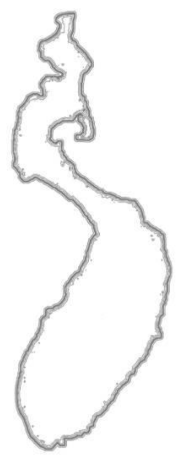
Summary Report

Bedrock Mapping Investigation for Groundwater Exploration
Prudence Island, RI



For

Northeast Water Solutions, Inc.
Exeter, RI

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Introduction

Groundwater Resources International (GRI) has been contracted by Northeast Water Solutions (NWSI) to perform a limited scope on-site mapping of geology and brittle structure to determine location, strike and dip directions of bedrock fracture elements commonly linked to fractured bedrock water supply development. The investigations were performed during an initial site inspection and a subsequent two day mapping exercise.

Background Information

Prudence Island is located in Narragansett Bay a few miles west of the Town of Bristol, Rhode Island. The island possesses a subdued topography and is underlain by the Rhode Island formation, a series of metamorphosed Pennsylvanian Age sedimentary rocks (sandstones, shale and shaley sandstones) of nonmarine origin. Rhode Island Formation metamorphic grade varies from biotite grade on the east side of the island to garnet grade on the extreme west side of the island.

Prudence Island bedrock is overlain by a thin veneer of glacial till. While the till may contain some sandy facies, especially in the area of Indian Springs, we did not identify permeable alluvial deposits of sufficient thickness and extent to warrant overburden groundwater exploration. A small area of windblown sand was observed during our brief inspection of an alternative target area (Brent Property) located on a hillside on the northwest side of the island (see map). However, we were not able to determine whether the windblown sand layers were underlain by more impermeable glacial till. Glacial till deposits are capable of yielding only small quantities of water and cannot be reliably developed for community water supply purposes.

Prudence Island bedrock groundwater reserves are stored within and transmitted through the Island's fracture network comprising narrow, permeable horizons in variably dipping bedrock formations, N, NE, NNW and ENE striking, near vertical common joints and macrojoints, shallow, east dipping weathered foliation/cleavage planes and shallow east dipping faults (see below for further discussion). The magnitude and sustainability of these groundwater resources depend upon the size and openness of individual bedrock fractures, the density and degree of hydraulic interconnectedness of fracture networks, the rate at which surface water is recharged to the bedrock aquifers through local soils and the interaction of seawater with local fracture networks.

Field Investigation

Limited-scope reconnaissance level mapping of brittle fracture elements was conducted during a site inspection and subsequent mapping visit in April of 2013. Numerous bedrock exposures were examined, principally along the west and east coasts of the island where rock outcroppings were abundant; several outcrops and subcrops were also examined in the interior of the island where exposed bedrock is rare. Over 40 outcrop sections were examined to obtain information about the brittle structure of the island. The outcrop stations are identified by number on the accompanying map (Lineament /Brittle Feature Trend Coincidence Map). Measurements were collected for brittle fabric features including common joints, macrojoints, foliation/cleavage, bedding, common veins, gash veins and faults. A total of 343 separate brittle feature measurements were obtained, collated, grouped by outcrop proximity for future study and were used to generate area stereonet pole plots and wind rose diagrams (see Appendix I for data table). Stereonets were constructed to compare feature strike directions and dip angles among stations. Wind rose diagrams were plotted to show brittle feature element population frequency and preferred strike directions. Stereonet and wind rose plots are provided for each brittle element type as attachments to this report (Appendix II). A brief description of findings and photolineament trend correlations previously identified by D.L. Maher are provided below for each brittle feature element type.

Common Joints

Common joint data was collected to determine preferred strike orientation, dip angle and direction and degree of joint consistency across the island. Common joints are often interconnected with macro joint sets and faults, bedding planes and foliation/cleavage planes and can act as vertical transmission conduits for groundwater, especially where highly concentrated. Local divergences in common joint trends can also indicate proximity to faults and structural features of interest. Examination of Prudence Island common joints sets reveals two strongly displayed joint trends with the most prominent set striking 110 -120° and dipping steeply NNE and SSW. The second most prominent set strikes 70-80° and dips steeply NNW and SSE. Both of these sets were observed at stations throughout the middle section of the island.

The 110-120° striking set is also trend-coincident with several ESE trending photolineaments identified in the middle sections of the island. Additional work must be conducted to ascertain whether these features individually possess the proper transmission characteristics to warrant further study.

