FINAL
Preliminary
Feasibility Study

West O'Daniel Seep
Howard County, Texas

Prepared for:

Railroad Commission of Texas
Oil and Gas Division
Site Remediation and Special Response

William B. Miertschin, Assistant Director

Prepared by:

TRC
505 East Huntland Drive, Suite 250
Austin, Texas 78752

Mark A. Robbins, Project Manager

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July 2007

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1.0 INTRODUCTION

1.1 Site Background

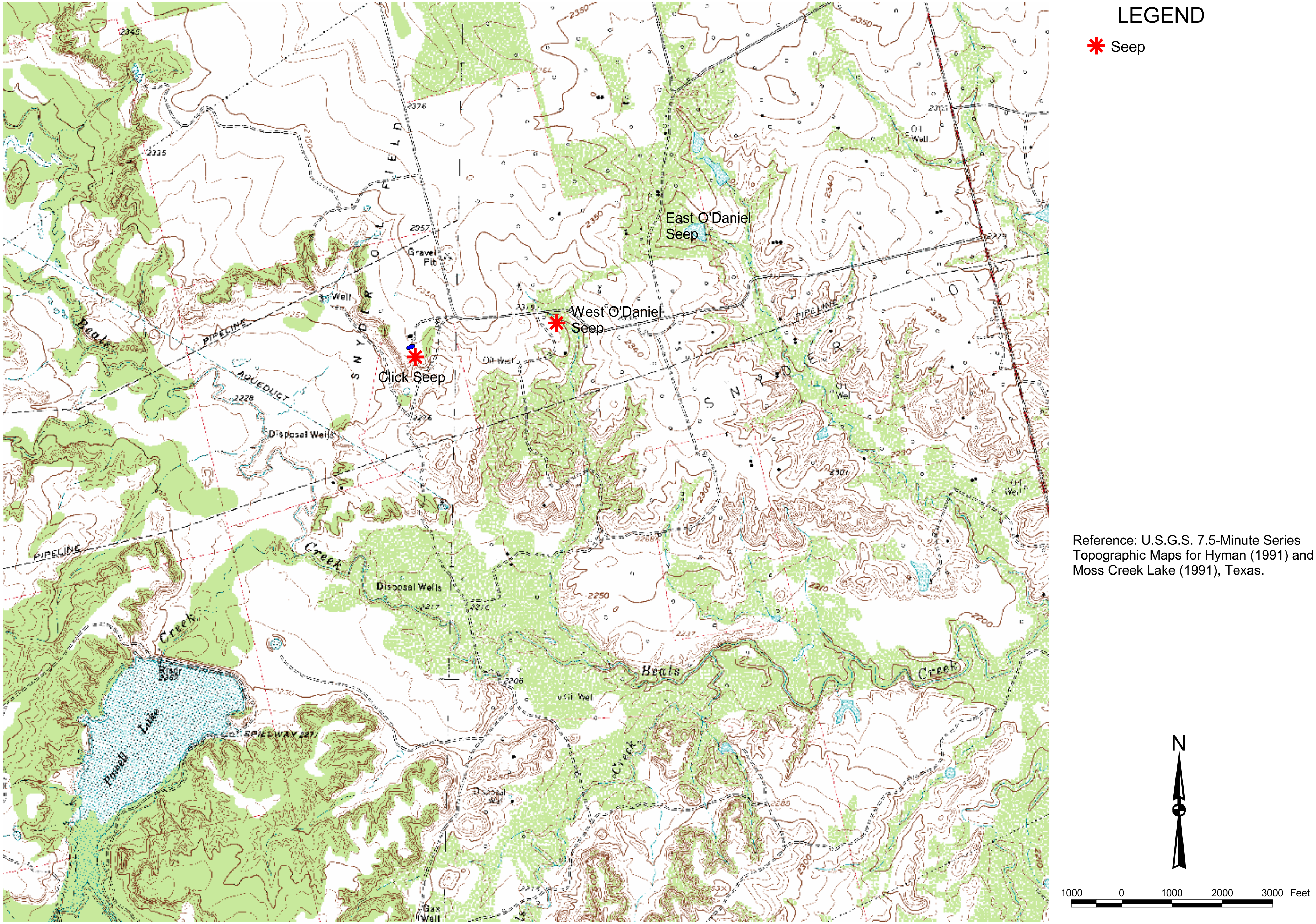
The Railroad Commission of Texas (RRC), Oil and Gas Division, has documented the occurrence of several saltwater seeps in the Snyder Oil Field, Block 30, of Howard County, Texas. The site is located about 5.5 miles southeast of Coahoma in the eastern part of Howard County, Texas. The saltwater seeps in the Snyder Oil Field, including the West O'Daniel Seep, emanate from the base of an outlier of the Ogallala Formation, which overlies the Dockum Group (Ogallala/Dockum Contact). The Ogallala Aquifer in this area has been impacted by past oil field operations causing total dissolved solids (TDS), sulfate and chloride (hereafter referred to as salinity/TDS) in groundwater to be elevated as compared to background levels. The impacted groundwater associated with this seep discharges into tributaries of Beals Creek, which ultimately empties into the Colorado River. The West O'Daniel Seep and Beals Creek are shown on Figure 1-1.

Preliminary investigations of the East O'Daniel Seep and Click Seep (which are adjacent to the West O'Daniel Seep but not subjects of this report) documented elevated chloride concentrations and areas of distressed vegetation, indicative of impacts from saline waters. These findings led to the investigation of the West O'Daniel Seep. The locations of the West O'Daniel Seep, East O'Daniel Seep, and Click Seep are shown on Figure 1-2.

The Total Maximum Daily Load (TMDL) Section of the Texas Commission on Environmental Quality (TCEQ) placed Segment 1411 of the Upper Colorado River, E. V. Spence Reservoir, on the State's 303(d) list because it did not meet water quality standards for TDS, sulfate and chloride. The TMDL goals are 1,500 milligrams per liter (mg/L) for TDS, 450 mg/L for sulfate, and 950 mg/L for chloride. The RRC was awarded a nonpoint source grant by the United States Environmental Protection Agency (US EPA) through the TCEQ to determine if oil and gas operations are contributing to the elevated salinity in the reservoir. The objective of the grant is to assess and determine the source(s) leading to the elevated TDS and chloride in the Upper Colorado River drainage basin upstream of the E. V. Spence Reservoir (Segment 1411), develop best management practices (BMPs) to reduce the TDS and chloride, and implement the BMPs.

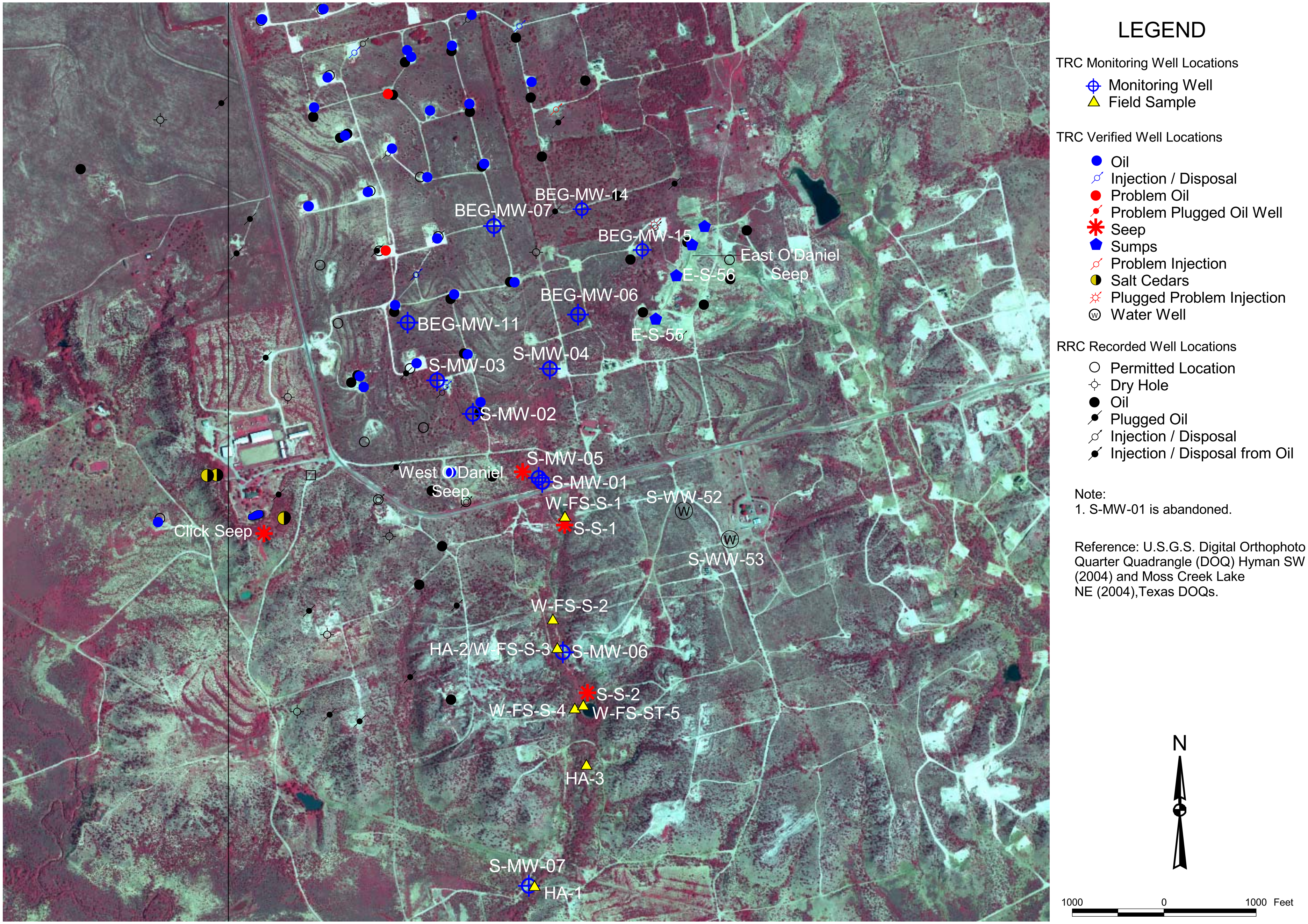
The RRC retained TRC Environmental Corporation (TRC) to perform an assessment of potential sources associated with the West O'Daniel Seep and conduct a feasibility study to identify remedies to reduce the salinity/TDS of the affected drainage ways and ultimately the Colorado River. The assessment work was completed in April

Figure 1-1. Site Location Map



Reference: U.S.G.S. 7.5-Minute Series Topographic Maps for Hyman (1991) and Moss Creek Lake (1991), Texas.

