EXHIBIT B

SCOPE OF WORK

Introduction

The INTERA Team's technical approach for conducting an evaluation of brackish groundwater in the Rustler Aquifer will result in a high quality product for the Texas Water Development Board (TWDB) that is completed on schedule and within the allotted budget. This section describes our approach to the scope of work tasks, the organizational and management approach we will use to complete the tasks, and the reports and other documentation that we will deliver to the TWDB over the course of the project.

Our technical approach to the scope of work tasks is based on more than 30 years of experience, both in west Texas and in southeast New Mexico, on projects involving characterization and modeling of the Rustler Formation. As part of developing the Rustler Groundwater Availability Model (GAM), INTERA worked closely with the TWDB Brackish Resources Aquifer Characterization System (BRACS) division staff to co-develop the Rustler structural contacts in the Delaware Basin. We have also recently completed several detailed hydrostratigraphic and groundwater resource evaluations in the Rustler Formation. The Rustler is a complex aquifer system with lithologic variability, fracturing (secondary porosity), dissolution collapse residuum, and structural features that include fault throws large enough to offset the entire Rustler sequence by more than 600 feet. Based on our experience in the Delaware and other basins, we believe that standard log-based water quality analysis techniques will be insufficient to adequately delineate water quality in the Rustler Aquifer. In light of this, we will augment standard techniques with more sophisticated technologies developed for the oil and gas industry. The INTERA Team's overall approach to completing the tasks necessary to delineate and quantify brackish groundwater in the Rustler incorporates the following key features.

Access to Additional Geophysical Logs. In order help obtain important geophysical logs for the project, we have established formal agreements with two commercial providers of well logs. Both firms—Drillinginfo and The Subsurface Library—have agreed to provide, at a minimum, the portions of the logs that include the Rustler Formation to the TWDB for public use.

Construction of a Log Database. In conjunction with the currently publicly-available logs, the additional logs acquired from Drillinginfo and The Subsurface Library will provide us with the geographically-distributed information needed to better define aquifer lithology, structure, and water quality across the Rustler footprint. We will design and construct a log database using a subset of the BRACS database schema to facilitate subsequent integration.

Rustler Stratigraphy and Lithology. As applicable, the INTERA Team will use the logs to make picks in the Rustler Aquifer footprint for the Vaca Triste Sandstone Member of the Salado Formation and all member units of the Rustler Formation. The presence and thickness of the Vaca Triste Sandstone correlates with Salado dissolution and concomitant collapse and development of secondary fracture and/or vuggy porosity in the overlying Magenta and Culebra Dolomites (Powers et al., 2003).

Delineation of Salinity Zones. The identification of fresh, brackish, and saline groundwater will be based on the classification developed by the U.S. Geological Survey (USGS) (Winslow and Kister, 1956).

Calculation of Volumes. We will develop and apply a methodology to calculate brackish volumes that is based on TWDB's approach to calculating Total Estimated Recoverable Storage. This methodology will incorporate the lithology, primary or secondary porosity controls, water bearing zones, and total dissolved solids (TDS) profiles obtained from the analyses of geophysical logs and validated using a resistivity sensitivity analysis.

Identification of Transmissive Brackish Areas. Potential production areas (PPAs) will be evaluated using a combination of legislative mandates, geophysical log interpretation (mainly presence/absence of definable member units) and, where available, water well production information.

Identification of Hydrogeological Barriers. As part of our work developing the Rustler GAM (Ewing and others, 2012), we mapped major faults in the Rustler and characterized their throw. The conductance of faults was estimated through conceptualization and calibration. Building on this knowledge, we will review lithologic boundaries to define features that may serve as hydrologic barriers between brackish and other types of groundwater that may potentially hinder production.

Assessment of Available Volumes. The INTERA Team will develop and apply groundwater flow models to determine the volume of brackish groundwater that can be produced over 30- and 50-year time periods without causing significant impacts to fresh groundwater or areas with existing brackish groundwater use. Multiple model runs will be performed to evaluate the sensitivity of the predicted pumping impacts to modeling assumptions and aquifer parameters. Sensitivity to fault conductance will also be evaluated.

In developing our approach to performing the brackish groundwater evaluation for the Rustler Aquifer, we considered three key criteria—all of which are indicative of the feasibility of the approach. As described below, these criteria are: scientific soundness, time efficiency, and cost effectiveness.

Scientific Soundness. First and foremost, our approach has to be scientifically-sound and produce results that are technically-defensible. Using geophysical well logs to determine water quality in areas that lack sampled water quality, like the Rustler Aquifer, is a scientifically proven and technically defensible method used regularly in water resource evaluations. Furthermore, because of the limited geographic coverage of available logs that include the Rustler, the INTERA Team has enlisted the support of Dr. Carlos Torres-Verdin, an expert in geophysical log analyses, to perform sensitivity analysis on the available geophysical logs and to provide further validation that the water quality interpretations we make are consistent with current, state-of-the-science petrophysical methods.

Time Efficiency. Our approach has to be time efficient and implementable within the required timeframe for the project (final version completed by 30 days after the Project Completion Date). One of the more time-consuming activities associated with the project is locating geophysical logs that are suitable for use in evaluating the Rustler Aquifer (i.e., logs with data that includes the Rustler interval). This is particularly true when only using public log databases. We have established formal agreements with two private log libraries/providers that not only provide us with access to vast quantities of catalogued geophysical logs, but that will allow the Rustler portions of acquired logs to be made available for public dissemination. This will enable us to focus more of our time on log interpretation which is critical to producing a high quality project that is accomplished in accordance with the TWDB's schedule requirements.

Cost-Effectiveness. Our approach has to be cost-effective in terms of meeting the TWDB's estimate for completing the Rustler Aquifer project. Accordingly, our approach defines a level of activities that is consistent with meeting the TWDB's cost expectations. INTERA's 15+ year track record of delivering work products to the TWDB at the agreed-upon cost provides added assurance that the budgetary constraints for this project will be met.

As the following detailed discussion of the scope of work tasks will confirm, the INTERA Team's approach is not only technically feasible, but will result in a high quality evaluation of brackish groundwater in the Rustler Aquifer that is completed on-time and on-budget. We are fully committed to delivering the information needed to support the TWDB's report to the legislature on brackish resources in the Rustler and three other aquifers by December 1, 2016.

We have divided the brackish groundwater evaluation of the Rustler Aquifer into six tasks. Discussions of the activities associated with each task, and our approaches to executing the tasks, are provided below.

Task 1 – Project Management

An expedited study of brackish groundwater in the Rustler Aquifer requires expertise in several facets of hydrogeology and well log interpretation. Imperative to the success of the project is a project manager that is intimately familiar with hydrogeologic data, models, the geology of the Rustler, and the TWDB groundwater program. To meet these requirements, Mr. Van Kelley, PG will serve as our Project Manager. Mr. Kelley has previously managed six TWDB contracts covering development and calibration or recalibration of seven GAMs including the model of the Rustler Aquifer. In his role as Project Manager, Mr. Kelley will serve as the single point of contact for the TWDB and stakeholders. We understand that given the importance, complexity, and accelerated schedule for completing the project, regular coordination and communication with the BRACS division staff will be critical to project success. Mr. Kelley's project management responsibilities will include providing prompt and comprehensive information to TWDB and stakeholders regarding the project's schedule, budget, and technical considerations. Specific project management activities include submitting monthly progress reports, attending review meetings with the TWDB, and providing senior technical review of the INTERA Team's project deliverables. Additional details on our project organization and management approach are provided in Figure7-6 (see Exhibit A). The INTERA Team's proposed project organization is shown in Figure 7-5 (see Exhibit A). Our organization and management approach is designed to satisfy the following objectives: provide timely and effective administration of the contract; be highly responsive to TWDB; ensure efficient access to and optimal use of our personnel as required by each specific technical task; provide complete, on-schedule, on-budget, quality-assured performance on all tasks; and provide effective communication among team members and the TWDB and other stakeholders.

Our Project Managers use Axiom's Ajera Complete, a computer-based project control system that integrates time keeping, accounting, and accounts receivable. The Project Manager can monitor project hours and charges in real time since the system updates with every hour added on a timesheet (time is entered on a daily basis). This system provides for detailed tracking of resources and schedules and allows early identification of problem areas so that any required corrective measures can be applied in a timely manner. A key component to our management and control plan is the development of a detailed task plan. We have divided the Rustler Aquifer project scope of work into six primary tasks. These tasks are divided into subtasks that further break out the work scope. Our Project Manager will establish the budget for each task, and assign each element of work an appropriate task code designation. The Project Manager will monitor the performance of each work element and will prepare monthly progress reports.

Monthly status reports, including technical information regarding progress on the in the preceding month, will be provided to TWDB. The monthly report will summarize project progress relative to the schedule. Cost summaries, by task and subconsultant, will be provided to the TWDB with our monthly invoices. These cost summaries include personnel hours and direct costs charged to date, current estimates to complete the project, and a comparison of the current estimated total with the previously established budget. Monthly project reports will be used as a means of documenting issues, either technical or programmatic, which require consultation with the TWDB. Coordination with TWDB staff will be critical throughout the project. Exhibit E provides guidelines for a progress report.

