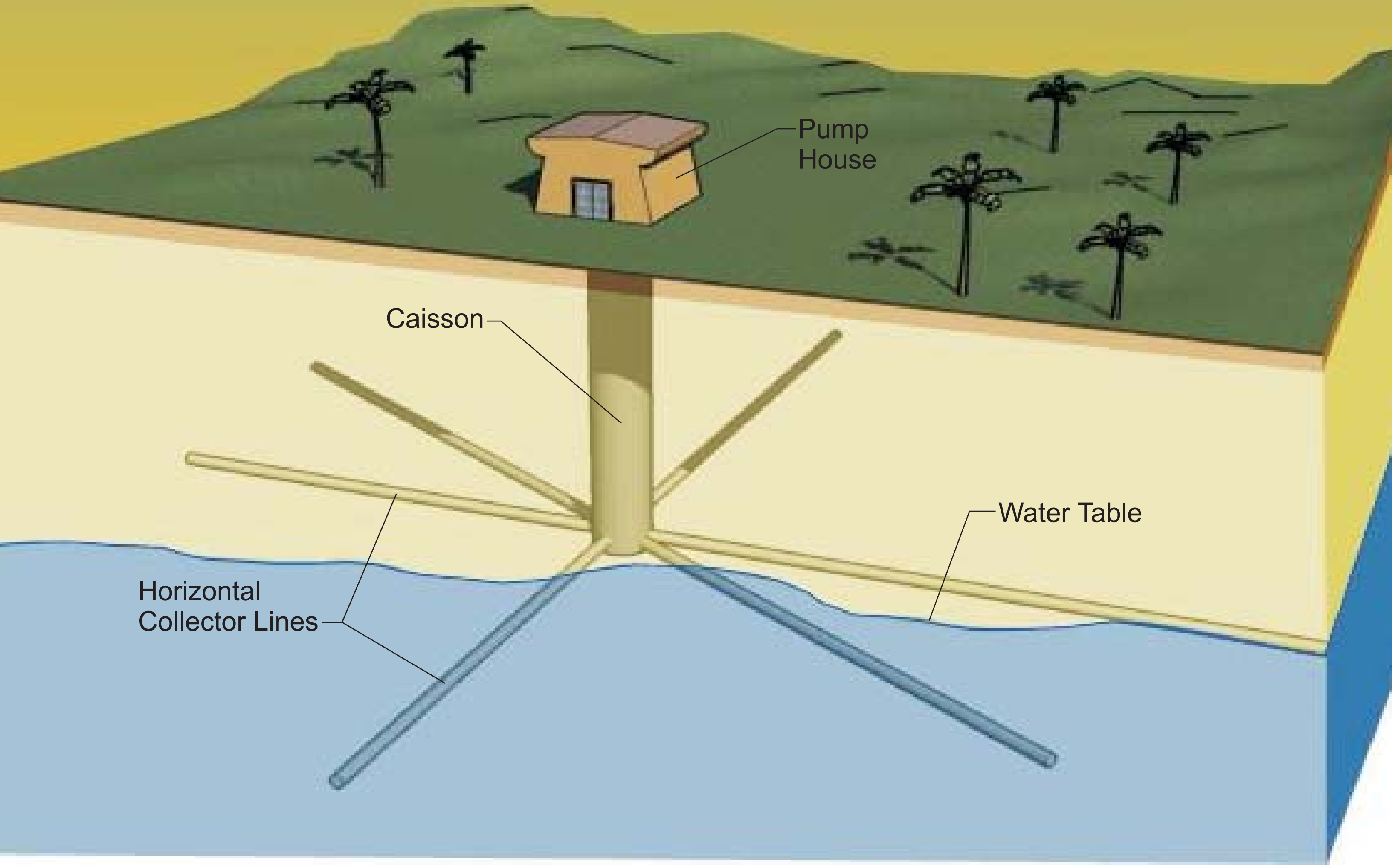
APPENDIX 2D:

COLLECTOR WELL FEASIBILITY STUDIES, PHASES 1 AND 2

Radial Collector Wells for Guam Waterworks Authority Phase I Draft Feasibility Study Report



May 2006

Prepared for:

Prepared by:

GUAM WATERWORKS AUTHORITY

COLLECTOR WELLS

PHASE 1 FEASIBILITY STUDY

DRAFT REPORT

MAY 2006

Prepared by:

BROWN AND CALDWELL

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF APPENDICES

LIST OF ACRONYMS AND ABBREVIATIONS

AACE	Association for the Advancement of Cost Engineering
CW	collector well
ERT	electrical resistivity tomography
FS	feasibility study
GCI	Geotechnical Consultants Inc.
GPM	gallon per minute
GPR	ground penetrating radar
GWA	Guam Waterworks Authority
HDPE	high density polyethylene
MSHA	Mine Safety and Health Administration
OME	order of magnitude estimate
OSHA	Occupational Safety and Health Administration
PGE	Pacific Geotechnical Engineers, Inc.
TDH	total dynamic head

EXECUTIVE SUMMARY

Multiple radial collector wells have recently been studied by the Guam Waterworks Authority (GWA) as an alternative potable water supply system to the approximately 120 vertical wells in the present system (GWA, 2005). It is GWA's opinion that by using radial collector wells, the groundwater can be gently pumped from the basal limestone aquifer as a means of protecting it from saltwater intrusion, while allowing for centralized water treatment facilities. GWA estimated that the length and associated cost of transmission mains would be reduced and the number of disinfection sites would be reduced from 120 down to six.

Brown and Caldwell's scope for Phase 1 of this Feasibility Study is to evaluate the technical feasibility of the approach, the potential costs of sinking the collector well shafts and hoisting requirements, and assess the mine safety issues. Brown and Caldwell subcontracted with Pacific Geotechnical Engineers, Inc. (PGE) for the geotechnical component of this study, and consulted with JS Redpath Corporation (Redpath) in Sparks, Nevada for evaluating the technical and potential costs for the project.

We have relied upon information provided by GWA and other parties in developing this report, and unless otherwise expressly indicated, have made no independent investigation with respect to such information. This preliminary conceptual study is intended for planning purposes only and is not intended to be used for design or construction. In particular, site-specific exploration borings will be necessary at each location prior to design. Furthermore, this study was limited to the conceptual central shaft, surface site construction layout, collector room and did not include an assessment of the radial collector wells or hydrogeology.

This Phase I feasibility study provides a preliminary evaluation of the use of radial collector wells to supply potable water for GWA. The study addresses three major issues: 1) constructability of the central vertical shafts; 2) requirements for the lifting hoists, and 3) identification of safety mining issues. Conceptual cost images were also generated. The conclusions and recommendations of this Phase I study are summarized below:

1. Brown and Caldwell's geotechnical subconsultant, PGE, concluded that the construction of a vertical central shaft at the sites being considered by GWA is feasible from a geotechnical point of view. However, heterogeneous zones of lithified, brecciated, and unconsolidated limestone can be expected. The site-specific ground conditions would need to be confirmed at each collector well location prior to detailed design, and may significantly impact technical feasibility and costs of construction at specific sites.

2. Based on conceptual technical information obtained from Redpath, the constructability of a central vertical shaft and a collector room that can house up to four pumps appears feasible. An 18-foot inside diameter and 500-foot depth 'gun-barrel' type shaft with a 12-inch-thick continuous non-reinforced concrete lining are preliminarily selected for the conceptual technical shaft sinking utilizing conventional construction methods. Three 2,500-gallon per minute (gpm), 650-foot total dynamic head (TDH) submersible pumps are envisioned (with two pumps in operation and one in standby mode) to meet the required approximate flow capacity of 4500 gpm from each radial collector well.

3. With respect to the mining safety issues, the lead safety agency is determined by the purpose of the project. Since the primary purpose of the project is water supply development (not mining for product sale), Occupational Safety and Health Administration (OSHA) should be the regulating agency. General underground safety concerns include workplace ground control inspection, ventilation and air monitoring, and escape ways.

4. An order of magnitude estimate (OME) of the constructed shaft costs using Association for the Advancement of Cost Engineering (AACE) guidelines based on recent similar experience with other projects is approximately $24 million. The estimated costs are within the previous preliminary conceptual cost opinion by GWA of $44 million which also included costs to install the horizontal portion of radial collector wells, equip the wells, pumps, appurtenant infrastructure and cover engineering design, construction management and administration costs.

Based on the above findings of this first phase, Brown and Caldwell recommends that the feasibility study proceed to the second phase. The second phase will include research into the geological and hydrological conditions and the preferred approach and costs for the collector wells. An assessment of the feasibility of construction and associated cost of the horizontal collector wells will help to further refine the conceptual cost estimate for the project.

SECTION 1

INTRODUCTION

1.1 Background

Multiple radial collector wells have recently been studied by GWA as an alternative potable water supply system (GWA, 2005). It is GWA's belief that radial collector wells will allow for centralized water treatment and the groundwater can be gently pumped from the basal limestone aquifer as a means of protecting it from saltwater intrusion. GWA estimated that six of these radial collector wells could replace the production of the current 120 vertical wells in the present system. GWA estimated that the length and associated cost of transmission mains would be reduced and the number of disinfection sites would be reduced from 120 down to six. Based upon an average production rate of 225 gallons per minute (gpm) for the 120 existing wells, the total water production requirements are approximately 27,000 gpm. The equivalent flow capacity from each radial collector well would therefore need to be about 4,500 gpm. The approximate locations of these six horizontal collector wells have been provided by GWA (Figure 1-1; GWA, 2005).

GWA previously estimated the cost to install six radial collector wells at about $44 million (GWA, 2005). The report also estimated an additional cost of $33 million for transmission mains, or a total of $76 million for the six collector wells and transmission mains to existing storage tanks. In comparison, GWA estimated the cost to install transmission lines for the existing 120 wells at $115 million. Based upon GWA's initial assessment, the cost to install six new radial collector wells would result in a potential savings of about $38 million (GWA, 2005). To validate the constructability and estimated costs of constructing the radial collector wells, GWA retained Brown and Caldwell to conduct this preliminary feasibility study.

1.2 Objective of Study

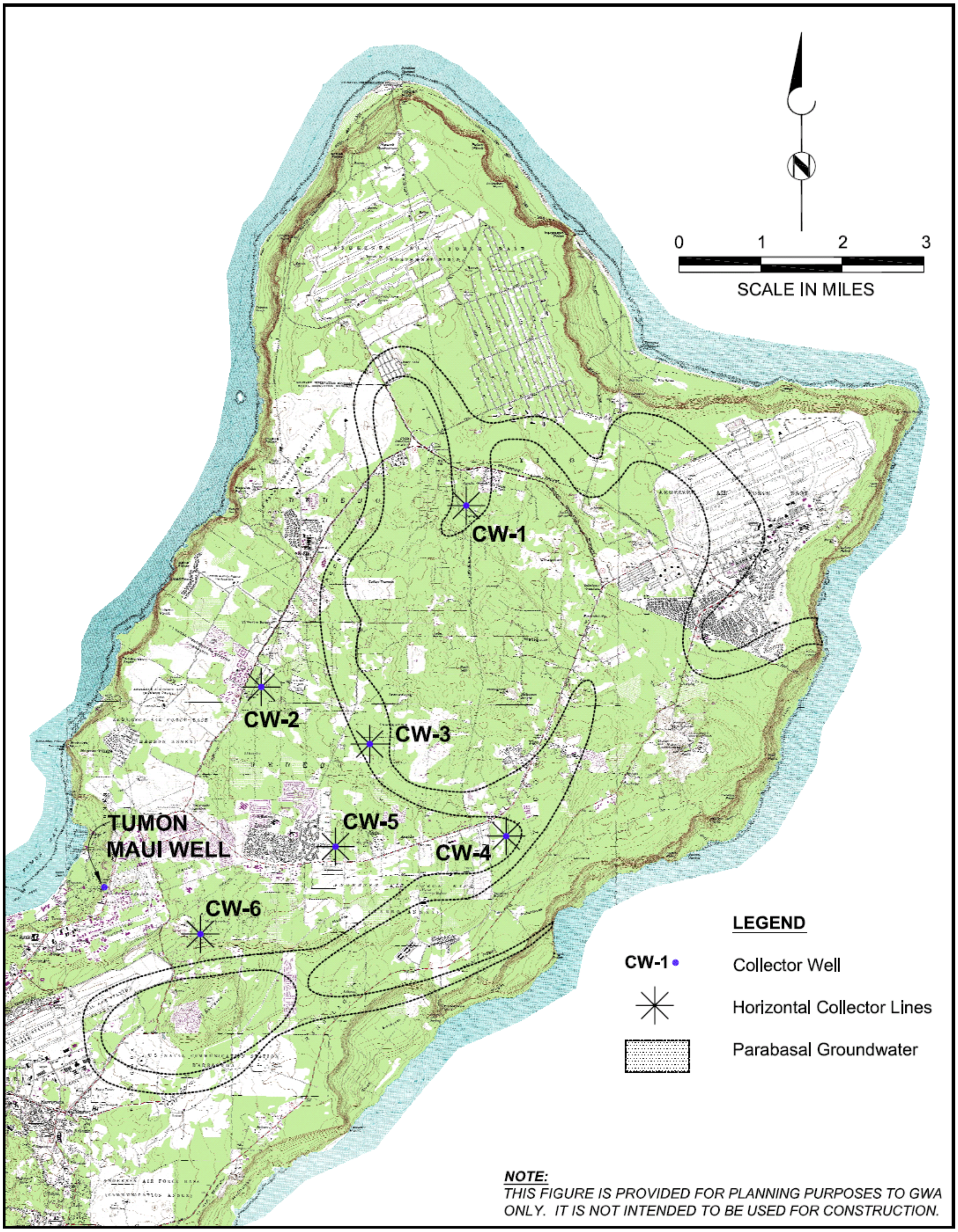
The first phase of the feasibility study is to 1) investigate constructability of the central vertical shaft and collector room, 2) determine the requirements for the lifting hoist, and 3) identify mining safety issues. The study is also intended to provide a conceptual cost estimate for constructing the central vertical shaft, collector room, and associated lifting hoist.

If these initial items are determined to be feasible and cost-effective, the second phase will commence to evaluate the radial collector wells. The second phase will include research into the geological and hydrological conditions that will affect construction of the horizontal radial collector wells. Conceptual cost estimates will also be developed for the radial collector wells. For this preliminary study, it has been assumed that no groundwater modeling will be necessary.

1.3 Approach

Brown and Caldwell evaluated the feasibility of the technical approach and the potential costs of sinking the collector well shafts by conducting a conceptual planning level analysis. We subcontracted with PGE and their subconsultant, Dr. James Mahar, LPG, of Geotechnical

Figure 1-1 – Approximate Location of Collector Wells



Consultants, Inc. (GCI), of Honolulu with respect to geologic, groundwater, and geotechnical considerations. Brown and Caldwell also consulted informally with Redpath for evaluating the technical and potential costs for this aspect of the project. Redpath is the American subsidiary of The Redpath Group, which is a specialty construction contractor with over 40 years of international shaft sinking and underground construction experience. Additionally, Redpath has previous experience with the OSHA in completion of similar underground construction projects of comparable scope and technical complexity.

The opinions provided on estimates within the following sections are OME opinions only, using AACE guidelines. The estimates are based on very limited geotechnical and no site-specific data. AACE describes an OME as an approximate estimate made without detailed engineering data. Normally, plus 50 percent to minus 30 percent contingency is a typical range of cost deviation for cost estimates of this level. Brown and Caldwell provides these estimates as opinions solely for conceptual planning by GWA. Collection of data necessary to move beyond this level of estimating are provided at the end of Section 2.

1.4 Description of Collector Wells

Based on using a central vertical shaft, the conceptual design of the collector wells includes the following components:

1. A central caisson shaft with a 10- to 30-foot diameter shaft that extends from the surface to the water table (approximately 400 to 500 feet deep);
2. A collector room at the bottom of the shaft to accommodate the drilling equipment used to construct a series of horizontal radial tunnels, and to house pumps and pumping appurtenances;
3. Pumps, motors, controls, and discharge piping;
4. A hoist lift;
5. Several horizontal collector wells or tunnels extending an estimated 500 to 1,200 feet radially from the central shaft with the crown of the radial tunnels located below the water table; and
6. Air supply system.

1.5. Limitations

This report was prepared solely for GWA in accordance with industry standards at the time the services were performed and in accordance with the specific scope of work contained in our February 3, 2006 proposal. We have relied upon information provided by GWA and other parties in developing this report, and unless otherwise expressly indicated, have made no independent investigation with respect to such information. This preliminary conceptual study is intended for planning purposes only and is not intended to be used for design or construction as detailed in Section 2.1. In particular, site-specific exploration borings will be necessary to characterize ground conditions at each location prior to design. Furthermore, this study was limited to the central shaft and collector room, and did not include an assessment of the radial collector wells or hydrogeology.

SECTION 2

TECHNICAL FEASIBILITY OF THE CENTRAL SHAFT & COLLECTOR ROOM

This section evaluates the technical feasibility of the proposed collection system, which would consist of a central shaft with several drilled horizontal collector wells radiating from the bottom of the shaft to act as collection galleries to the central sump. A working stage, sump and several pumps would be installed in a pump room at the shaft bottom to convey water to the surface treatment plants and storage reservoirs.

2.1 Geotechnical Information and Preliminary Design

The preliminary design and geotechnical data provided for the feasibility assessment included a conceptual layout design provided by GWA (GWA, 2005) and a preliminary geotechnical report developed by PGE. for this study (Appendix A - PGE, 2006). The geotechnical report describes ground conditions as Barrigada and Mariana limestone formations with widely varying zones of lithified, brecciated and unconsolidated granular limestone. Consistent with the deposition in a lagoonal geologic setting, the report states that ground conditions anticipated would include voids, limey clay and potentially perched water aquifers.

Given that Guam is located in a seismically active region, that active faults are present in the area, and that perched water and/or sinkholes or cavities could be encountered, initial and permanent support will be needed along the full depth of the shaft excavations. Potential ground concerns include loosening of rock blocks and raveling, flowing ground, and swelling of clay zones.

The Barrigada Limestone, of late Miocene to Pliocene age, forms the bulk of the aquifer underlying north Guam and would occur at the water table at most if not all of the proposed sites. According to the U.S. Geological Survey (Gingerich, 2003), the formation consists of fire-grained, pure foraminiferal-detrital limestone with high permeability.

For this evaluation, Brown and Caldwell assumed a shaft diameter of 18 feet. This is based on similar recently completed projects by Redpath which allows for multiple options in completing the collection wells and pump room infrastructure layout. All of the estimates conservatively assume 500 feet, even though some of the proposed site locations are only 300 feet above sea level (GWA, 2005). Based on the geotechnical report (Appendix A) for this feasibility report, an average of 25 percent of the excavated shaft advance was assumed to be in need of grouting but not in a free running condition (where granular material is transported into the excavation via uncontrolled groundwater flow).

The conceptual estimate also assumes the following:

- A minimum of two acres of surface area without waste rock stockpiling space is available for surface infrastructure support;

- Local storm drainage systems are adequate for excavation dewatering which will be significant when the shaft bottom intersects the primary water table;
- An additional one- to two-acre area may be required for temporary stockpiling of waste rock while awaiting transportation to permanent disposal sites;
- Existing roads are adequate to handle anticipated construction loads;
- Overhead power and utility lines will not interfere with mobilization of oversize equipment to the site;
- The site has adequate electrical power and temporary noise attenuated on-site generation will not be required;
- Water, phone and other appurtenant utility infrastructure are readily available at the site and site-fencing is in place;
- Construction could be scheduled with multiple shifts, with a potential for 24-hour operations;
- Reservoir tanks are located nearby and pumping requirements assume total dynamic head (TDH) of 650 feet is adequate for conceptual pump sizing;
- Preliminary water demands required from each collector well are assumed to be 4,500 gpm each for a total demand capacity of 27,000 gpm.

2.2 Conceptual Pump Room and Shaft Layout

The actual shaft configuration will be highly dependent upon the pump room layout and technical approach to construction of the radial collection galleries. The pumping alternative selected will impact the pump room layout and the infrastructure necessary for hoisting, utility lines, and access. The radial collection well drilling equipment will require minimum clearance distance for mobilization access down the shaft, physical set up room at the bottom station, and space for handling cuttings removal.

Three alternative potential pumping schemes were considered for the preliminary conceptual design evaluations. The three pump alternatives are a conventional submersible turbine, long-line shaft turbine, and horizontal/inclined turbine pumps. For this preliminary evaluation, three turbine pumps submerged in the sump were selected as the most favorable alternative (Section 2.5). Configuration of the pumps with submersible motor or surface motor with line shaft drive are equally feasible and can utilize the same basic configuration.

A potential benefit of the three turbine pump set up is that it would minimize the need for underground access to maintain the radial collection wells and sump. Pump maintenance would be performed from the surface by pulling the pump similar to current GWA well operations. This aspect is discussed in more detail later in Section 2.5.

For this conceptual evaluation, each pump room would be equipped with three 2,500 gpm, 650-foot TDH submersible pumps. An example of a submersible pump with this capacity is a 2,300 volt Byron Jackson 500 horsepower pump (overall length ~130 inches) with six-stage, 17-inch-diameter bowls (overall length ~90 inches). The line shaft turbine would only have the pump unit itself in the sump. Two pumps would operate to meet the demand and one would serve as a standby maintenance back-up pump. A fourth pump could potentially be added but the tri-pump conceptual approach would ensure adequate room for the hoist system and utility lines mounted to the side of the central shaft. The pump discharge column would be 12-inch-diameter pipe inside a 20-inch-diameter steel or high density polyethylene (HDPE) guide tube. The guide tube would facilitate installation and removal of the pump through the shaft.

The shaft section would mount the pump riser columns at third points within the shaft. This conceptual layout provides optimal distancing per shaft diameter limitations between the pump cans in the sump area and a straight conveyance line up the shaft to the surface. Anticipated hoist and utility lines would be mounted within one of the third points between the pump column risers, and also include:

- 30-inch-diameter air-duct;
- 4-inch-diameter air supply service;
- Four 4-inch-diameter electrical service conduits;
- 3-inch-diameter potable water service line;
- 2-inch-diameter communication conduits;
- Hoist system: electrically-driven double track U-600 Alimak Climber [1000 Kg (2,200 pound) capacity] (Appendix B); and
- Secondary manway facilitated by ladders installed on 20-foot intermediate partial circumference shaft stage landings with an open frame screening wall.

A conceptual headframe layout plan and section are provided on Figure 2-1 and 2-2, respectively. A workstage layout plan for the vertical shaft is shown on Figure 2-3. A top coping plan is provided on Figure 2-4. Photographs illustrating the shaft sinking operations on one of Redpath's projects are shown on Figure 2-5. Figure 2-6 shows an example of a conceptual shaft layout plan.

Figures 2-1 and 2-2 show conceptual surface site layout plan and elevation of conceptual spatial requirements for set up of the hoist building, portable head frame, winch hoists.

- Figure 2-1 depicts the conceptual plan layout with a 40-foot by 100-foot Quonset building enclosing all of the shaft sinking equipment including the man access, hoists and appurtenant electrical equipment. Not shown here, but requiring additional surface site area would be the maintenance, personnel and temporary waste rock storage as described previously.

- Figure 2-2 is an elevation section which displays the relationship of the portable head frame with respect to the vertical shaft, skip (sinking bucket) hoist, winches and muck (waste rock) removal system. The skip bucket is loaded at the shaft bottom by a Cryderman mucker shaft. The skip bucket is hoisted to the surface. Once the skip bucket clears the mechanical dump door, the dump door is mechanically deployed and diverts the skip bucket discharge to the chute. Once discharged the dump door is retracted to allow the skip bucket to pass and go to the shaft bottom to repeat the cycle.

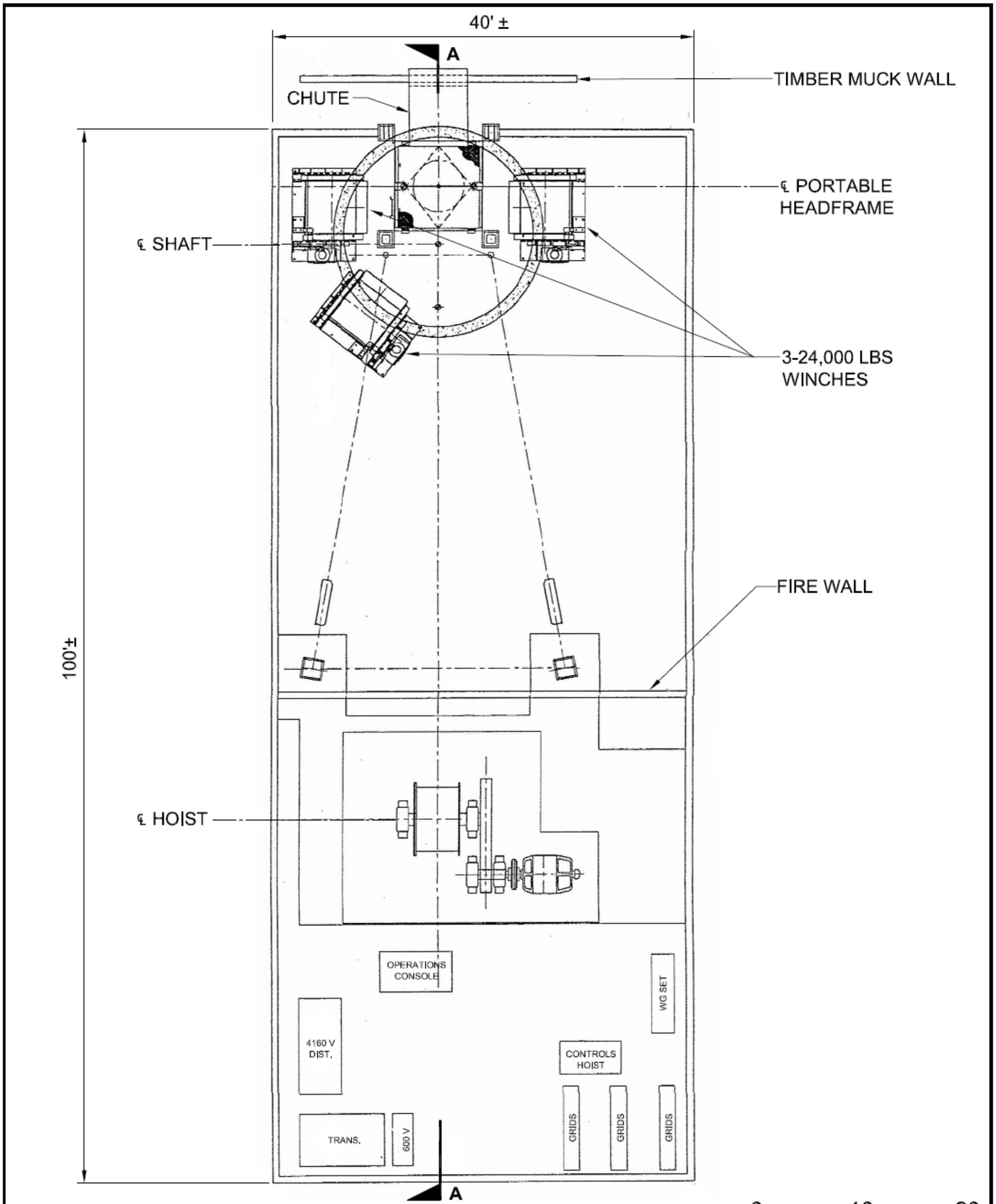
Figure 2-3 is a conceptual layout of a typical floor section of the sinking stage which is used as a mobile elevator platform during mining operations. The sinking stage provides a platform to work from and protection from falling materials. The stage is retracted during the blasting cycle and lowered with the sinking drills and mucker shaft to drill the next round or muck the waste rock after a blasted round. Additional infrastructure includes the sheave wheels for the wire stage rope pulleys, 30-inch air vent way, skip bucket and hoist access.