Figure 1-2. Site Plan (April 2006)



2006 and reported to the RRC in a *Site Investigation Report* dated August 2006. The preliminary feasibility study is provided in this report.

1.2 Scope of Preliminary Feasibility Study

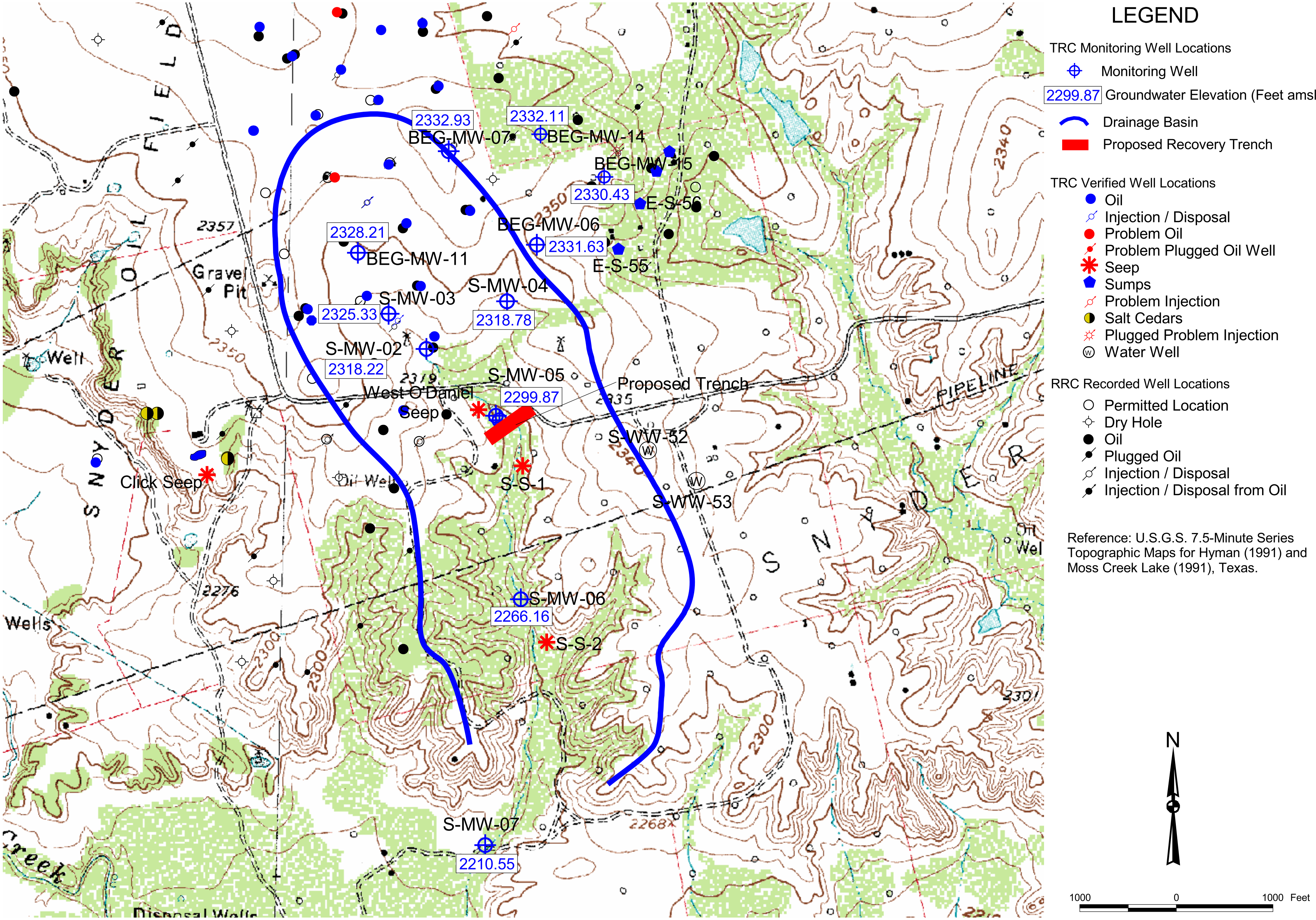
The objectives of this preliminary feasibility study are to use the results of the previous investigation to develop remedies (i.e., best management practices) to abate the high salinity/TDS water emanating from the West O'Daniel Seep and flowing into Beals Creek and eventually into the Colorado River. The scope of this feasibility study is restricted to the drainage basin associated with the West O'Daniel Seep. The drainage basin is shown on Figure 1-3 and is discussed in Section 2.0 regarding the conceptual site model.

The feasibility study considered alternatives for addressing the impacted water including containment, recovery, in-situ treatment, ex-situ treatment, and disposal. The feasibility study evaluated the best management practices by determining the effectiveness, implementability, regulatory agency and stakeholder acceptance, and cost of these options to meet the objective. The abatement measures that have already been deployed at the East O'Daniel Seep were considered in this evaluation. Impacts at the East O'Daniel Seep are being addressed by recovery using an interceptor trench with sumps and disposal using the operator's disposal well.

1.3 Report Contents

The remainder of this report provides a conceptual site model (Section 2.0), alternatives for salinity/TDS abatement (Section 3.0), design alternatives (Section 4.0), and the recommended solution (Section 5.0).

Figure 1-3. Drainage Basin for West O'Daniel Seep and Associated Tributaries



2.0 CONCEPTUAL SITE MODEL

The domain for this feasibility study is defined as the drainage basin in which the West O'Daniel Seep is located. The drainage basin is shown on Figure 1-3. This includes areas hydraulically upgradient and downgradient of the West O'Daniel Seep, which discharges into Beals Creek located 1.2 miles downstream of the seep.

A conceptual site model was developed to define the physical setting in which the impacted water is present and migrates, and is critical to designing the most effective remedy. The conceptual site model includes a description of the geology/hydrogeology, chemicals of concern, potential sources of salinity/TDS, and pathways for migration of saline-impacted water.

2.1 Geology and Hydrogeology

The study area is underlain by the Quaternary Blackwater Draw Formation, the Tertiary Ogallala Formation, and the Triassic Dockum Group. These lithologic units are described as follows from top to bottom (i.e., youngest to oldest):

- The Blackwater Draw Formation consists of fine-grained aeolian and alluvial sand that is rarely greater than 20 feet thick. This formation is present at approximately 80 percent of the study area.
- The Ogallala Formation is the main groundwater-bearing zone in the area and has a maximum thickness of 40 feet. It consists of fine-grained sand and gravel, buried caliche caprock, and a basal coarse-grained gravel.
- The Dockum Group is mostly comprised of reddish-brown clay with silt, fine-grained sand and coarse-grained sand stringers. The contact of the Ogallala Formation and Dockum Group is exposed in areas of topographic relief. The Dockum Group has a thickness of as much as 1,200 feet.

The surface sediments of the Blackwater Draw and Ogallala Formations consist of generally permeable, fine-grained sand allowing for rapid infiltration. Subsurface fluid migration is mostly dictated by the relief of the Dockum Group clay because it acts as a confining layer inhibiting vertical groundwater flow. As a result, groundwater is primarily present in a thin saturated zone of the Ogallala Formation just above the Dockum Group contact. Discharge from this zone is primarily to seeps and springs, as well as water supply wells.

Seeps and springs at the site occur at or just above exposures of the Ogallala Formation/Dockum Group contact. The water that drains from the Ogallala Formation, as seeps and springs, flows downstream within the drainage feature and eventually infiltrates into the alluvium within the drainage basin. This groundwater then migrates within the alluvium until it discharges into Beals Creek, which ultimately discharges into the Upper Colorado River (Figure 1-1). Field observations of the West O'Daniel Seep and drainage basin in April 2006 indicated that the original documented site of the West O'Daniel Seep was dry. Surface water was observed from approximately 650 feet to 1,100 feet downstream of the West O'Daniel Seep. This surface water exposure is most likely due to lower surface topography intersecting the groundwater bearing zone.

Based on groundwater elevation data collected from monitoring wells, groundwater occurs under unconfined conditions in the Ogallala Formation and drainage basin alluvium. Portions of the Ogallala Formation at higher elevations are dry. The depth to groundwater ranges from near surface (typically alluvium) to 30 feet below ground surface (bgs). The groundwater flow pattern roughly follows the surface topography and trends to the south at a hydraulic gradient of 0.019 feet per foot. A contoured groundwater elevation map is provided as Figure 2-1. There is a minor groundwater flow component to the east towards the drainage basin that contains the East O'Daniel Seep. A cross-section location map is provided as Figure 2-2 and Cross-Sections A-A' through D-D' are provided as Figures 2-3 to 2-6. These cross sections show the lithologic boundaries and occurrence of groundwater. Due to air rotary drilling, the Ogallala Formation and alluvium could not be differentiated throughout the site.

The drainage basin associated with the West O'Daniel Seep is believed to be hydraulically isolated from the drainage basins associated with the East O'Daniel Seep and Click Seep. The Dockum Group clay mimics the topographic surface in the area meaning the Dockum Group clay occurs at higher elevations under the topographic ridges (Figures 2-3 to 2-6). This isolates groundwater in each of these drainage basins (i.e., Click Seep, West O'Daniel Seep, and East O'Daniel Seep) and creates a preferential pathway for groundwater originating from the West O'Daniel Seep to flow south towards Beals Creek.

