Groundwater Well Siting Study

for

Canyon and Arena Study Areas
Kanosh, UT

Prepared For:

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1.0 INTRODUCTION AND BACKGROUND

1.1 Introduction

This report presents the results of a geophysical investigation to locate the best possible target(s) for water well drilling within two study areas in Kanosh, Utah (see Figure 1). The two areas, about 10 acres each, are referred to as Site 1 or the "Canyon Area", and Site 2 or the "Arena Area". Also explained in this report are the geophysical methods used to identify the drill targets within highly permeable fracture zones.

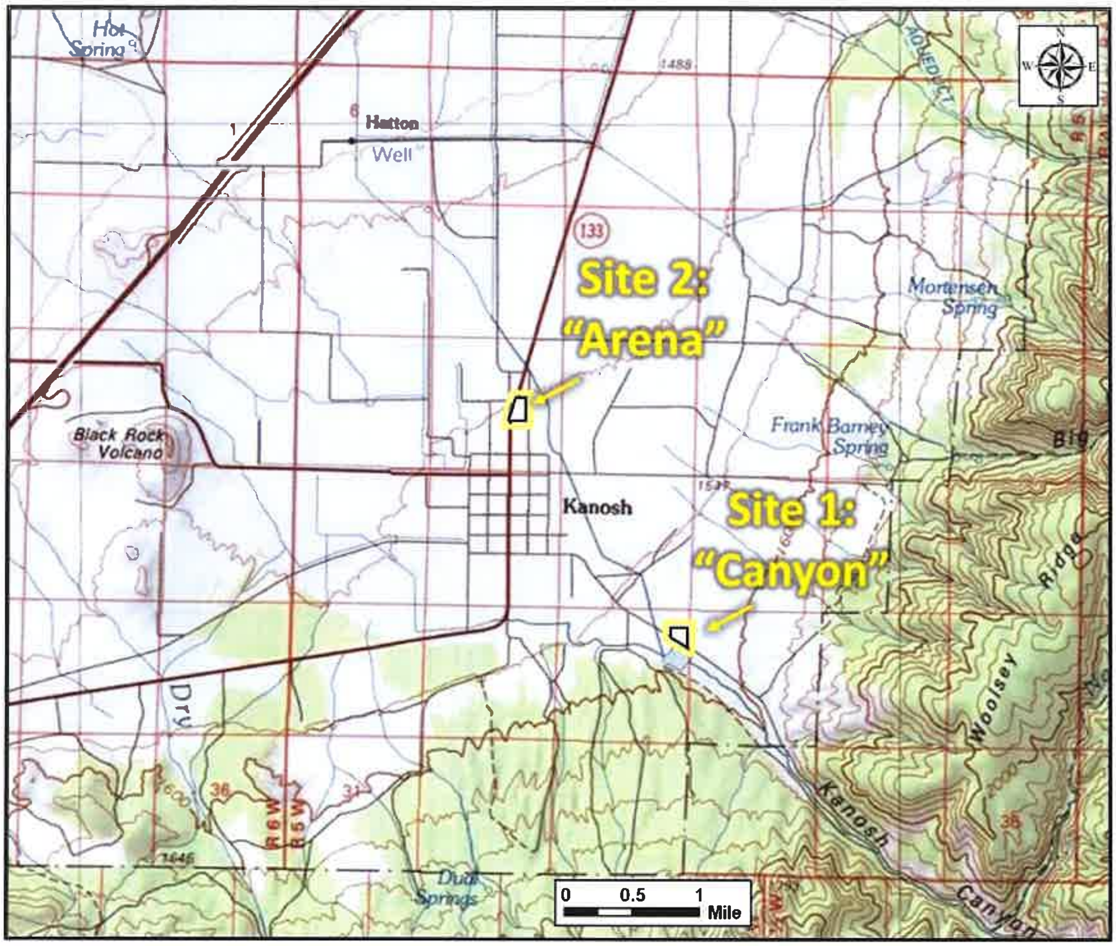
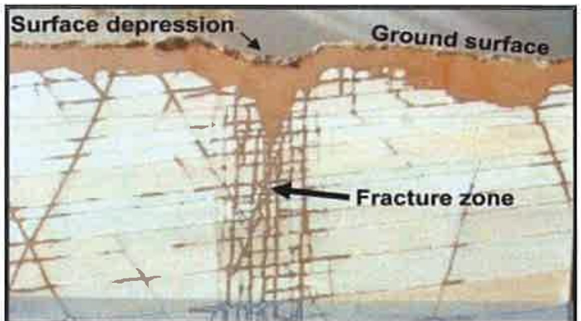