Figure 2-4 is a conceptual layout of the coping plan. The coping plan is the initial temporary set up necessary to sink the initial shaft deep enough to get through unstable surficial materials and provide enough working room to install and operate the sinking stage. The foundation plan is for support of the temporary head frame, final shaft cover and is typically sized with respect to the shaft depth, local site conditions and operational conditions.

Figure 2-5 show photographs of various phases of shaft sinking on a Redpath project. The upper left photograph shows installation of the sinking stage. The upper right and lower picture show installation of the portable headframe unit.

Figure 2-6 shows the conceptual layout for the 18-foot-diameter shaft cross section. This section shows three 12-inch-diameter discharge pipes inside 20-inch guide risers located at third points within the shaft. The hoist area is for the Alimak U-600 hoist. The partial circumference landings will allow installation of ladders for a secondary manway and access to utility lines located along the shaft wall. The landings would be supported by recessed pre-fabricated supports embedded in the shaft walls during shaft sinking. An open woven wire fabric screening wall would provide separation from the main shaft compartment. Hoisting of oversize equipment would be facilitated by removing the Alimak climbing cage (climbing cage is removable at the surface from the tracks). This will allow a larger space for hoisting equipment requiring the extra space or exceeding the rating capacity of the Alimak hoist. Mahogany guide rail is shown here conceptually to facilitate the safety 'dogs' on the cross head guides for heavy or oversize lifting. Safety dogs are spring loaded interlock devices which will clamp the mahogany guide rails in the event of hoist or cable failure. Mahogany is typically used in this application due to its strength and service life in extreme humid environments. The rails would need to be supported on prefabricated brackets embedded in the shaft wall. The actual guide system may utilize other types of guide rails depending on the final system design requirements.

Figure 2-1 – Shaft Sinking Operation Conceptual Yard Layout Plan



NOTE:
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Figure 2-2 – Conceptual Headframe Elevation

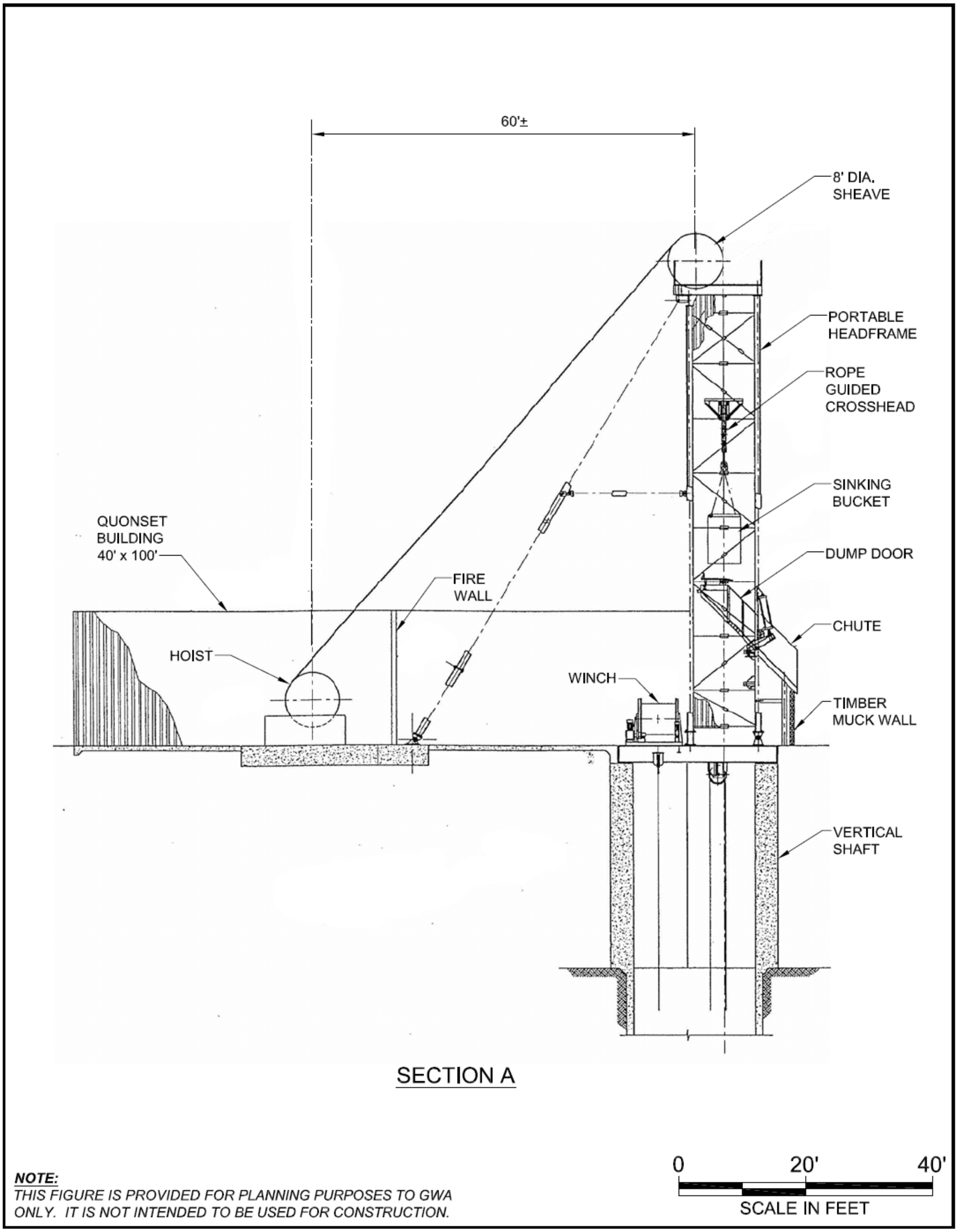

Figure 2-3 – Conceptual Working Stage Plan

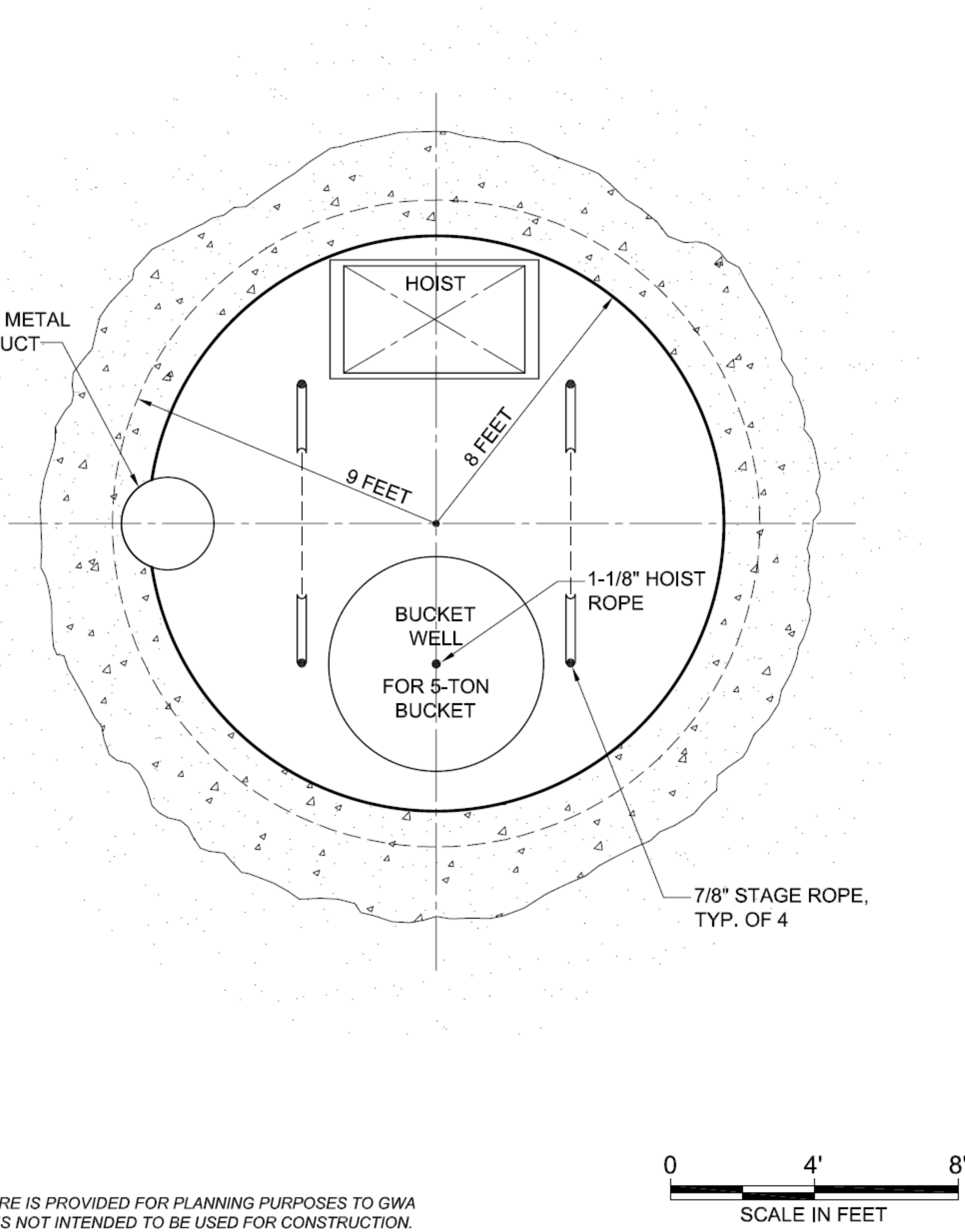

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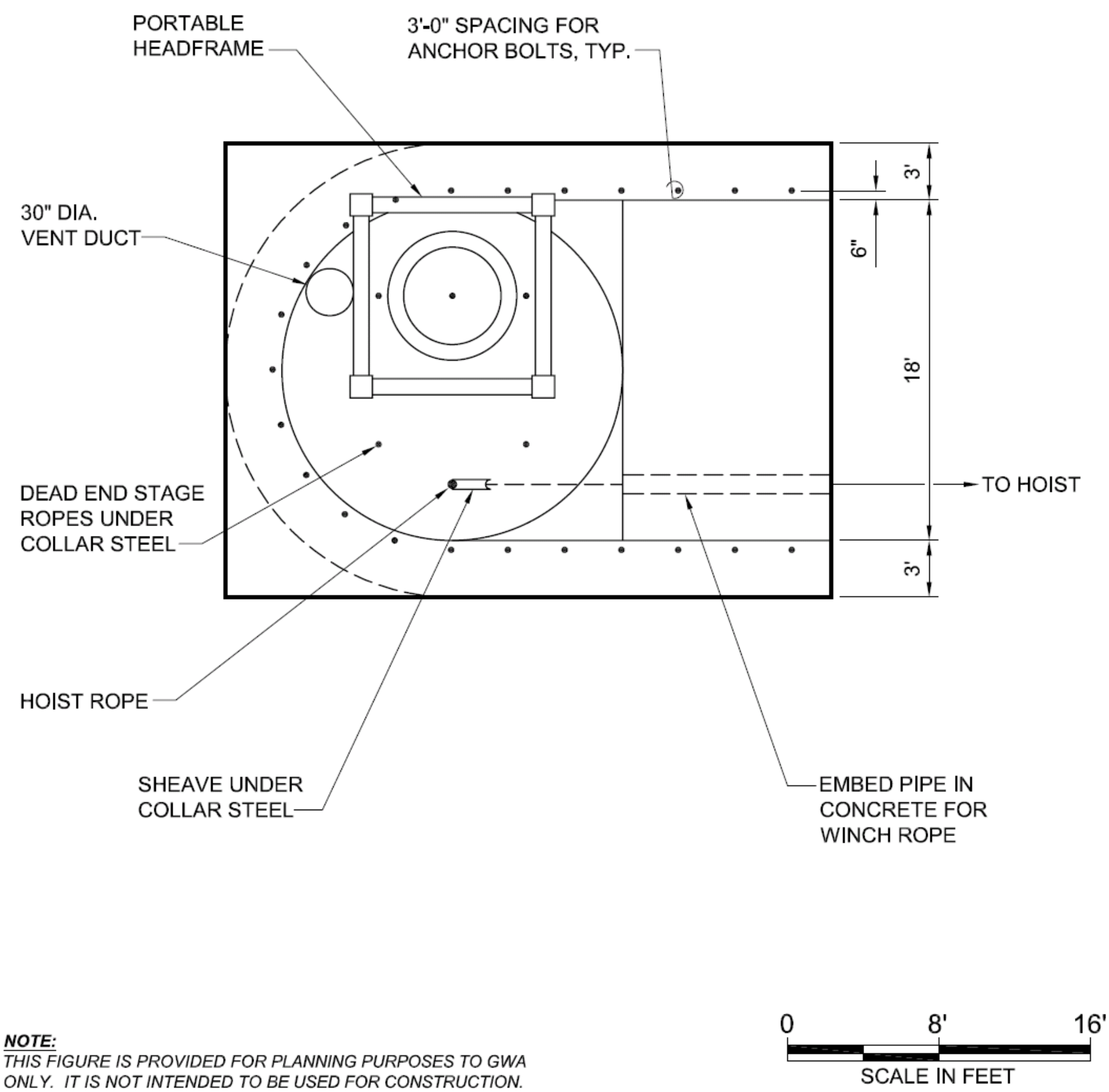
Figure 2-4 – Conceptual Coping Plan



NOTE:
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Figure 2-5 – Representative Photographs of Shaft Sinking Operations

NOTE:
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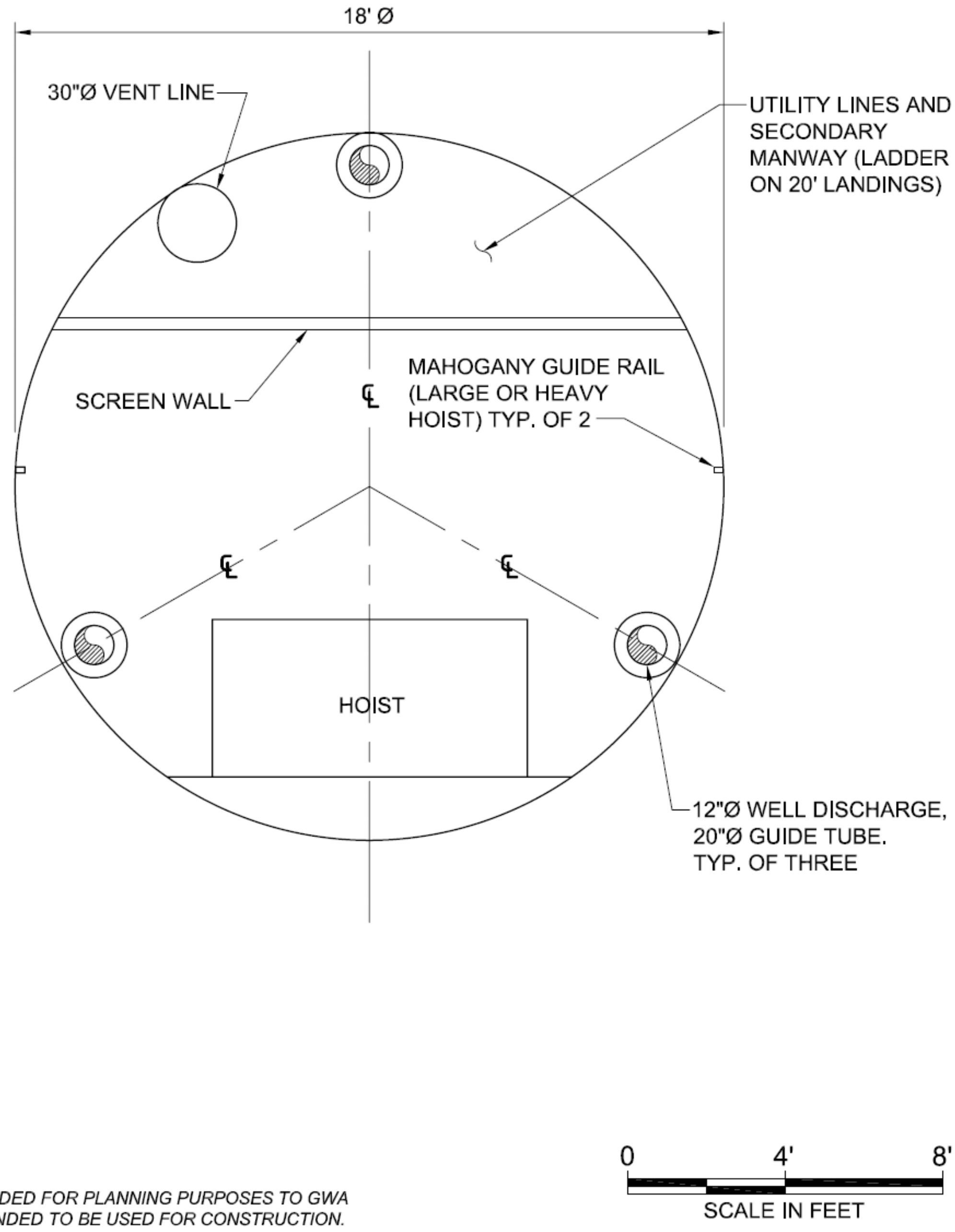
SOURCE: COURTESY OF JS REDPATH CORP., SPARKS, NV.

Figure 2-6 – Conceptual Shaft Layout Plan



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2.3 Technical Shaft Sinking Operation

The conceptual technical shaft sinking approach assumes an 18-foot inside diameter 'gun-barrel' type shaft with a 12-inch-thick continuous non-reinforced concrete lining. Shaft sinking is anticipated to be through conventional mining methods of drilling, blasting and mucking (removal of waste rock) from the sinking stage to facilitate advance. Initial shaft sinking operation anticipates ground sinking through unconsolidated surface materials with a concrete ring and beam. Once through the unconsolidated materials, excavation of the shaft would be facilitated from the sinking stage lowered with two winch hoists. Ground control would be dictated by local conditions as described in the preliminary geotechnical reports. Mucking would be completed with a Cryderman Mucker Shaft to the sinking (skip) bucket and hoisted with a single drum hoist. The skip bucket would have a maximum four-ton capacity running on wire rope guides within the working stage (Figure 2-3). A third hoist would be used for a 'chippy' hoist for lowering men, equipment and materials.

Surface support facilities anticipated include a portable head frame in the shaft collar area, hoist building, maintenance shops, lay down area and change (dry) trailers. The shaft collar layout would incorporate a portable head frame for the shaft sinking operation. Surface support infrastructure would include room for a 40 by 100-foot hoist building approximately 60 to 70 feet away from the center line of the portable head frame (Figure 2-1). The skip bucket would dump to a side chute at the top landing for off-loading to the temporary waste rock stock pile area. The surface area would also include maintenance, lay-down and appurtenant support buildings.

2.4 Opinion of Anticipated Costs

Based on the aforementioned conceptual layout, OME opinions have been developed based on recent similar Redpath experience with other projects. The unit cost opinions are based on mobilization of equipment from Ontario, Canada to remote international sites including Mongolia, China. The unit costs include mobilization/demobilization, surface preparation and site set-up based on the assumptions listed previously, labor and materials. Redpath's opinion is a unit cost of $6,000 to $6,500 per foot would be appropriate for project feasibility estimating based on recent project experience including the Mongolia project. Redpath has experienced a variation of costs in similar projects ranging from as low as $4,000 per foot to in excess of $10,000 per foot. Per Redpath's OME opinion of cost, this estimate assumes $6,500 per foot unit cost.

Adverse ground conditions will have a huge impact on the cost of the project. The geotechnical report anticipated voids, brecciated ground and foraminiferal sands. As identified in the geotechnical reports, these areas will require grouting prior to advancing the shaft. Redpath's opinion on these costs typically add in the range of $1,000 to $6,500 per foot of advance, where the accelerated rates typically are experienced and in some instances have been exceeded in areas of running ground. Per Redpath's OME opinion of cost, this estimate includes $3,500 per foot for the initial assumption that 25 percent of linear shaft advance will require grouting.

The Alimak U-600 consists of an enclosed climber cage which travels on a double rail track. The Climber Cages are removable from the track system. This OME conservatively assumes each shaft is fully equipped with double track and the climber cage, which in the final design may be reduced to equipping the wells with the double track only and sharing two or three climber cages between the collector wells. Based on these assumptions and six vertical 500-foot deep shafts, the cost opinion for shaft construction with inclusion of the Alimak Hoist system are:

Shaft Sinking:	3000 feet * $6,500/foot	=	$19,500,000
Grouting:	750 feet * $3,500/foot	=	$ 2,625,000
Hoist System:	Six units * $300,000 each	=	$ 1,800,000
Total Constructed Shaft and Hoist Cost			**$23,925,000**

2.5 Preliminary Pump Room Layout

The pump room will depend on two preliminary factors, which include the pumping method and radial collector well gallery extension. Radial collector well extension drilling equipment may require up to 30 feet or more in length to facilitate the drilling equipment. This minimum dimension will require the pump rooms to be under-reamed to plan dimensions larger than the proposed 18-foot shaft diameter. Oversize equipment would be lowered lengthwise and rotated into place for operation. Common to all three scenarios, the pump room will require a stilling well, intake reservoir, false floor, working floor and safe retreat space. The stilling well is to allow coarse particle settlement prior to entering the pump intake reservoir. A working floor above the stilling wells and intake reservoir are required to access equipment and mitigate contaminating the wells. The false floor would be a removable roof for protection during work performed within the shaft wall limits on the working floor. The safe retreat space would be equipped with communications and ventilation extension to provide refuge area during hoisting operations. The three pumping scenarios require design and construction considerations which will have additional varying cost impacts to finishing the shaft bottom. A discussion on each of the alternative pump types follows.

Submersible Pump: Conceptually this layout would provide a concentric stilling well surrounding the central intake reservoir. The intake reservoir would have 3 pump cans sunk into the shaft bottom floor aligned vertically with the shaft walls as depicted in Figure 2-6. The pump cans would be installed to a depth of approximately 30 to 35 feet to facilitate housing the pump, motor and meeting required hydraulic intake requirements. Benefits of this pump type would include minimizing access into the shaft to maintaining the radial collector wells and collection gallery. The additional benefit is this concept minimizes the installation of utility services to the bottom station. Conversely, this option will require a crane to access the pump and motor. Installation will require a relatively deep pump can in the floor of the sump to house the pump and submerge the motor for cooling.

Long Shaft Line Turbine Pump: This pump type would provide similar benefits to the submersible pump option. Additional benefits are having the motor accessible at the surface and it require an 11-foot shorter pump can installation in comparison to the submersible pump (the pump can will require less length since the can will encase the pump assembly only). Conceptually this pump can would extend approximately 19 to 24 feet below the shaft floor to house the pump and meet hydraulic intake requirements. Detriments of this option include the need for a crane to access the pump, lubrication and the dynamics of the drive line. Lubrication of the drive line would need to consider lubrication with a food grade oil. This is due to the driveshaft length and anticipated low water system head available at the surface being within close proximity of the surface storage tanks. The dynamics for the drive shaft will need to be understood prior to shaft sinking. The design should consider adequate drive shaft encasement support and vibration dampening, so it can be constructed properly during shaft sinking.

Horizontal/Inclined Turbine Pump: This option is included as an alternative only in the event that the conventionally installed vertical turbine pump options encounter significant design/construction hurdles due to localized site conditions. This option would install the turbine pumps horizontally or at an incline with centralizing studs. Benefits with this pump type include installation utilizing same equipment for the installation of the lateral collector wells. A detriment to this set up is that it is the most complex to construct and operate. The shaft will need to be equipped with a heavier hoist and guides to facilitate installation and removal. The bottom room will require additional space and an auxiliary pneumatic crane for servicing the pump and motors. It will require maintenance people to enter the shaft regularly for maintenance, which in turn will require full service utilities equipped and maintained in the bottom station. The inlet for this is relatively more complex to meet suction head requirements and coordination of the intake reservoir and stilling wells. All of these factors would significantly increase costs relative to the conventional turbine pump options.

Centrifugal Pump: This option is included as an alternative only in the event that the turbine pump options encounter significant design/construction hurdles due to localized site conditions. Benefits with this pump type include robust operation without a pump can. A detriment to this set up is that it is the most complex to construct and operate. The shaft will need to be equipped with a heavier hoist and guides to facilitate installation and removal. It will require maintenance people to enter the shaft regularly for maintenance, which in turn will require full service utilities equipped and maintained in the bottom station. The inlet for this alternative would be fairly complex to meet suction head and priming requirements on the pump intake side. All of these factors would significantly increase costs relative to the turbine pump options.