2.2 Potential Sources of Groundwater Impacts

The present study is concerned with the abatement of salinity/TDS impacts to Beals Creek, which is a tributary to the portion of the Colorado River upstream of the E. V. Spence Reservoir. The primary source of the salinity/TDS present in groundwater is attributed to oil production activities within the Snyder Oil Field. A review of the *Investigation of the Snyder Field Site, Howard County, Texas*, report prepared by the Bureau of Economic Geology (BEG) dated April 1999 provided the following information on potential sources for groundwater contamination. Oil production was

Figure 2-1. Groundwater Elevation Map (April 2006)

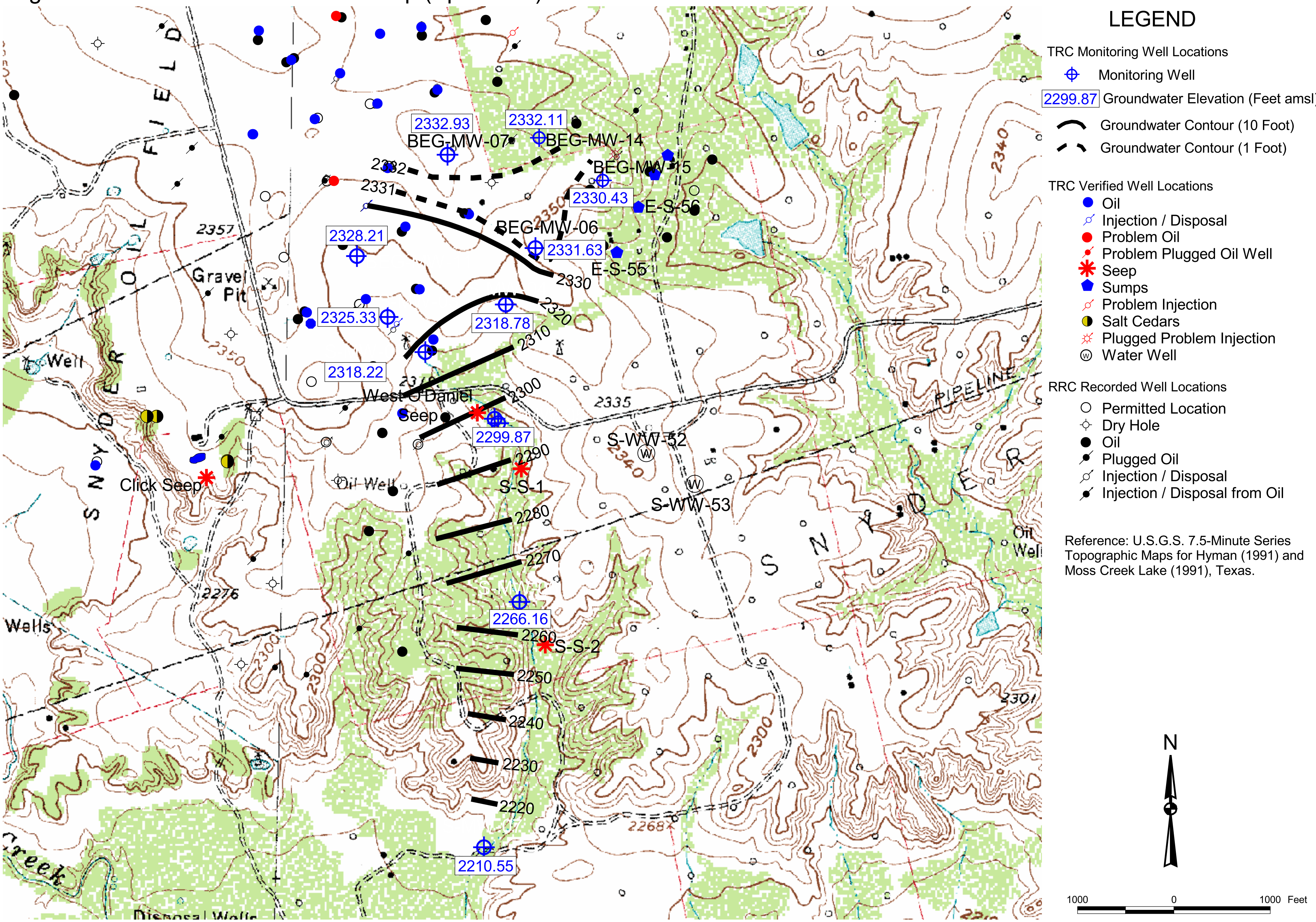
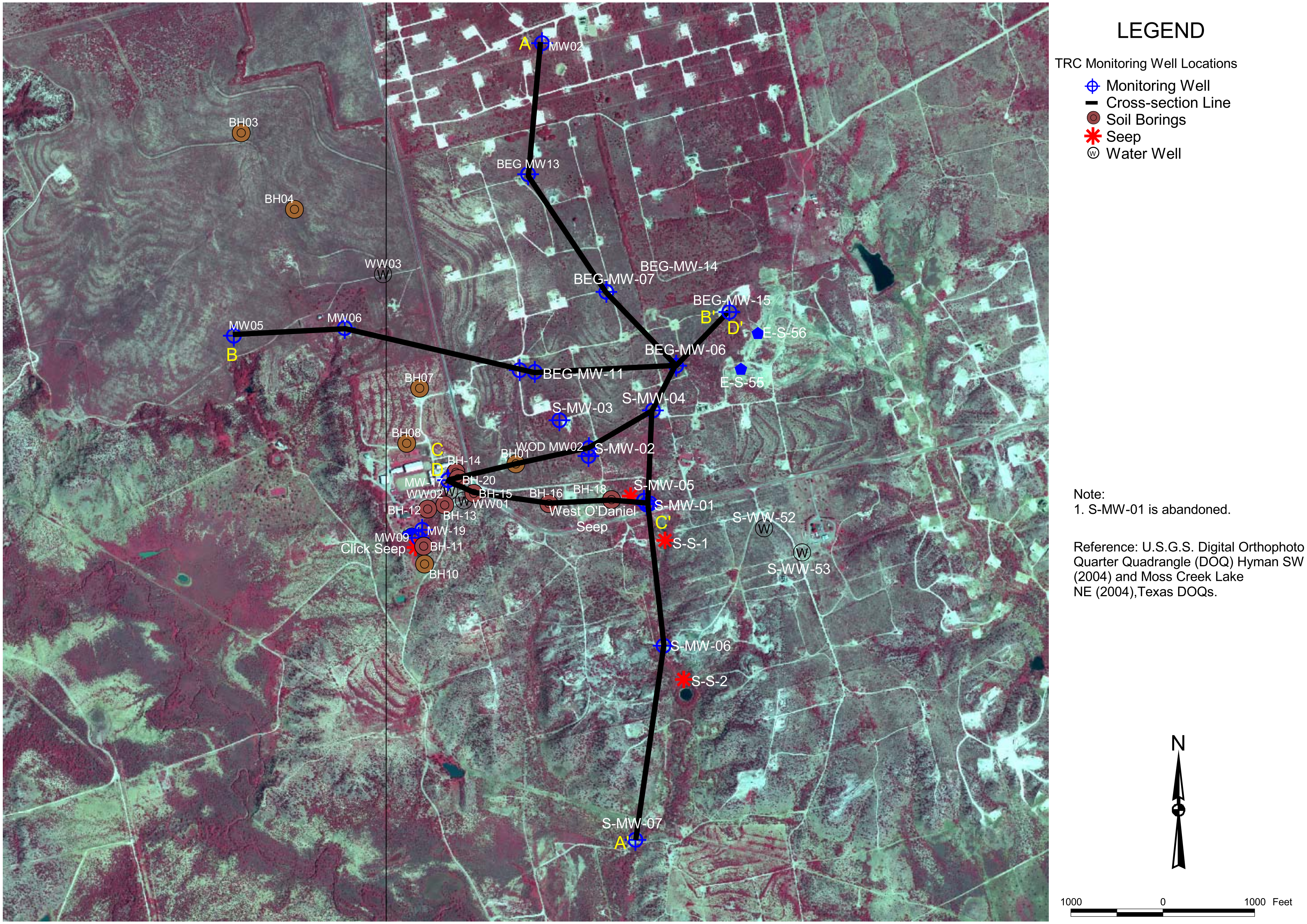
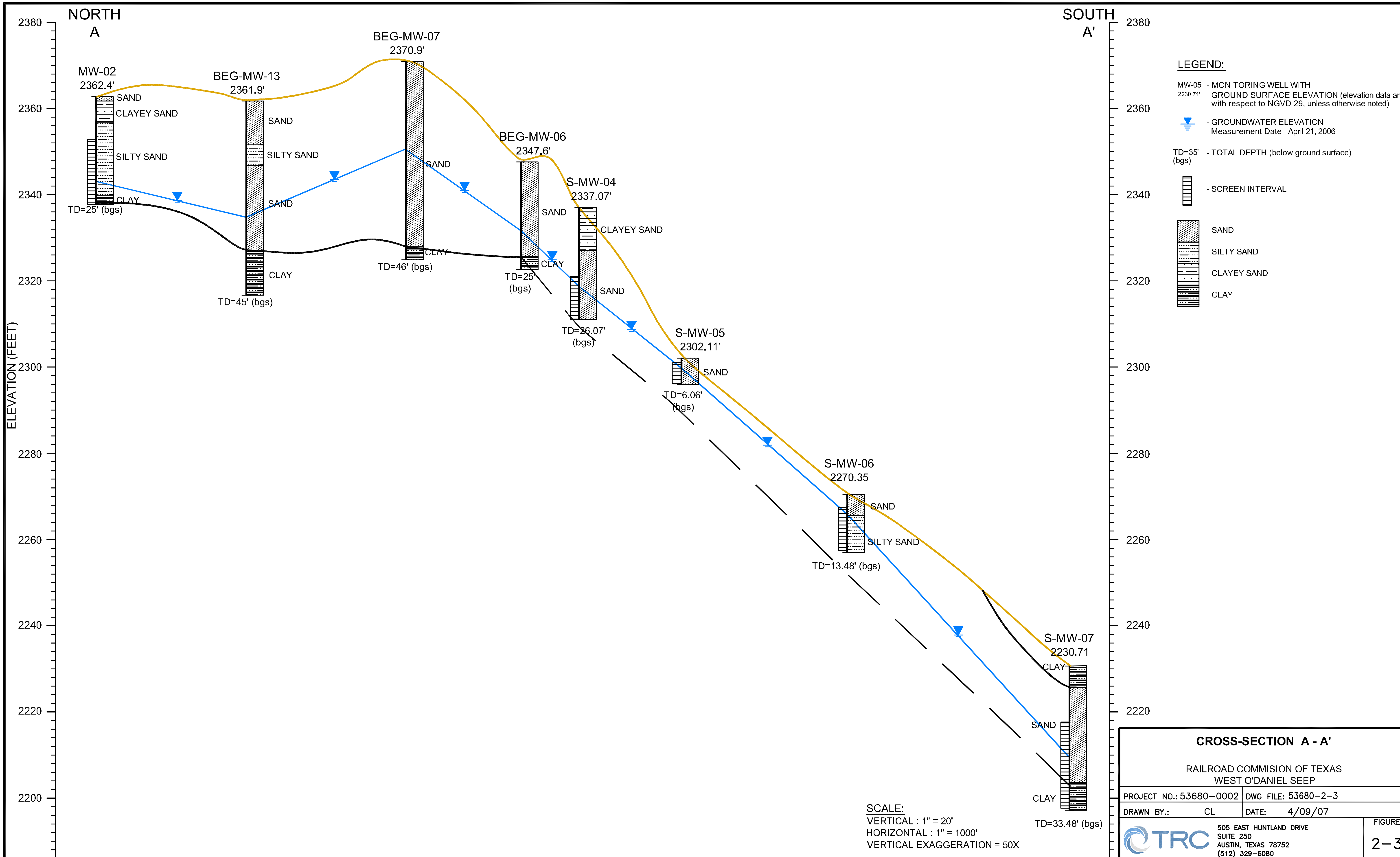


Figure 2-2. Location of Cross Sections



Note:
1. S-MW-01 is abandoned.