Figure 1 - Inland outcrop showing steeply dipping joint sets

Macrojoints

Macro joint data, similar to common joint data, was collected to determine feature strikes and dips and assess joint consistency. Macrojoints can often act as major conduits for the vertical transmission of groundwater into other brittle feature systems or if closely spaced or hydraulically interconnected with shallow dipping, permeable bedding, foliation, faults or release joints, can themselves be tapped as high yield water supply sources. A total of three prominently displayed macro joint sets were identified during the investigation. The most strongly displayed set occurs at seaside stations along the west side of the island.

Figure 2 Cross cutting macro joints on west shore

The set strikes 30-40° and generally dips steeply to the NW. The second most prominently displayed set strikes generally N; dips steeply west and can be found at outcrop stations along east coast, west coast and in the mid-section of the island. Some macrojoints on the east side of the island are parallel to steeply dipping bedding planes and will act as vertical conduits for the recharge of area bedrock. The third most prominently displayed set strikes 110-130° and dips steeply NNE and SSW. The most strongly displayed macro joint set is trend-coincident with several extended length NE–ENE trending photolineaments. The third most prominent macro joint set (110-130°) is trend-aligned with the most strongly displayed common joint set and numerous photolineaments concentrated in the midsection of the island. Land areas possessing an increased number of common joints, macrojoints and prominently displayed photolineaments should be more fully evaluated.

Faults

Figure 3 Shallow Qtz. filled fault on west shore offset from foliation

Fault orientation, dip angle and dip direction information were measured as high yield groundwater supplies are often found either within or in close proximity to faulted bedrock. Though faults may act as underground barriers to groundwater flow, the majority of faults are storage and transmission conduits for groundwater. While usually few in number, area faults can provide important clues regarding the preferred direction of bedrock permeability. During this time-limited mapping exercise, fault features were found only along the western side of Prudence Island, striking N–NNE and dipping E-ESE at low angles. Fault plane strikes are subparallel to foliation and bedding planes and slickensides trend generally NE and plunge 20-25° N. Some faults show steep-oblique to dip slip movement on shallow dipping planes. Rotation axes generally trend SE and plunge shallowly at 20-25° with motion sense to the right, suggesting east over west block thrusting. Motion sense determinations were somewhat problematic as the slickensided fault planes were few and surfaces often irregularly coated with quartz infillings. There was no evidence of slickenside overprinting.

The faults appear to cut foliation/cleavage planes at very shallow angles. While quartz mineralization is present along fault surfaces, it appears that some planes may be open and potentially able to transmit water. Water transmission may also be enhanced in this area because faults, bedding planes and foliation/cleavage features all dip shallowly eastward at about the same angle, aiding and enhancing the development of bedding-parallel planes of weakness. Area fault strike directions are coincident with only one elongated N-S trending Maher photolineament located in the general area. It should be understood, however, that faults with shallow dip planes are not likely to be expressed as linear features where topographic relief is present. Assuming that the identified photolineament is real and actually represents the surface expression of a structural feature, it is more likely to be associated with a north striking and steeply dipping macro joint or a hidden fault.

Foliation/Cleavage

Measurement of area foliation/cleavage features were obtained because foliation/cleavage planes can be major sites of structural weakness and often act as major conduits for the storage and transmission of groundwater. Foliation/cleavage is developed as a result of the heating, folding and compression of bedrock by tectonic processes. Once created, foliation/cleavage features, can be reshaped by further tectonic stress. While conjectural, pending further mapping, it appears that the forces that generated the consistent north striking and shallow east dipping foliation/cleavage features on Prudence Island folded the bedrock layers back on themselves in an isoclinal fashion. The resultant penetrative foliation/cleavage appears to have been aligned with the axial planes of folds that have been overturned to the west.

Figure 4 Shallow foliation/cleavage on west shore (dipping east)

Prudence Island foliation/cleavage strike and dip trends are very consistent and are prominently displayed at a number of outcrop stations throughout the island. Area foliation/cleavage strikes N- NNE and dips shallowly at 15-25° E- ESE. Foliation cleavage features are trend and dip coincident with island bedding planes found in the western and central sections of the island but transect formation bedding at high angles on the eastern side of the island where N striking and steeply west dipping beds predominate. The cause of the nonalignment of foliation with bedding is somewhat problematic, although quite common