Brown and Caldwell's opinion is that the turbine pumps provided in Option 1 and 2 are equivalently feasible alternatives. Both of these options provide conventional operation and maintenance from the surface similar to what GWA currently operates. This minimizes necessity to complete permanent services to the shaft bottom and curtails the necessity of accessing the shaft for routine maintenance. The differences that will provide the final selection of the submersible versus the line shaft pump would be design and operational efficiency. The line shaft pump motor would be substantially less than the submersible pump motor but this cost savings may be offset by additional construction requirements necessary to stabilize the driveline shaft support. The incline or horizontal turbine installation would be the least desirable alternative.

2.6 Additional Technical Considerations

Typical conventional civil construction projects will range in the area of or fall below 18 percent design, construction and administration costs. Our opinion is this project should anticipate costs exceeding the 18 percent range due to advanced collection and evaluation of baseline data necessary to define final design goals.

Consideration of this data collection should incorporate the following:

- A comprehensive hydrogeologic understanding of the water table and island system water balance. The determination of the final elevation of the shaft bottom will be set according to the best data for sustainable production from an understanding of the fresh water table.
- Advanced geotechnical and geophysical data collection will be necessary to determine locally complex adverse ground conditions. Exploratory drilling should be coupled with seismic surveys, electrical resistivity tomography (ERT) and/or ground penetrating radar (GPR). The exploratory program may need to employ some or all of these methods to understand project requirements of shallow and deep ground conditions.

An alternative method for gaining access to the water table is via decline. The benefits for this method include less technical design and skill in execution, but will require access under unencumbered ground and more excavation distance and volume. Based on a ramp decline of 15 percent this would require approximately 3,300 lineal feet of decline per collector well, or 20,000 feet total. Informal costs of this method are in the neighborhood of $1,000 to $1,200 per foot for application of this method in the Western United States and will experience significant additional costs in poor ground conditions or high ground water inflow. Factors which will have a significant impact on the feasibility of this method include:

1. Acquiring right-of-way or unencumbered ground
2. Origination of Contractor skill sets to perform the work
3. Significant space and conveyance costs for removing waste rock to permanent dump space (this impact could be offset if a gravel company was interested in purchasing the waste rock but would introduce regulatory permitting and oversight complications as discussed in Section 3)

These factors would need to be considered in making a final assessment of this method's feasibility over conventional shaft sinking.

Another method of shaft sinking is via large diameter bore drilling proposed by Shaft Drillers, Inc of Morgantown, West Virginia. This method utilizes a large diameter 3 to 5.5 meter drill bit driven by drilling rigs capable of 300 to 500 tons of driving capacity. The drilling methods require either standard or reverse circulation of drilling fluids or mud for removal of cuttings and lubrication of the bit or drill head. This method is typically more cost efficient in competent ground but may result in significant cost impacts exceeding conventional shaft sinking in encountering voids, loose ground or other factors effecting drill fluid circulation. A thorough understanding of site specific conditions would be required to fully assess the feasibility of this method. Redpath also performs large bore diameter shaft sinking but declined to provide OME costs on this method due to the unfavorable preliminary geotechnical information provided in the reports generated by PGE & GCI (Appendix A).

Brown and Caldwell's opinion is to use the conventional shaft sinking over drilled vertical shaft as the preferred method for the feasibility analysis for the following reasons:

1. Preferred alternative based on preliminary geotechnical report and Redpath's opinions,

2. Large Bore Shaft sinking requires return circulation of drilling fluids which is impractical in formations containing significant void spaces,

3. More definitive site specific geotechnical information would be required to thoroughly assess the large bore drilling approach,

4. Conventional shaft sinking provides an acceptable conservative opinion with respect to the limited site specific data available.

SECTION 3

SAFETY ISSUES

3.1 Lead Safety Agency

The lead safety agency is determined by the purpose of the project. If the sale of the removed material is the primary purpose of either a shaft (hoist operation) or decline (rubber-tire) project, the Mine Safety and Health Administration (MSHA) would be the lead agency. If the underground construction project is secondary to another purpose, the OSHA regulations will be the lead. Since the primary purpose is water supply development, OSHA should be the regulating agency. Both MSHA and OSHA regulations were reviewed, and the regulations pertinent to this project are similar for both agencies. MSHA regulations that are applicable to this project are provided in Appendix C. Appendix D includes only selected OSHA regulations, although most of the MSHA requirements would also apply. Appendix E includes the interagency agreement between MSHA and OSHA.

3.2 General Underground Safety Concerns

There are a number of critical safety areas that affect all underground projects that warrant mention:

- Workplace ground control inspections are required on every work shift. In operations with bad ground control, haulage and travel ways may need examination every work shift (Appendix D).
- Ventilation is a critical (and fairly costly) component of the safety of underground projects. The underground air must be monitored for a large number of contaminants along with oxygen levels and flow rates (Appendix D). If the surrounding rock releases enough methane or hydrogen sulfide for the workings to be classified "Gassy", then additional requirements and stricter standards that define the use of "permissible equipment" are put in place.
- Escapeways (secondary to the main access) are required for all underground projects. Emergency refuge areas are required for all employees who cannot reach the surface from two separate escapeways within one hour.

3.3 Additional Safety Concerns for Hoist-based Systems

The safety regulations regarding hoists-based systems (either vertical shaft or inclined) require additional inspections and examinations (requiring more downtime) that rubber-tired declines. These additional inspections deal mostly with the hoisting mechanisms (wire rope inspections, sheave inspections, safety catch inspection/testing) and with inspection of the shaft. Also, if the project is not run on a 24 hours per day, 7 days a week schedule, then more inspections are required before production operations can begin after the shutdown (i.e. Monday morning after a weekend off). Additionally, hoist-based operations will be required to follow strict illumination requirements beyond those imposed on rubber-tired based operations. These additional illumination requirements are mainly in the station areas of hoist-based systems.

3.4 Other Safety Regulations

There are other safety regulations (too numerous to mention in this preliminary study) affecting underground operations, this brief overview covers only the most critical regulations involved with the types of underground operations being considered. Additionally, there has been no discussion of the numerous safety regulations that affect surface and underground operations equally. Before any project commences all safety regulations that affect the project should be reviewed and observed. More detailed information of safety mine issues are provided in Appendix C, D, and E. Both MSHA and OSHA have virtually the same regulations, but MSHA regulations (since they are written for a single industry – mining) are listed in a more concise format. While OSHA has virtually the same regulations these are written for general industry and therefore are more general in nature. For clarity and ease of understanding, MSHA regulations are listed in detail with examples of OSHA regulations included in Appendix C and D.

SECTION 4

CONCLUSIONS AND RECOMMENDATIONS

This Phase I feasibility study provides a preliminary evaluation of the use of radial collector wells to supply potable water for GWA. The study addresses three major issues: 1) constructability of the central vertical shafts; 2) requirements for the lifting hoists, and 3) identification of mining safety issues. Conceptual cost images were also generated. The conclusions and recommendations of this Phase I study are summarized below:

1. Brown and Caldwell's geotechnical subconsultants, PGE and GCI, concluded that the construction of a vertical central shaft at the sites being considered by GWA is feasible from a geotechnical point of view. However, heterogeneous zones of lithified, brecciated, and unconsolidated limestone can be expected. The site-specific ground conditions would need to be confirmed at each collector well location prior to detailed design, and may significantly impact technical feasibility and costs of construction at specific locations.

2. Based on conceptual technical information obtained from Redpath, the constructability of a central vertical shaft and a collector room that can house up to four pumps appears feasible. An 18-foot inside diameter and 500-foot depth 'gun-barrel' type shaft with a 12-inch-thick continuous non-reinforced concrete lining are preliminarily selected for the conceptual technical shaft sinking approach. Three 2,500-gpm, 650-foot TDH submersible pumps are envisioned (with two pumps in operation and one in standby mode) to meet the required approximate flow capacity of 4500 gpm from each radial collector well.

3. With respect to the mining safety issues, the lead safety agency is determined by the purpose of the project. Since the primary purpose of the project is water supply development (not mining for product sale), OSHA should be the regulating agency. General underground safety concerns include workplace ground control inspection, ventilation and air monitoring, and escape ways.

4. An OME of the constructed shaft costs using the AACE guidelines based on recent similar experience with other projects is approximately $24 million. The estimated costs are within the previous preliminary conceptual cost opinion by GWA of $44 million which also included costs to install the horizontal portion of radial collector wells, equip the wells, pumps, appurtenant infrastructure and cover engineering design, construction management and administration costs.

5. Two other alternatives for shaft sinking received a cursory review, which include access via decline and drilled vertical shaft. Due to limited applicability of both methods, more detailed site specific information is required to make a final determination of feasibility. Based on the preliminary data available for this report, the site specific data would require substantially more favorable conditions to be considered feasibly viable over conventional shaft sinking methods.

Based on the above findings of this first phase, Brown and Caldwell recommends that the feasibility study proceed to the second phase. The second phase will include research into the geological and hydrological conditions for the collector wells. An assessment of the feasibility of construction and associated cost of the horizontal collector wells will help to further refine the conceptual cost estimate for the project.

SECTION 5

REFERENCES

Brown and Caldwell, 2006. Water Resource Master Plan (Draft), Volume II, Chapter 3 – Water Budget.

Camp, Dresser, and McKee, Inc. (CDM), 1982. Northern Guam Lens Study, Groundwater Management Program Aquifer Yield Report. Prepared for the Guam EPA; in association with Barrett, Harris, & Associates, Inc.

GWA, 2005. Water Lens Supplies Using Long Horizontally Drilled Ranney Type Collector Wells, Guam Waterworks Authority. Authored by P. Kemp, July 15.

Pacific Geotechnical Engineers, Inc. (PGE), 2006. Consultation letter, Geotechnical Consultation Feasibility Study, Radial-Type Collector Wells, Guam Waterworks Authority. Prepared for Brown and Caldwell in Association with Geotechnical Consultants, Inc. (GCI). May 11, 2006.

Gingerich, S.B., 2003. Hydrologic Resources of Guam. U.S. Geological Survey Water Resources Investigation 2003-4126.

APPENDIX A

GEOTECHNICAL CONSULTATION LETTER BY PACIFIC GEOTECHNICAL ENGINEERS, WITH ATTACHED REPORT BY JAMES W. MAHAR, GEOTECHNICAL CONSULTANTS, INC.

Pacific Geotechnical Engineers, Inc.
Soils & Foundation Engineering Consultants

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May 11, 2006
Job No. 8499-002

Brown and Caldwell
119 Merchant Street, Suite 200
Honolulu, Hawaii 96813

Attention: Mr. Douglas Lee

Subject: *Pre-Final* Consultation Letter
Geotechnical Consultation
Feasibility Study
Radial - Type Collector Wells
Guam Waterworks Authority
Guam, Mariana Islands

Gentlemen:

1.0 INTRODUCTION

This letter summarizes the results of the geotechnical consultation services we performed to initially assess the feasibility of central shafts for Radial - type collector wells that the Guam Water Authority (GWA) is considering for Guam. For this consultation, we retained Dr. James Mahar, Ph.D.-LPG of Geotechnical Consultants, Inc. (GCI) to assist us in this assessment including discussing potential main mine safety issues that may need to be considered for the central shafts. A copy of Dr. Mahar's report and a supplemental letter are included as an appendix to this letter. This consultation was limited to the central shafts and did not include an assessment of the horizontal tunnels for the Radial - type system.

Please note that the comments and recommendations presented herein are initial in nature and should not be used for design and construction. Detailed geotechnical and geological explorations will need to be performed for design and construction.

2.0 PROJECT CONSIDERATIONS

According to a July 15, 2005 GWA article, six (6) collector wells constructed in the limestone of Guam's north plateau would be able to replace the water production of the 120 wells presently feeding the system. The general locations of where wells are being considered are shown on the Island Map and Geologic Map presented on Plates 1 and 2, respectively.

The collector well concept consists of a central caisson shaft extending into the water table with several horizontal tunnels radiating outward, collecting water evenly over a wide area. The collector wells are expected to extend to the water table at/or slightly above sea level. Because the project is in the feasibility assessment phase, details of the shafts and tunnels are not yet known.

3.0 SCOPE OF SERVICES

Based on the above considerations, the following initial geotechnical consultation services were performed:

1. *Review of Readily Available Data* – Readily available data on subsurface and geologic conditions in the general vicinity of the proposed shaft sites were reviewed. The sources of this review included information in our files, a report by Tracey, et al (1964) on the geology of Guam, and other readily available information.

2. *Initial Analysis of Available Data* - Based on our review of available data, initial analysis was performed and initial comments were developed for the central shafts regarding:

   a. Anticipated geologic conditions,
   b. Potential rock structure and tectonic setting,
   c. Ground water and solution features,
   d. Potential main shaft construction considerations,
   e. Potential main ground support concerns, and
   f. Recommendations for detailed geotechnical and geological explorations.

3. *Consultation Letter Preparation* – This letter has been prepared to summarize the results of this consultation. Please note that geotechnical and geological explorations, site visits, and other related tasks were not included in this consultation. Assessing the feasibility of horizontal collector tunnels was also not included in the scope of our services.

4.0 DISCUSSION

Based on the results of this consultation and an assessment by GCI (March, 2006 and May, 2006), it is our initial opinion that central shafts at the sites being considered by GWA are feasible from a geotechnical engineering standpoint. Initial potential main geotechnical and geologic concerns and considerations for the shafts, such as expected geologic conditions, potential ground behavior, ground support concerns, and shaft excavation / support requirements are discussed in detail in GCI's attached report and letter, and are summarized herein.

Please note that this initial consultation and GCI's assessment have relied heavily on Tracey's Geology of Guam (1964) and general knowledge of geologic conditions based on our previous work on Guam. Based on our discussions, we understand that logs of existing water supply wells in the vicinity of the proposed wells are not readily available.

Site specific geotechnical and geological explorations will need to be performed at each proposed shaft location and for the collector tunnels. The comments and feedback presented herein are initial in nature and should not be used for design and construction.

Based on a review of readily available information and according to GCI, expected geologic conditions, ground behavior, and shaft excavation requirements for the proposed Radial - type collector well system are summarized below. Please note that Tracey's Geologic Map (1964) presented on Plate 2 represents general surficial geology. Actual geologic and subsurface conditions below the surface will need to be characterized by site specific subsurface exploration and testing.

- *Expected Geologic Conditions* - Geologic units in the project area are expected to include detrital and molluscan facies of the Mariana limestone formation, the Barrigada limestone formation, and the base volcanic rocks of the Alutom Formation. The Barrigada and Mariana limestones are mainly lagoonal in origin and characteristically friable to well-cemented. The Alutom rocks include water-laid pyroclastic and flow rock ranging from shale to boulder conglomerate and block breccia. The conceptual model for this assessment assumed that the collection wells would be installed into the permeable limestone formations. Due to low anticipated permeability and possible water quality issues, it was assumed that the wells would not be installed into the Alutom formation. GCI has summarized estimated surficial geologic conditions at the tentative shaft sites in their May 5, 2006 letter which is included in the appendix to this letter.

- *Rock structure and tectonic setting* – Geologic structures present in the limestone that are expected in the proposed shaft excavations include joint sets, high-angle normal faults, joint / brecciated zones, and minor faults. These structures would not only increase the permeability of the limestone formations, but would also require continuous support in the shaft excavations. Guam is located in a seismically active region and seismic considerations will need to be addressed in the design of the shafts.

  Proposed shaft CW-6 is sited just north of an inferred west-east fault on Tracey's geologic map presented on Plate 2. The presence and nature of inferred faults in the vicinity of this shaft and at the other potential shaft sites and potential impacts to the shafts will need to be assessed as a part of site specific explorations. This information would not only be needed for design, but would also be needed to determine if modifications to the shaft sites, such as re-siting, are needed.

  As indicated in GCI's May 5, 2006 letter, active faults should be avoided at the shaft locations. Shaft locations intersected by major faults and fault zones with wide gouges and broken zones should also be avoided. We preliminarily anticipate that the shafts could probably be advanced through dormant faults. However, excavation and support difficulties could potentially occur that may result in an increase in construction difficulty and cost.

- *Ground water and solution features* – Readily available records of wells drilled in the north plateau presented in Tracey, et al (1964) indicate that the groundwater table in the vicinity of the proposed shafts is likely to be present slightly above sea level. These records also show that the top of the volcanic base within the project area is generally present below sea level. Freshwater lying on these impermeable volcanic base rocks forms a parabasal groundwater lens.

  Solution features, such as sinkholes and cavities, are common in the limestone of the north plateau, and are important in recharging the groundwater table, but would present shaft support problems. If encountered, they must be grouted behind permanent shaft lining.

  Wells and borings drilled into this limestone have also encountered localized zones of perched water. Perched water or where regional groundwater levels are encountered in poorly or uncemented limestone could result in potential instability of the shaft walls and temporary bottom of the shaft excavations. The term “temporary bottom” refers to an intermediate level in the shaft excavation between the top and bottom of the opening.

- *Shaft Construction* – Initial and permanent support will need to be provided along the full depth of the shaft excavations. A possible main concern with the construction of the shafts is initial support of their walls. Based on the anticipated geologic and subsurface conditions, it is our initial opinion that initial shaft support could probably be accomplished using fully lagged or shotcreted ring beams in raveling zones and shotcrete with rock bolts in more competent, cemented zones. Permanent support of the shafts could possibly be accomplished by the placement of a reinforced concrete lining after the shaft is driven. All voids, solution features, and areas of lost ground behind the lining will need to be grouted. A conceptual sketch by GCI of the plan and cross section of a possible Radial - type collector well system for this project is presented on Plate 3.

  Shaft excavation may require disc cutter or drill/blast methods in well-cemented limestone. Conventional excavation equipment such as small backhoes may be used in friable and uncemented zones. Shaft excavation and initial support methods, and permanent support design will depend on the results of a site specific exploration program.

- *Potential Ground Support Concerns* - Based on the above anticipated subsurface conditions and the general shaft construction considerations discussed herein, the following initial potential main ground support concerns are anticipated:

    - *Loosening of rock blocks and raveling* – Fast raveling with associated ground loss will tend to occur in uncemented intervals of the shaft excavation and where fault / fault zones, joint zones, or brecciated zones are encountered, and in soil and rock filled solution cavities. Continuous support of the shaft sidewalls will need to be installed to the bottom of each excavated interval.

    - *Flowing ground (movement of soil with inflowing ground water)* – Flowing ground is defined in this letter as the movement of soil with inflowing ground water. It may occur in localized portions of the shaft excavations where perched water zones on Limy Mudstone of the Mariana Detrital Facies are encountered and in the portions of the shaft above and below the water table. Probing will likely need to be performed before excavating each interval of the shaft to locate potential perched water. Injection grouting may need to be performed to reduce the amount of flowing ground into the shafts. Injection grouting may also be needed at the bottom of the shaft, below the ground water table.

    - *Swelling of clay zones* – Clay zones can result in swelling and squeezing. These zones should be identified and checked during site specific geotechnical explorations and during construction.

5.0 DETAILED GEOTECNICAL AND GEOLOGICAL EXPLORATIONS

As discussed herein, detailed geotechnical and geological explorations will need to be performed at the shaft sites for design. We anticipate that these explorations may generally include the following surface and subsurface explorations:

Surface Explorations:

- Surface geotechnical / geological reconnaissance on and around the proposed shaft sites

- Study of rock exposures at locations such as quarries or major cuts

- Evaluation of potential geotechnical and geologic conditions based on rock exposures along the Tamuning-Yigo Fault zone

- Providing feedback regarding possible selection of more favorable shaft sites based on the surface geotechnical / geological reconnaissance and available space considerations

Subsurface Explorations:

- Exploratory borings drilled from the top of shaft to a depth of least 20 feet below the proposed shaft invert. We preliminarily anticipate that at least 2 to 3 borings will be needed at each shaft location. The borings will need to be continuously sampled and cored. We are not aware of drilling equipment on Guam that is capable of performing the detailed and continuous sampling, coring, and testing needed for the shafts. We anticipate that the drilling equipment will likely need to be mobilized to Guam from off-island locations. In-place penetration testing, pressure injection permeability testing, and coring will need to be performed in the borings at select depths. Borehole cameras should also be utilized where appropriate. After the completion of the drilling and sampling, piezometers or observation wells should be installed to monitor groundwater levels and water quality. Laboratory testing of select soil and rock samples should be performed to determine soil / rock classifications and engineering properties of the subsurface materials that are encountered.

Please note that the above outlined exploratory program may need to be modified after the specific project requirements are known.

6.0 LIMITATIONS

This geotechnical consultation letter has been prepared for the use of Brown and Caldwell in accordance with generally accepted soils and foundation engineering practices. No warranty or guarantee, expressed or implied or other representation is made as to the professional advice included in this consultation letter and none should be inferred.

This consultation letter has been developed for the use of Brown and Caldewell for the Feasibility Study for Radial - type collector wells being considered by the Guam Waterworks Authority for Guam, Mariana Islands. It does not contain sufficient information for the purposes of other parties or for other uses.

The scope of our services for this feasibility study was limited to an initial assessment of potential main geotechnical and geologic considerations based on readily available information. Should this well concept proceed to the design stage, it is highly recommended that detailed geotechnical and geological explorations be performed to develop appropriate recommendations for the design and construction of the collector wells. Should the well concept change from those assumed herein, we should be retained and consulted to review the comments and feedback presented herein. Our comments and GCI's feedback should not be used for design and construction.

The scope of our services for this project was limited to conventional geotechnical services and did not include any environmental assessment or evaluations. Silence in this consultation letter regarding any environmental aspects of the site does not indicate the absence of potential environmental problems.

Our scope of services specifically excluded the investigation, detection, or assessment of the presence of Biological Pollutants in or around any existing or planned structure. Accordingly, this consultation letter includes no interpretations, recommendations, findings, or conclusions for the purpose of detecting, preventing, assessing, or abating Biological Pollutants. The term "Biological Pollutants" includes, but is not limited to molds, fungi, spores, bacteria, and viruses, and/or any of their byproducts.

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Please do not hesitate to contact the undersigned if you have any questions regarding this letter.

Yours very truly,

PACIFIC GEOTECHNICAL ENGINEERS, INC.

Glen Y.F. Lau, P.E.
President

Attachments:	Plate 1	-	Island Map
	Plate 2	-	Geologic Map
	Plate 3	-	Conceptual Sketch of Radial - Type Collector Well System
	Appendix	-	GCI Report, Feasibility Study, Radial - type Collector Well System, 29 March 2006 and Supplemental Letter, 5 May 2006

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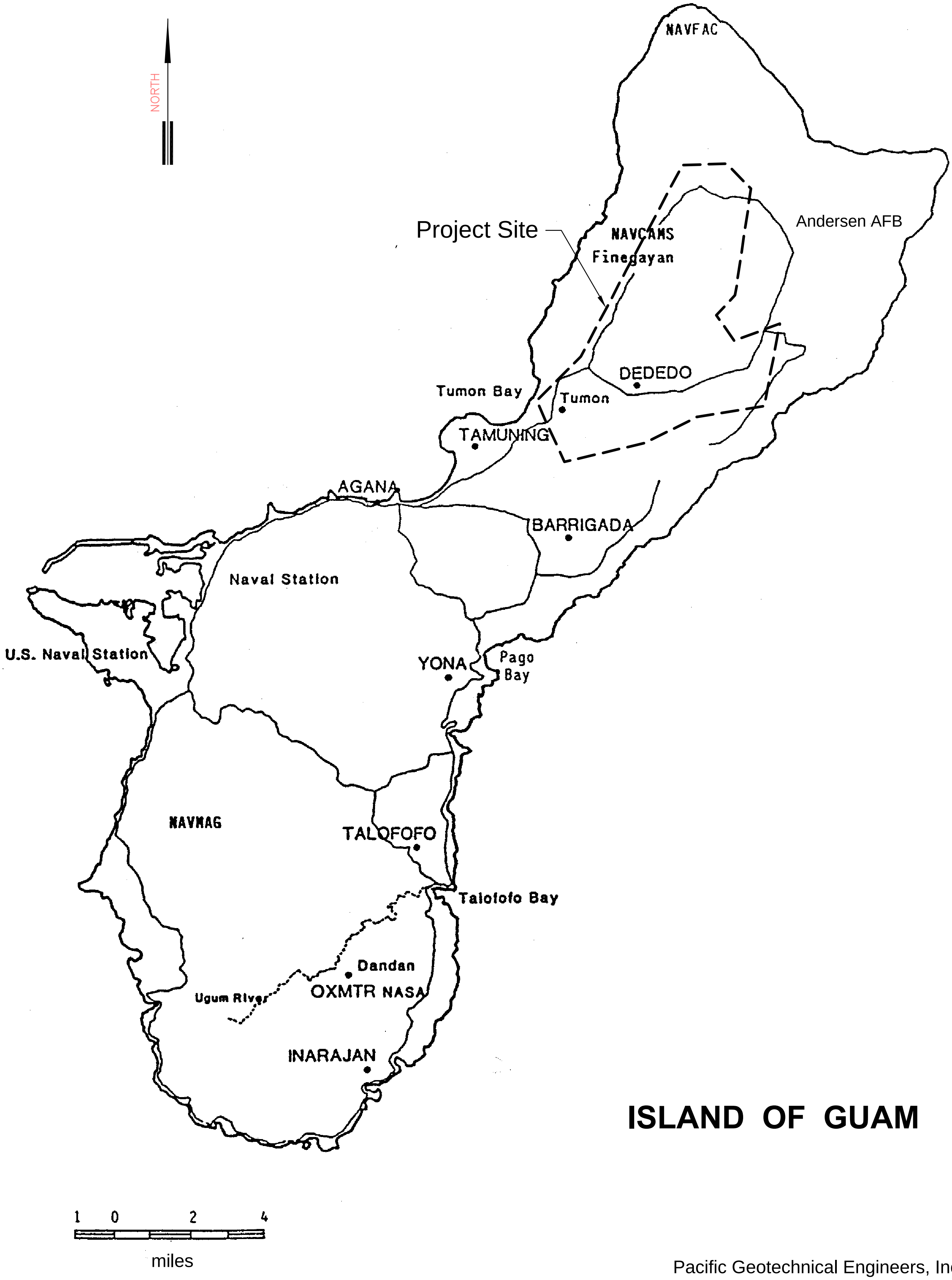

ISLAND OF GUAM

Pacific Geotechnical Engineers, Inc.