Reference: U.S.G.S. Digital Orthophoto Quarter Quadrangle (DOQ) Hyman SW (2004) and Moss Creek Lake NE (2004),Texas DOQs.



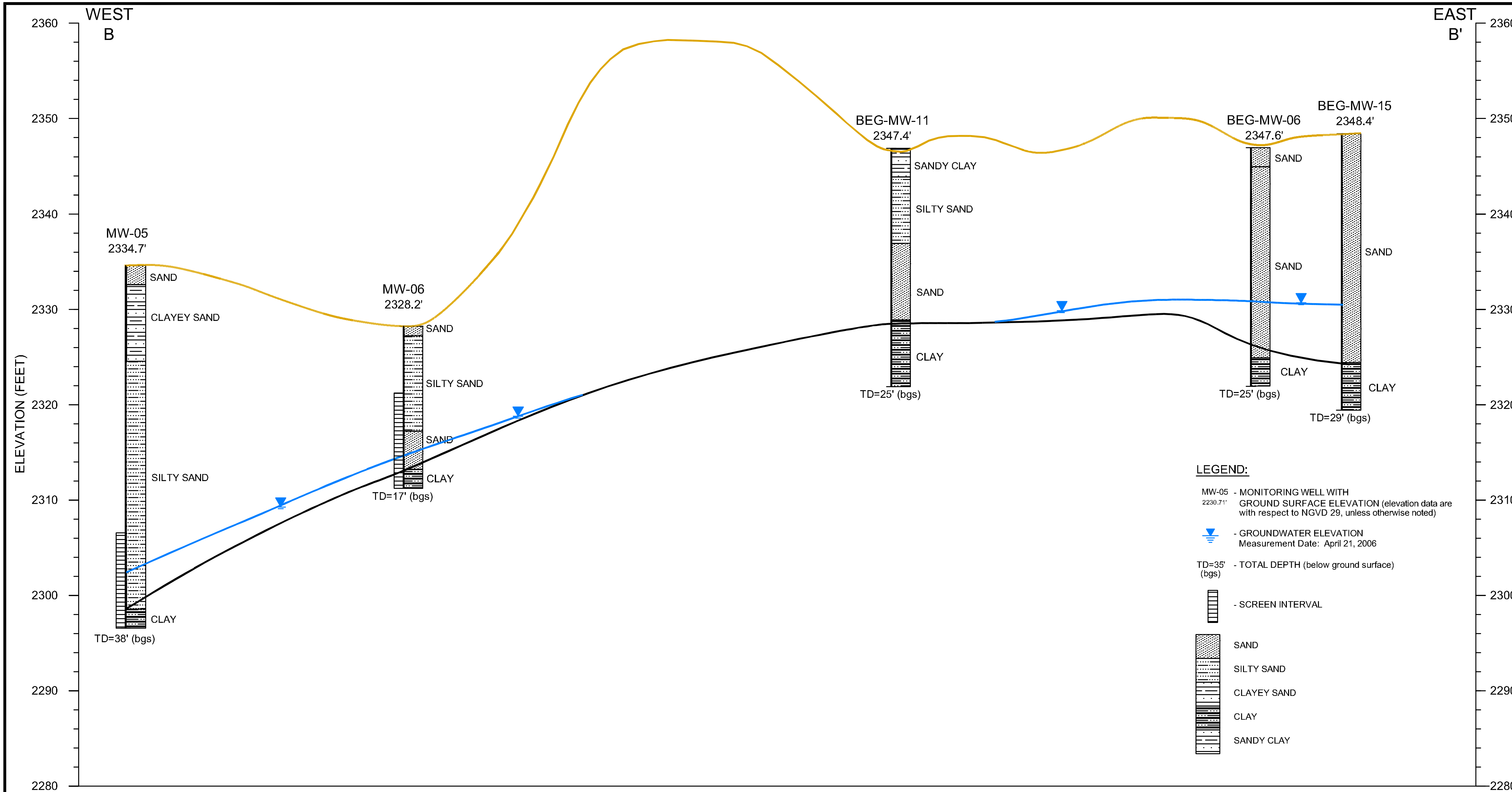
CROSS-SECTION A - A'

RAILROAD COMMISION OF TEXAS
WEST O'DANIEL SEEP

PROJECT NO.: 53680–0002	DWG FILE: 53680-2-3
DRAWN BY.: CL	DATE: 4/09/07

TRC
505 EAST HUNTLAND DRIVE
SUITE 250
AUSTIN, TEXAS 78752
(512) 329-6080

FIGURE
2-3



SCALE:
VERTICAL : 1" = 10'
HORIZONTAL : 1" = 500'
VERTICAL EXAGGERATION = 50X

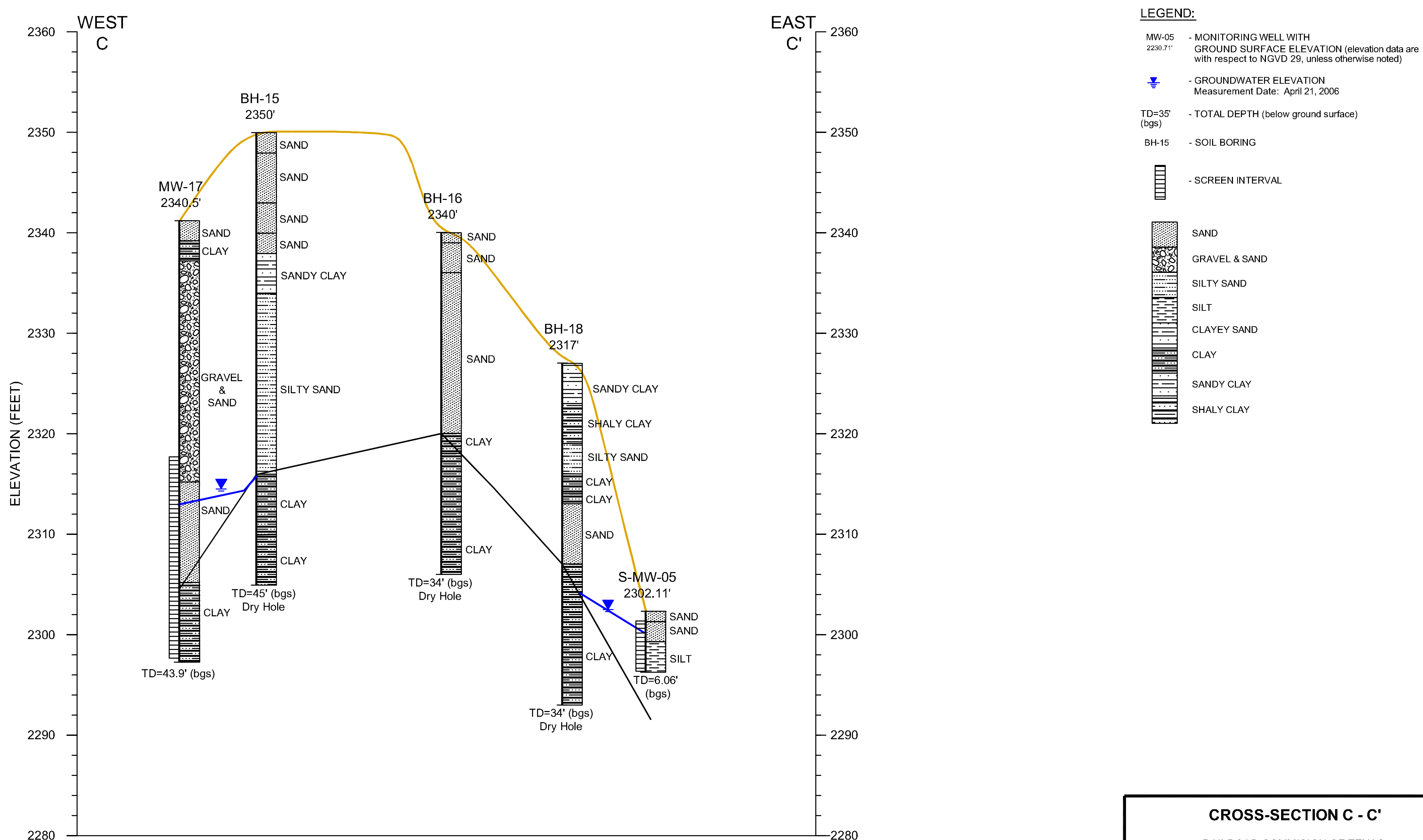
CROSS-SECTION B - B'