The project management task also includes a minimum of six meetings. The minimum number of meetings includes Stakeholder Meetings 1 and 2 and TWDB Meetings 1, 2, 3, and 4. Stakeholder Meeting 1 already occurred on October 26, 2015 and was attended by at least one member of the INTERA Team. TWDB Meeting 1 will be for the project initiation, TWDB Meeting 2 will discuss and approve methodology, TWDB Meeting 3 will follow Stakeholder Meeting 2 and create a prioritized list of potential production areas for capacity analysis, and at TWDB Meeting 4 a formal presentation will be given at the completion of the project. Mr. Kelley will schedule and attend the project initiation meeting with the TWDB immediately after contract award and the project completion meeting upon submittal of the final technical report summarizing the project. He will also coordinate with the TWDB to establish the date, time, and location of Stakeholder Meeting 2. This meeting will provide information on the results of the project and solicit input on the identified potential production areas. The INTERA Team will attend and present data and interpretations at the meeting. Prior to this meeting, we will discuss an approach with the TWDB for presenting data and discussing technical issues. No later than four (4) business days before the meeting, we will provide a draft presentation to TWDB for review and comment. In addition, we anticipate regular communications with the TWDB's Project Manager and other TWDB staff during the project. These additional meetings will be held either in person, through a webinar, or teleconference. INTERA's Austin office, located approximately five miles from the TWDB office, will facilitate communication throughout the project.

In accordance with the schedule requirements defined in the RFQ, the INTERA Team will have a draft version of the deliverables to TWDB by the Project Completion Date. Then TWDB will have two weeks to review the draft and the INTERA Team will have two weeks to respond to TWDB comments. Therefore, the final version of the report is due 30 days after the Project Completion Date. Table 7-1 (see Exhibit A) provides a breakdown of the percent of effort to be expended for each task along with a labor hour breakdown for each of the INTERA Team companies and consultants.

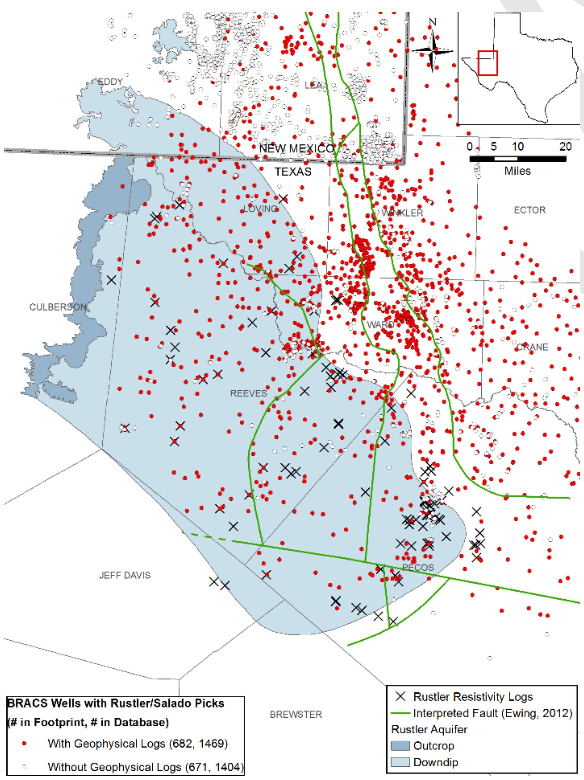
<u>Task 1 Related Deliverables</u>
See Section II of the Request For Qualifications (RFQ) NO. 580-16-RFQ0008 for detailed description of monthly progress reports, meetings and deliverables (Exhibit I). See Exhibit D for report formatting guidelines, Exhibit G for data requirements, and Exhibit H for report outline.

- Monthly Progress Reports.
    - Original or adjusted schedule and relative progress.
    - Project invoices.
    - Consistent with the budget description.
    - Issues that may arise.
    - See Exhibit E for guidelines.
- Stakeholder Meeting 1: Already held on October 26, 2015 in Austin, TX to explain TWDB's approach in implementing House Bill 30, solicit feedback on what constitutes "significant impact", and receive general comments concerning implementation of the legislation.
- TWDB Meeting 1: Project Initiation Meeting.
- TWDB Meeting 2: Discussion and approval of Project methodology; date to be determined by the Contractor.
- Presentation for the second stakeholder meeting no later than 4 business days before Stakeholder Meeting 2 for the TWDB to review.
- Stakeholder Meeting 2: Presentation and discussion of potential production areas with stakeholder in the morning; The Contractor will set the date and provide a minimum of one-month advance notice to TWDB. TWDB staff will organize the meeting and invite stakeholders.
- TWDB Meeting 3: Discuss prioritization of potential production areas for production calculations with TWDB staff in the afternoon on the same day or soon after Stakeholder Meeting 2. If agreed upon by both TWDB and INTERA, adjustments to the timing of meetings and review periods may be made to accommodate unanticipated delays that are outside of the contractor's control due to the aggressive schedule and unmovable deadline of 30 days after the Project Completion Date.
- TWDB Meeting 4: Project completion; formal presentation at the end of the Project.
- Draft final report and deliverables to TWDB by the Project Completion Date.
- Final Report and deliverables, with responses to TWDB comments, to TWDB 30 days after the Project Completion Date.

Additional technical meetings may be scheduled either in person, through a webinar, or teleconference venue to discuss project progress and issues. TWDB staff may periodically visit the Contractor's work premises to assess progress on the project.

Task 2 – Delineate Vertical and Horizontal Extent of Fresh, Brackish, and Saline Groundwater

The distribution of water wells with water quality data in the Rustler Aquifer from the TWDB's Groundwater Database, the USGS National Water Information System, and in various studies that incorporated groundwater quality (SPWLA (1982), Texas Water Commission (1989), Small and Ozuna (1993), Boghici (1997), Brown (1998), Boghici and Van Broekhoven (2001), TWDB (2015)) is shown in Figure 7-1. Ewing and others (2012) provided a dataset for all available water quality samples for the Rustler Formation in and surrounding the Rustler Aquifer footprint (Figure 7-1 shown here and Figure 4.8.2 in Ewing and others, 2012). The Ewing data is from the TWDB's historical records that were available in November 2012, published reports, and the USGS in New Mexico (Ewing and others, 2012).



In addition to the records Ewing and others (2012) compiled to develop the Rustler GAM, the INTERA Team has acquired three additional water quality samples from the TWDB records, six from the USGS records, and 15 water resistivity samples from a 1982 Society of Professional Well Log Analysts (SPWLA) publication. After querying the TWDB GWDB and USGS databases for water quality values in the project area, one of the resulting points appears to be a duplicate between the two datasets. However, the sampled water quality is in different ranges (Figure 7-1). Because the SPWLA samples include an R_w value, they provide both calculated water quality and additional data to estimate the resistivity of the water from the resistivity recorded on the geophysical logs (R_w from R_t). This concept is discussed in more detail in later sections.

Even with this additional data, the distribution of water quality samples within the Rustler Aquifer is still sparse. To help improve data coverage, the INTERA Team will contact GCDs that overlie the Rustler Aquifer in an effort to obtain additional water quality samples and well completion information for the public domain. With the advent of hydraulic fracturing, more oil and gas companies are using Rustler water for their operations. Our experience has shown that these companies commonly share well completion and water quality information with the GCDs. INTERA will use stakeholder meetings, in addition to the two stakeholder meetings required by the RFQ, to make requests to non- GCD entities or persons for additional water quality data in the Rustler.

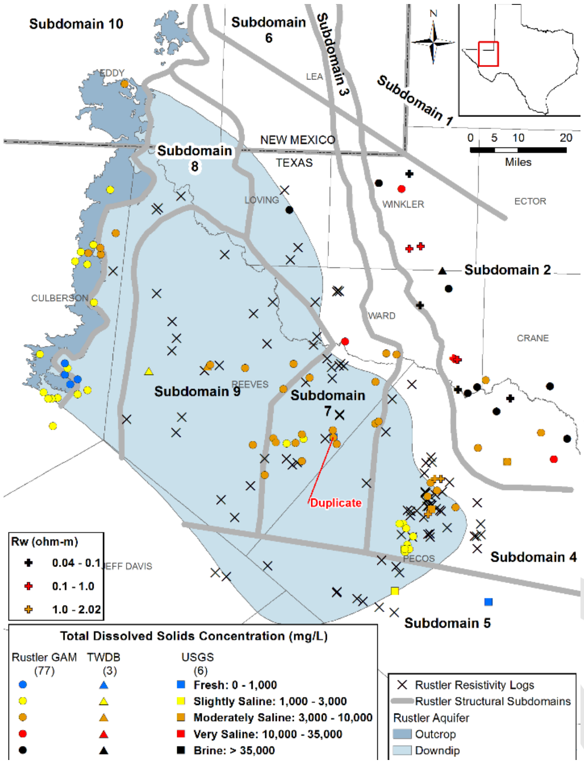


Figure 7-2. Rustler project area base map showing BRACS well log and pick availability along with inferred faults (from Ewing and others, 2012). Resistivity logs shown from a query of IHS data.

Given the sparse vertical and horizontal distribution of water quality samples from the Rustler Aquifer, additional water quality estimates would be of considerable value in delineating the brackish groundwater zones. Because calculated water quality, as opposed to sampled water quality, can provide a reasonable proxy for trends in the distribution of Total Dissolved Solids (TDS) in a groundwater basin, INTERA proposes to use electric logs to augment the data shown in Figure 7-1. In the Delaware Basin, oil and gas wells are typically drilled to the base of useable quality water, surface casing is installed, and the well is then drilled to the base of the Castile Formation, generally using a saturated saltwater mud to prevent dissolution of the Castile and Salado evaporites. A second string of casing is then normally installed. This often negates the possibility of an open-hole log being run through the aquifer(s) that overlie the evaporites. Although electric logs are not commonly run through the Rustler Aquifer, they do exist, and it is merely a matter of locating them, assessing their quality, establishing a means to provide them to the TWDB for public dissemination, and interpreting them. While all of these tasks are a challenge for the Rustler Aquifer, we have developed a strategy for acquiring useful well logs that can be made available to the public. The following subtask discusses this strategy.