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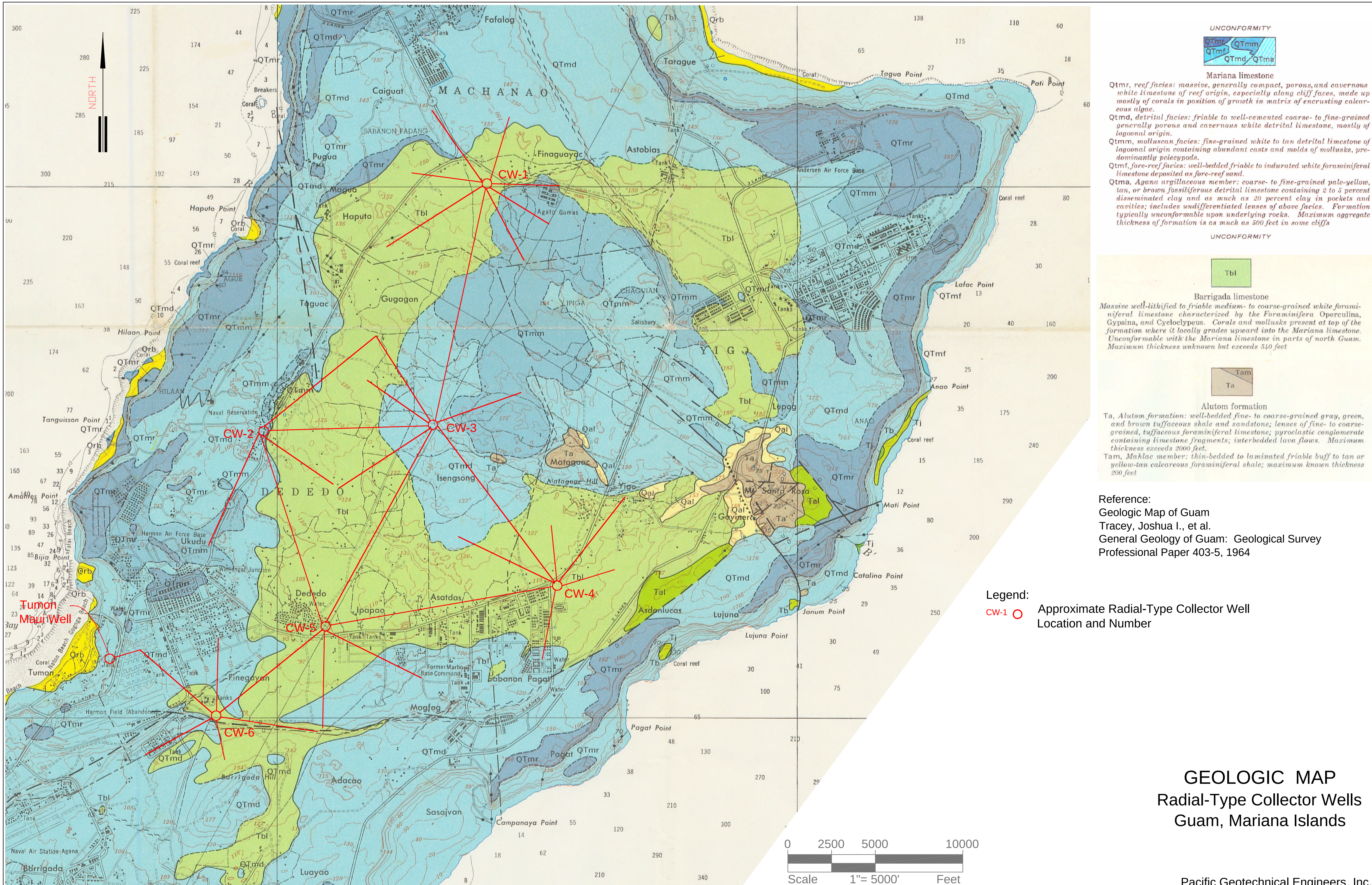
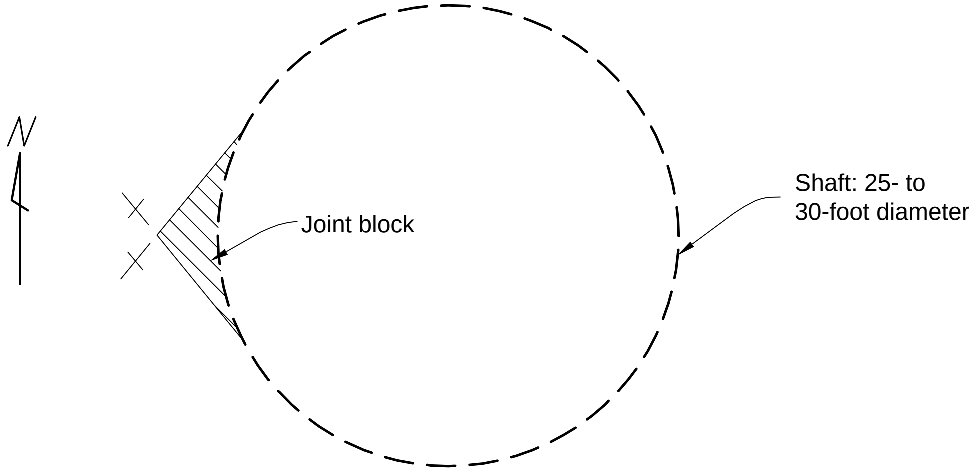
PLATE 1


NORTH
CW-1
CW-2
CW-3
CW-4
CW-5
CW-6
Tumon Maui Well
MACHANAO
DEDEDO
YIGO
UNCONFORMITY
QTmr QTmm QTmf QTmd QTma
Mariana limestone
Qtmr, reef facies: massive, generally compact, porous, and cavernous white limestone of reef origin, especially along cliff faces, made up mostly of corals in position of growth in matrix of encrusting calcareous algae.
Qtmd, detrital facies: friable to well-cemented coarse- to fine-grained generally porous and cavernous white detrital limestone, mostly of lagoonal origin.
Qtmm, molluscan facies: fine-grained white to tan detrital limestone of lagoonal origin containing abundant casts and molds of mollusks, predominantly pelecypods.
Qtmf, fore-reef facies: well-bedded friable to indurated white foraminiferal limestone deposited as fore-reef sand.
Qtma, Agana argillaceous member: coarse- to fine-grained pale-yellow, tan, or brown fossiliferous detrital limestone containing 2 to 5 percent disseminated clay and as much as 20 percent clay in pockets and cavities; includes undifferentiated lenses of above facies. Formation typically unconformable upon underlying rocks. Maximum aggregate thickness of formation is as much as 500 feet in some cliffs
UNCONFORMITY
Tbl
Barrigada limestone
Massive well-lithified to friable medium- to coarse-grained white foraminiferal limestone characterized by the Foraminifera Operculina, Gypsina, and Cycloclypeus. Corals and mollusks present at top of the formation where it locally grades upward into the Mariana limestone. Unconformable with the Mariana limestone in parts of north Guam. Maximum thickness unknown but exceeds 540 feet
Tam
Ta
Alutom formation
Ta, Alutom formation: well-bedded fine- to coarse-grained gray, green, and brown tuffaceous shale and sandstone; lenses of fine- to coarse-grained, tuffaceous foraminiferal limestone; pyroclastic conglomerate containing limestone fragments; interbedded lava flows. Maximum thickness exceeds 2000 feet.
Tam, Mahlac member: thin-bedded to laminated friable buff to tan or yellow-tan calcareous foraminiferal shale; maximum known thickness 200 feet
Reference:
Geologic Map of Guam
Tracey, Joshua I., et al.
General Geology of Guam: Geological Survey Professional Paper 403-5, 1964
Legend:
CW-1 Approximate Radial-Type Collector Well Location and Number
0 2500 5000 10000
Scale 1"= 5000' Feet
GEOLOGIC MAP
Radial-Type Collector Wells
Guam, Mariana Islands
Pacific Geotechnical Engineers, Inc.



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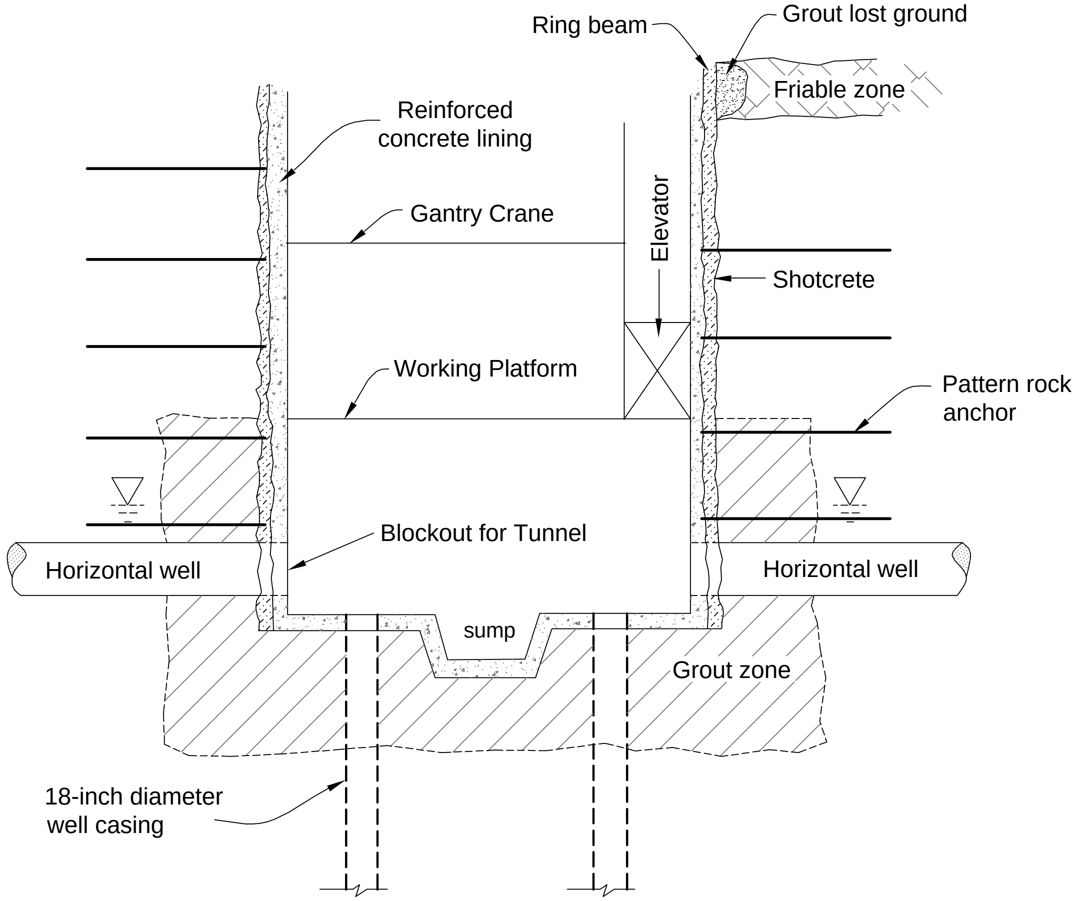

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Conceptual Sketch
Radial-Type Collector Well System
Guam, Mariana Islands

Pacific Geotechnical Engineers, Inc.

APPENDIX - GCI REPORT, FEASIBILITY STUDY
RADIAL - TYPE COLLECTOR WELL SYSTEM

GEOTECHNICAL CONSULTANTS, INC.

Telephone: (217) 351-8707 • Facsimile: (217) 351-8700

4 College Park Court
P.O. Box 125
Savoy, IL 61874-0125

29 March 2006

Pacific Geotechnical Engineers
429-B Waiakamilo Road
Honolulu, Hawaii 96817

RE: Feasibility Study
Radial Type Collector Well System
Guam Waterworks Authority
Guam, Marianas Islands

Mr. Glen Lau PE:

The following report summarizes my analysis of the expected geologic conditions, ground behavior, ground support safety issues and shaft excavation/support requirements for the proposed collector well system on Guam. This report deals only with the collector shaft and does not address the horizontal microtunnels. From a geotechnical/construction perspective, it is my opinion that the Radial Type Well Collector System is feasible for the northwest portion of Guam. Final design, cost and schedule details will depend on an analysis of the site specific conditions.

The summary and recommendations given in this report are based on my study of the Tracey et al 1964 USGS Professional Paper, on the 2005 Guam Waterworks Authority article and on my 35-years as a geotechnical consultant involving design and construction of shaft excavations and hydrogeologic conditions. This experience includes work in Hawaii, the Marshall Islands, the continental US and Egypt which have similar volcanic-limestone geologic settings.

Respectfully submitted,

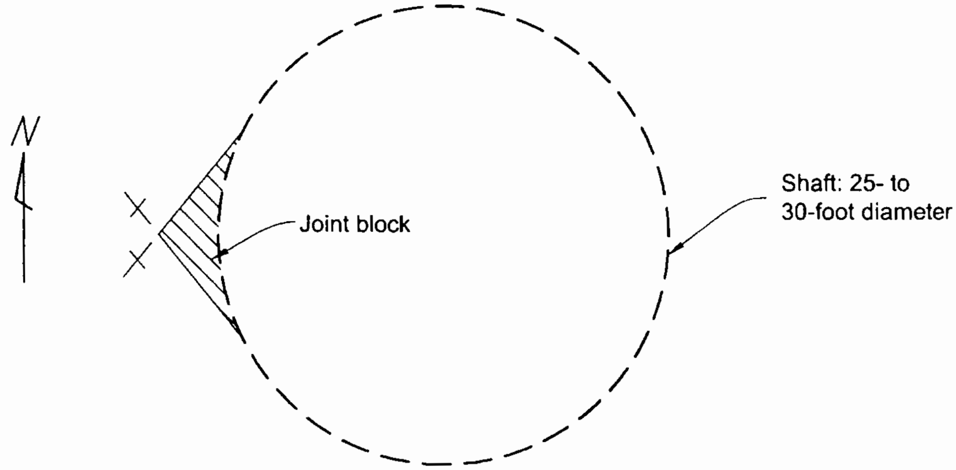
GEOTECHNICAL CONSULTANTS INC

James W. Mahar PhD-LPG

1. INTRODUCTION

The Guam Waterworks Authority is considering construction of a Radial Well System to supply potable water on the northwest end of the Island (North Plateau). The Radial system is basically one or more vertical shafts excavated to a depth below the ground water table. Horizontal tunnels (wells) are then driven out from the central collection chamber at the bottom of the shaft to supply fresh ground water which in turn is pumped to a storage tank located at the ground surface.

Based on your letter of 10 March 2006, each collector will have a central shaft, collector room, pump room and freight elevator. In order to accommodate the proposed equipment and to provide sufficient working space for the mircotunnel operation, I recommend that one collector shaft be driven full depth to the bottom of the chamber. A circular shaft is preferred and a preliminary estimate of the shaft diameter is 25 to 30 ft (see Fig.1 of this report). A working platform and overhead gantry will likely be needed in the chamber. The elevator and well casings would be supported along the sides of the shaft. The intent is to use the lower portion of the shaft as the collection chamber without widening the excavation as indicated on page 3 in the Guam Waterworks Authority article. Injection of grout will be needed to seal the opening below the highest ground water table. In this analysis, the regional ground water table is assumed to be at or near sea level as stated by Tracey et al (1964) (see Section 4.1 of this report).



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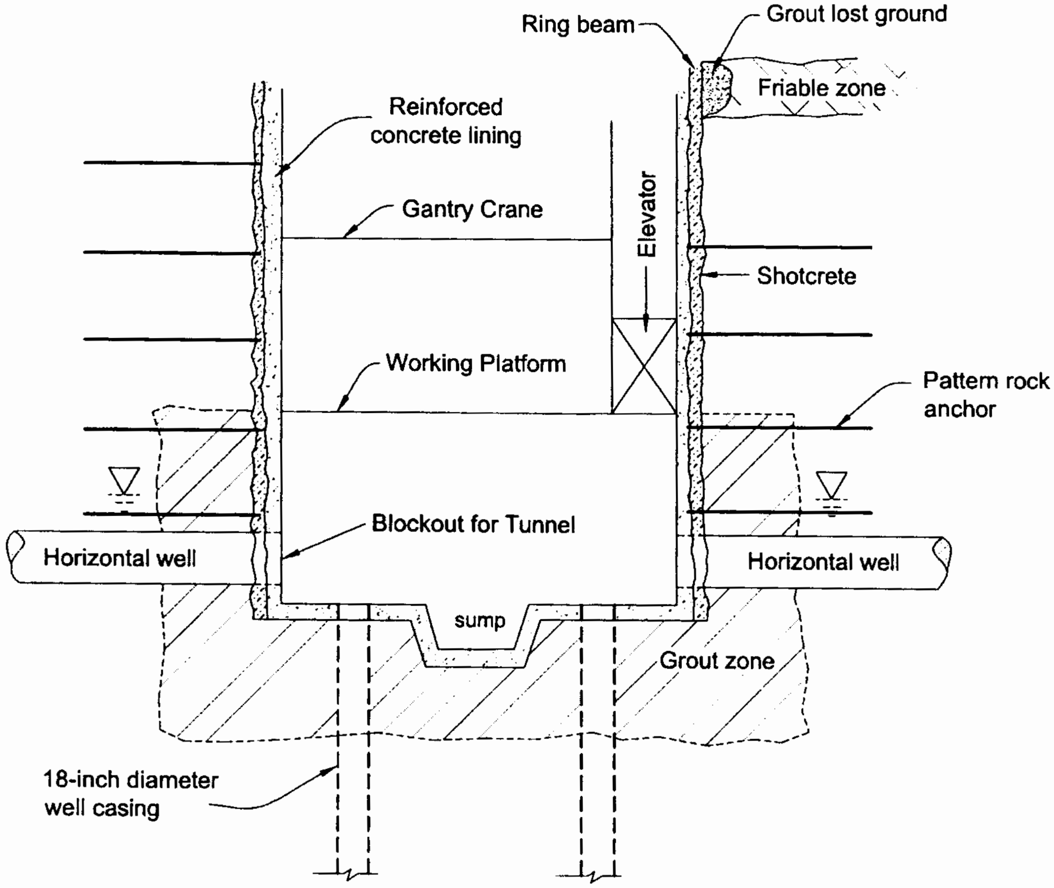

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(NOT TO SCALE)

Radial-Type Collector Well System
Guam, Mariana Islands

FIGURE 1

2. ESTIMATED GEOLOGIC CONDITIONS

2.1 INTRODUCTION

The rock units expected in the shaft excavations are Pleistocene and Tertiary sedimentary rocks associated with carbonate reef deposits. The following rock layer descriptions are taken from the text and geologic map prepared by Tracey et al (1964). The geologic formation descriptions are given in descending age as would be encountered starting at the top of the shaft. Not all of the formations will be present at each shaft location. The rock sequence encountered in the shaft excavations will depend primarily on the elevation at the top of the shaft, location of the shaft and the distribution of the geologic units in the project area.

2.2 GEOLOGIC FORMATION CHARACTERISTICS

A total of five geologic formations have been mapped in the project area by the United States Geologic Survey (Tracey et al 1964). The geotechnical features of each formation are summarized in the following sections of this report.

2.2.1 MARIANA LIMESTONE (Qtm)

The Mariana Limestone is subdivided into five units based primarily on origin and fossil assemblage. The five units are listed as follows:

- Reef Facies
- Detrital Facies
- Molluscan Facies

- Fore-Reef Facies and
- Agana Argillaceous Member.

Based on the geologic map of the North Plateau and on Figure 20 in the Tracey report, the first three units are expected to be encountered in the project area. The Fore-Reef facies occurs along the outside edge of the island and the Argillaceous Member is found on the southwest end of the North Plateau. Neither unit is expected in the proposed shaft excavations.

The general geologic character of the Mariana Limestone is given the boring log of Drill Hole 2109 (No 15) located on Barrigada Hill near proposed Collector Well CW-6. The following log is taken directly from the Tracey et al (1964 report):

Depth (feet)	*Description*
	Mariana limestone:
0–10	Not cored. Soil zone (few inches) and rubbly limestone.
10–25	Limestone, hard to friable, very porous, fossiliferous. Contains poorly preserved traces of *Porites* and mollusk shells. Solution channels and light-yellow staining to base of unit.
25–30	Limestone, coarse, white, sandy.
30–63.5	Limestone, fossiliferous, detrital. *Porites* and *Acropora* are common in sticklike molds near top. Mollusks abundant at 45 ft.
63.5–67	Limestone, granular and detrital, chalky.
67–104	Limestone, fossiliferous, chalky. Mollusks abundant at 75 ft. Cavernous at 90 ft; granular or sandy at 98–104 ft.
104–155	Limestone, detrital, fossiliferous. Corals and mollusks common at 115, 148 ft. *Gypsina* found at 148 ft. Partly recrystallized to tan limestone in patches.
155–197	Barrigada limestone: Detrital, white and chalky, finely porous and even-grained. Typical Barrigada Foraminifera, such as *Operculina*, are present at 183 ft. and abundant at 196 ft.

The log describes a cavernous section at a depth of 90 ft and a granular or sandy zone between 98 and 104 ft. The boring log is not sufficiently detailed to design and construct a shaft excavation, but provides a general representation of the Mariana and Barrigada stratigraphy.

REEF FACIES (Qtmr)

The Reef Facies tends to occur near the outside edge of the North Plateau at and below the present ground surface. The Reef Facies deposit was formed by coral colonies cemented in an algae matrix. A bullet summary of the rock properties is given as follows:

- massive
- generally compact
- well cemented
  - cemented skeletal structure
- porous at top
- cavernous
  - large unfilled pockets and cavities between coral colonies
- recrystallation in joints and fissures.

The Reef Facies is generally described as a white limestone and appears to have the strongest rock mass properties of the Mariana Formation carbonate deposits in the project area because the rock was formed by cementation. However, some filled and unfilled cavities should be expected in the shaft excavations. Most layers in the unit are expected to require disc cutter or drill/blast excavation methods. Moreover, common excavation equipment such as small backhoes will have difficulty and may encounter refusal in the Reef Facies. Initial and final support will be required in the shaft walls.

DETRITAL FACIES (Qtmd)

The Detrital Facies tends to occur beneath the reef deposits (see Fig. 20 in Tracey report). The Detrital Facies was

> "... formed in a lagoon or on the lagoon margin of a reef" and "covers extensive areas of the north plateau." (word "and" added) (taken from Tracey et al 1964 p. A45).

The geotechnical features of the Detrital Facies are summarized as follows:

- coarse to fine grained
- friable to well cemented and
- generally porous and cavernous.

The Detrital Facies is generally described as a white detrital limestone. The facies ranges from a

> "... coarsely granular ... containing scattered coral heads ... to fine-grained, almost sublithographic, limestone containing scattered molds of mollusks." (Tracey et al 1964. p. A45)

The Glossary of Geology defines a lithographic limestone as a

> "... compact, dense, homogenous, exceedingly fine grained limestone having a pale creamy yellow or grayish color and a conchoidal of subconchoidal fracture..." (Jackson 1997).

Six subfacies were identified in the Detrital Facies unit by the USGS geologists. The subfacies contacts tend to be gradational. The Detrital Coral Subfacies includes a

> "... medium- to coarse-grained white to buff limestone containing scattered to abundant coral heads and fragments." (Tracey et al 1964. p. A45)

Locally, the Coral Subfacies contains coarse rubble or coral conglomerate.

The Detrital Facies also contains a Limy Mudstone Subfacies. The Tracey report describes the Limy Mudstone Subfacies as a

> "... compact fine-grained limestone, chaulky to sublithographic in texture..."

and as a

> "... lithified limy mud..." (Tracey et al 1964. p. A46)

The Limy Mudstone Subfacies

> "... is generally found in swales and hollows of the north plateau and appears to represent deposits of fine limy mud that filled quiet hollows and depressions on the floor of the Mariana lagoon..." (Tracey et al 1964. p. A46)

The presence of the Limy Mudstone Subfacies may be important in shaft construction because of its apparent lower permeability which could create perched water table conditions above the regional ground water level. Such perched conditions will tend to develop instability in the walls and temporary bottom of the shaft excavation. Based on the geologic report, the Mudstone Subfacies occurs in relatively limited exposures and lenses and thus poses local rather than regional shaft behavior problems.

MOLLUSCAN FACIES (Qtmm)

The Molluscan Facies is characterized as a

- medium to fine grained
- white to tan detrital limestone.

The rock was deposited in a lagoon. The detrital (erosion/weathering and deposition) origin of the Molluscan Facies indicates that the limestone is variably cemented and would include uncemented sections of the rock mass similar to all of the subfacies in the Detrital Facies.

2.2.2 BARRIGADA LIMESTONE (Tbl)

The Barrigada Limestone is older and underlies the Mariana Formation. The Tertiary age Barrigada is described as

- massive
- compact/well lithified to extremely friable
- weak grains and

· medium to coarse grained.

The Barrigada is generally described as a white detrital limestone. The fines content (-#200 size fraction) is approximately 4%.

The Barrigada Limestone is unlithified (not cemented) in Harmon Quarry. Furthermore, one of the test holes drilled at the Naval Air Station located in Agana, Guam south of the project area encountered

> "... 50 ft or more of typical coralliferous limestone (Mariana) overlying unconsolidated calcareous sand." (Tracey et al 1964. p. A39)

Based on the text, the unconsolidated sand is in the Barrigada Limestone. The maximum thickness of the Barrigada is greater than 450 ft. The limestone is brecciated and friable where intersected by fault zones.

2.2.3 ALUTOM FORMATION (Ta)

The Barrigada Limestone is underlain by a volcanic/sedimentary rock sequence with a maximum thickness greater than 2000 ft. Cross-section A-A′ in the geologic map in the Tracey report shows the Alutom Formation above sea level on the north end of the island. The formation contains the following rock units:

<u>TUFFACEOUS SHALE AND SANDSTONE</u>

· well bedded

· fine to coarse grained

<u>FORAMINIFERAL LIMESTONE</u>

- fine to coarse grained
- tuffaceous

<u>PYROCLASTIC CONGLOMERATE</u>

<u>INTERBEDDED LAVA FLOWS</u>.

In this report, the conceptual model for the collection well system is to terminate the collector shafts and to drill the horizontal mircotunnels in the Limestone Formations. Moreover, the shafts are not expected to penetrate the Alutom Formation because of the potentially low formation permeability and possible water quality issues.