RAILROAD COMMISION OF TEXAS
WEST O'DANIEL SEEP

PROJECT NO.: 53680–0002	DWG FILE: 53680–2–4
DRAWN BY: K.S.	DATE: 04/09/07

TRC
505 EAST HUNTLAND DRIVE
SUITE 250
AUSTIN, TEXAS 78752
(512) 329–6080

FIGURE
2–4



SCALE:
VERTICAL : 1" = 10'
HORIZONTAL : 1" = 500'
VERTICAL EXAGGERATION = 50X

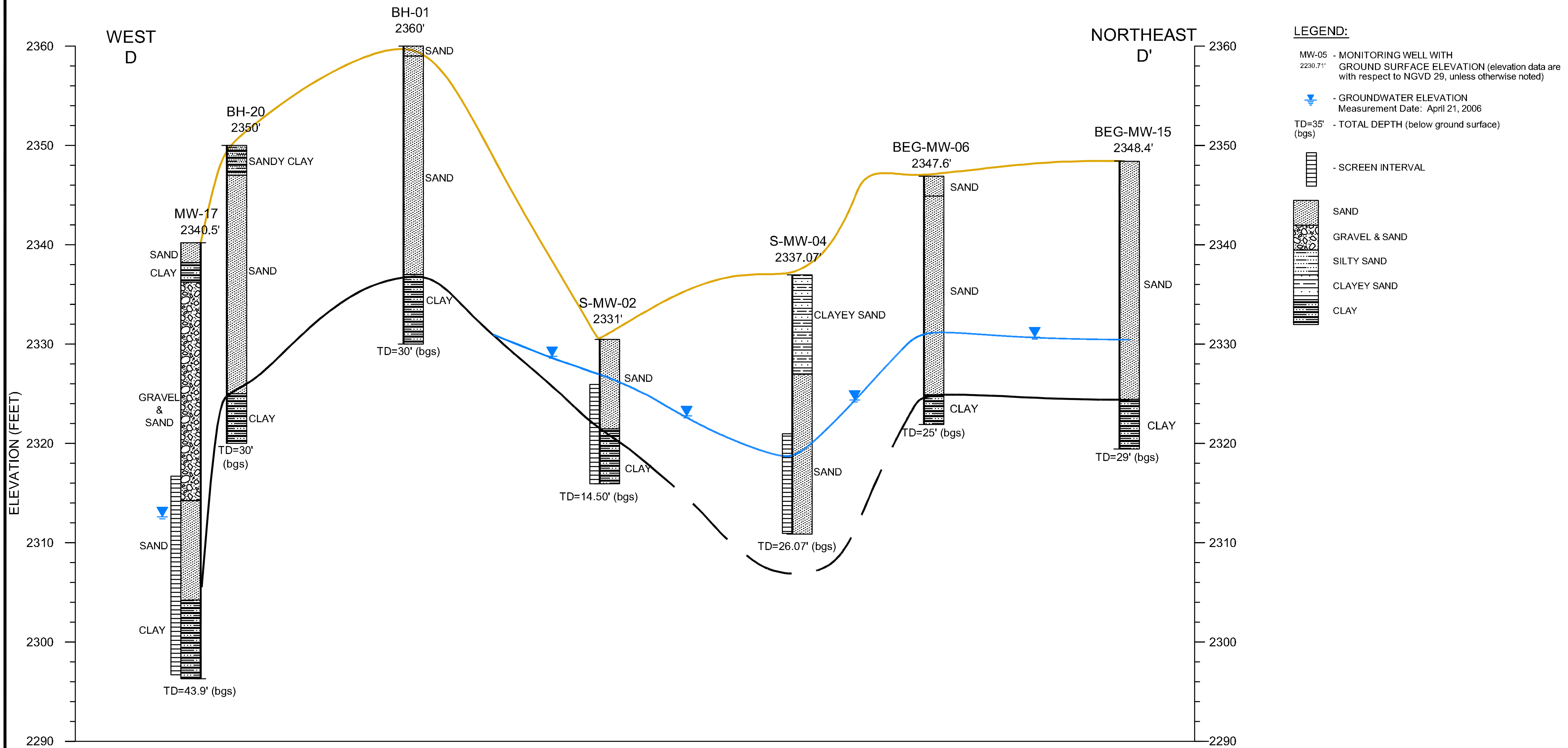
CROSS-SECTION C - C'

RAILROAD COMMISION OF TEXAS
WEST O'DANIEL SEEP

PROJECT NO.: 53680–0002	DWG FILE: 53680–2–5
DRAWN BY: K.S.	DATE: 04/09/07

TRC
505 EAST HUNTLAND DRIVE
SUITE 250
AUSTIN, TEXAS 78752
(512) 329–6080

FIGURE
2–5



SCALE:
VERTICAL : 1" = 10'
HORIZONTAL : 1" = 500'
VERTICAL EXAGGERATION = 50X

CROSS-SECTION D-D'

RAILROAD COMMISION OF TEXAS
WEST O'DANIEL SEEP

PROJECT NO.: 53680–0002	DWG FILE: 53680–2–6
DRAWN BY: K.S.	DATE: 04/09/07

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AUSTIN, TEXAS 78752
(512) 329–6080

FIGURE
2–6

initiated in the Snyder Field in 1927. Systematic development of the oil reservoir began around 1953. A no-pit order for the Snyder Oil Field was issued in 1959, several years before the statewide order. Saltwater impacts to shallow groundwater and the use of saltwater disposal pits were first reported in the late 1950s. Data from the Underground Injection Control (UIC) department indicate that some operators were using injection wells for the disposal of produced water as early as 1967 in the O'Daniel Leases. Historical data indicate that saltwater impacts were discovered at the seeps in 1988, which was concurrent with the re-pressuring of the oil field in the area through water flooding.

Based on the information gathered from the BEG report, the RRC field records, and TRC's field investigations, sources for saltwater impacts to the Ogallala Aquifer outlier in the subject area include the use of saltwater disposal pits in the 1950s and 1960s, migration of fluids from the oil reservoir to the Ogallala Aquifer, and/or leaks from saltwater injection wells that are improperly sealed or have compromised seals. Ongoing releases of saltwater have not been confirmed but cannot be ruled out entirely.

2.3 Migration Pathways

The impacted groundwater migrates within the relatively thin Ogallala in directions dictated by the slope of the Ogallala/Dockum contact. At locations where the Ogallala/Dockum contact is exposed, groundwater discharges to the surface via springs and seeps. Whereas, at locations where the Ogallala/Dockum contact is covered by the alluvium, groundwater flows from the Ogallala into the drainage basin alluvium.

2.4 Area Impacted by Salinity/TDS

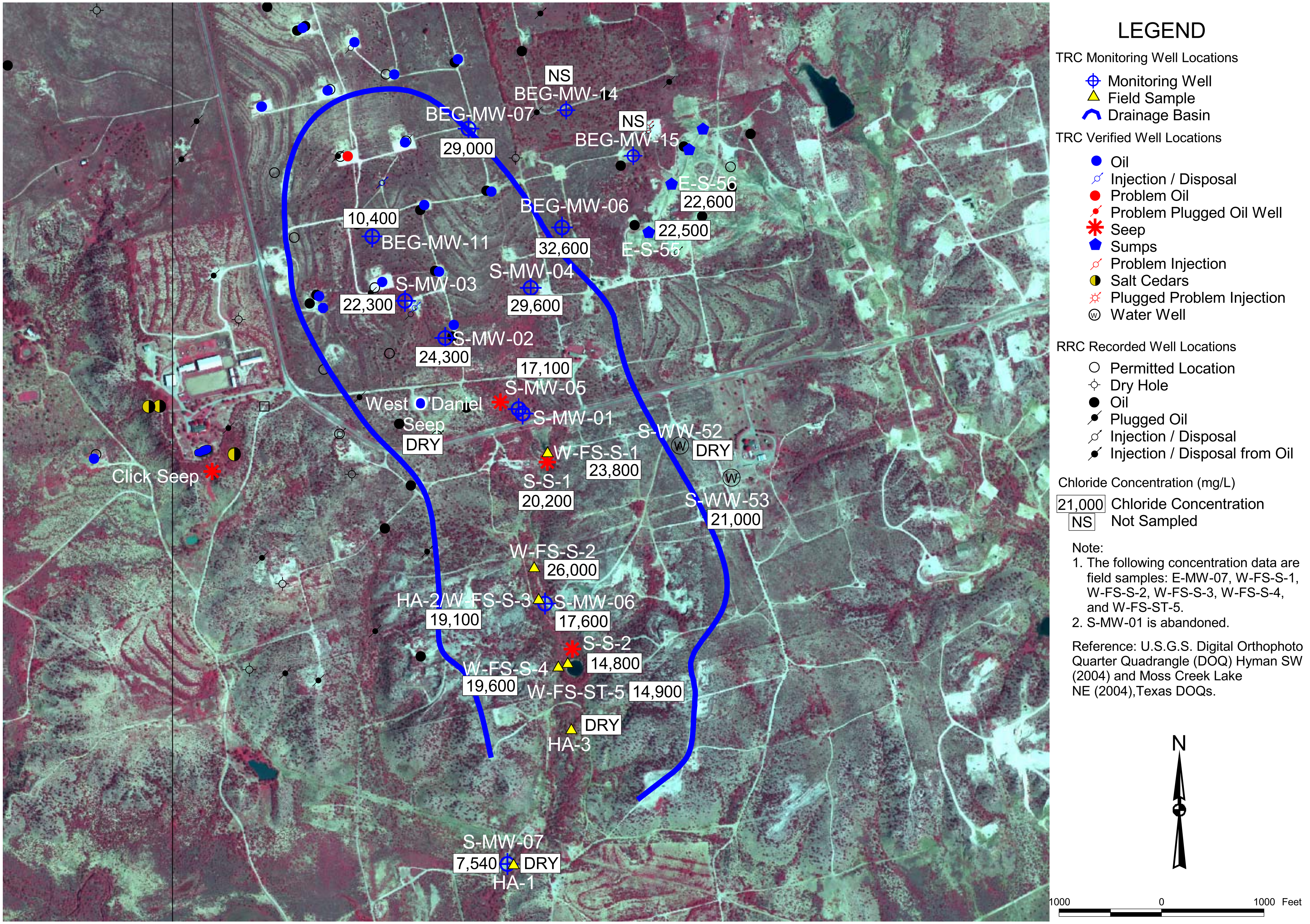
The 1999 BEG investigation report documented that chloride concentrations, used to define saltwater impacts, typically range from 100 to 1,000 mg/L in the Ogallala Formation in Howard County, and that background chloride concentrations in the Ogallala Formation within the investigation area ranged from 100 to 700 mg/L (BEG, 1999). For the purposes of this study, chloride concentrations below 1,000 mg/L are considered indicative of background conditions typical of the Ogallala Formation in this area.

Based on the most recent investigation data from April 2006, chloride concentrations in all of the samples collected in the West O'Daniel Seep investigation area exceeded the background level. Therefore, the groundwater in the entire investigation area is considered to have been affected by saltwater impacts. Several wells located approximately 0.5 miles north of the West O'Daniel Seep investigation area and sampled as part of the Click Seep investigation had concentrations indicative of background conditions. Figure 2-7 presents a chloride distribution map for data collected in April 2007.

The highest chloride concentrations (29,000 to 32,600 mg/L) are located near monitoring wells BEG-MW-06, BEG-MW-07, and S-MW-04, which are at the upgradient extent of the investigation area. In general, the chloride concentrations decrease in the downgradient direction with the lowest concentration occurring at S-MW-07 (7,540 mg/L), located at the downgradient extent of the investigation area. The chloride concentration decreases rapidly from BEG-MW-06 (32,000 mg/L) to S-MW-05 (17,100 mg/L) that is near the West O'Daniel Seep, then stays relatively stable from S-MW-05 (17,100 mg/L) to S-MW-06 (17,600 mg/L), and finally decreases rapidly from S-MW-06 (17,600 mg/l) to S-MW-07 (7,540 mg/L) (Figure 2-7).

As shown on Figure 2-7, the area of impacted groundwater that is sourcing the West O'Daniel Seep, and therefore the subject of this study, lies within the West O'Daniel Drainage basin. Impacted water outside of this area is believed to be flowing either east to the East O'Daniel area or west to the Click Seep area.

Figure 2-7. Chloride Distribution Map (April 2006)



3.0 ALTERNATIVES FOR SALINITY/TDS ABATEMENT

TRC evaluated available recovery, treatment and disposal methods for saltwater-impacted water. The following discussion reviews the technologies available based on the following criteria:

- Effectiveness
- Implementability
- Regulatory agency and stakeholder acceptance
- Cost

Technologies were reviewed for potential application to the West O'Daniel Seep project. Many technologies are available for the treatment of saline-impacted water. However, there were no industry standard in-situ treatments for the remediation of saline groundwater. Each treatment technology scenario reviewed involves collection and ex-situ disposal of the groundwater.

