen 70 slot	200	ft	$ 300.00	$ 60,000.00
11	Installation of Gravel Pack - 8-12	600	ft	$ 90.00	$ 54,000.00
12	Installation of Annular Grout Seal	150	ft	$ 90.00	$ 13,500.00
13	Initial Well Development	40	hr	$ 650.00	$ 26,000.00
14	Install Pump for Development and Testing	1	lump	$ 30,000.00	$ 30,000.00
15	Well Development by Pumping	80	hr	$ 350.00	$ 28,000.00
16	Step-Rate Drawdown Test	10	hr	$ 350.00	$ 3,500.00
17	Constant-Rate Discharge Test	24	hr	$ 350.00	$ 8,400.00
18	Video Camera Survey	1	lump	$ 2,500.00	$ 2,500.00
19	Plumbness and Alignment Testing	1	lump	$ 5,000.00	$ 5,000.00
20	Well Disinfecting	1	lump	$ 4,000.00	$ 4,000.00
21	Well Head	1	lump	$ 2,000.00	$ 2,000.00
22	Well Capping	1	lump	$ 500.00	$ 500.00
	Subtotal for Zone 3 Geophysical Survey/Drill Pad				***$ 117,000.00***
	Subtotal for 1st Well				***$ 558,400.00***
	Subtotal for 2nd Well				***$ 558,400.00***
	Contingency	***20%***			***$ 246,760.00***
	Total Cost (rounded to the nearest $1,000)				**$ 1,481,000.00**

This opinion of probable construction is based on experience with past projects of similar construction. It is understood that Bowen Collins & Associates has no control over economical factors or unknown conditions that may have a significant impact on actual project costs. Bowen Collins & Associates does not guarantee its cost estimates and accepts no liability for problems created by the difference in actual costs and this opinion of probable construction cost.

Engineers Opinion of Probable Cost

BOWEN COLLINS & ASSOCIATES

Alternative 2 - Horizontal Wells 3000 ft 600 gpm *Date: 4/29/20*

Project: Alternative 2 Horizontal Wells 2 Horizontal Production Wells

Prepared by: CM

Owner: Hildale City

No.	Item	Quantity	Units	Unit Cost	Cost
1	Mobilization/Demobilization/Cleanup	1	lump	$ 140,000.00	$ 140,000.00
2	Conductor Casing and Seal (16" hole/12" casing)	100	ft	$ 500.00	$ 50,000.00
3	Drill 10" Borehole	2900	ft	$ 200.00	$ 580,000.00
4	Well Installation - 6" Perforated Steel Casing	3000	ft	$ 80.00	$ 240,000.00
5	Initial Well Development	40	hr	$ 650.00	$ 26,000.00
6	Video Camera Survey	1	lump	$ 5,000.00	$ 5,000.00
7	Well Disinfecting	1	lump	$ 4,000.00	$ 4,000.00
8	Well Head	1	lump	$ 5,000.00	$ 5,000.00
9	Well Capping	1	lump	$ 500.00	$ 500.00
	Subtotal for Mobilization Fee				***$ 140,000.00***
	Subtotal for 1st Horizontal Well				***$ 910,500.00***
	Subtotal for 2nd Horizontal Well				***$ 910,500.00***
	Contingency	***20%***			***$ 392,200.00***
	Total Cost				**$ 2,354,000.00**

This opinion of probable construction is based on experience with past projects of similar construction. It is understood that Bowen Collins & Associates has no control over economical factors or unknown conditions that may have a significant impact on actual project costs. Bowen Collins & Associates does not guarantee its cost estimates and accepts no liability for problems created by the difference in actual costs and this opinion of probable construction cost.

Preliminary Opinion of Probable Construction Cost

BOWEN COLLINS & ASSOCIATES

Project: Civil Improvements to Maxwell Canyon Well *Date: 2/7/2020*

Owner: Hildale City *Prepared by: TO*

No.	Item	Quantity	Units	Unit Cost	Cost
	Reservoir and Site Work				
1	Mobilization and Demobilization	1	LS	$123,300	$123,300
2	Construction Surveying	1	LS	$20,000	$20,000
3	Clear and Grub	1	LS	$8,000	$8,000
4	Road Construction (assumed 22' x 4230')	10,360	SY	$27	$279,720
5	Drill Pad (assumed 100' x 150')	1,670	SY	$9.00	$15,030
6	Drill Pad Embankment	26,000	CY	$35	$910,000
	Subtotal:				**$1,356,050**
	Contingency:	*30%*			***$406,815***
	Total Cost (rounded to the nearest $1,000):				**$1,763,000**

This opinion of probable construction is based on experience with past projects of similar construction. It is understood that Bowen Collins & Associates has no control over economical factors or unknown conditions that may have a significant impact on actual project costs. Bowen Collins & Associates does not guarantee its cost estimates and accepts no liability for problems created by the difference in actual costs and this opinion of probable construction cost.