Formation Bedding

Formation bedding trends, dip angles and dip direction were measured to determine whether and to what degree bedrock underlying the island has been reshaped by tectonic forces and how that reshaping may impact the storage and transmission of groundwater. Area bedding planes located in the west and central portions of the island, strike generally north and dip shallowly East at 15-25°, whereas bedding planes located along the east coast and slightly inland strike generally north but dip steeply to the west at 60-80°. The wide discrepancy in bedding dip direction between outcrops on west and east shores indicates that the bedrock underlying the island has been significantly folded or possibly faulted. If these formations have been folded, the bedrock would resemble a slightly overturned U in cross section, with the western limb of the U angled up from the horizontal about 15-25° and the eastern limb of the U bent down about 10-20° from its normal upright position. The fold axis (bottom-most point) of the bent U would be angled in a northerly direction and for reference sake, if the fold axis center line is plotted as a straight line on a map using a southern starting and northern ending point, the southern starting point would begin a few hundred feet west of the new storage tank and the northern ending point would be plotted about 500-1,000 feet east of the Indian springs wells.

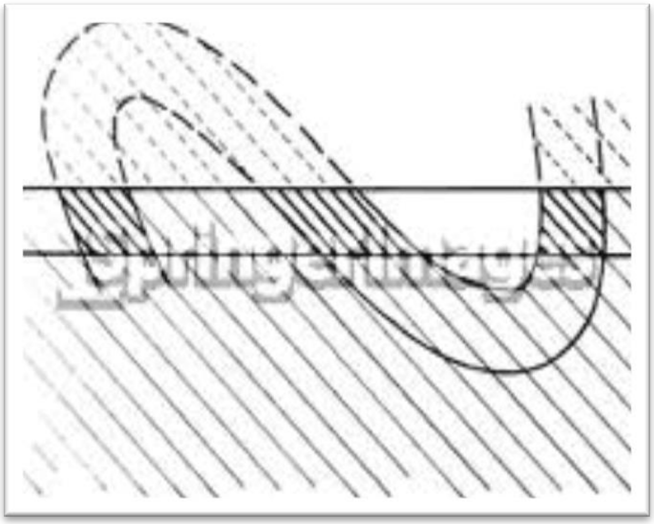

Figure 5 Projected schematic cross section of overturned fold on Prudence Island (from W - E)

Extrapolating the results obtained from the PW #4 borehole video survey, the implications for groundwater transmission and capture by each of two hypothetical wells, one placed on the shallow east dipping fold limb and the other placed on the steeply west dipping fold limb under this scenario are as follows:

1. Wells located on the shallow east dipping limb (within central and western portions of the island) would derive water primarily from permeable, but widely separated, somewhat friable and weathered water bearing zones embedded within shallow, east dipping bedrock formations. Depending upon where the well site has been targeted with respect to underlying iron bearing zones, the well would either be iron-bearing or low in iron content. Recharge water would be potentially derived from several sources including N, NNW and NNE trending, steeply dipping macro joint sets, N trending, shallow dipping fault planes and/or ENE to ESE trending, steeply dipping common joint sets. Geophysical surveys are recommended to identify vertically oriented water bearing fractures and also attempt to map the surface and down dip locations of shallowly dipping weathered zones potentially containing iron rich sediment. Detection and subsequent avoidance of these iron rich horizons has the greatest likelihood of success with the use of a high resolution multielectrode electrical resistivity array.

2. Wells located in the extreme eastern portions of the island would derive water from potentially permeable horizons within N striking and steeply west dipping metasedimentary (arenaceous) bedrock formations. As the bedrock formations are very steeply dipping in this area, vertical wells will only be able to penetrate a limited section of the bedrock formation. Consequently, it will be especially important to accurately pinpoint the location of test well sites using geophysical surveying techniques suitable for this type of feature (such as VLF and high resolution resistivity so as to maximize the probability of encountering water bearing fractures.

Gash Type Veins and Quartz Filled veins, Jointing and Fractures

Gash type veins and quartz filled joints, veining and fractures were mapped in order to identify the orientations, dip angles and dip directions of potentially older fractures and attempt to determine whether there has been any more recent fault or fracture reactivation. Review of the vein data reveals that while it appears that gash veins may possess shallower dips than common joints or macrojoints, gash veins and quartz filled veins joints and fracture strike trends are relatively consistent with macro joint trends It appears that gash veins and quartz filled veins, joints and fractures are generally trend aligned with more recently developed brittle features, implying that a preexisting anisotropy guided later development of jointing and fracturing. While gash veins and quartz filled veins, joints and fractures were found on both sides of the island, the low number of stations was the veins were found and the low number of measurements renders further assessment problematic.