3.0 ROCK STRUCTURE/TECTONIC SETTING

3.1 INTRODUCTION

Several geologic structures are present in the limestone and volcanic/sedimentary rock sequence. The following structural geologic features are present in the rocks of the North Plateau:

- joint sets
- high-angle normal faults
- joint/brecciated zones
- tight folds
- older thrust faults and
- minor faults.

The tight folds and older thrust faults are in the volcanic/sedimentary rocks and are not expected to be in the shaft excavations.

3.2 JOINT SETS

The rocks in the North Plateau contain horizontal to near horizontal bedding/bedding partings and vertical to subvertical joints sets. The orientation of bedding in the North Plateau limestone is not given in the Tracey report. However, based on the tilt of the Machanao structural block, the bedding dip is estimated to be west southwest at an inclination of 25 ft/mile (essentially horizontal).

Tracey et al (1964) give the following rectilinear joint set orientations:

- N 35 E 90°
- S 54 E 90°.

Both joint sets are described as closely spaced. On the east side of the North Plateau, the joints spaced 1 to several ft apart.

3.3 NORMAL FAULTS AND FAULT ZONES

The most prominent faults/fault zones in the North Plateau rocks are the Tamuning-Yigo Fault Zone and transverse faults in the Mount Saint Rosa area. The Tamuning-Yigo Fault Zone is a high-angle to vertical fault zone that separates the Machanao structural block on the north from the Barrigada block on the south. The Tamuning-Yigo Fault Zone has an east northeast strike and contains breccia zones (broken and soil-like) zones. The fault has a maximum displacement of 200 ft with the south side up in the Barrigada Hill area.

The transverse faults/fault zones in the Mount Santa Rosa area are oriented north northwest and are generally perpendicular to the Tamuning-Yigo Fault Zone (see Tracey Figure 25 on p. A54.). The transverse faults are also high-angle normal faults.

The older faults and tight folds in Mount Santa Rosa are in volcanic-sedimentary rocks of the Alutom (Tam) Formation below the Barrigada and Mariana Limestones. The thrust faults strike northeast and dip northwest. The fold axes also strike northeast. The thrust faults and folds are cut by the younger high-angle normal faults and strike slip faults. Minor, randomly oriented faults are also present in the Alutom rocks. The minor faults have displacements "of a few inches to a few feet" (Tracey et al 1964 p. A58).

3.4 JOINT AND BRECCIA ZONES

The Barrigada and Mariana Limestones contain joint and breccia zones. On page A55, the Tracey report defines joint zones as

> "... dominant sets of parallel joints in limestone along which solution has produced wide, deep fissures separating elongate pinnacled ridges".

Furthermore, the

> "... joint zones in places, are gradational along strike into well-defined faults and breccia zones." (see Tracey et al 1964 p. A56.

The trends of the joint zones are northwest and northeast.

The breccia zones are described on page A56 as

> "... crushed and brecciated zones that generally grade along strike into faults."

3.5 ROCK STRUCTURE IN THE BARRIGADA AND MARIANA LIMESTONES

The rock structures in the Barrigada and Mariana Limestones are treated separately in the Tracey report. The formations contain all of the geologic structures in the Alutom Formation except for the older thrust faults and folds. The geologic structures along with carbonate solutioning are important in providing rock formation permeability but will also require support in the shaft excavations.

3.5.1 BARRIGADA LIMESTONES

The Barrigada Limestone contains the following geologic structures:

- high-angle normal faults
- several sets of joints
- faults and joint zones
    - northeast
    - northwest and
- numerous breccia zones
    - angular fragments of limestone.

On page A60, the Tracey report also states that

> "(C)rushed chaulky zones are common, especially in the Barrigada Limestone"

Some of the joint zones in the Barrigada have been recrystallized and the healed zones are stronger (more indurated) than the adjacent rock.

3.5.2 MARIANA LIMESTONE

Not all faults/fault zones and joints in the older rock units extend up into the Mariana Formation (see Tracey et al 1964 p. A60). However, the same types of geologic structures are present in both limestones. Moreover, the structural geologic conditions in the Mariana Limestone include "near vertical faults, joints and breccia zones" (Tracey et al 1964 p. A60). The faults and fault zones in the Mariana Formation "are generally characterized by very wide brecciated zones" (Tracey et al 1964 page A60).

3.6 TECTONIC/SEISMIC SETTING

Tracey et al (1964) have interpreted the origin of the tight folds and thrust faults in the Alutom Formation as slump features that developed along the margins of an Eocene volcanic cone west of Guam (see Figure 28 on page A58). Thus, they conclude on page A58 that the folds and older thrust faults were not formed by "deep folding and compression." Clearly, the presence of the high-angle normal faults in the younger limestone formations indicate that the regional tectonic stresses are extension and not compression.

The tectonic setting suggests that squeezing and slabbing ground behavior associated with high horizontal stresses will not be encountered in the shaft excavations. Moreover, the ground behavior is expected to be loosening/ravelling with possible flowing conditions if perched ground water or where the regional ground water levels are encountered in poorly or uncemented limestones.

Guam is located in a seismically active zone and seismic considerations must be addressed in the design of the permanent shaft structures. Moreover, earthquakes are moderately common in Guam. The seismic activity is associated with crustal movements in and around the Mariana Trench which is located approximately 70 miles east of Guam. Between 1825 and 1936 estimated earthquake intensities which are rated based on human sensory/damage levels in Guam ranged between V to IX on the Modified Mercali scale. Between 1912 and 1936, Guam experienced four earthquakes of magnitude 6 to 7 on the Richter scale. No consistent records were kept between 1944 and 1956. Since 1960, seismic data have been recorded at the Guam Magnetic Observatory.

4.0 GROUND WATER AND SOLUTION FEATURES IN THE NORTH PLATEAU

4.1 GROUND WATER LEVELS

Little to no information has been provided on the elevation of the regional ground water table and on the elevation of the fresh water/seawater interface in the North Plateau. Because of the near absence of stream flow except during intense rainfall in the North Plateau, Tracey et al (1964) conclude that

> "(R)ainfall sinks directly into porous limestone and passes through to the water table, which is about at sea level in areas not underlain by volcanic rocks." (see p. A62).

4.2 SOLUTION FEATURES

Karstic features are visible in many areas of the North Plateau. Tracey et al (1964) describe sinkholes as varying

> "... from a few feet to about 75 feet deep over most of the plateau." (page A62).

On page A62, the solution features

> "... are sinks or enclosed depressions that may be as much as half a mile in diameter and 40 to 50 feet in depth."

Some areas of the island have sink holes that are aligned and

> "... appear to follow fault zones or the contact between the Mariana and Barrigada Limestones." (Tracey et al 1964 p. A62).

The presence of solution features is important in recharging the ground water table, but present support problems in the shafts and must be grouted behind the final shaft lining.

5.0 SHAFT BEHAVIOR AND SHAFT CONSTRUCTION

5.1 EXPECTED GROUND BEHAVIOR

The ground behavior in the shaft excavations is expected to be loosening of rock blocks and ravelling in uncemented zones. The rock blocks are expected to be bounded by the northeast-northwest trending joint sets or isolated by friable zones. Fast ravelling with associated lost ground will tend to occur in uncemented intervals and where fault/fault zones, joint zones or brecciated zones are encountered in the excavation. In addition, fast raveling will also tend to take place in soil and rock-filled solution features. Short rounds with fully lagged or shotcreted ring beam support will be required in poorly or uncemented sections of the shaft excavation and where solution features are encountered. In addition, continuous side wall support will be needed along the full depth of the shaft excavation. The support must be installed to the bottom of each excavated round. The lengths of the rounds may be increased in fully well cemented reaches of the shaft.

Flowing ground (movement of soil with inflowing ground water) may occur in isolated portions of the shaft excavations. The flowing conditions will take place in perched water zones such as above the Limy Mudstone Subfacies of the Mariana Detrital Facies and in portions of the shaft below the regional ground water elevation. Probe hole drilling in advance of excavation at intermediate levels in the shaft bottom should be required to locate potential water bearing/uncemented zones. Injection of cement and possible chemical grout may be needed to control flowing ground in perched water bearing zones depending on the lateral extent of the water bearing interval. Grout injection to form a curtain wall and plug will be required around the sides and in the bottom of the shaft excavation below the regional ground water table. Clearly, the bottom of the shaft will have to be sealed in the collection zone to reduce water inflow, to prevent possible flowing ground and to seal the shaft at the mircotunnel portals.

The clay mineral Halloysite is a weathering product of the limestone (see Tracey et al 1964 p. A78). Moreover,

> "(H)alloysite is the chief and only clay mineral in all the soils on limestone..."

Halloysite can be a swelling soil. Although no squeezing/swelling conditions are expected, the swelling characteristics of any intensely weathered limestone at the shaft locations should be investigated as part of the site specific geotechnical investigation.

5.2 INITIAL AND FINAL SHAFT SUPPORT

Initial and permanent support is expected along the full depth of the shaft excavations. Initial support of the collector shaft walls can be accomplished using ring beams and wood lagging and by rock bolts and shotcrete. Use of ring beams will require excavation of a circular opening. Where collared in soil or weathered/ fractured rock, the upper portion of the shaft will require steel sets and wood lagging or shotcrete. Rock bolts and shotcrete can be used in cemented intervals. Steel sets are recommended in friable or uncemented zones. Pre-excavation injection of grout is recommended in the thicker friable and solutioned ground reaches. Final determination of the shaft excavation and initial support methods cannot be established until results of site specific bore holes are obtained and analyzed.

The shaft excavations will require placement of a reinforced concrete lining for permanent support after the shaft is driven. The lining will need to be designed on a site specific basis and will depend on the results of the exploration program. All voids, solution features and areas of lost ground must be effectively grouted behind the concrete lining in order to bring the permanent support in intimate contact with the limestone. Based on this preliminary evaluation of the North Plateau conditions, contact and formation grout takes behind the permanent lining are expected to be high.

5.3 SHAFT EXCAVATION

Most of the cemented layers such as in the Reef Facies are expected to require disc cutter or drill/blast excavation methods. Common excavation equipment such as small backhoes can be used in friable and uncemented zones but will have difficulty and may encounter refusal in the cemented layers. Large and hard residual rock blocks should be expected in some of the poorly cemented zones.

6.0 SUMMARY AND CONCLUSIONS

A feasibility study of a Radial Type Collector Well System has been carried out for the Guam Waterworks Authority. The well system is proposed as a water supply for the northwest portion of Guam in the Marianas Islands. The proposed project includes construction of a series of collector wells drilled at 6 sites in the northwest portion of the island. The Radial water supply system consists of a deep, vertical shaft and horizontal wells which collect ground water and pump the water to the ground surface.

The shafts are to be excavated in a series of variably cemented limestones that are jointed and solutioned. On a regional basis, the limestone is also cut by faults and joint/breccia zones. A single, cylindrical, vertical shaft 25 to 30 ft diameter is estimated to accommodate the equipment and to provide sufficient space for the mircotunnel-driven horizontal wells. The rock in the side walls and bottom of the shaft will have to be grouted in the water bearing zone to minimize water inflow, prevent possible flowing ground and to advance the microtunnels from the shaft into the permeable limestone formations. The shaft walls will require initial and permanent support.

In my opinion, the project is feasible. Shaft details, cost and schedule cannot be determined until site specific exploratory borings are drilled, soil/rock samples logged and tested and results are analyzed.

7.0 REFERENCES

Guam Waterworks Authority (2005): Water Lens Supplies Using Long Horizontal Drilled Ranny Type Collector Wells.

Jackson, J.A. (1979): Glossary of Geology, American Geologic Institute Alexandria, Virginia.

Tracey, J.I., S.O. Schlanger, J.T. Stark, D.B. Doan and H.G. May (1964): General Geology of Guam, US Geological Survey Professional Paper 403-A, United States Government Printing Office, Washington, D.C.

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5 May 2006

Pacific Geotechnical Engineers
429-B Waiakamilo Road
Honolulu, Hawaii 96817

RE: Feasibility Study
Radial Type Collector Well System
Guam Waterworks Authority
Guam, Marianas Islands

Dear Glen:

The following outline report summarizes my comments on the request for information made by your client: Brown and Caldwell in their letter of 27 April 2006.

1. Term "Ranny" has been changed to "Radial" in our geotechnical report.

2. GWA article dated 2005 and not 2006 in our geotechnical report.

3. A feasibility report should contain descriptions of all area-wide geologic units pertinent to the project. Moreover, the available data on the pertinent rock units including the Barrigada Limestone have been summarized in our geotechnical report of 29 March 2006. Additional data on the Barrigada Formation as well as the remaining rock units will be developed based on the site specific exploratory investigation.

   The tentative shaft locations have been superimposed on the geologic map provided by the Tracey et al (1964) report (see Plate 1). The following outline is a summary of the estimated surficial geologic conditions at the approximate shaft locations:

   - Shaft Site: CW-1
     - Barrigada Limestone

- Shaft Site: CW-2
  - Mariana Limestone
    - contact area:
      - Molluscan/Detrital Facies

- Shaft Site: CW-3
  - thick sequence of Mariana Limestone
    - Detrital Facies

- Shaft Site: CW-4
  - Barrigada Limestone

- Shaft Site: CW-5
  - Barrigada Limestone

- Shaft Site: CW-6
  - Barrigada Limestone

Not all sites will "collar or quickly reach the Barrigada limestone". I would reserve such statements for an interim report after the site field work and/or subsurface investigation is complete. The rock conditions at the top of the shaft are just as significant as the conditions at depth.

4. Plate 2 in the Tracey et al (1964) report is a map of sample locations. The plate does not indicate the presence of faults in the mapped area. Moreover, the dashed lines on Plate 2 appear to be geographic/ political boundaries and not faults.

   The geologic map of the north end of Guam is given in Plate 1. When the approximate location of Shaft Site CW-6 is superimposed on the geologic map, the suggested shaft site is north of an inferred west-east fault indicated by a dashed line on the map. The presence and nature of the inferred fault south of CW-6 should be investigated as part of the site specific surface and subsurface program. Moreover, the presence of faults and fault zones should be determined as part of the site exploration work not only at the location CW-6 but at all potential shaft sites. The impact of any fault or fault zones should be determined based on the results of the site investigation.

A discussion of plate tectonics and extensional block faulting is premature in a feasibility report. The structural geologic conditions which involve a combination of older folding and thrust faulting (compressive stresses related to slump on the lower slopes of volcanoes) along with the more recent block tilt and normal faulting are complex and will have to be investigated and validated. In my experience, seismic ground motions cause very little or no damage in underground structures where they are properly grouted so that the lining is in intimate contact with the soil/rock and the openings are not intersected by active faults or fault zones. In the Los Angeles Metro Tunnels the only damage caused by the Northridge earthquake was at the intersections of the stiff cross-overs and the running tunnels. The damage in the interface area consisted on small opening of existing cracks and formation of new crack less than 1/16 in. wide. The greatest impact of the Northridge earthquake was on ground water quantity (flowing wells) and quality (elevated sulfate concentrations). This case history does not mean that seismic considerations should be ignored but that such studies are part of later stage investigations.

5. The term "temporary bottom of the excavation" refers to intermediate levels in the shaft excavation between the top and bottom of the opening.

6. Pacific Geotechnical must have provided a statement on use of consultation letter.

7. General recommendations for "detailed geotechnical and geologic investigation" are summarized as follows:

SURFACE INVESTIGATIONS

- surface geotechnical investigation on and around proposed shaft sites
- study of rock exposures in quarries
- evaluation of geotechnical conditions based on rock exposures along Tamuning-Yigo Fault Zone

- use surface geotechnical/available space data to identify best shaft sites

SUBSURFACE INVESTIGATIONS

- core holes drilled from the top of shaft to a depth of at least 20 ft below proposed shaft invert
  - at least 2 to 3 boring/proposed shaft location
  - need continuous samples: no intermittent sampling intervals
  - possible spilt spoon samples or vibro-cores in low core recovery zones
  - pressure injection tests
  - install piezometers and monitor ground water levels
  - possible use of bore hole camera.

GEOTECHNICAL LOGS

- preparation of detailed geotechnical logs

LABORATORY TESTS

- rock/soil classification tests
- compressive strength tests

8. Plate 2 with a legend is not contained in the 29 March 2006 Geotechnical Report.

9. In the North Plateau, the Tamuning-Yigo fault extends between the Agana Small Craft Harbor on the southwest coast to Mount Santa Rosa on the northeast coast. Based on the Tracey et al (1964) Plate 1 and Figure 25, the trace of the Fault is summarized as follows:

- starts at the Agana Small Craft Harbor on southeast coast

- progresses east northeast to Harmon Field

- at Harmon Field to fault turns east-west to Mogfog and then

- east northeast to Santa Rosa. At Santa Rosa, the Tamuning-Yigo fault is cut by a younger north northwest trending transverse fault which offsets the northern portion of the Tamuning-Yigo fault to the southeast.

The Tamuning-Yigo fault is approximately 8 miles long. There is very little detailed information on the nature of the materials in the fault.

Active faults should be avoided at the shaft locations. Shafts can be advanced through dormant faults and fault zones however excavation and support difficulties can occur. If possible, shaft locations intersected by major faults and fault zones with wide gouge and broken zones should be avoided if possible, because of potential increased in construction cost.

Based on Tracey et al (1964) Plate 1 and Figure 25, the Tamuning-Yigo fault is located southeast (not southwest of Mount Santa Rosa. Moreover, Section 3.3 of the GCI report does not state that the Tamuning-Yigo is on the "SW side of Mt. Santa Rosa". Both the geologic map (Plate 1) and Cross-section B-B clearly show that the rocks on southeast side of the Tamuning-Yigo fault have been displaced downward in the Santa Rosa area. The rocks on the southeast side of the Tamuning-Yigo fault are the younger Mariana Limestone since the fault is a normal fault which dips southeast (see southeast end of Cross-Section B-B). The movement along the fault has displaced the younger rocks Mariana Limestone against the older rocks of the Alutom Formation.

On page A56, the Tracey et al 1964 paper describes the displacement along the Tamuning-Yigo fault observed in quarries near Barrigada Hills as follows:

"...the south side of the fault is uplifted a maximum of 200 feet." (see page A56.)

The statement is consistent with the nature of the relative fault movement shown on the geologic map in Plate 1. Northeast of Barrigada Hills, the nature of the fault displacement is reversed: the south side of the fault is down. This includes the far northeast end of the Tamuning-Yigo fault on the southeast side of Mount Santa Rosa.

10. Question 10 answered in response to Question 4.

11. GCI has not received any additional seismic data which post dates the information contained in the in Tracey et al (1964) USGS Professional Paper. Review of post-1964 seismic data will be useful particularly if the magnitudes exceed the 6 to 7 Richter values given in the Tracey et al report or additional data are available on the nature of the ground motions.

12. Based on the Pacific Geotechnical literature search, there are four articles that may provide additional geologic data on Guam. The articles are listed as follows:

- Ayers, J.F. and R.N. Clayshulte (1984): A Preliminary Study of the Hydrogeology of Northern Guam. Environmental Protection Agency, United States Department of the Interior.
- Mink, J.F. and T.M. Quinn (2004): Hydrogeology and of Northern Guam in Geology and Hydrogeology of Carbonate Islands, Elsevier Publishing Co.
- ... (1976) Groundwater Resources of Guam: Occurrence and Development. Report #1

· ... (1999(Karst Geology and Hydrology of Guam: A Preliminary Report #89.

Respectfully submitted,

GEOTECHNICAL CONSULTANTS INC

James W. Mahar PhD-LPG

APPENDIX B

ALIMAK U-600 GENERAL SPECIFICATION

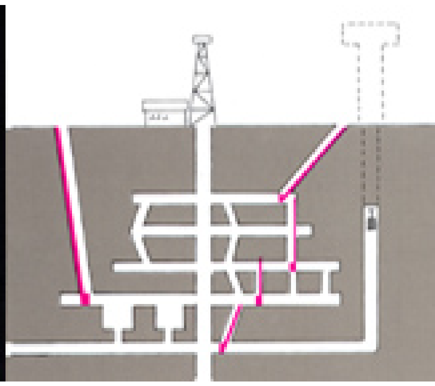
(Note: This information is for illustration purposes only.)

ALIMAK U-600
General specification

Inspection/Interlevel Lifts for installations underground

Wherever in mines and underground shafts a lift for inspection, emergency or interlevel hoisting is required, the ALIMAK U-600 Rack & Pinion lift is the most economical choice. It requires no machine room, it can be installed at any inclination and provides a time saving, safe and comfortable transport facility. So far, the longest installation goes 650 m deep. The ALIMAK U-600 range offers load capacities from 400 to 1200 kg for 3–12 passengers. It travels at speeds of up to 0.8 metres per second and is equipped with the proven Alimak GF safety device.

Payload capacity	400–1,200 kg
Speed	up to 0.8 m/s.
Max. lifting height	Practically unlimited (longest installation goes 650 m deep)
Car width (internal)	0.7–1.0 m
Car length (internal)	0.9–1.9 m
Car height (internal)	2.15 m
Motor control	DOL
No. of motors	1–2
Safety device type	GF
Power supply range	380–690 V, 50 or 60 Hz, 3 phase
Type of mast	U-600 guide rail
Length mast section	1.508 m
Weight mast section with 1 rack	81 kg
Rack module	8



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APPENDIX C

MSHA SAFETY REGULATIONS PERTAINING TO SHAFT VERSUS DECLINE COMPARISONS

(Regulations are from 30CFR)

Regulations involving Shafts and Steep Inclines (requiring hoisting equipment)

57.11040 – Inclined Travelways

Travelways steeper than 35 degrees from horizontal shall be provided with ladders or stairways.

57.11055 – Inclined Escapeways.

Any portion of a designated escapeway which is inclined more than 30 degrees from the horizontal and that is more than 300 feet in vertical extent shall be provided with an emergency hoisting facility.

57.11056 – Emergency hoists.

The procedure for inspection, testing and maintenance required by standard 57.19120 shall be utilized at least every 30 days for hoists designated as emergency hoists in any evacuation plan.

57.19023 – Hoist Rope Examinations.

(a) At least once every fourteen calendar days, each wire rope in service shall be visually examined along its entire active length for visible structural damage, corrosion, and improper lubrication or dressing. In addition, visual examination for wear and broken wires shall be made at stress points, including the area near attachments, where the rope rests on sheaves, where the rope leaves the drum, at drum crossovers, and at change-of-layer regions. When any visible condition that results in a reduction of rope strength is present, the affected portion of the rope shall be examined on a daily basis.

(b) Before any person is hoisted with a newly installed wire rope or any wire rope that has not been examined in the previous fourteen calendar days, the wire rope shall be examined in accordance with paragraph (a) of this section.

(c) At least once every six months, nondestructive tests shall be conducted of the active length of the rope, or rope diameter measurements shall be made:

(c)(1) Wherever wear is evident;

(c)(2) Where the hoist rope rests on sheaves at regular stopping points;

(c)(3) Where the hoist rope leaves the drum at regular stopping points; and

(c)(4) At drum crossover and change-of-layer regions.

(d) At the completion of each examination required by paragraph (a) of this section, the person making the examination shall certify, by signature and date, that the examination has been made. If any condition listed in paragraph (a) of this section is present, the person conducting the examination shall make a record of the condition and the date. Certifications and records of examinations shall be retained for one year.

(e) The person making the measurements or nondestructive tests as required by paragraph (c) of this section shall record the measurements or test results and the date. This record shall be retained until the rope is retired from service.

57.19055 – Availability of hoist operator for manual hoists.

When a manually operated hoist is used, a qualified hoistman shall remain within hearing of the telephone or signal device at all times while any person is underground.

57.19056 – Availability of hoist operator for automatic hoists.

When automatic hoisting is used, a competent operator of the hoist shall be readily available at or near the hoisting device while any person is underground.

57.19057 – Hoist operator's physical fitness.

No person shall operate a hoist unless within the preceding 12 months he has had a medical examination by a qualified, licensed physician who shall certify his fitness to perform this duty. Such certification shall be available at the mine.

57.19058 – Experienced hoist operators.

Only experienced hoistmen shall operate the hoist except in cases of emergency and in the training of new hoistmen.

57.19129 – Examinations and tests at beginning of shift.

Hoistmen shall examine their hoists and shall test overtravel, deadman controls, position indicators, and braking mechanisms at the beginning of each shift.

57.19130 – Conveyance shaft test.

Before hoisting persons and to assure that the hoisting compartments are clear of obstructions, empty hoist conveyances shall be operated at least one round trip after:

(a) Any hoist or shaft repairs or related equipment repairs that might restrict or obstruct conveyance clearance;

(b) Any oversize or overweight material or equipment trips that might restrict or obstruct conveyance clearance;

(c) Blasting in or near the shaft that might restrict or obstruct conveyance clearance; or

(d) Remaining idle for one shift or longer.

57.19131 – Hoist conveyance connections inspection.

Hoist conveyance connections shall be inspected at least once during any 24-hour period that the conveyance is used for hoisting persons.

57.19132 – Safety catches testing and inspections.

(a) A performance drop test of hoist conveyance safety catches shall be made at the time of installation, or prior to installation in a mockup of the actual installation. The test shall be certified to in writing by the manufacturer or by a registered professional engineer performing the test.

(b) After installation and before use, and at the beginning of any seven day period during which the conveyance is to be used, the conveyance shall be suitably rested and the hoist rope slackened to test for the unrestricted functioning of the safety catches and their activating mechanisms.

(c) The safety catches shall be inspected by a competent person at the beginning of any 24-hour period that the conveyance is to be used.

57.19133 – Shaft Inspection.

Shafts that have not been inspected within the past 7 days shall not be used until an inspection has been conducted by a competent person.

57.19134 – Sheaves Inspection.

Sheaves in operating shafts shall be inspected weekly and kept properly lubricated.

Regulations involving Declines (travel by foot or rubber tired equipment – no hoisting equipment required)

57.3401 – Examination of ground conditions.

Persons experienced in examining and testing for loose ground shall be designated by the mine operator. Appropriate supervisors or other designated persons shall examine and, where applicable, test ground conditions in areas where work is to be performed, prior to work commencing, after blasting, and as ground conditions warrant during the work shift. Underground haulageways and travelways and surface area highwalls and banks adjoining travelways shall be examined weekly or more often if changing ground conditions warrant.