Figure 1 – Project Location

1.2 Background

Many large-scale hydrogeologic studies have concluding statements that indicate wells drilled into fractured rock zones tend to have far greater yield than the average wells. For example, in a 2013 hydrogeologic study which compared over 90 well logs in an area in Utah, the conclusions point out the highest yield wells were drilled into *"highly fractured"* volcanic rocks, and *"the greatest potential for water movement is where faulting has bisected the rocks at depth"* (Iron Springs Corporation, 2013). The key is to target the highly fractured or faulted zones—no matter what the rock type. The advantage of doing so is emphasized in an article published on the PennState Extension web site titled "Water Well Location by Fracture Trace Mapping" (Swistock and Sharpe, 2015). The following table from the article shows the significant increase in yields recorded in wells across Pennsylvania when fracture zones are specifically targeted by fracture detection methods (see Table A).



Rock Type	Avg. Yield (gpm)	Yield from Fractures (gpm)
Crystalline (marble, etc)	1-20	200-500
Sandstone, shale	5-60	100-500
Carbonate (limestone, etc)	5-500	500-3,000
Unconsolidated (gravel, sand)	100-1,000	Not applicable

Table A. Comparison of water yield from typical wells versus fracture-trace wells in various rock types (from Swistock & Sharpe, 2015)

Indeed, a significant body of evidence—beyond the scope of this report—exists that strongly supports the reasoning for seeking highly fractured and deeply connected fracture zones for prospective well targets. It has been observed, especially in mountainous regions, that aquifers can be very "hit and miss"—more like a "plumbing system" with deeply-rooted sources in somewhat vertically-oriented fracture zones rather than a simple holding basin. Precision drilling in such conditions is a must. This investigation uses a patented passive seismic technique to specifically target fractured rock zones, and it is used in conjunction with a radiometric gamma system that is tuned specifically for discriminating water-filled fracture zones versus dry fracture zones. The combination is key for optimal target selection. More about these techniques is explained in the next section.

2.0 INVESTIGATIVE APPROACH

2.1 Geophysical Survey Tools for Pinpoint Targeting

Since 2004, Willowstick has specialized in groundwater mapping and leakage flowpath detection and has completed over 400 groundwater leakage mapping projects worldwide. One of its primary tools, also called the "Willowstick" method or "AquaTrack", is explained in a peer-reviewed article in Geophysical Journal International (see Jessop et al., 2018), also in patents (Kofoed et al., 2017 and Jessop et al., 2014), as well as in many other publications with case studies exhibiting its successful application in mining, dams, environmental applications and more. The method was also used in a number of successful well-siting studies including a 2,500-gpm producing well for a municipality in Idaho—made possible by having an accessible energizing point from a large spring nearby. Although this method is highly useful for tracking seepage flow paths between two accessible points of contact, it has only limited use in most cases of groundwater well siting, when searching for highest yield potential within a given area. For the specific objectives of this investigation, we utilize geophysical methods in our toolkit that are better suited for the specific task—namely, Rapid Acoustic Profiling or RAP, a passive seismic method, and Radiometric Gamma.

Resonance Acoustic Profiling (RAP), a passive seismic method:
The RAP system detects geomechanical weakness in rocks with "laser-like" measurements called "shots". It is apt for locating fracture zones for high accuracy drilling. Depending on settings, the system can bring out the detail in shallow or deep zones and detect up to depths of 3000 ft (1000 m) or in some cases up to 6000 ft (2000 m) in ideal conditions. Natural movement of the earth (earth tides) creates continuous microseismic energy for this method—energy which undergoes particular transitions in the faults and fractures of earth's crust, or the zones of stress release for the earth-tide motion. The results are analyzed in conjunction with Radiometric Gamma data to identify highly permeable zones *with* a water-presence indicator for prospective drill targets.

Radiometric Gamma Scintillation Counter:
The Gamma system measures the aggregate gamma emissions from subsurface rocks and soil. Most importantly, the signal drops where water occurs in permeable (fracture) zones in earth's crust, making it an excellent tool to use in conjunction with the RAP system to locate highly permeable (fracture) zones *with* high water content. Because this system takes measurements in free space, much larger areas can be covered in shorter time, making it the "scouting" tool to quickly generate prospects that can be further studied, qualified or ruled-out as the case may be, with the RAP system or other follow-up studies.

2.2 Work Schedule and Proceedings

The field work for this investigation was conducted December 15th and 16th, 2021. The first step was to scout out each study area collecting gamma data. Maps were then created and used to better focus the RAP seismic detail work. All gamma data and RAP shots were collected in conjunction with GPS coordinates to locate and correlate the findings.