Other Observations

Brent Parcel Site inspection

During our two day brittle feature mapping excursion in April, we were asked to perform an impromptu site inspection of a newly accessible parcel of land (Brent Parcel) located in an elevated area known as "The Desert", approximately 1,000 feet south of Nag Bog and 1,000 feet east of the western PI coastline. Site access was gained via a trail extending southerly from the roadside parking area near Pulpit Rock. The area soils along the beginning of the trail were grayish in color and medium grained, then turned light tan and became very fine grained and sandy as we headed southward. Tan, fine grained sand remained underfoot as we proceeded south up the hillside. We soon intersected a north-south trending stone wall part way up the hill and followed the path along the stone wall south. Soon after that we crossed a roughly east-west trending stone wall (Division Wall) and preceded further uphill. This uphill area contains a large stand of conifers that indicate the presence of well drained soils, most likely composed primarily of fine sands. However, it is not known whether these soils are underlain by relatively impermeable till cover at depth and geophysical surveys would be necessary to determine the depth and composition of

Speaking of Lineaments……

It is worth remembering that lineament interpretation is not an exact science and misinterpretations occur all the time. In fact, when lineament mapping was just becoming reputable, my college brittle mapping group professor published a tongue and check professional paper concerning the prats and pitfalls of lineament analysis. He aptly coined the term, "Linear GeoArt" to describe photolineament analysis.

At GRI, we have been conducting lineament analysis for nearly 35 years and know only too well that lineaments are sometimes only in the eye of the beholder and do not always correlate with bedrock structure. That is why it is common practice in the industry to have analysts' results independently corroborated by a second experienced analyst.

Joe Ingari, PG

overburden materials. More field work is also needed in the area on the west side of the hill and adjacent lowlands that we were unable to access because of heavy bull briar growth.

Small N to NE trending swales are present in low areas west of the western side of the main hill. A large rock outcropping was seen in this area few hundred feet west of the path, but could not be reached due to briar growth. A copy of the D. L. Maher photolineament map was reviewed onsite and compared to observed topographic features. The generally north trending swale west of the pine stand does not appear to be azimuthally coincident with the two NE trending D. L. Maher photolineaments. While highly conjectural, it appears from a distance that the sides of the swale may be underlain at shallow depths by bedrock.

We next turned to the review of the very long E-W photolineament now to our north. Walking back down the hill we encountered the E-W trending stone wall previously identified (Division Wall). This wall is in very close proximity to our estimated location of the photo interpreted E-W trending D. L. Maher lineament. The close proximity and coincident direction of the wall to the D. L. Maher lineament makes us suspect that this photolineament is not real but the result of a misrepresentation of the east-west trending stone wall as a geologic structure. Rigid reliance on the results of photolineament mapping alone to locate fractures is fraught with uncertainty. Nevertheless, the area may still provide moderate amount of groundwater if a significant portion of the recharge area is overlain by permeable fine sand deposits. While in proximity to the salt water marsh (Nag Pond) and shallow eastward dipping seaside formations which could potentially carry brackish water westward into the area, under the right circumstances this site might be viable for development of a groundwater supply depending on the source(s) of recharge and we recommend continuing more detailed evaluation of this location.

Discussion of Target Areas

A **Lineament /Brittle Feature Trend Coincidence Map** for Prudence Island where interpreted photolineament feature trends are coincident with mapped brittle fracture feature trends was prepared for this report. The pink circles represent locations where photolineament trends are coincident with the strike directions of strongly expressed brittle feature elements mapped in outcrop.

As discussed above, it is not known whether the interpreted photolineaments plotted on the map are meaningful or that they actually represent the surface expressions of an underlying water bearing fractures. Oftentimes, high yield groundwater supplies can be developed in areas devoid of photolineaments. This often occurs when the fracture conduits that deliver groundwater to the well are nearly flat or shallowly dipping. Under these conditions the intersection of shallowly dipping bedrock fractures with the ground surface will not occur at or near the well site but at some distance away, depending upon dip angle. Topographic expressions of more steeply dipping fracture conduits may also be completely masked by thick overburden deposits, with no surface manifestation of the feature of interest.

This situation demonstrates that borehole video inspections are an extremely useful and cost effective tool for providing the updated and accurate structural information necessary to locate and develop sustainable bedrock groundwater supplies.

The recent borehole video inspection at the Indian Springs Well PW #4 showed that the bulk of the water is entering the well from shallowly dipping fractures. These fractures dip at low angles (from 10-20 °) in an easterly direction and projected up-dip will surface some 500 to 600 feet west of the production well. The original interpretation of the bedrock structure at the site presupposed that near vertical or steeply dipping faults or fractures were the main conduits for groundwater flow and the mapped N-NNE trending lineaments represented the surface manifestation of those water bearing features. While it is possible that steeply dipping fractures are present in the Indian Springs area, it is also evident that most of the water is entering the well through subhorizontal and shallowly dipping fractures.