Important Regulations involving all MSHA regulated underground facilities

57.11050 – Escapeways and Refuges.

(a) Every mine shall have two or more separate, properly maintained escapeways to the surface from the lowest levels which are so positioned that damage to one shall not lessen the effectiveness of the others.

(b) In addition to separate escapeways, a method of refuge shall be provided for every employee who cannot reach the surface from his working place through at least two separate escapeways within a time limit of one hour when using the normal exit method. These refuges must be positioned so that the employee can reach one of them within 30 minutes from the time he leaves his workplace.

APPENDIX D

OSHA SAFETY REGULATIONS PERTAINING TO UNDERGROUND CONSTRUCTION INSPECTIONS

(Regulations are from 29CFR)

1926.800(j)(1)(iii)(A)

The atmosphere in all underground work areas shall be tested quantitatively for carbon monoxide, nitrogen dioxide, hydrogen sulfide, and other toxic gases, dusts, vapors, mists, and fumes as often as necessary to ensure that the permissible exposure limits prescribed in 1926.55 are not exceeded.

1926.800(j)(1)(iii)(B)

The atmosphere in all underground work areas shall be tested quantitatively for methane land other flammable gases as often as necessary

1926.800(o)(3)(i)(A)

A competent person shall inspect the roof, face, and walls of the work area at the start of each shift and as often as necessary to determine ground stability.

1926.800(o)(3)(i)(B)

Competent persons conducting such inspections shall be protected from loose ground by location, ground support or equivalent means.

1926.800(o)(3)(ii)

Ground conditions along haulageways and travelways shall be inspected as frequently as necessary to ensure safe passage.

APPENDIX E

INTERAGENCY AGREEMENT BETWEEN THE MSHA US DEPARTMENT OF LABOR AND THE OSHA US DEPARTMENT OF LABOR

The Mine Safety and Health Administration (MSHA), U.S. Department of Labor, and the Occupational Safety and Health Administration (OSHA), U.S. Department of Labor, have entered into this agreement to delineate certain areas of authority, set forth factors regarding determinations relating to convenience of administration, provide a procedure for determining general jurisdictional questions, and provide for coordination between MSHA and OSHA in all areas of mutual interest.

E.1 Authority and Principle

1. The Federal Mine Safety and Health Act of 1977, Pub. L. 91-173 as amended by Pub. L. 95-164 (Mine Act), authorizes the Secretary of Labor to promulgate and enforce safety and health standards regarding working conditions of employees engaged in underground and surface mineral extraction (mining), related operations, and preparation and milling of the minerals extracted.
2. The Occupational Safety and Health Act of 1970 (OSHAct) gives the Secretary of Labor authority over all working conditions of employees engaged in business affecting commerce except those conditions with respect to which other Federal agencies exercise statutory authority to prescribe or enforce regulations affecting occupational safety or health. The OSHAct also provides that States may operate their own occupational safety and health programs under a plan approved by the Secretary.
3. This agreement is entered into to set forth the general principle and specific procedures which will guide MSHA and OSHA. The agreement will also serve as guidance to employers and employees in the affected industries in determining the jurisdiction of the two statutes involved. The general principle is that as to unsafe and unhealthful working conditions on mine sites and in milling operations, the Secretary will apply the provision of the Mine Act and standards promulgated thereunder to eliminate those conditions.

   However, where the provisions of the Mine Act either do not cover or do not otherwise apply to occupational safety and health hazards on mine or mill sites (e.g., hospitals on mine sites) or where there is statutory coverage under the Mine Act but there exist no MSHA standards applicable to particular working conditions on such sites, then the OSHAct will be applied to those working conditions. Also, if an employer has control of the working conditions on the mine site or milling operation and such employer is neither a mine operator nor an independent contractor subject to the Mine Act, the OSHAct may be applied to such an employer where the application of the OSHAct would, in such a case, provide a more effective remedy than citing a mine operator or an independent contractor subject to the Mine Act who does not, in such circumstances, have direct control over the working conditions.

E.2. Clarification of Authority

1. Section 4 of the Mine Act gives MSHA jurisdiction over each coal or other mine and each operator of such mine. Section 3(d) defines "operator" and includes in that definition independent contractors performing construction at mines.
2. Section 3(h)(1) of the Mine Act gives MSHA jurisdiction over lands, structures, facilities, equipment, and other property used in, to be used in, or resulting from mineral extraction or used in or to be used in mineral milling. This includes the authority to regulate the construction of such facilities, structures and other property. Further, Section 3(h)(1) directs the Secretary of Labor, in making a determination of what constitutes mineral milling, to give due consideration to the convenience of administration resulting from the delegation to one Assistant Secretary of all authority with respect to the health and safety of miners employed at one physical establishment.
3. Appendix A provides more detailed descriptions of the kinds of operations included in mining and milling and the kinds of ancillary operations over which OSHA has authority. Notwithstanding the clarification of authority provided by Appendix A, there will remain areas of uncertainty regarding the application of the Mine Act, especially in operations near the termination of the milling cycle and the beginning of the manufacturing cycle.
4. Under section 3(h)(1), the scope of the term milling may be expanded to apply to mineral product manufacturing processes where these processes are related, technologically or geographically, to milling. Or, the term milling may be narrowed to exclude from the scope of the term processes listed in Appendix A where such processes are unrelated, technologically, or geographically, to mineral milling. Determinations shall be made by agreements between MSHA and OSHA.
5. The following factors, among others, shall be considered in making determinations of what constitutes mineral milling under section 3(h)(1) and whether a physical establishment is subject to either authority by MSHA or OSHA: the processes conducted at the facility, the relation of all processes at the facility to each other, the number of individuals employed in each process, and the expertise and enforcement capability of each agency with respect to the safety and health hazards associated with all the processes conducted at the facility. The consideration of these factors will reflect Congress' intention that doubts be resolved in favor of inclusion of a facility within the coverage of the Mine Act.
6. Pursuant to the authority in section 3(h)(1) to determine what constitutes mineral milling considering convenience of administration, the following jurisdictional determinations are made:
   a. MSHA jurisdiction includes salt processing facilities on mine property; electrolytic plants where the plants are an integral part of milling operations; stone cutting and stone sawing operations on mine property where such operations do not occur in a stone polishing or finishing plant; and alumina and cement plants.
   b. OSHA jurisdiction includes the following, whether or not located on mine property: brick, clay pipe and refractory plants; ceramic plants; fertilizer product operations; concrete batch, asphalt batch, and not mix plants; smelters and refineries. OSHA jurisdiction also includes salt and cement distribution terminals not located on mine property, and milling operations associated with gypsum board plants not located on mine property.

7. "Borrow Pits" are subject to OSHA jurisdiction except those borrow pits located on mine property or related to mining. (For example, a borrow pit used to build a road or construct a surface facility on mine property is subject to MSHA jurisdiction). "Borrow pit" means an area of land where the overburden, consisting of unconsolidated rock, glacial debris, other earth material overlying bedrock is extracted from the surface. Extraction occurs on a one-time only basis or only intermittently as need occurs, for use as fill materials by the extracting party in the form in which it is extracted. No milling is involved, except for the use of a scalping screen to remove large rocks, wood and trash. The material is used by the extracting party more for its bulk than its intrinsic qualities on land which is relatively near the borrow pit.
8. When any question of jurisdiction between MSHA and OSHA arises, the appropriate MSHA District Manager and OSHA Regional Administrator or OSHA State Designee in those States with approved plans shall attempt to resolve it at the local level in accordance with this Memorandum and existing law and policy. Jurisdictional questions that can not be decided at the local level shall be promptly transmitted to the respective National Offices which will attempt to resolve the matter. If unresolved, the matter shall be referred to the Secretary of Labor for decision.

E.3 Enforcement Procedures

In the interest of administrative convenience and the efficient use of resources the agencies agree to the following enforcement procedures:

1. When OSHA receives information concerning unsafe or unhealthful working conditions in an area for which MSHA has authority for employee safety and health, OSHA will forward that information to MSHA.
2. When MSHA receives information regarding a possible unsafe or unhealthful condition in an area for which MSHA has authority and determines that such a condition exists but that none of the Mine Act's provisions with respect to imminent danger authority or any enforceable standards issued thereunder provide an appropriate remedy, then MSHA will refer the matter to OSHA for appropriate action under the authority of the OSHAct.
3. When MSHA receives information regarding unsafe or unhealthful working conditions in an area for which OSHA has authority for employee safety and health, MSHA will forward that information to OSHA for appropriate action.
4. Each agency agrees to notify the other of the disposition of enforcement matters forwarded to it for appropriate action.
5. OSHA will not conduct general inspections of mine or mill sites except with respect to those areas set forth in this Agreement and its Appendix A.

E.4 Interagency Coordination

1. The Office of Legislative and Interagency Affairs in OSHA and the Office of the Assistant Secretary in MSHA shall serve as liaison points to facilitate communication and cooperation between the participating organizations.
2. MSHA and OSHA will endeavor to develop compatible safety and health standards, regulations, and policies with respect to the mutual goals of the two organizations including joint rulemaking,

where appropriate. This interagency coordination may also include cooperative training, shared use of facilities, and technical assistance.

E.5 Subagreements

Subagreements to accomplish the purposes set by this agreement may be developed and modified, as deemed necessary, by OSHA and MSHA. Such subagreements will include specific provisions for detailing the coordination between the agencies.

E.6 Period of Agreement

This Interagency Agreement shall continue in effect unless terminated by mutual consent of both parties or terminated by either party upon thirty (30) days advance written notice to the other and approved by the Secretary in either case.

This agreement will become effective on the date of the last signature and it supersedes the Memorandum of Understanding between OSHA and MESA dated April 22, 1974.

Mine Safety and Health Administration
Assistant Secretary of Labor
for Mine Safety and Health
Dated: March 29, 1979

Occupational Safety and Health Administration
Assistant Secretary of Labor
for Occupational Safety and Health
Dated: March 29, 1979

Approved: Secretary of Labor
Dated: March 29, 1979

Definitions:

"Coal or other mine" is defined in the Mine Act as:

(A) an area of land from which minerals are extracted in non-liquid form or, if in liquid form, are extracted with workers underground, (B) private ways and roads appurtenant to such area, and (C) lands, excavations, underground passageways, shafts, slopes, tunnels and workings, structures, facilities, equipment, machines, tools, or other property including impoundments, retention dams, and tailing ponds, on the surface or underground, used in, or to be used in, or resulting from, the work of extracting such minerals from their natural deposits in non-liquid form, or if in liquid form with workers underground, or used in, or to be used in, the milling of such minerals, or the work of preparing coal or other minerals, and includes custom coal preparation facilities.

"Miner" is defined in the Mine Act as:

Any individual working in a coal or other mine.

"Operator" is defined in the Mine Act as:

> Any owner, lessee, or other person who operates, controls, or supervises a coal or other mine or any independent contractor performing services or construction at such mine.

"Mining and Milling":

> Mining has been defined as the science, technique, and business of mineral discovery and exploitation. It entrails such work as directed to the severance of minerals from the natural deposits by methods of underground excavations, opencast work, quarrying, hydraulicing and alluvial dredging. Minerals so excavated usually required upgrading processes to effect a separation of the valuable minerals from the gangue constituents of the material mined. This latter process is usually termed "milling" and is made up of numerous procedures which are accomplished with and through many types of equipment and techniques.
>
> Milling is the art of treating the crude crust of the earth to produce there from the primary consumer derivatives. The essential operation in all such processes is separation of one or more valuable desired constituents of the crude from the undesired contaminants with which it is associated.
>
> A CRUDE is any mixture of minerals in the form in which it occurs in the earth's crust. An ORE is a solid crude containing valuable constituents in such amounts as to constitute a promise of possible profit in extraction, treatment, and sale. The valuable constituents of an ore are ordinarily called valuable minerals, or often just minerals; the associated worthless material is called gangue.
>
> In some ores the mineral is in the chemical state in which it is desired by primary consumers, e.g., graphite, sulphur, asbestos, talc, garnet. In fact, this is true of the majority of nonmetallic minerals. In metallic ores, however, the valuable minerals in their natural state are rarely the product desired by the consumer, and chemical treatment of such minerals is a necessary step in the process of beneficiation. The end products are usually the result of concentration by the methods of ore dressing (milling) followed by further concentration through metallurgical processes. The valuable produce of the oredressing treatment is called Concentrate; the discarded waste is Tailing.*

Specific Examples of MSHA Authority

Mining-MSHA

Following is a list indicating mining operations and minerals for which MSHA has authority to regulate.

- Mining Operations
- Underground Mining
- Open Pit Mining
- Quarrying

*Preface, p.v., Handbook of Mineral Dressing, Arthur P. Taggart, Second Printing, March 1947, John Wiley and Sons, Inc.

Solution Mining (Precipitate & Leaching)

Dredging (when the primary purpose of the dredging operation is to recover metal or nonmetallic minerals for milling and/or sale or use.)

Hydraulicing

Ponds - Brine Evaporation

Auger Mining

Minerals

Coal

Metals:
(Included but not limited to)

Alumina
Antimony
Bauxite
Beryl
Bismuth
Chrome
Cobalt
Copper
Gold
Iron
Lead
Manganese
Mercury
Molybdenum
Nickel
Rare Earths
Silver
Titanium
Tungsten
Uranium
Vanadium
Zinc
Zirconium
Magnesite
Salt
Shale
Sodium Compounds
Sulfur
Talc, Soapstone, and Pyrophllite
Vermiculite
Wollastonite

Nonmetals:
(Included but not limited to)

Abrasives
Aplite
Asbestos
Barite
Baron
Bromine
Calcium Chloride
Clay
Mica
Mineral Pigments
Oil Shale
Peat
Perlite
Potash
Pumice
Potash Rock
Diatomite
Feldspar
Fluorspar
Gilsonite
Graphite
Gypsum
Kyanite

Subgroups of Nonmetals (Sand and Gravel, and Crushed and Dimension Stone Industries)

Sand	Marble
Gravel	Native Asphalt
Cement	(impregnated stone & sand)
Gabbro	Quartizite
Gneiss	Schist
Lime	Slate
Limestone	Taprock or Diabase

Milling - MSHA Authority

Following is a list with general definitions of milling processes for which MSHA has authority to regulate subject to Paragraph B6 of the Agreement. Milling consists of one or more of the following processes: crushing, grinding, pulverizing, sizing, concentrating, washing, drying, roasting, pelletizing, sintering, evaporating, calcining, kiln treatment, sawing and cutting stone, heat expansion, retorting (mercury), leaching, and briquetting.

Crushing

Crushing is the process used to reduce the size of mined materials into smaller, relatively coarse particles. Crushing may be done in one or more stages, usually preparatory for the sequential stage of grinding, when concentration of ore is involved.

Grinding

Grinding is the process of reducing the size of a mined product into relatively fine particles.

Pulverizing

Pulverizing is the process whereby mined products are reduced to fine particles, such as to dust or powder size.

Sizing

Sizing is the process of separating particles of mixed sizes into groups of particles of all the same size, or into groups in which particles range between maximum and minimum sizes.

Concentrating

Concentrating is the process of separating and accumulating economic minerals from gangue, or the upgrading of ore or minerals.

Washing

Washing is the process of cleaning mineral products by the buoyant action of flowing water.

Drying

Drying is the process of removing uncombined water from mineral products, ores, or concentrates, for example, by the application of heat, in air-actuated vacuum type filters, or by pressure type equipment.

Roasting

Roasting is the process of applying heat to mineral products to change their physical or chemical qualities for the purpose of improving their amenability to other milling processes.

Pelletizing

Pelletizing is the process in which finely divided material is rolled in a drum, cone, or an inclined disk so that the particles cling together and roll up into small spherical pellets. This process is applicable to milling only when accomplished in relation to, and as an integral part of, other milling processes.

Sintering

Sintering is the process of agglomerating small particles to form larger particles, cakes or masses, usually by bringing together constituents through the application of heat at temperatures below the melting point.

This process is applicable to milling only when accomplished in relation to, and as an integral part of, other milling processes.

Evaporating

Evaporating is the process of upgrading or concentrating soluble salts from naturally occurring, or other brines, by causing uncombined water to be removed by application of solar or other heat.

Calcining

Calcining is the process of applying heat to mineral materials to upgrade them by driving off volatile chemically combined components and effecting physical changes.

This process is applicable to milling only when accomplished in relation to, and as an integral part of, other milling processes.

Kiln Treatment

Kiln Treatment is the process of roasting, calcining, drying, evaporating, and otherwise upgrading mineral products through the application of heat.

This process is applicable to milling only when accomplished in relation to, and as an integral part of, other milling processes.

Sawing and Cutting Stone

Sawing and cutting stone is the process of reducing quarried stone to smaller sizes at the quarry site when the sawing and cutting is not associated with polishing or finishing.

Heat Expansion

Heat expansion is a process for upgrading material by sudden heating of the substance in a rotary kiln or sinter hearth to cause the material to bloat or expand to produce a lighter material per unit of volume.

Retorting

Retorting is a process usually performed at certain mine sites, and is accomplished by heating the crushed material in a closed retort to volatilize the metal, material or hydrocarbon which is then condensed and recovered as upgraded metal, material or hydrocarbon.

Leaching

Leaching is the process by which a soluble metallic compound is removed from a mineral by selectively dissolving it in a suitable solvent, such as water, sulfuric acid, hydrochloric acid, cyanide, or other solvent, to make the compound amenable to further milling processes.

Briguetting

Briquetting is a process by which iron ore, or other pulverized mineral commodities, are bound together into briquettes, under pressure, with or without a binding agent, and thus made conveniently available for further processing.

MSHA Authority Ends - OSHA Authority Begins

Subject to Paragraph B.5. of the Agreement, the following are types of operations which may be on or contiguous to mining and/or milling operations listed above, over which MSHA does not have authority to prescribe and enforce employee safety and health standards, and over which OSHA has full authority, under the Act, to prescribe and enforce safety and health standards regarding working conditions of employees.

OSHA regulatory authority commences as indicated in the following types of operations:

Gypsum Board Plant

If the plant is located on mine property, commences at the point when milling, as defined, is completed, and the gypsum and other materials are combined to enter the sequential processes necessary to produce gypsum board. If not located on mine property, OSHA has authority over entire plant.

Brick, Clay Pipe and Refractory Plants

Commences after arrival of raw materials at the plant stockpile.

Ceramic Plant

Commences after arrival of the clay and other additives at the plant stockpile.

Fertilizer Products

Commences at the point when milling, as defined, is completed, and two or more raw materials are combined to produce another product. Note that a "kiln", as it relates to these products for roasting and drying, is considered to be within the scope of the milling definition.

GUAM WATERWORKS AUTHORITY

PHASE II COLLECTOR WELLS

FEASIBILITY STUDY

DRAFT REPORT

AUGUST 2006

Prepared by:

BROWN AND CALDWELL

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

LIST OF ACRONYMS AND ABBREVIATIONS

3-D	three-dimensional
AACE	Association for the Advancement of Cost Engineering
ASTM	American Society for Testing and Materials
CTD	conductivity-temperature-depth
CW	collector well
EPA	Environmental Protection Agency
ERT	electrical resistivity tomography
FRP	fiberglass reinforced plastic
FS	feasibility study
ft^2	square feet
GCI	Geotechnical Consultants, Inc.
GEPA	Guam Environmental Protection Agency
gpd	gallon per day
gpm	gallons per minute
GPR	ground penetrating radar
GWA	Guam Waterworks Authority
K	hydraulic conductivity
LHD	Load-Haul-Dump
mgd	million gallons per day
MSHA	Mine Safety and Health Administration
msl	mean sea level
NGL	Northern Guam Lens
NGLS	Northern Guam Lens Study
NWWG	North Watershed Working Group
OME	order-of-magnitude estimate
OSHA	Occupational Safety and Health Administration
PGE	Pacific Geotechnical Engineers, Inc.
PVC	polyvinylchloride
TDH	total dynamic head
USGS	U.S. Geological Survey
WERI	Water and Environmental Research Institute of the Western Pacific
WHPA	Wittman Hydro Planning Associates, Inc.
WRMP	Water Resources Master Plan

EXECUTIVE SUMMARY

Radial collector wells have recently been considered by Guam Waterworks Authority (GWA) to replace the approximately 120 vertical wells in northern Guam. Six collector wells with a capacity of about 4,500 gallons per minute each would be sufficient and would permit centralized water treatment facilities. Brown and Caldwell recently completed the Phase I Feasibility Study (FS), which concluded that vertical shafts were technically feasible and not cost-prohibitive.

This Phase II FS provides a preliminary evaluation of the use of radial collector wells to supply potable water for GWA. The Phase II FS included research into:

- The geological and hydrological conditions for the collector wells,
- An assessment of the feasibility of construction and technical approach, and
- An order-of-magnitude estimate (OME) opinion of construction costs for the laterals.

In conjunction with Phase I, this study completes the conceptual cost estimate for the project.

The conclusions of the Phase II FS are as follows:

- The geology of northern Guam is heterogeneous limestones that will require a comprehensive site-specific exploration program to adequately characterize each potential site.
- The groundwater hydrology of the general area of the sites is likewise variable, and although the range of groundwater conditions in the basal and parabasal aquifer lenses is theoretically sufficient for the desired collector well yields, site-specific aquifer testing will be necessary prior to design and construction.
- Standard hydraulic-jacking methods for lateral installation are not feasible in the hardrock limestone terrain, and underground mining of skimmer tunnels is cost-prohibitive.
- Drilling and installation of small diameter lateral screens is feasible and the preferred approach.
- Layne Christensen's OME opinion of costs is approximately $26,000,000 for the laterals, pumping, equipment, and associated appurtenances. In conjunction with the Phase I caisson and lift equipment costs of $24,000,000 and an additional $2,000,000 for shaft riser pipes, decking, access, and utility lines; it brings the total cost for the collector wells to approximately $52,000,000.

Given the large range of the OME opinion (plus 50 percent to minus 30 percent), this estimate is more than but within the range of GWA's original budget estimate of $44,000,000.

As a result of the above findings, Brown and Caldwell recommends that the use of collector wells be further pursued through site-specific characterization and groundwater flow modeling and monitoring to develop the baseline data necessary for decision-making and ultimate design and construction. Such work should be closely coordinated with the Guam Environmental Protection Agency (GEPA), U.S. Geological Survey, and Water and Environmental Research Institute of the Western Pacific (WERI) to ensure compatibility with current Northern Guam Lens groundwater management practices.

SECTION 1

INTRODUCTION

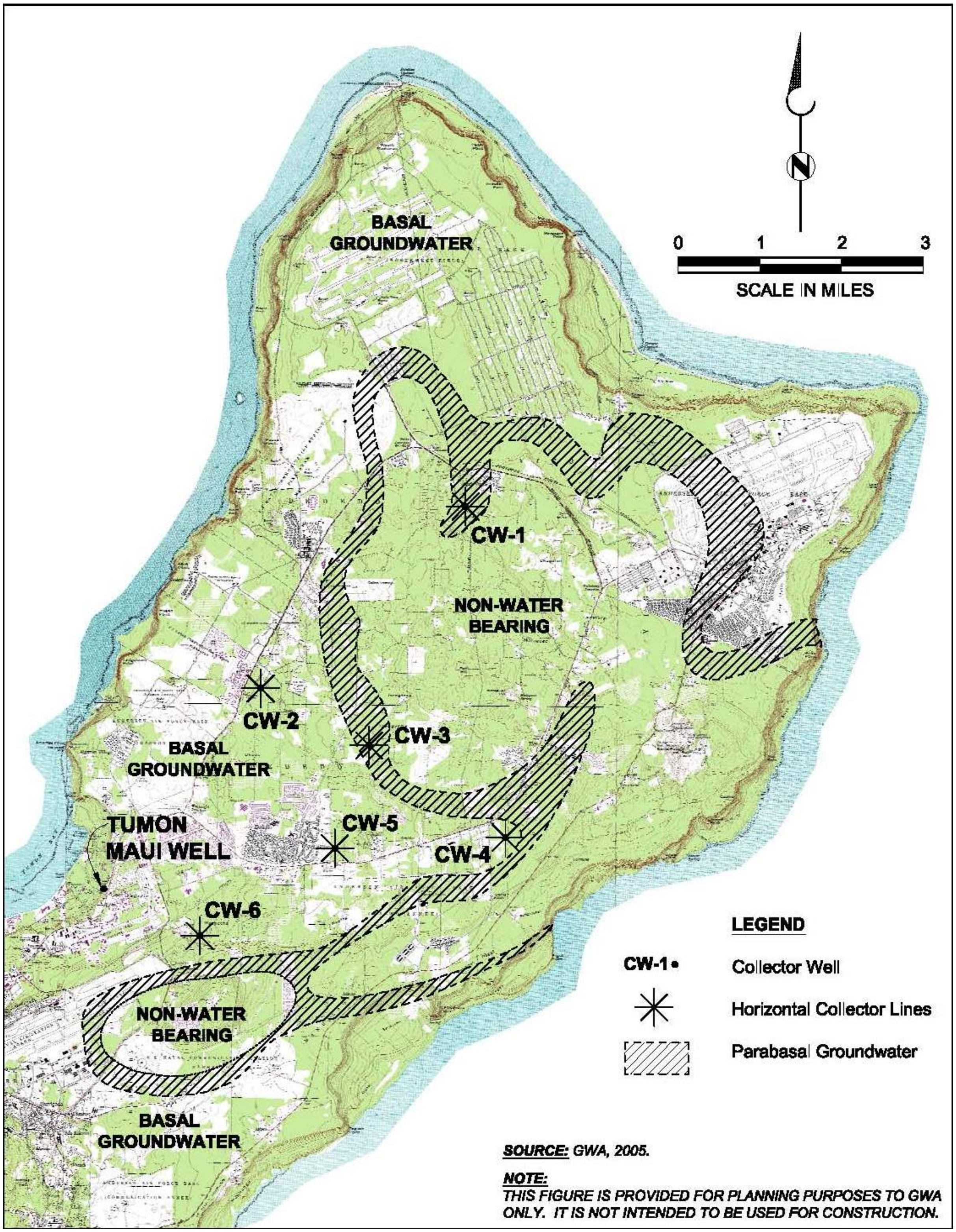
1.1 Background

Multiple radial collector wells have recently been studied by GWA as an alternative potable water supply system (GWA, 2005). It is GWA's belief that radial collector wells will allow for centralized water treatment and that the groundwater can be gently pumped from the basal limestone aquifer as a means of protecting it from saltwater intrusion. Centralized treatment may be necessary in the future if parts of the groundwater aquifer are determined by the GEPA to be under the direct influence of surface water. GWA estimated that six of these radial collector wells could replace the production of the current 120 vertical wells in the present system. GWA estimated that the length and associated cost of transmission mains would be reduced and the number of disinfection sites would be reduced from 120 down to six. Based upon an average production rate of 225 gallons per minute (gpm) for the 120 existing wells, the total water production requirements are approximately 27,000 gpm. The equivalent flow capacity from each radial collector well would therefore need to be about 4,500 gpm. The approximate locations of these six horizontal collector wells have been provided by GWA (Figure 1-1; GWA, 2005).