Task 2.1 – Acquire and Digitize Geophysical Well Logs. The ability to efficiently access public and private well log databases to supplement currently available information is critical to the success of this project. For the public databases, we first queried TWDB's BRACS database. Shown in Figure 7-2, there are 682 wells within a 10-mile buffer around the Rustler Aquifer footprint with picks for either the Rustler or Salado and that have at least one raster log. In addition, there are 671 wells that do not have a geophysical log but have a pick for the Rustler or Salado. Geophysical logs and associated metadata in the BRACS database that fit the criteria for this evaluation will be integrated into a Petra- based project database. Petra is an integrated software application with a common database and interface for project and data management, well log analysis, mapping, cross-sections and seismic data integration. As INTERA demonstrated during the development of the High Plains Aquifer System GAM (Deeds and others, 2015), using Petra facilitates the process of formatting data for ultimate entry into the BRACS database.

Other public databases in Texas that offer some potential to provide geophysical logs run through the Rustler Aquifer, but do not have the necessary metadata to readily query, are the databases at the Railroad Commission, the Bureau of Economic Geology and the University Lands. In New Mexico the Oil Conservation Division (OCD) retains the majority of all logs run in the state of New Mexico. The key issue with these log databases is that they lack the ability to query and subsequently access the logs in an efficient and timely manner on the scale required to support the evaluation of brackish groundwater in the Rustler. It is important to have a database that catalogues the top and bottom logging interval of every curve on the geophysical log for the well. With the exception of the BRACS database which will be used over the entire Rustler Aquifer extent, all of the aforementioned public databases will be used to infill small areas where there are data gaps as opposed to being primary data sources.

While public log databases are ideal when evaluating a small number of wells in a geographically small area, for larger areas and time-critical applications, more time can be spent on the actual analysis of the geophysical logs when the majority of the front end work has been completed by specialized commercial log database companies. The INTERA Team has developed a strategy that allows leveraging the efficiency and comprehensiveness of commercial log databases while allowing the logs to be made public as required for the proposed work.

To better evaluate the availability of resistivity logs, INTERA used our IHS subscription to determine the distribution of these logs in and around the Rustler Aquifer footprint. IHS has the world's largest log database for the Permian Basin. All wells that overlie the Rustler Aquifer footprint within a 5-mile buffer were queried, resulting in approximately 7,000 wells. For these wells, there were over 120,000 geophysical logs. A majority (>95%) of the logs had a top logging interval well below the base of the Rustler Formation, essentially making them unusable for this analysis. We then queried wells having a resistivity/induction or any other type of electric log run through the Rustler Aquifer with a buffer of 200 feet below the top of the Rustler and 200 feet above the base of the Rustler. The 200-foot buffer was applied in an attempt to not throw out logs that have the majority but not all of the Rustler Formation logged. This query resulted in a total of 329 wells with all of the logs having a gamma curve and 97 of them having some type of a resistivity (Figure 7-1).

Given the stipulation in the RFQ that "Geophysical well log data obtained for the project must be non- confidential and submitted in a Tagged Image Format (TIFF) and, if available, Log ASCII Standard (LAS) format", we cannot use the logs from the IHS database since IHS is unwilling to provide the geophysical well logs for public dissemination. However, recognizing the contribution that the private log databases can provide to the project, INTERA has received a written commitment (provided in Exhibit A) from Drillinginfo, an Austin based private log library with a log database comparable to the IHS Permian Basin database, to release to the TWDB for ultimate public dissemination the Rustler Aquifer portion of any logs purchased specifically for this project. Accordingly, INTERA will acquire logs from Drillinginfo, and these logs will be redacted below the Castile Formation/ top of the Delaware Mountain Group. Acquiring these logs means that less of the project budget will be spent on searching for publicly available logs and integrating them into our Petra database. Conversely, more time can be spent to ensure the accurate evaluation of the logs. In addition, since Drillinginfo will be working with INTERA to query out these logs, the end result will be a much larger number of higher quality logs that will ultimately be integrated into the BRACS database and provided to the public.

Drillinginfo, working with INTERA, has queried their database in the project area for logs with a curve in addition to natural gamma. The resulting dataset contained 548 wells with geophysical logs, in addition to gamma, that are run through the Rustler Formation with a buffer of 200 feet below the top and 200 feet above the base of the Rustler Formation. Drillinginfo will physically examine each one of these geophysical logs and determine/catalog the type of logs that are run through the Rustler Formation. We anticipate that the Drillinginfo database will include a large percentage of the resistivity logs we identified in the IHS database as well as additional logs not identified by IHS. For the resistivity logs that are not in the Drillinginfo database and for geographic areas that do not have any data in the database, we will use The Subsurface Library to search for logs (in addition to natural gamma) in the specific areas where additional data is needed. The Subsurface Library has also committed to allowing the Rustler portion of any acquired logs to be made publically available (see letter in Exhibit A).

In addition to resistivity/induction logs, the INTERA Team will search the databases for neutron porosity logs to support the analysis of structure, stratigraphy, and lithology for all of the member units of the Rustler Formation. Figure 7-3 (see Exhibit A) shows the units that comprise the Rustler Formation. Logs from the BRACS database will be the first to be integrated. Based on our past experience in assembling and analyzing logs, we believe it is likely that the majority of the logs for the 548 wells in the Drillinginfo database will have a neutron porosity log run through casing. While a neutron log run through casing is not ideal, Dr. Dennis Powers, a member of the INTERA Team, has considerable experience in evaluating these logs. In combination with the natural gamma signature, the neutron porosity log can be used to delineate the member units of the Rustler Formation and provide insights into the lithologic patterns and distribution of cementation, in addition to identifying areas of Salado Formation collapse. We are confident that an adequate distribution of logs can be assembled to refine the structure and lithology of the Rustler Formation and its member units.

<u>Task 2.1 Related Deliverables</u>
See Section II and III of the Request For Qualifications NO. 580-16-RFQ0008 for detailed descriptions of deliverables (Exhibit I). See Exhibit D for report formatting guidelines, Exhibit G for data requirements, and Exhibit H for report outline.

- Log database using a subset of the BRACS database schema to facilitate subsequent integration, for the final report.
- Copies of water well reports, water quality reports, and geophysical well logs used in the project that were not already in the BRACS database, for the final report.
- Figure showing the project area and distribution of logs for the final report.

Task 2.2 – Draft Techniques and Approaches Report and Meeting. Once the best possible population of resistivity and neutron porosity/natural gamma logs has been identified, we will document the findings and draft a technical approach report for submission to the TWDB. The specific approach for geophysical well log interpretation of aquifer TDS concentration will be dependent on the availability and type of geophysical logs. The report will include information on the types of geophysical well logs available in the Rustler Aquifer area, how the interpreted TDS concentration from well log analysis relates to existing aquifer water chemistry as determined by direct measurements, how the log correction factors are determined, and how the interpretation techniques will be applied across the entire salinity range within the aquifer. We will then meet with staff at the TWDB to discuss the techniques and establish consensus on the overall approach.

After receiving TWDB approval of our approach, INTERA will digitize relevant logs to .las files and catalog all of the available header parameters. The digitized logs will serve two purposes. First, they will be used to facilitate the development of a series of structural cross-sections through the area of interest. Second, the digitized logs are essential for making calculations and correcting log signatures based on borehole conditions and formation thicknesses/parameters. For example, with water quality calculations from resistivity logs, areas of mud filtrate invasion must be identified before calculations of water quality can be made. If the log is digitized and the resistivity of the mud filtrate is documented in the log header, algorithms can be used to identify areas where the resistivity is reflective of the borehole mud filtrate as opposed to the formation water resistivity.

<u>Task 2.2 Related Deliverables</u>
See Section III of the Request For Qualifications NO. 580-16-RFQ0008 for more detailed descriptions of deliverables (Exhibit I). See Exhibit D for report formatting guidelines. See Exhibit G for data requirements.

- A draft report documenting the technique(s) and approaches for geophysical well log interpretation of aquifer total dissolved solids concentration approaches to TWDB up to 10 business days prior to TWDB Meeting 2 (see Task 1 for list of meetings) in both Microsoft Word and PDF formats.
- Digitized relevant logs as .las files for the final report.
- Cataloged header parameters for integration into the BRACS database for the final report.
- TWDB Meeting 2: Discussion and approval of Project methodology; date to be determined by the Contractor.

Task 2.3 – Evaluate Structure and Lithology. The first step in this task will be a thorough literature review encompassing publications relevant to the stratigraphy, structure, lithology, and water chemistry of the Rustler Formation. A significant repository of relevant Rustler publications was amassed by the INTERA Team as part of developing the Rustler GAM (Ewing and others, 2012) and by the BRACS group as part of the study on the Structure and Brackish Groundwater in the Pecos Valley Alluvial Aquifer (Meyer and others, 2012). Historical publications of significance include Hiss' 1975 PhD dissertation on the Stratigraphy and Ground-Water Hydrology of the Capitan Aquifer (Hiss, 1975) in addition to the structural map that he created for the Rustler Formation (Hiss, 1976). Dr. Dennis Powers used these and other publications as references for developing the structure of the Rustler Formation as part of the Rustler Aquifer GAM that was submitted to the TWDB (Ewing and others, 2012). Since the completion of the Rustler GAM and the Pecos Valley Alluvial Aquifer study, the USGS has published a series of reports related to the hydrogeology and hydrogeochemistry of the Edwards-Trinity and related aquifers in the Pecos County Region (Pearson and others, 2012, Bumgarner and others, 2012 and Clark and others, 2014). While these reports are mainly focused on the Edwards-Trinity system, data acquisition, analysis, and modeling efforts included the Rustler Formation and these reports will be used as a reference when considering the hydrogeology and hydrogeochemistry of the Rustler Aquifer.