It is not uncommon in this area, as in many places in the Intermountain West, that the shallow aquifer zone (typically 50-250 ft) yields little or no water, and higher production can often be achieved by carefully tapping the deeper "plumbing system", typically in the range of 300 to 800 feet—but it must be tapped with precision drilling, or the risk of a dry hole may be high. This study aims to identify specific targets that will maximize water yield. In hard rock/fractured rock drilling, we recommend using a method that allows water yield to be observed while drilling. It is also best to keep the borehole straight as possible. We generally recommend the air rotary drilling method, which tends to leave a cleaner bore with less blockage of aquifer pores. The mud rotary drilling method blocks pores (until fully developed) and prohibits observation of water yield while in process; therefore, it is not recommended unless there are other reasons—such as to prevent a high concentration of unconsolidated soil layers from collapsing while drilling if such a case presents itself. An experienced driller could give recommendations for each particular case.

3.0 SURVEY RESULTS

3.1 Results of Radiometric Gamma Survey

After data acquisition and initial processing and filtering, the results were collected into a GIS file set for analysis, comparison, and interpretation along with generation of maps, figures, and depth profiles. The radiometric gamma data was collected, processed and filtered to produce a gamma map covering each study area, which is shown in Figure 2.

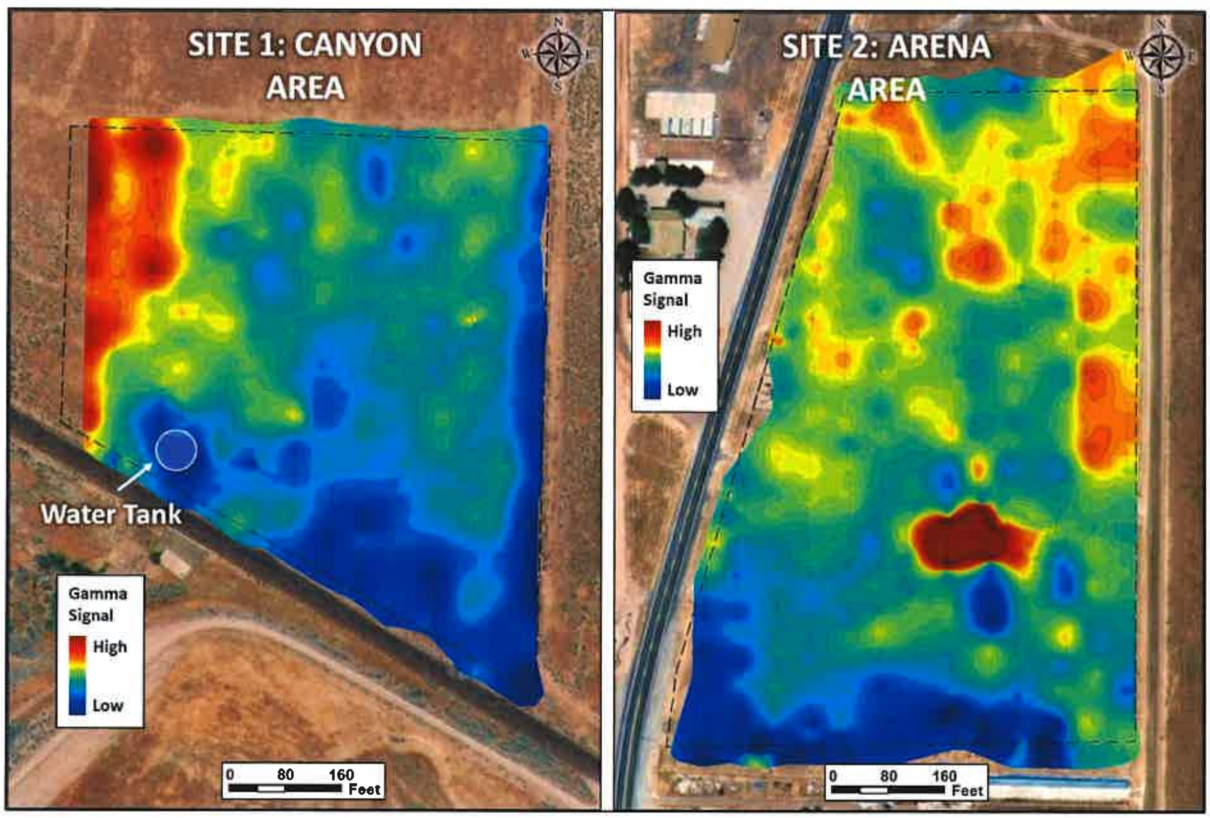


Figure 2 – Gamma Maps at Sites 1 and 2

The gamma intensity is indicated by contours and a color-scale ranging from blues to yellow to orange to red. The readings are relative for each area and are interpreted by relative comparison, so absolute numbers are not shown; nevertheless, the range from Low to High in these maps represents about a 60% change in gamma intensity as measured by the scintillation counter.