GWA previously estimated the cost to install six radial collector wells at about $44 million (GWA, 2005). The report also estimated an additional cost of $33 million for transmission mains, or a total of around $77 million for the six collector wells and transmission mains to existing storage tanks. In comparison, GWA estimated the cost to install transmission lines for the existing 120 wells at $115 million. Based upon GWA's initial assessment, the cost to install six new radial collector wells would result in a potential savings of about $38 million (GWA, 2005). To validate the feasibility and cost of constructing the radial collector wells, GWA retained Brown and Caldwell to conduct a preliminary feasibility study through an amendment to the Water Resources Master Plan Project.

Brown and Caldwell's Phase I FS (Brown and Caldwell, 2006a) provided a preliminary evaluation of the use of radial collector wells to supply potable water for GWA. Phase I addressed three major issues: 1) constructability of the central vertical shafts (caissons); 2) requirements for the lifting hoists, and 3) identification of mine safety issues. Brown and Caldwell's geotechnical subconsultant, Pacific Geotechnical Engineers (PGE), concluded that the construction of a vertical central shaft at the sites being considered by GWA is feasible from a geotechnical point of view, although the site-specific ground conditions would need to be confirmed by exploration borings at each collector well location prior to detailed design. Based on conceptual technical information obtained from JS Redpath Corporation (Redpath), the constructability of a central vertical shaft and a collector room that can house up to four pumps appears feasible. Since the primary purpose of the project is water supply development (not mining for product sale), Occupational Safety and Health Administration (OSHA) will most likely be the regulating agency. General underground safety concerns would include workplace ground control inspection, ventilation and air monitoring, and escape ways. An OME of the constructed shaft costs is approximately $24 million (Brown and Caldwell, 2006a).

Figure 1-1. Approximate Location of Collector Wells



Based on the above findings of the first phase, GWA authorized Brown and Caldwell to proceed with this second phase of the FS. Phase II includes research into the geological and hydrological conditions and the preferred approach and costs for the collector well laterals.

1.2 Objective of Study

The objective of Phase II of the FS is to characterize the geological and hydrogeological conditions and recommend a preferred well lateral construction approach and provide estimated costs for the collector well laterals. Several alternative techniques have been investigated and conceptual cost estimates have been developed for the radial collector wells, pumps, and associated appurtenances. For this preliminary study, it has been assumed that groundwater modeling will not be necessary.

1.3 Approach

Brown and Caldwell evaluated the geology and hydrology of the region using only published literature and unpublished reports, information and opinions. In Phase I, we subcontracted with PGE and their subconsultant, Dr. James Mahar, LPG, of Geotechnical Consultants, Inc. (GCI). In Phase II, we have relied upon PGE's report as well as numerous other publications on Guam's geology and hydrology, including those of the U.S. Geological Survey (USGS), GEPA, WERI, University of Guam, other academic investigators, and private consultants. For a proposed approach to three-dimensional (3-D) numerical modeling of the complex flow in the vicinity of the proposed GWA collector wells, we consulted with Wittman Hydro Planning Associates, Inc. (WHPA), a Bloomington, Indiana-based firm that specializes in the use of traditional and customized groundwater modeling tools to solve complex groundwater problems. To assist in the development of the technical approach and estimated costs for the installation of the horizontal collector well laterals, we consulted with Layne Christensen Company (www.laynechristensen.com; Layne), the largest water supply contracting company in the U.S. Layne is the most experienced collector well design/installation firm in North and South America, having acquired both Collector Wells International, Inc. and the Ranney Division of Reynolds, Inc.

The opinions provided on estimated costs within the following sections are OME opinions only, using Association for the Advancement of Cost Engineers (AACE guidelines). The estimates are based on very limited, non-site-specific geotechnical information. AACE describes an OME as an approximate estimate made without detailed engineering data. Normally, plus 50 percent to minus 30 percent contingency is a typical range of cost deviation for cost estimates of this level. Brown and Caldwell provides these estimates as opinions solely for conceptual planning by GWA. Collection of data necessary to move beyond this level of estimating is described at the end of Section 3.

1.4 Description of Collector Wells

Based on using a central vertical shaft, the conceptual design of the collector wells includes the following components:

1. A central caisson shaft with a 10- to 30-foot-diameter shaft that extends from the surface to the water table (approximately 400 to 500 feet deep);
2. A collector room at the bottom of the shaft to accommodate the drilling equipment used to construct a series of horizontal radial tunnels, and to house pumps and pumping appurtenances;
3. Pumps, motors, controls, and discharge piping;
4. A hoist lift;
5. Several horizontal collector wells or tunnels extending radially from the central shaft with the crown of the radial tunnels located below the water table; and
6. Air supply system.

Radial collector wells are typically constructed in shallow alluvial sand and gravel deposits underlying and hydraulically connected with surface water sources, such as rivers, lakes, or oceans (Hunt, 2005; Spiridonoff, 1964). Within a few feet of the bottom of the caisson shaft are one or more tiers of horizontal perforated steel pipes or well screens that are connected to a valve port in the caisson wall. The ports are usually no less than 22½ degrees apart. The total length of collector pipe required depends on a number of variables, including porosity and permeability of the formation. The length of the individual collector pipes is typically in the range of 110 to 200 feet (Spiridonoff, 1964). Neither Brown and Caldwell or Layne are aware of radial collector wells having been constructed previously in hardrock limestone terrains, such as those present in northern Guam. The hydrogeological and construction issues therefore require special consideration.

1.5. Limitations

This report was prepared solely for GWA in accordance with industry standards at the time the services were performed and in accordance with the specific scope of work contained in our February 3, 2006 proposal. We have relied upon readily available information provided by GWA and other parties in developing this report, and unless otherwise expressly indicated, have made no independent investigation or site visits to verify such information. This preliminary conceptual study is intended for planning purposes only and is not intended to be used for design or construction as detailed in Section 3.1. The preliminary costs are OME opinions. In particular, site-specific exploration borings will be necessary to characterize ground conditions at each location prior to design. Furthermore, this study was limited to a desktop analysis, and did not include site visits, exploration borings, testing, or groundwater flow modeling.

SECTION 2

GEOLOGY AND HYDROLOGY

This section presents the results of a preliminary review of the geology and hydrology of the general area of the proposed collector wells in northern Guam. A preliminary discussion of potential collector well yields and design issues is also included.

Guam is the largest and southernmost island of the Mariana archipelago in the west central Pacific (Figure 4). It is located about 3,800 miles west-southwest of Hawai'i and 1,600 miles east of the Philippines. The island is about 30 miles long and 4 to 12 miles wide (North Watershed Working Group [NWWG], 1998).

Northern Guam is underlain by at least a 250-meter section of Neogene limestones, deposited as reef systems on an early Tertiary seamount (Tracey, et al, 1964) (Figure 5). The two aquifers in northern Guam are the Miocene Barrigada Limestone, considered by earlier studies to represent deeper water, off-reef platform conditions and the Pleistocene Mariana Limestone which contains a wide spectrum of shallow-water carbonate facies, but is believed on many lines of evidence to represent a Pleistocene reef-margin complex (Tracey et al, 1964, Schlanger, 1964). Geomorphically, northern Guam is a terraced plateau comprised of karstic areas the locations of which and degree of development are controlled by normal faults and shear zones extending into the volcanic basement (Barrett et al 1982).

2.1 Geology

Phase I of the FS included a conceptual layout design provided by GWA (GWA, 2005) and a preliminary geotechnical report developed by PGE for this study (Brown and Caldwell, 2006a). Plate 2 of PGE's report shows the geology of northern Guam (Appendix C). The geotechnical report describes ground conditions as Barrigada and Mariana limestone formations with widely varying zones of lithified, brecciated, and unconsolidated granular limestone. The PGE report states that ground conditions anticipated would include voids and limey clay aquifers. Given that Guam is located in a seismically active region, that active faults are present in the area, and that sinkholes or cavities could be encountered, difficult drilling conditions can be anticipated.

The Barrigada Limestone, of late Miocene to Pliocene age, forms the bulk of the aquifer underlying northern Guam and would occur at the water table at most if not all of the proposed sites. According to the U.S. Geological Survey (Gingerich, 2003), the formation consists of fire-grained, pure foraminiferal-detrital limestone with generally high permeability. The underlying volcanic basement (known as the Alutom Formation) typically has low permeabilities and would be unsuitable for collector wells.

2.2 Hydrology

In northern Guam, most groundwater is contained within the aquifer termed the Northern Guam Lens (NGL) that occurs within karstic and highly permeable Barrigada and Mariana Limestones. Groundwater flow occurs within the NGL both as diffused flow porous sections and conduit flow through solution channels. The water table rises from sea level at the coast to tens of feet in southern portions of the NGL where the limestone is in close proximity to volcanic rock which has contributed significant amounts of clay during deposition of the limestone thus reducing the permeability of the aquifer. The GEPA designated the NGL as a principal source aquifer in 1978 (NWWG, 1998).

Most of the freshwater supply is contained in a characteristics "lens" beneath the limestone plateau in the northern part of the island. This groundwater lens occurs in two conditions. Whenever the total depth of the porous limestone extends significantly below sea level, it is termed a "basal" condition. Under basal conditions the fresh groundwater lens is underlain by salt water. Where impermeable volcanic material protrudes into the aquifer at or near sea level, a "parabasal" condition exists (i.e., the fresh water lens is underlain by volcanics). These relationships are shown diagrammatically on Figure 2-1 (from Gingerich, 2003).

In the basal zone, freshwater exists in equilibrium contact with saltwater. Freshwater extends some 40 feet below sea level for each foot of head above sea level, as developed by pressure differences due to density differences of the fluids present in the aquifer. The transition zone between freshwater and saltwater is thickest near the coast, where it is affected by tidal forces, and thinnest at the furthermost point inland.

The high permeability of the limestone aquifer generally limits the static head of groundwater to a few feet. However, heads in the parabasal aquifer and in the limestone where low permeabilities occur due to high clay content, heads can reach up to 30 feet above sea level. A quasi-equilibrium of such a groundwater lens is achieved by leakage from the lens to the sea through springs and seeps along the coastline, and recharge which takes place as rainfall percolates into the ground and flows through channels and interconnected pores in the limestone into the freshwater lens (NWWG, 1998).

Design of a radial collector well system is much more sensitive to fluctuations in water levels (seasonal or annual) than vertical wells. Significant declines in head over the laterals could reduce or eliminate yield. Based on the monitoring well data in the mid-1980s (Barrett, 1992), most wells fluctuated one foot or less seasonally and over the course of four years (1984-1988). However, one well (A-20), fluctuated as much as 15 feet in 1985 and 10 feet from 1985 to 1988. The water levels in this well are 30 to 52 feet above mean sea level (msl), so it is most likely parabasal and not representative of basal water levels. These fluctuations would provide a challenge in designing the collector well, and an evaluation of water level fluctuations in the vicinity of each potential site using existing or new monitoring wells is recommended prior to final design of any wells.

Water levels in the basal aquifer are relatively constant at roughly 3.0 to 3.5, with pumpage nearly consistent throughout the year. Rainfall (recharge) is highly seasonal with the wettest months being

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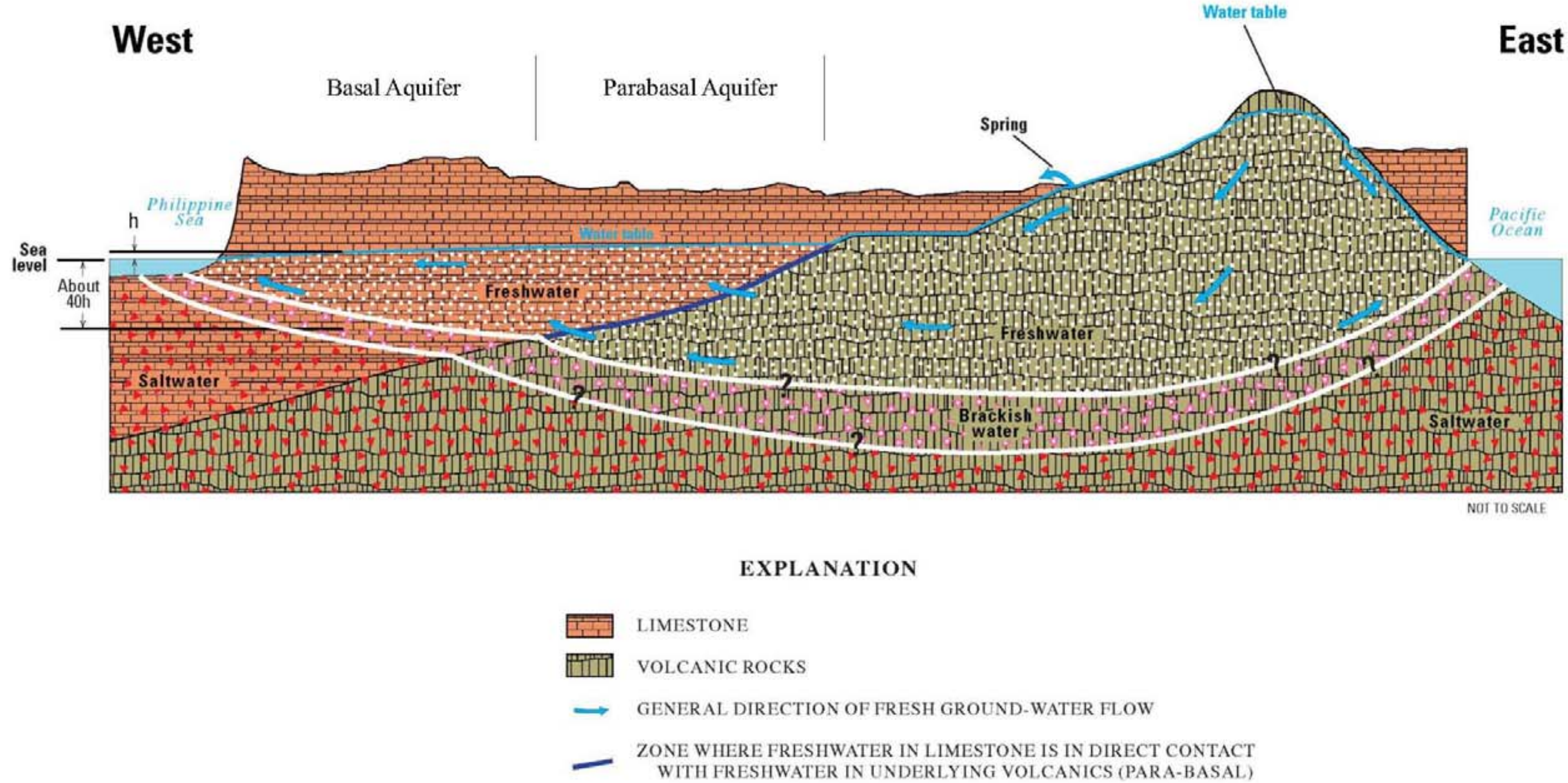


Source: Gingerich, 2003; USGS WRI 03-4126

BROWN AND CALDWELL	PROJECT 127553	SITE GWA Collector Wells	Figure
	DATE 8-7-06	TITLE Diagram Showing Generalized Groundwater Occurrence, Northern Guam	2-1

July to November. Heads nevertheless decay less than 0.5 feet during the dry season (Barrett, 1992). Such minor seasonal and annual fluctuations would not affect collector well performance, assuming these fluctuations have not changed to date.

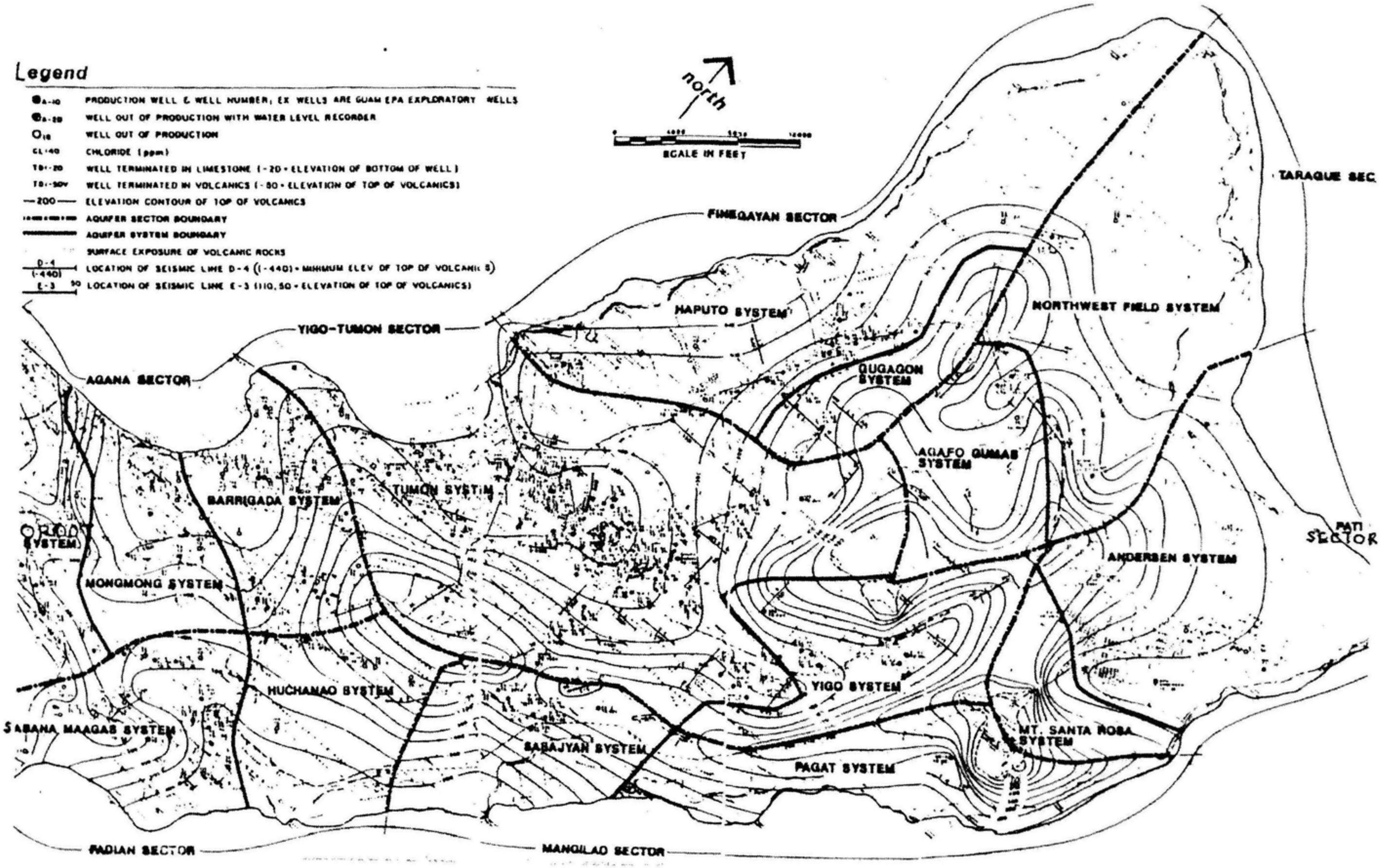
Parabasal groundwater is hydraulically continuous with basal groundwater, but it rests on the low permeability volcanic basement. Parabasal groundwater resources are less voluminous, but they are capable of higher yields because they resist mixture with saltwater unless the overall groundwater extraction exceeds a safe limit (Brown and Caldwell, 2006b).

There has been extensive research and analysis of the fresh water lens in the Northern Guam Aquifer for 30 years (Mink 1976, Mink and Vacher 1997, Barrett Consulting 1992, Mylroie et al. 2001, Lander 2003, Lander and Jenson 2003, Gamble et al. 2003, Presley 2006, Kemp 2005). Data collected on the island show that the fresh water lens can be as thick as 150 feet in the interior and the lens naturally expands and contracts in response to pulses of intense rainfall and extended drought. Discharge from the aquifer is either to one of the 120 plus wells that are scattered over the northern portion of the island or to the ocean, sometimes through caves that extend from the shore into the island.

The most comprehensive review of northern Guam's water resources, the Northern Guam Lens Study (NGLS), was conducted almost 25 years ago (CDM, 1982). That study organized and evaluated existing hydrogeologic data, made analyses relevant to groundwater production, and subdivided all of northern Guam into Subbasins and Management Zones. This classification formed the basis for GEPA management decisions about the expansion of groundwater development. In the NGLS, only 67 square miles of the total of 100 square miles in northern Guam were considered favorable for the production of potable water. This production area was divided into 47 Management Zones, each having an average area of somewhat more than one square mile. The outlines of the zones reflect hydrogeological and topographic features, but each is too small to be uniquely identified by these parameters. Strict adherence to a zone as a management unit inhibits flexibility in taking advantage of groundwater conditions.

A more recent study (Barrett, 1992) proposed aquifer categories that followed the methodology created for Hawai'i and other Pacific Islands. The divisional hierarchy starts with the Aquifer Sector, which is divided into Aquifer Systems, which in turn are subdivided into Aquifer Types. At this stage, only the Sectors and Systems have been identified for northern Guam. The Aquifer Sectors are the same as the Sub-basins referred to in the NGLS report, but each Aquifer System embraces several of the NGLS Management Zones. The NGL Aquifer Sectors and Systems are shown on Figure 2-2. The Sector-System arrangement allows for a simpler and more direct discussion and allocation of the groundwater resources, and the revised sustainable yields are shown in Table 3-7 of the WRMP (Brown and Caldwell, 2006b).

Figure 2-2. Aquifer Sectors and Systems



2.3 Design Issues and Potential Yields

A change from distributed vertical supply wells to centralized collector wells would need to be evaluated in light of the existing groundwater management framework. Should GWA decide to further exploit the upgradient areas of the parabasal or basal aquifer with collector wells, a monitoring network needs to be in place to monitor chloride concentrations in the adjacent sections of the aquifer. In addition, a comprehensive continuous data collection system must be in place to measure actual lens geometry response to present pumping conditions, and modified pumping schemes must be designed to maximize yield while preserving freshwater integrity. This monitoring effort should be well coordinated among GEPA, GWA, and WERI, a research unit of the University of Guam.

The collector well project presents several important design problems:

- How will the collector well design and well field layout affect total yield?
- What drawdown can be expected in the aquifer from sustained pumping?
- How would drawdown be affected by reduction in recharge (multi-year drought) and seasonal increases in water use?
- How will horizontal well design and well field layout affect water quality? Will there be any significant change in the position of the fresh water – salt water transition zone?

These questions cannot be thoroughly analyzed in this preliminary FS, and will need to be addressed in subsequent site-specific investigations. Regional hydraulic conductivity (K) estimates are approximately 20,000 feet/day, while local scale estimates from pumping tests are at least one to three orders of magnitude less (Jocson, et al, 1999). The exceptionally high regional K and large range between local and regional estimates suggests discrete pathways of rapid, turbulent flow. These preferential pathways (most likely karst features, faults, and/or fractures) present difficult challenges to both investigations and modeling of collector well performance.

Typical vertical wells in the basal aquifer of the NGL yield 150 to 200 gpm, or 0.22 to 0.29 million gallons per day (mgd). Parabasal wells typically pump 200 to 700 gpm (0.29 to 1 mgd). Even at these relatively low yields, salinity has increased in 64 of the 120 monitored wells since the 1970s (Brown and Caldwell, 2006b).

These large hydrogeologic heterogenetics preclude using common analytical solutions (Hantush and Papadopulous, 1962) to accurately calculate drawdown distribution around discharging collector wells. However, a very rough estimate of the yield of a collector well can be made using the following formula presented by Mikels and Klaer and generally referred to as the general equilibrium formula, modified to evaluate collector well yield (Hunt, 2005):

$$Q = \frac{2 \pi K m s}{2.3 \log_{10} (2D/r)}$$

Where:

Q = discharge, or yield, of the well, in gallons per day (gpd)

K = hydraulic conductivity, in gpd/square feet $(ft)^2$

m = average saturated thickness, in feet (assumed 150 feet)

s = corrected amount of drawdown observed or expected, feet (assumed 2 feet)

D = effective distance from pumped well to the line source of recharge, or line of infiltration (assumed 5,000 feet)

r = effective radius of the pumped well (assumed 300 feet)

Detailed aquifer testing would be required to obtain data to identify hydraulic boundaries and calculate aquifer characteristics, but using the parameters and the K's presented above, a range of Q from 60 to 6,000 gpm is estimated for the range of local hydraulic conductivities. The actual collector well yield would probably be within this range, so the necessary yield of 4,500 gpm (6.5 mgd) collector well would be near the high end and is certainly not guaranteed.

Two existing water development tunnels give an indication of the potential yields of collector wells. The Tumon Maui well yields approximately one mgd (700 gpm) without inducing salinity intrusion. It is ideally located to intercept flow in the Yigo Trough, and could probably extract considerably more water. On the other hand, the ACEORP tunnel failed to yield large quantities of potable water. These examples suggest that sustainable collector well yields of 4,500 gpm are questionable, and a phased approach of careful siting and testing would be necessary.

Although it is in basaltic rock, the Kahalu'u shaft on the Big Island of Hawai'i is a Maui-type well (inclined shaft with 800 feet of mined skimming tunnels) that provides a somewhat comparable facility. Hydraulic conductivities are in the range of 500 to 34,000 feet/day. Nearby vertical wells yield roughly 1 mgd (700 gpm), and the Kahalu'u shaft yields approximately 4 mgd (2800 gpm). Both have impacted the freshwater/saltwater transition zone, and measures are currently being taken to address elevated salinities (Brown and Caldwell, 2006c, in preparation). However, precipitation and infiltration are both significantly lower than Guam's.