Finally, the TWDB commissioned an evaluation of the hydrochemical and isotopic data in GMA 3 and GMA 7 (Kreitler and others, 2013). Data and conclusions from this report will be evaluated and used appropriately when considering the water quality in the Rustler Aquifer.

The INTERA team will maximize the use of available data by using the gamma and neutron porosity logs, along with any other supplementary logs, to make picks on the member units of the Rustler Formation along with a refined distribution of halite cementation and Salado collapse in the Rustler Aquifer footprint. A portion of the structure of the Rustler was jointly developed by INTERA and the BRACS Group as part of developing the Rustler GAM (Ewing and others, 2012 and Meyer, 2011). The structure of the Rustler is complex and a hydrostructural conceptual model was developed in Ewing and others (2012). The BRACS structure and the hydrostructural conceptual model will provide a foundation for this work. We will further evaluate halite presence, and dissolution and secondary cementation to help develop a model of lithology that will be central to log interpretation and ultimately quantification of groundwater volumes.

Halite in the Rustler commonly indicates where porosity is occluded, permeability is extremely low, and the salinity of any water is close to saturation with respect to halite (e.g., Powers et al., 2003, 2006). Specific log characteristics have been used to map halite cementation margins for Rustler members in parts of the Delaware Basin (Powers et al., 2003). These log characteristics were determined from shaft mapping (Holt and Powers, 1984, 1986, 1990) as well as core analysis and geophysical log interpretations (Holt and Powers, 1988, 2010; Powers, 2008; Ewing and others, 2012). The main source of data for developing the distribution of halite cementation is geophysical logs. The most thorough analysis can be made for boreholes with a more complete suite of logs (natural gamma, caliper, and density or sonic) (Powers and Holt, 2000). While drill holes with this suite of logs are variably distributed, they do provide good benchmarks. Through his more than 40 years of experience working in the Rustler Formation, Dr. Powers has acquired a series of these benchmarking logs. The stratigraphy of the Rustler is dominantly determined on the basis of natural gamma (Holt and Powers, 1988; Powers and Holt, 2000). Members and informal units are widespread and facies changes are most common in the halitic units. Interval thickness and changes in the log character can be reasonably determined through gamma and neutron logs, again with corroborating evidence from a more complete suite, as available.

Another important contributor to Rustler hydraulic properties is dissolution of salt from the upper Salado. An evaluation of the distribution of hydraulic heads shows that the Tessey Limestone and the Rustler Aquifer outcrops in the Rustler Hills are the most likely locations for recharge to the Rustler Formation (Ewing and others, 2012). In these areas preferential flow paths are developed where recharged groundwater dissolves the halite cemented porosity in the Culebra and Magenta dolomites or recharging groundwater is initiating Salado dissolution and subsequent Rustler collapse. This serves to create a feedback loop where the transmissivities increase as the Rustler Formation Culebra and Magenta Dolomites continue to fracture following Salado collapse.

A metric for identifying upper Salado dissolution developed in the Delaware Basin uses the thickness of the interval between the Culebra Dolomite Member of the Rustler and the Vaca Triste Sandstone Member of the Salado Formation. Both units are widespread. Regional trends in depositional thickness (Powers et al., 2003) are disrupted at dissolution margins that are relatively sharp (Powers et al., 2003; Holt and Powers, 2010). Across large areas the upper Salado also displays natural gamma as well as other log characters (including neutron) that are related to regionally extensive marker beds and other units. For more detail, local log cross-sections can be correlated to reveal truncation of upper Salado beds (Powers, unpublished presentation to WIPP Peer Review Panel). The natural gamma character of the basal Rustler (Los Medaños Member, comprising siliciclastics, halitic mudstones, muddy halite, and sulfates (mainly anhydrite)) can reveal the amalgamation of upper Salado residues. Identifying these areas will contribute to discretization of areas of Salado collapse. Where Salado collapse has occurred, it is anticipated that the Rustler Formation Dolomites will exhibit a more cavernous (secondary) porosity and this will be factored into the delineation of potential production areas (PPAs).

<u>Task 2.3 Related Deliverables</u>
See Section II and III of the Request For Qualifications NO. 580-16-RFQ0008 for detailed descriptions of deliverables (Exhibit I). See Exhibit D for report formatting guidelines, Exhibit G for data requirements, and Exhibit H for report outline.

- At least 4 cross-sections (two along strike and two along dip) showing the overburden, Rustler Formation, member units of the Rustler Formation, top of the Salado Formation and top and base of the Vaca Triste Sandstone Member of the Salado Formation. These cross-sections will be used to highlight regional structure and log signatures for different lithologic regimes within the Rustler for the final report.
    - In areas where the individual member units of the Rustler Formation are indistinguishable, picks will be made for the Lower, Middle and Upper Members of the Rustler Formation.
    - It is anticipated that areas will exist where the discretization of the Rustler Formation into its component Member Units will not be possible. These areas will likely be the result of solution collapse and they will be identified in a plan view map of the project area.
- An adequate distribution of geophysical logs with picks data for the BRACS Database, where discernable, for the tops of the Rustler Formation/Forty-Niner Member, Magenta Dolomite, Tamarisk, Culebra Dolomite, Los Medaños Member, top of the Salado Formation and top

and base of the Vaca Triste Sandstone Member of the Salado Formation, for the final report.
- Figure showing the stratigraphy for the final report.
- Description of the stratigraphy and structure for the final report.

Task 2.4 – Generate Surfaces Defining Member Units of Rustler. Component member units of the Rustler Formation (see Figure 7-3 in Exhibit A) that were interpreted as part of Task 2.2 will be interpolated across the TWDB Rustler Aquifer extent using an interpolation algorithm in ESRI's ArcGIS v10.2 Spatial Analyst package. Surfaces for the top of the Vaca Triste Sandstone Member of the Salado Formation and top of the Salado Formation along with the tops of the Los Medaños, Culebra Dolomite, Tamarisk, Magenta Dolomite, and Forty-Niner members of the Rustler Formation will be interpolated to the extent possible. In areas where the formation tops are not identifiable, a best approximation for the top and base of the Rustler Formation will be made and these areas will be identified. In addition, domains reflecting like formational characteristics, mainly porosity (primary or secondary based on ability to identify member units), will be delineated and used to guide a formation parameter sensitivity analysis and to calculate volumes of available fresh, brackish, and saline groundwater in the Rustler Aquifer.

To assist in this process, all TWDB groundwater database wells and digitized submitted drillers reports with recorded production rates and screen information will be documented. For these wells, the top and bottom of the Rustler Formation will be established and all wells that fall within the Rustler Aquifer and have production values will be posted along with the areas of Salado Formation collapse. The distribution of the production rates will be evaluated in combination with the areas of Salado collapse to determine the existence of trends.

<u>Task 2.4 Related Deliverables</u>
See Section II and III of the Request For Qualifications NO. 580-16-RFQ0008 for detailed descriptions of deliverables (Exhibit I). See Exhibit D for report formatting guidelines, Exhibit G for data requirements, and Exhibit H for report outline.
- Description of the interpolation algorithm in ESRI's ArcGIS v10.2 Spatial Analyst package used to create surfaces and the data and parameters used as inputs for the final report.
- Tools, files and/or scripts used to interpolate surfaces developed for the project.
- Structural surfaces for the top and base of the Rustler Formation along with the tops of the Los Medaños, Culebra Dolomite, Tamarisk, Magenta Dolomite and Forty-Niner Members of the Rustler Formation. Where no further discretization of the Rustler into its member units is possible, a best approximation for the top and base of the Rustler Formation will be made for the final report.
- A plan view map and shapefiles displaying areas where the Rustler Formation is still intact and likely a primary porosity flow system and areas where Rustler collapse has occurred and is likely a secondary porosity flow system. This map will be based on analysis from geophysical logs and production rates from wells screened to the Rustler Formation for the final report.
- Map and shapefiles for wells where the formation tops are not identifiable and a best approximation for the top and base of the Rustler Formation was made for the final

report.

Task 2.5 – Formation Parameter Sensitivity Analysis. The calculation of water quality (calculated TDS) from resistivity is a standard technique to supplement areas where sampled water quality (sampled TDS) measurements are sparse. Examples of this include Alger (1966), Ayers and Lewis (1985), Fogg (1980), Fogg and Kreitler (1982), Fogg and Blanchard (1986), Hamlin (1988), Estepp (1998), and Meyer (2012). The majority of these applications were performed in the unconsolidated sediments of the Gulf of Mexico Basin where data availability and geographic distribution of electric logs is far greater than it is for the Rustler Formation within the TWDB Rustler Aquifer footprint. One possible exception is Collier's (1993a, b) evaluation of various consolidated formations (e.g., Cretaceous Edwards Formation, Trinity Group, Paleozoic limestones, etc.). In addition to the sparse distribution of resistivity logs, no detailed publications have been found that adequately discuss the calculation of water quality from resistivity or spontaneous potential measurements specifically in the Rustler Formation. Given the lithologic complexity of the units that make up the Rustler, standard techniques for water quality calculations can vary over many orders of magnitude if specific properties such as layer thickness, log type, porosity, cementation exponent, geothermal gradient, and permeability are not constrained.

Where resistivity logs exist (Figure 7-1), it is paramount that the sensitivities to potential variables be quantified. To that end, the INTERA Team includes Dr. Carlos Torres-Verdin, a professor in the University of Texas at Austin's Petroleum and Geosystems Engineering Department. Dr. Torres-Verdin will work closely with Dr. Powers and INTERA to evaluate the distribution of geophysical logs and determine, based on data density and availability, the best approach to characterizing water quality using resistivity logs.