It is a fact that groundwater absorbs and weakens the gamma radiation emitting from earth's crust, especially in "pockets" or along lineaments where deep fissures and/or water-filled fracture zones exist. Therefore patterns in the gamma signal provide an indicator of groundwater extraction potential. The gamma trends and patterns are also sensitive to different geologic rock types, dikes and fault structures; therefore, it should be understood that the color of the map (such as the blue) by itself does not automatically indicate the most water. Patterns suggesting higher volumes of groundwater in a given area may occur at various color levels, although the low blues do tend to be more attractive. The gamma results serve as a scouting tool to help focus the detailed RAP measurements which will identify targets in highly permeable fracture systems where groundwater can more likely be pumped at higher flow rates.

At both sites, the lowest gamma signals tend to occur in the southern parts of the study areas. At Site 1, the gamma signal dropped very low over the water tank, as expected. We also noted the low-gamma trend occurring along the property's eastern edge, and it was later recognized that a berm exists there—likely of wet clay or some material that tends to cut down on the gamma signal. This trend was therefore disregarded, but not until RAP measurements had already been collected there. The soil or material brought in for the arena in Site 2 tends to cause slightly lower gamma signals as well; accordingly, the arena itself was not a focus area for the RAP measurements, but many places around it and especially south of it. Variations in all other parts of the maps are believed to be caused by predominantly natural sources, and are taken as indicators of groundwater yield potential, in general terms, but keep in mind the ultimate selection of drill target(s) must be made by choosing fracture systems with high permeability in conjunction with generally low gamma trends occurring in the vicinity—or particularly within several hundred feet, where it is likely to have the greatest drawdown from pumping.

3.2 RAP Seismic Results

The RAP data was focused along specific lines to search for fracture systems at depth that correspond with ideal gamma patterns to find prospective targets and narrow them down. A total of 12 RAP lines were collected, 6 at each site. Figure 3 shows the location of RAP lines 101 to 106 at Site 1 and lines 201 to 206 at Site 2.