A work plan should therefore be developed that outlines how collector well yield, drawdown, and the effect on the position of the salt water – fresh water transition zone would be determined. Data for the analysis will be provided by the extensive work that has already been completed by the

USGS, University of Guam, GEPA and previous researchers. Analysis should include an assessment of how the uncertainty in the properties of the system could affect predictions.

As part of the current FS, Brown and Caldwell consulted with WHPA, who proposed using a patented analytic element model to evaluate alternative designs and answer the above questions. Groundwater flow patterns in the vicinity of a collector well are very complex. The well interacts with regional flow in the aquifer, and usually also with nearby wells and, where they exist, surface waters. In this case, the proposed collector well arms extend beneath the water table aquifer and will be used to skim the fresh water from the lens in a way that, ideally, will not induce up-coning of the salt water below the lens. A model of a collector well in this setting will need to be able to examine the local effects of this setting, including:

- Hydraulic resistance between vertical layered aquifers;
- Hydraulic resistance into the lateral arms;
- Connectivity of the lateral arms with fracture zones;
- Vertical hydraulic conductivity of the aquifer; and
- Head losses due to flow in the lateral arms.

A local groundwater model would be used to estimate the drawdown in the well and in the aquifer and can also assist in the subsequent water quality (salt water – fresh water transition zone) analysis. Field data collected at the well site collaborates with the model for:

- Accurately determining the 3-D source area for the collector well;
- Estimating the travel times along path lines towards the well; and
- Estimating the perimeter fluxes that would result from any particular configuration of lateral arms, well spacings, and lateral configurations.

WHPA estimates that such modeling could be done for approximately $200,000 using its patented software. Commercially available programs could be used for considerably less cost.

The development of the site investigation, monitoring, and/or modeling approach should be done in association with the existing regional models of flow in the system and be used to evaluate how new high capacity wells could affect the fresh water – salt water interface. Close collaboration with GEPA, USGS, and WERI is therefore recommended, particularly since a change in the allowable yields of aquifer sectors and systems would need to be approved by GEPA. In addition, a phased approach that demonstrates that collector well yields and impacts will be sustainable and acceptable through comprehensive groundwater monitoring using guidelines such as those of the American Society for Testing and Materials (ASTM, 2001) is recommended.

SECTION 3

ESTIMATED COSTS OF HORIZONTAL COLLECTOR WELLS

This section includes a discussion of several alternative technical approaches to the installation of the horizontal laterals, an opinion of anticipated costs, and additional technical considerations.

3.1 Technical Approach

Once the caisson has been sunk to its design depth and the bottom sealing plug is poured as described in the Phase I FS (Brown and Caldwell, 2006a), the lateral projection can be accomplished. There are several different technologies for screen installation:

- Underground Mining of the Collector Gallery Laterals,
- Original Ranney Method,
- Pipe Projection Method,
- Gravel-Packed Laterals, and
- Drilling and Screen Installation.

3.1.1 Underground Mining of the Collector Gallery Laterals

Collector galleries installed using conventional mining methods typically involve a two-phase construction sequence. The initial phase is a lateral driven to the desired length above the water table. The second phase mines a collection slot out of the lateral floor to the desired depth into the water table. Brown and Caldwell consulted informally with JS Redpath (Redpath), Sparks, Nevada on mining methods, equipment and potential OME costs.

The lateral method was estimated using four lateral headings of 200 feet each. The lateral headings assume a 10-foot by 10-foot cross section and the collector slot is assumed to be 3 feet wide by 6 feet deep. The lateral headings would be advanced using conventional manual drilling and blasting. Muck removal would be facilitated by a 1.25 yard Load-Haul-Dump (LHD) rubber tired unit. Muck hoisting to the surface would utilize the hoist bucket used to initially sink the shaft. Ground control is assumed to be accomplished with conventional split set rock bolting. The lateral floor would install approximately 2.5-foot-wide reinforced concrete aprons abutting the lateral ribs. The concrete would provide a working floor for installing grating above the collector trench for use during construction and operations.

Due to the relatively short length of the laterals, installation of the collection gallery slot would utilize manual conventional mining techniques. This method assumes manual jack leg drilling and blasting for defining the collection slot and using a conventional double drum slusher with single block and bucket for mucking rock back to the shaft area for removal.

Based on these assumptions Redpath recommended an OME cost of approximately $4000/foot. As previously reported by Brown and Caldwell, Redpath confirmed that typical OME lateral costs are in the $1,100 to $1,200/ foot range for mining in North America. The relatively higher costs anticipated for this method is due to the labor intensive means of installing the collector trench. Poor ground conditions may increase these costs, and assuming shotcrete is an applicable method to remedy localized poor ground conditions, an additional cost of $500/foot may be incurred.

The OME costs for the six collector wells are based on a total of approximately 800 feet per well for a total lateral length of 4,800 feet. This would provide an OME cost of approximately $19,200,000 for lateral construction. Assuming 25 percent of the ground may need shotcrete ground control, an additional cost of $600,000 may be incurred. This yields a total OME cost of approximately $20,000,000 for comparing costs with other methods of lateral installation.

The 800 feet of laterals is roughly comparable to the Kahalu'u shaft, a Maui-type well on the Big Island of Hawai'i. Since these costs are much higher than Layne's estimate for 36,000 feet of screened laterals (which would spread pumping over a much larger area), this approach is not recommended.

3.1.2 Original Ranney Method

This method uses a perforated pipe for well screen construction. The (pipe) screen is made with either punched slots or saw-cut slots. This technology has been limited to sites where the sands and gravel are coarser in nature and where a natural gravel-pack of sufficient coarseness can be developed from the formation deposits. This has been the predominant technology used in the United States from the 1930's to the mid 1980's.

Installation of laterals of this type is accomplished by hydraulically jacking (projecting) lateral well screen sections, typically eight feet in length, out from the bottom of the caisson. The screen sections are typically constructed of 1/4 to 3/8 inch thick steel usually of standard carbon steel composition variety, however, stainless and other alloy steels can also be used depending upon local ground water quality conditions. The screen sections are fitted together by welding, using threaded- and coupled connections or socket joints. The perforations are either made by flat sheet steel and then rolled, or saw-cut into already rolled pipe sections. The nominal diameter of the well screens range between 8 and 18 inches with the average and most commonly used sizes being 8 to12 inches. Screens of this design have also been made of fiberglass reinforced plastic (FRP) carefully projected into finer sand deposits, notably in salt water environments.

The screen sections are hydraulically projected out through the port assembly set into the caisson wall. Each lateral is fitted with a "digging head" that is seated or welded to the first screen section. The digging head is generally conical in design to help direct the path of the lateral well screen as it is projected, and help cut through thin seams of clays or silts that may be encountered. Several openings are cut into the head to correspond to the size and nature of aquifer materials observed during the initial exploratory and testing program. The object of the holes is to allow select sizes of aquifer materials to enter the head and be transported through the sandline back into the caisson.

The laterals have been projected out to maximum lengths of about 350 feet, although average lengths of between 150 and 250 feet appear optimal for developing the maximum yields.

The sandline is a pipe of smaller diameter, usually 3 or 4 inches, that is seated into the casting of the digging head inside of the lateral screen. The sandline conveys aquifer materials that enter the head back to the caisson by hand or mechanical means. The aquifer materials are washed through the sandline using the hydrostatic pressure in the aquifer. Alternatively, high-pressure air can be forced out through the sandline to agitate the aquifer materials in front of the digging head to assist in the washing and removal process. Once the lateral has been projected to its design length, the sandline is removed and the lateral is fitted with a control valve in the caisson to facilitate dewatering of the caisson in the future, if needed (Hunt, 2005).

3.1.3 Projection Pipe Ranney Method

This method requires the projection of blank casing to the full length in a similar manner to that described above, also fitted with a digging head. Once the full length has been reached, well screen sections are installed within the blank casing and the casing is pulled back to expose the screen to the formation materials, in much the same manner as setting a vertical well screen with cable tool drilling equipment. During the projection of the bank casing, samples of the formation zones encountered are collected from the sandline and analyzed for grain-size distribution to develop gradation profiles along the length of the line. This data permits each section of well screen to be custom designed to suite the specific aquifer deposits in which the screen will be installed. This capability allows for improved well screen efficiencies and enables screen design to consider horizontal variances in the aquifer.

Because the well screens are slipped into the blank casing after it has been projected, the well screens can be made of a greater variety of materials as they will not be subjected to jacking and friction pressures which occur during screen projection of the perforated pipe described above in Section 3.1.1. This methodology permits screens made of polyvinylchloride (PVC), FRP, Teflon, or other plastics in addition to wire-wrapped steel screens to be used to better accommodate aquifer formation and water quality conditions.

3.1.4 Ranney Gravel-Packed Laterals

This method involves the installation of blank casing, as above, but instead of slipping screens into the casing and using natural formation materials, well screens of special design are used, and an artificial gravel-pack is placed into the annulus between the screen and the blank casing when the casing is withdrawn. The artificial gravel-pack materials are washed into the annulus after the screen sections have been inserted full-length. The ability to install this gravel-pack filter provides a transition zone between the natural formation and the screen slots to provide maximum efficiency. In some vertical wells, pre-packed well screen sections using a gravel-pack fixed to the screen with an epoxy-type bond; or screen sections with a double-walled screen assembly with gravel placed in the annulus have been used. These pre-packed screen methods are not preferred since the gravel-pack is essentially fixed, and cannot be agitated during redevelopment maintenance to allow fines and precipitates to be effectively removed. The type of gravel-pack and the method of emplacement should be considered carefully to maximize efficiency and facilitate future maintenance.

3.1.5 Layne's Drilling and Screen Installation Method

The Ranney Division of Layne has developed new methods for the drilling and installation of well screens for which patents are pending. Drilling is particularly well-suited to the hardrock limestone terrain of Guam, in which the above three variations of hydraulic jacking are most likely not feasible (and certainly not to the desired lengths). Layne is not willing to reveal the details of their proprietary methods at this time, and would propose to complete the project on a design/build delivery approach, in part to prevent needing to disclose their methods.

Layne believes that collector wells will be most efficient and productive and have less impact on saltwater intrusion utilizing multiple small diameter laterals projected out to lengths of 300 to 400 feet from the caisson's interior wall. They also think that the caisson and working area will be safer and better suited if it is not under-reamed, and their drilling equipment is designed to be installed in wells 18 feet in diameter and smaller. Based on the initial caisson design provided in Brown and Caldwell's May 2006 Phase I FS (Brown and Caldwell, 2006a), Layne estimates each well will need to be equipped with approximately 20 laterals totaling 6000 feet of nominal 6-inch-diameter, stainless steel – slotted casing per well. The drilling technique to complete this installation is highly technical and complicated and requires specialized equipment designed specifically for this operation and these conditions. Layne's experience with lateral lengths greater than 300 feet is that the outer third to half of these laterals tend to not be productive and can be cost-prohibitive to construct due to their lack of production. This being said, a design may be proposed that extends the lateral lengths and provides only non-screened casing for the sections nearest the caisson on alternating laterals. Each lateral will be equipped with a valve and hard-piped into a main manifold. This manifold will be plumbed directly to the pumping equipment. The objective of this plumbing system is to provide a dry, working area in the bottom of each of these wells for maintenance and inspections. The photographs in the Appendices of this report illustrate typical screens, their installation, and plumbing. Brown and Caldwell has not identified other firms that have experience installing laterals in hardrock at such depths or have confidence that they have the capability. For the purposes of this FS, we have therefore used Layne's approach and cost estimate to evaluate the feasibility of collector wells.

3.2 Opinion of Anticipated Costs

Based on the aforementioned conceptual approach, OME opinions have been developed based on recent similar Layne experience with other projects. The cost estimate to design and build the six (6) collector wells as described in this report is approximately $52,000,000 as show in Table 4-1. This includes approximately $24,000,000 in contracted services and installed equipment as detailed in sections 2.1 through 2.4 of the Phase I report from a qualified mining shaft contractor such as J.S. Redpath Group for the shafts, hoists, and surface equipment. Final installation of shaft riser pipes, decking, access and utility lines are estimated to add an additional $2,000,000. The estimate for an approximate additional cost of $26,000,000 for the horizontal collector wells includes the following tasks and equipment, based on the design requirements and assumptions suggested in Phase I and this report:

Table 3-1. Design and Build Cost Estimate

Phase I – Contracted services and equipment	$24,000,000
Phase I Subtotal	$24,000,000
Hydrogeologic site investigation and test drilling program	$1,500,000
Caisson design and layout (to accommodate drilling method)	$100,000
Design of pumping equipment and controls	$100,000
Design and installation of pump and valve control decks including lateral-to-pump collection manifold, electrical supply to the pumps and discharge raw water main to surface	$3,300,000
Lateral installation and construction including approximately 36,000 feet of laterals	$14,000,000
Supply and installation of pumping equipment, piping, discharge and controls	$6,500,000
Project management and site supervision	$500,000
Phase II Subtotal	$26,000,000
Final installation costs	$2,000,000
Total	$52,000,000

3.3 Additional Technical Considerations

Typical conventional civil construction projects will range in the area of or fall below 18 percent design, construction and administration costs. Our OME opinion is this project should anticipate costs exceeding the 18 percent range due to advanced collection and evaluation of baseline data necessary to define final design goals.

Consideration of this data collection should incorporate the following:

- A comprehensive hydrogeologic understanding of the water table and island system water balance. The determination of the final elevation of the shaft bottom will be set according to the best data for sustainable production from an understanding of the fresh water table. Unpublished groundwater level and quality data (Jenson and Jocson, 1998) should be obtained from the USGS and GEPA for this purpose.
- Advanced geotechnical and geophysical data collection will be necessary to determine locally complex adverse ground conditions. Exploratory drilling should be coupled with seismic surveys, electrical resistivity tomography (ERT) and/or ground penetrating radar (GPR). The exploratory program may need to employ some or all of these methods to understand project requirements of shallow and deep ground conditions.

- Comprehensive aquifer testing with multiple observation wells, including at least one deep well that can be logged with a conductivity-temperature-depth (CTD) probe so that the thickness of the freshwater lens and transition zone can be established and monitored.
- Site-specific groundwater flow modeling as described in Section 2 to predict collector well impacts and sustainability.
- Close coordination with GEPA, USGS, and WERI to ensure an acceptable project that is compatible with the existing NGL groundwater management practices.
- Construction methods are reviewed with FedOSHA to ensure appropriate safety measures are included in the final project design documents.
- Additional site-specific geotechnical investigation and analysis to ensure structural integrity of the laterals in earthquakes. In particular, faults and fracture zones (such as those present at the proposed location of CW-6; Appendix C) need to be avoided, especially since they can provide vertical conduits for upward vertical flow of saline water to wells.

SECTION 4

CONCLUSIONS AND RECOMMENDATIONS

This Phase II FS provides a preliminary evaluation of the use of radial collector wells to supply potable water for GWA. The Phase II FS included research into:

- the geological and hydrological conditions for the collector wells,
- an assessment of the feasibility of construction
- an OME opinion of construction costs for the laterals

In conjunction with Phase I, this study completes the conceptual cost estimate for the project.

The conclusions of the Phase II FS are as follows:

- The geology of northern Guam is heterogeneous limestones that will require a comprehensive site-specific exploration program to adequately characterize each potential site.
- The hydrology of the general area of the sites is likewise variable, and although the range of groundwater conditions in the basal and parabasal aquifer lenses is theoretically sufficient for the desired collector well yields, site-specific aquifer testing will be necessary prior to design and construction.
- Standard hydraulic-jacking methods for lateral installation are not feasible in the hardrock limestone terrain, and underground mining of skimmer tunnels is cost-prohibitive.
- Drilling and installation of small diameter lateral screens is feasible and the preferred approach.
- Layne's OME opinion of costs is approximately $26,000,000 for the laterals, pumping, equipment, and associated appurtenances. In conjunction with the Phase I caisson and lift equipment costs of $24,000,000 and an additional $2,000,000 for shaft riser pipes, decking, access, and utility lines, this brings the total to approximately $52,000,000.

Given the large range of the OME opinion (plus 50 percent to minus 30 percent), this estimate is within the range of GWA's original budget estimate of $44,000,000.

As a result of the above findings, Brown and Caldwell recommends that the use of collector wells be further pursued through site-specific characterization and groundwater flow modeling and monitoring to develop the baseline data necessary for design. Such work should be closely coordinated with GEPA, USGS, and WERI to ensure compatibility with current NGL groundwater management practices.

SECTION 5

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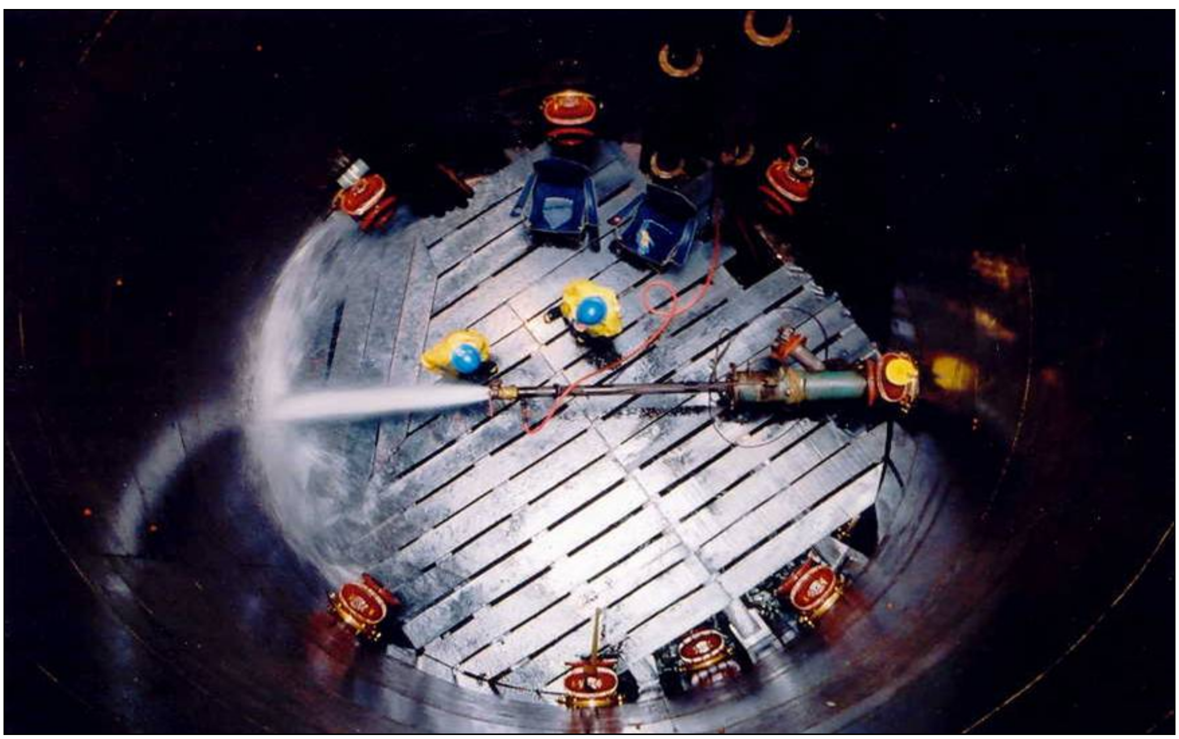
APPENDIX A

COLLECTOR WELL PHOTOGRAPHS FROM LAYNE CHRISTENSEN

Jacking machine installing lateral from caisson.

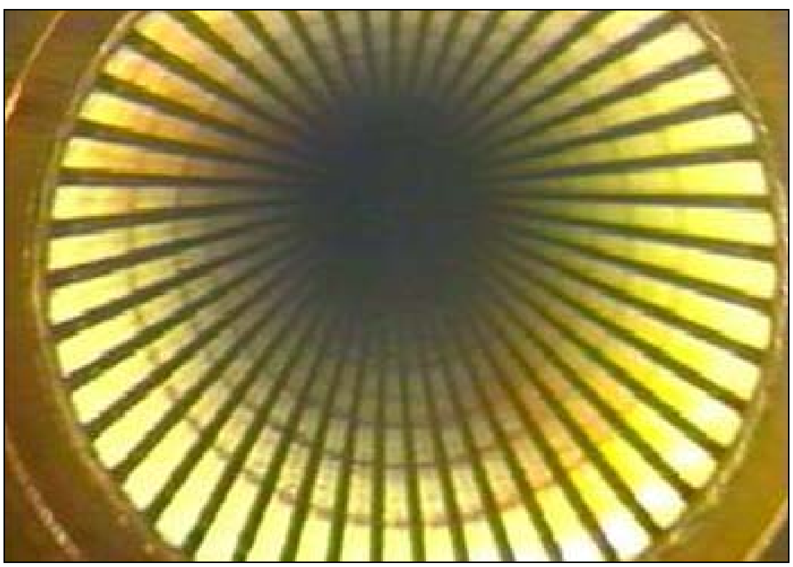
Jacking machine close-up.

Jacking machine installing screen.



Collector well laterals, vertical view.

Collector well screens, prior to installation.



Lateral screen, inside view.

Lateral screen, close-up view.

Collector well lateral, view from caisson.

APPENDIX B

STATE OF CALIFORNIA SACRAMENTO RIVER COLLECTOR WELL PHOTOGRAPHS (STEINPRESS, 7/14/06)

Concrete surface completion.

Collector well pump.

Pump bowls.

Collector well laterals, piped to manifold at bottom.

APPENDIX C

GEOLOGIC MAP, GUAM COLLECTOR WELLS (PGE PLATE 2)

8499-002 geology map.dwg (05-11-06)

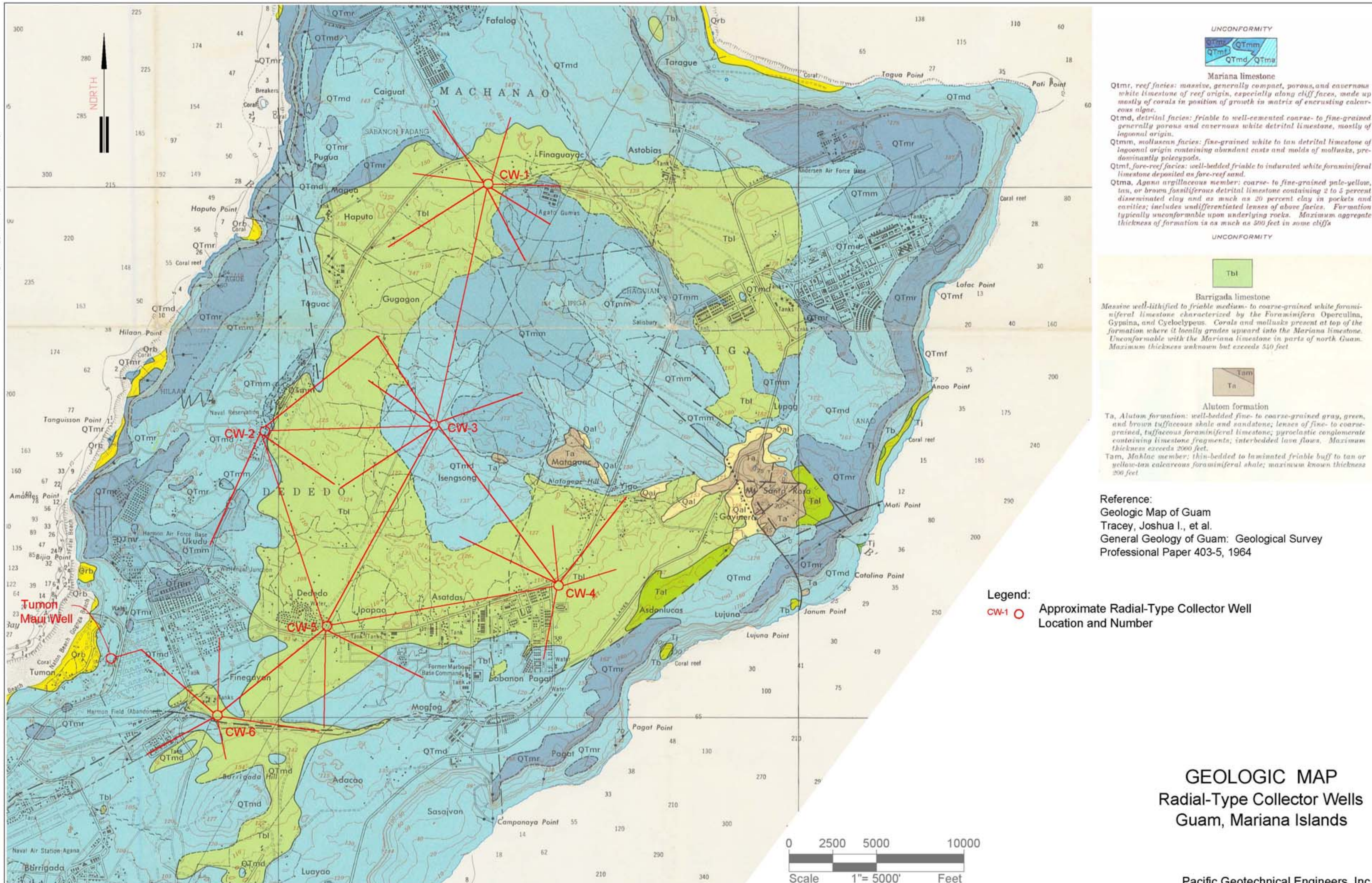


PLATE 2

Asphalt-Mixing Plant

Commences after arrival of sand and gravel or aggregate at the plant stockpile.

Concrete Ready-Mix or Batch Plants

Commences after arrival of sand and gravel or aggregate at the plant stockpile.

Custom Stone Finishing

Commences at the point when milling, as defined, is completed, and the stone is polished, engraved, or otherwise processed to obtain a finished product and includes sawing and cutting when associated with polishing and finishing.

Smelting

Commences at the point when milling, as defined, is completed, and metallic ores or concentrates are blended with other materials and are thermally processed to produce metal.

Electrowinning

Commences at the point when milling, as defined, is completed, and metals are recovered by means of electrochemical processes.

Salt and cement distribution terminals not located on mine property.

Refining

Commences at the point when milling, as defined, is completed, and material enters the sequential processes to produce a product of higher purity.