Before water quality can be assessed from well logs, it is necessary that all borehole variables included in them be quantified. Depending on the specific conditions, some of the petrophysical affects can be greater than the impact of water quality. Well logs acquired in water-bearing rocks can be substantially affected not only by water quality (i.e., ion concentration, ion types, etc.) but also by rock properties such as porosity, permeability, irreducible water saturation, mud-filtrate invasion, borehole size, and layer thickness, in addition to the properties of the specific tools used to acquire them, especially considering the age of most of the logs run through the Rustler Formation. Most of the latter effects included in well logs are not typically accounted for by logging companies when providing well logs such as gamma ray, SP, resistivity, density porosity, and neutron porosity. Modern methods used in the interpretation of well logs invoke some degree of numerical simulation to quantify the relative impact of borehole and layer environmental effects in the interpretation of layer petrophysical properties and saturating fluids.

The numerical simulation of well logs is performed by first defining all pertinent, available, geometrical properties such as borehole size, mud type (i.e., types of ions in solution and their concentrations), temperature, layer thicknesses, etc. Next, layer properties such as porosity, volume of shale, permeability, total water saturation, irreducible water saturation, and water quality are used to calculate effective layer properties such as electrical resistivity, natural radioactivity, compressional and shear wave velocities, and nuclear properties. The calculated layer physical properties, together with the definition of layer thicknesses and specific tool properties are then used to numerically simulate all well logs (e.g., gamma, SP, resistivity, etc.). Comparison of numerically simulated well logs against measured well logs provides quantitative verification of the relative impact of relevant formation properties on the well logs, including water quality.

A central contribution of the numerical simulation of well logs is the generation of expected well-log signatures for a wide variety of petrophysical, fluid, and water quality conditions, for comparison against existing well logs. When all petrophysical and geometrical conditions are accounted for in the numerical simulation of well logs, the matching of available well logs and their numerical simulations can explicitly yield quantitative estimates of water quality without invoking ad-hoc and/or empirical correlations. The method can equally be used for interpretation of evaporitic, clastic, or carbonate formations, all of which exist in the Rustler Formation.

<u>Task 2.5 Related Deliverables</u>

See Exhibit D for report formatting guidelines. See Exhibit G for data requirements.

- An analysis in the form of figures and text showing the relative sensitivity of the resistivity logs to geometrical and petrophysical conditions. This sensitivity analysis will guide the analysis of the resistivity logs for calculation of water quality for the final report.
- A value for the resistivity of the formation water (R_w) factoring in the sensitivity of the resistivity signature to the aforementioned geometrical and petrophysical conditions.
- Consultation on this methodology for the final report.
- Copy of the simulated well logs to add to the BRACS database for the final report.

Task 2.6 – Interpret Water Quality Based on Distribution of Resistivity. Resistivity (ohm-m2/m or ohm-m) can be defined as the degree to which a substance resists the flow of an electrical current. In general, resistivity is inversely related to conductivity (millisiemens per meter or mS/m) and generally inversely related to Total Dissolved Solids (mg/L). That is, the higher the resistivity, the fresher the water and the lower the resistivity, the more brackish the water. Resistivity is measured in a borehole by lowering a logging tool down the borehole and using a multiple-electrode array to apply a constant current into the formation and measure the voltage drop. The resulting True Resistivity (R_t) is recorded on a geophysical log and represents the varying resistivity values within and amongst the formations contacted in the borehole. Assuming that the units contacted by the borehole had no electronic, as opposed to electrolytic, conductivity, then the rocks are electrical insulators and would exhibit an infinite resistivity. However, since rocks have a least some small amount of interconnected porosity, and that porosity is filled with a conducting fluid (oil, gas or water), the rock will have a measureable resistivity. Where the formation is 100 percent saturated with water (S_w = 100%) as opposed to some combination of water, oil or gas (S_w < 100%), as it is in the Rustler Aquifer, then the True Resistivity (R_t) is equal to the Resistivity of the rock filled with formation water (R_o). The Resistivity of the Water (R_w) is related to the Resistivity of the water filled formation (R_o) through the Archie Equation (Archie, 1942):
Where:

$$R_w = \frac{1}{\Phi^m} \times R_o$$

Where:

R_w = the resistivity of the water within the formation

Φ = porosity (provided from geophysical log interpretations and sensitivity analysis)

m = the cementation exponent (varied based on permeability of the Dolomite Members)

R_o = the resistivity of a 100 percent water saturated formation

The value of m reflects the tortuosity of current flow through the maze of rock pores (Dewan, 1983). Uncertainty in both the porosity and cementation exponent can result in a wide range of R_w calculations if not properly constrained. Fortunately, through numerical simulation using existing geophysical logs such as gamma, neutron porosity, resistivity, etc. in combination with known characteristics of the Rustler Aquifer, the porosity and cementation exponent can be appropriately constrained, resulting in a constrained calculation of R_w from R_t.

Once the resistivity of the formation water (R_w) has been parsed out of the true resistivity (R_t), the calculation of water quality (calculated TDS in mg/L) is relatively straightforward using the Archie Equation as an approximate guide:

First, the R_w at formation temperature must be corrected to R_w at 75°F based on formation temperature. Then, the formation water resistivity at 75°F ($R_{w\ 75}$) will be converted to Specific Conductance at 75°F:

$$C_{w75} = \frac{10{,}000}{R_{w75}}$$

Where:

C_{w75} = Specific Conductance at 75°F

R_{w75} = Formation water resistivity at 75°F

This is followed by the calculation of sodium chloride equivalent TDS:

$$TDS_{NaCl} = ct \times C_{w75}$$

Where:

TDS_{NaCl} = Sodium chloride equivalent Total Dissolved Solids in milligrams per liter (mg/L)

ct = C_{w75} - TDS conversion factor (derived using water quality samples from water wells producing from the formation of interest which would be the Rustler in this case)

C_{w75} = Specific Conductance at 75°F

This conversion of R_w to TDS diverts from Estepp's R_{wa} Minimum TDS method (Estepp, 1998) in that we do not apply a correction factor based on ionic makeup of the water, but instead assume that the calculation is for a sodium chloride equivalent TDS. Based on analysis performed by Ewing and others (2012), the Rustler Formation water makeup is high calcium, high sulfate, and low carbonate.

The extra step in this calculation requires a conversion from sampled TDS at the well to TDS_{NaCl} using the Schlumberger Chart Gen-4 (formerly Gen-8) shown in Figure 7-4 of Exhibit A (2009). The chart is used to approximate the parts-per-million (ppm) concentration of a sodium chloride solution for which the total solids concentration of the solution is known (Schlumberger, 2009). Individual values for the ionic makeup of the Rustler Aquifer will be used to calculate an equivalent TDS_{NaCl} from the formation water samples and a ratio of the TDS_{NaCl} to calculated TDS will be developed. There are roughly 85 locations that have the necessary water quality data needed to calculate this ratio. This ratio will be used as the last step to convert from TDS_{NaCl} to calculated total dissolved solids (TDS_{calc}) using the following equation:

$$TDS_{calc} = TDS_{NaCl} \times cf_{Rustler}$$

TDS_{calc} = Calculated Total Dissolved Solids in milligrams per liter (mg/L)
TDS_{NaCl}= Equivalent sodium chloride TDS calculated from R_w
$cf_{Rustler}$ = Correction factor specifically derived for the Rustler Aquifer from existing water quality samples (Figure 7-1) and Schlumberger Chart Gen-4 (Figure 7-4 of Exhibit A)

While there are other methods for calculating TDS from resistivity logs, primarily the Mean Ro Method (Estepp, 2010), we do not anticipate that the data will be available to use this method. In addition to the Mean Ro Method, the spontaneous potential curve can be used to calculate TDS. However, given the high salt content of the drilling mud, our experience has shown that the margin of error from calculations using the SP log is too large. Regardless, this method will be investigated in combination with the sensitivity simulations generated in Task 2.4.

Geophysical logs with resistivity curves will be digitized to .las format. The resistivity signatures over the dolomite members of the Rustler Formation, as defined in Task 2.2 and 2.3, will be compared to the simulated resistivity logs generated as part of the sensitivity analysis performed in Task 2.4. Resulting comparisons will guide the parsing of R_w from R_t on a log-by-log basis. In addition, R_w values derived from SPWLA (1982) will be used as a general guide for the parsing of R_w from R_t.

Corrected resistivity values on a per-foot basis over the Culebra and Magenta dolomites will be used to calculate TDS. These calculated TDS values will then be averaged over each of the dolomite members of the Rustler Formation, where they are identifiable in Task 2.2. Where the two dolomite members are not identifiable, and it is suspected that collapse has occurred, resistivity measurements will be evaluated over the entire Rustler Formation thickness. In these areas, an effort will be made to find and justify resistivity values that appear to make sense and that are not in stark contrast to surrounding water quality calculations or measurements. Resistivity logs in suspected collapse areas will be treated with caution. Where applicable, calculated TDS values will be compared to sampled water quality from water wells.
If values are significantly different, results from the sensitivity analysis will be used to guide modifications to the approach in order to reduce this mismatch. The result will be a calculated TDS for the Culebra and Magenta dolomites where they are able to be distinguished and

calculated TDS over the entire Rustler Formation in areas where the dolomite members are not distinguishable.

Averaged water quality calculations, conversions of R_w to TDS_{calc}, and water quality samples will be tabulated. In areas where the calculation is being made from resistivity logs and the Culebra and Magenta dolomites are distinguishable, there will be one calculation for the Culebra and one for the Magenta. If the two values are reasonably close, they will be averaged for consistency. In areas where there is a water quality sample or a conversion from R_w to calculated TDS, the TDS measurement will be applied to both of the units. Where the Rustler Formation is suspected to be collapsed, the water quality sample, measurement, or conversion will be applied over the entire Rustler Formation thickness.