3.1 Evaluation of Recovery Options

In order to minimize chloride loads into the downstream surface water bodies, the saltwater-impacted groundwater will need to be recovered by means such as an interceptor trench, pumping, or other hydraulic recovery measures. The groundwater is shallow and occasionally flows to the surface. There are two common options for the physical removal of groundwater from the shallow subsurface: a recovery well or a recovery trench. An alternative technology for groundwater control and saltwater removal is phytoremediation (the use of plants to remove contaminants). Each of these technologies is discussed below.

3.1.1 Recovery Wells

A recovery well is used to recover contaminated groundwater through a pump. A recovery well is a point source for the removal of subsurface fluids. Each recovery well has a capture zone, which represents the area of groundwater drawn into the well during pumping. The capture zone radiates from the well to a dimension dictated by formation properties, formation thickness, groundwater velocity, pump depth, well construction, and pumping rate. In order to successfully capture a wide area of groundwater in a thin saturated zone, a series of recovery wells is typically necessary. Superposition can be used to place recovery wells in a line with overlapping capture zones sufficient to collect impacted groundwater in the targeted area and/or to create a local hydraulic barrier to groundwater flow. Recovery wells have been used with success in many similar projects.

Where groundwater is located at significant depth, recovery wells may be the only option for efficient collection of groundwater.

The technology to install a well is readily available and generally of low cost depending on the required extraction rates. Some large well diameters require specialized and less available technology.

Recovery wells are connected through a manifold of collection lines to transport the recovered groundwater from each well to the treatment/disposal location. Depending on the number of wells necessary to create the desired hydraulic barrier, above ground recovery piping can become a logistical problem and a major component of system cost.

Feasibility Criteria:

Effectiveness:	Moderate
Implementability:	Moderate
Agency Acceptance:	High
Cost:	Moderate

3.1.2 Recovery Trench

A recovery trench utilizes highly permeable media to enhance groundwater migration into the trench, pumps to collect and remove groundwater, and pumps and/or an impermeable barrier to restrict downgradient groundwater migration. Groundwater is recovered by pumps that are placed in the sumps within the trench. A recovery trench represents a linear source for removal of subsurface fluids. The capture zone of a recovery trench is approximately the cross sectional area of saturated sediment that it intersects and the upgradient groundwater that will flow into the trench.

The technology used to install a recovery trench is readily available and inexpensive for shallow (less than 25 feet deep) installations. Typically, standard excavation equipment is used to create a trench which is filled with coarse-grained material and large diameter standard pipe to act as sumps. In deeper installations, specialized equipment and trench stabilization technology are typically required and are less available and more expensive.

Recovery trenches work well with water-bearing zones located close to the surface. The design and cost of the trench becomes simplified at shallow depths. A recovery trench typically blocks groundwater migration through the trench by means of hydraulic control. In some cases an impermeable wall (e.g., high density polyethylene) can be used to further control migration through the trench as needed to control transport. The trench is typically backfilled with a highly permeable fill material into which groundwater flows preferentially and is captured by pumps. Pumps are activated by the height of groundwater within each sump, which acts to protect the sump pumps from operating when there is insufficient water.

Recovery lines are used to transport the recovered groundwater from each sump to the treatment/disposal location. The number of sumps and associated transfer piping required depends on removal necessary to achieve the desired hydraulic barrier. The number of sumps and length of trench needed to obtain capture and control is dependent of hydrogeologic conditions and can significantly affect the cost.

Feasibility Criteria:

Effectiveness:	Moderate to High
Implementability:	Moderate
Agency Acceptance:	High
Cost:	Moderate

3.1.3 Recovery Through Halophytic Vegetation

The saturated thickness is approximately 5 to 10 feet, due to the shallow occurrence of the Dockum Clay. A phytoremediation approach is a possible alternative to groundwater recovery approaches. Halophytes such as tall wheatgrass, tall fescue, bermuda grasses, wheatgrass, rhode grass, salt grass, and other species described in Section 3.2.4 can be planted along the width of the alluvium for a determined length that would result in measurable water uptake through the plants' root systems. The effectiveness of this technology is limited to the effective depth of the plant root zones and is therefore applicable to very near surface issues only.

The technology to install this option is simple and easily obtained. The major cost component of this technology is operational and maintenance rather than capital. The initial installation requires daily maintenance until substantial growth is established. Establishment of the interdependent biota may require many months until they become a self-sustaining system.

The implementation of this technology would involve an operations and maintenance (O&M) plan that would include cropping, harvest, and disposal. Maintenance may be difficult because heavy precipitation events in the drainage basin could wash away the plants. Phytoremediation as a chlorides treatment alternative is discussed in further detail in Section 3.2.4.

Feasibility Criteria:

Effectiveness:	Low
Implementability:	Difficult
Agency Acceptance:	Unknown
Cost:	Low to Moderate

3.1.4 Technology Selection for Recovery

Upon examination of the design alternatives discussed for the collection of groundwater, the recovery trench technology is judged to be most effective in maintaining local hydraulic control while recovering impacted groundwater. The shallow groundwater conditions at the site indicate that the recovery trench would best control the downgradient migration of contaminated groundwater. The recovery trench is preferred over recovery wells because the trench will provide more comprehensive coverage for recovery of the impacted groundwater. The limitation to phytoremediation is greater time frame for full implementation and the longer period for O&M.

In the case of the West O'Daniel Seep, the design concept would be to install the recovery trench to fully intercept groundwater flow within the alluvium of the drainage channel, downstream from the West O'Daniel Seep. As such, the trench will be anchored into the Dockum clay below the alluvium.

3.2 Evaluation of Treatment and Disposal Options

Salinity in general and chlorides in particular are very conservative (i.e., chemical and physical interactions are limited) in the groundwater environment. Consequently, treatment technologies available to treat and/or dispose of high saline water are limited. A survey of available treatment and disposal options for saline water recovered from an engineered system is provided below.

3.2.1 Evaporation Ponds

Recovered saltwater-impacted groundwater can be conveyed to lined pits for evaporation. The necessary evaporation pits can be designed to dimensions required to produce evaporation along the surface area at a rate that meets the inflow rate of the recovery system. The pond would be lined with black-colored polyethylene liner and placed on a geotextile layer to enhance evaporation rates. This method would require periodic disposal of highly saline sludge/sediment that accumulates from the ongoing evaporation. Therefore, disposal options for the brine and highly saline sludge/sediment will be necessary. Possibilities for disposal of brine are disposal wells. Options for disposal of sludge/sediment are at an off-site landfill.

Evaporation ponds present O&M costs and construction issues. Evaporation ponds must be monitored to assure leakage is not occurring. The technology is well established and available. The climatic conditions in the West O'Daniel area are well suited for use of evaporation ponds due to a very high net annual evaporation rate (approximately 53 inches per year).

The down side of evaporation ponds is the need to manage sludge/sediment accumulation in the ponds. Other challenges posed for the installation of an evaporation pond include permitting and land owner approval, especially in cases where such ponds may occupy a large area on the property.

Feasibility Criteria:

Effectiveness:	Moderate to High
Implementability:	Moderate
Agency Acceptance:	Unknown
Cost:	Moderate

3.2.2 Desalination Technologies

There are essentially four basic techniques to remove salt from water: distillation, reverse osmosis, electrodialysis, and ion exchange. Distillation and freezing remove fresh water from saline water leaving behind more concentrated brine. Reverse osmosis and electrodialysis are processes in which membranes are used to separate salts from fresh water. Ion exchange involves passing saline water over resins which exchange more desirable ions for less desirable dissolved ions. These technologies are presented for completeness but are known to have very high energy demands and costs.

These technologies are suitable for point-of-use treatment for potable water quality requirements, rather than control and abatement measures for reducing saltwater impacts to downstream reservoirs. In addition, electrodialysis and ion exchange processes are limited to treating brackish water with TDS concentrations below 10,000 mg/L, which rules out these methods. For salinities above 10,000 mg/L, reverse osmosis, freezing processes, and distillation or evaporation are the only treatment options. However, the costs associated with energy intensive facilities constructed and installed in a rural setting would be significantly higher than other options.

Feasibility Criteria:

Effectiveness:	High
Implementability:	Moderate
Agency Acceptance:	High
Cost:	Very High

3.2.3 Disposal Wells

Saltwater recovery from the adjacent East O'Daniel Seep has been managed using disposal wells regulated under 16 Texas Administrative Code (TAC) Part 1, Chapter 3, §3.9 Disposal Wells and §3.46 Fluid Injection into Productive Reservoirs (i.e., RRC Rules 9 and 46). Costs associated with this method will depend on the injection capacity of the local operator's existing disposal wells or nearby commercial disposal wells, the price of disposal on a per volume or fee basis, and the required design capacity.

The options for injection include the installation of a new disposal well in a non-production zone, treatment and disposal through an existing nearby facility that would require approval of the operator, or transporting recovered saltwater to an off-site commercial disposal facility. Saltwater disposal into disposal wells will require treatment for biological organisms prior to injection.

The advantages of disposal through a new or existing disposal well include relative proximity to the recovery area, and the use of a well known technology previously implemented in the site vicinity. The disadvantages for injection in a new well are cost associated with permitting and drilling to an injection depth on the order of 5,600 feet bgs. The RRC has identified problems with saltwater impacts to groundwater units located above the existing injection zones at depths of 2,200 to 2,800 feet bgs, as discussed in Section 4.2.3. Hence, saltwater disposal into existing disposal wells may contribute to an ongoing problem of saltwater impacts to usable groundwater resources.

Feasibility Criteria:

Effectiveness:	High
Implementability:	Moderate
Agency Acceptance:	High
Cost:	Variable (see discussion in Section 4)

3.2.4 Phytoremediation

The drainage basin alluvium downstream of the seep can be cropped with halophytic vegetation as described below. A study would need to be conducted regarding the growth potential of each plant species and ecologic interactions. The advantages of this treatment would include the lowering of the water table in the alluvium with discharge via evapotranspiration, and limited salt uptake removals over time via the root surface area and penetration within the saturated zone.

The primary advantage of incorporating phytoremediation is based on the cost effective nature of implementing these systems. The O&M associated with phytoremediation strategies is economical, as established plant communities are self-supportive and require little maintenance other than harvesting and disposal. Phytoremediation systems also greatly reduce erosion, runoff, and dust. However, phytoremediation does have several limitations. The process requires sufficient time for plant establishment and operation, often needing several growing seasons for optimal performance. Since phytoremediation is most effective when contamination is within the reach of plant roots, groundwater depths may also be a limiting factor for a groundwater phytoremediation strategy; in order to ensure proper root contact with the water table, maximum groundwater depth would be limited to 3 to 6 feet for herbaceous plants and 10 to 15 feet for trees and some shrub species.