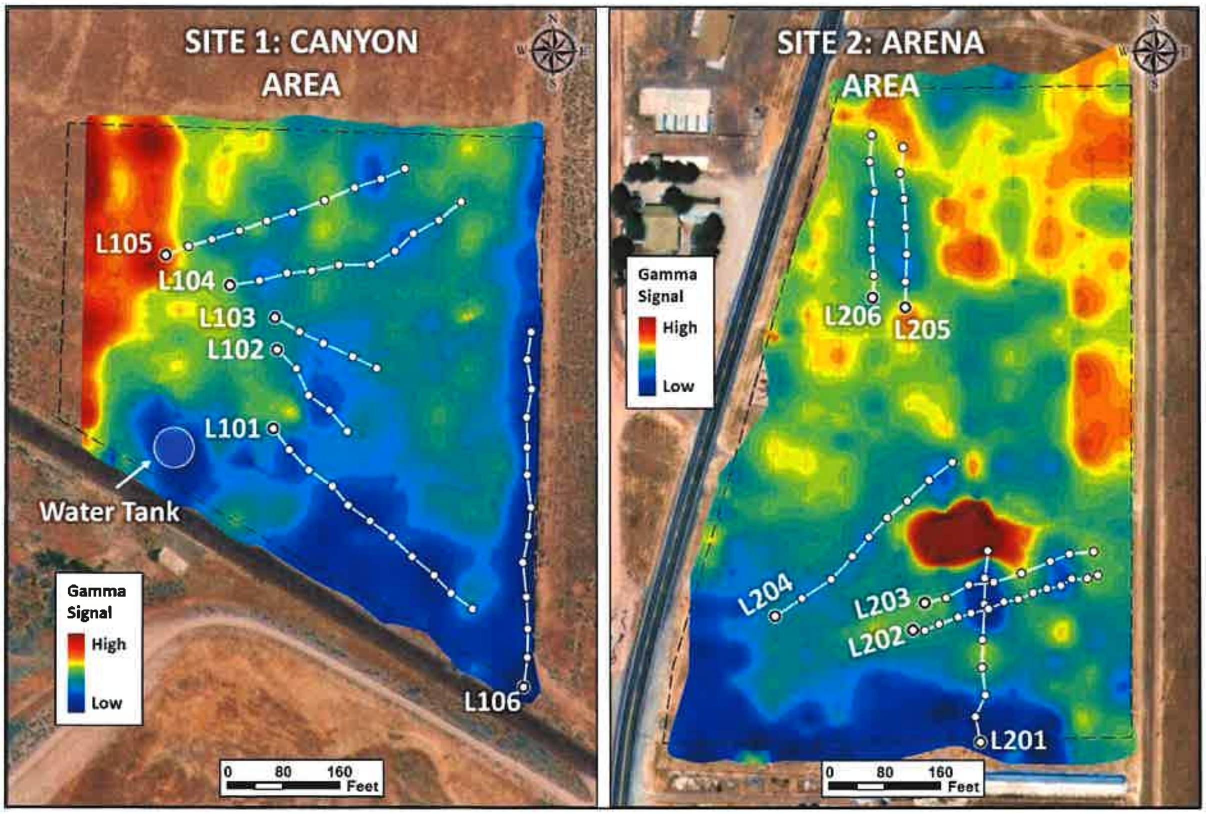


Figure 3 – Location of RAP Lines 101-106 at Site 1, and Lines 201-206 at Site 2

Shots are spaced at 40-foot intervals except for Line 202 which is at 20-foot intervals. Lines are labeled at the starting point (0 station) or first shot of each line, with a slightly larger white circle denoting the first shot, so that line directions are known and kept in mind when viewing each RAP profile.

For each RAP shot, the aggregate RAP signal or resonance intensity beneath the weathered zone provides a relative indicator of the expected porosity/permeability to be encountered, which helps to see the best locations on the map and also to quantitatively rank the shots. Before showing the details of the RAP profiles themselves, the map in Figure 4 shows the aggregate RAP intensity for all RAP shots using graduated symbols (red circles). RAP intensity labels are placed on some of the most prospective shots for quantitative comparison.

At Site 1, the top recommended drill target (T1) is the third shot (Station 80) on Line 101, with a RAP "score" of 206. This was chosen after analyzing all the RAP and Gamma data. If this spot were pumped, visualizing a "drawdown zone" or cone of depression around this spot at 200-ft radius (to be conservative) would encompass most of the southern half of the property and most of the "blue gamma" area. It is also recognized that the ideal well target be at least 100 feet away from the property boundary. In this regard, T1 is ideally located—it is 114 feet from the edge of property and 165 feet east of the water tank.