These point location values, along with the shapefile for porosity zonation generated in Task 2.4, will be brought into ArcGIS and interpolated to delineate cutoffs for fresh, slightly saline, moderately saline, and very saline groundwater based on the classification by Winslow and Kister (1956).

<u>Task 2.6 Related Deliverables</u>
See Section II and III of the Request For Qualifications NO. 580-16-RFQ0008 for detailed descriptions of deliverables (Exhibit I). See Exhibit D for report formatting guidelines, Exhibit G for data requirements, and Exhibit H for report outline.

- Tabulated calculations, conversions and water quality samples for integration in the BRACS database, for the final report, including:
    - Roughly 85 calculations of ionic values to equivalent TDS_{NaCl}.
    - Ratio(s) for TDS_{NaCl} to TDS_{calc} for the conversion of R_w.
    - R_w values parsed from R_t on a log-by-log basis.
    - Corrected resistivity values on a per-foot basis over the Culebra and Magenta dolomites.
    - Averaged resistivity values for each dolomite pick where the two were identifiable, evaluated resistivities for the entire Rustler where collapse is suspected.
    - Calculated TDS for the Culebra and Magenta dolomites where they are able to be distinguished and calculated TDS over the entire Rustler Formation in areas where the dolomite members are not distinguishable.
- Interpolated surfaces for fresh, slightly saline, moderately saline, and very saline for the final report.
- Extent polygons for salinity classes for the final report.
- Text describing Task 2.6 methodology for the final report.
- Figures describing Task 2.6 methodology for the final report.

Task 3 – Quantify Volume of Fresh, Brackish, and Saline Groundwater

The INTERA Team will develop a GIS-based application to calculate volumes of fresh, slightly saline, moderately saline, and very saline groundwater by aquifer (Rustler), member (Culebra and Magenta dolomites), county, GCD, and groundwater management area for the Rustler Aquifer. The application will consist of scripts that automate the workflow in ArcMap (and the Spatial Analyst extension) and enable volumes to be calculated. This guarantees both reproducible results and the ability to quickly assess sensitivity of volume calculations to uncertain parameters, such as storage properties.

Notable features of the scripted workflow include:

- Calculations made based on a snap grid to ensure a consistent raster-based geometry with a common origin, extent, and cell size.
- Incorporates surface rasters developed by the INTERA Team as part of this analysis for the top and base of the Culebra and Magenta dolomite members of the Rustler Formation and top and base of the Rustler Formation. A shapefile developed as part of Task 2.4 will be used to distinguish between areas of primary and secondary porosity. In areas that are identified as having primary porosity, volumetric calculations will be confined to the Culebra or Magenta dolomite or the combination of the two units. Porosities in these areas will be interpolated from porosities derived from neutron porosity logs. In areas identified as having secondary porosity, the volumetric calculations will be calculated over the entire Rustler Formation thickness and the porosity values will be reflective of secondary porosity systems in the project area.
- Provides options for different assumptions and approaches to calculate volume either based on porosity, as derived from a geophysical logs, or a drainage volume such as specific yield (S_y), as derived from the Rustler GAM (Ewing and others, 2012).
- Allows the user to calculate groundwater volumes for any polygon-defined area (i.e., allows subdivision of larger salinity zones into the PPAs for volume calculations).

The scripted workflow will be implemented in the following 6-step sequence.

Step 1. ***Load the BRACS database into the GIS project.*** The database will contain the porosity values, identification of porosity type (primary or secondary), thicknesses of the Culebra and Magenta Dolomites, and water quality estimates from the geophysical logs and water quality samples from water wells.

Step 2. ***Load Additional Control Points.*** To guide calculation of groundwater volumes in regions where the geophysical data is sparse or complex, the INTERA Team will develop a set of control points for porosities, specific yield, unit thicknesses (Rustler or Dolomite units) and TDS concentrations that are based on an interpretation and extrapolation of geophysical data, measured water TDS concentrations at groundwater wells, R_w based water quality calculations, and published literature.

Step 3. ***Load Extents for Salinity Classes.*** The delineated areas for each salinity class will be defined by polygon shapefiles.

Step 4. ***Generate Unit Thickness and Average Porosity (or Specific Yield) by Formation for***

Each Raster Cell. The application will include scripts to generate rasters of unit thickness and average porosity. The interpolation of the data in the BRACS database and Control Points will use one of the several options supported by ArcMap. The scripts will include raster calculations that ensure that inversions in thickness or porosities outside of physical ranges do not occur.

Step 5. ***Generate Unit Thickness for each Water Quality Type.*** The application will provide scripts to calculate the thickness associated with each defined water quality category (fresh, slightly saline, moderately saline, or saline) by unit.

Step 6. ***Calculate Groundwater Volumes.*** The area of interest will be specified by using an existing shapefile or a list of grid cells and assumptions regarding drainage porosity and the unit(s) of interest. The GIS application will create an ASCII file containing the tabulated results and will create shapefiles that show the spatial distribution of fresh, slightly saline, moderately saline, and very saline groundwater volumes.

Prior to developing the GIS application to calculate groundwater volumes for the project, we will meet with the TWDB to explain the data available for the application, the options available for interpolating the data, and the options for calculating water volumes. The GIS application deliverable to the TWDB will include the top and bottom raster surfaces, thickness maps of the Culebra and Magenta dolomites in areas with suspected primary porosity, thickness maps of the Rustler Formation in areas of suspected secondary porosity, thickness maps of the Rustler over the entire TWDB-defined Rustler Aquifer boundary, salinity classification zone top and bottom raster surfaces, PPA top and bottom raster surfaces, well control point files, and project raster snap grid. All raster surfaces will share the same map projection and snap grid attributes.

<u>Task 3 Related Deliverables</u>

See Section II and III of the Request For Qualifications NO. 580-16-RFQ0008 for detailed descriptions of deliverables (Exhibit I). See Exhibit D for report formatting guidelines, Exhibit G for data requirements, and Exhibit H for report outline.

- Consultation on how to use the INTERA Team developed GIS-based application to calculate volumes.
- Tools, files and/or scripts used to delineate salinity zones and volumes for the final report.
- Shapefile of additional control points created from best professional judgement to guide interpolation for the final report.
- Extent polygons of the salinity classes for the final report.
- Thickness and average porosity rasters of stratigraphic unit(s) agreed upon after the TWDB meeting to discuss the draft report documenting techniques and approaches for the final report.
- Thickness rasters associated with each defined water quality category (fresh, slightly saline, moderately saline, or saline) for the final report.
- Snap raster for the final report.
- Table showing the volumes of different groundwater salinity classes for zone, county, groundwater conservation district, and groundwater management area for the final report.
- Description of the salinity zones for the final report.
- Description of volume calculations for the final report.

- Description of the volumes for the final report.

Task 4 – Delineate Potential Production Areas (PPAs)

The INTERA Team will identify the vertical and lateral extent of brackish and saline groundwater in the Rustler in Task 3. This will generally define potential production areas (PPAs) for brackish groundwater in the Rustler. In Task 4, we will identify the areas where long-term pumping of a brackish zone will not significantly impact fresh groundwater or a brackish groundwater source currently serving as a significant water supply. To accomplish this task, we will extend our hydrostructural and transmissivity model developed in Ewing and others (2012), map potential hydrogeological barriers, and identify specific areas to be protected.

Task 4.1 Refine Hydrostructural Model and Transmissivity Estimates. The most refined regional structural analysis, and the only regional assessment of transmissivity of the Rustler, was performed as part of developing the Rustler GAM (Ewing and others, 2012). The structure of the Rustler is very complex (see Figure 7-2 showing major faults). Likewise, the hydrogeologic nature of the Rustler is a product of depositional environment, lithology, diagenesis, and post-depositional alteration of the Rustler and the underlying Salado Formation. As previously discussed, these factors are a proxy for interpreting transmissivity of the Rustler. In such a complex aquifer with a general lack of aquifer test data, we will rely on a conceptual understanding of the factors described above to estimate transmissivity on a regional basis. Ewing and others (2012) developed a conceptualization for the Rustler, termed a hydrostructural model, that was used to help define flow systems within the aquifer and to develop a model for transmissivity and storativity of the aquifer. We will use this framework as a foundation for our analysis. Any new results from the current project will be used to modify or refine the regional understanding documented in Ewing and others (2012).

<u>Task 4.1 Related Deliverables</u>
See Sections II and III of the Request For Qualifications NO. 580-16-RFQ0008 for detailed descriptions of deliverables (Exhibit I). See Exhibit D for report formatting guidelines, Exhibit G for data requirements, and Exhibit H for report outline.

- Overview of the existing Rustler GAM for the final report.
- Description of any new results from the current project and modifications made to incorporate those results in the Rustler GAM for this project for the final report, as applicable.

Task 4.2 Map Hydrogeologic Barriers. The primary objective of mapping hydrogeological barriers is to provide geologic constraints on the location and deliverability of brackish groundwater in the Rustler. Specifically, it is important to identify anhydrite or polyhalite sequences within the aquifer that act as regional aquitards/aquicludes or major structural features (faults) that separate sections of the aquifer. Ewing and others (2012) initiated the process of defining, through a hydrostructural conceptual model, lithology and diagenesis or post-depositional alteration that likely play a role in aquifer transmissivity. All major faults were mapped, fault throws were examined, and the regions where the Rustler remains in contact across the faults or the degree of separation that occurs, were defined. Using this structural data and through model calibration, fault conductances were calculated and their sensitivity to model calibration was investigated. The new research from this project will be used to augment the framework developed in Ewing and others (2012). Because cross-formational flow can be important to portions of the Rustler Aquifer flow field and the concepts of isolation, we will use stratigraphic contacts as well as modeled vertical conductance to review vertical isolation. This will include contacts across faults. In general, consideration of isolation below the Rustler is not warranted.