While phytoremediation systems are very successful as remediation strategies, the site conditions and project requirements of the West O'Daniel Seep site present some challenges and limit the usefulness of this technology. In particular, a portion of the plants would be placed within the center of the drainage basin and these plants could be washed away during heavy precipitation events.

The most effective strategy for saline groundwater remediation at the West O'Daniel Seep site would be to implement a mixture of grass and tree species to maximize the establishment of vegetation, promote a healthy functioning ecosystem, efficiently transport groundwater, and successfully remove salts from groundwater. Under the scope of this feasibility study, sowing a mixture of grasses would be beneficial as a complementary remediation strategy for salt removal in locations; however, it is not judged to be sufficient or time effective to manage the amount of saline water that potentially needs to be treated.

This measure offers only a limited reduction of chloride load towards the downstream outlet. However, if implemented in combination with other technologies, it may result in measurable cost reductions to the overall system.

3.2.5 Technology Selection for Treatment and Disposal

As previously mentioned, only ex-situ options were available for treatment of recovered saline-impacted groundwater. Desalination was judged to be too costly with respect to energy consumption. Phytoremediation was judged to be a good complementary technology but will not provide sufficient treatment in a reasonable timeframe to serve as the primary technology. Treatment of the recovered water through the use of an evaporation pond is a recommended solution as a simple and low-cost initial option to reduce the volume of water that requires more costly disposal via injection. The remaining water will be treated via injection into a new disposal well with a pre-treatment system, a local operator's existing disposal well, or an off-site commercial saltwater disposal facility.

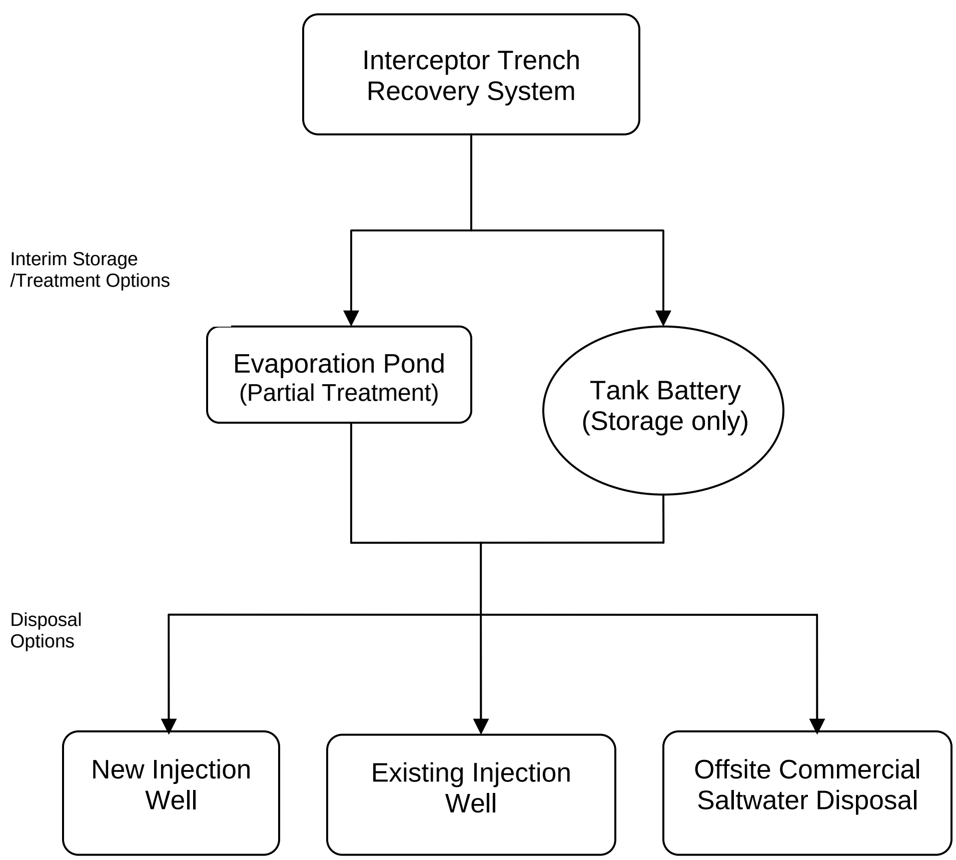
4.0 DESIGN ALTERNATIVES

This section presents the alternatives for a recovery and disposal system with descriptions and cost estimates for each of the components for the purpose of technology selection among various system design solutions. Based on the review of the alternatives in this section, a proposed solution is presented in Section 5.0. Supporting documentation for the order of magnitude engineer's cost estimates provided below are presented in Appendix A.

4.1 Basic System Design

Based on the remedial objective, conceptual site model, and an evaluation of the technologies for groundwater recovery, storage, evaporation, and disposal options, the following basic design is recommended (Figure 4-1).

Figure 4-1. System Design Alternatives



The system design and cost estimates were determined at a scale that will accommodate the maximum estimated groundwater recovery rate of 300 barrels per day, representing an upperbound estimate of the required system and costs.

4.2 Components Description and Cost Estimates

The following subsections present the various components of the system design and discuss their estimated design parameters. Also included are assumed costs for installation and O&M.

4.2.1 Recovery Trench

The recovery trench design is estimated to span 200 feet across the drainage basin. Based on limited soil boring data for the area, the Dockum clay is expected to occur between depths of 7 to 20 feet bgs along the alluvial channel. The average thickness of the saturated zone is estimated to be 7 feet (Figure 4-2). Based on the hydraulic gradient and alluvial soil texture, the total seep discharge is estimated to range between 7,000 to 12,000 gallons per day (GPD), or 170 to 300 barrels per day (bbls/day).

The recovery trench system components include up to three sumps equipped with a pump (e.g., submersible or pneumatic), level switches, and control panel. The trench will be filled with pea gravel or coarse sand at a designed transmissivity rate to accommodate the expected inflow rate. A piping manifold will route recovery from the individual sumps in series to the evaporation pond or tank battery. The O&M costs include equipment repair and replacement, periodic system monitoring, etc.

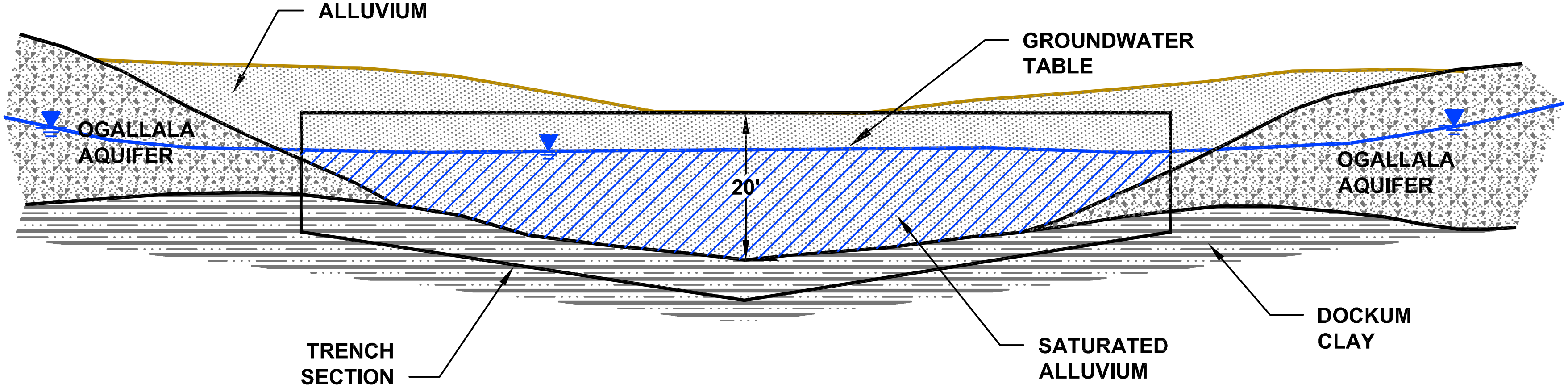
Recovery Trench Costs

Capital Expenditures:	$104,500
Annual O&M:	$49,075
5-yr Total Costs:	$349,875

4.2.2 Interim Storage Alternatives

Evaporation Pond

Preliminary calculations were made for estimating the average rate of evaporation from a lined pond in the West O'Daniel Seep area. Averaging the meteorological data on an annual basis for the area, the estimated evaporation rate is in the order of 0.1 centimeters per day (cm/day). For treatment of the entire daily recovery from the trench system via evaporation, the pond would require dimensions ranging between approximately 7 to 12 acres, based on the estimated flow range of 170 to 300 bbls/day. However, the evaporation rates during the winter months are expected to be significantly



NOT TO SCALE

TRENCH SECTION CONCEPTUAL DESIGN

RAILROAD COMMISION OF TEXAS
WEST O'DANIEL SEEP

PROJECT NO.: 53680–0002	DWG FILE: 53680–4–2
DRAWN BY: K.S.	DATE: 04/09/07

TRC
505 EAST HUNTLAND DRIVE
SUITE 250
AUSTIN, TEXAS 78752
(512) 329–6080

FIGURE 4–2

lower than 0.1 cm/day. Therefore, this technology is not suitable as a sole method for disposal.

A smaller evaporation pond was considered for the purpose of achieving partial treatment of the recovered groundwater to reduce the costs of disposal by injection. Thus, the evaporation pond serves the dual purpose as a temporary holding tank and a partial treatment method. A 3-acre evaporation pond will reduce the total annual volume of disposal by approximately 33 percent, which equates to an estimated annual cost reduction of $15,000 if using a local operator's existing disposal well or an estimated annual cost reduction of $60,000 if using a commercial disposal well.

The disadvantages of an evaporation pond include a large area of land necessary to produce a significant discharge by evaporation, the pond O&M, and sludge/sediment disposal.

O & M costs include periodic removal and disposal of saline sludge/sediment, and periodic cleaning of the pond lining.

Evaporation Pond Costs (3 acres)

Capital Expenditures:	$114,650
Annual O&M:	$36,300
5-yr Total Costs:	$296,150

Tank Battery

The temporary holding tank system may consist of a tank battery to serve as a reservoir prior to disposal. Advantages of a tank battery include low cost and easy implementation. Costs include all materials, labor, associated piping, valves, and required ancillary equipment. O & M costs include periodic inspections and anticipated repairs and replacements.

The advantages of installing a tank battery are the simplicity of design and construction, using a well-known, widely available, and non-intrusive technology that is not likely to receive opposition from land owners in the area. The disadvantage of this option for temporary storage is that the entire volume of recovered seep water will need to be routed for disposal, with no reductions from evaporation.