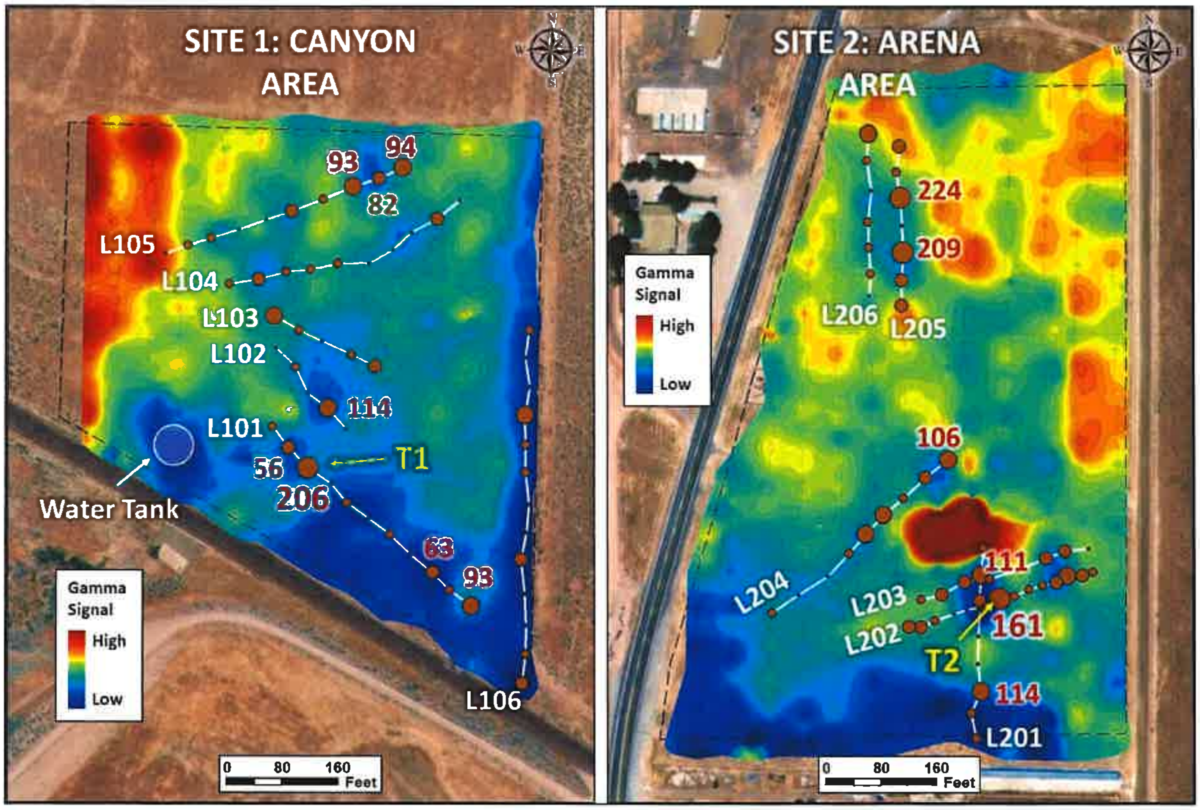


Figure 4 – RAP Intensity Aggregate per shot, 200-900 ft depth

The top recommended target at Site 2 is designated T2. All things considered, T2 is secondary to T1 and therefore ranks second overall as a target. More will be discussed about Site 2 and Target T2 after finishing the discussion on Site 1 and showing RAP profiles from Site 1.

Figure 5 shows RAP Profile Line 101 processed to a depth of 1000 feet, where details of the fracture system detected at T1 can be seen. The distance across the top is also given, in feet. In the RAP color-scale, the white color indicates high geomechanical strength or competent rock, while the yellow to orange to pink—going up the scale in RAP intensity—represent higher and higher degrees of geomechanical weakness or rock fracturing, or degree of permeability which facilitates high flow rates of water.

At T1, the strongest RAP intensity (fracture zone) occurs from about 700 to 800 ft below ground surface (bgs), and a fair degree of porosity/permeability is also expected across much of the profile, especially beyond the 500 ft bgs level.

At Site 1, a possible second choice for a drill target would be the fourth shot (Station 120) on Line 102, which has an overall RAP "score" of 114. This would still potentially capture a lot of water, and still have a strong degree of permeability immediately around the borehole, which is always important to enable high flow rates. RAP Profile Line 102 is shown in Figure 6. Although only the most prominent ones are shown here, full-sized figures of these and all RAP profiles are given in the slides that accompany this report.