<u>Task 4.2 Related Deliverables</u>
See Sections II and III of the Request For Qualifications NO. 580-16-RFQ0008 for detailed descriptions of deliverables (Exhibit I). See Exhibit D for report formatting guidelines, Exhibit G for data requirements, and Exhibit H for report outline.

- Description of any hydrogeologic barriers identified for the final report.
- GIS datasets of any hydrogeologic barriers identified for the final report.
- Figure showing any hydrogeologic barriers identified for the final report.

Task 4.3. Identify Excluded Areas. As described in the RFQ, PPAs cannot include an aquifer with an average TDS concentration of more than 1,000 mg/L and that is serving as a significant source of water supply for municipal, domestic, or agricultural purposes. To identify these areas, we will review a current listing of groundwater registrations and permits from the GCDs in the aquifer boundaries, a current listing of public water supply (PWS) wells from the TCEQ, and the large-diameter wells listed in the TWBD's database on submitted driller's reports. In addition, we will coordinate with the TWDB to locate any other databases that can help identify a significant water source of interest. We will present potential significant sources at the second stakeholder meeting and take stakeholder input on the meaning and/or intent of "significant source." The RFQ also states that a PPA cannot include a part of a geologic stratum that is designated or used for wastewater injection through the injection or disposal wells. To identify these areas, we will review the TCEQ and Railroad Commission of Texas databases that contain records of permitted injection and disposal wells.

<u>Task 4.3 Related Deliverables</u>
See Sections II and III of the Request For Qualifications NO. 580-16-RFQ0008 for detailed descriptions of deliverables (Exhibit I). See Exhibit D for report formatting guidelines, Exhibit G for data requirements, and Exhibit H for report outline.

- Presentation on possible excluded areas for the second stakeholder meeting.
- Description of areas excluded from consideration as potential production areas, following the TWDB Meeting 3 (see Task 1 for the list of meetings), for the final report.
- GIS datasets delineating areas excluded from consideration as potential production areas for the final report.
- Figure showing areas excluded from consideration as potential production areas for the final report.

Task 4.4. Identify and Present Potential Production Areas (PPAs). Based on the findings from Tasks 4.1 through 4.3, the INTERA Team will identify PPAs. The areas must be brackish/saline, potentially productive, and hydrogeologically isolated from the excluded areas. As part of identifying PPAs, Dr. Justin Sutherland of Carollo will assist in determining the feasibility for treatment of any specific groundwater constituents that can impede desalination of brackish groundwater. These feasibility evaluations will be used as one of the evaluation criteria for prioritizing PPAs. Each of the PPAs will be assigned a unique identification number, and maps showing the locations of the PPAs will be created prior to Stakeholder Meeting 2 (see Task 1 for the meeting list) to discuss the PPAs with stakeholders.

Task 4.4 Related Deliverables

See Sections II and III of the Request For Qualifications NO. 580-16-RFQ0008 for detailed descriptions of deliverables (Exhibit I). See Exhibit D for report formatting guidelines, Exhibit G for data requirements, and Exhibit H for report outline.

- Tools, files and/or scripts used to delineate potential production areas produced as part of this project.
- Write up on potential production areas identified for the final report, each assigned a unique ID.
- Potential production areas GIS datasets with all production area attributes for the final report.
- Potential production areas table for integration into the BRACS Database for the final report.
- Figure(s) showing potential production areas for the final report.
- Before Stakeholder Meeting 2, create a description of possible impacts to water availability and water quality if the areas were produced
- A draft document of stakeholder input from Stakeholder Meeting 2.
- Feasibility evaluations for treatment of any specific groundwater constituents that can impede desalination of brackish groundwater for the potential production areas for the final report.

Task 4.5. Prioritize Potential Production Areas (PPAs). The INTERA Team will meet with TWDB staff for TWDB Meeting 3 (see Task 1 for the meeting list) to discuss the stakeholder comments on the identified PPAs from Stakeholder Meeting 2. Criteria for prioritizing the PPAs will be presented and specific areas for further analysis will be identified. The TWDB will provide the final criteria for prioritizing the PPAs. At the end of the meeting, or soon thereafter, a list of priority PPAs will be developed.

Task 4.5 Related Deliverables

See Sections II and III of the Request For Qualifications NO. 580-16-RFQ0008 for detailed descriptions of deliverables (Exhibit I). See Exhibit D for report formatting guidelines, Exhibit G for data requirements, and Exhibit H for report outline.

- After the Stakeholder Meeting 2 and TWDB Meeting 3, a prioritized list of potential production areas for 30-year and 50-year pumping estimates.

Task 5 – Determine Availability of Brackish Groundwater in

Potential Production Areas (PPAs)

During TWDB Meeting 3, the INTERA Team will discuss an approach for using a groundwater model to determine brackish groundwater availability in the identified PPAs. For priority PPAs, the modeled availability will be calculated for 30-year and 50-year production periods. The modeling will evaluate metrics, agreed upon by TWDB and INTERA, to be used in later studies to define significant impacts.

Based on the complexity of the Rustler and the limited time frame and budget available for model development activities, we will use the Rustler GAM as the basis of our calculations to the extent practicable. Because brackish PPAs may have relatively small footprints and near-field hydraulics may be important to vertical connections, the model grid (currently on a 1/4-mile grid scale) may need to be refined. This can be accomplished with the MODFLOW-NWT (Niswonger and others, 2011) code used for the GAM or by using MODFLOW-USG (Panday and others, 2013). If the current GAM is determined to be inadequate for simulating the required hydraulics, we will adapt a semi-analytic approach. This, or another, approach will be discussed in detail with the TWDB before it is applied.

The number of PPAs to be modeled will be determined in consultation with the TWDB at TWDB Meeting 3. Once the modeling approach and formulations are approved, the next step will be to assign aquifer properties. While the current Rustler GAM is calibrated, as discussed in Ewing and others (2012), properties including transmissivity, storativity, and vertical and fracture/fault conductances are not well constrained. In addition, as part of this project we will be defining the individual members of the Rustler that may be contributing flow as well as the importance of secondary versus primary porosity on productivity. As a result, based on the GAM estimates and the characteristics of the brackish PPA groundwater bearing members, we will assign a best estimate (likely from the GAM unless inconsistent with current project interpretation), an upper value, and a lower value for each aquifer hydraulic property.

For the top prioritized brackish PPAs, a steady-state predevelopment scenario will be used as the initial condition for the 30-year and 50-year pumping scenarios. For the pumping scenarios, we will perform a series of Monte Carlo-type runs based on three to six different values of pumping and seven to 15 different sets of assumed aquifer parameters. The boundary condition and fault conductances can be evaluated using the GAM as well as the base case simulation. To look at uncertainty in hydraulic diffusivity of the Rustler due to reduced pore volume, secondary porosity, or general lack of data, we will post-process the base case results. Because the process being modeled is confined groundwater flow, it will be linear with the possible exception of some areas near boundaries (which can be tested using the GAM). The ensemble of simulated hydraulic heads for each model run will be processed using scripts to calculate pumping impacts. Examples of pumping impacts that can be quantified include average drawdown across a region, drawdown values at a boundary, drawdown at existing wells, or changes to Desired Future Conditions.

<u>Task 5 Related Deliverables</u>
See Sections II and III of the Request For Qualifications NO. 580-16-RFQ0008 for detailed

descriptions of deliverables (Exhibit I). See Exhibit D for report formatting guidelines, Exhibit G for data requirements, and Exhibit H for report outline.

- Tools, files and/or scripts used to estimate the capacity of potential production areas over 30 and 50 year periods, to calculate metrics approved by TWDB that will be used by stakeholders and TWDB to define significant impact, as defined in Task 4, for the final report.
- Description of the various pumping values, aquifer parameters and capacities for potential production areas over 30 and 50 year periods, for the final report.
- Table(s) or matrix and graph(s) of various pumping values, aquifer parameters and capacities for potential production areas over 30 and 50 year periods and associated metrics to be used to characterize significant impact by stakeholders and TWDB, without causing a significant impact, as defined in Task 4, for the final report.

Task 6 – Final Report, Documentation, and Technology Transfer

Because the Identification of Potential Brackish Groundwater Production Areas - Rustler Aquifer will support planners and decision makers in better formulating water management strategies for the resource, the thorough documentation of the project data, the methods used to generate the data, and the data analyses results is critical to ensuring it is scientifically-defensible. All documentation for the project will be prepared in a manner consistent with the format and content specified by TWDB in Section III – Deliverables of the RFQ (Exhibit I).

An abridged list of final deliverables, as specified by TWDB in Section III – Deliverables of the RFQ (Exhibit I), include:

- Final technical report summarizing the results of the project, delivered in both Microsoft Word and PDF formats. See Exhibit D for formatting guidelines and Exhibit H for the report outline.
- Updated data for the BRACS Database containing all new well records used in the project.
- Copies of water well reports, water quality reports, and geophysical well logs used in the project (unless those reports and logs already exist in the TWDB Groundwater or BRACS databases).
- Three-dimensional GIS datasets that delineate each of the groundwater salinity zones, PPAs, and the estimated volumes of brackish groundwater production for the prioritized PPAs in 30- and 50-year timeframes.
- All geophysical well logs interpreted for TDS and all interpretation data values documented in table(s) with links to attributes in a Microsoft Access database format that can be linked to existing BRACS Database tables.
- Tools and techniques used for determining the extent and volumes of the required ranges of total dissolved solids in the groundwater.

- The calculated volumes of groundwater within each aquifer and each TWDB-prioritized potential production areas organized by salinity classification zone, county, groundwater conservation district, and groundwater management area.

Having produced dozens of draft and final reports associated with our work on other hydrogeological studies and GAM projects for the TWDB, INTERA is intimately familiar with the BRACS and other program contract data requirements, including GIS data and map projection standards, BRACS database standards, and well report and geophysical well log file naming and organization standards.