Tank Battery Costs

Capital Expenditures:	$49,000
Annual O&M:	$14,700
5-yr Total Costs:	$122,500

4.2.3 Disposal Alternatives

New Disposal Well

The current water flood program using produced water injected into the producing reservoir is reported to be migrating upwards into usable groundwater-bearing zones. As such, any new disposal well would be required to be installed at a depth below the existing injection zone, which is in the order of 2,200 to 2,800 feet bgs. Consultations between Mr. Prude of the RRC and oil well drilling companies in the area suggested that the necessary depth for a new disposal well would be on the order of 5,600 feet bgs to ensure isolation from the current production zone depth.

Costs for the new disposal well system include a tank battery and pre-treatment to prevent bio-fouling. The total estimated engineering design and construction costs for such a well is summarized below. The advantage of this alternative is the disposal of all recovered groundwater without any limitations imposed by the operator and cost/dependence on a commercial facility. The disadvantage of this alternative is the high cost of capital expenditures for the installation of a new disposal well.

New Disposal Well Installation

Capital Expenditures:	$836,000
Annual O&M:	$24,000
5-yr Total Costs:	$956,000

Existing Disposal Well System

The estimated cost for injection into an existing disposal well near the site includes pre-treatment for dissolved oxygen and biological content. Based on discussions with an operator near the site, the estimated cost for using an existing disposal well is approximately $0.30 per barrel for pre-treatment and $0.10 per barrel for disposal. The pre-treatment system includes chemical treatments for scavenging the oxygen and application of biocides to prevent the blooming of biota within the injection formation.

The advantage of this alternative is the significant cost savings for disposal including treatment and injection. A limitation on this alternative is that the operator has specified that the maximum capacity they can receive from the subject recovery system is 200 BBLS/day, as well as dependence upon the operator's system. As such, this option will require an additional means to dispose of the estimated remaining recovery of up to 100 BBLS/day.

Existing Disposal Well System

Capital Expenditures:	$0 (included with evaporation pond or tank battery)
Annual Disposal Costs:	$48,180
5-yr Total Costs:	$240,900

Off-Site Commercial Disposal

Off-site disposal via a commercial hauling service and commercial saltwater disposal facility were evaluated. The price for disposal of saltwater is $0.50 per barrel at a commercial disposal facility. At a labor rate of $80 per hour, a vacuum truck operator can haul loads of 130 barrels per trip, requiring a minimum of two hours for loading, travel to the facility at approximately 15 miles distance, and unloading.

Advantages for this disposal option are the simplicity of implementation, the low cost of saltwater disposal ($0.50 per barrel), lack of dependence on a local operator, and proximity to the commercial saltwater disposal facility. The disadvantage of this alternative is the high cost of transportation. The total estimated annual and 5-year costs for commercial disposal are summarized below:

Off-Site Commercial Disposal Costs

Capital Expenditures:	$0 (included with evaporation pond or tank battery)
Annual Disposal Costs:	$208,505
5-yr Total Costs:	$1,042,525

5.0 RECOMMENDED SOLUTION

This preliminary feasibility study was performed to evaluate and recommend BMPs to abate salinity/TDS impacts into Beals Creek originating from the West O'Daniel Seep drainage basin. Based on the screening of recovery, treatment, and disposal technologies discussed in Section 3.0 and cost evaluations of select technologies compared in Section 4.0, the following solution is recommended.

- An interceptor trench is recommended for recovery of the saline groundwater. The trench would span the width of the saturated alluvium within the drainage channel as shown in Figure 1-2. The proposed trench is located directly downgradient of the seep, near surface sampling point W-FS-S-1. The trench is located in the area of the highest chloride concentrations. The decreasing chloride concentrations downgradient of the proposed trench are indicative of dilution by lateral flow of groundwater from the Ogallala Aquifer that has lower chloride concentrations. Therefore, further downgradient placement of the trench will result in recovery of a greater volume of lower concentration (i.e., lower load) water.

- Interim storage and treatment can be achieved by a tank battery, an evaporation pond, or a combination of these options. The selection is driven by the cost of the disposal method. If an existing or commercial disposal well is used, then the driving cost is the disposal volume. Thus, the reduction in disposal volume by the evaporation pond will likely outweigh the O&M and sludge/sediment disposal costs associated with the evaporation pond. If a new disposal well is used, the primary cost is the initial capital rather than the disposal volume; and thus a tank battery is the better option due to its lower O&M and sludge/sediment disposal costs. These options may be moot and the tank battery selected if the landowner does not agree to the significant land area for an evaporation pond.

- Disposal at a commercial saltwater disposal facility is recommended because it is the option with the fewest complications. Use of an existing operator's disposal well is the most cost effective option and should be used if the RRC can obtain and guarantee access from the operator and there is sufficient injection capacity available. Installation of the new disposal well has a significant upfront commitment of capital, but will provide the greatest value if the system operates for a longer period of time. In addition, the timeframe required to permit and drill a new disposal well may be prohibitive.

The scale of the recommended configuration and the engineer's cost estimates are based on an upperbound estimate of groundwater flux in the drainage channel. Designing the proposed remedy will require the following additional site information:

- Determine the depth of the contact between the saturated alluvium/Ogallala and the underlying Dockum clay at the specific location of the recovery trench. This would be accomplished through completion of soil borings and possibly geophysics.
- Determine the thickness of the saturated zone at the location of the proposed recovery trench using soil borings, monitoring wells and possibly geophysics.
- Determine groundwater parameters, most importantly hydraulic conductivity, via aquifer testing.

6.0 REFERENCES

The University of Texas at Austin, Bureau of Economic Geology (BEG). 1999. *Final Technical Report, Investigation of the Snyder Field Site, Howard County, Texas*. April 1999.

Railroad Commission of Texas. 2006. *Investigations and Abatement of Produced Water Impacts and Seeps to Surface Water, Section 319 Nonpoint Source Grant, Upper Colorado River Basin, Upstream of Spence Reservoir (Segment 1411), Howard and Mitchell Counties, Texas, Quarterly Report, Fourth Quarter, FY 2006.* September 15, 2006.

TRC Environmental Corporation. 2006. *Final Site Investigation Report, West O'Daniel Seep, Howard County, Texas*. August 2006.

APPENDIX A

ENGINEER'S COST ESTIMATE

Recovery Trench

CAPITAL EXPENDITURES (Installed)	UNIT	UNIT COST	QTY	EXTENSION
Recovery Trench	Each	$ 75,000	1	$ 75,000
(3) 24" Diameter Carbon Steel Slotted Sump				
40-mil HDPE				
Pea Gravel				
Landscape Filter Fabric				
Transfer Piping				
Equipment Installation	Each	$ 10,000	1	$ 10,000
Pumps (Hydromatic sump Pump)				
Control Panel				
Electrical				
DESIGN AND PLANNING COSTS				
Design and engineering				$ 10,000
Subtotal - Capital (Includes 10% Contingency)				$ 104,500
OPERATIONS AND MAINTENANCE (Annual)				
Twice Per Monthly Inspections (12 months)	HR	$ 75	400	$ 30,000
Equipment replacement	EA	$ 17,500	1	$ 17,500
Subtotal - O&M (Includes 5% Contingency)				$ 49,875
TOTAL (Years of Operation)	YR		5	**$ 353,875**

Evaporation Pond

CAPITAL EXPENDITURES (labor included)	UNIT	UNIT COST	QTY	EXTENSION
60-mil HDPE (smooth, black, UV resistant)	SF	$ 0.68	131000	$ 89,080
Sand - Backfill	TON	$ 3.70	40	$ 148
Wet Well and Pump Installation	Each	$ 5,000.00	1	$ 5,000
Design and engineering				$ 10,000
Subtotal (Includes 10% Contingency)				**$ 114,651**
OPERATIONS AND MAINTENANCE				
Monthly Inspection	HR	$ 75.00	120	$ 9,000
Annual Sediment Removal Labor	HR	$ 75.00	104	$ 7,800
Annual Waste Disposal	CY	$ 60.00	270	$ 16,200
Subtotal (Includes 10% Contigency)				**$ 36,300**
TOTAL (Years of Operation)	YR		5	**$ 296,151**

Tank Battery and Pump Station

CAPITAL EXPENDITURES	UNIT	UNIT COST	QTY	EXTENSION
300 bbls Holding Tanks	EA	$ 10,000	2	$ 20,000
Piping, Valves, Fittings, Gauges, etc	EA	$ 4,000	1	$ 4,000
3 HP Centrifugal Pump	EA	$ 930	1	$ 930
2" Polypropylene Fast Line Including Fittings	FT	$ 5	2,000	$ 9,600
Design and engineering				$ 10,000
Subtotal (Includes 10% Contingency)				**$ 48,983**
OPERATIONS AND MAINTENANCE (Annual)				
Monthly Inspection, 12 months	HR	$ 75	120	$ 9,000
Equipment Repairs and Replacements	EA	$ 5,000	1	$ 5,000
Subtotal (Includes 5% contingency)				**$ 14,700**
TOTAL (Years of Operation)	YR		5	**$ 122,483**

New Disposal Well

CAPITAL EXPENDITURES	UNIT	UNIT COST	QTY	EXTENSION
Installation of New Disposal Well to 5000 FT BGS	EA	$ 750,000	1	$ 750,000
Design and engineering				$ 10,000
Subtotal (Includes 10% Contingency)				**$ 836,000**

OPERATIONS AND MAINTENANCE (Annual)	UNIT	UNIT COST	QTY	EXTENSION
Monthly Inspection	HR	$75.00	200	$ 15,000
Pre-Treatment	BBLS	$0.06	109500	$ 6,570
Subtotal (Includes 10% Contingency)				**$ 23,727**
TOTAL (Years of Operation)	YR		5	**$ 954,635**

Existing On-Site Disposal Well System

CAPITAL EXPENDITURES	UNIT	UNIT COST	QTY	EXTENSION
None				$0
Subtotal				**$0**
OPERATIONS AND MAINTENANCE (Annual)				
Saltwater Treatment	BBLS	$0.30	109500	$32,850
Disposal into Injection Well	BBLS	$0.10	109500	$10,950
Subtotal (Includes 10% Contingency)				**$48,180**
TOTAL (Years of Operation)	YR		5	**$240,900**

Commercial Saltwater Disposal

CAPITAL EXPENDITURES	UNIT	UNIT COST	QTY	EXTENSION
None				$0
Subtotal				**$0**
OPERATIONS AND MAINTENANCE (Annual)				
Haul Labor	HRS	$80.00	1685	$134,800
Diposal Fee	BBLS	$0.50	109500	$54,750
Subtotal (Includes 10% Contingency)				**$208,505**
TOTAL (Years of Operation)	YR		5	**$1,042,525**

New Parks Environmental Services (NPES)