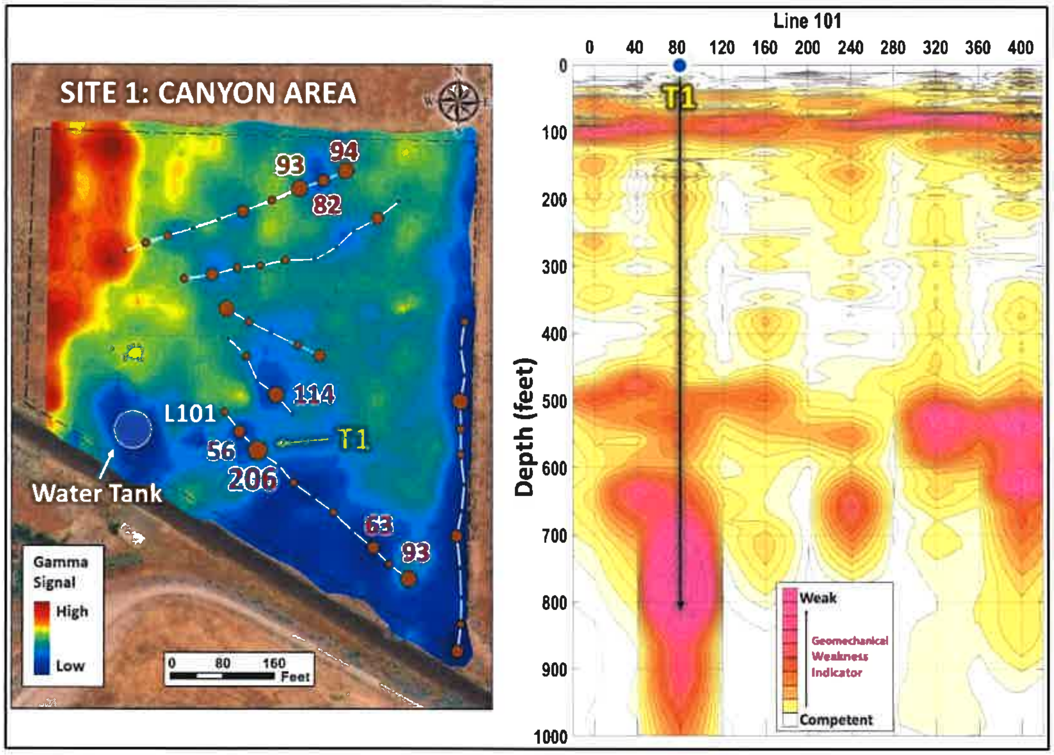


Figure 5 – RAP Profile Line 101

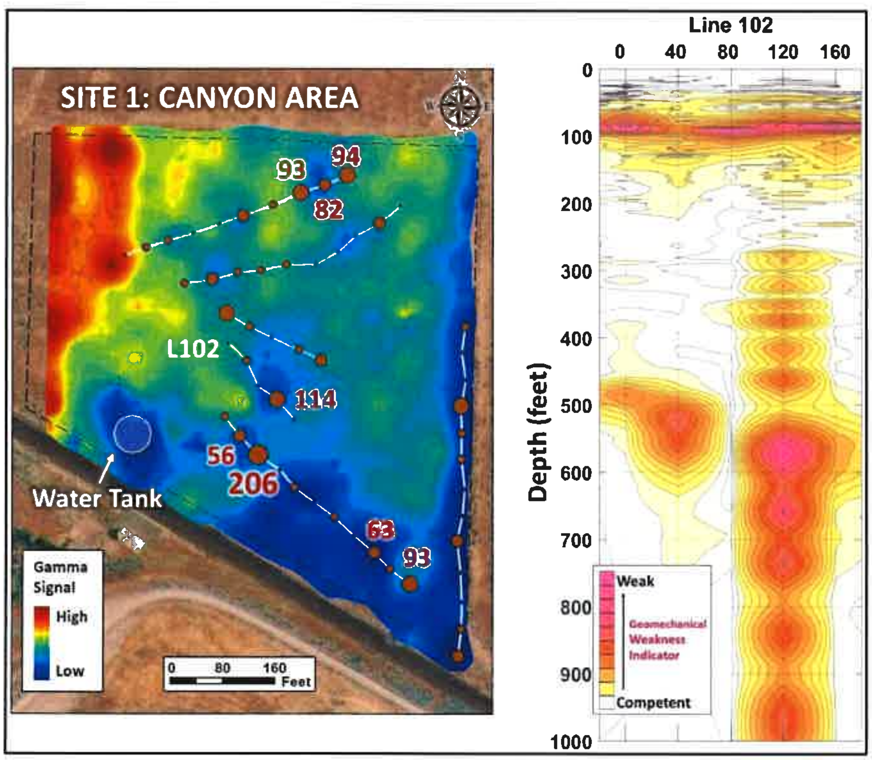


Figure 6 – RAP Profile Line 102

At Site 2, RAP Line 201 shows two strongly fractured locations at Station 80 and 240, with RAP scores of 114 and 111, respectively (see Figure 7). Crossing Line 201 is RAP Line 202, which includes the top recommended drill target for Site 2 (see Figure 8), designated T2.