References

Alger, R.P., 1966, Interpretation of electric logs in fresh water wells in unconsolidated sediments, in Society of Professional Well Log Analysts, Tulsa, Oklahoma, 7th Annual Logging Symposium Transaction, 25 p.

Archie, G.E., 1942, The electrical resistivity log as an aid in determining some reservoir characteristics: Petroleum Transactions of AIME 146: 54–62.

Ayers, W.B., Jr., and Lewis, A.H., 1985, The Wilcox Group and Carrizo Sand (Paleogene) in East-Central Texas: depositional systems and deep-basin lignite: Bureau of Economic Geology, The University of Texas at Austin, Geologic Folio No. 1, 19 p., 30 plates.

Boghici, R., 1997, Hydrogeological investigations at Diamond Y Springs and surrounding area, Pecos, County, Texas: The University of Texas at Austin, unpublished MA thesis.

Boghici, R., and Van Broekhoven, N.G., 2001, Hydrogeology of the Rustler Aquifer, Trans-Pecos, Texas, in Mace, R.E., Mullican, III, W.F., and Angle, E.S., eds, Aquifers of west Texas: TWDB, Report 356.

Brown, E.M., 1998, Water quality in the Rustler Aquifer: TWDB, Hydrologic Atlas No. 9.

Bumgarner, J.R., Stanton, G.P., Teeple, A.P., Thomas, J.V., Houston, N.A., Payne, J.D., and Musgrove, MaryLynn, 2012, A conceptual model of the hydrogeologic framework, geochemistry, and groundwater-flow system of the Edwards-Trinity and related aquifers in the Pecos County region, Texas: U.S. Geological Survey Scientific Investigations Report 2012–5124, 74 p.

Clark, B.R., Bumgarner, J.R., Houston, N.A., and Foster, A.L., 2014, Simulation of groundwater flow in the Edwards-Trinity and related aquifers in the Pecos County region, Texas (ver.1.1, August 2014): U.S. Geological Survey Scientific Investigations Report 2013–5228, 56 p. http://dx.doi.org/10.3133/sir20135228.

Collier, H.A., 1993a, Borehole geophysical techniques for determining the water quality and reservoir parameters of fresh and saline water aquifers in Texas, Volume I: Texas Water Development Board, Report 343, 414 p., 1 Appendix, 5 plates.

Collier, H.A., 1993b, Borehole geophysical techniques for determining the water quality and reservoir parameters of fresh and saline water aquifers in Texas, Volume II: Texas Water Development Board, Report 343, 216 p.

Dewan, John T., 1983, Essentials of Modern Open-hole Log Interpretation: PennWell Corporation, Tulsa, Oklahoma, 361 p.

Estepp, J., 1998, Evaluation of ground-water quality using geophysical logs: Texas Natural Resource Conservation Commission, unpublished report, 516 p.

Ewing, J.E., Kelley, V.A., Jones, T.L, Yan, T., Singh, A., Powers, D.W., Holt, R.M., Sharp, J.M., 2012. Groundwater availability model report for the Rustler Aquifer. Contracted report prepared for the Texas Water Development Board, 460 p.

Fogg, G.E., 1980, Geochemistry of ground water in the Wilcox aquifer, in Kreitler, C.W., Agagu, O.K., Basciano, J.M., Collins, E.W., Dix, O., Dutton, S.P., Fogg, G.E., Giles, A.B., Guevara, E.H., Harris, D.W., Hobday, D.K., McGowen, M.K., Pass, D. and Wood, D.H., 1979, Geology and Geohydrology of the East Texas Basin A Report on the Progress of Nuclear Waste Isolation Feasibility Studies: Bureau of Economic Geology (1979), The University of Texas at Austin, Geologic Circular No. 80-12, p. 73-78.

Fogg, G.E., and Kreitler, C.W., 1982, Groundwater hydraulics and hydrochemical facies in Eocene aquifers of the East Texas Basin: Bureau of Economic Geology, The University of Texas at Austin, Report of Investigation No. 127, 75 p.

Fogg, G.E., and Blanchard, P.E., 1986, Empirical relations between Wilcox groundwater quality and electric log resistivity, Sabine Uplift area, in Kaiser, W.R. ed., Geology and Groundwater hydrology of deep-basin lignite in the Wilcox Group of East Texas: Bureau of Economic Geology, The University of Texas at Austin, Special Report No. 10, p. 115-118.

Hamlin, H.S., 1988, Depositional and ground-water flow systems of the Carrizo-Upper Wilcox, South Texas: The University of Texas at Austin, Bureau of Economic Geology, Report of Investigations No. 175.

Hiss, W.L., 1975, Stratigraphy and ground-water hydrology of the Capitan aquifer, southeastern New Mexico and western Texas: University of Colorado, Ph.D. Dissertation, 396 p.

Hiss, W.L., 1976, Structure of the Permian Ochoan Rustler Formation, southwest New Mexico and west Texas: United States Geological Survey, Open File Report 76-54.

Holt, R.M., and Powers, D.W., 1984, Geotechnical activities in the waste handling shaft, Waste Isolation Pilot Plant (WIPP) project, southeastern New Mexico: United States Department of Energy, WTSDTME 038, Carlsbad, New Mexico.

Holt, R.M., and Powers, D.W., 1986, Geotechnical activities in the exhaust shaft, Waste Isolation Pilot Plant: United States Department of Energy, DOE-WIPP 86-008, Carlsbad, New Mexico.

Holt, R.M., and Powers, D.W., 1988, Facies variability and post-depositional alteration within the Rustler Formation in the vicinity of the Waste Isolation Pilot Plant, southeastern New Mexico: United States Department of Energy, WIPP-DOE-88-004, Carlsbad, New Mexico,.

Holt, R.M., and Powers, D.W., 1990a, Geotechnical activities in the air intake shaft (AIS): United States Department of Energy, DOE/WIPP 90-051, Carlsbad, New Mexico.

Holt, R.M, and Powers, D.W., 1990b, Halite sequences within the late Permian Salado Formation in the vicinity of the Waste Isolation Pilot Plant, in Powers, D.W., Holt, R.M., Beauheim, R.L., and Rempe, N., eds., Geological and hydrological studies of evaporites in the northern Delaware Basin for the Waste Isolation Pilot Plant (WIPP): Geological Society of America, Dallas Geological Society, Guidebook 14, p. 45-78.

Holt, R.M., and Powers, D.W., 2010, Evaluation of halite dissolution at a radioactive waste disposal site, Andrews County, Texas: Geological Society of America Bulletin, v. 122, p. 1989-2004.

Kreitler, C.W., Beach, J.A., Symank, L., Uliana, M., Bassett, R., Ewing, J.E., Kelley, V.A., 2013, Evaluation of Hydrochemical and Isotopic Data in Groundwater Management Areas 3 and 7. Texas Water Development Board Report, 265p.

Meyer, J.E., Wise, M.R., and Kalaswad, S., 2012, Pecos Valley aquifer, West Texas: structure and brackish groundwater: Texas Water Development Board Report 382, 86 p.
Small and Ozuna, 1993,

Niswonger, R.G. S. Panday, and M. Ibaraki. 2011. MODFLOW-NWT, A Newton Formulation for MODFLOW-2005: U.S. Geological Survey Techniques and Methods, Book 6, Chap. A37, 44 p.

Panday, Sorab, Langevin, C.D., Niswonger, R.G., Ibaraki, Motomu, and Hughes, J.D., 2013, MODFLOW–USG version 1: An unstructured grid version of MODFLOW for simulating groundwater flow and tightly coupled processes using a control volume finite-difference formulation: U.S. Geological Survey Techniques and Methods, book 6, chap. A45, 66 p., http://pubs.usgs.gov/tm/06/a45.

Pearson, D.K., Bumgarner, J.R., Houston, N.A., Stanton, G.P., Teeple, A.P., and Thomas, J.V., 2012, Data collection and compilation for a geodatabase of groundwater, surface-water, water-quality, geophysical, and geologic data, Pecos County region, Texas, 1930–2011: U.S. Geological Survey Data Series 678, 67 p.

Powers, D.W., Holt, R.M., Beauheim, R.L., and McKenna, S.A., 2003, Geological factors related to the transmissivity of the Culebra Dolomite Member, Permian Rustler Formation, Delaware

Basin, southeastern New Mexico, in Johnson, K.S., and Neal, J.T., eds., Evaporite karst and engineering/environmental problems in the United States: Oklahoma Geological Survey Circular 109, p. 211-218.

Powers, D.W., Holt, R.M., Beauheim, R.L., and Richardson, R.G., 2006, Advances in depositional models of the Permian Rustler Formation, southeastern New Mexico, in Land, L., Lueth, V.W., Raatz, W., Boston, P., and Love, D.W., eds., Caves & karst of southeastern New Mexico: New Mexico Geological Society, Fall Field Conference, Guidebook 57, p. 267-276.

Schlumberger, 2009, Log interpretation Charts, Schlumberger, Houston, Texas

SPWLA, 1982, a survey of resistivities of water from subsurface formations in west Texas and southeastern New Mexico: Society of Petroleum Engineers Permian Basin Section and Permian Basin Well Logging Society of Professional Well Log Analysts, 17 p.

Texas Water Commission, 1989, Ground-water quality of Texas: Texas Water Commission, Report 89-01.

TWDB BRACS, 2015, Brackish Resource Aquifer Characterization System: website http://www.twdb.texas.gov/innovativewater/bracs/database.asp, accessed November 2015.

Winslow, A.G., and Kister, L.R., 1956, Saline-Water Resources of Texas, U. S. Geological Survey Water Supply Paper 1365, 105 p.