Findings and Recommendations

Prudence Island is underlain predominantly by a thin and relatively impermeable mantle of glacial till and associated till soils. As a consequence, sustainable high-yield, alluvial (sand and gravel) supplies and not available and fractured bedrock groundwater supplies receiving recharge from tills are yield limited due to slow recharge.

Bedrock and brittle feature mapping results indicate that there are a number of opportunities for additional groundwater supply development on the island. Moderate yield (15-40 gallons per minute) bedrock groundwater supplies are likely available at specific areas where fracture density and hydraulic interconnectivity of local fracture and fault sets, formation sections and permeable foliation/cleavage planes are elevated.

Also, the mapping results strongly suggest that the bedrock formations of Prudence Island have been tectonically folded and overturned in a manner similar to how a taco shell would look when it is placed on a table so that the bottom side of the taco rests at an angle of about 15-25° from horizontal and the top side of taco (assuming it is now flexible) would be tilted upward and to the right crossing a vertical plan then bent some 10-20 degrees to the right of vertical. The position of the lower portion of the taco shell represents those shallow east dipping rock units found on the western, central and east central portions of the island. The nearly vertical half of the taco shell represents the position of the steeply westward dipping rock units along and just west of the eastern side of the island. The shape of the fold dictates to a great degree how likely it may be that fractures occurring as a result of the folding process can act as groundwater conduits (see previous discussion of Formation Bedding, above).

In order to minimize the potential for the capture of iron bearing groundwater from new wells, we recommend conducting high resolution electrical resistivity surveys especially in western, central and east central portions of the island where the potential for penetrating iron bearing horizons is elevated due to the presence of a shallow east dipping fold limb. The surveys should be able to discriminate shallow dipping conductive iron bearing formations from steeply dipping brittle features expected to transmit water both laterally and vertically into bedrock.

The targeting of fractured bedrock wells requires a program of detailed geophysical exploration involving electromagnetic and/or electrical resistivity mapping within and adjacent proposed target areas. The results of the geophysical surveys will assist in identification of specific drill sites for bedrock wells. Pending the outcome of geophysical surveying one or more test/production wells can be installed at a specific Priority Target Area(s)

The brittle feature data sets and information contained in this report should be maintained for future reference and augmented as funding and resources allow. The information can be used to assist in the assessment and targeting of bedrock wells and manage potential contaminant threats throughout the island.

Recommended Actions for the Short Term

The following actions should be taken to forward the exploration and development of future groundwater resources on Prudence Island:

1. Prioritize all available target areas identified in this report and previously that may be accessible for groundwater development in anticipation of creating a ranking of these parcels that requires a more detailed consideration of factors such as surficial geology, recharge and well interconnectivity, potential contamination threats, and access issues.

2. Before additional work is undertaken at one or more of the proposed exploration sites, water quality samples should be obtained from any nearby private wells and tested for iron, manganese, bacteria, turbidity and other objectionable parameters. Additionally, the well owner should be asked for any more specific information regarding the well and its operation over time, including physical condition, taste and odor, yield and yield declines, well depth, and contamination.

3. Conduct Borehole camera inspections of select wells to determine location, types and orientations of brittle features for correlation with brittle feature data obtained from outcrops. The information derived from these investigations should be employed in the assessment and ranking of new target areas for groundwater development.

4. Upon securing land parcel(s), conduct geophysical surveys in selected target areas to pinpoint the location of test drilling target sites. Geophysical surveying will entail the cutting of 2-3 foot wide survey lines, establishing geophysical stations with markers and flagging and conducting nondestructive geophysical surveys both within and adjacent to each target area. For the purpose of collecting necessary background geophysical information, permission to take nondestructive geophysical measurements on adjacent properties may likely be necessary from property owners.

**It is important to note that the information contained in this report is derived from a limited scope on-site geological reconnaissance mapping survey. While care has been taken to provide a high level of professional judgment concerning the existing information, this report should not be considered a definitive treatment of Prudence Island geology, structure and brittle feature elements relative to new groundwater resource development.*

Appendices

Appendix I - Geologic Structures Data Table

Appendix II - Structural Data Plots

A. Stereonets

Common Joints
Macrojoints
Fault Planes
Foliation/Cleavage
Bedding
Quartz Filled Joints, Veins and Fractures
Gash Veins and Fractures

B. Rose Diagrams

Common Joints
Macrojoints
Fault Planes
Foliation/Cleavage
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Gash Veins and Fractures