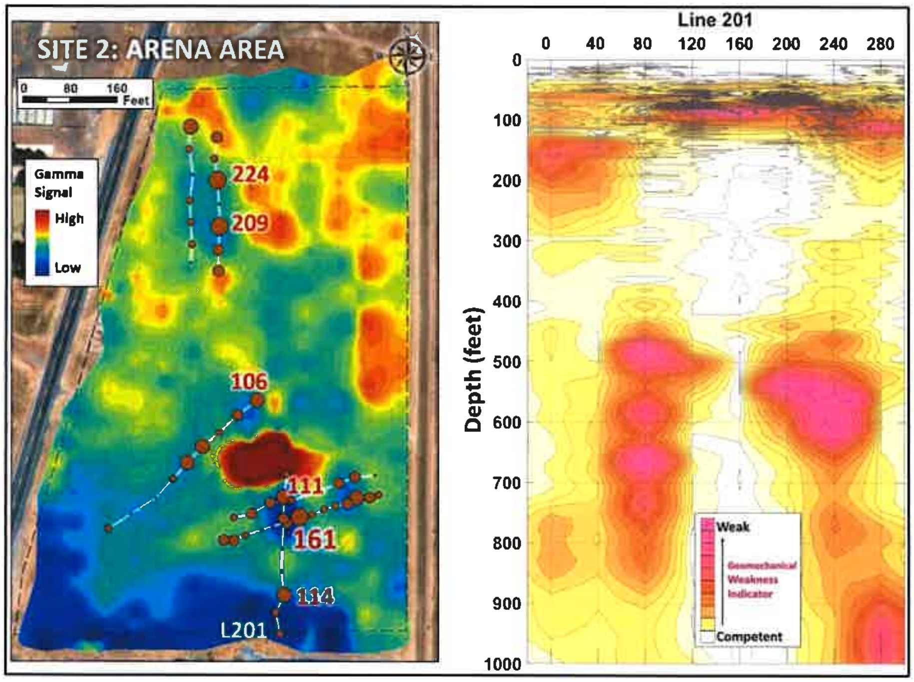


Figure 7 – RAP Profile Line 201

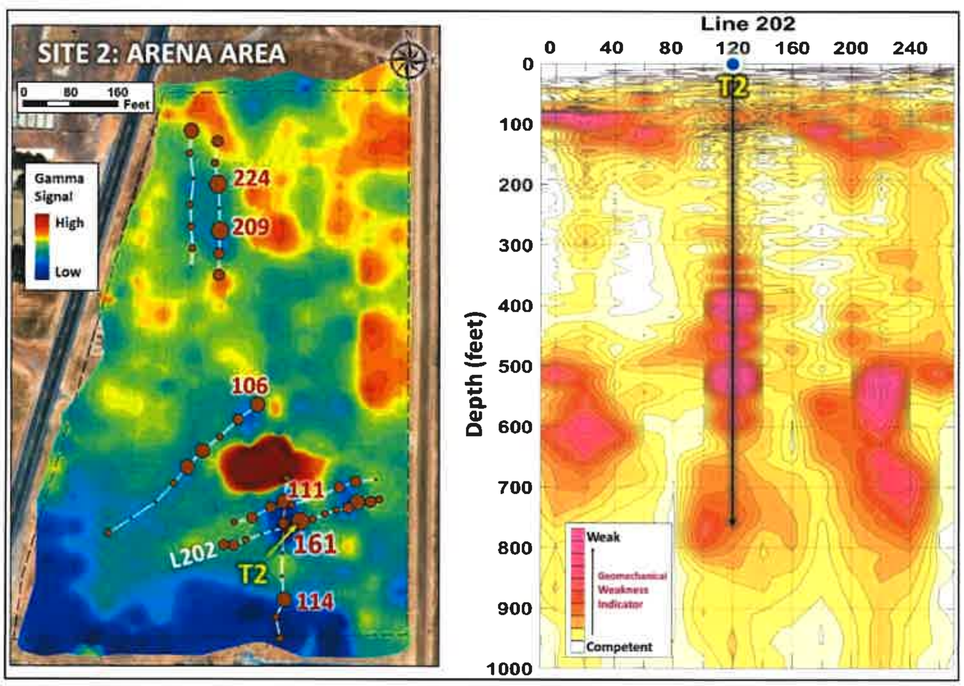


Figure 8 – RAP Profile Line 202

T2 is the seventh shot on Line 202, at Station 120 with a RAP score of 161. This location is about 184 ft from the east property boundary and 195 ft from the south boundary. Take these as approximate values, because the accuracy of the property line we have is not known. T2 is only 43 ft away from Station 240 on Line 201 which has a RAP score of 111. The gamma pattern around T2 suggests a significant amount of water comes up from depth through fissures, and it is close to the more extensive "blue zone" along the southern edge of the property and likely to be well-connected to it by the ubiquitous fracture systems.

In the northern part of Site 2, strong RAP intensities were observed in two shots on Line 205 (with scores of 209 and 224); yet, the gamma indicator suggests less water exists in the vicinity, so these prospects did not become the top recommendation. Again, full-sized figures of all 12 RAP profiles are given in the slides that accompany this report.

4.0 CONCLUSION

4.1 *Summary and Recommendations*

This study combined the use of Rapid Acoustic Profiling (RAP) with a Radiometric Gamma method to detect and target fracture zones at depth that have a high probability of yielding water that can flow easily when pumped. These tools were deployed to scout out and narrow down targets within the two study areas—Site 1 and Site 2—to determine the best drilling location(s). Two prospects stood out above the rest, and they are designated T1 and T2. Both are shown in Figure 9. The top recommended drill target is T1, located at Shot #3 (Station 80) of Line 101. T2 is location at Shot #7 (Station 120) of Line 202. Lat/Lon and UTM coordinates are also provided in the table. The GPS coordinates are based on one of the highest precision Garmin units available (the Garmin 66sr) but still could be off by up to 5 m (16 ft). Nevertheless, we believe the positions are accurate enough to intercept high permeability fracture zones.

Target ID	Best fracture zone Depth Range (ft)	Line#	Shot#	UTM Zone 12 Coordinates (WGS84) Easting m	Northing m	Topo Elev ft	Lat/Lon Coordinates (WGS84) LAT	LON
T1	500-800	101	3	377263	4293973	5179	38.785962	-112.413144
T2	300-750	202	7	375337	4296681	4978	38.810087	-112.435805

Figure 9 – Recommended Drill Targets T1 and T2 with Table of Coordinates

For Target T1, the recommended drill depth for maximum yield potential is 800 ft bgs, and for T2 it is 750 ft bgs. The data gathered cannot predict production capacity or flow rates. Keep in mind the RAP sections do not provide a perfect depth estimate; they are based on seismic velocity estimates from typical rock types. From experience, RAP depths are generally accurate to within about 10%. For example if considering a target at 500 feet, in most cases an accuracy of about ±50 ft could be expected.

5.0 REFERENCES

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